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# Spatial and temporal nitrate-nitrogen patterns in rivers across Iowa

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SPATIAL AND TEMPORAL NITRATE-NITROGEN
PATTERNS IN RIVERS ACROSS IOWA

by

Jacob Kevin Nielsen

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CERTIFICATE OF APPROVAL

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MASTER'S THESIS

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This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis
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To Sasha, for your never-ending love and support.

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# ABSTRACT

High nutrient levels are responsible for the hypoxic conditions in the Gulf of Mexico. Iowa contributes significant nitrate loads to the Mississippi River which then contributes to the formation of an annual hypoxic zone. The primary object of this research was to calculate Iowa's statewide nitrate load export from 1999-2015. Evaluating the statewide load will provide a means to track the effects of the Iowa Nutrient Reduction Strategy developed in 2012. This research also evaluated nitrate patterns to identify spatial and temporal variables that may be responsible for much of the variability in average nitrate yields and annual nitrate loads. Data from 62 sites within the Iowa Department of Natural Resources (DNR) ambient water quality monitoring network were linearly interpolated from monthly grab samples. Twenty-three of the study sites were main study basins. The remaining watersheds were subbasins within the main basins. The main study basins were used to extrapolate annual statewide load. Percent row crop and water yield were used to predict spatial average annual nitrate yields. Additionally, linear regression modeling using annual water yield was found to best replicate temporal annual nitrate loads. Regional regression equations were formulated using temporal water yield regression equation parameters (slope and intercept) for the 62 subbasins organized by Major Land Resource Area (MLRA). DNR ambient nitrate loads were also compared to nitrate loads from the Iowa Water Quality Information System (IWQIS), a high-resolution water quality sensor network operated by IIHR— Hydroscience and Engineering at the University of Iowa. Nitrate loads between the two networks can vary significantly during April through July. Nutrient load reduction could be more confidently determined with improved statewide load export estimations.

# PUBLIC ABSTRACT

Excess nutrients from agricultural land are often transported to streams and rivers. High levels of nutrients in rivers such as the Mississippi River are the primary cause of hypoxic conditions in regional water bodies, including the Gulf of Mexico. Nitrate concentration and discharge data were evaluated for 62 water monitoring sites across Iowa. Twenty-three of the 62 sites were considered main watershed areas that capture drainage to the Mississippi or Missouri river basins. Monthly data was obtained through the Iowa Department of Natural Resources (DNR) ambient water quality database. The monthly samples were then linearly interpolated to obtain daily nitrate concentration estimates. Daily nitrate loads were calculated at co-located stations and then summed to estimate annual nitrate loads. The annual nitrate loads for the main 23 sites were used to calculate an annual statewide nitrate load. Linear regression modeling was used to analyze data at a spatial scale to understand what variables impact the differences in average nutrient yields between sites. Percent of land cultivated as row crop and annual streamflow water yield were the main predictors of spatial nitrate yields. Regression modeling was also used to fit data to identify what variables could be used to predict temporal annual nitrate loads. Streamflow water yield was the main predictor of temporal nitrate loads. Regional equations were developed to predict temporal equation parameters (slope and intercept). These regional equations could be used to estimate annual or long-term nitrate loads and yields. DNR ambient nitrate loads were also compared to loads from a high-resolution water quality sensor network. Nitrate loads between the two networks can vary significantly during the summer. Nutrient load reduction could be more confidently determined with improved statewide load export estimations.

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| | |
|---|---|
| BMP | Best Management Practice |
| DNR | Department of Natural Resources |
| ESRI | Environmental Systems Research Institute |
| GIS | Geographic Information System |
| HUC 8 | 8-digit Hydrologic Unit Code |
| IIHR | IIHR—Hydroscience and Engineering |
| INRS | Iowa Nutrient Reduction Strategy |
| IWQIS | Iowa Water Quality Information System |
| MLRA | Major Land Resource Area |
| MRDB | Mississippi River Drainage Basin |
| PRISM | Parameter-elevation Relationships on Independent Slopes Model |
| STORET | Storage and Retrieval |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| UV | Ultraviolet |
| VBA | Visual Basic for Applications |
| WHAT | Web-based Hydrograph Analysis Tool |

# CHAPTER 1: INTRODUCTION

High nitrate-nitrogen (nitrate) concentrations in rivers and streams can lead to a variety of environmental concerns, including excessive nutrient enrichment, eutrophication in streams, and marine life declines in hypoxic regions near estuaries (USEPA, 2000). These concerns are true where the Mississippi River drains into the Gulf of Mexico. Excessive nutrient loads from the Mississippi River Drainage Basin (MRDB) are carried into warm seawater at the Gulf. The presence of excessive nutrients causes algae blooms. As algae die they settle to the bottom of the Gulf and decompose. The process of decomposition uses oxygen that in turn leads to hypoxic conditions. Hypoxic conditions caused by excessive nutrient loads are magnified as stratification does not allow mixing of less dense seawater that is oxygen-rich with denser, oxygen-poor seawater (USEPA, 2015). Figure 1 shows the stratification process typical of coastal estuaries where warm fresh water meets cool seawater (Estuarine Science: What is Dissolved Oxygen?, 2001). Hypoxia in the Gulf of Mexico has impacted the marine industry because crabs and shrimp die and fish avoid the region.
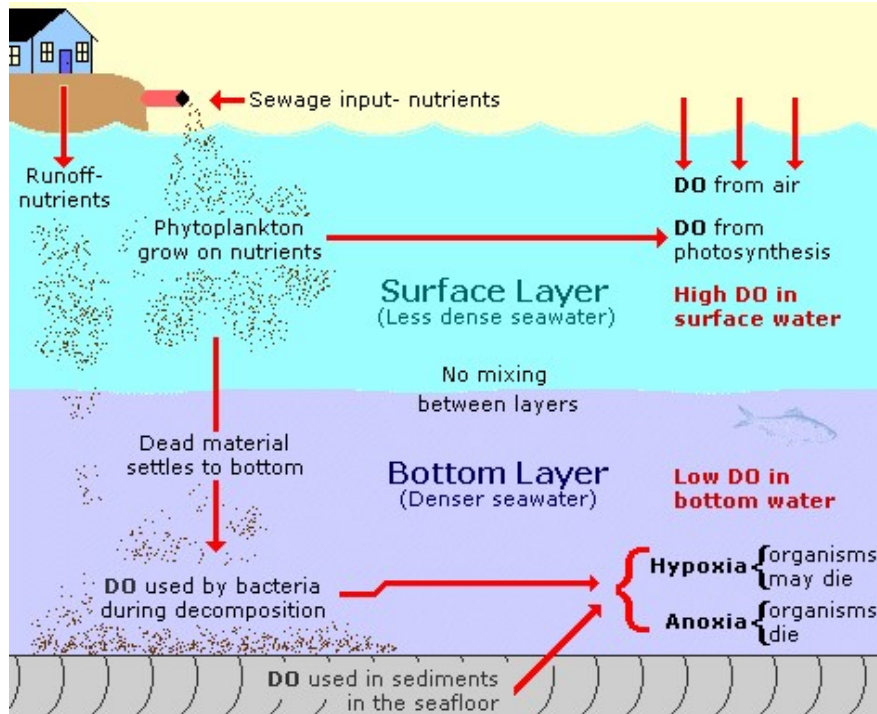
*Figure 1: Representation of stratification near estuaries.*

Beginning in 2001 the United States Environmental Protection Agency (USEPA) started setting goals and making plans to reduce and control the hypoxic zone by 2015 (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2001). USEPA's 2006-2007 Science Advisory Board established the goal of 45 percent reduction in total riverine nitrogen and phosphorus loads (USEPA, 2008). In 2008 the Gulf Hypoxia Action Plan called on states within the MRDB to develop nutrient reduction strategies (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008). In 2015, USEPA published a revised goal which postponed until 2035 the goal of reducing the current long-term average hypoxic areal extent of 13,751 square kilometers ($km^2$) to 5,000 $km^2$. In addition, a benchmark goal aimed to be achieved by 2025 called for a 20 percent load reduction in total riverine nitrogen and phosphorus (USEPA, 2015).

On average, Iowa contributes about 25 percent of the nitrate load delivered to the Gulf of Mexico while only occupying about 5 percent of the land in the MRDB (Libra, 1998). Near the end of 2012 the Iowa Nutrient Reduction Strategy (INRS) was developed following the USEPA recommended framework (INRS, 2012). The INRS is a science- and technology-based plan to track and measure annual statewide nutrient reductions in Iowa. Nitrate data from 2000 to 2010 was used to establish a baseline nitrate load for the strategy. The baseline load was determined by averaging three different load estimation methods. The methods consisted of estimating load from existing land use relationships, nitrate concentration relationships between tile and subsurface water from literature, and estimates of water yield to streams. Nitrate loads were calculated and accumulated for each Major Land Resource Area (MLRA) (ISU Science Team, 2012).

Since nitrate loads vary considerably year by year with climate fluctuations (mainly precipitation amounts), it is difficult to determine a true baseline nitrate loading condition for Iowa. A 10-year average (2000-2010) was assumed to be the baseline in the INRS and it is assumed that trends in the baseline load can be approximated as a statewide 10-year moving average nitrate load. The primary objectives of this research project were:

1. Calculate annual statewide nitrate loads using Iowa Department of Natural Resources (DNR) ambient water quality data.
2. Observe nitrate trends in subbasins.
3. Fit linear regression models to best match calculated nitrate loads.
4. Compare DNR ambient data to Iowa Water Quality Information System (IWQIS) sensor data.

Because the INRS calls for nutrient load reductions, this research does not focus on the prediction of nitrate concentrations. Rather, it focuses on calculation and prediction of nitrate loads and yields that were the focus of the strategy.

Objective 1

Beginning in 1999, nitrate concentrations have been measured monthly at major river sites in Iowa through the Iowa DNR ambient stream monitoring program. These monthly nitrate concentrations were linearly interpolated to a daily time scale and used to estimate annual nitrate loads. The 62 watersheds evaluated vary in size and cover about 73 percent of the state of Iowa.

Objective 2

This study evaluated trends within subbasins. According to Schilling and Zhang (2004), looking at the spatial and temporal variation patterns is one of the keys to reducing nitrate exports. Once the variables which have the greatest impact on predicting nitrate loads and yields are identified, preventative measures can be explored to better manage them.

Objective 3

DNR ambient nitrate data was fit to spatial and temporal regression equations. The spatial regression models identified what variables were most significant to estimate average nitrate yield. Individual site temporal regression models identified which hydrologic variables can best predict annual nitrate loads. The temporal regression equations for each subbasin serve as an additional baseline to identify changes in nitrate loads and estimate historic loads within subbasins. Measuring river nitrate concentrations

can also be expensive, so the ability to estimate annual nitrate loads with more widely available variables (precipitation, stream discharge, baseflow, etc.) would be helpful to estimate annual statewide nitrate load exports.

Spatial variability within the developed temporal regression models was also investigated by generating Major Land Resource Area (MLRA) regression equations. These MLRA regression equations could be used to input land description data to predict temporal regression parameters (slope and intercept) in unmonitored basins. The regional regression equations can be used to estimate annual and long-term nitrate load or yield estimates.

Objective 4

This study compared nitrate loads estimated from DNR ambient monthly samples to nitrate loads measured using continuous water quality sensors. Accurate nitrate load estimates are important to confidently track nutrient reductions. Daily concentrations obtained by interpolating monthly grab samples are subject to overestimation or underestimation depending on when the samples are collected. Use of continuous sensors could provide a high-resolution view of nitrate fluctuations not possible with monthly samples. The load estimate comparison from monthly grab samples to those from continuous water quality sensors was done at seasonal, annual and period-of-record scales.

It is important to evaluate historic data and develop descriptive regression equations so that we can quantify the past trends and evaluate future progress towards load reduction goals. The use of higher resolution nitrate data from continuous sensors provides more confidence in annual statewide nitrate load calculations.

# CHAPTER 2: LITERATURE REVIEW

The processes of nitrate fate and transport are introduced in this chapter before evaluating nitrate load patterns in subsequent chapters. The nitrogen cycle will be discussed to better understand the role of nitrate and the forms of nitrogen. Nitrate sources and transport are also identified to determine possible variables to predict statewide nitrate loads and yields. Previous techniques of predicting and collecting nitrate concentrations are also discussed.

Nitrogen Cycle

Organic nitrogen represents the nitrogen associated with plant decomposition, animal waste, or amino acids and proteins in living plants. As bacteria consume organic nitrogen it is converted into ammonium or ammonia. Under aerobic conditions ammonia reacts with oxygen to become microbially mediated nitrate. In anaerobic conditions additional bacteria consume nitrate and release nitrogen gas (Plant & Soil Sciences eLibrary, 2017).

