E1. Comparing Source Assessment with Monitoring and Modeling Results

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The source assessment of Nitrogen (N) delivery to surface waters, as conducted by the University of Minnesota and the Minnesota Pollution Control Agency (UMN/MPCA) and described in Chapters D1 to D4, have areas of uncertainty. For example, one area of uncertainty is the quantity of N reaching surface waters from the cropland groundwater component. This uncertainty stems largely from: a) limited studies quantifying leaching losses under different soils, climate and management; and b) extreme variability in denitrification losses, which can occur as groundwater slowly flows toward rivers and streams. Another area of uncertainty is the tile drainage acreages, which were estimated based on soils, slopes and crops, and which have been increasing at during the previous few years.

Because of these and other source assessment uncertainties, we compared the N source assessment results with other related findings, using five different ways to check the findings as follows:

1) **Monitoring results** – Comparing HUC8 watershed and major basin scale monitoring results with loads estimated by summing the source estimates (Chapter E1).
2) **SPARROW model** – comparing modeled estimates of major source categories to source assessment findings (Chapter E1).
3) **HSPF model** – Comparing Minnesota River Basin HSPF modeled estimates of sources, pathways and effects of precipitation with the source assessment findings (Chapter E1).
4) **Watershed characteristics analysis** – Comparing watershed and land use characteristics with river monitoring-based concentrations and yields (Chapter E2).
5) **Literature review** – Comparing findings of studies in the upper-Midwest related to N sources and pathways with source assessment findings (Chapter E3).

In this chapter, N source estimates reported in Chapters D1 to D4 are compared with the first three approaches noted above, including: 1) monitoring-based load calculations; 2) SPARROW modeling source category results; and 3) HSPF modeling of the Minnesota River Basin. Subsequent chapters include the Watershed Characteristics Analysis (Chapter E2) and Literature Review (Chapter E3).

Monitoring results comparison with sum of source loads

Monitoring results obtained near major basin outlets (1991-2010) and near HUC8 watershed outlets (2005-09) were compared with the sum of individual source load estimates documented in Chapters D1-D4. The purpose was to see how closely the sum of individual source loads compared to loads calculated from major river and watershed monitoring. With the exception of urban nonpoint source and forest N loss coefficients, which were based on small scale watershed monitoring, the source estimates were determined from methods that did not involve watershed monitoring. Since the monitoring data used in this comparison was not used to derive any of the source load estimates, it represents an independent check of the source assessments.

It is important to note that there are three important limitations associated with this comparison. First, the source estimates in Chapters D1-D4 do not consider N losses within streams, rivers or reservoirs. The source estimates are expected delivery to the stream; not delivery within the streams. Losses within streams can be minimal to substantial, depending on the hydrologic conditions. For example, reservoirs with a long residence time can result in large decreases of N from algal uptake and subsequent settling to the reservoir bottom, and to denitification. Due to this issue, the sum of the estimated source loads by the UMN/MPCA would be expected to be higher than the monitoring-based loads, if everything else was equal.

Second, the source estimates do not consider the time lag between when nitrate leaches below the root zone in the soil to the time that it moves into and through groundwater and ultimately discharges into the stream. This lag time is particularly important with the groundwater flow pathway below cropland, and could cause monitoring results to be lower than the source assessment results in watersheds which are largely influenced by groundwater transport, such as in karst and sand plain regions.

The third limitation in comparing the source estimates with monitoring results is the challenge of obtaining representative monitoring-based load results. Nitrogen loads can vary tremendously from year to year due to climatic differences. Additionally, load calculations from monitoring information have uncertainty because samples are not collected continuously. The effect of this third limitation was minimized by using long-term average loads for the major basins analysis. For the HUC8 watershed load analysis, we used two-year averages from years without extremely low or high annual flow volumes, and limited the watersheds to those which had two years of monitoring-based load calculations during "normal" flow years between 2005 and 2009, as described in Chapter B3.

While recognizing these anticipated differences between watershed source assessments and watershed monitoring results, the comparison of findings from watershed monitoring with estimated loads from cumulative source estimates can still be useful as an indication of whether the source estimates are generally reflecting actual watershed loading conditions. This validation at larger scale watersheds is important since the source assessment was conducted by using mostly smaller field-scale research/monitoring and expanding the results to larger scales through the use of statewide geographical spatial data.

The source assessment results would need to be questioned if the monitoring results and the sum of the source assessment results were markedly different in watersheds without: a) large reservoirs or other identified N transformation processes; b) extreme climatic conditions during monitoring years; or c) some other scientific explanation. If, on the other hand, the monitoring results and the sum of the source assessment results are reasonably close, then we can have a greater level of confidence in the source assessment results. A reasonably close comparison does not prove the complete validity of the source assessment results, but provides one line of evidence that the source assessment may be providing reasonably accurate estimates.

Basin level comparison with monitoring

Monitoring of Minnesota's major rivers is described in Chapter B2. The total nitrogen (TN) loads based on monitoring of major rivers were compared to the sum of N sources to waters in those same basins for average, wet, and dry years (Figures 1 to 3).

