Patterns in Nutrient Transport and Load

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Summary

This report provides an assessment of 1) the temporal and spatial patterns of surface water nitrate and phosphorus loads and the degree to which local weather and flow conditions influence these patterns and 2) point source contributions to nitrate and total phosphorus loading to Iowa rivers. These assessments are made on the basis of 1) the Iowa Department of Natural Resources STORET, Des Moines River Water Quality Network (DMRWQN), Des Moines Water Works (DMWW), and US Geological Survey (USGS) data and 2) municipal water treatment plant effluent data supplied by the Ames, Marshalltown, and Des Moines municipal water treatment facilities.

<u>Point Source contribution to River loads</u> (Pages 3-9)

1) Averaged across all sites and years, municipal effluent contributed 2.6% of the N load and 11.4% of the P load for the Des Moines, South Skunk, and Iowa Rivers at Des Moines, Ames, and Marshalltown (Table 1, Figures 1-N1 and 1-P1). However, the effluent contribution to annual loads was a larger fraction in drier years, and annual effluent contributions ranged from 1-25% for N and 2-75% for P.
2) For all three sites, municipal effluent contributed a large fraction of N and P loads during low flow periods extending for several months in most years. (Figures 1-N2 and 1-P2)
3) Municipal effluent contributed >50% of the daily N load 13-33% of the time and >50% of the daily P load 23-45% of the time. (Table 1, Figures 1-N3 and 1-P3)
4) While municipal waste water sources contribute the majority of the nitrate and total phosphorus loading during dry periods, riverine loads are so low during low flow periods that point source loads primarily impact local water quality but have low impact on loads to the Gulf of Mexico.

<u>Non-Point Source contribution to River loads</u> (Pages 10-23)

Loads in the ambient monitoring rivers are influenced by point source loading, in-stream processes including sediment deposition and resuspension, bank erosion, phosphorus sorption and desorption dynamics, nitrogen cycling, and delivery scale processes that supply water to these streams. On the basis of the ambient monitoring data alone it is not possible to accurately separate and evaluate the contribution of these various processes. Accordingly while the ambient monitoring data may be utilized to obtain estimates of loading and loading trends, those results are not attributable solely to current agricultural practices and land use. Additionally, because riverine loads are correlated with river discharge, evaluation of loading trends must consider the effects of discharge on loading patterns.

<u>General Conclusions</u> (Page 24)

Agriculture contributes over 95% of the long-term N and over 85% of the long term P loads in the study basins. However, urban sources can contribute 50-90% of these loads during critical low flow periods extending for several months most years. Load reduction goals should consider both annual and seasonal patterns to protect local as well as downstream waters.

Table 1. Average municipal effluent nitrate (N) and total phosphorus (TP) loads and effluent percent of river load for selected Iowa rivers.

City	Approximate Population (thousands)	River	Watershed Area (sq. mi.)	Average Nitrate-N Load (kg/d)	Percent Effluent N	Percent of days having N effluent load > 50% river load	Average TP Load (kg/d)	Percent Effluent TP	Percent of days having TP effluent load > 50% river Load
Ames	59	South Skunk	556	485	4.1	33	86	16.4	45
Marshalltown	27	Iowa	1532	438	1.5	13	125	12.7	23
Des Moines Metro	460	Des Moines	9879	4,140	2.5	22	1,080	6.8	25

Nitrate

Total Phosphorus

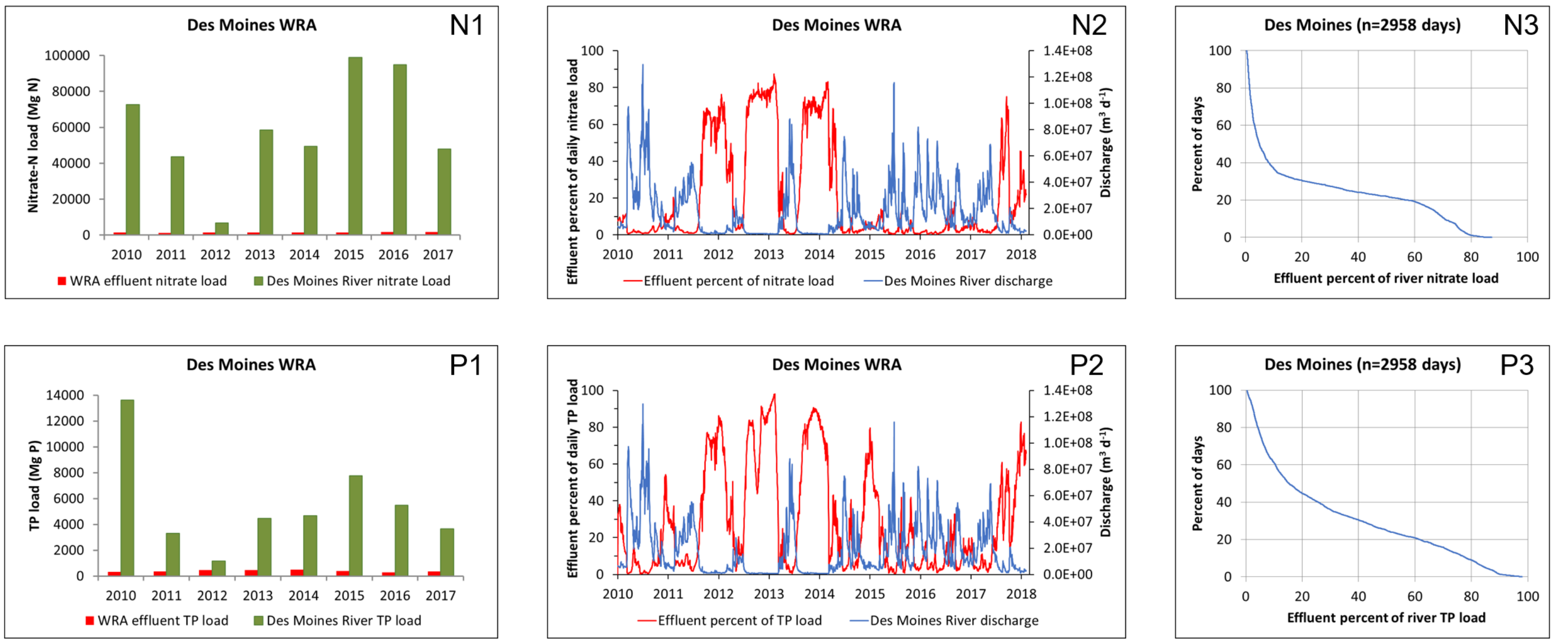

Figure 1. These figures show results for Des Moines for illustration; both the Ames and Marshalltown data showed similar patterns.

Point Source Contribution to River Loads

Data were obtained for effluent volume and nitrogen and phosphorus concentrations in effluent discharged to local rivers from three waste water treatment facilities in Iowa: Des Moines Wastewater Reclamation Authority, Ames Water Pollution Control, and Marshalltown Water Pollution Control Plant. These data were used to quantify the loads of nitrate and/or total nitrogen and total phosphorus (TP) in plant effluent water that is delivered to local Iowa rivers.

These plant effluent discharges were compared to loads in the receiving rivers. River loads were estimated using data from several sources including USGS gaged river discharge and river sample concentrations obtained from the Des Moines River Water Quality Network (DMRWQN), Iowa STORET database, and the Ames Water Pollution Control Plant.

Des Moines Wastewater Reclamation Authority

The Des Moines Wastewater Reclamation Authority (WRA) plant discharges wastewater effluent to the Des Moines River downstream of Des Moines, IA.

The Des Moines WRA effluent nitrate and TP loads are based on approximately monthly samples collected from May 5, 2010 to March 8, 2018. Linear interpolation between measured concentrations was used to estimate effluent concentrations for days that did not have a sample. Effluent discharge during 2010 and 2011 was estimated from the average of monthly discharge values from 2003 to 2005. Effluent discharge from 1/1/2012 to 2/28/2018 was based on daily measures. Daily effluent loads were estimated as the product of the effluent discharge and concentration. Loads during the 1/1/2010 to 5/4/2010 period when no samples were available were assumed to be equal to the daily average load for the remainder of the 2010-2018 period having samples.

Daily river mean discharge data were obtained from the Raccoon River at Van Meter (USGS station 05484500) and the Des Moines River at Saylorville (USGS station 05481650). River TP and nitrate concentration data were obtained from the DMRWQN database – these data vary from one to three samples per month, with greater sampling frequency during the warmer months. Linear interpolation between measured sample concentrations was used to estimate concentration for days not having a sample. The daily river load is the product of the concentration and the discharge.

Effluent discharge accounted for an average of 4.1% of the total river nitrate load, with annual averages ranging from 1.4% to 17.3% from 2010 to 2017 (Figure 2-N1 and Table 2). Effluent discharge accounted for an average of 6.8% of the TP load in the river, with annual averages ranging from 2.4% to 29 % from 2010 to 2017 (Figure 2-P1 and Table 2).

The total river load is calculated as the sum of the upstream river load and the effluent discharge load. While the WRA contribution to the total river load is low on an annual basis, on a daily basis the WRA effluent frequently contributes the major share of the total river load during low flow periods (Figures 2-N2 and 2-P2). Figures 2-N3 and 2-P3 show the distribution of days for the period of record where the effluent exceeds some percentage of the total river load. For example, the effluent comprises 40% or more of the river nitrate and TP loads about 24% (Figure 2-N3) and 30% (Figure 2-P3), respectively, of the 2985 days in the period of record.

Ames Water Pollution Control

The Ames Water Pollution Control (WPC) plant discharges wastewater effluent to the South Skunk River downstream of Ames, IA.