Nitrate Sources

Nitrate sources can be divided into two main categories, point source and non-point source. Point sources, like wastewater effluent, are generally discrete locations where nitrate concentrations and discharge rates can be easily quantified. Non-point sources, like overland flow or baseflow seepage, are more difficult to measure. These are an aggregate of many disperse sources.

The main sources of Iowa's nitrate are row crop cultivation, livestock production, and soil mineralization. Livestock manure and various forms of nitrogen fertilizer are

applied to agricultural fields for row crop cultivation. Other nitrate sources include

atmospheric deposition, urban runoff, and wastewater treatment effluent (Burkart &

James, 1999; USEPA, 2015).

Atmospheric deposition of nitrate primarily comes from volatized ammonia and

atmospheric nitrogen gas split by lightening. Ammonia is converted to nitrate through

nitrifying bacteria in the soil and oxidation (Nitrification Primer, 2004). Volatized

ammonia from manure is lighter than air making it more likely to rise into the

atmosphere. Once in the atmosphere the ammonia can be converted into nitrate (Nova

Scotia Agricultural College, 2007). Nitrate is also naturally formed in the atmosphere

when lightning splits nitrogen gas and the ions bond with oxygen (Hill, Rinker, &

Wilson, 1980). Atmospheric nitrate from volatized manure and lightning dissolves into

rain droplets and is deposited on the ground through precipitation. This is a small source

of nitrate to the soil profile.

As precipitation infiltrates the ground it dissolves organic N and fertilizer N

present in the soil profile, which provides a much larger source of nitrate available for

plants to use as a nutrient. Atmospheric nitrate can become fixated to the root system of

legumes like soybeans. Much of this fixated nitrate remains behind once the crop has

been harvested and can be processed with other organic matter (Burkart & James, 1999).

After crops are harvested, the crop residuals begin to decompose. The residual

organic matter can then be processed to become a source of nitrate (Nitrification Primer,

2004). Of the main nitrate sources presented, mineralized soil organic matter makes up

the largest component, followed by fertilizer (Burkart & James, 1999). The application of

nitrogen fertilizer increased rapidly from 1960 to 1980, after which the rate leveled off and has remained fairly consistent across the Midwest (Wortmann, et al., 2013).

Nitrate Export

Much of the nitrate that the crop consumes leaves the field when the crop is harvested. This constitutes the largest output of nitrate from cropped fields. Sometimes crop harvesting removes more nitrate than the mass of fertilizer applied (Burkart & James, 1999). Though harvesting grain removes nitrate, harvesting also leaves behind portions of the crop. This organic matter then has the opportunity to decompose.

Nitrate is also exported through volatilization of ammonia in manure and fertilizer. This volatized ammonia accounts for 20 to 80 percent of the total ammonia lost within three to five days after application. The greatest levels of volatilization occur within the first day of application. Loss rates are significantly affected by weather, method of application, storage condition, and soil surface condition. In the case of weather, ammonia volatilization increases when air temperature, wind speed, or solar radiation are high (Nova Scotia Agricultural College, 2007). Ammonia volatilization decreases the available nutrients to support crops and makes the manure or fertilizer less efficient. This can lead to applying excess fertilizer which increases the potential for nitrate to enter waterways.

Another way nitrate is exported is through denitrification. This occurs when bacteria consume nitrate and release nitrogen gas. Soil denitrification generally occurs when there is little oxygen present, which usually corresponds with saturated or high moisture content soil. Unless a field is irrigated, water input from precipitation can be random which means the amount of nitrate that can be denitrified can vary (Burkart &

James, 1999). Saturated or vegetated buffers are one of the ways to facilitate denitrification (Osborne & Kovacic, 1993). Denitrification is highly temperature dependent (Henriksen, Bloom, & Spanswick, 1990; Rolston, 1981). Temperatures of 20 degrees Celsius or warmer enhance denitrification (Braker, Schwarz, & Conrad, 2010). This leads to more nitrate removal during summer months. Nitrate can also be removed through denitrification in streams or rivers (Jones, Kim, & Schilling, 2017).

Nitrate Residuals

Nitrate residuals constitute the available mass of nitrate that can be transported. After looking at nitrate sources and methods for removal, Burkart and James (1999) evaluated the nitrate residuals for the MRDB. Their study found a maximum of 58-129 kg/ha of residual N in the Midwest that could be transported. Though this does not mean that all 58-129 kg/ha will be transported into the Mississippi River, it represents the total mass that could be transported. Goolsby et al. (2001) found that the majority of the rivers in Iowa that drain directly to the Mississippi River contribute around 15-31 kg/ha of total N per year delivered to the Gulf of Mexico. The average of 15-31 kg/ha (23 kg/ha) divided by the average of 58-129 kg/ha (93.5 kg/ha) shows that about 25 percent of the available nitrate is transported to the Gulf of Mexico annually.

Zhang and Schilling (2005) looked at a 28-year record on the Raccoon River in Iowa. The study determined that nitrate leaching in streamflow and baseflow appeared random with a half-year and one-year cycle. Winter and spring provide cooler weather conditions and high flow periods. The high flows can mobilize nitrate and the cooler weather does not allow for much in-situ or in-stream denitrification. This results in much of the leached nitrate reaching the Gulf of Mexico (Royer, Tank, & David, 2004).

Nitrate Transport

Hydrology has a direct impact on nitrate transport because the main nitrate delivery mechanism to streams is ground water discharge as tile drainage and baseflow (Hallberg, 1989; Power & Schepers, 1989; Schilling, 2002). Ground water discharge is difficult to measure directly, however it typically makes up a substantial portion of streamflow (Lim, et al., 2005). Schilling and Libra (2003) looked at 13 streamflow gages with 70 years or more of streamflow data. The study concluded that baseflow percentages significantly increased over the period evaluated. Additionally, the study determined that more precipitation than in the past is being routed to streams and rivers as baseflow. Increased baseflow would increase the potential to flush more nitrate out of the soil profile and into waterways.

Schilling (2005) looked at many of the same watersheds in the 2003 study to determine if percent row crop in those watersheds correlated with increased baseflow. That study found that increased row crop production generated more baseflow to streams and rivers. Due to an increase of precipitation moving through the ground instead of over land and an increase in row crop percentages, there would likely be more baseflow moving through nitrate laden soils. This could increase how much nitrate is carried to streams and rivers through baseflow seepage. In the Raccoon River watershed in Iowa, baseflow was found to carry about two-thirds of the nitrate load export, and over 80 percent of the export occurred during spring and late fall (Schilling & Zhang, 2004).

Higher nitrate loads are exported through row-cropped, tile-drained fields with higher water yields (David, Drinkwater, & McIsaac, 2010). Row crop fields typically have greater fertilizer application rates and are generally tile drained. This combination of

factors results in an agricultural system that is efficient at leaking or transporting

nutrients to streams and rivers (Baker, David, Lemke, & Jaynes, 2008). Throughout much

of Iowa, the quantity of available nitrogen to transport is typically not the limiting factor

in load exports. Load exports appear to be more a function of stream discharge (Blesh &

Drinkwater, 2013; Schilling & Lutz, 2004).

Data Collection

Nitrate data can be recorded using water quality sensors or collecting grab

samples and analyzing them in a laboratory. The collection of nitrate data using

continuous water quality sensors produces high-resolution data. Nitrate concentrations

collected by high-resolution sensors are considered measured data (Schilling, et al.,

2017). They could improve the daily mean concentration estimates and subsequently the

daily, monthly, and annual nitrate loads estimates. Better quantification of the annual

nitrate loads will lead to improved extrapolation of statewide load estimates. More

accurate load reductions can be confidently estimated as load estimates are improved.

Nitrate Estimation

Accurate nitrate load estimation techniques are important when nitrate data is

unavailable or has gaps. This allows for more confident estimates of annual statewide

nitrate loads used to track nutrient reduction. Because nitrate is mobilized by water, most

studies use a hydrologic input (streamflow, baseflow, tile discharge, etc.) to evaluate

relationships between nitrate concentrations, loads, and yields.

Schilling et al. (2017) investigated the variability among many of the existing

nitrate concentration and load estimation models. The project objective was to identify a

model that the state of Iowa could use to quantify the success of the load reduction strategy. The study concluded that linear interpolation of nitrate concentrations was the recommended method for simplicity and consistency. Use of linear interpolated nitrate concentrations is consistent with research performed by Royer et al. (2006).

Summary

Numerous studies have evaluated and discussed the factors affecting nitrate fate and transport. These studies have concluded that the main sources of nitrate are row crop cultivation, livestock production, and soil mineralization. Many nitrate inputs, like fertilizer application rates, are largely within human control. Conversely, many of the processes to remove and transport nitrate are highly variable because they are strongly dependent on factors like weather, in-situ conditions (atmospheric, soil, and stream), temperature, and humidity. The difficulty in controlling nitrate removal and transport factors highlights the need for more widespread implementation of conservation practices. These practices could include both customized nutrient application rates to agricultural land and construction or rehabilitation of land to increase opportunities for nitrate processing. Effects of conservation implementations may take many years to observe significant changes; thus, long-term observation of the statewide 10-year moving average of nitrate loads is necessary to accurately quantify nutrient load reductions.

# CHAPTER 3: METHODOLOGY

The methods described in this chapter were consistent with those used in the development of the INRS nitrate baseline load. Calculation of annual statewide nitrate load was meant to replicate the process currently being performed by the DNR.

## Study Area

The research area comprised of 62 sites spread relatively evenly across Iowa. These sites are monitored by the DNR as part of their ambient stream monitoring water quality program. These sites were selected because they have an extended period-of-record (~17 years) of monthly nitrate concentrations. Additionally, most of the sites were located near, or collocated with, a USGS gaging station. Figure 2 shows the location of the DNR ambient sites, USGS gages, and corresponding basins and subbasins studied. The 23 DNR ambient sites outlined by the thick black lines represent the main study basins. The remaining basins outlined by blue lines represent subbasins within the main study basins. The DNR ambient site identification numbers, associated USGS gage, and corresponding drainage areas ($km^2$) are located in Appendix A.
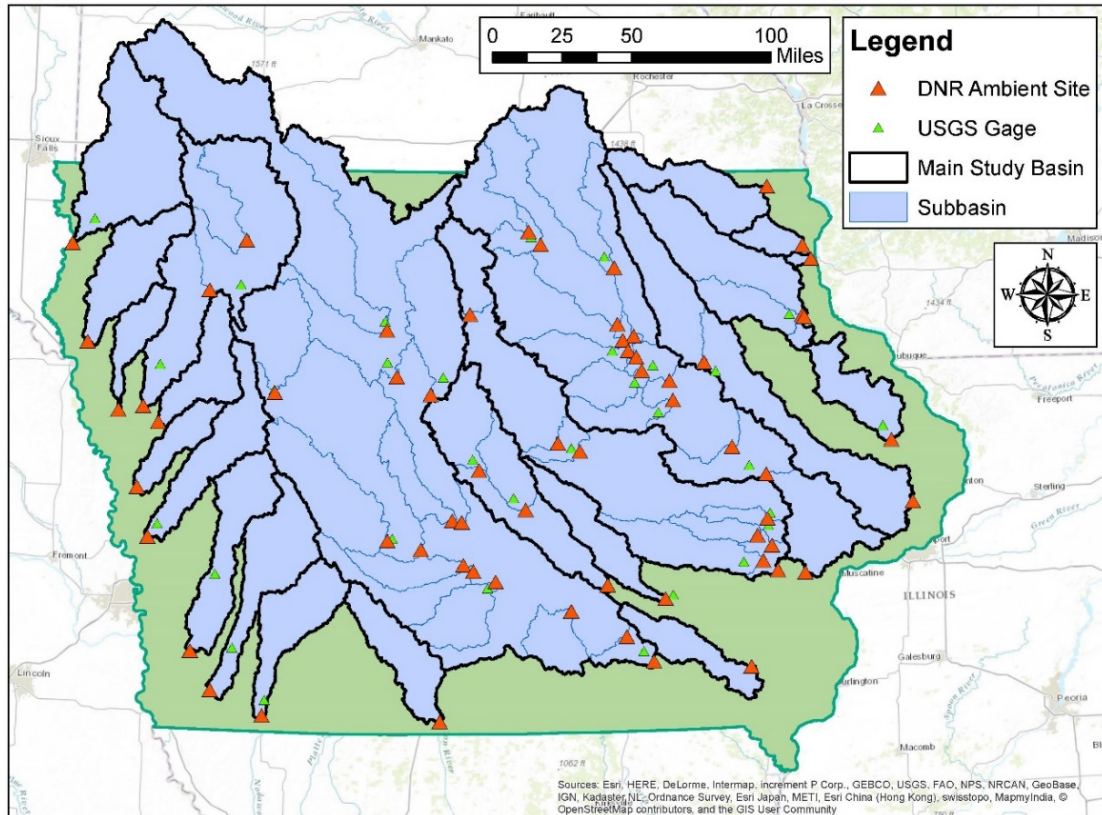
*Figure 2: Study area.*

Load Calculation

Monthly water samples for the 62 sites were manually collected starting in 1998-1999. The water samples were analyzed at the University of Iowa's State Hygienic Laboratory. Once the lab analyzed the samples the data was electronically transferred to the Iowa STORET website (available at: https://programs.iowadnr.gov/iastoret/srchStations.aspx) (Iowa DNR, 2016). STORET is an electronic data system developed by the USEPA for the storage (STO) and retrieval (RET) of water quality data (USEPA, 2017). Many different analytical tests were performed on each water sample, but the only one used in this study was nitrate+nitrite concentrations (mg/L). The detectable limit for the dataset was 0.1 mg/L. For this study,

any data points that were recorded as "Not Detected" were assumed to have a nitrate concentration of half the detectable limit (0.05 mg/L).

