4.0 Recommendations

4.1 Recommendations for Lowering Phosphorus and Associated Water Quality Benefits

This section provides recommendations for lowering phosphorus loadings to surface waters from each source category, along with general discussions about the associated water quality benefits, where appropriate.

4.1.1 Point Sources

The recommendations for lowering the phosphorus export are presented in two parts. The first part discusses recommendations for lowering phosphorus amounts discharged to POTWs and the second part discusses recommendations for lowering the point source phosphorus amounts discharged to basins and statewide. A more detailed discussion is included in Appendix B.

4.1.1.1 Phosphorus Loading to POTWs

The results of this study are intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122., as follows:

The state goal for reducing phosphorus from non-ingested sources entering municipal wastewater treatment systems is at least a 50 percent reduction developed by the commissioner under section 166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment systems in calendar year 2003.

For purposes of complying with this legislation, this study has estimated that the current non-ingested phosphorus load entering POTWs is 2,573,000 kg/yr. A 50 percent reduction would require decreasing the phosphorus discharged to POTWs by least 1,286,000 kg/yr. The applicability of reduction tactics for each of the non-ingested sources entering POTWs are discussed in descending rank order, by component, below:

- Next to human wastes, a variety of industrial and commercial dischargers contribute the most phosphorus to POTW influent streams. The contribution of phosphorus from these commercial and industrial sources accounts for approximately 46 percent of the non-ingested phosphorus load discharged into POTWs. Total removal of phosphorus from commercial and industrial wastewater is not expected to be feasible. In most cases, reduction would have to come from resource/product substitution, waste minimization through recycling and reuse, improvements in technology, and through pretreatment of wastewater prior to discharge to the POTW. Reducing the commercial and industrial phosphorus contribution to POTWs by one half would reduce the total non-ingested phosphorus discharged to POTWs by almost 23 percent. Excise taxes and/or effluent strength charges may be useful in reducing this influent source of phosphorus.

- Food soils and garbage disposal wastes account for approximately 28 percent (725,000 kg/yr) of the non-ingested phosphorus discharged to POTWs. This is a substantial amount, but it is unlikely amenable to direct modification (e.g. product modification), or prohibiting discharge of food wastes into the sewer systems. Approximately 25 percent of the phosphorus from this source is discharged into the sewer system as garbage disposal waste. Garbage disposal waste could be sent elsewhere (trash, compost, etc.) but it would be more difficult to manage the phosphorus from dish rinsing and dish washing. Short of inducing the food product industries to reduce their use of phosphates or eliminating garbage disposals and discharge of food wastes down the drain, relatively little appears possible for reducing this phosphorus load to POTWs. Public education may be the best option to reduce discharge of food wastes down the drain.

- Residential ADWD detergent contributes approximately 7.3 percent or 326,000 kg/yr to the total influent phosphorus load discharged into POTWs and almost 13 percent of the non-ingested phosphorus load. Eliminating all phosphorus from residential ADWD detergents would reduce the non-ingested phosphorus load discharged to POTWs by almost 13 percent. Although there has been a slight decline in the consumption of phosphorus for residential ADWD detergents, SRI states that it is unlikely that detergents with much lower phosphorus contents will be available in the near future. Currently, at least one brand of ADWD does not contain phosphorus; the phosphorus content of other brands varies significantly. Advertising and prominent content labeling would help reduce this source by aiding consumers in choosing low phosphorus products. Public education about the use of ADWD based on hardness and the availability of no- and low-phosphorus content products should be encouraged.

- Commercial and institutional ADWD detergent contributes a statewide average of approximately 6 percent (152,000 kg/yr) of the influent non-ingested phosphorus load discharged into POTWs. Public education about the use of ADWD based on hardness and the availability of no- and low-phosphorus content products should be encouraged.

- The influent phosphorus loads to POTWs from water supply chemicals were estimated to average approximately 5.5 percent of the non-ingested phosphorus load to POTWs statewide. Use of phosphorus for sequestration of metals typically is an aesthetics issue. On the other hand, corrosion control of lead and copper is a human health issue and is required by law for those communities that do not pass the state corrosion tests. One option would be to substitute alternative water treatment chemicals in place of those with phosphorus.

- Dentifrices account for less than two percent of the total non-ingested phosphorus load to POTWs. Because the phosphorus load from this source is so minimal, it does not warrant major steps to reduce phosphorus discharges from toothpastes and denture cleaners.

- The results of this study indicate that inflow and infiltration contribute a negligible amount of phosphorus to POTW influent. There are reasons to limit inflow and infiltration into sewer systems, such as to prevent hydraulic overloading of treatment facilities, but the reduction of influent phosphorus is not one of them.

Given that food soils would be very difficult to reduce, and that dentifrices and I & I contribute so little to the influent phosphorus load discharged to POTWs, it is recommended that reduction efforts focus on residential ADWD, commercial and industrial process wastewater, commercial and institutional ADWD, and water treatment chemicals. A summary of the phosphorus load discharged to POTWs and the reduction potential is presented in Table 4-1.

