NITROGEN AND PHOSPHORUS BUDGETS FOR IOWA AND IOWA WATERSHEDS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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ABSTRACT

Inputs and outputs of nitrogen (N) and phosphorus (P) were estimated for the state of Iowa and 68 of its major watersheds. Included in the input estimates are nutrients from fertilizer, legumes, soil processes, manure, atmospheric deposition, and human and industrial waste discharges. Output estimates include nutrients removed by crop harvest, grazing, volatilization, soil processes, denitrification, and stream discharge. Inputs and outputs were estimated based on the best available data using standard agronomic and hydrologic approaches. Data represent an average year during the 1997-2002 period. Stream load estimates were based on monthly monitoring of 68 watersheds, for the period 2000-2002. These watersheds cover about 80 percent of the state.

The estimated inputs and outputs appear reasonable and represent the first comprehensive attempt to map the state's nutrient budget status. However, the budget figures are estimates. For nitrogen, inputs and outputs via soil processes and atmospheric inputs are the most problematic to estimate. Stream load estimates for nitrogen appear reasonable and are consistent with past studies. Estimates of most inputs and outputs for phosphorus appear reasonable. However, stream loads of phosphorus, much of which is associated with sediment, are difficult to estimate based solely on monthly monitoring. In addition, the phosphorus content of Iowa soils and sediments complicates interpretations of the relationship between inputs and stream concentrations and loads.

Inputs of nitrogen (N) to the state total about 4 million tons per year or about 216 pounds per acre. Agriculturally related inputs dominate. Inputs and outputs generally appear in balance. Soil processes and nitrogen fertilizer account for about half of the inputs, while soil processes and crop harvest account for about two-thirds of the outputs. Iowa streams discharged about 200,000 tons of nitrogen during the relatively dry 2000-2002 period, an amount equivalent to 11 pounds per acre annually. This represents about 5 percent of the inputs. This percentage is likely higher during more typical or wetter-than-average climatic conditions. The stream N load from Iowa is equivalent to about 20 percent of the long-term N load carried by the Mississippi River to the Gulf of Mexico.

Inputs of phosphorus to the state are about 240,000 tons per year, or about 13 pounds per acre. Agriculturally related inputs dominate. Fertilizer and manure account for virtually all the inputs. Outputs are estimated to be 270,000 tons annually. Harvest and grazing account for virtually all of the outputs. Stream P loads, while difficult to estimate accurately, appear to be about 11,000 tons annually, equivalent to 4 percent of the inputs.

Estimated annual nitrogen inputs to individual watersheds range from 143 to 347 pounds per acre. Inputs and outputs appear generally balanced for individual watersheds. Phosphorus inputs to individual watersheds vary from 6 to 37 pounds per acre per year. Inputs and outputs of P appear less well-balanced on a watershed basis. Comparison of the mass of point source inputs of N to stream N loads suggests point sources account for about 8 percent of the stream N loads statewide, varying from 1 to 15 percent for individual watersheds. Nonpoint sources account for the remainder. Point sources of P account for 20 percent of stream P loads statewide, varying from 1 to 52 percent for individual watersheds. Point source contributions are likely lower during average to wetter than average years. As there is more confidence in the total stream load estimates for N than for P, there is likewise more confidence in the point versus nonpoint contribution estimate for nitrogen than for phosphorus.

Preliminary analysis of watershed-based nutrient budget factors and water quality data suggest relationships between higher stream nitrogen concentrations and greater inputs of fertilizer-N, agricultural fertilizer-N, manure-N, soybean-N, soil-process N, total N inputs, and the percentage of row crop in the watershed. Greater stream N loads are related to fertilizer-N, ag-fertilizer-N, and total N inputs. Budget factors show little relationship to the concentrations or loads of P in streams, likely because of the complications with sediment-associated P and the difficulty in accurately assessing stream P status. The analysis suggests a trend towards higher concentrations of dissolved P for watersheds with greater P inputs.

INTRODUCTION

The 2002 Iowa Legislature passed Senate File (SF) 2293, which directed the Iowa Department of Natural Resources (DNR) to develop a nutrient strategy for the state. SF 2293 further directed the DNR, as part of the strategy, to undertake the "development of a comprehensive state nutrient budget for the maximum volume, frequency, and concentration of nutrients for each watershed that addresses all significant sources of nutrients in state water on a watershed basis." The major nutrients of concern in Iowa waters are nitrogen (N) and phosphorus (P). This report describes how nutrient inputs and outputs to the state and its major watersheds were estimated; compiles these inputs and outputs for the state and by major watersheds; and compares estimated inputs to outputs.

The nutrients N and P are essential compounds for plant growth and for life itself. However, excess N and P in water may have negative impacts on aquatic life and limit the use of water bodies for recreation and as drinking water sources. N and P have natural sources and cycles of movement and transformation in the environment. Human activities are superimposed on these natural cycles. Some human activities, such as fertilization, add nutrients to watersheds. Others, such as harvesting crops and exporting them from a watershed, subtract nutrients. Yet other activities do not directly add or remove nutrients from a watershed, but rather make existing nutrients more or less environmentally mobile, and therefore more or less likely to be used by growing plants or transported to water bodies. The nutrient budget focuses on the inputs and outputs of these compounds to the state and its watersheds. It is an accounting of N and P sources and sinks, which is necessary for understanding nutrient delivery to water bodies and aids in the development of a state nutrient strategy.

BUDGET DESIGN

In 1999, the White House Office of Science and Technology Policy's Committee on Environment and Natural Resources (CENR) reported on an investigation into the hypoxic (low oxygen) conditions in the Gulf of Mexico, and the role of nutrients in causing these conditions. Part of this effort included compiling N and P budgets for selected watersheds within the Mississippi River basin. The budget design used by CENR (Goolsby and others, 1999) was adopted for the Iowa statewide and watershed-level N and P budgets. The budgets' inputs and outputs are shown in Figure 1. The inputs include:

- Fertilizer — N and P inputs from commercial fertilizer; estimates made for different crops, pastures, lawns.
- Legume Fixation — The atmospheric N added to the soil-crop system by soybeans, alfalfa and other legumes; estimated by legume type.
- Soil Process N — N released ("mineralized") from soil organic matter, becoming "available" for crop uptake or transport; estimates based on soil type and land use.
- Manure — N and P contained in livestock waste; estimated for beef, hogs, sheep, and poultry, and by manure storage and application methods.

- Atmospheric Deposition — Wet and dry nitrogen dissolved in rain, attached to wind-blown particles, or existing as aerosols. Estimated from rainfall monitoring and CENR report methods.
- Human — N and P in human waste; estimated for waste management practices, and using standard values per capita.
- Industrial Discharges — N and P discharged from industrial plants; estimated from plant distribution and hypoxia report methods.

Nutrient outputs include:

- Harvested — N and P removed in crops; estimated by crop type.
- Grazing — N and P in pasture forage; directly "harvested" by livestock.
- Crop Volatilization — N compounds (mainly ammonia) that volatilize from growing and withering crops (senescence).
- Soil Process N — N that enters the soil organic matter pool, becoming stored (immobilized).
- Manure Volatilization — Ammonia-N that volatilizes from livestock manure during storage and application.
- Fertilizer Volatilization — Ammonia-N that volatilizes from applied N-fertilizer.
- Denitrification — Nitrate-N lost to the atmosphere as N_2 compounds.
- Streams — N and P loads in streams; calculated from water quality and stream flow measurements.

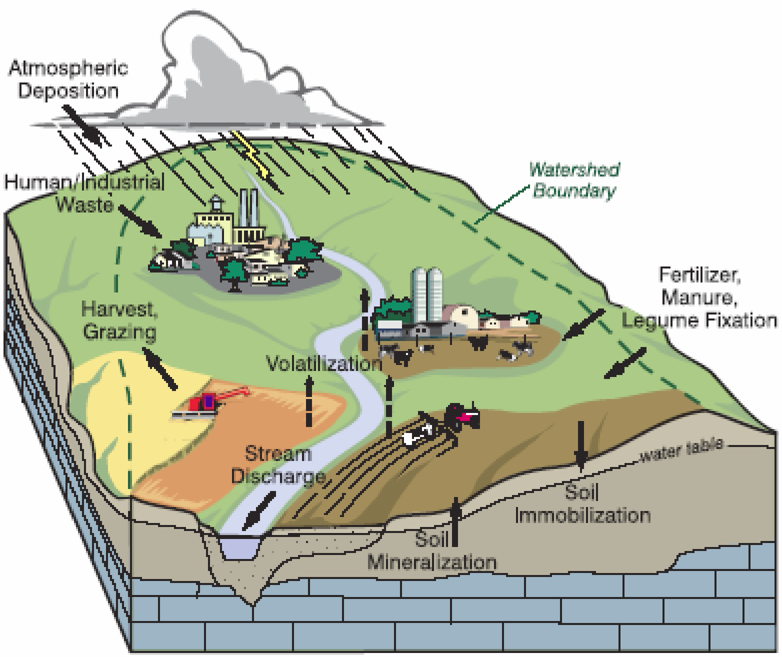

Figure 1. Nutrient inputs and outputs to a watershed

"Soil process" inputs and outputs of N are typically referred to as mineralization and immobilization, respectively. In the strict sense, these processes don't add or remove N from a watershed. However, they do make N available or unavailable for crop uptake or transport to water bodies**.** The budget follows the convention of the 1999 CENR Hypoxia report in referring to these processes input and outputs for accounting purposes.

NUTRIENT ESTIMATION METHODS

Appendix I documents how nutrient inputs and outputs were estimated and apportioned across the state. A variety of data sources were used for these estimates, including:

- U.S. Department of Agriculture-Census of Agriculture and annual agriculture statistics
- DNR animal feeding operations permit and manure management plan information
- Iowa Department of Agriculture and Land Stewardship fertilizer sales data and livestock count estimates
- Iowa State University turf-grass surveys and experimental data
- DNR Geographic Information System (GIS) coverages and aerial imagery
- DNR wastewater plant data

Data sources ranged over the 1997-2002 time period, so the resulting estimates should be viewed as representing a typical recent year. Nutrient loads contained in manure, human waste, harvested crops, and input or output via soil and other agronomic processes were developed with advisory teams of DNR staff, Iowa State University faculty and research scientists from the USDA National Soil Tilth Laboratory. Standard references, sometimes modified for Iowa conditions or recent research by the agronomic specialists on the advisory team, were the basis of this process. Examples include:

- Iowa State Extension publications
- Midwest Plan Services documents
- North Central Association of Ag-Experiment Station reports
- *Modern Corn and Soybean Production*

References for data sources are given in Appendix 1. County-level and more localized estimates of inputs and outputs were distributed across the landscape using a Geographic Information System (GIS)-based approach. This allowed the incorporation of pertinent details such as land use, cropping patterns, typical crop yields, soils types, average rainfall, and the location of livestock operations and wastewater discharges. GIS coverages (electronic data maps) were developed for each input and output type, as well as for total N and P inputs and outputs. Summing these yielded the N and P budgets for the state as a whole.