Streamflow (Q) was needed to convert nitrate concentrations (mg/L) into nitrate loads (Mg/day). Daily mean streamflow was downloaded from the USGS National Water Information System for the period January 1st, 1998 to December 31st, 2015. The streamflow needed to be scaled from the USGS drainage area to the DNR ambient drainage area because the DNR ambient drainage basins were not always located at the USGS gage. This was done using a drainage ratio (α). The drainage ratio was calculated using Equation 1. The drainage ratios for all of the sites can be found in Appendix A.

*Equation 1: Drainage ratio calculation.*

$$Drainage\ Ratio\ (\alpha) = \frac{DNR\ Ambient\ Drainage\ Area\ (km^2)}{USGS\ Drainage\ Area\ (km^2)}$$

Microsoft Excel spreadsheets were used to process and maintain most of the study data. Nitrate concentrations and streamflow for each site were exported from their respective databases and stored in Excel spreadsheets. Visual Basic for Applications (VBA) is Excel's internal coding language. VBA was used to extract and process nitrate concentration and streamflow data from the spreadsheets for each of the 62 sites evaluated. Linear interpolation was used to estimate nitrate concentration on days when nitrate concentration was not measured. This allowed the monthly concentrations to be linearly interpolated to a daily time scale. Daily mean streamflow was scaled by the respective drainage ratio. The daily load was calculated for all 62 study sites using Equation 2 and then totaled annually. VBA was used to compile the resulting annual

loads for all 62 sites into a summary spreadsheet. The data processing and developed

interpolation VBA code can be found in Appendix B.

*Equation 2: Load calculation.*

$$Load\left(\frac{Mg}{day}\right) = N\ Conc.\left(\frac{mg}{L}\right) * \alpha * Q\left(\frac{ft^3}{sec}\right) * \frac{1\ Mg}{1\ x\ 10^9\ mg} * \frac{86400\ sec}{1\ day} * \frac{28.3168\ L}{1\ ft^3}$$

An annual total monitored nitrate load was calculated by summing the annual

nitrate loads from the available 23 main study basins. The total monitored area was also

calculated each year as the sum of the drainage area of the available 23 main study

basins. An annual monitored nitrate yield was calculated by dividing the total monitored

nitrate load by the total monitored area. This annual monitored nitrate yield was then

multiplied by the total area of Iowa to obtain an annual statewide nitrate load estimate.

The contributing basins used to calculate the total monitored nitrate load and area varied

from year to year because there were a few basins that did not have a complete year of

nitrate load data. The basins with incomplete nitrate data were excluded from the total

monitored load and area for the year in which there was not complete data. After annual

statewide nitrate loads were estimated, the load estimates were fit using regression

analysis.

Variables Used in Analysis

Annual nitrate loads were used to evaluate spatial and temporal variability. Both

the spatial and temporal variability regression models were run using the statistical

software Minitab 17 (Minitab version 17.3.1, 2017). Some common variables used in

developing models are basin morphology, hydrologic patterns, and vegetation patterns

(Smakhtin, 2001).

The hydrologic variables evaluated in this study were: precipitation (mm), runoff coefficient, baseflow (mm), and streamflow water yield (mm). These were selected because each one tracks the mobilization of nitrate differently. Evaluating the strength between each hydrologic variable and nitrate predictability gives insight into which hydrologic variable best follows nitrate export patterns.

The variables used to describe land variability were: upstream drainage area ($km^2$), average ground slope, percent of land with manure application (percent manure), percent of the land classified as row crop land use (percent row crop), and percent of the land assumed to have tile drainage (percent tiled soils). Drainage area provides a way to scale and compare the nitrate load exports throughout the study area. Slope is an important factor to describe how long water takes to flow into streams and rivers and ultimately out of a basin and state. Percent manure, row crop, and tiled soils describe the agricultural intensity and land use within a watershed. Percent row crop is assumed to best describe the agricultural intensity across the state due to the widespread availability and resolution of land use data.

All hydrologic and land description variables mentioned were used as the predictive input variables to evaluate spatial variability. Only the hydrologic variables were used to evaluate temporal variability. Upstream area, slope, percent manure, percent row crop and percent tiled soils were considered constant for individual basins, therefore they were excluded from the temporal analysis.

Data Acquisition and Assimilation

Annual precipitation data was obtained from the Parameter-elevation Relationships on Independent Slopes Model (PRISM) Climate Group, a precipitation

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model run by Oregon State University. This model predicts precipitation using regression equations based on climate and elevation. The model also takes into account precipitation measurements from gage stations (Daly, et al., 2008). PRISM outputs a monthly and annual precipitation (mm) on a 4 kilometer (km) grid. This study only considered the annual precipitation grids from 1998-2015. Watershed size made it necessary to increase the resolution of the precipitation grid. Environmental Systems Research Institute's (ESRI) Geographic Information System (GIS) was used to resample the 4 km raster to a 30 meter (m) resolution. This grid was then intersected with a watershed boundary polygon. The sum of the intersected cells represented an annual precipitation for that basin.

Runoff coefficient is a simple way to partition what percentage of precipitation leaves a watershed as streamflow. The runoff coefficient is calculated by dividing the annual water yield (mm) by the annual precipitation (mm). Runoff coefficient is typically on the order of 0.30. This means around 30 percent of the water that falls as precipitation leaves a watershed as streamflow. Evapotranspiration accounts for the remaining 70 percent of the total incoming water in the water balance. Baseflow typically makes up around two-thirds of streamflow.

Many studies have used baseflow as the hydrologic variable to replicate nitrate trends. Baseflow is estimated using a variety of hydrograph separation techniques. This inconsistency adds uncertainty to the already uncertain separation techniques. Despite the range of uncertainty in baseflow estimation, baseflow was still evaluated in this study as a possible hydrologic variable used to fit data in regression analysis.

Baseflow was estimated using the hydrograph separation tool Web-based

Hydrograph Analysis Tool (WHAT) developed by Purdue University (Lim, et al., 2005).

After inputting a USGS gage number, WHAT connects to the USGS database to obtain

daily streamflow data and output an average daily, monthly, or annual baseflow estimate.

The baseflow estimation method used was the "Recursive Digital Filter" with the

following settings:

- Aquifer type: Perennial streams with porous aquifers

- Filter Parameter: 0.98

- $BFI_{max}$: 0.80

The annual baseflow estimation output is based on the water year (October-

September) and not a calendar year (January-December). Since the rest of the data in this

study was based on a calendar year, the baseflow also needed to be on calendar year.

WHAT returns monthly baseflows as an average of daily baseflow estimates throughout

the given month in cubic feet per second. The monthly baseflow averages were converted

to baseflow yields (mm/day) and averaged to obtain a calendar year annual average

baseflow ($\bar{Q}_{b,annual}$). As long as streamflow data was available on the USGS database,

WHAT provided a baseflow estimate. This provided annual baseflow averages from

1999-2015 for all 62 DNR ambient sites. Similar to the water yield, the average baseflow

was estimated at a USGS gage; therefore, the values were scaled by the drainage ratio to

the DNR ambient drainage area using Equation 3. The annual average baseflow

(mm/day) was multiplied by 365 (days) to give an annual total in millimeters per year.

*Equation 3: Baseflow yield calculation.*

$$Baseflow\ Yield\left(\frac{mm}{year}\right) = \frac{\bar{Q}_{b,annual}\left(\frac{ft^3}{sec}\right) * \alpha * \frac{86400\ sec}{1\ day} * \frac{365\ days}{year} * \frac{28.3168\ L}{1\ ft^3}}{1 \times 10^6\ m^2 * Upstream\ Area\ (km^2)}$$

Daily streamflow was summed annually and divided by upstream area to calculate water yield. The conversion to the correct units was calculated using Equation 4.

*Equation 4: Water yield calculation.*

$$Water\ Yield\left(\frac{mm}{year}\right) = \frac{\Sigma_{Annual}\ Q\left(\frac{ft^3}{sec}\right) * \alpha * \frac{86400\ sec}{1\ day} * \frac{28.3168\ L}{1\ ft^3}}{1 \times 10^6\ m^2 * Upstream\ Area\ (km^2)}$$

Watersheds were delineated for each of the 62 DNR ambient sites using the online USGS StreamStats Interactive Map (available at: https://water.usgs.gov/osw/ streamstats/iowa.html). Generally, the 62 watershed delineations correspond to the 8-digit Hydrologic Unit Code (HUC 8) delineations. Only the 23 main study basins were used for estimating statewide loads. All nested subbasins were ignored to avoid double counting nitrate loads. All 62 basins and subbasins were used to observe statewide trends and perform regression analysis. StreamStats outputs a polygon shapefile representing the watershed boundary. Using GIS, the area of these polygons was calculated to give the area of the watershed in km$^2$. Main study basins were assigned numbers starting at 1 in the northeast corner of Iowa to 23 in the northwest corner of the state. The main study basin and subbasin numbering is shown in Figure 3.
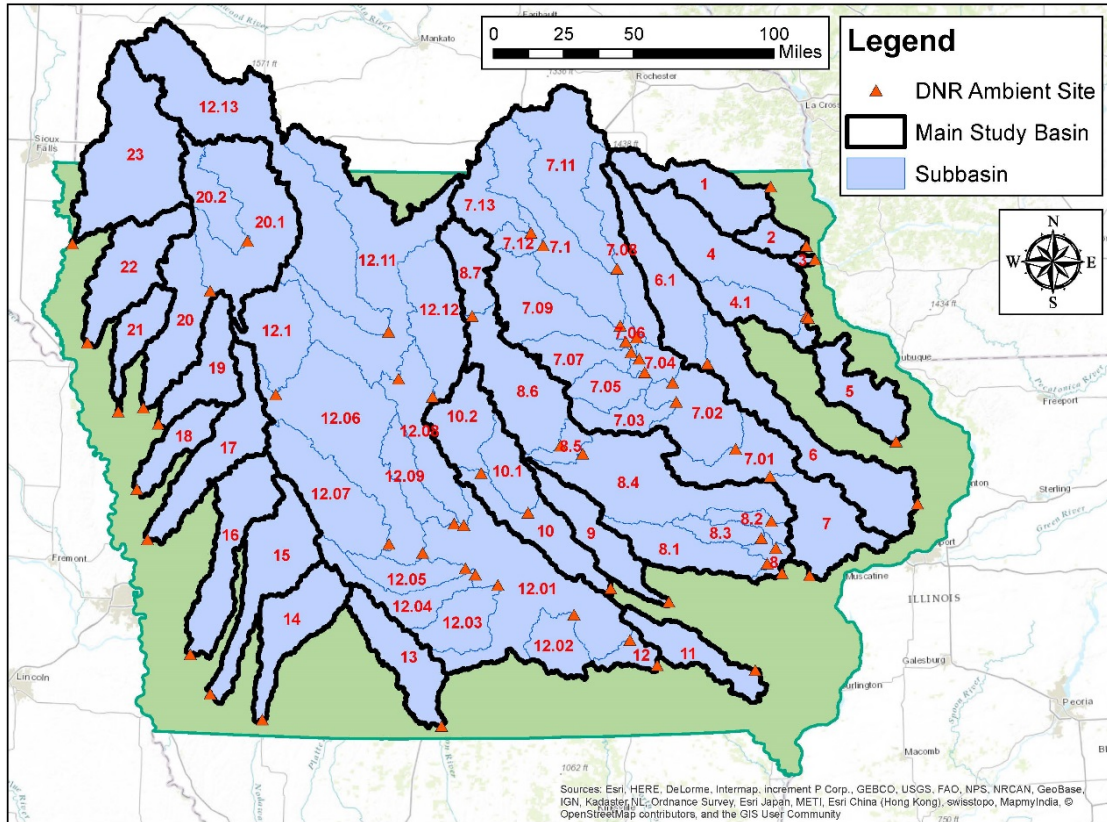
*Figure 3: Main study basin and subbasin numbering.*

The remaining predictive variables (slope, percent manure, percent row crop, and percent tiled soils) were extracted by using GIS to overlay shapefiles downloaded from the Iowa DNR GIS Library with the delineated watersheds. The slope was obtained by calculating the average of the slope raster values within a watershed. The land use coverage was a three meter high-resolution shapefile with 15 different land use types. Only the combined areas represented by corn and soybean were used to estimate percent row crop. Minnesota land use data was used for portions of watersheds that lie within that state. Manure application and tile drainage coverages were not available in Minnesota. For watersheds that were partially in Minnesota, only the Iowa portion of the watershed was used to calculate percent manure and percent tiled soils. The percent tiled soils

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shapefile coverage was developed based on land use, soil type, and slope to estimate

where tile drains are most likely installed. Percent manure, percent row crop, and percent

tiled soils each extracted the number of cells within a watershed boundary. Using the cell

area and number of contributing cells, the area of each variable was calculated. This area

was then divided by the watershed area to obtain a percent of the watershed with a given

characteristic. Instructions for how to process raw precipitation and land description data

can be found in Appendix C. Table 1 identifies the source of the shapefiles and how they

were used.