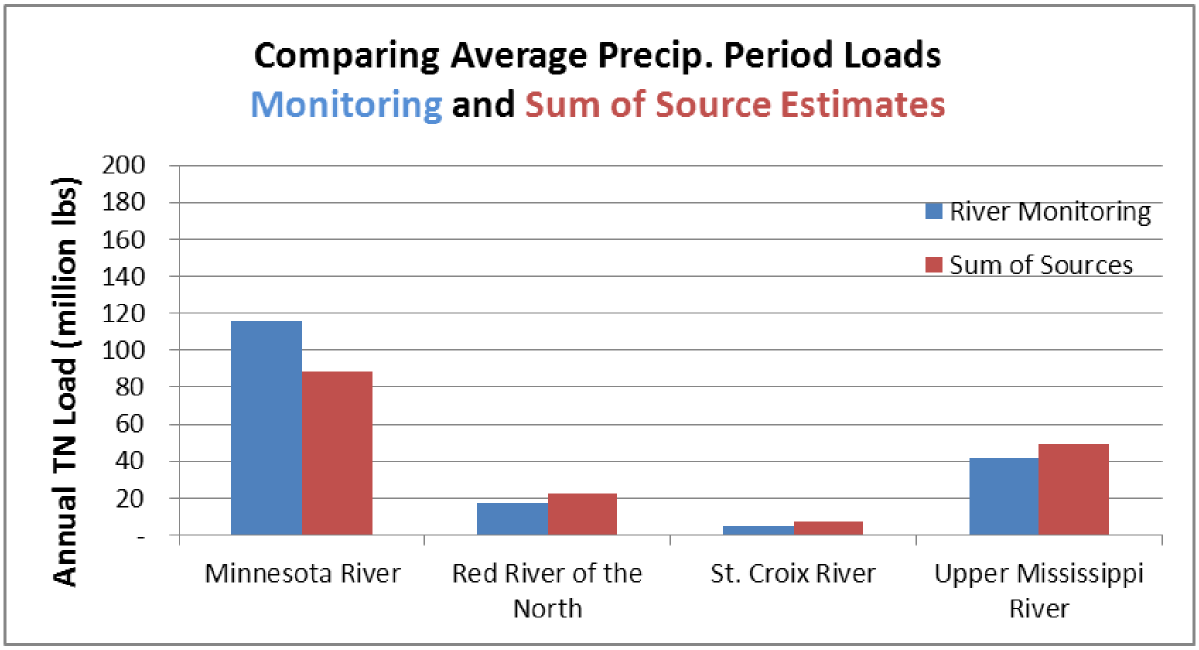

Figure 1. Average TN loads based on monitoring (avg. 1991-2010) of the Minnesota River (Jordan), Red River (Emerson), St. Croix River (Stillwater) and Upper Mississippi River (Anoka), as compared to the sum of estimated N sources to waters for average precipitation conditions.

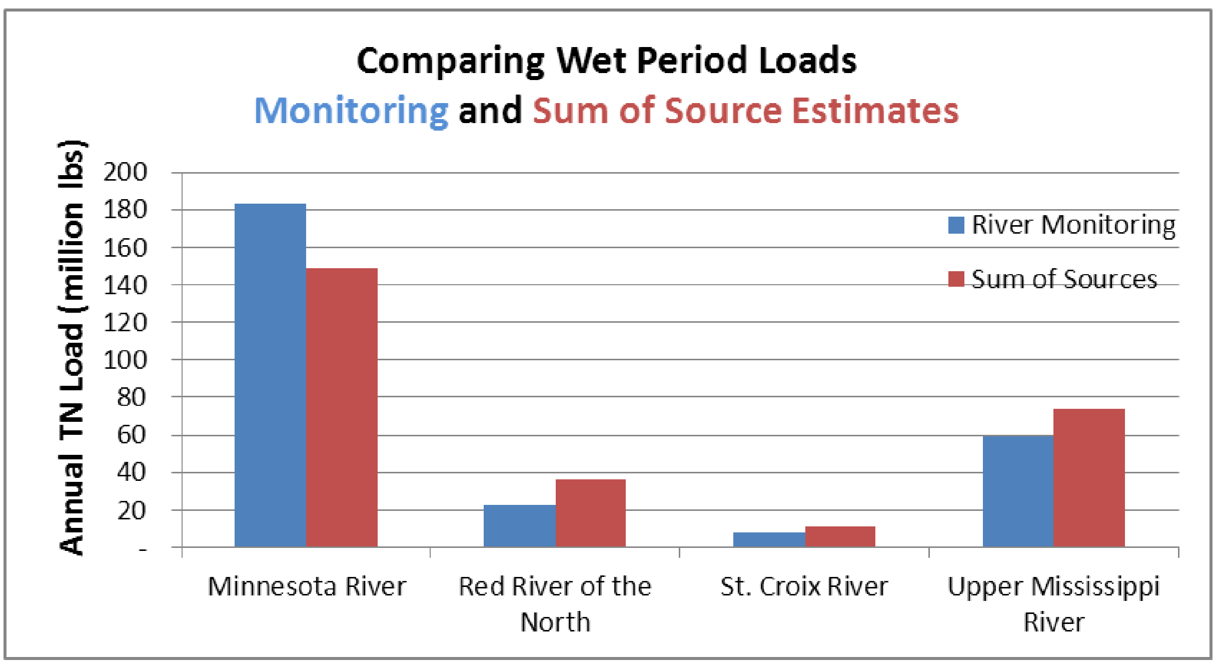

Figure 2. Wet period (90th percentile) TN loads based on monitoring (avg. 1991-2010) of the Minnesota River (Jordan), Red River (Emerson), St. Croix River (Stillwater) and Upper Mississippi River (Anoka), as compared to the sum of estimated N sources to waters for wet period conditions.