N and P outputs in stream flow from the state were calculated for the 68 watersheds that are monitored and gauged as part of the DNR's ambient water quality monitoring program. Water quality samples were collected and analyzed by the University of Iowa Hygienic Laboratory following U.S. Environmental Protection Agency approved methods and quality-assurance protocols. Stream gauging was conducted by the U.S. Geological Survey (USGS)-Iowa District staff following USGS national gauging network standards. The monitoring and gauging allow for the calculation of total nutrient outputs, or loads, from the watersheds. These loads are the estimated tonnage of N and P discharged from individual watersheds by their streams. Daily stream flow volumes and, typically, monthly water quality data were used for the stream load estimates. These data were collected during water-years 2000-2002 (e.g., water year 2000 is the October 1 1999-September 30 2000 period).

Several methods were evaluated for estimating stream nutrient loads:

> 1) ESTIMATOR (Cohn and others, 1989; 1992), a multivariate regression approach developed by the U.S. Geological Survey. This method was used to assess nutrient flux to the Gulf of Mexico for the CENR report (Goolsby and others 1999);
> 2) The Beale Ratio, or Autobeale method (Beale, 1962; Baun, 1982), which uses flow-stratified flux-discharge relationships; and
> 3) Combining a simple linear interpolation between subsequent nutrient concentrations with daily discharges.

Typically ESTIMATOR provided the largest loads, and interpolation the smallest. Autobeale consistently produced intermediate values, and results from this method were therefore used. The load estimation also provided annual mean concentrations for N and P. Loads and concentrations for phosphorus were estimated for “ortho” P, which is P dissolved in water, and for “total” P, which includes both dissolved P and the P that is associated with sediment. Nitrogen loads and concentrations represent total nitrogen, accounting for nitrate-, nitrite-, ammonia-, and organic-N. The 68 gauged and monitored watersheds cover about 80 percent of the state; the per-acre N and P loads from these watersheds were applied to the total area of the state, providing statewide estimates of N and P loads.

The data maps assembled for the state allow for nutrient inputs and outputs to be summarized for specific geographic areas. As directed by Senate File 2293, this was done on a watershed basis. For this, the 68 ambient water quality monitoring program watersheds were again used. All individual inputs and outputs of nitrogen and phosphorus (e.g., fertilizer, human waste) were summed for each watershed. These values were then divided by the total acreage of each watershed to create inputs and outputs of each nutrient on a per acre basis. These numbers could then be used to compare watersheds, and to assess how well each watershed’s nutrient inputs and outputs were balanced.

BUDGET CAVEATS

The budget’s estimates for nutrient inputs and outputs are based on standard methods and data sets, and were derived with the advice of many of the State’s leading technical experts. It represents the first comprehensive mapping of the distribution of major nutrient sources across the state. However, it should be emphasized that the budget is an estimate. The best available data are often county-based. Average values were used for sources, sinks, and processes. Some of these are affected by climate and individual production methods. The data sources cover a range of years. Still, the budget derived for the state and its watersheds present a reasonable picture of Iowa's current nutrient status.

For nitrogen, the greatest uncertainties occur with estimating the amount of N that is released from and returned to soil organic matter during an average year. The budget estimates are based on these processes being in balance. While available evidence suggests that these processes should not be greatly imbalanced, even small changes in this balance involve large amounts of N. The amount of N deposited from the atmosphere is also viewed as a less firm estimate than other N inputs and outputs. Stream N loads and average concentrations appear consistent with those generated by a variety of past work (e.g., Goolsby et. al, 1999; Schilling and Libra, 2000) and therefore are considered reasonable estimates.

Relative to N, there are fewer inputs and outputs of P to estimate. Phosphorus inputs from fertilizer and manure, and outputs of the P contained in harvested/grazed crops, are relatively standard estimates. However, the estimate for P in manure is complicated by recent changes in feeds and feed additives (such as phytase), primarily for hogs. Hog manure P inputs were decreased from those provided in standard references to account for these changes, based on advice from agronomy professionals. However, there is no current documentation on how significant the decrease has been and therefore the accuracy of the reduction estimate is unclear. In addition, there are difficulties in assessing the significance of the P budget and its relationship to stream P concentrations and loads. These come from several factors. First, the state's sediments — soils, glacial materials, and stream beds and banks — contain considerable naturally-occurring P, often in the 300 to 700 part per million range (Fenton, 1999). Erosion of soil particles therefore can deliver significant amounts of P to streams. Second, inputs of P from manure and fertilizer also tend to attach to sediment particles. Third, the most significant erosion and delivery of sediment and sediment-associated P to streams occurs during infrequent heavy rains or snowmelt periods. With a monthly stream sampling frequency, the short periods when large amounts of P are discharged by streams at high concentrations are likely missed. This may result in an underestimation of stream P loads and concentrations. In sum, these factors make it difficult to adequately characterize stream P loads or relate them to the inputs and outputs in the budget.

STATE NITROGEN BUDGET

Table 1 lists the estimated nitrogen inputs and outputs for Iowa by category. Figure 2 summarizes the estimated inputs of nitrogen for the state on a percentage basis. Statewide, estimated N inputs and outputs appear roughly in balance. Inputs and outputs are estimated to be about 4 million tons, or about 216 pounds per acre. Soil nitrogen that is released (mineralized) from the soil organic matter pool accounts for about a quarter of this nitrogen, or about 1 million tons. This occurs primarily on land that has been plowed and planted to corn and soybeans. Application of commercial fertilizer accounts for roughly the same amount. Over 90 percent of the nitrogen fertilizer is used for agricultural purposes, and the vast majority is applied to corn. Less than 10 percent of the fertilizer is applied to non-agricultural grass (lawns, parks, general use areas, golf courses, etc.). About 20 percent of the inputs, or almost 800,000 tons, is added to the state annually by legumes. Legume crops, such as soybeans and alfalfa, “fix” atmospheric nitrogen and add it to the State’s soil-crop-water system. Soybeans account for about two-thirds of the legume nitrogen. Atmospheric deposition of nitrogen (wet and dry) and livestock manures add 16 percent and 13 percent of the total, respectively. About 45 percent of the manure-N input, which is about 500,000 tons, is generated by hogs. Beef and dairy cattle account for 42 percent and 6 percent, respectively. Human and industrial wastes add a very minor amount of nitrogen to the state, about 17,000 tons, or well below 1 percent of the total. Much of this nitrogen, however, is discharged directly to streams via wastewater plants, while the majority of the other inputs are applied to land.

Table 1. Estimated nitrogen inputs and outputs for Iowa

N Inputs	***Tons***
Fertilizer	984,000
Legumes	762,000
Wet Deposition	363,000
Soil N	1,014,000
Manure	493,000
Human	16,000
Dry Deposition	254,000
Industry	2,800
Total	***3,888,000***

N Outputs	***Tons***
Harvest	1,565,000
Grazing	172,000
Crop Volatilization	353,000
Soil N	1,014,000
Manure Volatilization	249,000
Fertilizer Volatilization	17,000
Denitrification	413,000
Streams	198,000
Total	***3,981,000***

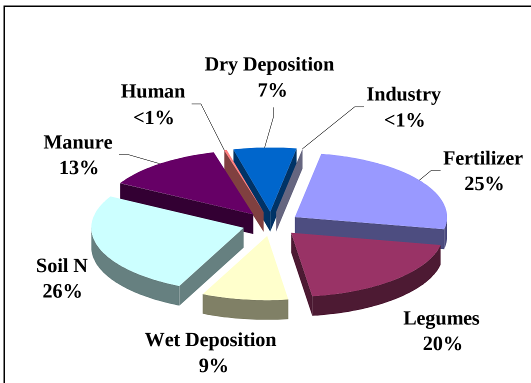

Figure 2. Statewide nitrogen inputs on a percentage basis

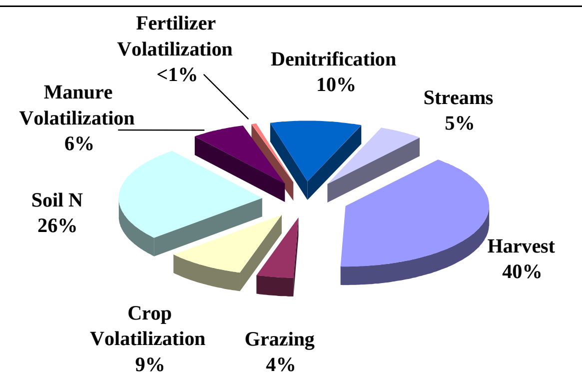

Figure 3. Statewide nitrogen outputs on a percentage basis

Figure 3 summarizes the estimated annual nitrogen outputs from the state on a percentage basis. Harvesting and grazing of crops account for the greatest output, about 1.7 million tons, which is 44 percent of the total outputs. Roughly 1 million tons of nitrogen is estimated to return annually to the soil organic matter pool, accounting for about a quarter of the outputs. About 15 percent of the nitrogen is volatilized into the atmosphere as ammonia from crops, manure, and fertilizer. This nitrogen is redeposited on the land, but its fate is poorly understood. Another 10 percent is “denitrified,” a process that produces true atmospheric nitrogen, which is not immediately returned to the land. Finally, the average annual loss of nitrogen from the state in streams accounted for 5 percent of the total during water years 2000-2002. This was a relatively dry period in much of the state, and during normal to wet years, stream losses of nitrogen could account for 10 percent or more of the outputs (Libra and others, 2001). Whether conditions are wet or dry, the budget suggests that the losses of N to streams are a small portion of the entire N cycling through the environment. However this is a small portion of a large amount; 5 percent of the total N is about 200,000 tons, which is equivalent to 11 pounds for each acre of the state. The CENR report (Goolsby and others. 1999) estimated that during typical years in the 1990s, the Mississippi River system delivered about 1 million tons of nitrogen per year to the Gulf of Mexico. The budget indicates Iowa contributes about 20 percent of this nitrogen, a percentage that is likely higher during wetter years Goolsby and others (1999) estimated Iowa's contribution as 19 percent during the 1980's and 1990's).

STATE PHOSPHORUS BUDGET

Table 2 lists the estimated phosphorus inputs and outputs for Iowa by category. Figure 4 summarizes P inputs on a percentage basis. Phosphorus inputs to the state are about 240,000 tons and come almost entirely from fertilizer and manure. Point source discharges from human and industrial wastewaters are about 1 percent of the total. Phosphorus outputs total about 270,000 tons; these are summarized on a percentage basis in Figure 5. Harvest and grazing account for virtually all of the phosphorus removal. Stream losses account for the remaining 4 percent. In total, stream P loads were about 11,000 tons, which is equivalent to 0.7 pounds per acre.