*Table 1: GIS data sources.*

| Shapefile Name | Source & Publication Date (MM-DD-YYYY) | Use |
|---|---|---|
| Delineated watersheds | https://water.usgs.gov/osw/streamstats/iowa.html | Calculate polygon area to get watershed drainage area. Clipping land use, manure, tiled soil, and precipitation. |
| DNR ambient sites | ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/hydrologic/surface_waters/storet_sites.zip (01-23-2013) | Locate 62 study sites. |
| Iowa boarder | ftp://ftp.igsb.uiowa.edu/gis_library/IA_State/Admin_Political_Boundary/iowa_border.zip (09/02/2003) | Map visual aid. |
| Iowa land use | ftp://ftp.igsb.uiowa.edu/gis_library/IA_State/Land_Description/Land_Cover_2009/hrlc_2009_3m.zip (09-04-14) | Clip by watershed to generate percent of Iowa watershed area classified as row crop. |
| IWQIS sites | requested from: https://iwqis.iowawis.org/data.html | Locate comparable IWQIS and DNR ambient sites. |
| Landform regions | ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/geologic/landform/landform_regions.zip (12-11-2009) | Grouping to develop regional regression equations. |
| Manure | ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/agriculture/manure_2006/manure_2006.zip (03-10-2008) | Clip by watershed to generate percent of Iowa watershed area applied with manure. |
| Minnesota land use | https://gisdata.mn.gov/dataset/biota-landcover-nlcd-mn-2011 (06-19-2014) | Clip by watershed to generate percent of Minnesota watershed area classified as row crop. |

*Table 1 (Cont.)*

| Shapefile Name | Source & Publication Date (MM-DD-YYYY) | Use |
|---|---|---|
| MLRA | https://www.nrcs.usda.gov/wps/portal/nrcs/detail /national/home/?cid=nrcs142p2_053624 (2006) | Grouping to develop regional regression equations. |
| Precipitation | http://www.prism.oregonstate.edu/recent/ | Clip by watershed to generate zonal statistics to calculate precipitation yield. |
| Slope | ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/eleva tion/NED/NED_30m/pcnt_slope_i/pcnt_slope_i. zip (03-04-2008) | Clip by watershed to generate zonal statistics to calculate average slope. |
| Tiled soils | ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/agric ulture/tiled_soils/tiled_soils.zip (09-23-2008) | Clip by watershed to generate percent of Iowa watershed area using tile drainage. |
| USGS gages | ftp://ftp.igsb.uiowa.edu/gis_library/IA_State/Hyd rologic/Surface_Waters/USGS_gages.zip (08-24-2012) | Locate associated USGS gages to DNR ambient study sites. |

Summary

The methods of obtaining and processing data were discussed. Monthly nitrate concentrations were interpolated to daily concentrations. Daily streamflow and nitrate concentrations were used to calculate daily nitrate loads. Nitrate loads were summed to obtain annual nitrate loads for each basin. The annual nitrate loads were used to extrapolate annual statewide nitrate loads for the state of Iowa. Common engineering methods of calculating precipitation, runoff coefficient, baseflow yield, and water yield were used. Additional land description variables were obtained to predict spatial patterns. The selection of land description variables was generally based on those identified in literature to be a source of nitrate or to have a large impact on hydrology and nitrate transport. Calculation and prediction of annual statewide loads will assist in the monitoring efforts to reduce total nitrogen loads to meet INRS load reduction goals.

# CHAPTER 4: DNR AMBIENT PATTERNS AND MULTIPLE LINEAR REGRESSION RESULTS AND DISCUSSION

In this chapter, daily nitrate loads were summed into annual loads for all study sites. Annual statewide nitrate loads were then extrapolated using the annual nitrate loads of the 23 main study basins. Spatial patterns in the annual nitrate loads and yields were observed and linear regression modeling was used to develop spatial and temporal regression equations. Regression models were validated by comparing results to DNR ambient data. Regional regression equations were then formulated to predict temporal regression parameters (slope and intercept) based on land description variables. This provides a method to estimate year-to-year nitrate load and yield variability in unmonitored locations as well as track statewide nitrate trends.

## Statewide Trends Using DNR Ambient Data

Similar to the findings of Schilling and Lutz (2004), most of the 62 DNR ambient sites displayed seasonal patterns with higher nitrate concentrations during the spring and fall. Nitrate concentrations typically decrease in the middle of July partially because this is the peak of the crop growing season and much of the available nitrate is used by the crop to grow. This reduces the amount of available nitrate that can enter streams. Additionally, the canopy formed by the growing plants alters the surface hydrology as well as intercepts moisture before it can reach tile drains. Instream denitrification also contributes to the concentration reduction. Nitrate concentrations typically increase again after harvest in the fall because crops are no longer using nitrate, the ground is more susceptible to erosion, and surface water dissolves nitrate throughout the soil column as it percolates to tile drains. Despite a concentration decrease in the middle of July, the

months with the greatest nitrate loads were April through July. This is a result of high streamflow throughout spring and summer. These months are hereafter referred to as the "active season."

Annual statewide nitrate patterns can be seen in the extrapolated nitrate load calculation. Figure 4 shows the extrapolated annual statewide nitrate-N load time series based on average DNR ambient monitored nitrate yield.



● Total Load　■ 10-Year Moving Average
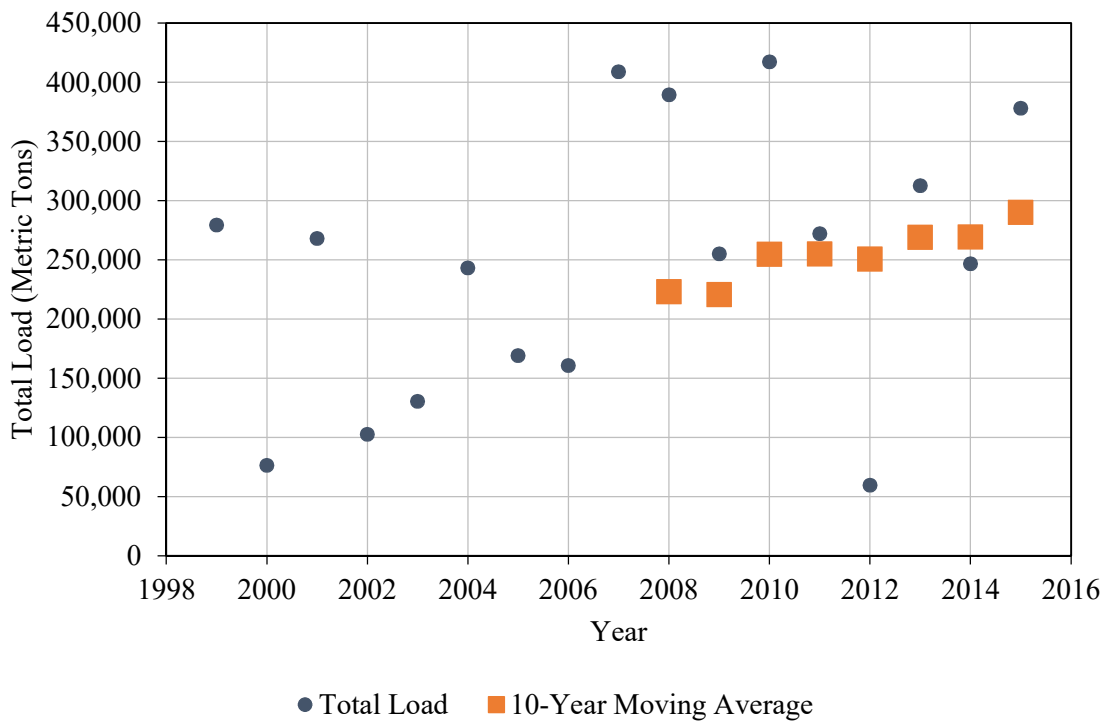
*Figure 4: Annual statewide nitrate load estimate (1999-2015).*

The Des Moines and Cedar rivers accounted for about 50 percent of the annual monitored nitrate load. Annual variability in nitrate load is largely due to the annual variability in precipitation and runoff. Low points in the years 2000 and 2012 correspond to drought years. Since there was less streamflow, the nitrate loads were lower. The opposite can be seen in 2007, 2008, and 2010. These were much wetter years, which resulted in much higher delivery of nitrate to rivers.

Similar to the nitrate baseline established in the INRS, a 10-year moving average was calculated to better capture the overall trend of statewide nitrate loads. The 10-year moving average in Figure 4 shows a steady increase in statewide nitrate loads. This could be due to the increasing trends in precipitation and streamflow discussed by Slater and Villarini (2016). From 2008 to 2015 the 10-year moving average has increased by 30 percent. The 10-year moving average nitrate load in 2015 was 14 percent higher than the 2010 value, corresponding to the establishment of the INRS baseline.

In addition to calculating the annual statewide nitrate load, patterns in subbasins were also observed. The annual statewide 10-year moving average nitrate load was calculated to monitor load exports and quantify load reductions in accordance with the INRS. A similar analysis was performed in each subbasin to identify which subbasins showed the greatest increases in nitrate load exports. A normalized 10-year moving average load was calculated for most of the 62 DNR ambient subbasins by dividing the site's 10-year moving average load by the site's period-of-record average load. A trend line was fit to the resulting dataset for each subbasin. The trend line slope represents a percentage, in decimal form, of the site's average load. For example, at the Cedar River near Conesville, the slope through the normalized 10-year moving average loads was 0.033 (Mg/Mg per year), as shown in Figure 5. This represents a 3.3 percent increase in the average nitrate load each year.
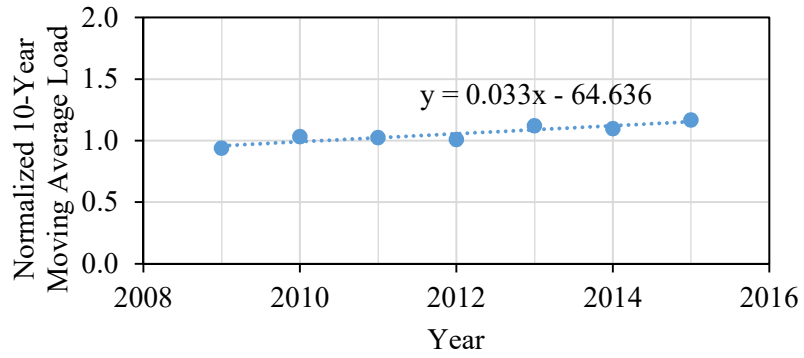
*Figure 5: Example of trend line through subbasin 10-year moving average nitrate loads. Data from Cedar River near Conesville, IA.*