Table 4-1 Reduction Potential for Phosphorus Loads to POTW

Summary		**Portion of Total Load to POTW**
Total Phosphorus Load Discharged to POTWs	4,468,000 kg/yr	
Human Waste	1,900,000 kg/yr	43
Non-ingested Waste	2,573,000 kg/yr	57
Phosphorus Source	**% Reduction to Non-Ingested Phosphorus Load (%)**	**Cumulative Reduction to Non-Ingested Phosphorus Load (%)**
Residential ADWD reduced to 0	13	13
Commercial ADWD reduced to 0	6	19
Commercial and Industrial reduced by one half	23	42
Total Reduction		**42**

If residential and commercial/institutional ADWD and water treatment chemicals were eliminated completely, the required commercial and industrial process wastewater reduction is estimated to be more than 64 percent. Given that it will be difficult to completely eliminate commercial/institutional ADWD and water treatment chemicals and reduce the commercial and industrial process wastewater loading by more than 64 percent, a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs appears to be an ambitious goal.

4.1.1.2 Phosphorus Loading to Surface Waters

Phosphorus effluent from POTWs represents, on average, more than 80 percent of the total point source loads to waters of the state. The largest source of phosphorus is from large (> 1.0 mgd) POTWs and phosphorus reduction efforts should begin at these facilities. As discussed previously, many POTWs have implemented phosphorus removal and others will begin to implement it in the near future. The lowest effluent limits to date have been 1 mg/L with two exceptions, the Bemidji and Ely WWTPs are treating to levels at or below 0.3 mg/L.

Privately owned wastewater treatment systems account for less than 0.5 percent of the total point source phosphorus discharged to the basins and increased phosphorus removal at these facilities will not have a large impact on the statewide point source phosphorus load.

Commercial and industrial dischargers to the basins constitute approximately 18 percent of the point source phosphorus load. It was not within the scope of this study to categorize the phosphorus loading data by NAICS code number or to determine which industries are the largest contributors. However, it is recommended that industrial dischargers that make major contributions to the phosphorus loadings be evaluated in further detail.

4.1.2 Cropland and Pasture Runoff

Four alternative agricultural management scenarios were investigated and compared to a baseline scenario involving an average climatic year and existing rates of adoption of conservation tillage and existing rates of phosphorus fertilizer applications.

The potential future impacts of improved phosphorus fertilizer management can be quite significant. Reductions in phosphorus fertilizer usage could occur if University of Minnesota recommendations were followed more consistently. For instance, phosphorus fertilizer and manure is spread on significant areas of land in the Minnesota River basin even if soil test phosphorus levels exceed the threshold set by the University above which crops do not respond to additional fertilizer. This is because recommendations made by the fertilizer industry are often based on the concept of fertilizing at a rate equivalent to crop removal, if soil test phosphorus levels are above 21 ppm. Excess applications in the past were considered cheap forms of insurance for crop yield needs and since even high soil phosphorus levels were wrongly perceived not to be released from soils the environmental impact was considered minimal. In the Minnesota River basin, reductions in the rate of phosphorus fertilizer and manure application could potentially reduce phosphorus losses to surface waters by about 81,000 kg/yr as compared to existing conditions, for a 16% reduction. Comparable levels of reduction could occur with improved phosphorus fertilizer management in the Red River, and the Upper and Lower Mississippi River basins.

The potential impact of improved manure application methods is significant in the Red River basin. Phosphorus loads to surface waters reduction estimates are about 75,000 kg/yr, for a 20% reduction in the Red River basin. Reductions are estimated to be much smaller in other basins with significant phosphorus loads from agricultural land. Improved manure application methods are estimated to reduce phosphorus loads to surface waters by 12%, 7% and 7% in the Upper Mississippi, Lower Mississippi, and Minnesota River basins. In general, the effects on phosphorus loads of improvements in method of manure application are greatest for basins that have large numbers of beef cattle, and least for basins with large numbers of hogs.

The last scenario involves decreasing or increasing the area of cropland within 100 m of surface waterbodies. Decreases in area of cropland could correspond to land retirement programs such as those promoted in the Conservation Reserve and Conservation Reserve Enhancement Programs. Increases in cropland area would correspond to putting grass or forest riparian areas into production, alternatively this could be viewed as increasing the amount for cropland areas that contribute phosphorus to surface waters. The results from this scenario indicate that retiring land in close proximity to surface waters would decrease the phosphorus loadings as expected. Retiring land farther away has diminishing returns as the distance from surface waters increases. It should be noted that throughout most of Minnesota, we believe that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for a significant amount of surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of P to surface waters from runoff and erosion on adjacent cropland.

4.1.3 Atmospheric Deposition

Soil dust is expected to be the largest source of atmospheric phosphorus. Therefore, reducing soil dust, particularly from agricultural fields, through the application of best management practices (shelterbelts, no till planting, use of cover crops, etc.) would seem to be a high priority. Another potential activity on a much smaller and local scale to reduce soil dust might include the periodic wetting of exposed soil at large construction sites during dry periods to minimize soil dust being entrained into the air due to wind erosion.