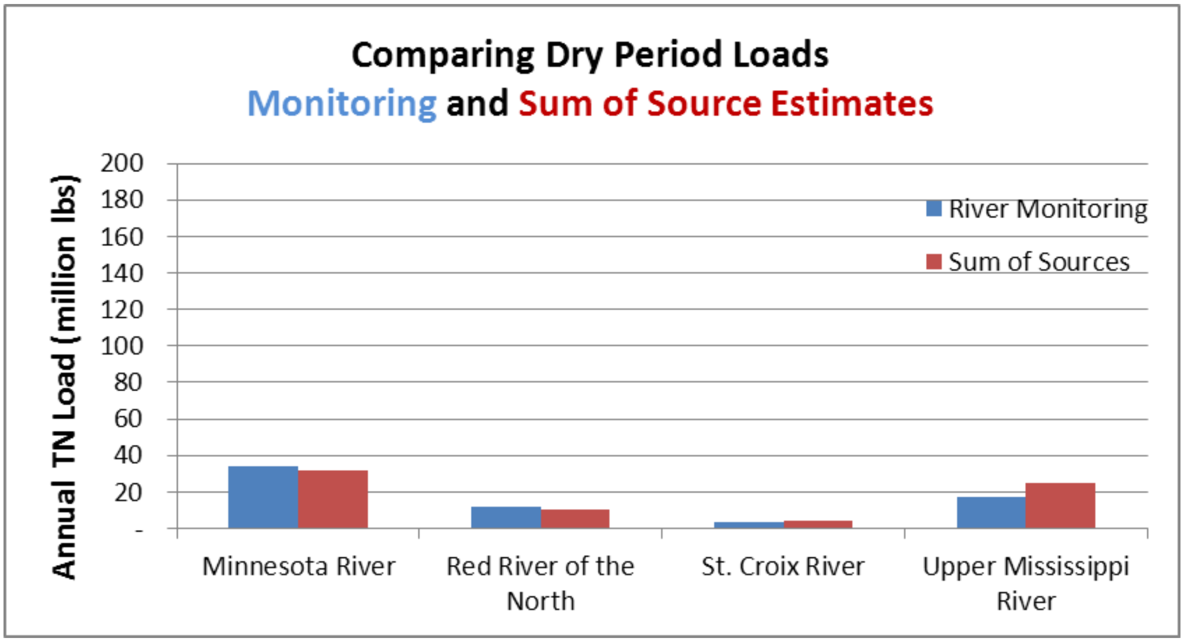

Figure 3. Dry period (10th percentile) TN loads based on monitoring (avg. 1991-2010) of the Minnesota River (Jordan), Red River (Emerson), St. Croix River (Stillwater) and Upper Mississippi River (Anoka), as compared to the sum of estimated N sources to waters for dry period conditions.

Even with the limitations of this type of comparison, the source assessment based loads at the major basin scale were reasonably similar to the monitoring-based results. The relatively close comparison is particularly remarkable when considering that river/stream monitoring results were not used to develop the nonpoint source and point source load assessments, nor were they used to calibrate the source-based load estimates.

In the Minnesota River Basin, the 20-year average monitoring-based results were slightly higher than source-based estimates for the Minnesota River Basin (Jordan). Monitoring-based loads were 31%, 23%, and 8% higher than source-based estimates during average, wet and dry periods, respectfully. As previously noted, we would expect the monitoring results to be less than the sum of sources in areas that are not dominated by groundwater nitrogen inputs to streams. This is because in-stream nitrogen losses are not accounted for in the source assessment, but they are inherently reflected in the monitoring results. Therefore, it is likely that in this basin, which has nitrate levels controlled more by tile drainage than groundwater inputs, the source assessment is under-predicting the sources.

In the other basins, the monitoring-based loads were lower than the source-based estimates. In the Red River Basin (Emerson, Manitoba) monitoring-based loads were 78%, 61%, and 115% of source-based estimates during average, wet, and dry periods, respectfully.

The St. Croix River loads are considerably lower than the other three major rivers during all three precipitation conditions. In the St. Croix River (Stillwater), monitoring-based loads were 69%, 74%, and 89% of source-based estimates during average, wet, and dry periods, respectfully.

In the Upper Mississippi Basin (Anoka), monitoring-based loads were 84%, 80%, and 71% of source-based estimates during average, dry, and wet periods, respectfully.

The relatively close comparison indicates that at the basin scale, the monitoring results alone do not provide a reason to suggest that the source estimates are unreasonable.

HUC8 level comparison with monitoring

Chapter D4 presented a comparison of HUC8 level monitoring results with the nonpoint source (NPS) load estimates in corresponding watersheds. Two analyses were presented: 1) bar graphs showing NPS load estimates with monitoring-based load averages obtained from one to multiple years of monitoring in each watershed; and 2) an X-Y plot showing correlation between NPS load estimates and monitoring-based loads obtained by averaging monitoring results. A discussion of these comparisons is included in Chapter D-4.

In this section of the report, monitoring-based results from average loads during normal flow conditions are compared with the sum of the estimated nonpoint source loads, point source loads, and atmospheric deposition falling directly into rivers and streams.

The 28 watersheds and associated monitoring-based data used for this comparison are described in Chapter B3 under the section "Independent HUC8 Watershed Loads (mid-range flow averages)." The monitoring results are only from those watersheds which are independent HUC8 watersheds (not influenced by upstream main stem rivers) and which had two-year average load results obtained during years with mid-range river flows (between 2005 and 2009). Therefore, the monitoring results are a) recent; b) do not depend on a single year of monitoring; c) do not include extreme dry or wet years; and d) are not influenced by water flowing into the watershed from upstream main stem rivers.

Source load estimates were derived by adding point source contributions from Chapter D2, NPS contributions Chapter D4, and atmospheric contributions directly into rivers and streams from Chapter D3.

The comparison shows that most of the HUC8 watershed monitoring results are reasonably similar with the sum of source loads (Figure 4), especially when considering that the source load estimates were mostly derived from small-plot and field scale research rather than watershed scale monitoring, and that the sum of sources does not include in-stream N losses. Yet there are also some notable differences in certain watersheds.