Higher slopes identify subbasins with a more rapid increase in average nitrate load exports. The slope of the trend lines for most of the 62 sites were mapped across the state in Figure 6.
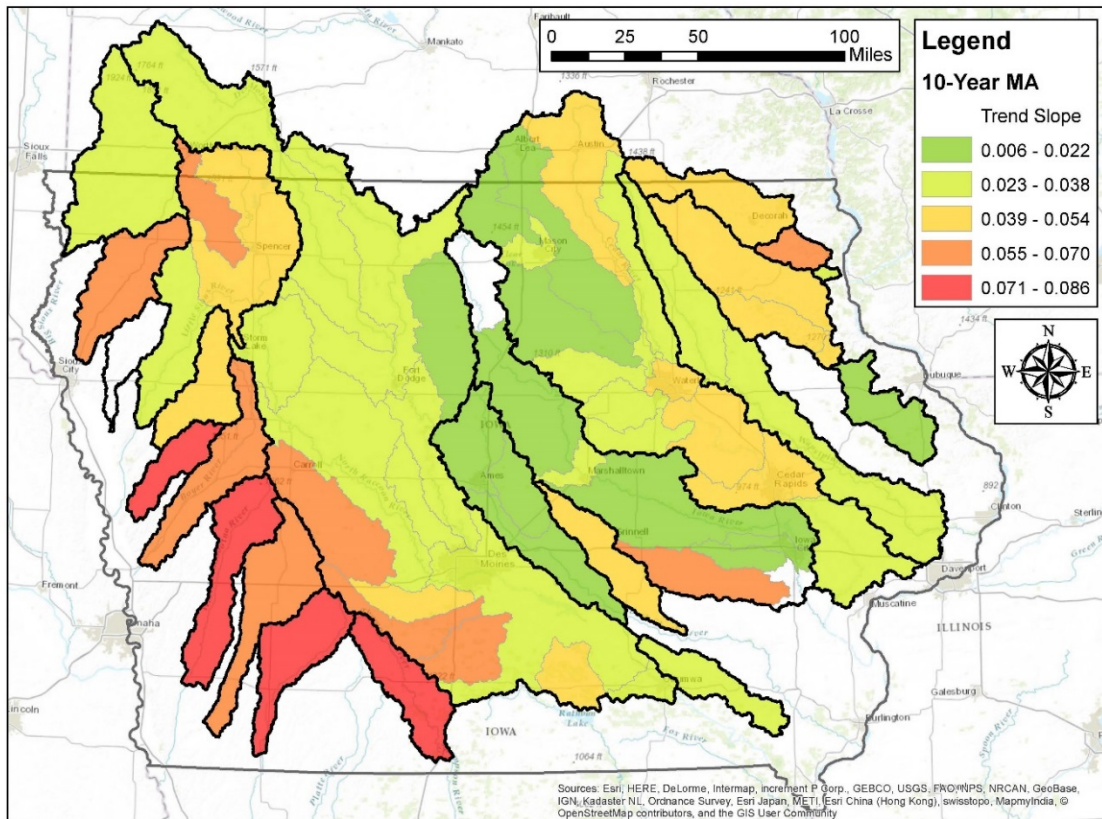


*Figure 6: Individual site 10-year moving average (MA) trend line slope.*

None of the 10-year moving average trend lines showed a negative slope. This indicates that during the study period none of the reported subbasins reduced their typical nitrate load export. The southwest corner of Iowa showed the highest trend line slopes, indicating the most rapid increase in nitrate load exports. The annual nitrate load contribution from the southwest corner of Iowa is not as significant as larger watersheds such as the Des Moines River. Regardless, the trend of increasing nitrate load export deserves attention.

Although random precipitation patterns could have influenced this region during the 17-year window evaluated, these results could also represent more permanent changes in precipitation and hydrology patterns in the southwest region. More rapidly increasing load per year could also be the result of an increase in agricultural land cultivation or amount of fertilizer being applied. Further research should be performed to understand why the more rapid increase in nitrate exports is occurring in the southwest corner of Iowa.

Nitrate load is primarily a function of upstream drainage area because larger basins have more land contributing nitrate exports. Another parameter used to evaluate statewide nitrate patterns was nitrate yield because it normalizes the nitrate load by dividing by the basin area. The slope of nitrate loads showed which basins exported more nitrate load than normal. Nitrate yield, on the other hand, provides a way to compare basin exports with other basins. This comparison between basins can be done regardless of significant scale variability in nitrate load exports and upstream areas.

Figure 7 shows the average annual nitrate yield across Iowa. The average of all 62 site averages was 18.7 kg/ha (16.7 lbs/acre) per year. The average yield ranged from

approximately 2-30 kg/ha per year. This average was consistent with the findings of Goolsby et al. (2001), where the average nitrate yield was reported to be 15-31 kg/ha per year. The highest loads were concentrated in the north-central to northeast part of the state. This region can be described as generally low relief land with high percentages of row crop. Because of the high productivity of agriculture in this region of Iowa, the possibility of nitrate leaching is increased. There is also a precipitation gradient across the state with lowest precipitation in the northwest corner and increasing to southeast corner.
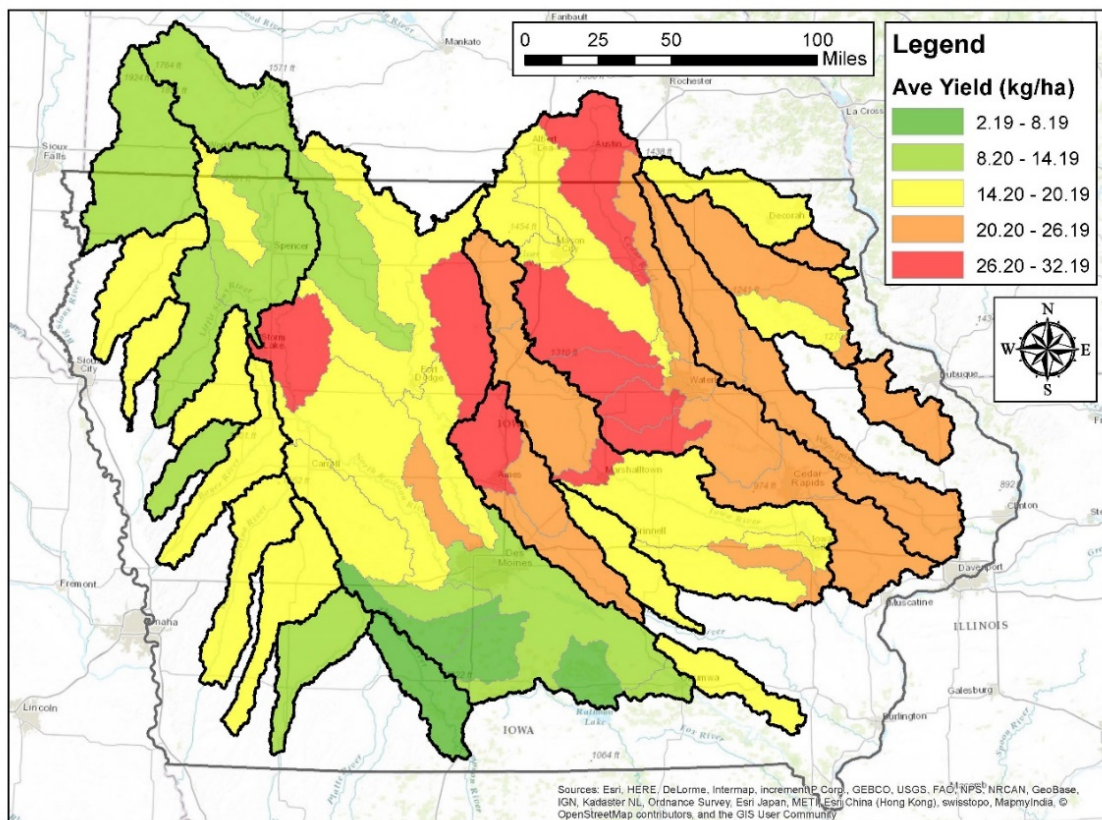


*Figure 7: Average annual nitrate yield (kg/ha).*

Other notable patterns in the DNR ambient data showed that average nitrate yield, nitrate concentration, and flow-weighted nitrate concentration display a strong dependency on percent row crop in the watershed. This was consistent with previous

research (David, Drinkwater, & McIsaac, 2010; Schilling & Libra, 2000). Annual flow-weighted average nitrate concentration (mg/L) was found by converting the total annual nitrate load (Mg) into milligrams (mg) and dividing by the total annual streamflow (L). All annual flow-weighted nitrate concentrations were averaged for each basin to obtain the average flow-weighted nitrate concentration. The annual average nitrate concentration for each basin was calculated by averaging all interpolated nitrate concentrations from DNR ambient data for a given year. All annual average nitrate concentrations for each basin were averaged to obtain the average nitrate concentration.

Schilling and Libra (2000) found that a preliminary estimate of the average nitrate concentration could be calculated by multiplying the percent row crop by 0.1. The average nitrate concentration from DNR ambient data was plotted versus percent row crop to evaluate how the ambient data followed the trend suggested by Schilling and Libra. This is shown in Figure 8. A similar plot using the flow-weighted average nitrate concentration is found in Figure 9.
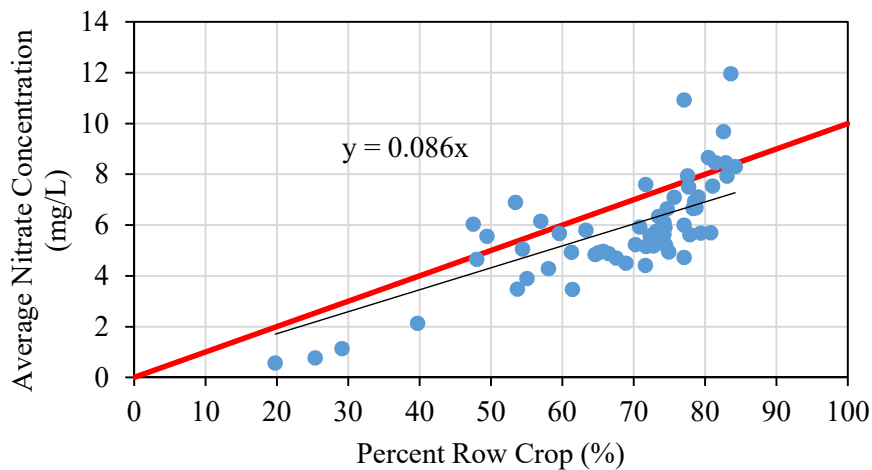


*Figure 8: Average nitrate concentration (mg/L) vs. percent row crop. The red line represents 0.1 multiplied by percent row crop. The black line represents the equation shown.*
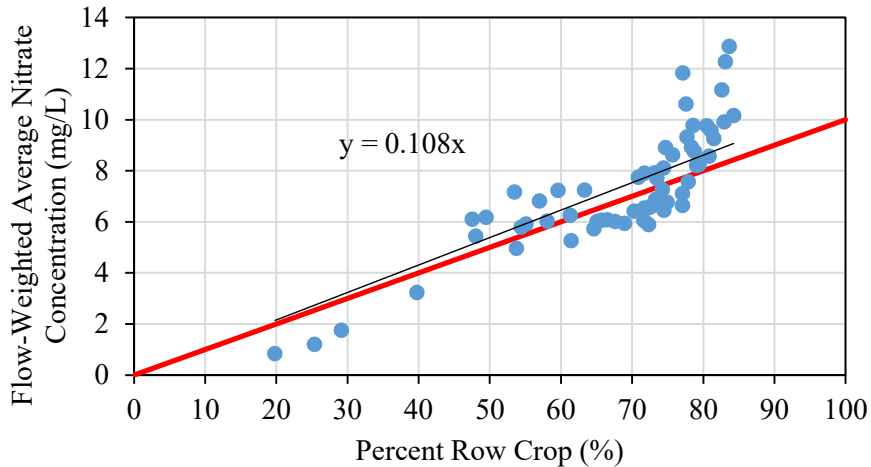
*Figure 9: Flow-weighted average nitrate concentration (mg/L) vs. percent row crop. The red line represents 0.1 multiplied by percent row crop. The black line represents the equation shown.*

The red line represents 0.1 multiplied by percent row crop. Average nitrate concentration produced a relationship of 0.086 multiplied by percent row crop. Flow-weighted average nitrate concentration produced a relationship of 0.108 multiplied by percent row crop.

The flow-weighted average of DNR ambient nitrate data fit the Schilling and Libra relationship better than the average nitrate concentrations. Schilling and Wolter (2005) assumed that a flow-weighted average would be a better representation of the annual average nitrate concentration, rather than the annual average of periodic grab samples. Their study made this assumption because the total nitrate load exported is directly tied to the flow that transported the nitrate.

Another possible explanation for why the slope in Figure 8 is less than the relationship described by Schilling and Libra (2000) is the influence of large basins. Schilling and Libra (2000) found the slope of the average nitrate concentration versus percent row crop decreased with increasing basin area.