Table 2. Estimated phosphorus inputs and outputs for Iowa

P Inputs	***Tons***
Fertilizer	126,954
Manure	109,214
Human	3,600
Industry	650
Total	***240,418***

P Outputs	***Tons***
Harvest	243,197
Grazing	22,545
Streams	10,844
Total	***276,586***

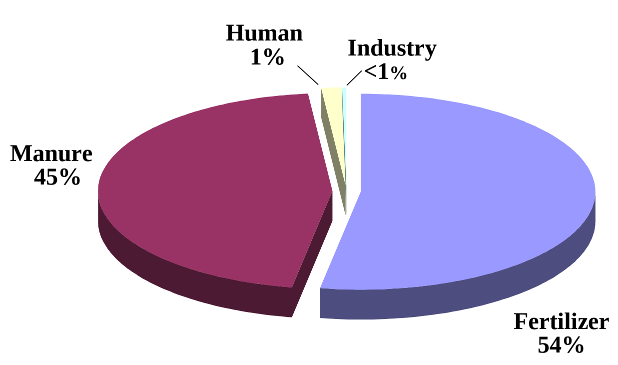

Figure 4. Statewide phosphorus inputs on a percentage basis

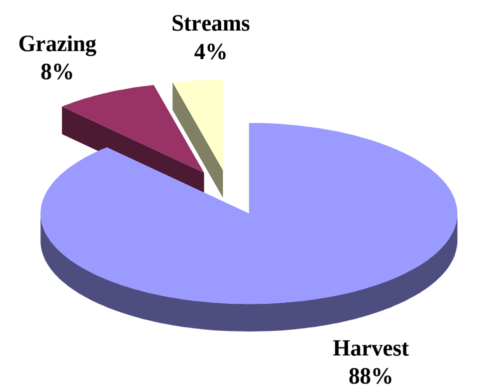

Figure 5. Statewide phosphorus outputs on a percentage basis

The budget estimates that on a statewide basis, more phosphorus is being removed than is being added to the state. However, the estimates suggest outputs exceed inputs by only 11 percent, and so the results should be viewed as suggesting that for the state as a whole, P inputs and outputs are roughly in balance. This likely was not the case in the past when inputs exceeded outputs, as evidenced by the common occurrence of soils testing high in crop-available P (ISU, 1986). The estimated decrease in manure P resulting from feed additives accounts for about half of the difference between the inputs and outputs.

WATERSHED NUTRIENT BUDGETS

Budgets were prepared for 68 watersheds tracked by the DNR's ambient water quality monitoring program. Total N and P inputs and outputs, along with water quality data for these watersheds, are contained in Appendix II. Figure 6 shows the total nitrogen inputs to each watershed, and Figure 7 shows the total phosphorus input. Nitrogen inputs for the state averaged 216 pounds per acre. Among the individual watersheds, inputs range from 143 to 347 pounds per acre. Statewide, phosphorus inputs averaged 13 pounds per acre. Among individual watersheds, inputs ranged from 6 to 37 pounds. The greatest inputs of both nutrients occur in north central and northwest Iowa, areas typified by intensive row crop agriculture, organic-rich soils, and/or large livestock populations. Lesser inputs occur in the less intensively row cropped parts of southern Iowa.

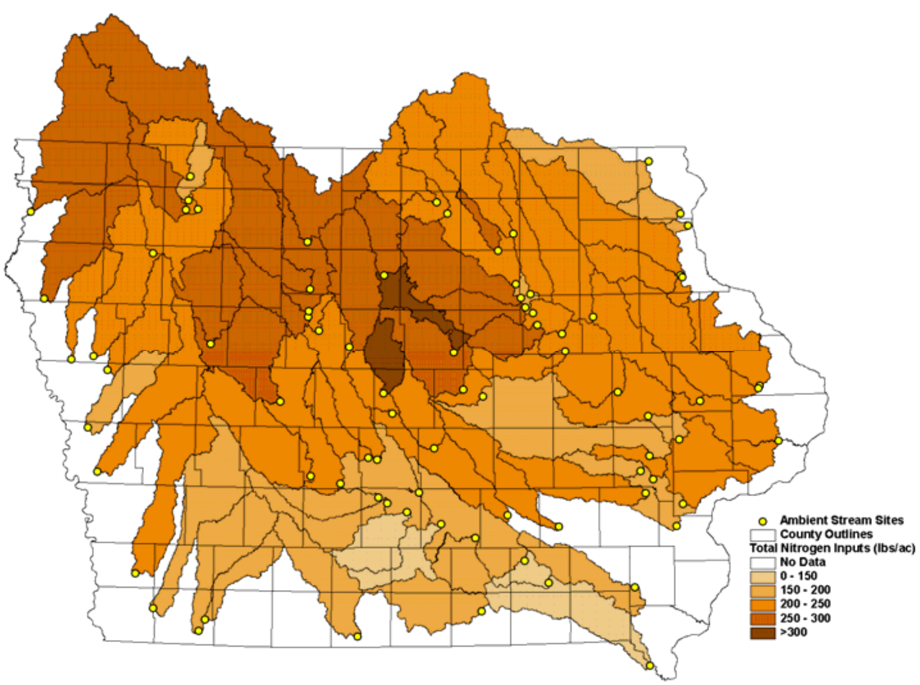

Figure 6. Estimated total N inputs to Iowa watersheds

Statewide, estimated N inputs and outputs are roughly in balance. On a watershed scale, this condition of relative balance is also apparent. Of the 68 watersheds, 74 percent are within 5 percent of balance, and 94 percent are within 10 percent. The four watersheds that are furthest out of balance are those with the lowest total N inputs. They show an excess of inputs relative to outputs.

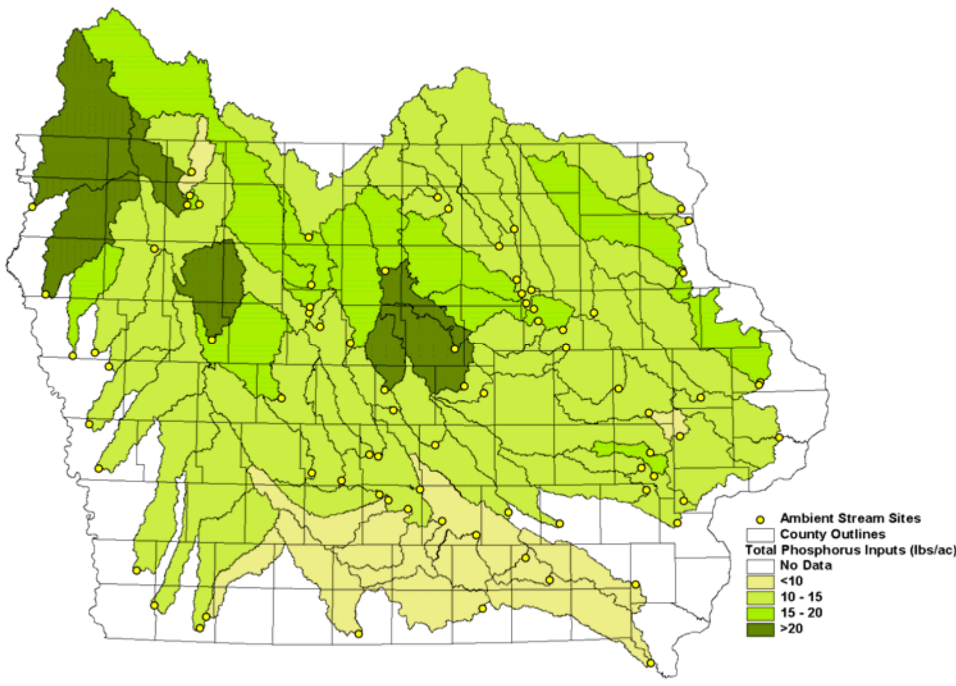

Figure 7. Estimated total P inputs to Iowa watersheds

While P outputs are estimated to exceed inputs on a statewide basis, the P balance for individual watersheds is quite variable, compared to the balance for nitrogen. The majority of the watersheds (62 percent) show outputs exceeding inputs, while 38 percent of watersheds are estimated to have inputs exceeding outputs. Only 19 percent of the watersheds are within 5 percent of being in balance, and only 37 percent are within 10 percent.

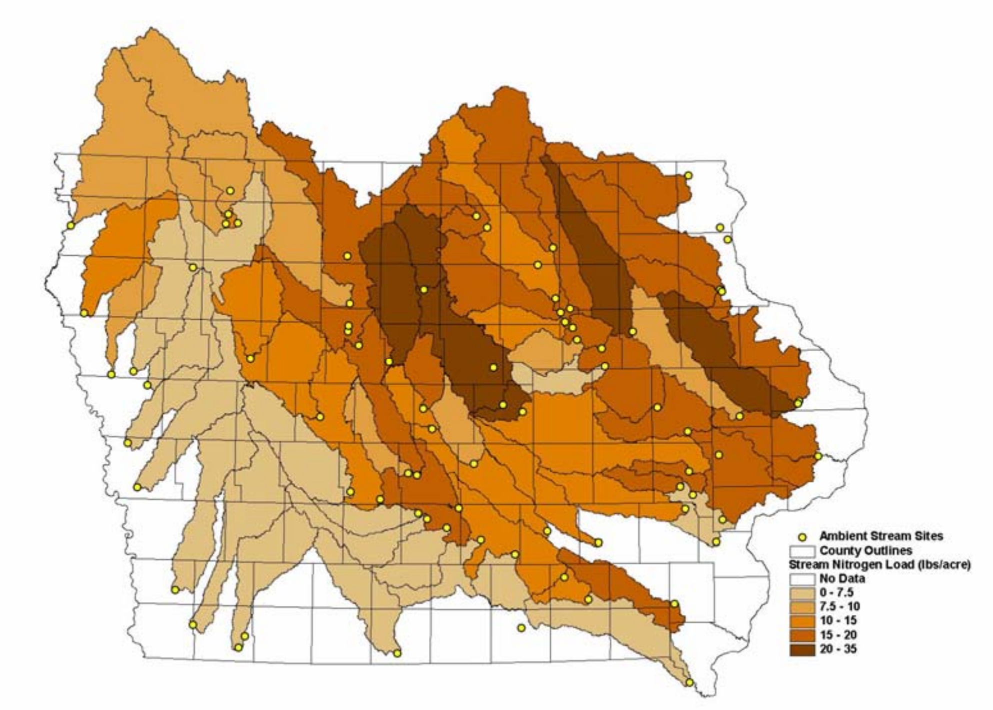

Figure 8. Stream N-Loads for monitored watersheds

Stream outputs of N and P for the state are estimated at 13 and 0.7 pounds per acre, respectively. For individual watersheds, stream N loads varied from 3 to 34 pounds per acre. Stream P loads ranged from 0.3 to 3.2 pounds per acre. Figures 8 and 9 show N and P stream loads for the watersheds.