Monitoring results in the Blue Earth and LeSueur watersheds show substantially higher loads than the sum of the sources. Since the point source contributions in these watersheds are rather small in comparison to nonpoint sources, the lower estimates from the source assessment could be due to an underestimate in the nonpoint source load estimates in these watersheds. Some possible reasons for these differences are discussed by Mulla et al. in Chapter D-3. One watershed that had sum of source estimates considerably higher than the monitoring results was the Chippewa River, indicating that sources may have been overestimated for this watershed or that large in-stream N losses are occurring in this watershed.

The results at the HUC8 level monitoring and basin levels both indicate that source estimates may be reasonable for both scales, but that they are better suited for large scale use, such as the basin level.

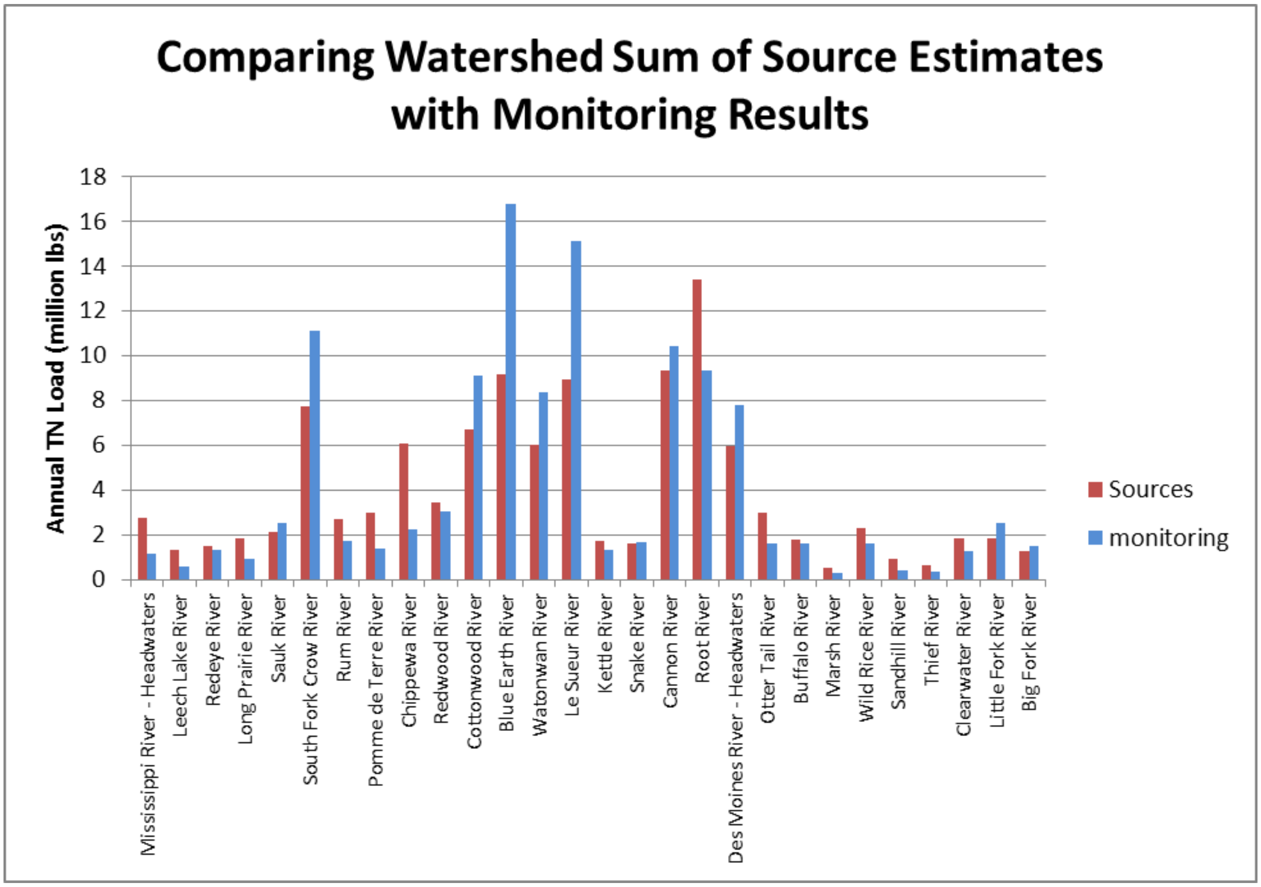

Figure 4. Two-year normal flow average TN loads based on monitoring within the 2005 to 2009 timeframe for independent HUC8 watersheds, as compared to the sum of estimated N sources to waters for average precipitation conditions.

SPARROW nitrogen delivery to receiving waters by source category

The SPARROW model was used to estimate the delivery of nitrogen to receiving waters by major source categories of: agriculture, wastewater point source, and non-agricultural nonpoint sources to waters. The SPARROW modeling effort for this study is described in more detail in Chapter B4. Background information about the SPARROW model is included in Appendix B4-1. The SPARROW model results were compared with the UMN/MPCA source estimates to waters from Chapters D1-D4. While the source categories from the SPARROW modeling in Chapter B4 and the UMN/MPCA source estimates from Chapters D1-D4 were originally categorized differently, we were able to lump the source assessment findings into like categories for comparison purposes, as follows:

"Agriculture" sources include the cropland tile drainage, cropland groundwater and cropland runoff from the UMN/MPCA source assessment.

"Non-agricultural Nonpoint Sources" include all other sources which are not included in the agriculture or point source categories. SPARROW outputs label this as atmospheric deposition, and it includes atmospheric deposition and other non-agricultural nonpoint sources which are carried to waters by precipitation.