<u>Linear Regression Modeling</u>

Regression modeling is a very useful tool to predict parameters using simple or

easy to measure variables. As was discussed previously, the linear regression analysis

was broken up into two parts, spatial and temporal variability and prediction. An

important principle to keep in mind when running linear regression models is

multicollinearity, or collinearity. Multicollinearity is when two or more variables in a

regression equation are highly correlated. This can result in a regression equation that is

unstable and unreliable. To avoid problems with multicollinearity, a correlation table can

be used to discover which variables are highly correlated. Variables that are highly

correlated should not be used in the same regression equation. Typical values of the

correlation coefficient that are considered highly correlated are values greater than 0.70

or less than -0.70. Table 2 reports the correlation coefficient between all of the variables

in the study. Correlation values considered highly correlated are highlighted in red.

*Table 2: Correlation table.*

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | X | 0.727 | 0.590 | 0.890 | -0.121 | 0.325 | -0.673 | -0.482 | -0.287 |
| 2 | 0.727 | X | 0.909 | 0.952 | 0.114 | -0.185 | -0.392 | 0.008 | 0.246 |
| 3 | 0.590 | 0.909 | X | 0.821 | 0.202 | -0.149 | -0.304 | 0.166 | 0.187 |
| 4 | 0.890 | 0.952 | 0.821 | X | 0.010 | 0.002 | -0.520 | -0.185 | 0.036 |
| 5 | -0.121 | 0.114 | 0.202 | 0.010 | X | -0.269 | 0.035 | 0.123 | 0.289 |
| 6 | 0.325 | -0.185 | -0.149 | 0.002 | -0.269 | X | -0.474 | -0.766 | -0.908 |
| 7 | -0.673 | -0.392 | -0.304 | -0.520 | 0.035 | -0.474 | X | 0.581 | 0.395 |
| 8 | -0.482 | 0.008 | 0.166 | -0.185 | 0.123 | -0.766 | 0.581 | X | 0.646 |
| 9 | -0.287 | 0.246 | 0.187 | 0.036 | 0.289 | -0.908 | 0.395 | 0.646 | X |
| *1: Precipitation Yield, 2: Runoff Coefficient, 3: Baseflow Yield, 4: Water Yield, 5: Upstream Area, 6: Average Slope, 7: % Manure, 8: % Row Crop, 9: % Tiled Soils | | | | | | | | | |

Precipitation, water yield, and runoff coefficient are too closely correlated

because the first two are the variables that define the runoff coefficient. Even though

precipitation and baseflow yield have a high correlation of 0.6, their relationship is distant enough to be used in the same regression equation because baseflow is a subset of water yield. Average slope was highly inversely correlated to percent row crop and percent tiled soils. This is likely because row crop farming and installation of tile drainage are less common in areas with steep slopes and much more common on flatter ground.

*Spatial Prediction*

Non-collinear combinations of variables were used to predict the period-of-record average nitrate load. Upstream area accounts for about 96 percent of the variability in average nitrate loads across Iowa. Because of such a high correlation, the average load that a watershed exports can almost entirely be predicated by upstream area. This was expected because nitrate load is a function of stream discharge and stream discharge increases with upstream drainage area. High correlation to upstream area is not instructive in explaining spatial load variation across the state. However, this relationship could be a suitable indicator to get a general idea of what the average load should be in an ungaged watershed. Excluding upstream area, the ability of all remaining variables to predict average nitrate loads was low for all non-collinear combinations. The highest adjusted $R^2$ value was around 0.175. This means that without upstream area, no variables in this study adequately predicted spatial variability in average nitrate loads across Iowa.

This led to a similar analysis in predicting long-term average annual nitrate yield. The study variables did a much better job at estimating nitrate yield. After evaluating many combinations of the variables, the best combinations, with their respective adjusted $R^2$ values, were narrowed down to those shown in Table 3.

*Table 3: Parameters to predict average nitrate yield.*

| Variable | Spatial Simulation # | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| % Manure | X | | | | X | X | |
| % Row Crop | X | X | X | X | X | X | X |
| Baseflow Yield (mm) | X | X | X | | X | | |
| Precipitation Yield (mm) | | | X | | X | | X |
| Water Yield (mm) | | | | X | | X | |
| Adjusted $R^2$ | 0.698 | 0.701 | 0.773 | 0.784 | 0.786 | 0.789 | 0.759 |

After reviewing the findings of Schilling (2005), Schilling and Libra (2000), and Schilling and Zhang (2004), it is not surprising that both percent row crop and baseflow yield were in the mix of variables that best predict nitrate yields. In all spatial simulations, percent row crop significantly increased the ability to predict annual average nitrate yield. From simulation 3 to 4 and from 5 to 6 the parameters baseflow and precipitation were replaced with water yield. This slightly improved the predictability while also lowering the complexity of the model. In addition, obtaining streamflow data from USGS to calculate water yield was also much simpler and less time-consuming than processing precipitation or baseflow data. As a result, average annual nitrate yield can most efficiently be predicted by percent row crop and water yield in a watershed (simulation 4). Adding percent manure (simulation 6) to the regression equation enhanced the predictability, but not significantly. Percent tiled soils provided similar land description information as percent row crop. Replacing percent row crop with percent tiled soils produced high adjusted $R^2$ values, but percent row crop always gave a better prediction. Regression equations for all seven spatial simulations are outlined in Table 4. All hydrologic variable inputs were average annual yields from 1999-2015.

*Table 4: Spatial simulation regression equations and adjusted $R^2$ values.*

| Spatial Simulation # | Regression Equation: Annual Average Nitrate Yield (kg/ha/year) = | Adjusted $R^2$ |
|---|---|---|
| 1 | = -14.29 + 2.93*% manure + 23.54*% row crop + 0.0977*baseflow (mm) | 0.698 |
| 2 | = -14.24 + 25.1*% row crop + 0.0939*baseflow (mm) | 0.701 |
| 3 | = -58.8 + 38.19*% row crop + 0.0364*baseflow (mm) + 0.0517*precipitation (mm) | 0.773 |
| 4 | = -24.46 + 34.39*% row crop + 0.0755*water yield (mm) | 0.784 |
| 5 | = -65.4 + 10.2*% manure + 34.68*% row crop + 0.0411*baseflow (mm) + 0.0592*precipitation (mm) | 0.786 |
| 6 | = -25.37 + 7.14*% manure + 31.46*% row crop + 0.0822*water yield (mm) | 0.789 |
| 7 | = -73.71 + 43.79*% row crop + 0.0713*precipitation (mm) | 0.759 |

Figure 10 shows a scatterplot of simulation 4. This displays how the regression equation replicates the average DNR ambient nitrate yields during the study period.
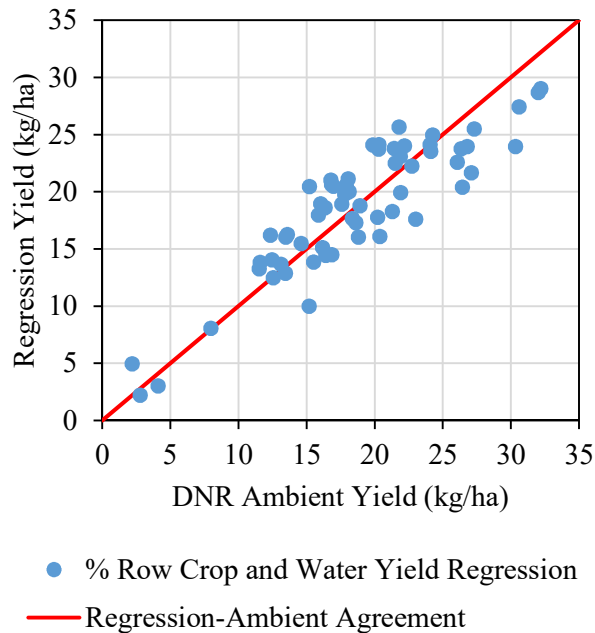


*Figure 10: Spatial simulation 4 (percent row crop and water yield).*

*Temporal Prediction*

Non-collinear combinations of variables were used to predict year-to-year variability in annual nitrate load for each subbasin studied. The possible combinations of hydrologic variables (precipitation, runoff coefficient, baseflow, and water yield) to predict temporal variations in nitrate load are found in Table 5. Four of the five possible simulations were a single variable predicting annual nitrate load because most of the hydrologic predictor variables were too highly correlated, as shown in Table 2.

*Table 5: Variables to predict nitrate load (Mg/year). Adjusted $R^2$ included.*

| Predictive Variables | Temporal Simulation # | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Precipitation Yield (mm) | X | X | | | |
| Runoff Coefficient | | | X | | |
| Baseflow (mm) | X | | | X | |
| Water Yield (mm) | | | | | X |
| Main Study Basin # | Adjusted $R^2$ | | | | |
| 1 | 0.962 | 0.558 | 0.821 | 0.965 | **0.972** |
| 2 | 0.969 | 0.787 | 0.906 | 0.972 | **0.984** |
| 3 | 0.966 | 0.322 | 0.787 | 0.960 | **0.966** |
| 4 | 0.936 | 0.725 | 0.883 | 0.933 | **0.945** |
| 5 | 0.953 | 0.639 | 0.850 | 0.950 | **0.963** |
| 6 | **0.811** | 0.774 | 0.752 | 0.800 | 0.786 |
| 7 | **0.876** | 0.757 | 0.794 | 0.853 | 0.848 |
| 8 | **0.703** | 0.670 | 0.657 | 0.679 | 0.690 |
| 9 | 0.799 | 0.634 | **0.849** | 0.812 | 0.808 |
| 10 | 0.671 | 0.685 | **0.706** | 0.653 | 0.649 |
| 11 | 0.621 | 0.558 | **0.814** | 0.637 | 0.701 |
| 12 | 0.806 | 0.783 | **0.819** | 0.800 | 0.806 |
| 13 | **0.836** | 0.810 | 0.825 | 0.803 | 0.827 |
| 14 | 0.855 | 0.848 | 0.845 | 0.823 | **0.864** |
| 15 | 0.867 | 0.809 | 0.854 | 0.862 | **0.883** |
| 16 | **0.951** | 0.874 | 0.865 | 0.937 | 0.942 |
| 17 | **0.958** | 0.810 | 0.770 | 0.946 | 0.937 |
| 18 | **0.969** | 0.694 | 0.715 | 0.957 | 0.954 |
| 19 | 0.944 | 0.572 | 0.769 | 0.947 | **0.951** |
| 20 | 0.875 | 0.344 | 0.823 | **0.883** | 0.869 |
| 21 | 0.968 | 0.540 | 0.717 | **0.969** | 0.944 |
| 22 | 0.982 | 0.346 | 0.850 | **0.983** | 0.981 |
| 23 | 0.968 | 0.291 | 0.881 | **0.968** | 0.964 |
| Average | 0.880 | 0.645 | 0.807 | 0.873 | 0.880 |

The temporal simulation that resulted in the maximum adjusted $R^2$ value for a given main study basin is shown in red text. Simulation 2 can be removed from consideration because it never produced a maximum $R^2$ for any of the main study sites. Additionally, its $R^2$ values averaged around 0.645, which was about 0.2 lower than the average $R^2$ for the other four simulations. Simulation 3 performed reasonably well, but not well enough to remain a viable option; its average $R^2$ value was 0.807. Simulation 1, 4 and 5 all produced similar $R^2$ values which were significantly higher than those of simulation 2 and 3. Therefore, the selection of the preferred model came down to the simplicity of the model and ease to collect and analyze the necessary predictive variables. Baseflow estimates are not as accurate or reliable as streamflow data because there is no current method to directly measure baseflow; instead, they are based on hydrograph separation models. Precipitation data from PRISM was more time-consuming to process compared to downloading streamflow data from USGS. For these reasons, temporal simulation 5—using water yield calculated from total annual streamflow—was the simplest model and easiest variable to use to predict annual nitrate loads.