The Ames WPC measured effluent nitrate and TN on a weekly to monthly basis (average 1 sample per 14 days) from 2003 to 2005. On average, nitrate comprised 96% of the effluent TN measured on the 71 days having sample assays for both nitrate and TN. Following this, TN, but not nitrate, was measured approximately monthly from 2010 to 2018. Effluent TP was measured approximately monthly from 2003 to 2018. Linear interpolation between measured sample concentrations was used to estimate concentration for days not having a sample. The daily effluent load is the product of the concentration and the discharge.

Daily river mean discharge data were obtained from the South Skunk River below Squaw Creek near Ames (USGS station 05471000). Upstream river TP and nitrate concentration data measured approximately weekly during 2003 to 2018 were obtained from the Ames WPC facility. River TN concentrations from the Iowa STORET database for station 10850002, South Skunk near Cambridge, collected monthly were used to estimate the river TN load. Linear interpolation between measured sample concentrations was used to estimate concentrations for days not having a sample. The daily river load is the product of the concentration and the discharge.

On an annual basis, effluent discharge accounted for an average of 4.1% of the river nitrate load, ranging from 2.4% to 25% from 2003 to 2017 (2006-2010 missing) (Figure 3-N1 and Table 3). On an annual basis, the effluent discharge accounted for an average of 16.4% of the TP load in to the river, ranging from 7.1% to 75% from 2003 to 2017 (Figure 3-P1 and Table 3).

The total river load is calculated as the sum of the upstream river load and the effluent discharge load. While the WPC contribution to the total river load is low on an annual basis, the WPC effluent frequently contributes the major share of the daily river load during low flow periods (Figures 3-N2 and 3-P2). Figures 3-N3 and 3-P3 show the distribution of days for the period of record where the effluent exceeds some percentage of the total river load. For example, the effluent comprises 40% or more of the river nitrate load about 38% (Figure 3-N3) of the 3657 days in the period of record. Similarly, the effluent comprises 40% or more of the river TP load about 55% (Figure 3-P3) of the 5383 days in the period of record.

Marshalltown Water Pollution Control Plant

The Marshalltown Water Pollution Control Plant (WPCP) plant discharges wastewater effluent to the Iowa River near north Marshalltown, IA. The Marshalltown WPCP also processes a waste stream from the JBS Swift pork processing plant.

The Marshalltown effluent nitrate loads are based on approximately 5 samples per week from 2003 to 2005 and then approximately weekly samples from July 2011 to 2018. TP loads are based on approximately weekly to monthly samples collected from May 2001 through 2018. Linear interpolation between measured concentrations was used to estimate effluent concentrations for days that did not have a sample. Effluent discharge was estimated from the single discharge value of 4.105 MGD given each year for 2003 to 2006. Daily effluent loads were estimated as the product of the effluent discharge and concentration.

Daily river mean discharge data were obtained from the Iowa River at Marshalltown (USGS station 05451500). Monthly river TP and nitrate concentration data were obtained from the STORET database Station 10640002, Iowa River Downstream of Marshalltown. Linear interpolation between measured sample concentrations was used to estimate concentration for days not having a sample. The daily river load is the product of the concentration and the discharge.

On an annual basis, effluent discharge accounted for an average of 1.5% of the total river nitrate load, ranging from 0.8% to 12% from 2003 to 2005 and 2012 to 2017 (Figure 4-N1 and Table 4). On an annual basis, the effluent discharge accounted for an average of 12.7% of the TP load in to the river, ranging from 7% to 57% from 2012 to 2017 (Figure 4-P1 and Table 4).

On a daily basis the effluent frequently contributes the major share of the total river load during low flow periods (Figures 4-N2 and 4-P2). The total river load is taken as the river load below Marshalltown. On some days, the estimated effluent discharge load was greater than the estimated total river load and the effluent load fraction was taken as equal to one. Figures 4-N3 and 4-P3 show the distribution of days for the period of record where the effluent exceeds some percentage of the total river load. For example, the effluent comprises 40% or more of the river nitrate load about 18% (Figure 3-N3) of the 3543 days in the period of record. Similarly, the effluent comprises 40% or more of the river TP load about 30% (Figure 3-P3) of the 5967 days in the period of record.

Tables 5 and 6 summarize the annual percent effluent loading results. The treated Des Moines, Ames, and Marshalltown populations are relatively constant over time (some small growth has occurred) resulting in similar annual effluent nitrate and phosphorus loading over the time period examined here. As a result, the annual variation in river percent loading attributable to waste water effluent is primarily due to variation in annual river flow. For example, the effluent percent in both Tables 5 and 6 is high during the drought year 2012 when river flow, and hence loading, was low. The variation between cities is due to differences in treated populations, differences in the receiving river discharge and constituent concentrations, and because the Marshalltown WPCP also processes a waste stream from the JBS Swift pork processing plant.

Table 2. Average municipal effluent nitrate (N) and total phosphorus (TP) loads and effluent percent of river load for the Des Moines Waste Reclamation Authority. Approximate treated population = 460,000; Des Moines River watershed area at treatment plant = 9879 sq. mi.

Average Effluent Nitrate-N Load (kg/d)	Overall Percent Effluent N	Percent of days having effluent N load > 50% of river load	Average Effluent TP Load (kg/d)	Overall Percent Effluent TP	Percent of days having effluent TP load > 50% of river Load
4,140	2.5 Annual Range 1.4-17	22	1,080	6.8 Annual Range 2.4-29	25

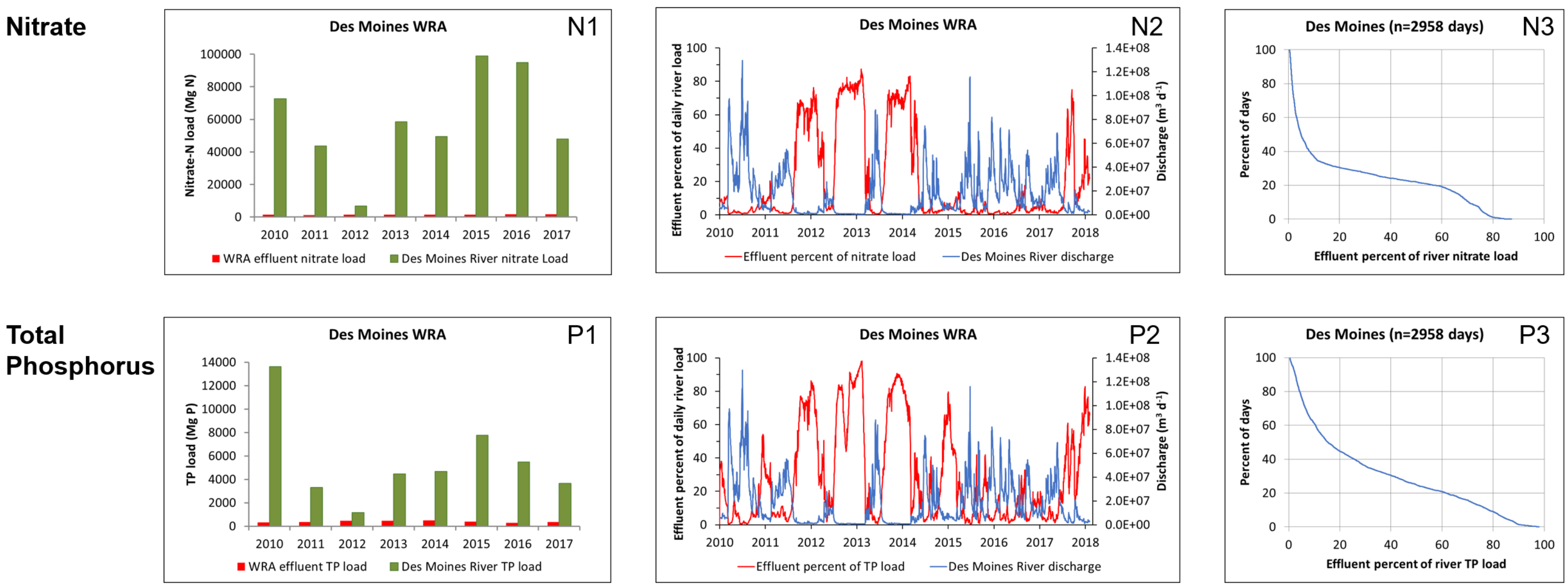

Figure 2. Des Moines Waste Reclamation Authority point source contribution to Des Moines River loading.

Table 3. Average municipal effluent nitrate (N) and total phosphorus (TP) loads and effluent percent of river load for the Ames water Pollution Control. Approximate treated population = 59,000; South Skunk River watershed area at treatment plant = 556 sq. mi.