The SPARROW modeling approach is very different than the approach used by UMN/MPCA to estimate N source loads. The SPARROW model leans heavily on statistics and monitoring-based load calculations.

The UMN/MPCA source estimates were developed mostly from small scale research, multiplied to larger scales through the use of GIS data layers.

The results of the comparison between SPARROW load estimates and the UMN/MPCA load estimates by source are quite similar for the broad source categorizations evaluated (Figures 5 and 6). SPARROW estimates of the percent of load coming from point sources was slightly lower than UMN/MPCA estimates (7% vs. 9%). Estimated agricultural contributions for the state are nearly the same with these two approaches (72% with the UMN/MPCA source assessment approach and 70% with the SPARROW model).

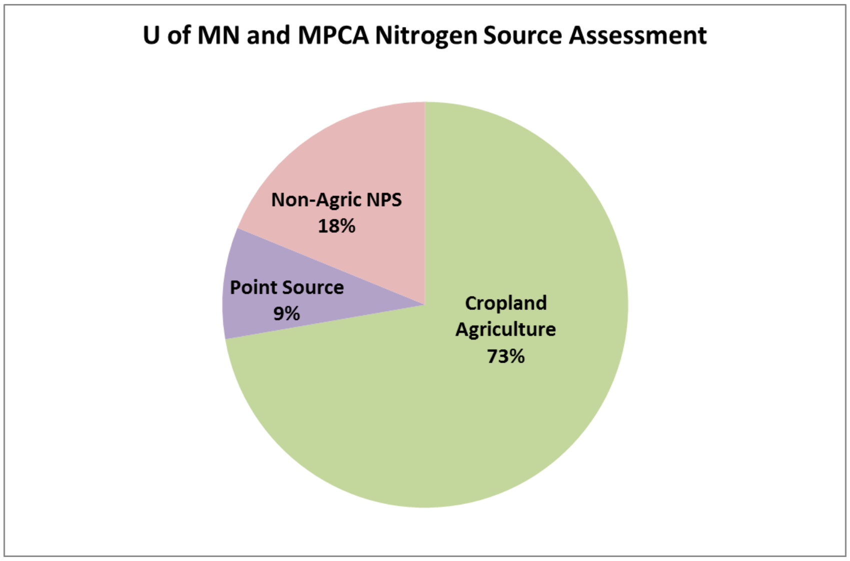

Figure 5. Minnesota statewide nitrogen sources to surface waters developed by the University of Minnesota and MPCA, (from Chapters D1-D4).

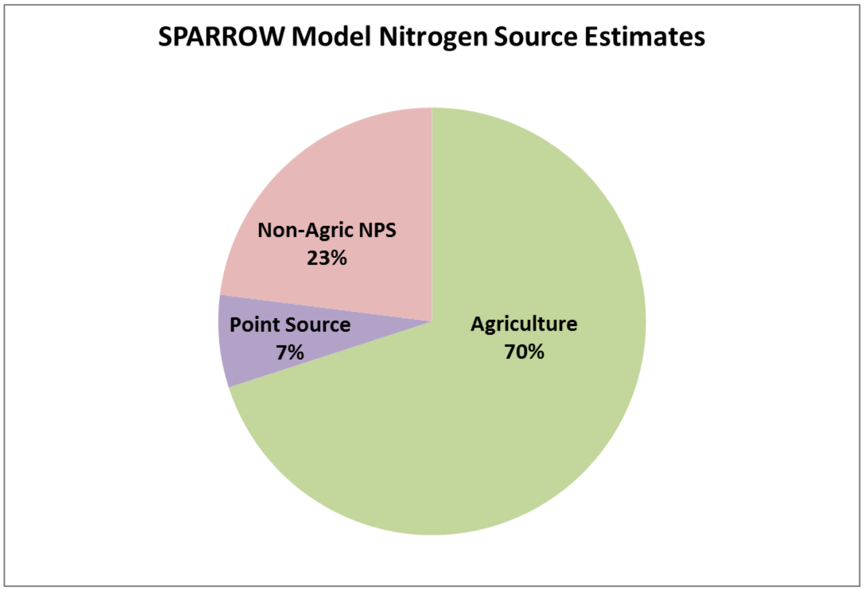

Figure 6. Minnesota statewide nitrogen source estimates for nitrogen delivery to surface waters based on the SPARROW model, as described in Chapter B4.

The close comparison of the SPARROW model source estimates provides another indication that the UMN/MPCA source assessment is reasonably accurate, at least within the broad categories of this comparison.

HSPF modeling – Minnesota River Basin

The Hydrological Simulation Program - FORTRAN (HSPF) model, as applied to the Minnesota River Basin, was used to evaluate NPS inorganic N: a) transport pathways to surface waters; b) sources to streams; and c) effects of wet and dry years on loads. The Minnesota River Basin has the highest N loads in Minnesota, contributing nearly half of all N which leaves the state in the Mississippi River. Since HSPF modeling for other basins was not completed at the time of this study, we were only able to compare Minnesota River Basin HSPF results to the UMN/MPCA source assessment results.

HSPF modeling results for all years between 1993 and 2006 were used to assess source and pathway findings. These results were then compared to the UMN/MPCA estimates presented in Chapters D1 to D4. HSPF uses a very different modeling approach than either the SPARROW model or the UMN/MPCA source assessment methods in sections D1-D4, allowing another rather independent check of source assessment results.

Only inorganic N loading was assessed with the HSPF model for this analysis. Long term monitoring results presented in Chapter B2 showed that inorganic N represents 85% of the TN load in the Minnesota River Basin (at Jordan). Point source discharges, which represent an estimated 4% of the TN long-term average load in the Minnesota River Basin, were not included in this HSPF modeling assessment.