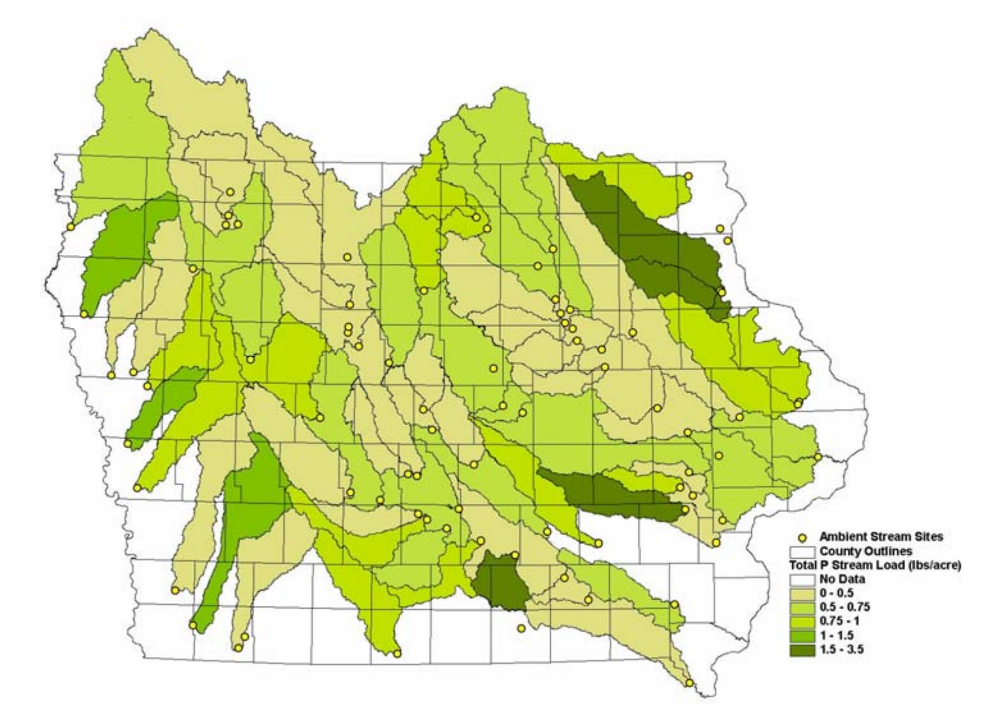

Figure 9. Stream P-Loads for monitored watersheds

NUTRIENT BUDGETS AND WATER QUALITY

A preliminary analysis of the relationships between nutrient inputs to watersheds and resulting stream nutrient concentrations and loads was undertaken. The results suggest that higher nitrogen concentrations occur in watersheds with greater inputs of nitrogen from fertilizer, agricultural fertilizer, manure, soybean-N, and soil-derived N. Watersheds with greater total N inputs and a high percentage of row crops also tend to have higher nitrogen concentrations in their streams, a relationship observed before for Iowa streams (Schilling and Libra, 2000). Larger stream N-loads are related to watersheds with greater inputs of fertilizer, ag-fertilizer, and total N inputs. For phosphorus, this preliminary analysis showed little in the way of clear relationships. As previously described, the picture for phosphorus is clouded by the considerable natural concentrations of P in Iowa sediments, the fact that P from manure and fertilizer tends to attach to soil and sediment particles, and the variable nature of P concentrations in streams under variable runoff conditions. The preliminary analysis does suggest a trend towards higher dissolved phosphorus concentrations in watersheds with greater P inputs. Further analysis of the relationships between nutrient inputs and stream quality are warranted, particularly for phosphorus.

NUTRIENT TRANSPORT TO STREAMS

Nitrogen and phosphorus from treated human and industrial waste, although small in comparison to land-applied nutrients, are often discharged directly to streams. Effluents discharged from wastewater plants are typically called “point sources” of nutrients, as opposed to land-applied nutrients, which are termed “nonpoint sources.” If the point source estimates are compared to the measured nitrogen load of streams, the point sources account for about 8 percent of the stream nitrogen statewide. Nonpoint sources, therefore, are estimated to account for the remaining 92 percent. For individual watersheds, point source inputs account for 1 to 15 percent of stream N. For phosphorus, point sources account for 20 percent of the stream phosphorus statewide; indicating that about 80 percent of the phosphorus is from nonpoint sources. For individual watersheds, point source inputs account for 1 to 52 percent of stream P. Note that these estimates assume all N and P from human waste are directly discharged to streams, when in fact some of the human N and P are land-applied as sludge, or via septic systems. This suggests the estimated percentage of point source contributions is probably high. In addition, the 2000-2002 period was drier than typical across the state, indicating that non-point source contributions in typical years are greater. In sum, the actual long-term point source contributions to N and P stream loads are likely smaller than those estimated above. Further monitoring of nutrient loads from wastewater plants is warranted, particularly for P.

Agricultural inputs of nitrogen and phosphorus dominate the total inputs to the state. For phosphorus, ag-inputs include essentially all the manure-P, roughly 90 percent of the fertilizer, and about 95 percent of the total P. Nitrogen inputs include essentially all the manure, soil-N, and legume inputs, 90 percent of the fertilizer, and, in aggregate, over 80 percent of the total N inputs.

While ag-related, nonpoint sources represent the largest N and P inputs in Iowa, delivery of these nonpoint source nutrients to streams (and to lakes, wetlands, and groundwater as well) depends on a variety of factors beyond just the total input, or whether inputs and outputs appear to be "in balance." Delivery rates vary in time and geographically, even where inputs and balances are similar. Nitrogen is typically transported to water bodies in the form of nitrate. Nitrate does not bind to soil particles and is mobilized by water that infiltrates through the soil zone (Baker and Johnson, 1981; Hallberg, 1989; Keeney, 1989). Therefore, landscapes, geologic settings, and land management practices that are conducive to high infiltration rates result in greater leaching of nitrate from the soil profile and to the water table. Once nitrate reaches the water table, it moves with shallow groundwater and/or tile drainage to streams, lakes, or deeper groundwater reservoirs. Relatively flat landscapes, areas underlain by shallow aquifers, areas with intensive tile drainage, and areas with management practices that leave soil exposed (e.g., row crop as opposed to cover crops or pasture; Randall and others, 1997) are at greater risk for infiltration of water and leaching of nitrate. These settings are also conducive to the leaching of dissolved P (which is not attached to sediment).

Phosphorus, on the other hand, attaches relatively strongly to soil particles, and so is dominantly transported to streams by processes that deliver soil and sediment. Overland runoff and the resulting erosion are the mechanisms that transport P to streams. Hilly landscapes and exposed, erodible soil are at greater risk for overland runoff, erosion, and P delivery to lakes and streams. Mallarino and others (2002) provide a detailed look at the factors affecting P transport from agricultural fields.

A final important factor in the delivery of nonpoint source nutrients to water bodies is the amount of precipitation that falls in a given location. Years with more precipitation provide more water for both overland runoff and infiltration, typically resulting in greater nutrient transport, and therefore higher concentrations and loads in Iowa streams (Libra and others, 2001). Further, there is interplay between the timing of rainfall and the timing of nutrient availability for mobilization. In sum, a variety of factors affect the delivery of N and P from nonpoint sources to streams. These include soil, geologic, and climatic conditions; management practices that affect the pathways followed by water; and the amount of nutrients applied to the land. The nutrient budget addresses the "amount of nutrients" factor. Strategies and management practices to limit or mitigate nutrient movement to water bodies must address all of these factors.

FURTHER ANALYSIS AND INFORMATION NEEDS

The nutrient budget estimates reported here are based on standard, readily available information and methods, and provide the first comprehensive picture of the nutrient status of the state and its major watersheds. However, there are areas where further work would add to the budget's accuracy and utility for aiding the development of a state nutrient strategy. The most pertinent of these include:

- A better understanding of the sources and transport of sediment-related P is needed, along with refined characterization of stream P concentrations and loads. Sediment and related P measured in streams may originate from a variety of

sources such erosion of cropland, erosion of stream banks, or scouring from stream beds. Both natural P and P from fertilizer or manure applications are associated with this sediment.
- Better documentation of nutrient concentrations in wastewater effluent is needed, particularly for consideration of point versus nonpoint phosphorus sources at the watershed level.
- Further and more sophisticated analysis of the relationships between nutrient inputs and measured water quality is warranted, particularly for P.
- The understanding of the transport and fate of atmospheric nitrogen and the role of soil processes in nitrogen cycling needs refinement.

SUMMARY

Our initial analysis of the information collected as part of the nutrient budget indicates:

- The nutrient budget represents the first comprehensive attempt to map the distribution of major nutrient inputs and outputs to the state. It provides reasonable estimates for these inputs and outputs for the state and its major watersheds.

- Total N inputs to Iowa are estimated to be about 4 million tons, or about 216 pounds per acre. Statewide, and for most watersheds, the estimated nitrogen inputs and outputs appear to be roughly balanced. Agricultural activities account for the majority of the inputs and outputs of N. Mineralization of soil N and applications of N-fertilizer account for about half of the total inputs.

- Stream outputs of N for the state were about 200,000 tons per year during the 2000-2002 period. This represents about 5 percent of the total N inputs to the state, and accounts for about 20 percent of the nitrogen load delivered annually to the Gulf of Mexico by the Mississippi River. As the 2000-2002 period was relatively dry, greater stream-N outputs likely occur in many years. The output is equivalent to about 11 pounds for each acre of the state. For individual watersheds, the outputs ranged from 3 to 34 pounds per acre.

- Total P inputs to the state are estimated to be about 240,000 tons, or about 13 pounds per acre. Outputs are estimated to be about 270,000 tons. Input-output balances for individual watersheds are more variable for P than for N. Ag-related inputs from manure and fertilizer account for the majority of the P sources in Iowa, while crop harvest and grazing account for the majority of the outputs.

- Stream outputs of P for the state were about 11,000 tons per year during the 2000-2002 period. As the 2000-2002 period was relatively dry, greater stream-P outputs likely occur in many years. As much P is transported with sediment during infrequent runoff events, monthly monitoring for P likely results in an underestimation of total P losses in stream flow. The current estimate is equivalent to 0.7 pounds per acre. For individual watersheds, the outputs ranged from 0.2 to 3.2 pounds per acre.

- Stream outputs for N and P are estimated to be 5 percent and 4 percent, respectively, of the total N and P inputs. These outputs are likely larger in years with average or wetter than average precipitation. Still, they appear to be a relatively small portion of the total nutrient inputs.

- Point sources of N and P are minor compared to nonpoint sources, but are direct discharges to streams. Statewide, point sources are estimated to account for 8 percent of stream N load and 20 percent of the P load. Therefore, nonpoint sources account for an estimated 92 percent of the N and 80 percent of the P in streams. Under more typical climatic and hydrologic conditions, point source contributions would likely be lower. There is a wide variation in the magnitude of point source contributions at the watershed level. There is more confidence in the estimates for N than for P.

- Higher nitrogen concentrations are related to watersheds with greater inputs of fertilizer, ag-fertilizer, manure, "net manure," soybean-N, soil-derived N, total N inputs, and the percentage of row crops in a watershed. Larger stream N loads are related to watersheds with greater inputs of fertilizer, ag-fertilizer, and total N inputs.

- Measured total phosphorus concentrations and loads appear largely unrelated to inputs. This likely results from the attachment of P to sediment; natural P concentrations of soil and sediment; and the difficulty in adequately characterizing stream concentrations and loads of sediment-attached chemicals. There is some indication of a relationship between high dissolved P concentrations and watersheds with large P inputs.

- A variety of factors affect the delivery of N and P from sources to streams. These include soil, geologic, and climatic conditions; management practices that affect the pathways followed by water; and the amount of nutrients involved. The nutrient budget addresses the "amount of nutrients" factor. Strategies and management practices to limit or mitigate nutrient movement to water bodies must address all of these factors.

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Appendix I.