Average Effluent Nitrate-N Load (kg/d)	Overall Percent Effluent N	Percent of days having effluent N load > 50% of river load	Average Effluent TP Load (kg/d)	Overall Percent Effluent TP	Percent of days having effluent TP load > 50% of river Load
485	4.1 Annual Range 2.4-25	33	86	16.4 Annual Range 7.1-75	45

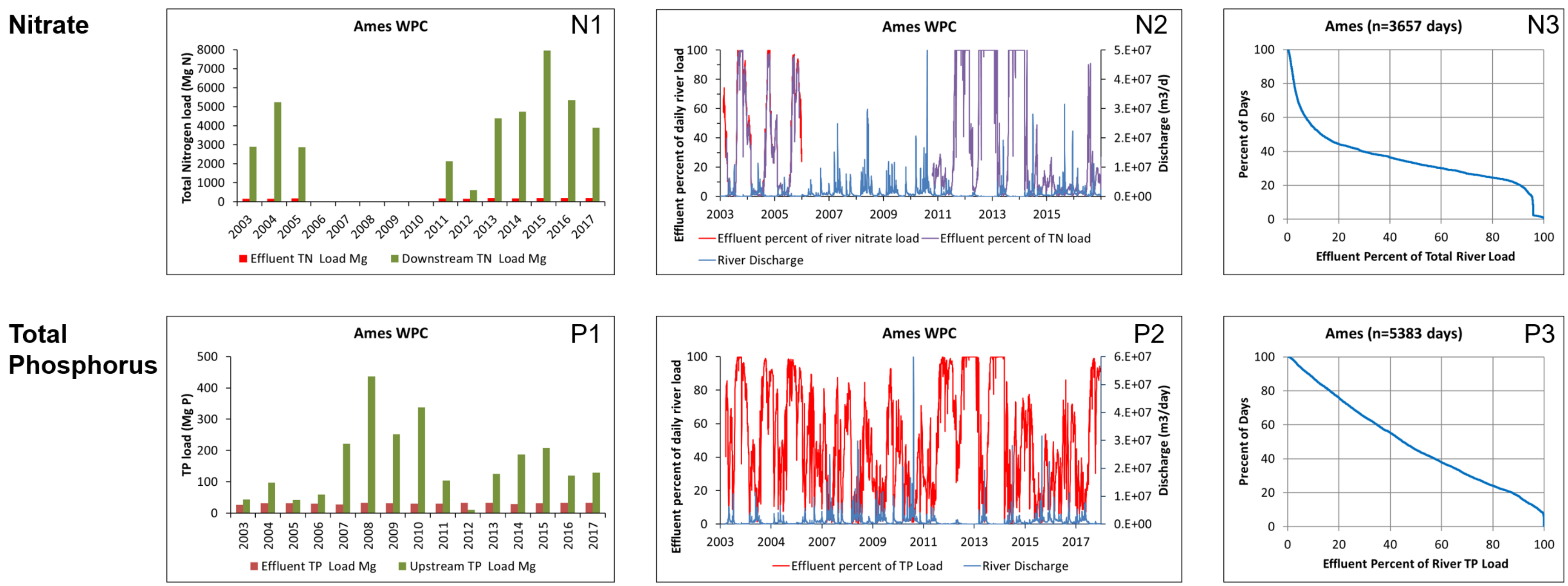

Figure 3. Ames Water Pollution Control point source contribution to South Skunk River loading. The 3002-3005 data indicate that nitrate comprised about 96% of the total nitrogen (TN) loading.

Table 4. Average municipal effluent nitrate (N) and total phosphorus (TP) loads and effluent percent of river load for the Marshalltown Water Pollution Control Plant. Approximate treated population = 27,000; Iowa River watershed area at treatment plant = 1532 sq. mi.

Average Effluent Nitrate-N Load (kg/d)	Overall Percent Effluent N	Percent of days having effluent N load > 50% of river load	Average Effluent TP Load (kg/d)	Overall Percent Effluent TP	Percent of days having effluent TP load > 50% of river Load
438	1.5 Annual Range 0.8-12	13	125	12.7 Annual Range 7-57	23

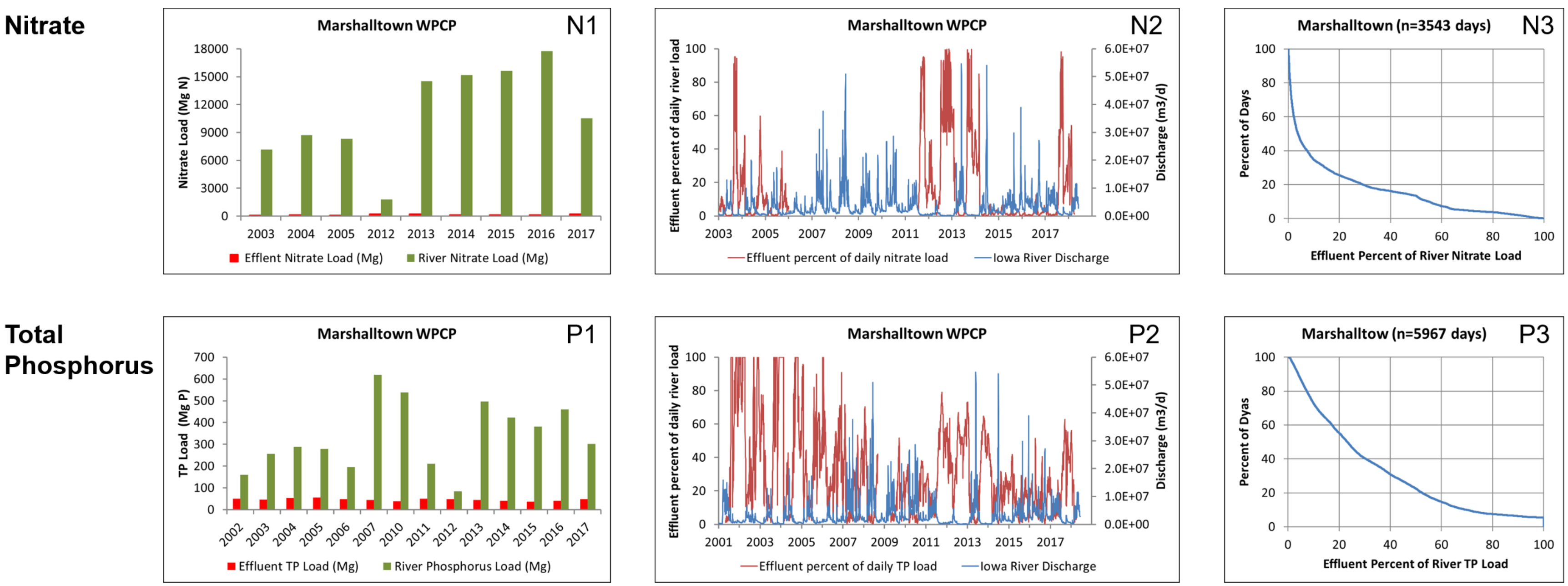

Figure 4. Marshalltown Water Pollution Control Plant point source contribution to the Iowa River loading.

Table 5. Annual effluent nitrate discharge load percent of river nitrate load.

Year	Des Moines WRA Effluent % of River Nitrate Load	Ames WPC Effluent % of River TN Load	Ames WPC * Effluent % of River Nitrate Load	Marshalltown WPCP Effluent % of River Nitrate Load
2003		6	4	1
2004		3	3	1
2005		6	5	1
2006-2009				
2010	2			
2011	3	8	7	
2012	17	25	25	12
2013	3	5	3	2
2014	3	4	3	1
2015	1	3	2	1
2016	2	4	3	1
2017	4	5	5	2

* 2011-2017 Ames WPC nitrate values are estimated as [NO3-N] = 0.958*[TN] based on 2003-2005 data.

Table 6. Annual effluent TP discharge load percent of river TP load.

Year	Des Moines WRA Effluent % of River TP Load	Ames WPC Effluent % of River TP Load	Marshalltown WPCP Effluent % of River TP Load
2002			32
2003		37	18
2004		24	19
2005		43	20
2006		34	25
2007		11	7
2008		7	
2009		11	
2010	2	8	7
2011	9	23	24
2012	29	75	57
2013	9	21	9
2014	10	13	9
2015	5	13	9
2016	5	22	9
2017	9	21	16

Non-Point Source Loading to Iowa Rivers

Ambient Monitoring Data

Data from the 60 Iowa STORET ambient monitoring stations were downloaded from the Iowa Department of Natural Recourses web pages (see Figure 20 for the locations of these stations). Data were obtained for nitrate, orthophosphate (OP), and phosphate phosphorus (total phosphorus or TP) concentrations. Examination of these data show that samples were collected monthly beginning about late 1998 to 2000 at 50 of the sites, during 2006 to 2018 at one site, and after 2010 at eight sites. Samples were collected approximately weekly beginning in 1991 at the Bloody Run Creek site in northeast Iowa. For each STORET site, daily river discharge data were obtained from the USGS Water Watch web pages for a station nearest the STORET sample location. There was not an adequate USGS flow station for the STORET site Maquoketa River at Spragueville for which there was only 2.6 years of ambient monitoring anyway. Accordingly, there are 51 STORET sites having data available for a long term (about 20 years or so) assessment, plus six additional sites having seven years of data and two having 3.8 and 4.8 years of data.

Additional data sources used in this section include the Des Moines Water Works (DMWW) nitrate data, the US ACE Des Moines River Water Quality Network (DMRWQN) N and P data, and the USGS National Stream Quality Accounting Network (NASQAN) nitrate data.

Load Estimation

Load, or mass flux, is estimated as the product of concentration and discharge. Estimates of discharge are generally available at many USGS stations as daily average (or more frequent) flow measurements. Concentration data are generally available with a much lower sampling frequency, such as weekly, or more commonly monthly. Accordingly, estimation of long term loading generally requires that concentrations or loads be estimated for days not having a sample. One of the simpler methods to estimate missing concentrations is to use a linear interpolation (i.e. a straight line) between adjacent data. Alternatively, statistical modeling procedures can be used that model concentration or load as functions of other available data, such as discharge, time, seasonal patterns, and/or previously observed values, and they can also provide an estimate of confidence in the estimated loads.

Examination of scatterplots of TP, OP, and nitrate concentrations versus discharge generally indicate that relatively simple statistical models that estimate concentration as a linear or quadratic function of discharge are generally inadequate. Table 7 lists some correlation statistics for measured TP, OP and nitrate concentrations with discharge (or water yield) for the 60 STORET monitoring stations. With the exception of a few cases, these correlations generally indicate relatively poor linear relationships between these measured nutrient concentrations and discharge. Examination of plots of these data generally show a great deal of scatter with no underlying non-linear behavior that could be easily modeled.

Table 7. Correlations between TP, OP, and nitrate concentration with discharge.