HSPF model background

The HSPF model is a comprehensive model for simulating watershed hydrology and water quality for both conventional pollutants such as nutrients, and toxic organic pollutants. HSPF incorporates the watershed-scale Agricultural Runoff Model (ARM) and NPS models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. HSPF allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at the outlet of any subwatershed.

The quantity of water discharged in surface streams is characterized in the HSPF model by surface runoff, interflow and baseflow. Surface runoff is the water flow that occurs after the soil is infiltrated to full capacity, and excess water from rain, meltwater or other sources flows over the land. Surface runoff is observed in river hydrographs soon after the runoff event. In addition to direct overland runoff, this component of flow can also include runoff which enters waters quickly through open tile intakes and side inlets to ditches. Interflow is water that first infiltrates into the soil surface and then travels fairly quickly in the subsurface to stream channels, reaching streams after surface runoff, but ahead of baseflow. A large component of interflow is tile drainage waters. Yet interflow also can include groundwater that quickly discharges into streams after precipitation events, such as in karst springs or alluvial sands along stream channels. Baseflow results from precipitation that infiltrates into the soil and, over a longer period of time, moves through the soil and groundwater to the stream channel. Baseflow includes most of the groundwater component, but can also include tile drain waters which continue to flow long after storms and melting events.

The HSPF model was calibrated by adjusting model parameters to provide a match to observed conditions. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients which were calibrated to data collected in the Minnesota River Basin. Once calibrated, the model was validated using data independent from that used in calibration. The monitoring data used for both HSPF calibration and validation was different from that used earlier in this chapter to compare monitoring results with the UMN/MPCA source assessment approach in Chapters D1 to D4.

Flow pathways comparison

The HSPF modeling of inorganic N hydrologic pathways to the Minnesota River shows that the subsurface pathways of interflow and baseflow are the dominant pathways. Combined, these pathways account for 89% of the inorganic N transport (Figure 7). Interflow represents the highest contribution (54.7%) and baseflow represents the next highest (34.3%). Tile drainage is a major contributor to the interflow pathway, but also can also represent a fraction of the HSPF model surface runoff and baseflow pathways.

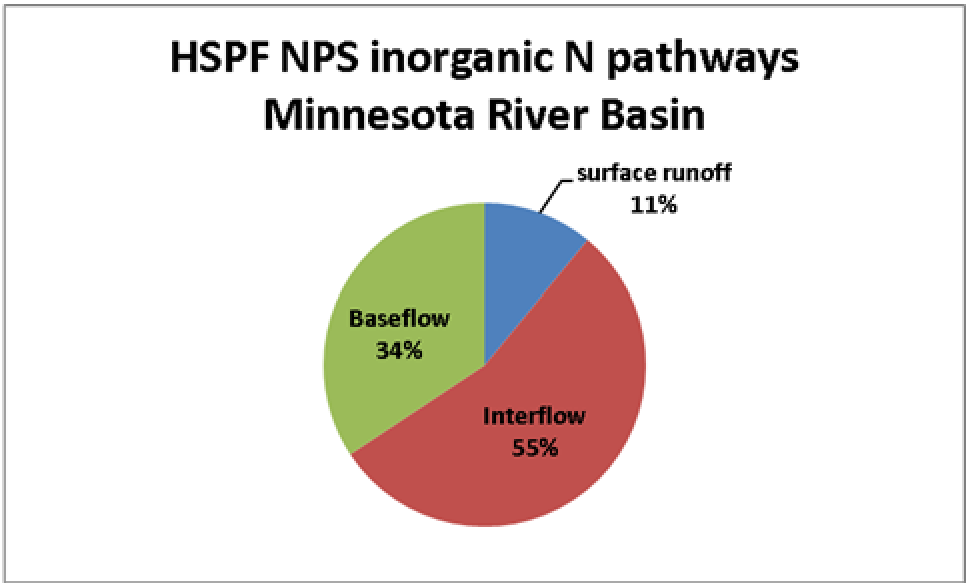

Figure 7. HSPF model estimates of the proportion of nonpoint source inorganic N which enters surface water through the three model flow pathways in the Minnesota River Basin during a typical precipitation year within the timeframe 1993-2006.

The UMN/MPCA estimates of the three major pathways (Figure 8) were determined by assuming the following:

- “Surface Runoff” includes all cropland N runoff, 80% of the N from urban/suburban NPS, 50% of the forested land N, and all feedlot runoff.
- “Groundwater” includes all cropland groundwater, all septic system N, 20% of the urban/suburban NPS component, and 50% of the forested land N.
- “Agricultural Drainage” includes all cropland tile drainage N estimates.