Documentation for Nutrient Budget Calculations

Nitrogen

Soil Nitrogen Mineralization

Data used:

- DNR 30-meter 2000 landcover grid
- 30-meter soil grid with Iowa Soil Properties and Interpretations Database (ISPAID)

Factors used:

- 20 lbs. N mineralized/acre/1 percent organic matter from North Central Regional Association of Agricultural Experiment Station Directors Hypoxia Project (NCT-167)

Procedure:

- The 2000 landcover grid was used to find corn and soybean ground and create a new grid.
- The corn and soybean grid was used to select the soil cells to use.
- The percent soil organic matter value in the soil was multiplied by 20 lbs. N/acre/1 percent organic matter and 0.2224 acres/cell to calculate the pounds of nitrogen mineralized per cell.
- The cells were summarized by watershed to determine the pounds of nitrogen mineralized in each watershed.

Nitrogen Deposition

Data used:

- NRCS Iowa Annual Precipitation coverage for 1961-1990

Factors used:

- 2.46 mg/l nitrogen in precipitation calculated from Iowa State University data (collected at the USDA Management Systems Evaluation Areas (MSEA) project at Walnut Creek in Story County) of 20 lbs. N/acre for 36 inches of precipitation

Procedure:

- The coverage of annual precipitation was converted into a 30-meter grid with the precipitation as the value for the cell.
- Pounds of nitrogen per cell for wet deposition were calculated as follows:

(inches of precipitation) x (0.0254 meters/inch) x (4046.856 square meters/acre) x (1,000 liters/cubic meter) x (2.46 mg N/liter) x (1kg/1,000,000 mg) x (0.2224 acres/cell) / (0.454 kg/pound).

- The dry deposition was calculated as 70 percent of the wet deposition using the method described in the USGS “Flux and sources of nutrients in the Mississippi – Atchafalaya River Basin -- Topic 3” hypoxia report.

Legume Fixation

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 National Agricultural Statistics Service (NASS) agricultural statistics for alfalfa, other hay and soybean acres and production by county
- 1997 NASS Census of Agriculture county data for pasture acreage

Factors used:

- 2 lbs. N/bu. soybean from NCT-167
- 50 lbs. N/ton alfalfa hay per ISU/National Soil Tilth Lab (NSTL) suggestion
- 90 lbs. N/acre other hay or pasture from NCT-167

Procedure:

Soybeans

- A soybean grid was created from the 2000 landcover grid.
- The 2000 soybean production by county was divided by the number of soybean cells in each county to create a grid of bushels of soybean per cell.
- This was summarized by watershed to calculate bushels of soybean harvested by watershed.
- This number was multiplied by the factor of 2 lbs. N/bu. soybean to calculate pounds of nitrogen fixed by soybeans in each watershed.

Alfalfa

- A grid of rural grass was derived from the 2000 landcover grid and the 2000 incorporated boundaries coverage by removing grass values that occurred within the incorporated boundaries.
- The 2000 alfalfa production by county was divided by the number of rural grass cells per county to create a grid of tons of alfalfa per cell.
- This grid was summarized by watershed to calculate tons of alfalfa produced in each watershed.
- This number was multiplied by the factor of 50 lbs. N/ton alfalfa to calculate pounds of nitrogen fixed by alfalfa hay in each watershed.

Other hay and pasture

- The 2000 other hay acreage by county was added to the 1997 county pasture acreage.
- This value was divided by total rural grass acres in each county, derived from the 2000 landcover grid and the 2000 incorporated boundaries coverage, to calculate the percentage of grass acres in other hay and pasture.
- This percentage was applied to each grass cell.
- This value was summarized by watershed to calculate the acres of other hay and pasture in each watershed.
- The acreage in each watershed was multiplied by the factor of 90 lbs. N/acre to calculate pounds of nitrogen fixed by other hay and pasture.

Total

- The three values of nitrogen fixation were then summed to generate total pounds of nitrogen fixed by legumes in each watershed.

Fertilizer Input

Data used:
- Iowa Department of Agriculture and Land Stewardship 2000 crop year nitrogen distribution data
- 1997 NASS Census of Agriculture county fertilizer expenditures
- 1999 ISU Extension Turf Grass Survey
- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage

Factors used: None

Procedure:
- Added the 1997 county fertilizer expenditures with the 1999 turf grass fertilizer expenditures.
- Assumed equal value for dollars spent and apportioned the tons of nitrogen sold between turf industry and agriculture.
- Created an urban grass grid from the 2000 landcover grid and the 2000 incorporated boundaries coverage.
- Apportioned the turf grass nitrogen equally to urban grass cells across the state.
- Apportioned the agricultural nitrogen by county using the 1997 Census of Agriculture fertilizer expenditures and applied it to the corn acres from the 2000 landcover grid.
- Summarized the turf grass nitrogen usage and agricultural nitrogen usage by watershed and added them together for total nitrogen fertilizer applied by watershed.

Manure Generation, Volatilization and Application

Cattle

Data used:
- 2001 NASS agricultural statistics by county for dairy and beef cattle
- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage

Factors used:
- 0.7 lbs. N/day for dairy cow from Midwest Planning Service MWPS-18 Section 1, Manure Characteristics, December 2000
- 0.33 lbs. N/day for beef cow from MWPS-18, December 2000
- 45 percent nitrogen loss from feedlot from DNR rules for Animal Feeding Operations (AFOs)
- 30 percent nitrogen loss from broadcast application of dry manure from DNR rules for AFOs

Procedure:
- The county dairy and beef cow numbers were apportioned throughout each county by the rural grass pixels, derived from the 2000 landcover grid and 2000 incorporated boundaries coverage, to create a dairy cow grid and a beef cow grid.

- Each grid was summarized by watershed to calculate the number of dairy and beef cows in each watershed.
- The appropriate nitrogen generation factor was applied to each type of cow to calculate total nitrogen generated in each watershed.
- Manure nitrogen losses in storage were calculated by multiplying the total nitrogen generated by 40 percent.
- Manure nitrogen losses in application were calculated by multiplying the remaining nitrogen in the manure by 30 percent.
- The volatilization losses were summed for each watershed and the remainder was nitrogen applied to the soil.

Sheep
<u>Data used</u>:
- 1997 NASS Census of Agriculture county animal numbers
- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage

<u>Factors used</u>:
- 0.04 lbs. N/day from MWPS-18, December 2000
- 45 percent nitrogen loss from feedlot from DNR rules for AFOs
- 30 percent nitrogen loss from broadcast application of dry manure from DNR rules for AFOs

<u>Procedure</u>:
- The county sheep data was apportioned by rural grass pixels, derived from the 2000 landcover grid and 2000 incorporated boundaries coverage, to create a sheep grid.
- The data were summarized by watershed to obtain the number of sheep in each watershed.
- The animal number was multiplied by 0.04 lbs. N/day to obtain the amount of nitrogen generated in each watershed.
- The nitrogen generated was multiplied by 45 percent and then by 30 percent to estimate the amount of nitrogen volatilized from the manure.
- The remaining nitrogen is the amount remaining in the watershed.

Swine
<u>Data used</u>:
- DNR AFO database
- DNR manure management plans
- DNR permitted CAFOs
- 2000 NASS Census of Agriculture statewide data
- Spring 2002 aerial photography

<u>Factors used</u>:
- 0.08 lbs. N/day for swine from MWPS-18 December 2000
- 80 percent nitrogen loss from lagoons from DNR rules for AFOs
- 25 percent nitrogen loss from pits from DNR rules for AFOs
- 30 percent nitrogen loss from tanks or basins from DNR rules for AFOs

- 2 percent loss from injection application (used for 75 percent of manure as per ISU discussion) from DNR rules for AFOs
- 25 percent loss from broadcast application (used for 25 percent of manure as per ISU discussion) from DNR rules for AFOs

Procedure:

- Compared point location data from the AFO database, the manure management plans and the permitted CAFO data with the 2002 aerial photography to see which sites had been built.
- Summed the known data from facilities that had been built to see how many hogs could be accounted for compared to the Census of Agriculture data.
- Found many animals unaccounted for and did a section by section search for confinements throughout the state using the aerial photography.
- Assigned animal numbers by building size (approximately one hog per square meter of building) and added manure storage method for new facilities found.
- Added the number of animals in the new facilities with those in the known facilities.
- The new total was within 15 percent of the Census of Agriculture number for the state.
- Multiplied the animal numbers by 1.143 to distribute the remaining 2 million missing hogs to the known facilities around the state.
- Summarized the point data by watershed to generate total hog numbers by watershed.
- Multiplied hog number by 0.08 lbs. N/day to calculate total nitrogen generated by hogs.
- Calculated percent of animals in each watershed having manure stored in lagoons, pits, tanks or basins.
- Multiplied total nitrogen generated in each watershed by the percentages for the four storage methods.
- Multiplied the nitrogen from each storage method by the appropriate volatilization factor to obtain the amount of nitrogen volatilized in storage.
- Multiplied 75 percent of the remaining nitrogen by 2 percent to obtain the amount lost in volatilization from injection application.
- Multiplied the other 25 percent of the remaining nitrogen by 25 percent to obtain the amount lost in volatilization from liquid broadcast application.
- Added up the amounts lost to volatilization and subtracted from the total to obtain the amount applied to the soil.

Chicken

Data used:

- DNR AFO database
- Spring 2002 aerial photography
- IDALS 2001 animal numbers

Factors used:

- 0.003 lbs. N/day from MWPS-18 December 2000
- 40 percent nitrogen loss from poultry litter from DNR rules for AFOs

- 30 percent nitrogen loss from broadcast application of dry manure from DNR rules for AFOs

Procedures:

- Compared point location of chicken facilities with aerial photography, which matched up.
- Summed animal numbers from chicken facilities and had agreement with IDALS number.
- Summarized point location animal numbers by watershed.
- Multiplied animal number by 0.003 lbs. N/day to obtain amount of nitrogen generated in the watershed.
- Multiplied the nitrogen generated by 40 percent to calculate the amount of nitrogen lost from the poultry litter.
- Multiplied the remaining nitrogen by 30 percent to calculate the amount of nitrogen lost from broadcast application of dry manure.
- Added the amounts lost through volatilization and subtracted from the amount generated to obtain the amount applied to the soil.

Turkey

Data used:

- DNR AFO database
- 2000 NASS Census of Agriculture animal numbers
- Spring 2002 aerial photography

Factors used:

- 0.0126 lbs. N/day from MWPS-18 December 2000
- 40 percent nitrogen loss from poultry litter from DNR rules for AFOs
- 30 percent nitrogen loss from broadcast application of dry manure from DNR rules for AFOs

Procedure:

- Compared point location of turkey facilities with aerial photography, which matched up.
- Summed animal numbers, but numbers were far less than the Census of Agriculture number.
- Performed a section by section search of the state using the aerial photography and located additional turkey facilities.
- Assigned an animal number by building size (10 turkeys per square meter of building) for new facilities found.
- Summed animal numbers from known and new facilities and had good agreement with Census of Agriculture number.
- Summarized the facilities by watershed to obtain number of turkey in each watershed.
- Multiplied animal number by 0.0126 lbs. N/day to obtain total nitrogen generated in each watershed.
- Multiplied the nitrogen generated by 40 percent to calculate the amount of nitrogen lost from the poultry litter.
- Multiplied the remaining nitrogen by 30 percent to calculate the amount of nitrogen lost from broadcast application of dry manure.