Variable	Correlation range	Average correlation
Total Phosphorus (TP)	-0.17 to 0.88	0.41
Orthophosphate (OP)	-0.46 to 0.53	0.18
Nitrate	-0.22 to 0.70	0.31

In the data we found available for this study, several datasets having greater than monthly sampling frequency. From these we simulated monthly sampling events by subsampling the data to assess the effects of monthly sampling on load estimation in Iowa rivers.

Raccoon River near Van Meter - DMWW, DMRWQN and NASQAN Data

We assembled Des Moines water works nitrate concentration data for the Raccoon River collected approximately one to five times weekly to from 1999 to 2018, DMRWQN data collected approximately weekly from 1976 to 1982, and then approximately monthly until 1991, and less frequently (about 22 or 23 samples per year) until 2018, and the USGS NASQAN data collected approximately monthly from 1975 to 1995. The NASQAN and DMRWQN water samples were collected near Van Meter and the DMWW samples were collected near the DMWW Fleur Drive Treatment Plant in Des Moines (about 25 km downstream from Van Meter). Where they overlap in time, there is generally good agreement between these data sources. Merging these data sets results in a nitrate concentrations about every three days overall, and about 4 samples per week from 1999 to 2018.

Raccoon River Nitrate Load Subsampling Simulation

Using this combined DMWW and DMRWQN data from 1999 to 2018 (averaging 4.1 samples per week), we sequentially selected 28 approximately 28 day sample events and estimated annual loads for each subsample for comparison with the complete data set. We developed a four parameter nonlinear least squares statistical model to estimate nitrate concentration as a function of discharge using all available observations (Figure 5). We also used the linear interpolation procedure to estimate missing concentrations for days not having a sample. For each data subsample, these estimation procedures were used to estimate loads for each day having an observed concentration and these were summed to give partial loads whereby only days having a sample were considered. The partial load estimates are then compared to the observed loads for those days having an observed concentration, for each year. Accordingly, the observed partial load based on the full dataset has no error, under the assumption that the measured concentrations and discharge accurately represent the true load on those days. The average of the annual partial loads for the 28 subsamples is plotted in Figure 6, along with error bars that represent two standard deviations of the annual load estimates for each year giving a 95% confidence interval for the true partial load. The statistical model loads are similarly averaged and plotted in Figure 6 along with two standard error bars based on the residual error variance from the statistical model. Note that while many statistical model forms could be developed for this purpose, and we do not claim the model we use is best by any measure, this model is reasonable and does illustrate some important points.

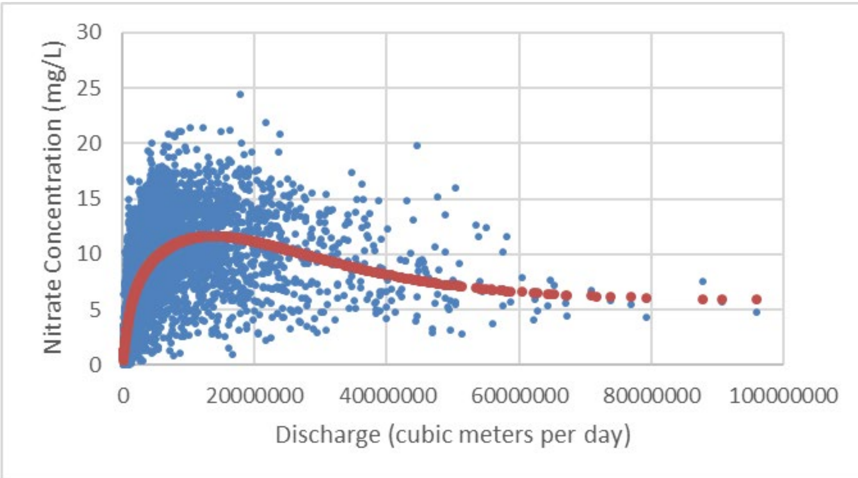

Figure 5. Combined DMWW, DMRWQN and NASQAN Raccoon River nitrate data versus discharge for 4978 samples.

The results of this subsampling, illustrated in Figure 6, indicate that the linear interpolation procedure generally compares favorably with the 'true' values (based on the full data set), and in particular, the 95% confidence intervals contain the true values each of the nineteen years. While the linear interpolation does show substantial variation (large error bar range), there is no indication of statistical bias. The statistical model does not appear to compare to the true values as favorably as the linear interpolation model, particularly in 2010, 2013 and 2015. More importantly, this statistical model has 95% error bars that do not contain the true value 13 out of the 19 years indicating that the statistical model shows evidence of load estimation bias for most years and is not as accurate as its error estimate claims it to be. However, with any one of the 28 subsamples, there might be no way to determine that this model is biased. This example suggests that appropriate care must be taken to develop an adequate model and verify the model performance.

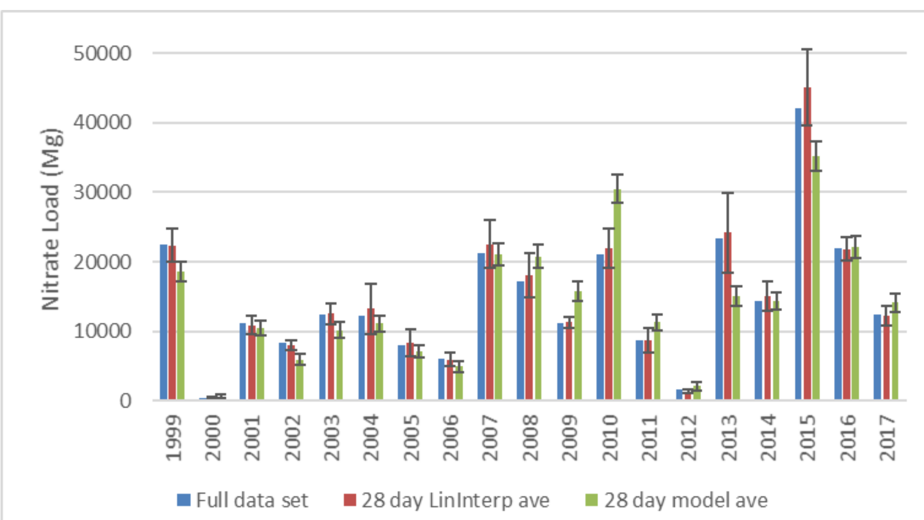

Figure 6. Partial loads of the full data set (about 4 samples per week) and partial loads estimated using linear interpolation and a regression model on the basis of 28 day subsamples of the full data set.

Raccoon River Load and Flow Weighted Average Estimation

Because the linear interpolation model performed fairly well (Figure 6), we used a linear interpolation between adjacent concentrations to estimate missing concentrations for all days not having a sample using the DMWW, DMRWQN and NASQAN data previously described. Annual nitrate loads (Figure 7) and flow-weighted Average (FWA) concentrations (annual load divided by annual discharge) were calculated for the 1976 to 2017 time period (Figure 8).

Figure 7 highlights the influence of water yield (WY) as a strong driver of annual nitrate loading in the Raccoon River near Van Meter, Iowa. Flow-weighted average nitrate concentrations respond to WY in a less direct manner (Figure 8). Years with very low WY (1977, 1981, 1989, 2000, and 2012) all have reduced FWA nitrate concentrations, but in each subsequent year having increased WY following these dry years the FWA concentration increased. This result indicates a time lag or carryover effect whereby residual nitrate accumulates in the soil profile during drought years and is subsequently flushed out during the next year having higher flow. In general, Figure 9 shows that low flow years have tended to have reduced concentrations, while years having water yields between about 0.1 to 0.5 m/yr tend to have FWA nitrate-N concentrations ranging from about 7 to 12 mg/L. The flood years of 1993 and 2010 (WY > 0.5 m/yr) show slightly reduced FWA nitrate-N concentrations likely associated with dilution from excess surface runoff. The high FWA concentration above 14 mg/L occurred during 2013 following the 2012 drought.

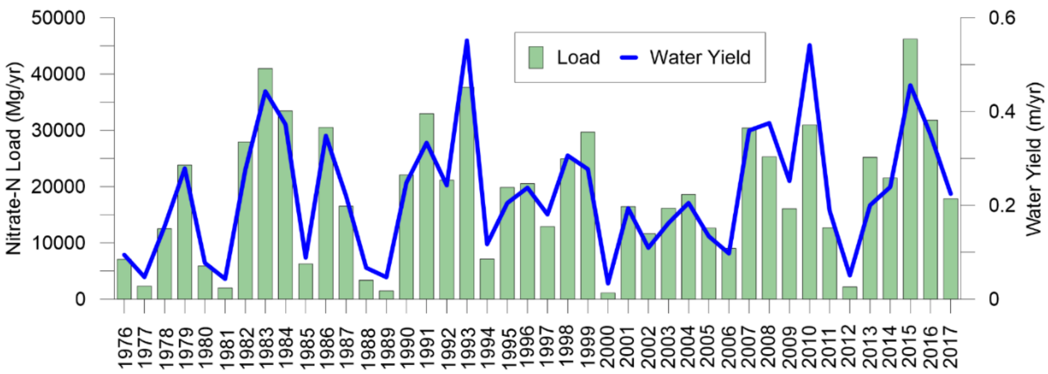

Figure 7. Raccoon River near Van Meter nitrate load (linear interpolation) and annual water yield versus year. Annual nitrate load is linearly related to water yield (R^2 = 0.94).