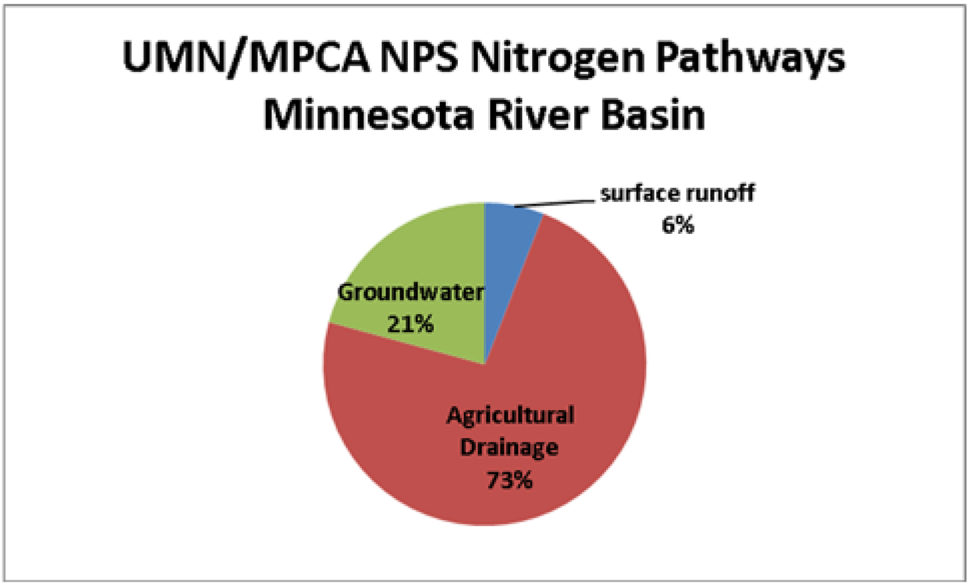

Figure 8. UMN/MPCA N source estimates of the proportion of TN which enters surface water through three major pathways in the Minnesota River Basin during average precipitation conditions(1981 to 2010).

Similar to the HSPF modeling, the UMN/MPCA source estimates show that the dominant pathway of TN in the Minnesota River Basin is subsurface flow, with 94% of N coming from the combined pathways of groundwater and tile drainage. This compares to 89% predicted by the HSPF model for the subsurface pathways. The UMN/MPCA source assessment shows that agricultural drainage is the pathway contributing the most N, representing 73% of the TN into rivers in the Minnesota River Basin. The HSPF model shows interflow to be the largest pathway, accounting for 55% of the inorganic N into the Minnesota River Basin surface waters. In the HSPF model, interflow is mostly affected by tile drainage waters, with a small fraction coming from groundwater adjacent to streams and ditches.

The reason that the HSPF estimated interflow TN fraction is lower than the UMN/MPCA tile drainage estimated TN fraction can be explained by the fact that some of the actual tile drainage waters is represented in HSPF outputs as "baseflow." When tiles continue to flow into streams long after rain or snowmelt events occur, this tile drainage will be considered as "baseflow" in the HSPF model. This hydrograph "baseflow" component of tile drainage is also supported by Schilling (2008), who found in heavily tiled Iowa watersheds that the "baseflow" component of the hydrograph increased by 40% in the March to July timeframe, the period of time when tiles are flowing. Yet Schilling found no differences in baseflow between drained and undrained lands during the fall to winter months (September to February). This showed that tile drainage waters likely have a substantial effect on the nitrate contributions from the baseflow part of the hydrograph. If 40% of the HSPF modeled baseflow is actually from tile drainage, then the UMN and HSPF estimates of the relative contribution from tile drainage would be nearly the same.

We only compared the HSPF and UMN/MPCA source assessment pathways for the entire basin. Yet, it is noteworthy that the fraction of HSPF estimated nitrate from these three pathways varies among HUC8 watersheds within the Minnesota River Basin (Figure 9). For example, the less-tiled Chippewa River watershed has an estimated 22% of its nitrate coming from interflow and 57% from baseflow, whereas the heavily tiled LeSueur watershed has an estimated 69% of its nitrate from interflow and only 15% from baseflow.

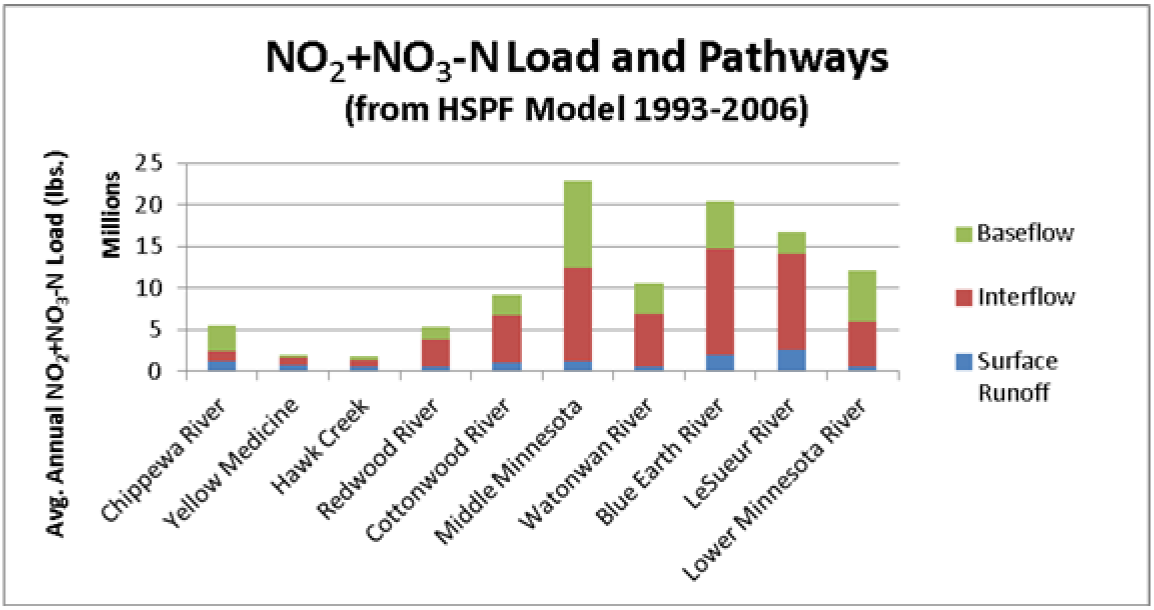

Figure 9. Nitrite+Nitrate-N pathways for HUC8 watersheds in the Minnesota River Basin, as estimated by the HSPF model.