- Added the amounts lost through volatilization and subtracted from the amount generated to obtain the amount applied to the soil.

Human waste input

Data used:
- 2000 U.S. Census data

Factors used:
- 9.9 lbs. N/year from DNR wastewater program

Procedure:
- Calculated population density per square mile from 2000 Census block coverage.
- Converted the coverage to a 30-meter grid with population per pixel by dividing population density by 2877.76 pixels/square mile.
- Summarized population grid by watershed to obtain population for each watershed.
- Multiplied population by 9.9 lbs. N/year to obtain nitrogen generated by humans for each watershed.

Industrial waste input

Data used:
- 2000 U.S. Census data
- USGS hypoxia report

Factors used:
- 1.858 lbs. N/person calculated from USGS hypoxia report basin industry numbers

Procedure:
- Summed the hypoxia report industrial point source numbers for the Des Moines, Iowa and Skunk basins and divided by the population in those basins to create an industrial waste value per person (1.858 lbs. N/person).
- Summarized population grid by watershed to obtain population for each watershed.
- Multiplied population by 1.858 lbs. N/person to calculate total industrial waste nitrogen generated per watershed.

Soil Nitrogen Denitrification

Data used:
- Total and volatilized nitrogen previously calculated from fertilizer, mineralization, manure and deposition for each watershed

Factors used:
- 15 percent of available nitrogen per ISU/NSTL discussion

Procedure:
- Calculate the available nitrogen from fertilizer, mineralization, manure and deposition previously calculated in each watershed by subtracting off any volatilized portion from the total input.

- Multiply remaining nitrogen by 15 percent to obtain amount of nitrogen denitrified within each watershed.

Soil Nitrogen Immobilization

Data used:
- DNR 30-meter 2000 landcover grid
- 30-meter soil grid with ISPAID

Factors used:
- 20 lbs. N immobilized/acre/1 percent organic matter per ISU discussion

Procedure:
- The 2000 landcover grid was used to find corn and soybean ground and create a new grid.
- The corn and soybean grid was used to select the soil cells to use.
- The percent soil organic matter value in the soil was multiplied by 20 lbs. N/acre/1 percent organic matter and 0.2224 acres/cell to calculate the pounds of nitrogen immobilized per cell.
- The cells were summarized by watershed to determine the pounds of nitrogen immobilized in each watershed.

Fertilizer Volatilization

Data used:
- IDALS 2000 crop year nitrogen distribution data

Factors used:
- 1 percent for anhydrous ammonia per ISU/NSTL suggestion
- 5 percent for urea from NCT-167
- 2.5 percent for UAN solution from NCT-167

Procedure:
- Calculated statewide average percent of total nitrogen fertilizer sold as ammonia, urea and UAN solutions from statewide distribution data.
- Multiplied amount of nitrogen fertilizer applied in each watershed by percentage distributed as ammonia, urea and UAN solution to calculate tons of nitrogen fertilizer applied as ammonia, urea and UAN solution.
- Multiplied the amount of each product applied by the appropriate factor to obtain amount volatilized from each product in each watershed.
- Added the amount volatilized from each product to obtain total nitrogen volatilized from fertilizer in each watershed.

Crop Volatilization

Data used:
- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 NASS agricultural statistics for alfalfa, other hay, soybean, corn, oats and wheat acres by county

- 1997 NASS Census of Agriculture county data for pasture acreage

Factors used:

- 25 lbs. N/crop acre per ISU/NSTL suggestion

Procedure:

- The 2000 agricultural statistics county soybean and corn acres were compared to the 2000 landcover corn and soybean cells and the value in each cell was adjusted to make the acres equal.
- The corn and soybean data were summarized by watershed to calculate acres of row crop by watershed.
- The 2000 county alfalfa and oats acres were compared to the rural grass acres, derived from the 2000 landcover grid and 2000 incorporated boundaries coverage, and adjusted as needed to make the acres equal.
- The alfalfa and oat acres were summarized by watershed and added to the row crop acres by watershed.
- The 2000 county other hay acreage was added to the 1997 county pasture acreage.
- The total acreage was divided by the rural grass acres in each county to calculate the percentage of grass acres in other hay and pasture.
- This percentage was applied to the rural grass cells derived from the 2000 landcover grid and 2000 incorporated boundaries coverage.
- The value was summarized by watershed to calculate the acres of other hay and pasture in each watershed.
- All crop acres were combined for each watershed and multiplied by the factor of 25 lbs. N/acre to obtain the amount of nitrogen lost through crop volatilization from each watershed.

Crop Removal

Corn

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 NASS county agricultural statistics

Factors used:

- 0.72 lbs. N/bu. grain from ISU Grain Quality Lab
- 7.0 lbs. N/ton silage from *Modern Corn and Soybean Production*

Procedure:

- A corn grid was created from the 2000 landcover grid.
- An average corn silage production rate was calculated from the acres of corn harvested for silage and the total corn silage production for the state from the agricultural statistics.
- This rate was used to calculate the silage production per county.
- The silage production per county was divided by the corn pixels in that county to give silage production per pixel.
- The corn grain production by county was divided by the corn pixels in that county to give a corn grain production per pixel.
- The silage and grain grids were summarized by watershed to obtain the amount of corn silage and corn grain produced in each watershed.

- The appropriate factor was multiplied by each corn product to obtain the amount of nitrogen harvested from corn for each watershed.

Soybean

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 NASS county agricultural statistics

Factors used:

- 3.36 lbs. N/bu. grain from ISU Grain Quality Lab

Procedure:

- A soybean grid was produced from the 2000 landcover grid.
- The soybean production by county from the agricultural statistics was divided by the soybean pixels in that county to give soybean production per pixel.
- The soybean production grid was summarized by watershed to obtain the amount of soybean produced in each watershed.
- The amount of soybean harvested in each watershed was multiplied by 3.36 lbs. N/bu. grain to obtain the amount of nitrogen harvested from soybean for each watershed.

Oats

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 NASS county agricultural statistics

Factors used:

- 0.59 lbs. N/bu. oats from *Modern Corn and Soybean Production*

Procedure:

- The county oat production from the agricultural statistics was divided by the county rural grass pixels, derived from the 2000 landcover grid and the 2000 incorporated boundaries coverage, to obtain an oat production per pixel.
- The oat production was summarized by watershed to obtain the amount of oats produced in each watershed.
- The oat production was multiplied by 0.59 lbs. N/bu. to calculate the amount of nitrogen harvested from oats for each of the watersheds.

Wheat

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 NASS statewide agricultural statistics

Factors used:

- 1.25 lbs. N/bu. from *Modern Corn and Soybean Production*

Procedure:

- The statewide wheat production was averaged over the rural grass pixels, derived from the 2000 landcover grid and the 2000 incorporated boundaries coverage, to obtain a wheat production per pixel grid.

- The wheat production grid was then summarized by watershed.
- The wheat production was multiplied by 1.25 lbs. N/bu. to calculate the amount of nitrogen harvested from wheat in each of the watersheds.

Hay

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 NASS county agricultural statistics

Factors used:

- 50 lbs. N/ton alfalfa from *Modern Corn and Soybean Production*
- 40 lbs. N/ton other hay from *Modern Corn and Soybean Production*

Procedure:

- The 2000 alfalfa production by county was divided by the number of rural grass cells in each county, derived from the 2000 landcover grid and 2000 incorporated boundaries coverage, to create a grid of tons of alfalfa per cell.
- This grid was summarized by watershed to calculate tons of alfalfa produced in each watershed.
- The tons of alfalfa was multiplied by 50 lbs. N/ ton alfalfa to obtain total pounds of nitrogen harvested in alfalfa hay from each watershed.
- The 2000 other hay production by county was divided by the number of rural grass cells in each county to create a grid of tons of other hay produced per cell.
- This grid was summarized by watershed to obtain tons of other hay produced in each watershed.
- The tons of other hay was multiplied by 40 lbs. N/ton other hay to obtain total pounds of nitrogen harvested in other hay from each watershed.

Pasture

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 1997 NASS Census of Agriculture
- 2000 NASS county agricultural statistics

Factors used:

- 40 lbs. N/ton pasture production from ISU University Extension pamphlet series PM-1811, November 1999, Managing Manure Nutrients for Crop Production

Procedure:

- Used the 1997 county pasture acres and multiplied by the 2000 county other hay yield values to create a pasture production value per county.
- Divided this value by the number of rural grass pixels in each county, derived from the 2000 landcover and 2000 incorporated boundaries coverage, to obtain a pasture yield per pixel grid.
- Summarized this grid by watershed to obtain total pasture production per watershed.

- Multiplied the watershed pasture production number by 40 lbs. N/ton pasture production to obtain total pounds of nitrogen harvested from pastures in each watershed.

Phosphorus

Fertilizer Input

Data used:
- IDALS 2000 crop year phosphorus distribution data
- 1997 NASS Census of Agriculture county fertilizer expenditures
- 1999 ISU Extension Turf Grass Survey
- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage

Factors used: None

Procedure:
- Added the 1997 county fertilizer expenditures with the 1999 turf grass fertilizer expenditures.
- Assumed equal value for dollars spent and apportioned the tons of phosphorus sold between turf industry and agriculture.
- Created an urban grass grid from the 2000 landcover grid and the 2000 incorporated boundaries coverage.
- Apportioned the turf grass phosphorus equally to urban grass cells across the state.
- Apportioned the agricultural phosphorus by county using the 1997 Census of Agriculture fertilizer expenditure data and applied to the row crop acres from the 2000 landcover.
- Summarized the turf grass phosphorus usage and agricultural phosphorus usage by watershed and added them together for total phosphorus fertilizer applied by watershed.

Manure Generation and Storage

Cattle

Data used:
- 2001 NASS agriculture statistics by county for dairy and beef cattle
- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage

Factors used:
- 0.16 lbs. P/day for dairy cow from MWPS-18 December 2000
- 0.066 lbs. P/day for beef cow from MWPS-18 December 2000

Procedure:
- The county dairy and beef cow numbers were apportioned throughout each county by the rural grass pixels, derived from the 2000 landcover grid and 2000 incorporated boundaries coverage, to create a dairy cow grid and a beef cow grid.

- Each grid was summarized by watershed to calculate the number of dairy and beef cows in each watershed.
- The appropriate phosphorus generation factor was applied to each type of cow to calculate total phosphorus generated in each watershed.

Sheep

Data used:

- 1997 Census of Agriculture county animal numbers
- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage

Factors used:

- 0.009 lbs. P/day from MWPS-18 December 2000

Procedure:

- The county sheep data was apportioned by rural grass pixels, derived from the 2000 landcover grid and 2000 incorporated boundaries coverage, to create a sheep per pixel grid.
- The data was summarized by watershed to obtain the number of sheep in each watershed.
- The animal number was multiplied by 0.009 lbs. P/day to obtain the amount of phosphorus generated in each watershed.