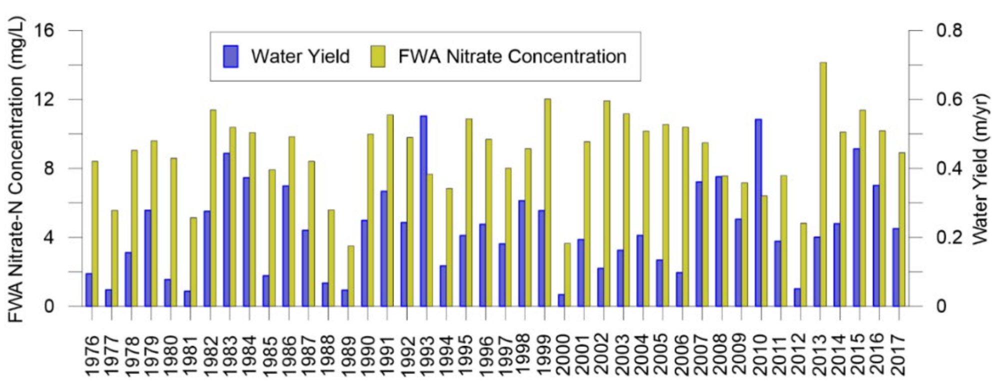

Figure 8. Raccoon River near Van Meter flow-weighted average nitrate-N concentration and annual water yield versus year.

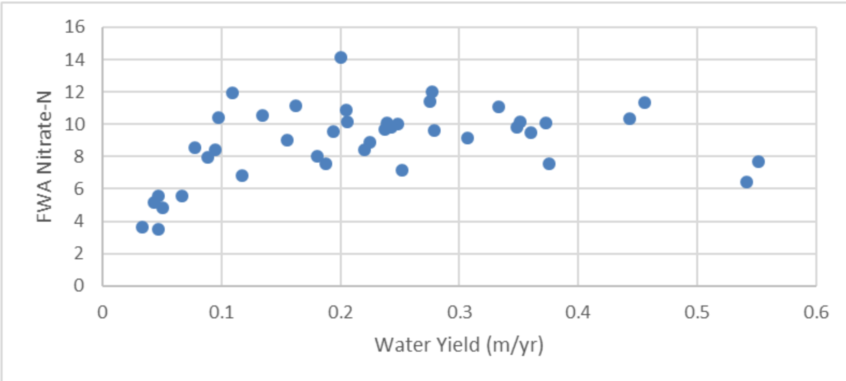

Figure 9. Raccoon River near Van Meter flow-weighted average nitrate-N concentration and plotted versus annual water yield.

<u>Bloody Run Creek – STORET Data</u>

Constituent concentration data in the Iowa STORET database is generally available only for monthly sampling events. However, the Bloody Run Creek site in northeast Iowa has weekly nitrate and TP data from October 1991 to January 2001. By subsampling this dataset, we simulated four monthly sampling events to assess the variation in estimating annual loads using monthly, relative to weekly, concentration data.

Nitrate loads

Nitrate concentrations for Bloody Run Creek were estimated using a linear interpolation between adjacent measured nitrate concentrations. These daily observed and estimated concentrations were multiplied by the discharge to estimate daily loads. Figure 10 shows a bar chart of the resulting annual load estimation based on all the data and the four subsamples along with the annual water yield. This figure indicates that the monthly sampling provides annual load estimates that were very similar to the load estimates using the weekly sampling data. The figure also shows the strong direct relationship between annual load and water yield indicating that discharge must be considered to properly interpret load trends over time. Figure 11 shows annual flow-weighted average (FWA) nitrate concentrations for these same subsamples schemes. The FWA concentrations appear to be relatively stable from 1992 to 1997 followed by a slight shift upward for the 1998 to 2001 time period.

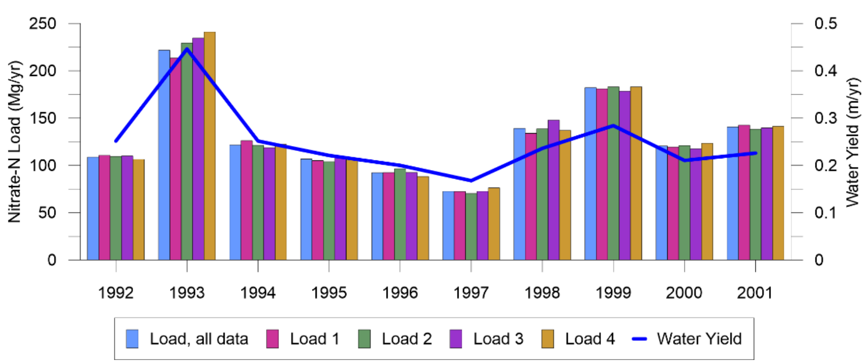

Figure 10. Annual nitrate-N load estimates for Bloody Run Creek in northeast Iowa based on weekly sampling and four monthly subsamples (load 1 to load 4) of the weekly data (all data).

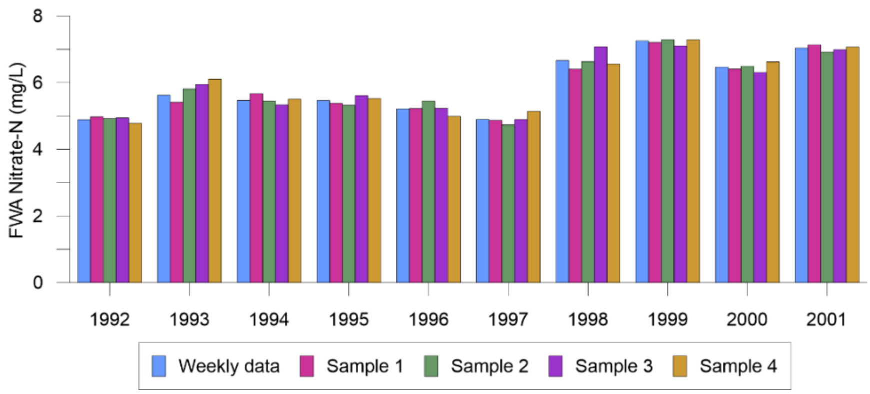

Figure 11. Annual FWA nitrate-N estimates for Bloody Run Creek in northeast Iowa based on weekly sampling (all data) and four monthly subsamples (Sample 1 to Sample 4) of the weekly data.

TP Loads

The weekly Bloody Run Creek data were used to create four monthly subsamples to assess load estimation on the basis of monthly samples. Annual TP loads were estimated using the weekly data and the four 28 day subsamples using a linear interpolation to estimate concentrations for days not having a sample. The variation between the full data set and the four 28 day subsample annual loads is large suggesting that monthly data are insufficient to estimate annual TP loads with linear interpolation (Figure 12). It is not known how well weekly samples can be used to estimate annual loads. This suggests that a more sophisticated model that accounts for TP concentration variation with discharge and possibly seasonal and longer term trends is necessary to more accurately model TP loads. As with nitrate, TP loads are generally strongly correlated with water yield.

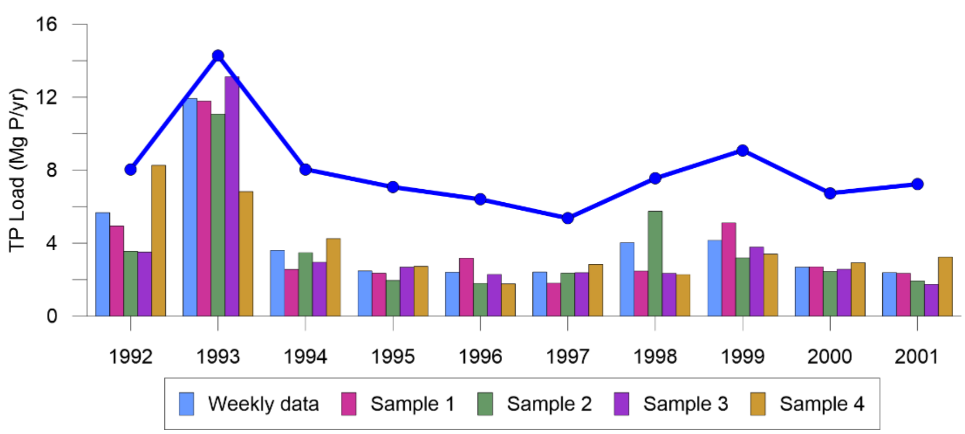

Figure 12. Annual TP load estimates for Bloody Run Creek in northeast Iowa based on weekly sampling and four monthly subsamples (sample 1 to sample 4) of the weekly data (all data).

<u>Long term trend evaluation – Suitability and Limitations of Ambient Water Quality Data</u>

Estimating loads using a linear interpolation procedure, as was done for some of the analyses herein, is not a statistical procedure and does not readily lend itself to a direct analysis of estimation error, although an estimate of error can still be made. Linear interpolation was utilized in much of the load estimation considered here because it is simple to use and it generally gives unbiased estimates.

However, compared with some regression models which show evidence of statistical bias, annual load estimation using linear interpolation appears to be less precise. This is likely true in part because loading is generally positively correlated with discharge, yet concentrations (at least for nitrate) may be affected by both recent flow events and flow during the prior year. However, estimating loading on the basis of monthly samples is subject to some level of uncertainty which can be estimated using statistical based procedures. This process can be time consuming because each dataset must be analyzed and tested separately to construct a proper statistical model from which a valid measure of confidence can be developed. Furthermore, once loading estimates are developed and the statistical uncertainty is evaluated, variations in water yield (which are strongly correlated with loads) must be accounted for in an effort to assess temporal loading trends. This could be accomplished by evaluating flow-weighted average concentrations or using a statistical regression of annual loading on both time and water yield to separate any time trend from the influence of WY. A major impediment to this, however, is the ability to reliably estimate annual loading and/or flow-weighted average concentrations on the basis of monthly samples. Stenback et al. (2010) concluded that use of a common regression based approach to load estimation for rivers in Iowa resulted in considerable lack of precision in TP estimation and overestimation bias and lack of precision for nitrate load estimation for sample frequencies ranging from weekly to monthly.