4.1.4 Deicing Agents

Efforts currently underway, as part of MnDOT's road weather information system (RWIS), use timely and accurate weather and road data in deicing application decisions to optimize the use of deicing materials. The Minnesota Legislative Auditor (1995) reported that "(M)ost counties (93 percent), cities providing their own service (91 percent), and townships providing their own service (59 percent) rely on television or radio weather reports, including the National Weather Service reports via telephone, for weather information." More accurate weather information could lead to reduced usage of deicing agents. The use of brines can also improve the effectiveness of deicing agents and thereby reduce the overall use of deicers.

The high phosphorus content of many of the agriculturally derived alternatives to road salt is noteworthy. In most cases the high phosphorus content for these alternatives is due to the corrosion inhibitor portion of the mixtures. Since concern for the environmental impacts of chlorides has increased, additional emphasis may be placed on the use of these alternatives. While this analysis does not make any attempt to quantify what those impacts would be, a review of the literature shows that many of these products have phosphorus concentrations 100 to 10,000 times greater than road salt or sand.

4.1.5 Streambank Erosion

There is the potential for substantial water quality benefits associated with lowering phosphorus export from streambank erosion; including reduced eutrophication, reduced sedimentation and improved biological habitat within reservoirs, lakes and wetlands, along with the river systems themselves. Careful land use planning that considers the potential adverse impacts associated with increased runoff volumes; well-designed stream road crossings that consider the potential hydrodynamic changes to the system; exclusion or controlled access of pastured animals and preservation of riparian vegetation; and rotational grazing. There are opportunities to reduce streambank erosion in watersheds that have experienced flow volume increases from land use changes.

4.1.6 Individual Sewage Treatment Systems/Unsewered Communities

Many of the counties are delegated to implement the Minnesota Rules (Chapter 7080) for ISTS, which require conformance with state standards for new construction and disclosure of the state of the existing ISTS when a property transfers ownership. Several counties require ISTS upgrades at property transfer. Lack of knowledge is thought to be a major impediment to making more rapid progress toward goals and objectives for ISTS and undersewered communities (MPCA, 2003b). This includes a lack of awareness of compliance requirements, management and operational requirements, and the environmental consequences of widespread system failure. The complexity of addressing undersewered community issues tends to discourage county compliance activity in this area. The availability of financial assistance, particularly low-interest loans, is thought to be an essential catalyst to accelerating fixes of nonconforming ISTS. This and other forms of financial assistance are needed to accelerate progress with undersewered communities (MPCA, 2003b).

Owners of ISTS that pose an "Imminent Public Health Threat," through direct discharge to tile lines or surface ditches or systems seeping to the ground surface should be identified through a statewide survey to help residents determine whether their ISTS are adequately treating and disposing of sewage below grade. Programs proposed to follow up on specific problems include homeowner education on compliance requirements and financial assistance to owners needing new systems. Residents of unsewered communities should be targeted to help them understand the need for wastewater treatment and assist them through each phase of the community decision-making process, while building the capacity of local and regional government staff to provide such assistance to other communities in the future (MPCA, 2003b). LUG ISTS permitting and inspection programs should be targeted with MPCA audits to determine adequacy of performance in a number of key areas, including spot checks on conformance on new ISTS installations, level of effort on ISTS inspections and follow-through on replacement of noncompliant systems, and dealing with problem ISTS professionals (MPCA, 2003b).

Since septic system failure is a widespread problem, a basinwide approach to addressing nonconforming systems with potential for high delivery of pollutants to public waters, such as straight pipe discharges and other types of ITPHS should be given priority attention. The LUGs should work with the MPCA to develop, populate and maintain a database, similar to MPCA's feedlot database that shows where each of the nonconforming systems, especially straight pipe discharges and other types of ITPHS are located. LUG personnel should be provided with an incentive to inventory all systems within their jurisdiction, and track system performance and maintenance.

4.1.7 Non-Agricultural Rural Runoff

The protection of natural areas is needed to insure they retain the hydrologic and ecologic functions that keep surface runoff volumes low, nutrient export low and groundwater recharge rates high. Many natural areas are under stress due to development pressures, invasion by exotic species and increased nutrient loading from adjacent land uses. While the statewide percentage of land cover represented by these natural plant communities is only 23%, they provide valuable ecologic and hydrologic value. All land use decisions should consider the loss of these functions, and provision of economic mechanisms that allow landowners to retain these functions.

Conservation easements, such as CREP and RIM, provide additional opportunities for reducing phosphorus export from contributory watershed areas. The impact of these easements on phosphorus export from converted agricultural lands is evaluated in greater detail as part of the analysis discussed in Appendix C.