NPS land use contributions in the Minnesota River Basin

The HSPF model results indicate that the dominant contributor of nonpoint source inorganic N to the Minnesota River is cropland, with an estimated contribution of 96.6% (Table 1). The UMN/MPCA estimates for cropland contributions in this same basin are very similar at 97.6%. All other sources are relatively small using both approaches. Note that these results did not include point source contributions, which are approximately 4% of the TN load in the Minnesota River Basin. Also note that the HSPF analysis for this chapter only included inorganic N and the UMN/MPCA assessment was for TN. Given that 85% of the Minnesota River TN is in the inorganic form of nitrate-N, this difference in N forms between the two approaches is not expected to greatly affect the relative source contributions of nonpoint source pollutants.

Table 1. Estimated NPS land use contributions of inorganic N (HSPF) and TN (UMN/MPCA) to surface waters during a typical precipitation year in the Minnesota River Basin.

Land use	HSPF estimated percent of total inorganic nitrogen from nonpoint sources	UMN/MPCA estimated percent of total nitrogen from nonpoint sources
Cropland	96.6%	97.6%
Urban stormwater	2.1%	0.7%
Feedlot facilities (note: manure application is included with “cropland”)	0.19%	0.06%
Forest	0.14%	0.7%
Other	0.97%	0.94
Total	100%	100%

Precipitation effects

The TN load from nonpoint sources was highly influenced by precipitation according to the UMN source assessment results (Chapter D4 – Mulla et al.). Nitrogen loads from the HSPF modeling for wet, normal, and dry years were compared with the loads from the UMN approach for similar climatic situations (Table 2). The increased loads predicted by HSPF for wet years are very similar to those predicted by the UMN source assessment (179% vs. 170% of the median precipitation year loads). Both approaches show substantially lower loads for the dry years (65% and 35% of median year loads). The UMN approach shows a more substantial drop in loads during the dry years. Part of the reason for the larger decrease in dry years from the UMN approach can be explained by the differences in the climatic period of record used for each approach. The HSPF results are based on the three driest years between 1993 and 2006. This period of time was relatively wet compared to the 30-year precipitation record used for developing the UMN/MPCA estimated effects of climate. The dry years between 1993 and 2006 were not as dry as the dry years between 1981 and 2010. The UMN/MPCA approach, using the 1981 to 2010 period of record, included more droughty years, such as the droughts during the late 1980s. Therefore, it is reasonable to expect that the UMN/MPCA approach would show lower loads for the dry years, if all other things are considered equal.

Table 2. Nitrogen loads for the Minnesota River Basin during dry and wet years shown as a percentage of the loads during the median (normal) precipitation. Dry and wet years for the HSPF results analysis considered the average of the 3 driest years (dry) and 3 wettest years (wet) during the period 1993-2006. The UMN/MPCA analysis considered the 10th percentile precipitation (dry) and the 90th percentile precipitation (wet) during the period 1981 to 2010.

Precipitation	**HSPF inorganic N load estimates** (percent of normal year load)	**UMN/MPCA total N load estimates** (percent of normal year load)
Dry years	65%	35%
Average years	100%	100%
Wet years	179%	170%

Summary

The basin and watershed monitoring results overall compared reasonably close to the sum of the sources estimated by the UMN/MPCA source assessment. The monitoring results were not expected to be the same as the sum of sources since the sum of sources do not consider in-stream N losses or lag times in groundwater N transport. Yet the fairly close agreement in the monitoring results, with the source assessment results developed independently from the watershed and basin scale monitoring, provides a greater level of confidence that the source estimates may be realistic. The monitoring results alone do not provide a reason to suggest that the source estimates are unreasonable.

The greatest differences between sum of sources and monitored loads were in the Minnesota River Basin and a few of the high N loading HUC8 watersheds within that basin. In this basin, TN monitoring results were higher than the sum of sources estimates. Monitoring results for the Minnesota River were 131%, 108%, and 123% of the sum of sources estimates for average, wet, and dry periods, respectively. Monitoring results for other basins were lower than the sum of sources.

The SPARROW and HSPF model source estimates both were consistent with the UMN/MPCA source assessment, indicating that cropland sources are the dominant N sources to Minnesota rivers (SPARROW) and surface waters within the Minnesota River Basin (HSPF). The two models use markedly different approaches to arrive at source and pathway estimates, and both models are also very different from the UMN/MPCA source assessment approach. The SPARROW model estimated that cropland sources represent 70% of the statewide TN load (2002), as compared to 73% by the UMN/MPCA source assessment. The HSPF model results estimated that NPS from cropland in the Minnesota River Basin represent 96.6% of the inorganic N to surface waters, as compared to a 97.6% estimated from the UMN/MPCA TN source assessment.

The HSPF model results of N pathways in the Minnesota River Basin were also generally consistent with the UMN/MPCA assessment. The HSPF model estimated that 89% of the Minnesota River Basin inorganic N transport to surface waters is via subsurface pathways of interflow and baseflow. Similarly, the UMN/MPCA N source assessment estimated that 94% of TN reaches waters by subsurface pathways of tile drainage and groundwater.

The effects of high and low precipitation years on N loading to surface waters was also found to be reasonably similar with the HSPF model and UMN/MPCA approach. Wet weather loads were 179% of normal weather loads according to the HSPF modeling, as compared to 170% of normal loads in the UMN/MPCA source assessment. Both approaches estimated substantial load reductions for dry weather periods, but the UMN/MPCA approach showed a much greater reduction, explained in part by the different dry weather climate situations in the timeframes used for the two approaches.

References

Schilling, Kieth E. and Matthew Helmers. 2008. Effects of subsurface drainage tiles on streamflow in Iowa agricultural watersheds: exploratory hydrograph analysis. Hydrol. Processs. Vol. 22 (4497-4506).