Furthermore, loads in the ambient monitoring rivers are influenced by point source loading, in-stream processes including sediment deposition and resuspension, bank erosion, phosphorus sorption and desorption dynamics, and nitrogen cycling, and delivery scale processes that supply water to these streams. On the basis of the ambient monitoring data alone it is not possible to accurately separate and evaluate the contribution of these various processes. Accordingly while the ambient monitoring data may be utilized to obtain estimates of loading and loading trends, those results are not attributable solely to current agricultural practices and land use.

Temporal Loading Patterns and the Effects of Local Flow and Weather Conditions

River discharge is variable from year to year, with periods of both wet and dry conditions which can occur during any time of year. Loads are generally positively correlated with discharge, and thus loads can be elevated any time of year if discharge is high. Nevertheless, general trends in monthly average water yields (WY) are similar across the state. Figure 13 shows a plot of 1998/99 through 2017 monthly average WY fraction of the annual WY by site for the 59 USGS stations associated with the STORET ambient monitoring sites having four or more years of at least monthly sampling. Fall and winter months generally show lower flow, with flow increasing throughout the spring and generally peaking in May and June, with declining flow through mid to late summer.

For the STORET ambient monitoring stations, nitrate, TP and OP concentrations were estimated using a linear interpolation between adjacent concentrations for days not having a sample. The daily load is the product of concentration and discharge. Daily loads are summed to estimate monthly and annual loads. The monthly fraction of the total annual load was determined for each STORET ambient monitoring site having at least five full years of monitoring data. While loads can be elevated at any time of year if the flow is high, the average monthly fraction of the annual load for these sites shows that fall and winter months generally have lower loads, with nitrate and TP loads increasing throughout the spring and generally peaking in May and June, followed by declining loads through mid to late summer (Figure 13). Orthophosphate loads show a similar pattern to TP loads, with the exception that most stations show a slight decline in orthophosphate loads during April, typically followed by increased loading in May and June.

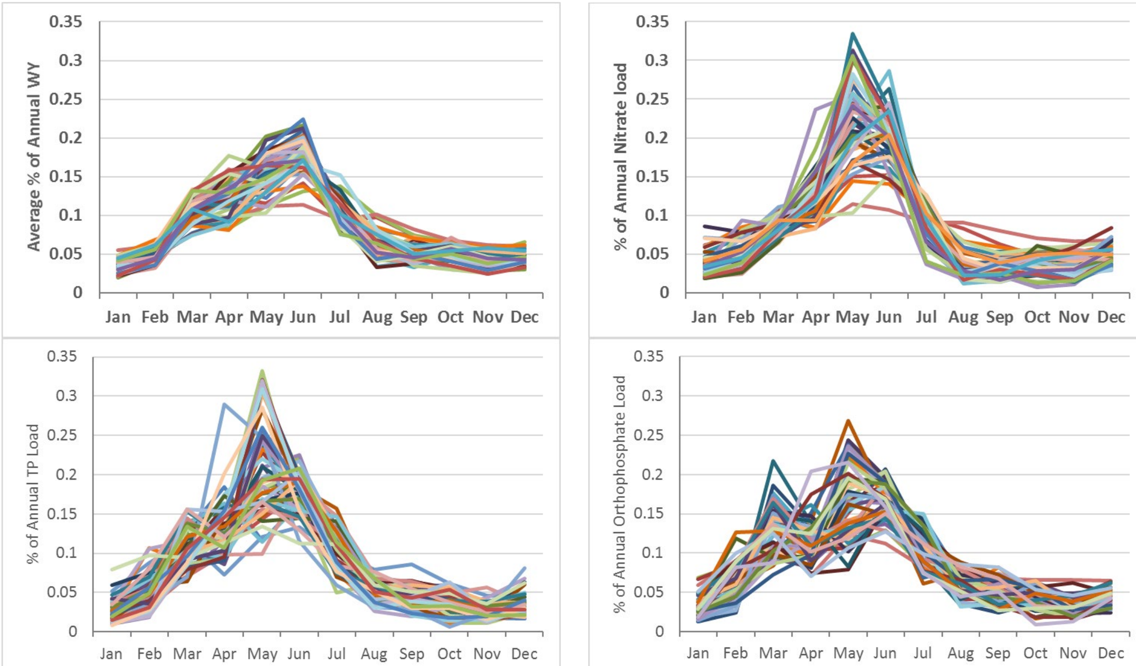

Figure 13. STORET site average 1998/1999-2017 monthly percent of annual sums for water yield (WY) and nitrate, orthophosphate, and TP loads.

The data in Figure 13 is summarized by further averaging across sites to illustrate typical monthly WY, nitrate and TP loading patterns (Figure 14). Comparing the WY and nitrate bars (Figure 14) shows that WY tends to increase in March to a greater extent than nitrate, likely due to low nitrate concentrations in snow melt runoff, while the nitrate load fraction tends to be proportionally greater than the WY fraction in May and June due to generally elevated nitrate concentrations during these months. TP loads more closely follow WY trends, with a notable difference during May when high TP loads result from elevated TP concentrations possibly associated with high flow and low vegetative cover during May. The high orthophosphate (OP) loading in February and March, followed by decreased loading fraction relative to WY in April is indicative of elevated OP concentrations in February and March.

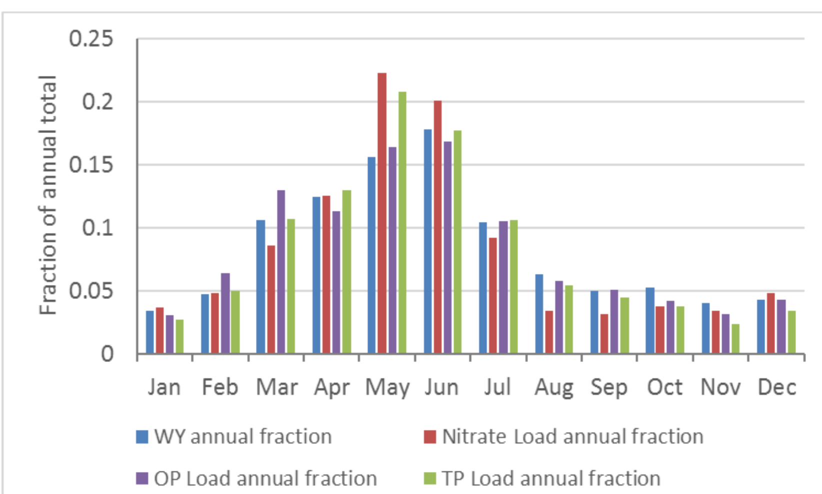

Figure 14. Long term (1998/99 to 2017) statewide average fraction of annual WY and nitrate, orthophosphate (OP) and TP load for all years at all STORET sites having at least five full years of data.

Land Use and Nutrient Concentration and Loading

We examined the relationship between row crop farmland, artificial tile drainage, and nutrient concentration at the scale of the STORET watershed drainage areas (range 34.3-14010 sq. miles, average 1693 sq. miles). All flow-weighted average (FWA) concentrations in this section are based on observed data only; i.e. as the sum of loads on days having a sample concentration divided by the sum of the flow on those days having a sample concentration. The watersheds were determined with Arcmap using Lidar data with the watershed outflow positioned at the STORET sampling location. The percent of land in row crop was determined using NASS agricultural statistics coverages for each year from 2001 to 2017 and the average of the 2001-2017 (where available, 2006-2017 for some watersheds not having adequate 2001-2005 coverage) was used for the work here. The percent of cropped land likely to be tile drained was estimated as the fraction of hydric soils that are row cropped based NRCS SSURGO soil coverages.

<u>Nitrate-N concentration versus row cropped and tile drained land</u>

Figure 15 show a plot of the long term STORET ambient monitoring site flow-weighted average nitrate-N concentration data versus fraction of the watershed in row crop. A simple linear regression gives a negative intercept so the regression line in Figure 15 was forced through zero. This suggests a riverine FWA nitrate-N concentration approximately equal to the product of the fraction of row crop and 11.3 mg/L for these Iowa rivers with an R^2 of 0.76. Adding the soils likely to be tile drained to the regression only increases the R^2 to 0.77, but nevertheless gives a statistically significant increase in FWA nitrate-N concentration with increasing fraction of tile drained cropland (Figure 16). Figure 16 illustrates that, when the fraction of rowcrop land that is tile drained is included, the riverine FWA nitrate concentration remains strongly related to the fraction of row crop and the fraction of tile drainage has a les substantial effect on the FWA nitrate concentration.

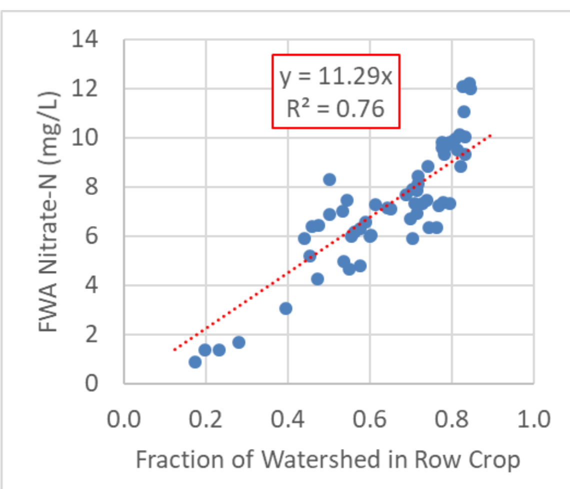

Figure 15. The FWA nitrate concentration is strongly related to the fraction of the watershed land in row crop agriculture (corn and soybean).