4.1.8 Urban Runoff

The design, construction and maintenance of watershed BMPs will help reduce pollutant loads to surface waters. However, the current dependence of watershed managers and regulators upon "NURP-type" ponds will not prevent the degradation of surface water resources due to increased phosphorus loadings. While the NURP-style ponds can remove particulate phosphorus, they are relatively ineffective at removing soluble phosphorus (which can comprise up to 50% of the phosphorus in urban runoff). The phosphorus removal efficiency of ponds are also only in the 40 to 50 percent range, so that in many urban developments, the phosphorus load increase exceeds the removal efficiency of ponds. The ponds required by regulators to mediate the increased runoff therefore do not fully mitigate the increases in runoff loads. In essence the BMP treatment, whether ponds or otherwise, never keeps the post-development loadings at pre-development levels once impervious area surpasses 40 – 50% (Schueler, 1995). Another problem is that many urban planners assume that urban turf grass is an effective infiltrator of runoff, when in reality, most urban turf grows on highly compacted soils and can have a runoff rate of up to 45% during large storm events (Schueler, 1996a, 1996b; Legg, *et al*, 1996). Urban soils need to be protected from compaction during development/construction activities and likewise need to be actively managed to reduce compaction and increase infiltration over the long term. Water quality protection requires that all urban development design use a water budget approach, where the preservation of the infiltration and evapotranspiration components of the hydrologic cycle are primary considerations. Site planning that reduces impervious surface area and preserves infiltration will help attain water quality protection. Caraco, et al (1998) recommends that site design in urban areas create urban spaces that:

- Reduce impervious cover
- Spread runoff over pervious areas
- Utilize open channel drainage
- Conserve forests and natural areas
- Reduce the amount of managed turf and lawn
- Create more effective stream buffers and riparian areas

A number of stormwater management and urban best management practices manuals are available that provide design guidance for controlling the impacts of urban runoff and promoting infiltration (Metropolitan Council, 2001; Schueler, 1995; Brach, 1989; US EPA. 2001).

The National Pollutant Discharge Elimination System (NPDES) permit administered by the MPCA regulates runoff from construction sites, industrial facilities and municipal separate storm sewer systems (MS4s) to reduce the pollution and ecological damage. Phase I focused on large construction sites, 11 categories of industrial facilities, and major metropolitan MS4s. Phase II broadened the program to include smaller construction sites, small municipalities (populations of less than 100,000) that were exempted from Phase I regulations, industrial activity, and MS4s. At a minimum, compliance with the stormwater pollution prevention planning requirements of this permit program is critical to minimize the phosphorus loadings associated with urban runoff.

4.2 Recommendations for Reducing Uncertainty and Error Terms in Future Refinements

This section provides recommendations for reducing uncertainty and error in the estimated phosphorus loadings to surface waters from each source category, as part of any future refinements that may be made to this analysis.

4.2.1 Point Sources

The variability and uncertainty associated with the point source data sources has been discussed throughout this report. The following paragraphs provide a discussion of the variability and uncertainty associated with each data source and recommendations for future refinements. A more detailed discussion is included in Appendix B.

Each station under each permit in the Delta database is coded to list the type of discharge: surface water, land application, spray irrigation, internal waste stream, etc. Because this information is submitted by permitees for entry into Delta by MPCA staff, there may be some error due to interpretation and it is possible that some discharge stations may have been miscategorized.

There are several areas of uncertainty associated with the influent and effluent phosphorus loading estimates. These estimates are based on the flow data discussed above and the average annual phosphorus concentration. In many cases, phosphorus concentration data was limited to a few data points or not available at all. It was necessary to estimate the phosphorus concentration for many of the permitees. In addition, there was some variability among the phosphorus data for a permit when it was available. This identified a need for good laboratory analysis of phosphorus and reporting of quality assurance data. The study used annual average flowrates multiplied by the average annual phosphorus concentration to estimate the annual phosphorus load. The load could also have been calculated on a daily basis or monthly basis and then the average annual load calculated, resulting in different values.

Many of the influent phosphorus sources are based on per capita values and there is some uncertainty associated with the available population data. Approximately 230 of the 576 POTW and privately owned treatment facilities had population data listed in the Delta database. An attempt was made to validate some of the data, but due to the number of permits, it was not possible to verify all of the population data received.

Data was collected on commercial and industrial dischargers to the MCES system and several out-state POTWs. However, not all of these facilities had phosphorus monitoring data. The phosphorus data that was available was often based on a limited number of sampling events and there was some variability between industries with similar NAICS code numbers. For the unmonitored facilities, most of the commercial and industrial process wastewater phosphorus values were estimates based on the data set collected from industrial dischargers to the MCES system and to the other communities that monitored for phosphorus. Given the limited data set, there is likely a high level of uncertainty associated with the estimates for this source.

The information on the phosphorus contribution from water supply chemicals in municipal water treatment was based on information from the MDH. While the information received is likely valid, it was not complete. Phosphorus concentrations were provided for only 120 of the 360 facilities noted as adding phosphorus. The phosphorus residual in the remaining 240 water treatment facilities was based on an estimate using the average phosphorus concentration in the other 120 communities.