The $R^2$ values for temporal simulation 5 of all 62 study sites were mapped in Figure 11 to determine what factors could be contributing to decreased $R^2$ values. The watersheds on the east and west boarders of Iowa all have $R^2$ values of 0.80 or higher, whereas lower $R^2$ values are generally clustered towards the middle of the state.
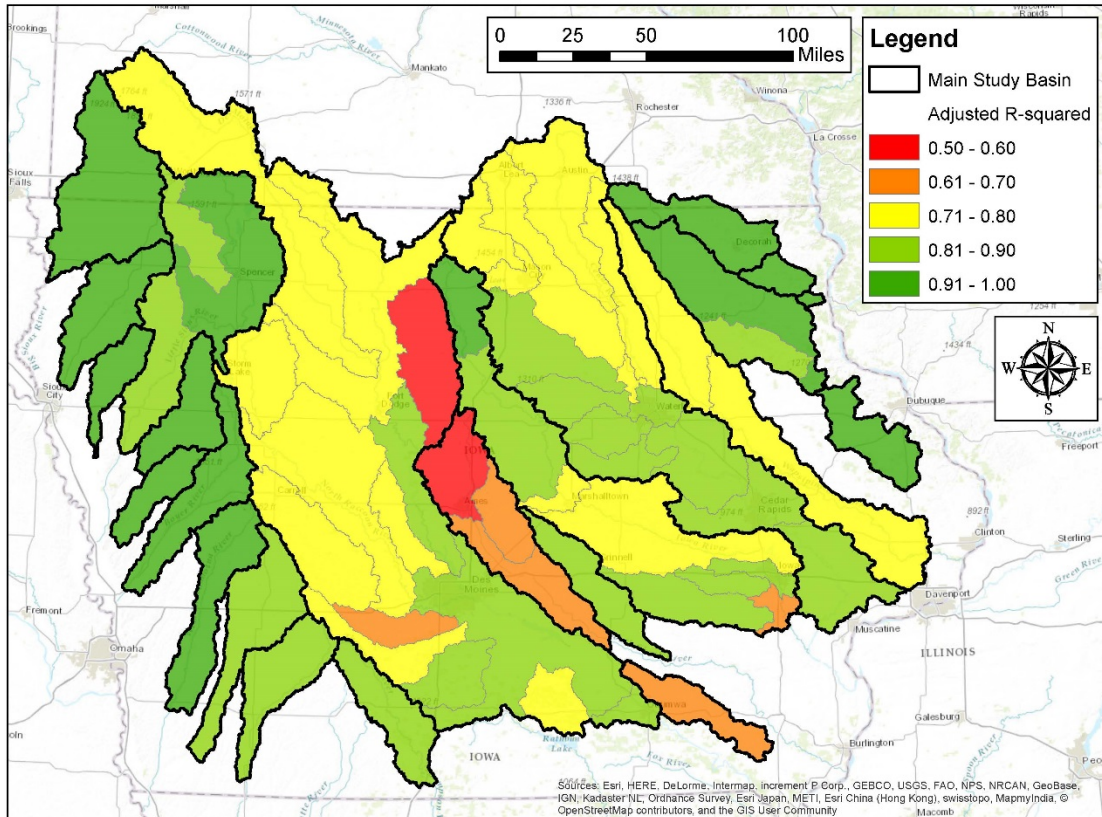
*Figure 11: Statewide water yield regression adjusted $R^2$ for all 62 subbasins.*

Figure 11 identified the regions across the state where the water yield regression model may not be adequate to accurately predict annual nitrate loads. Some of the subbasins with low $R^2$ also correspond to subbasins that produced some of the highest average nitrate yields. This correspondence suggests that the $R^2$ values may be affected by agricultural hydrology, including tile drains and ditches. These practices are used to drain water-logged areas in cropped fields and they can make the hydrology of agricultural areas unpredictable. The presence of artificial drainage may be a contributing factor into lower $R^2$ values. The $R^2$ value also appears to be a function of basin area. For basins smaller than 5,000 km$^2$, like the Turkey River near Garber, the $R^2$ value ranges from less than 0.6 to almost 0.98. The $R^2$ converges around 0.8 as basin area increases.

Besides tile drains and upstream area, the ability to predict annual loads could be affected

by the presence and efficiency of large reservoirs within a basin. Some of the river basins

that could be affected by large reservoirs are the Des Moines River and Iowa River.

Some of the sites with lower $R^2$ values appeared to follow a logarithmic

relationship between load and water yield instead of a linear one. Most sites, like the

North Fork Maquoketa River shown in Figure 12, that had high $R^2$ values generally

followed a linear relationship. In contrast, sites like the Des Moines River downstream of

Ottumwa in Figure 13 appeared to be better represented with a logarithmic relationship.
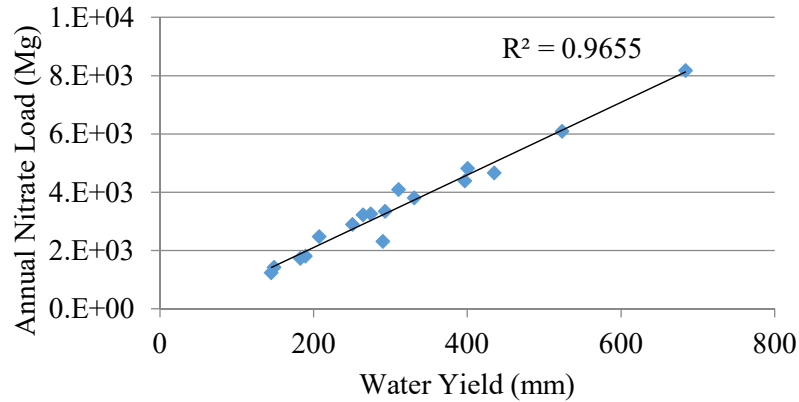


Figure 12: Example of high $R^2$ value for a linear relationship. Data
from North Fork Maquoketa River near Hurstville, IA.
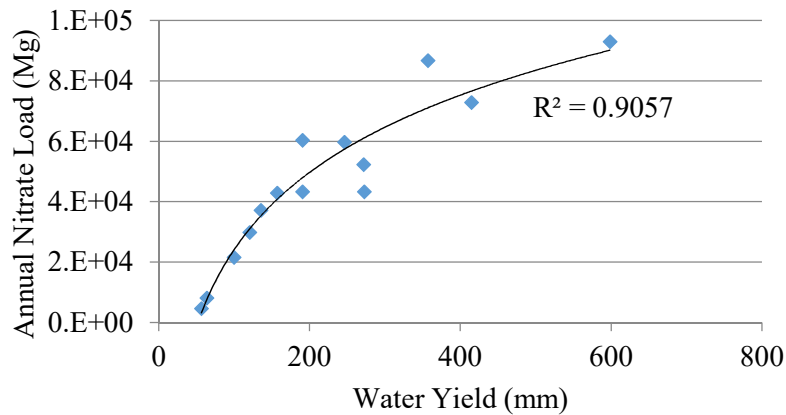


Figure 13: Example of high $R^2$ value for a logarithmic relationship.
Data from Des Moines River downstream of Ottumwa, IA.

The reasons for a linear or logarithmic relationship are not known at this point and further research is recommended to determine when or if a logarithmic relationship should be used instead of a linear relationship. A possible factor may be related to the storage capacity of nitrate in soil and its effect on nitrate transport. Some of the basins with higher $R^2$ values have thinner layers of top soil, which provides less storage of nitrate in the soil profile. Essentially, what goes into the soil profile is directly proportional to what leaves. This describes a linear relationship. The same factors that might be connected to low $R^2$ values may also be connected to when or if a logarithmic relationship should be used to fit nitrate load versus water yield data.

The temporal water yield model (simulation 5) was validated based on how well it could replicate the DNR ambient annual statewide nitrate loads. Figure 14 shows both the DNR ambient statewide nitrate loads and the statewide nitrate loads estimated from regression equations inputting water yield data. The annual statewide nitrate load extrapolation using the water yield regression at each of the main study basins produced load estimates that varied from the DNR ambient load estimations by an average of 16 percent. The regression equations did an even better job matching the 10-year moving averages. The 10-year moving average nitrate load estimates varied by less than 2 percent.
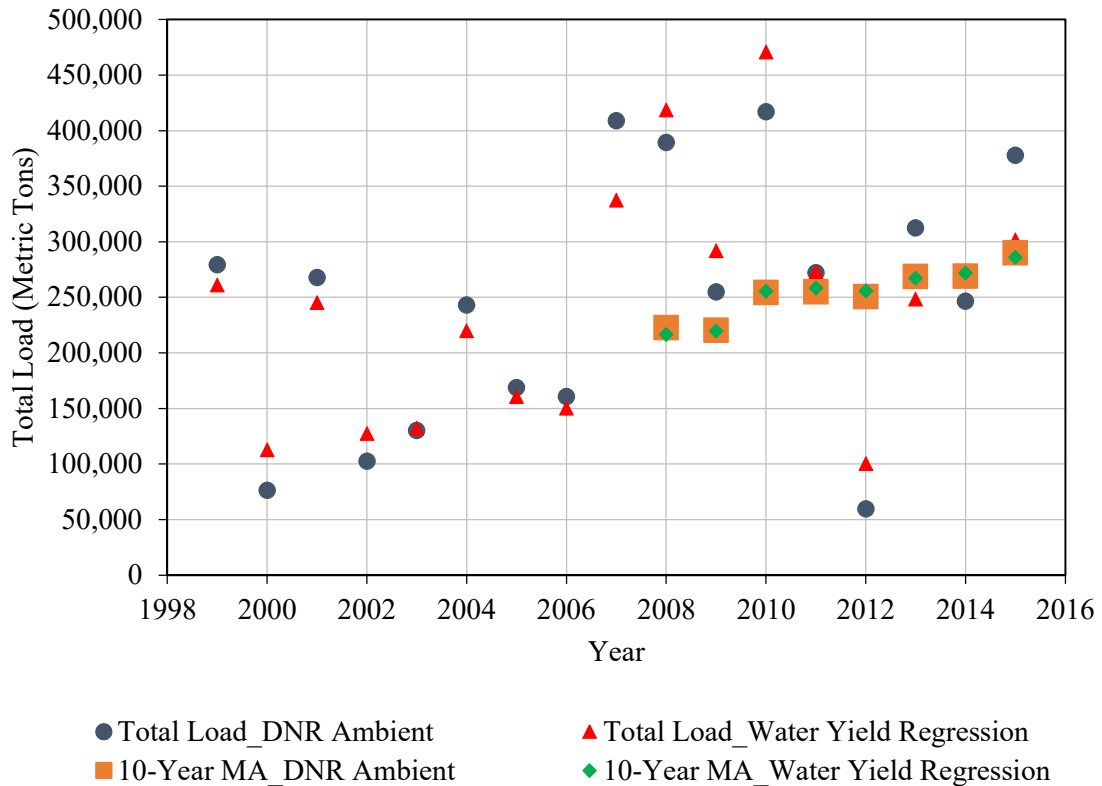
*Figure 14: Statewide DNR ambient load compared to water yield regression load.*

The temporal regression equations report the load in metric tons (Mg/year), which can be used to estimate the statewide annual load. However, predicting yield is also valuable. The load regression can be converted into a yield regression (kg/ha/year) by multiplying both regression parameters by ten and dividing both by the upstream area in $km^2$. Scatterplots of the simulation 5 regression yield versus DNR ambient yield for each of the 23 main study basins can be found in Appendix D. A list of load and yield regression equations (simulations 2, 3, 4, and 5) for all 62 subbasins and their associated $R^2$ values are found in Appendix E.

Using the developed regression equations for each basin, nitrate loads can be estimated prior to when DNR ambient data was collected. However, this is only applicable as long as land use is assumed constant. The regression equations are limited

because the regression equations were fit to data from 1999 to 2015 when land use was assumed to be constant. Historical land use acreages were obtained from the United States Department of Agriculture (USDA) Census of Agriculture Historical Archive database (available at: http://agcensus.mannlib.cornell.edu/AgCensus/homepage.do). The acreages of main land use were plotted for Iowa from 1950 to 1982 in Figure 15.
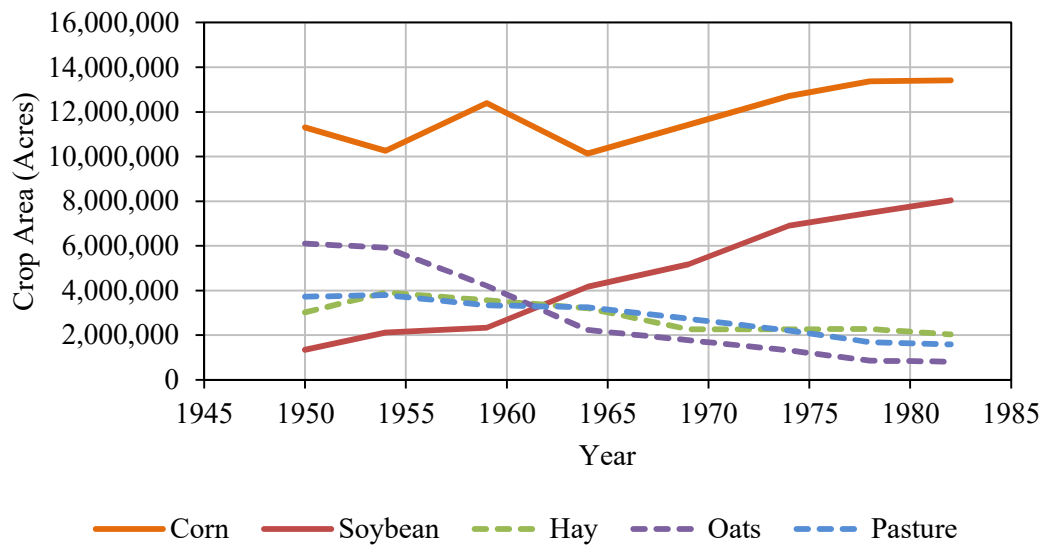


*Figure 15: Iowa crop acreage from 1950 to 1982.*

As seen in Figure 15, the land use transitioned from corn, soybean, hay, oats, and pasture to predominately corn and soybean around the 1970s. Because of this restriction, the water yield regression equations can be used to estimate historical nitrate loads back to around the 1970s.