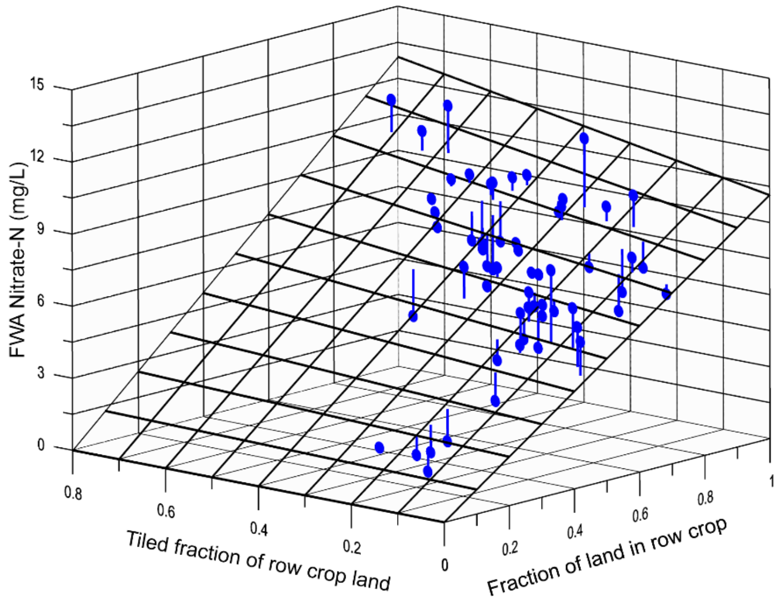

Figure 16. A surface plot of flow-weighted average (FWA) nitrate-N concentration regressed on fraction of land in row crop and fraction of row crop land that is likely to be tiled is plotted here. The regression equation is: FWA Nitrate (mg/L) = 10.14×(Row Crop Fraction)×(1 + 0.34*(Fraction of Tiled Row Crop)) with an R^2 of 0.77 (both coefficients are statistically significant at the 0.01 level).

<u>TP concentration versus row cropped and tile drained land</u>

Figure 17 shows plots of the long term STORET site flow-weighted average TP concentration data versus fraction of the watershed in row crop and soils likely to be tile drained. A regression of FWA TP concentration on both row crop and likely tile drained row crop indicates that only the fraction of row crop likely to be tile drained term is significant. While this relationship is weak (R^2 = 0.25), it does correspond with the generally lower FWA TP concentrations observed on the heavily tile drained Des Moines Lobe (Figure 21).

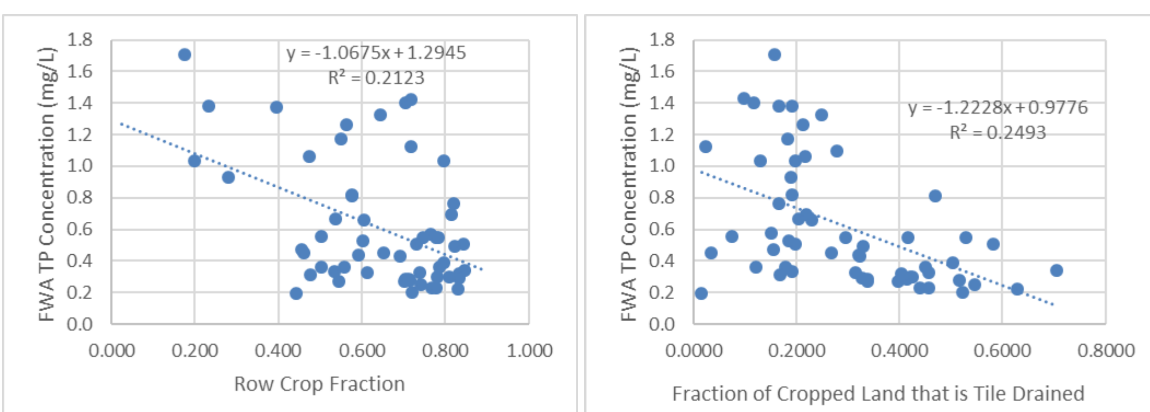

Figure 17. Plot of flow-weighted average (FWA) TP concentration versus fraction of land in row crop (left panel) and fraction of row crop land that is likely to be tiled (right panel) – both panels show statistically significant trend lines.

Orthophosphate concentration versus row cropped and tile drained land

Figure 18 shows plots of the long term STORET site flow-weighted average OP concentration data versus fraction of the watershed in row crop and soils likely to be tile drained. A regression of FWA OP concentration on both row crop fraction and likely tile drained row crop fraction indicates that only the row crop term is significant and that orthophosphate concentrations in the monitored rivers tend to increase with the fraction row crop agriculture.

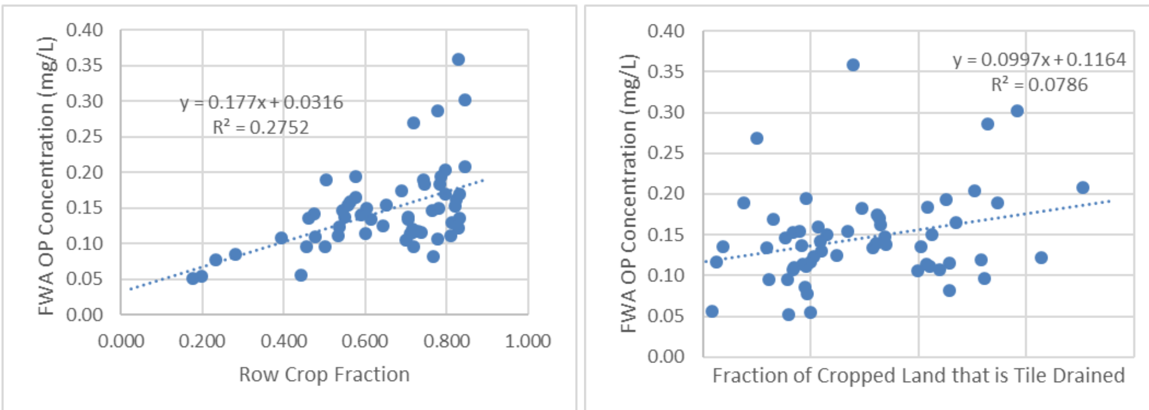

Figure 18. Plot of flow-weighted average (FWA) OP concentration versus fraction of land in row crop (left panel) and fraction of row crop land that is likely to be tiled (right panel) – both panels show statistically significant trend lines.

It is interesting to note that the FWA OP concentrations correlate with FWA nitrate concentrations stronger than they do with row cropped land fraction (Figure 19, compare with Figure 18). It is also of some interest to note that the FWA OP concentrations show no clear relationship to the FWA TP concentrations (Figure 19).

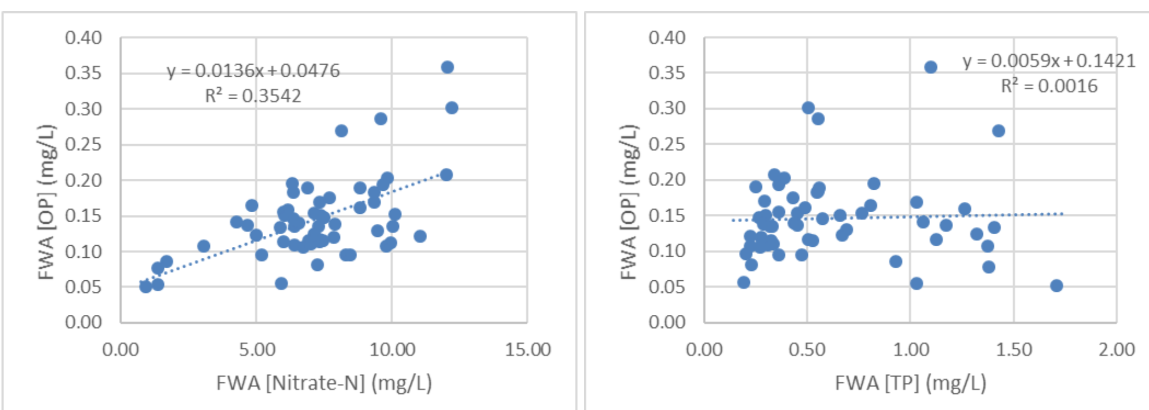

Figure 19. The FWA OP concentrations show a stronger relationship to FWA nitrate (left panel) than to the fraction of land in row crop (compare with Figure 18). The FWA OP concentrations show no relationship to FWA TP concentrations (right panel).

Spatial Patterns in Flow-Weighted Average Nutrient Concentrations

Figures 25, 26 and 27 show the FWA nitrate, TP and OP concentrations plotted near the STORET ambient monitoring station location. The background shading shows row cropped land in green and developed land in red with the Des Moines Lobe outlined in light red. All flow-weighted average (FWA) concentrations in this section are based on observed data only; i.e. as the sum of loads on days having a sample concentration divided by the sum of the flow on those days having a sample concentration over the entire period of record.

Figure 20 shows that the highest riverine nitrate concentrations tend to be on and to the west of the Des Moines Lobe and decline somewhat toward the northeast regions of Iowa, while the southern three tiers of counties generally show the lowest nitrate concentrations.