The phosphorus loading from residential ADWD detergents has some uncertainty associated with it due mainly to the population estimates. While the annual consumption of phosphorus in ADWD detergents reported (SRI, 2002) is likely an accurate number, the loading to the Minnesota basins was estimated based on a per capita value calculated from this national total. Because this estimate also relied on population data, there is some additional uncertainty associated with it due to the uncertainty in the population data discussed in a previous paragraph. The uncertainties associated with commercial and institutional ADWD detergents are similar to those discussed for the residential ADWD detergents.

The per capita value used to determine the food soils and garbage disposal waste contribution to the influent phosphorus loading to POTWs and privately owned treatment facilities was based on the average of three values obtained from studies conducted in the 1970s and 1980s, but they were in fairly good agreement. These data are more than 20 to 30 years old, which may introduce some uncertainty, since there has been a significant increase in the use of phosphorus in the food and beverage market. It follows then that there may be more phosphorus in the food disposed of down the drain. What is unknown is the trend in the amount of food and beverages disposed of down the drain. Also, because the food soils and garbage disposal wastes were based on per capita values, the loadings discharged to the treatment facilities are also based on the population served.

The method used to determine the dentifrice contribution to the influent phosphorus load to treatment facilities was based on a per capita value calculated from annual consumption in the U.S. This method assumes that Minnesota's dentifrice use is equivalent to that as the U.S. as a whole and because this is a per capita value and there is some uncertainty due to the population data.

The inflow and infiltration flow values were obtained from MCES and are estimates based on a few data points for each of their facilities. However, because the groundwater phosphorus concentration is quite low, even large variability in the flow values will not have a large impact on the total phosphorus to the POTWs from this source.

The phosphorus loading from human waste was calculated by difference. That is, all other estimated sources of phosphorus were subtracted from the total influent phosphorus load for each facility. This method of estimating the human waste phosphorus contribution leaves some uncertainty since it is based on all of the other source estimates. Therefore, the phosphorus contribution from human waste obtained by difference was compared to literature values. Literature values for phosphorus in human waste ranged from 1.6 g/p·d (*Siegrist et al.*, 1976) to 2 g/p·d (*Strauss*, 2000). The statewide flow weighted average for phosphorus in human waste was 1.53 g/p·d.

The following recommendations are made to improve the estimates of phosphorus point source loading to the basins in Minnesota:

1. Since the commercial and industrial loadings are a significant portion of the phosphorus load, additional monitoring of industrial effluent discharged to POTWs would improve the precision of estimates presented in this component.

2. It was not within the scope of this study to present or discuss the phosphorus contribution from individual industrial contributors of phosphorus to POTWs. It is recommended that this study be expanded to determine the specific industries that constitute the major phosphorus contributors.

3. This study assumed that the influent components of the POTW's and privately owned treatment plant's phosphorus from various sources were in the effluent in the same proportions as in the influent. A study on the percentage removal for the various sources at the different type of treatment plants would provide a more accurate estimate of the source of phosphorus loads to the waters of the state.

4. Many of the phosphorus sources discharge to POTWs were based on per capita estimates. Improving the population served data for each of the POTWs would improve the accuracy of these estimates.

5. Phosphorus data were not available for all permits. Increased phosphorus monitoring (both influent and effluent) would improve loading estimates. Good laboratory analysis of phosphorus and good quality assurance procedures would insure more accurate load calculations.

6. Calculation of phosphorus loads on a monthly basis and then totaled rather than on an annual basis would improve the estimates.

4.2.2 Agricultural Runoff

4.2.2.1 Cropland and Pasture Runoff

There are many possible sources of uncertainty in the estimated phosphorus loadings. These can be divided into errors in input data, errors in converting phosphorus index values to phosphorus export coefficients, errors in estimating the proportion of cropland that contributes to phosphorus loadings, and errors due to a lack of consideration for impacts of surface and subsurface drainage, wind erosion or snowmelt runoff on phosphorus loadings. The primary sources of errors in input data include those due to spatial variations in farm management practices at scales smaller than watersheds or agroecoregions, errors in estimating slope length for erosion calculations, and errors due to out of date landuse information (all cropland estimates in the contributing corridor around surface water bodies are based on 1992 landuse data). Appendix C provides a more detailed discussion about uncertainties in these phosphorus loading estimates.

The assumption made about the contributing corridor represents a source of uncertainty. In most of Minnesota, it its believed that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. This is consistent with research results from across the country, and with recommendations of the primary group of soil scientists conducting research on phosphorus transport to surface waters (the SERA-17 group). Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for significant surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of P to surface waters from runoff and erosion on adjacent cropland. Errors can also arise from improperly estimating the area of cropland within 100 m of surface water bodies. Also, the area of cropland within 100 m of surface water bodies was not varied when computing basin scale phosphorus loadings for dry, average, and wet years.