Swine

Data used:

- DNR AFO database
- DNR manure management plans
- DNR permitted CAFOs
- 2000 Census of Agriculture statewide data
- Spring 2002 aerial photography

Factors used:

- 0.019 lbs. P/day for swine from MWPS-18 December 2000
- 66.7 percent phosphorus stored in lagoons per ISU discussion

Procedure:

- Compared point location data from the AFO database, the manure management plans and the permitted CAFO data with the 2002 aerial photography to see which sites had been built.
- Summed the known data from the facilities that had been built to see how many hogs could be accounted for compared to the Census of Agriculture data.
- Found many animals unaccounted for and did a section by section search for confinements throughout the state using the aerial photography.
- Assigned animal numbers by building size (approximately one hog per square meter of building) and added manure storage method for new facilities found.
- Added the number of animals in the new facilities with those in the known facilities.
- The new total was within 15 percent of Census of Agriculture number for the state.

- Multiplied the animal numbers by 1.143 to distribute the remaining 2 million missing hogs to the known facilities around the state.
- Summarized the point data by watershed to generate total hog numbers by watershed.
- Multiplied hog number by 0.019 lbs. P/day to calculate total phosphorus generated by hogs.
- Calculated percent of animals in each watershed having manure stored in lagoons, pits, tanks or basins.
- Multiplied total phosphorus generated in each watershed by the percentage stored in lagoons and 0.667 to obtain the amount of phosphorus left in lagoons.
- Subtracted the amount of phosphorus left in lagoons from the total phosphorus generated in the watershed to obtain the amount applied to the soil in each watershed.

Chicken

Data used:

- DNR AFO database
- Spring 2002 aerial photography
- IDALS 2001 animal numbers

Factors used:

- 0.0009 lbs. P/day from MWPS-18 December 2000

Procedures:

- Compared point location of chicken facilities with aerial photography and they matched up.
- Summed animal numbers from chicken facilities and had good agreement with IDALS number.
- Summarized point location animal numbers by watershed.
- Multiplied animal number by 0.0009 lbs. P/day to obtain amount of phosphorus generated in the watershed.

Turkey

Data used:

- DNR AFO database
- 2000 Census of Agriculture numbers
- Spring 2002 aerial photography

Factors used:

- 0.005 lbs. P/day from MWPS-18 December 2000

Procedure:

- Compared point location of turkey facilities with aerial photography, which matched up.
- Summed animal numbers, but numbers were far less than the Census of Agriculture number.
- Performed a section by section search of the state using the aerial photography and located additional turkey facilities.
- Assigned an animal number by building size (10 turkeys per square meter of building) for new facilities found.

- Summed animal numbers from known and new facilities and had good agreement with Census of Agriculture number.
- Summarized the facilities by watershed to obtain number of turkey in each watershed.
- Multiplied animal number by 0.005 lbs. P/day to obtain total phosphorus generated in each watershed.

Human waste input

Data used:
- 2000 U.S. Census data

Factors used:
- 2.4 lbs. P/year from DNR wastewater program

Procedure:
- Calculated population density per square mile from 2000 Census block coverage.
- Converted the coverage to a 30-meter grid with population per pixel by dividing population density by 2877.76 pixels/square mile.
- Summarized population grid by watershed to obtain population for each watershed.
- Multiplied population by 2.4 lbs. P/year to obtain phosphorus generated by humans for each watershed.

Industrial waste input

Data used:
- 2000 U.S. Census data
- USGS hypoxia report

Factors used:
- 0.4336 lbs. P/person calculated from USGS hypoxia report

Procedure:
- Summed the hypoxia report industrial point source numbers for the Des Moines, Iowa and Skunk basins and divided by the population in those basins to create an industrial waste value per person.
- Summarized population grid by watershed to obtain population for each watershed.
- Multiplied population by 0.4336 lbs. P/person to calculate total industrial waste phosphorus generated per watershed.

Crop Removal

Corn

Data used:
- DNR 30-meter 2000 landcover grid
- 2000 NASS county agricultural statistics

Factors used:

- 0.164 lbs. P/bu. grain from ISU University Extension Pamphlet Series PM-1688, November 2002, General Guide for Crop Nutrient and Limestone Recommendations in Iowa
- 1.53 lbs. P/ton silage from ISU PM-1688

Procedure:

- A corn grid was created from the 2000 landcover grid.
- An average corn silage production rate was calculated from the acres of corn harvested for silage and the total corn silage production for the state from the agricultural statistics.
- This rate was used to calculate the silage production per county.
- The silage production per county was divided by the corn pixels in that county to give silage production per pixel.
- The corn grain production by county was divided by the corn pixels in that county to give a corn grain production per pixel.
- The silage and grain grids were summarized by watershed to obtain the amount of corn silage and corn grain produced in each watershed.
- The appropriate factor was multiplied by each corn product to obtain the amount of phosphorus harvested from corn for each watershed.

Soybean

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 NASS county agricultural statistics

Factors used:

- 0.35 lbs. P/bu. soybean from ISU PM-1688

Procedure:

- A soybean grid was produced from the 2000 landcover grid
- The soybean production by county from the agricultural statistics was divided by the soybean pixels in that county to give soybean production per pixel.
- The soybean production grid was summarized by watershed to obtain the amount of soybean produced in each watershed.
- The amount of soybean harvested in each watershed was multiplied by 0.35 lbs. P/bu. grain to obtain the amount of phosphorus harvested from soybeans for each watershed.

Oats

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 NASS county agricultural statistics

Factors used:

- 0.18 lbs. P/bu. oats from ISU PM-1688

Procedure:

- The county oat production from the agricultural statistics was divided by the county rural grass pixels, derived from the 2000 landcover grid and the 2000 incorporated coverage, to obtain an oat production per pixel.

- The oat production was summarized by watershed to obtain the amount of oats produced in each watershed.
- The oat production was multiplied by 0.18 lbs. P/bu to calculate the amount of phosphorus harvested from oats for each of the watersheds.

Wheat

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 NASS statewide agricultural statistics

Factors used:

- 0.26 lbs. P/bu. wheat from ISU PM-1688

Procedure:

- The statewide wheat production was averaged over the rural grass pixels, derived from the 2000 landcover grid and the 2000 incorporated boundaries coverage, to create a wheat production per pixel grid.
- The wheat production grid was then summarized by watershed.
- The wheat production by watershed was multiplied by 0.26 lbs. P/bu. to calculate the amount of phosphorus harvested from wheat in each of the watersheds.

Hay

Data used:

- DNR 30-meter 2000 landcover grid
- 2000 incorporated boundaries coverage
- 2000 NASS county agricultural statistics

Factors used:

- 5.46 lbs. P/ton alfalfa from ISU PM-1688
- 5.24 lbs. P/ton other hay from ISU PM-1688

Procedure:

- The 2000 alfalfa production by county was divided by the number of rural grass cells in each county, derived from the 2000 landcover grid and 2000 incorporated boundaries coverage, to create a grid of tons of alfalfa per cell.
- This grid was summarized by watershed to calculate tons of alfalfa produced in each watershed.
- The tons of alfalfa were multiplied by 5.46 lbs. P/ ton alfalfa to obtain total pounds of phosphorus harvested in alfalfa hay from each watershed.
- The 2000 other hay production by county was divided by the number of rural grass cells in each county to create a grid of tons of other hay produced per cell.
- This grid was summarized by watershed to obtain tons of other hay produced in each watershed.
- The tons of other hay was multiplied by 5.24 lbs. P/ton other hay to obtain total pounds of phosphorus harvested in other hay from each watershed.

Pasture

Data used:

- DNR 30-meter 2000 landcover grid

- 2000 incorporated boundaries coverage
- 1997 NASS Census of Agriculture
- 2000 NASS county agricultural statistics

Factors used:

- 5.24 lbs. P/ton pasture production from ISU PM-1688

Procedure:

- Used the 1997 county pasture acres and multiplied by the 2000 county other hay yield values to create a pasture production value per county.
- Divided this value by the number of rural grass pixels in each county, derived from the 2000 landcover and 2000 incorporated boundaries coverage, to obtain a pasture yield per pixel grid.
- Summarized this grid by watershed to obtain total pasture production per watershed.
- Multiplied the watershed production number by 5.24 lbs. P/ton pasture production to obtain total pounds of phosphorus harvested from pastures in each watershed.

APPENDIX II.

Watershed Nutrient Inputs, Outputs, and Water Quality Summary

NITROGEN

Watershed	Area	Total N Inputs	Total N Outputs	Stream N Load	Point Source N	Average N Concentration
	(square miles)	(pounds/ acre)	(pounds/ acre)	(pounds/ acre)	(percent of Stream N)	(mg/L)
Beaver Cr. near Cedar Falls	395	257	260	12.9	5.0	9.7
Beaver Cr. near Grimes	370	245	257	8.1	3.3	11.0
Bloody Run Cr. near Marquette	34	177	161	12.4	0.0	7.5
Boone R. near Stratford	888	286	297	23.4	8.2	14.0
Boyer R. near Missouri Valley	910	212	202	7.5	3.5	9.2
Cedar Cr. near Bussey	372	152	119	6.9	4.5	4.5
Cedar Cr. near Oakland Mills	533	195	189	15.4	7.9	7.5
Cedar R. at Carville	1097	241	251	18.6	7.7	8.6
Cedar R. downstream Cedar Rapids	6950	240	237	18.2	7.6	8.8
Cedar R. downstream Waterloo	5235	246	244	17.5	7.1	8.5
Cedar R. near Conesville	7782	236	233	16.4	6.9	8.4
Cedar R. near Janesville	1672	238	242	17.6	7.4	8.2
Cedar R. upstream Cedar Rapids	6340	242	241	15.6	6.4	7.6
Cedar R. upstream Waterloo	4720	245	246	17.5	7.1	8.5
Des Moines R. near Keokuk	14301	222	216	7.4	3.3	6.3
Des Moines R. downstream Des Moines	11637	241	240	15.0	6.2	10.0
Des Moines R. downstream Fort Dodge	4256	266	280	17.1	6.4	10.6
Des Moines R. downstream Ottumwa	13412	228	224	11.4	5.0	7.6
Des Moines R. upstream Des Moines	5840	262	273	16.8	6.4	10.0
Des Moines R. upstream Ottumwa	13236	230	226	11.3	4.9	7.6
E. Nishnabotna R. near Shenandoah	1021	200	196	5.8	2.9	7.8
English R. at Riverside	627	205	192	14.6	7.1	10.0
Floyd R. near Sioux City	886	280	270	10.3	3.7	14.6
Indian Cr. near Colfax	396	239	244	9.3	3.9	10.9
Iowa R. at Columbus Jct	12257	231	226	13.4	1.7	7.1