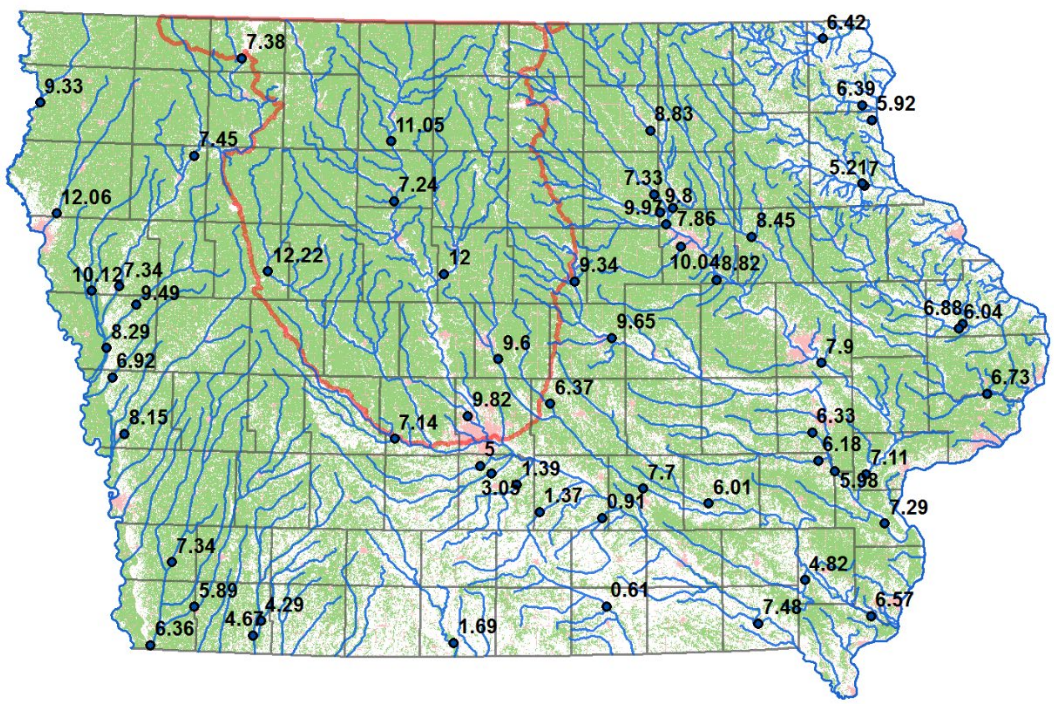

Figure 20. STORET derived FWA Nitrate-N concentrations (mg/L). Green tinted areas are row cropped land and red tinted area are developed land.

Figure 21 shows that FWA TP concentrations tend to be lowest on the Des Moines Lobe and in the northeast part of Iowa while, with a few exceptions in the southeast part of the state, concentrations on the west and southern four tiers of counties tend to be elevated. The exceptions are the Chariton River station which is below Rathbun Lake reservoir (FWA [TP] = 0.14 mg/L), the Des Moines River at Keosauqua (FWA [TP] = 0.27 mg/L), the Skunk River near Augusta (FWA [TP] = 0.44 mg/L), and the Iowa River near Wapello (FWA [TP] = 0.33 mg/L).

The FWA OP concentrations do not appear to show a strong pattern in their spatial distribution within the state (Figure 22).

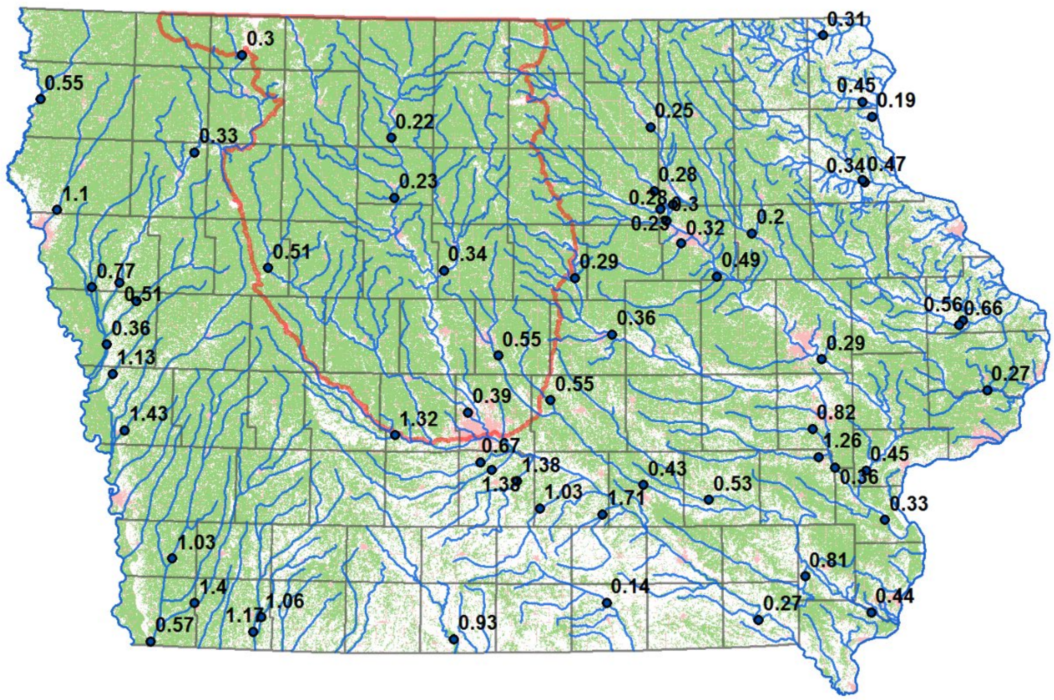

Figure 21. STORET derived FWA TP concentrations (mg/L). Green tinted areas are row cropped land and red tinted area are developed land.

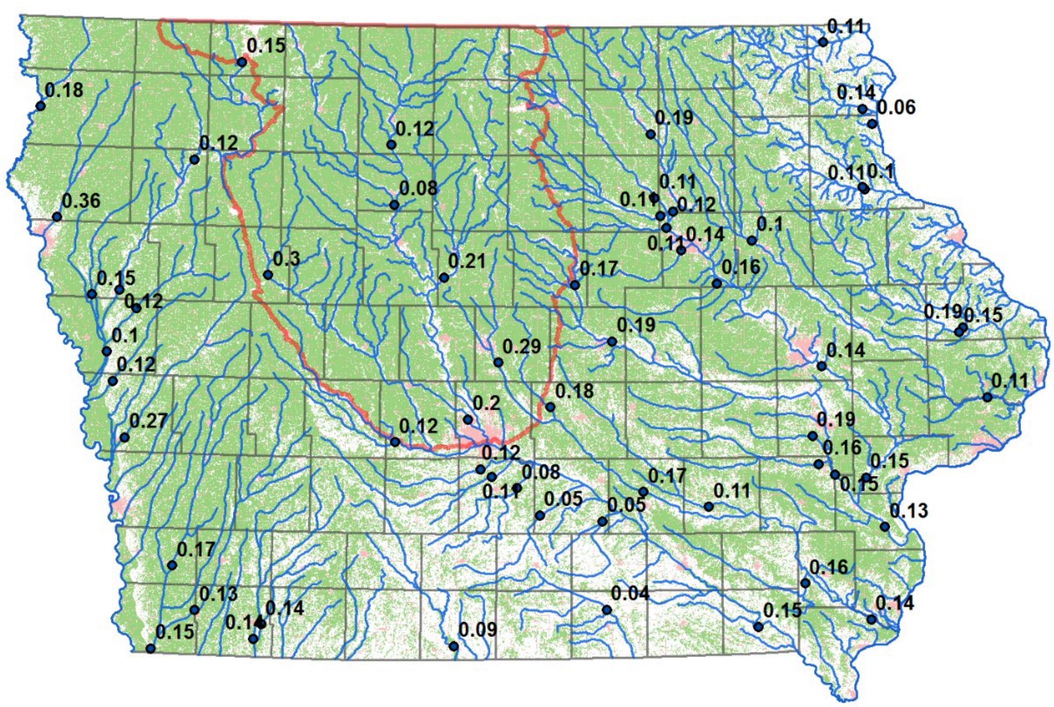

Figure 22. STORET derived FWA OP Concentrations (mg/L). Green tinted areas are row cropped land and red tinted area are developed land.

Conclusions

Point Source contribution to River loads

The point source load analyses indicate that municipal waste water effluent streams contributed nitrate loads averaging 1-7% annually with up to 25% during the 2012 drought year and total phosphorus loads averaging 2-40% annually and up to 75% during the 2012 drought year to the three Iowa rivers examined here. In each of these cases, municipal waste water sources contribute the majority of the nitrate and total phosphorus loading to rivers during dry periods. However, because total riverine annual loads are low during dry periods, including drought years, point source loads during these periods primarily impact local water quality and have less of an impact on loads delivered to the Gulf of Mexico relative to typical or wetter years. During most years, non-point source loads dominate the nitrate loading to the Gulf of Mexico while a more substantial portion, up to about 15%, of the TP load is delivered by municipal waste water point sources. During flood years such as 2010, non-point sources contribute the bulk of the annual riverine nitrate and TP loading.

Non-Point Source contribution to River loads

Overall, the STORET ambient stream monitoring data indicate that about 44 to 91 percent (average of 75%) of the variation in daily river nitrate loads is attributable to river discharge, with loads tending to increase with periods of higher flow. Similarly, about 9 to 95% (average 73%) of daily orthophosphate and 25 to 95% (average 68%) of daily TP load is attributable to river discharge, with loads tending to increase during periods of higher flow. Because of this, evaluation of loading trends must consider the effects of discharge on loading.

Loads in the ambient monitoring rivers are influenced by point source loading, in-stream processes including sediment deposition and resuspension, bank erosion, phosphorus sorption and desorption dynamics, nitrogen cycling, and delivery scale processes that supply water to these streams. On the basis of the ambient monitoring data alone it is not possible to accurately separate and evaluate the contribution of these various processes. Accordingly while the ambient monitoring data may be utilized to obtain estimates of loading and loading trends, those results are not attributable solely to current agricultural practices and land use.

General Conclusions

Agriculture contributes over 95% of the long-term N and over 85% of the long term P loads in the study basins. However, urban sources can contribute 50-90% of these loads during critical low flow periods extending for several months most years. Load reduction goals should consider both annual and seasonal patterns to protect local as well as downstream waters.

Reference

Greg A. Stenback, William G. Crumpton, Keith E. Schilling, Matthew J. Helmers, 2011. Rating curve estimation of nutrient loads in Iowa rivers. Journal of Hydrology 396 (2011) 158–169.