Our primary method of estimation does not consider the influence that surface tile intakes farther than 100 m may have on phosphorus loadings. To include the effects of surface tile intakes we would need to know the number of tile intakes per unit area, the area of cropland contributing to tile intake flow, and the phosphorus export coefficients for surface tile intakes. These data are not available for Minnesota in enough detail to be confident about their representativeness. Similarly, our primary method does not consider the influence of subsurface tile drainage on phosphorus export to surface waters. Surface and subsurface tile drainage load was estimated in the Minnesota River basin, but as concluded in Appendix B, more research is needed to accurately define the mean and range in phosphorus loading from subsurface drainage tiles. Other than the Minnesota River basin, subsurface drainage phosphorus loads were not estimated. The load from other basins would be much smaller, because tile drainage is of limited extent in basins other than the Minnesota River basin. In addition, 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 described above, this approach could substantially overestimate the phosphorus loadings in dry years.

Finally, we do not explicitly account for the effects of wind erosion or snowmelt runoff on phosphorus loadings to surface waters. Wind erosion may be particularly important in the Red River basin. It is not expected that wind erosion estimates, which represents a portion of the atmospheric deposition loadings completed for this study, would adequately account for "low level" wind blown soil deposited in drainageways. Snowmelt erosion is indirectly accounted for in the regional phosphorus index through the runoff factor, as well as in the method of manure application factor, so this error may not be large.

This study provides a broad overview of the impacts of agricultural lands on phosphorus loadings to surface waters. There are many detailed questions remaining that should be studied in further detail. Some of these are listed below:

- Comparison of watershed based phosphorus loadings with agroecoregion based phosphorus loadings at the scale of major watersheds
- Development of phosphorus delivery ratios for agricultural as well as non-agricultural sources of phosphorus as a function of area of contributing watershed, area of lake and wetland storage in the watershed, and landscape characteristics
- Investigation of the impacts that farm scale variability has on estimated phosphorus loadings within watersheds
- Further study of the distance from surface waters within which the majority of phosphorus losses from cropland to surface waters originate

- Further investigation of the variable source area concept as applied to phosphorus transport during dry, average and wet climatic years

- Further investigation of the contribution of surface tile intakes and subsurface drainage to phosphorus loads

- Study of the impact that wind erosion has on phosphorus loading to surface waters

4.2.2.2 Feedlot Runoff

There are several possible sources of uncertainty in the estimated phosphorus loadings from feedlot runoff. These sources of uncertainty are discussed in more detail in Appendix D. In addition, 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 runoff;

- Silage leachate runoff, which has high concentrations of phosphorus, but relatively low volumes;

- 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 number raised outside or the runoff from poultry manure stockpiles was considered negligible for basin-wide analysis.

- Runoff from pasturing animals, including animals with direct access to surface waters.

The following areas of uncertainty and variability exist in this 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. 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** – 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 varies significantly from the statewide average for several basins, but this variability was not accounted for in the analysis. Due to a lack of basin-specific information, it was 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 for from feedlots that were considered to be in compliance with state feedlot rules. Also, it was assumed that all of the animals in feedlots with open lots contribute manure to the open lot. 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. 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 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 with 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.

Based on the primary uncertainties in this analysis 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, as summarized below:

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.

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.

4.2.3 Atmospheric Deposition

The following recommendations are made to minimize uncertainty and improve the estimates of atmospheric (wet and dry) phosphorus deposition:

1. Additional one to two years of monitoring for [P] and [Ca] in precipitation to improve the ability to extrapolate the findings from the research sites to other locations in the state

2. Additional sites should be included in the wet deposition monitoring network, particularly in southwest and western Minnesota, to identify significant regional differences in the [P] and [Ca] relationship, and further improve the ability to extrapolate the findings to other locations

3. Assess the variability in annual dry deposition in relation to changes in annual precipitation to determine the significance of this project assuming dry deposition is constant for low, average, and high precipitation years

4. Determine the phosphorus deposition rate of the collected PM10 filters and verify the assumption that the [P] to [Ca] ratio in dry depositon is the same as that in precipitation

5. Additional particulate monitoring (TSP, P, PM10) in other areas of the state should be conducted, with a particular emphasis on rural areas, to determine whether extrapolation of the particulate filter data to larger regions or river basins is appropriate

6. A source apportionment study, using chemical mass balance or similar approach, for phosphorus should be conducted to determine if sources other than soil are significant, or could be significant, for phosphorus deposition

4.2.4 Deicing Agents

All of the loading estimates prepared for phosphorus from deicing agents were based upon information reported by road maintenance agencies whenever possible (see Appendix F for more discussion). MnDOT and other agencies readily acknowledge that better record keeping is needed and better measurements are needed to document the actual usage numbers. While MnDOT data is of relatively high quality, the near absence of local road agency data for use in this analysis creates concern for the accuracy of the final numbers beyond those for state maintained roads, given the amount of variability that currently exists due to year-to-year weather patterns and the resulting deicer usage patterns. To further evaluate the uncertainty, the actual MnDOT usage data was confined to the 1996 – 2003 time period, as it includes MnDOT operations since the start of implementation for the Salt Solutions study recommendations and most accurately represents current deicer use trends for the state highway system (Vasek, 2003).