Watershed	Area	Total N Inputs	Total N Outputs	Stream N Load	Point Source N	Average N Concentration
	(square miles)	(pounds/ acre)	(pounds/ acre)	(pounds/ acre)	(percent of Stream N)	(mg/L)
Iowa R. downstream Iowa City	3319	233	225	15.1	6.5	8.3
Iowa R. downstream Marshalltown	1634	275	271	20.3	7.4	11.0
Iowa R. near Rowan	427	265	273	23.5	8.9	10.0
Iowa R. upstream Iowa City	3148	235	229	14.7	6.3	8.2
Iowa R. upstream Marshalltown	1468	281	278	21.2	7.5	11.6
L. Sioux downstream Spencer	1008	255	259	10.8	4.2	8.9
L. Sioux upstream Spencer	544	214	216	8.9	4.2	7.3
Little Sioux R. near Larrabee	1854	249	261	5.9	2.3	7.8
Little Sioux R. near Smithland	2682	239	243	6.5	2.7	7.8
Maple R. near Mapleton	644	223	218	7.2	3.2	9.5
Maquoketa R. near Maquoketa	957	227	219	34.0	14.9	8.6
Middle R. near Indianola	489	165	149	4.5	2.8	6.6
N. Fork Maquoketa R. near Maquoketa	590	225	205	19.0	8.4	8.7
N. Raccoon R. near Jefferson	1587	279	278	13.2	4.7	12.5
N. Raccoon R. near Sac City	709	291	286	16.0	5.5	15.0
N. Skunk R. near Sigourney	637	204	197	14.1	6.9	8.5
North R. near Norwalk	349	192	182	5.1	2.6	8.8
Ocheyedan R. at Spencer	432	289	299	9.0	3.1	10.0
Old Mans Cr. near Iowa City	201	192	182	15.1	7.8	8.3
Raccoon R. upstream Des Moines	3424	251	251	14.6	5.8	11.3
Rock R. near Hawarden	1687	289	289	8.2	2.8	8.8
S. Raccoon R. near Redfield	980	214	205	6.5	3.0	7.3
S. Skunk R. near Cambridge	584	301	282	12.7	4.2	13.7
S. Skunk R. near Oskaloosa	1640	249	243	11.9	4.8	10.2
S. Skunk R. upstream Ames	318	347	319	19.4	5.6	15.4
Shell Rock R. at Shell Rock	1731	241	244	14.9	6.1	7.7
Soldier R. near Pisgah	408	189	187	7.4	3.9	7.9

Watershed	Area	Total N Inputs	Total N Outputs	Stream N Load	Point Source N	Average N Concentration
	(square miles)	(pounds/ acre)	(pounds/ acre)	(pounds/ acre)	(percent of Stream N)	(mg/L)
South R. near Ackworth	474	143	124	2.7	1.9	3.5
Thompson Fork of Grand R.	695	167	144	3.3	2.0	4.1
Turkey R. near Garber	1553	218	204	18.1	8.3	9.0
Upper Iowa R. near Dorchester	768	196	180	16.8	8.6	7.0
Volga R. at Elkport	403	204	189	15.1	7.4	9.0
W. Fk. Des Moines R. near Humboldt	2323	266	276	8.7	3.3	8.0
W. Fork Cedar R. at Finchford	851	257	254	19.2	7.4	9.5
W. Fork Ditch at Hornik	403	221	211	8.6	3.9	9.5
W. Nishnabotna R. near Malvern	969	214	210	3.4	1.6	6.8
W. Nodaway R. near Shambaugh	790	195	184	6.4	3.3	7.0
Wapsipinicon R. near DeWitt	2334	235	235	19.7	8.4	8.3
Wapsipinicon R. near Independence	920	247	251	21.1	8.6	9.0
Wapsipinicon R. near Olin	1625	236	237	20.7	3.7	8.6
Whitebreast Cr. near Knoxville	359	145	120	4.2	2.9	3.5
Winnebago R. downstream Mason	642	239	237	16.5	6.9	7.8
Winnebago R. upstream Mason	454	243	248	17.6	7.2	8.5

PHOSPHORUS

Watershed	Area	Total P Inputs	Total P Outputs	Stream Total P Load	Stream Ortho P Load	Average Total P Concentration	Average Ortho P Concentration	Point Source P
	(square miles)	(pounds/acre)	(pounds/acre)	(pounds/acre)	(pounds/acre)	(mg/L)	(mg/L)	(percent of Stream P)
Beaver Creek near Cedar Falls	395	15.8	18.1	0.30	0.13	0.23	0.10	19.4
Beaver Creek near Grimes	370	11.6	17.1	0.39	0.20	0.53	0.27	24.7
Bloody Run Creek near Marquette	34	12.6	14.4	0.23	0.13	0.14	0.08	22.0
Boone R. near Stratford	888	18.3	18.8	0.65	0.47	0.39	0.28	9.4
Boyer R. near Missouri Valley	910	14.2	14.4	0.99	0.31	1.23	0.39	5.5
Cedar Creek near Bussey	372	7.0	9.2	2.59	0.11	1.68	0.07	1.0
Cedar Creek near Oakland Mills	533	9.8	14.0	0.54	0.23	0.26	0.11	14.8
Cedar R. downstream Cedar Rapids	6950	14.2	16.7	0.70	0.28	0.34	0.13	28.3
Cedar R. downstream Waterloo	5235	15.1	17.1	0.50	0.18	0.24	0.09	25.9
Cedar R. upstream Cedar Rapids	6340	14.4	17.0	0.55	0.15	0.27	0.07	19.9
Cedar R. upstream Waterloo	4720	14.8	17.2	0.44	0.14	0.21	0.07	22.9
Cedar R. at Carville	1097	13.5	17.7	0.68	0.19	0.32	0.09	14.1
Cedar R. near Conesville	7782	13.9	16.6	0.65	0.28	0.33	0.14	26.2
Cedar R. near Janesville	1672	14.2	17.1	0.61	0.24	0.29	0.11	15.2
DesMoines R. near Keokuk	14301	12.8	14.6	0.35	0.20	0.30	0.17	39.5
DesMoines R. downstream DesMoine	11637	14.2	15.9	1.05	0.28	0.70	0.18	14.4
DesMoines R. downstream Fort Dodge	4256	15.5	18.6	0.73	0.29	0.45	0.18	33.7
DesMoines R. downstream Ottumwa	13412	13.3	15.0	0.43	0.28	0.29	0.19	9.2
DesMoines R. upstream DesMoines	5840	15.3	17.9	0.42	0.22	0.25	0.13	18.7
DesMoines R. upstream Ottumwa	13236	13.4	15.2	0.48	0.31	0.32	0.21	29.1
E. Nishnabotna R. near Shenandoah	1021	11.2	14.8	1.12	0.09	1.50	0.12	6.0
English R. at R.side	627	13.6	14.3	3.24	0.28	2.22	0.19	1.5
Floyd R. near Sioux City	886	24.5	18.0	1.17	0.33	1.66	0.47	9.0
Indian Creek near Colfax	396	12.0	17.1	0.39	0.15	0.46	0.18	20.6
Iowa R. downstream Iowa City	3319	15.3	15.4	0.49	0.27	0.27	0.15	28.6
Iowa R. downstream Marshalltown	1634	19.9	17.4	0.70	0.45	0.38	0.25	12.2
Iowa R. upstream Iowa City	3148	15.3	15.7	0.67	0.20	0.37	0.11	12.6
Iowa R. upstream Marshalltown	1468	20.7	17.7	0.64	0.33	0.35	0.18	7.8

Watershed	Area	Total P Inputs	Total P Outputs	Stream Total P Load	Stream Ortho P Load	Average Total P Concentration	Average Ortho P Concentration	Point Source P
	(square miles)	(pounds/acre)	(pounds/acre)	(pounds/acre)	(pounds/acre)	(mg/L)	(mg/L)	(percent of Stream P)
L. Sioux upstream Spencer	544	10.9	14.1	0.49	0.27	0.41	0.22	23.7
Little Sioux R. near Larrabee	1854	15.2	16.7	0.54	0.11	0.72	0.15	11.3
Little Sioux R. near Smithland	2682	14.7	15.9	0.39	0.11	0.47	0.14	14.5
Maple R. near Mapleton	644	13.8	14.4	0.79	0.10	1.05	0.14	5.8
Maquoketa R. near Maquoketa	957	14.9	16.8	0.84	0.39	0.21	0.10	7.7
Middle R. near Indianola	489	8.0	11.7	0.87	0.07	1.27	0.10	4.7
N. Fork Maquoketa R. near Maquoketa	590	17.6	17.3	0.89	0.39	0.40	0.18	7.3
N. Raccoon R. near Jefferson	1587	18.2	16.8	0.84	0.23	0.79	0.22	6.6
N. Raccoon R. near Sac City	709	21.4	16.9	0.73	0.42	0.68	0.39	10.1
N. Skunk R. near Sigourney	637	11.7	15.0	0.86	0.19	0.52	0.12	7.1
North R. near Norwalk	349	12.0	12.9	0.44	0.07	0.76	0.11	15.3
Ocheyedan R. at Spencer	432	20.8	18.7	0.21	0.12	0.23	0.14	17.4
Old Mans Creek near Iowa City	201	11.0	13.9	0.78	0.32	0.43	0.17	8.4
Raccoon R. upstream Des Moines	3424	15.4	16.0	0.77	0.29	0.60	0.22	8.2
Rock R. near Hawarden	1687	24.5	19.4	0.56	0.17	0.60	0.18	10.3
S. Raccoon R. near Redfield	980	13.9	14.1	0.38	0.08	0.43	0.09	16.8
S. Skunk R. upstream Ames	318	36.7	17.7	0.39	0.32	0.31	0.26	27.8
S. Skunk R. near Cambridge	584	26.1	16.9	0.49	0.48	0.53	0.52	52.3
S. Skunk R. near Oskaloosa	1640	16.6	16.4	0.63	0.21	0.54	0.18	20.0
Shell Rock R. at Shell Rock	1731	13.9	17.1	0.56	0.25	0.29	0.13	19.0
Soldier R. near Pisgah	408	11.5	14.3	1.21	0.11	1.30	0.12	2.2
South R. near Ackworth	474	6.1	10.0	0.64	0.07	0.85	0.09	9.1
Thompson Fork of Grand R.	695	8.7	10.5	0.77	0.06	0.97	0.08	3.2
Turkey R. near Garber	1553	15.5	15.7	2.66	0.25	1.33	0.13	1.7
Upper Iowa R. near Dorchester	768	13.7	14.1	0.78	0.28	0.33	0.11	10.0
Volga R. at Elkport	403	13.3	14.5	2.34	0.18	1.40	0.11	1.8
W. Fk. DesMoines R near Humboldt	2323	17.6	17.9	0.30	0.11	0.28	0.10	18.8
W. Fork Cedar R. at Finchford	851	16.8	17.4	0.46	0.21	0.23	0.10	9.2
W. Fork Ditch at Hornik	403	15.8	14.6	0.40	0.16	0.45	0.18	9.9
W. Nishnabotna R. near Malvern	969	13.3	15.6	0.18	0.08	0.35	0.15	26.8

Watershed	Area	Total P Inputs	Total P Outputs	Stream Total P Load	Stream Ortho P Load	Average Total P Concentration	Average Ortho P Concentration	Point Source P
	(square miles)	(pounds/acre)	(pounds/acre)	(pounds/acre)	(pounds/acre)	(mg/L)	(mg/L)	(percent of Stream P)
Wapsipinicon R. near Olin	1625	13.8	16.8	0.51	0.21	0.21	0.09	11.4
Whitebreast Creek near Knoxville	359	6.8	9.3	0.83	0.09	0.70	0.07	8.0
Winnebago downstream Mason	642	14.7	16.4	0.91	0.44	0.43	0.21	22.8
Winnebago upstream Mason	454	15.5	17.0	0.80	0.29	0.39	0.14	8.4