A state-wide sum of salt and sand usage for MnDOT maintained roads and the reported state-wide deicer use data from MnDOT allowed for an analysis of the loading estimate uncertainty against actual application information. The estimation methods were assessed against actual MnDOT usage levels and the results were summarized for the wet, average and dry years based upon a comparison to actual application quantities for similar years. The usage estimation for sand and salt usage, and thus the phosphorus load estimates from MnDOT uses for the three scenarios were reasonable given the limitations of the data (+/- 22%). The MnDOT salt usage estimate for the "average" year, i.e., for those years of data upon which the other scenario estimates were constructed has a smaller error than for the sand and brine. The error for Brine is about 30%, but the phosphorus loading due to brine is less than 0.001% of the total phosphorus load and thus is insignificant. Without further data for other road agencies the accuracy of the other estimates can only be assumed to be similar.

Much of the phosphorus content analysis for these deicing agents has been collected from widespread sources having differing and sometime poorly documented analysis methods. The limited number of studies and the ongoing citation of a few early studies by current investigators suggest that more analytical studies on deicing agents and phosphorus should be completed. The summary statistics for the data on salt and sand gleaned from the literature highlight the relative lack of data on the subject and the variability of concentrations. A data set that is confined to deicing agents used in Minnesota would provide a more accurate estimate of the loads.

4.2.5 Streambank Erosion

The variability and uncertainty of the phosphorus loading computations done for this analysis can be attributed to each of the following sources of error (described in more detail in Appendix G):

- The natural variability associated with the published streambank erosion and sediment yield data
- The uncertainty that is introduced in this analysis as a result of extrapolating the monitored sediment yield data to the unmonitored areas for each ecoregion
- The variation in sediment yield within each ecoregion

- The assumptions that the Simon and Hupp (1986) model of channel evolution applied to Minnesota streams and the slope of the suspended-sediment rating relationship could be used to characterize stable versus unstable streams, based on data published in Simon (1989a)
- The standard error in the regression between the slope of the suspended-sediment rating relationship and the sediment yield
- The assumption that the probability plot of Blue Earth River streambank erosion rates from Sekely et al. (2002) could be utilized to estimate the variation of streambank erosion during low and high flow conditions for the remaining streams in the state
- The variation in the total phosphorus concentration of the sediment eroding from streambank escarpments throughout the state

Many areas of the State have not been adequately sampled for definition of sediment-transport characteristics. Only a few or no sediment samples (with corresponding discharges) have been collected from most of the streams in northern and central Minnesota, with almost no samples present for the Northern Minnesota Wetlands Ecoregion (Tornes, 1986; Simon et al., 2003). Some rivers in west-central Minnesota, parts of the Red River of the North, the Rock River, and the Pomme de Terre River drain areas underlain by clayey or loess soils may have sediment yields that are similar to those in the southeast part of the State (Tornes, 1986). In addition, no sediment-transport curves or erosion assessments have been published for streams in the St. Croix River basin. The current lack of sediment-transport data and erosion assessments throughout the state make it difficult to adequately ascertain the impacts of streambank erosion, especially as it pertains to impaired biota. Collecting more data for streambank erosion assessments can be used to further refine this analysis, reduce the current level of uncertainty, and improve the understanding of the linkage between sediment and phosphorus loadings with biological impairments.

The MPCA should install continuous flow monitoring equipment, and begin developing stage-discharge-sediment transport curves, as a means of assessing erosion within some of the existing State milestone monitoring watersheds, that are not currently being monitored by the USGS. Additional streambank erosion assessments should be done in conjunction with stream water quality and biological monitoring, and channel evolution stage determinations, to develop and refine empirical models and provide a better understanding of the impacts of streambank erosion throughout the State. One such assessment, recently completed by the MPCA, was done to evaluate the relationship between suspended sediment transport, stream classification and fish index of biological integrity (IBI) scores (Magner et al., 2003). All of these assessments should also be done to evaluate streambank erosion during low and high flow conditions and address the variability and uncertainty associated with the estimates presented here. Also, more total phosphorus data should be collected from eroding streambanks across the state to further evaluate how much of the phosphorus loading is entering the streams from upland sources versus fluvial processes. Additionally, the connection of streambank erosion with land use changes causing hydromodifications needs to be better documented.

4.2.6 Individual Sewage Treatment Systems/Unsewered Communities

The primary sources (and estimated magnitudes) of variability and uncertainty in the total phosphorus loading computations done for this assessment (see Appendix H) include:

- Percentage of phosphorus attenuation in soil absorption field for permanent and seasonal residences—(these percentages are likely to vary by 50 percent or more, depending on the proximity to surface water, soils and water table characteristics, etc.; if the all of the conforming systems from the remaining ISTS category removed 100% of the P load produced, the 140,510 kg total P load discharged to surface waters would be reduced by approximately 30%)

- Portion of undersewered communities receiving various levels of treatment, more or less than septic tank removals (as assumed)—(these percentages are likely to vary by 50 percent or more, as some of the undersewered communities may be receiving good treatment with soil absorption, while others may not even receive treatment from septic tanks)

- Population of undersewered communities—(population figures may vary significantly within each basin depending on each counties ability to determine, report or verify and update the presence and population of undersewered communities)

- Population served and portion of direct-to-tile ISTS receiving various levels of treatment, more or less than septic tank removals (as assumed)—(these values are likely to vary by 100 percent or more, as the number of systems and population served are extrapolated from a small subset of areas studied in the MRAP which may or may not have already been counted with the ITPHS percentages, and some of the direct-to-tile ISTS may not even receive treatment from septic tanks)

- Population served and per capita P loadings for permanent versus seasonal residences—(the current P loading estimates assume that all of the population served by seasonal residences

[2.1 people per seasonal residence for 4 months each year] is in addition to all of the P loadings generated by the current permanent residents of Minnesota, which may overestimate the P load from permanent Minnesota residents that maintain seasonal residences, but helps to offset both the fact that seasonal residences may be under-represented in the databases and the fact that people from other states maintain seasonal residences; in addition, the per capita loadings for dishwashing detergents and dentifrices are based on actual nationwide consumption, while the per capita loadings for human waste and food soils are based on monitoring of permanent residences)

The following refinements are recommended to reduce the error terms or uncertainty of the phosphorus loading estimates:

- LUGs should work with the MPCA to develop, populate and maintain a geographic database, similar to MPCA's feedlot database that shows where each of the failing systems, straight pipe discharges and other types of ITPHS are located
- LUG personnel should be trained to assess the proper functioning of each type of system and be provided with an incentive to inventory all systems within their jurisdiction, and track system performance and maintenance
- The estimates for population served by conforming and nonconforming systems, as well as unsewered communities and direct-to-tile ISTS, should be refined, updated and linked to a geographic database
- Additional analyses should be done to study the treatment effectiveness of conforming and nonconforming treatment systems, throughout the state, to evaluate the variability of the estimated phosphorus loadings to surface waters under various settings

4.2.7 Non-Agricultural Rural Runoff

The variability and uncertainty of these phosphorus loading computations and assessment is currently difficult to assess due to the lack of monitoring data that would allow a rigorous evaluation of the application of the concepts of contributory area and the use of the basin runoff factor (see Section 2.2.2.6 and Appendix I).

Refinement of the application of export coefficients to Minnesota watershed will require further monitoring and research into the development and application of transmission coefficients. This work will require more detail investigation into the relationships that exist between phosphorus-flux coefficients, land use export coefficients, and transmission factors and their impact on the effective contributory area for large watersheds. As was seen in the literature review, many of the export coefficients for natural vegetation were developed on very small sites. Larger scale studies, comparable to the work by Sartz and others in the driftless area should be undertaken.

The width of the effective contributory area has major implications for water quality management. Much of the research conducted on buffer systems provides some insight into contributory watershed area functions. However, refinement of the interactions of soil type, topography and vegetative cover on the transmission of phosphorus to surface waters needs further research. Research and monitoring efforts on this topic should include GIS modeling efforts to help define these relationships and allow for state-wide spatial database development.

4.2.8 Urban Runoff

In an effort to define the accuracy of the pollutant loading estimates derived from the regression equations (see Section 2.2.2.7 and Appendix J), a comparison was completed using FLUX calculated loads for the Minneapolis Chain of Lakes watershed. This assessment was completed on the residential watersheds that had direct storm water flow from the 1991 monitoring stations. All of the sites had continuous flow measurement and flow-composite runoff samples; the data was reduced to a flow-weighted mean concentration using FLUX (MPRB, 1993; Walker, 1986). Not all of the watersheds assessed in the Chain of Lakes project were included in the assessment, as a number of them had upstream wetlands or large areas of natural land cover that attenuated the phosphorus loadings.

For purposes of this loading variability and uncertainty discussion, the loading regression equation developed for this assessment was used to calculate loads to the eight watersheds. All of the load estimates were calculated using the 1991 monitored flow volumes. The 1991 FLUX-derived loadings based upon FWMC concentrations were considered the baseline loadings. Annual loadings were also estimated using the mean 1991 EMC for each specific watershed, using a national EMC for residential watersheds of 320 µg/L (Center for Watershed Protection, 2003), and the regression equation result of 326 µg/L. The loads calculated with the national EMC for residential watersheds and the regression equation were 100.6% and 102.5% of the FLUX model loadings, respectively. The results of the regression equation are very similar to the monitored loads.

The regression equation developed for the urban land use loads estimation explains 19% of the variance for stormwater using precipitation and impervious percentage, which shows that there is considerable variability in the water quality of urban runoff due to several factors. Refinement of the load estimate for phosphorus in urban runoff will require that additional, long-term monitoring sites be established across the state. Most of the long-term monitoring locations used for the regression equation development were located within the Twin Cities metropolitan area or other large cities. There were some out-state sites but most lacked multiple years of data or were quite old and therefore were not appropriate for this assessment.