Additional streamflow data was downloaded from 1965 to 2016 at the 23 main study sites to calculate annual water yield. These annual water yields were then used to calculate annual nitrate load estimates with the developed regression equations for each main basin. The annual load estimates from 1965 to 2016 for all 23 main sites were used to extrapolate annual statewide nitrate loads. Streamflow data from 2016 was included in

this analysis to get a preliminary estimate for the 2016 statewide nitrate load. Figure 16 shows the 1965 to 2016 statewide water yield regression nitrate load estimate time series and 10-year moving average.

The 2016 water yield at the 23 main sites resulted in a statewide load estimate of 393,398 Mg (433,646 tons). The 2016 DNR ambient load was 513,788 Mg (566,354 tons). The 2016 regression equation underestimated the DNR ambient load by 23.4 percent. However, the 10-year moving average of the regression statewide load estimate (310,197 Mg) was only 4.6 percent less than the DNR ambient 10-year moving average (325,283 Mg).
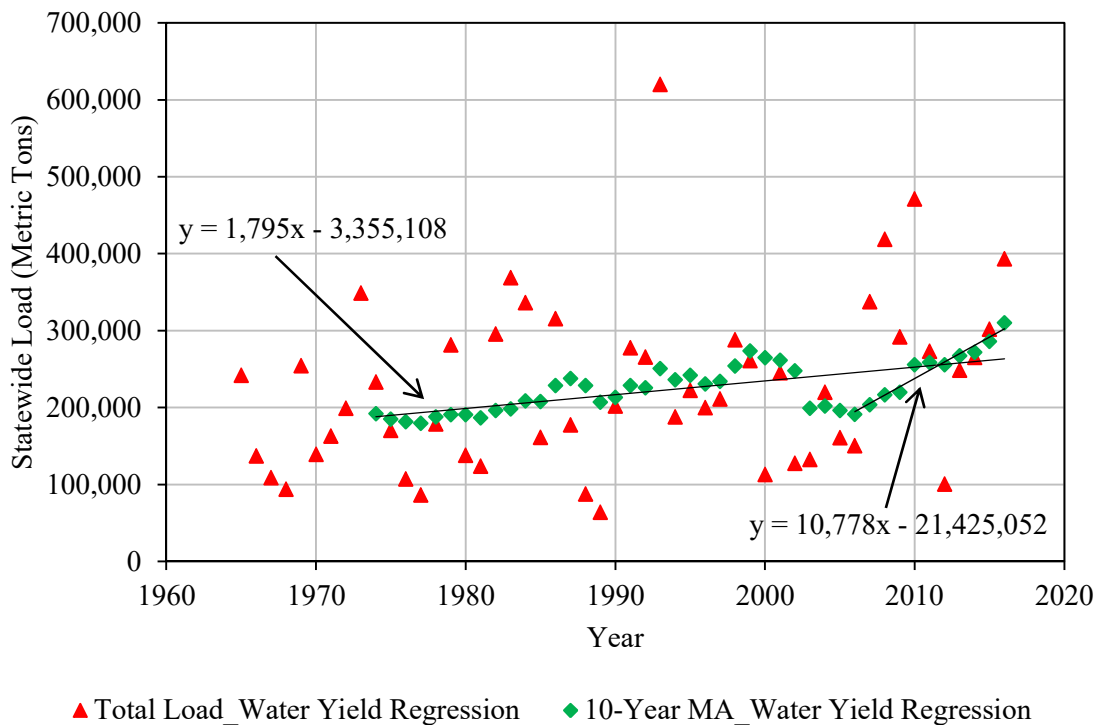


*Figure 16: 1965-2016 statewide water yield regression nitrate load estimate time series with 10-year moving average.*

Figure 16 indicates that the nitrate loads have been increasing over the long-term and increasing at a higher rate from 2006 to 2016. From 2006 to 2016 the slope of the

trend line through the 10-year moving average nitrate load increased to 10,778 Mg/year. Whereas, from 1965-2016 the slope of the 10-year moving average was 1,795 Mg/year.

*MLRA Temporal Regression*

The previous section indicated that regression equations can be used to predict annual load in each watershed. In this section, the potential for predicting the parameters (m and b) in the regression equation (y = mx + b) based on their location is explored.

All 62 subbasin regression equations were used to formulate regression equations that describe each MLRA. The 62 subbasins were divided up and placed within an MLRA that included most of the drainage area. Initially, landform regions across Iowa were used to divide up the watersheds, but they were too coarse to adequately describe the variability in regression parameters. The MLRAs divided up the watersheds into smaller regions which created better clustering of similar regression equations. Further divisions were necessary to cluster similar watersheds. The MLRA called "Central Iowa and Minnesota Till Prairies," known more commonly as the Des Moines Lobe, was divided into a north and south subregion. The MLRA called "Eastern Iowa and Minnesota Till Prairies," known more commonly as the Iowan Surface, was divided into an east and west subregion. Figure 17 shows the MLRA region locations and names. The subbasins that were used to fit regional regression equations in each MLRA region can be found in Appendix F.
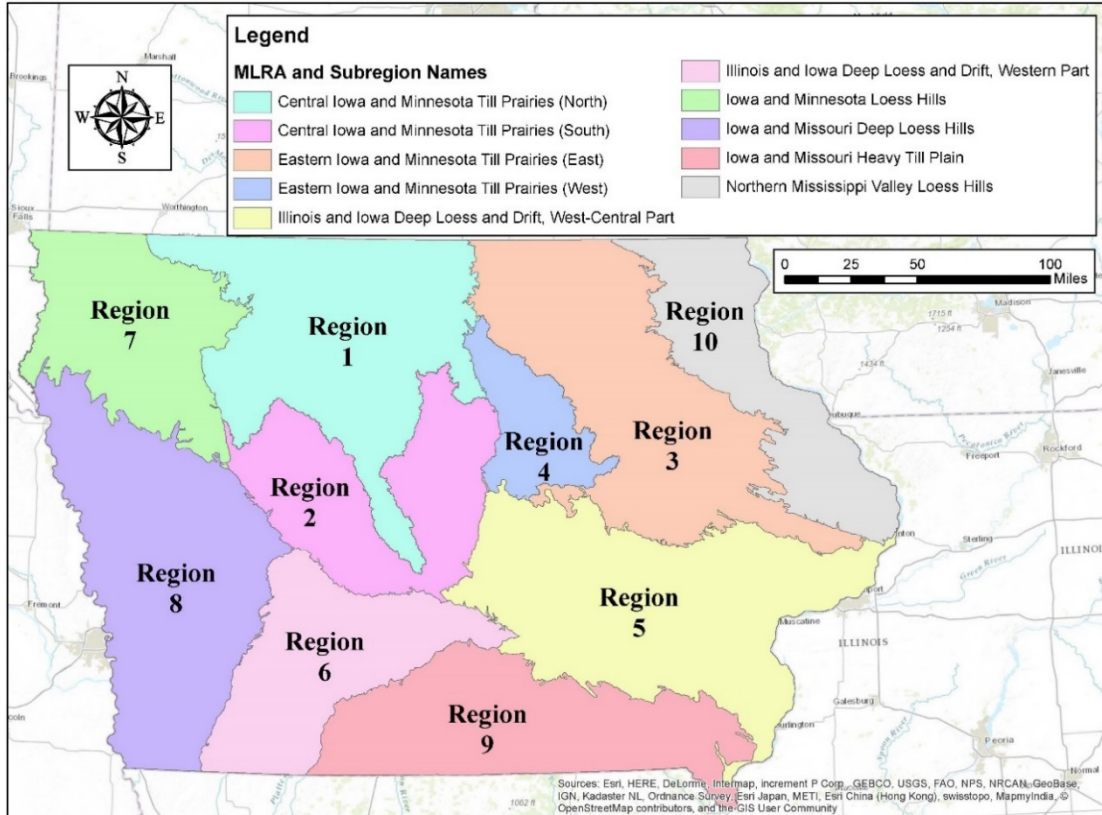
*Figure 17: MLRA region numbering and names.*

Each MLRA regression equation was found using combinations of percent row crop, percent manure, and percent tiled soils. The combination of variables with the highest adjusted $R^2$ was used to predict the water yield regression intercept (b) and slope (m). The necessary variables for each MLRA region to predict the water yield intercept (b) are shown in Figure 18. Similarly, the variables for the water yield slope (m) are shown in Figure 19. Table 6 and Table 7 list the regression equations for each MLRA identified in Figure 18 and Figure 19, respectively.
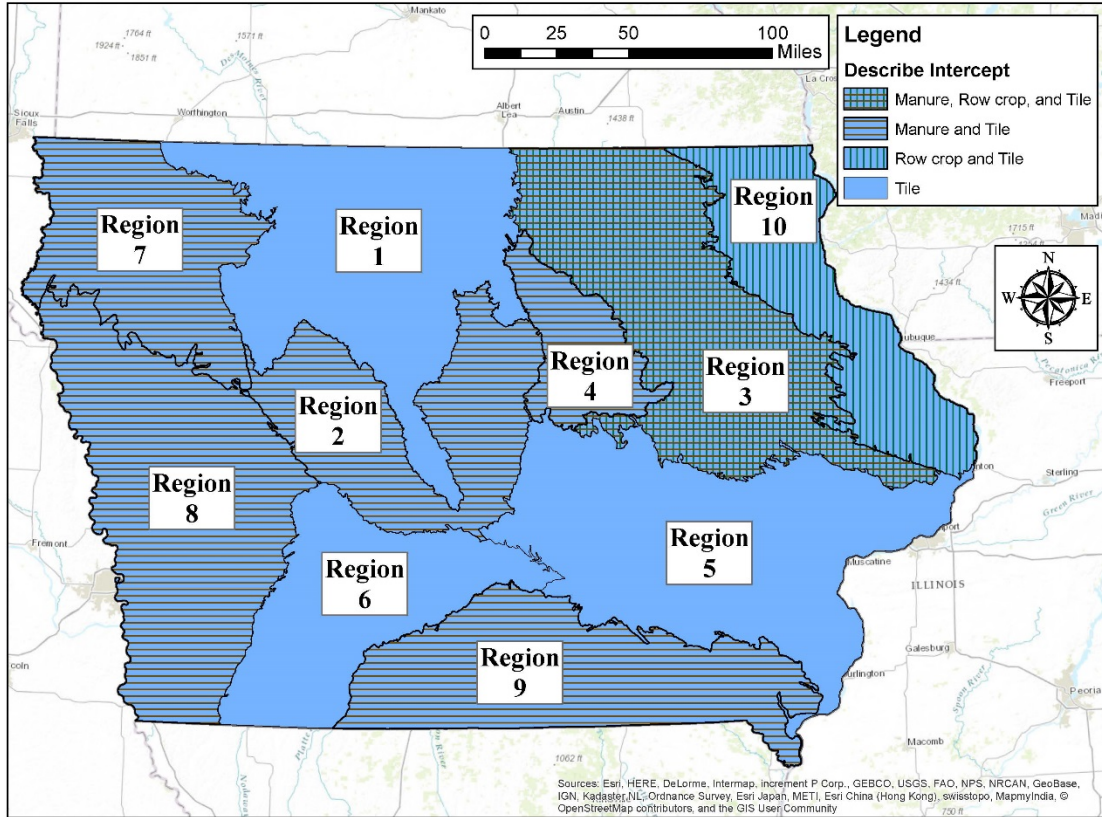
*Figure 18: Variables needed to predict water yield regression intercept (b).*

*Table 6: MLRA regression equations for intercept (b). With adjusted $R^2$.*

| MLRA Region # | Intercept (b) Regression Equation | Adjusted $R^2$ |
|---|---|---|
| 1 | $b = -21.1 + 37.2 \cdot x_1$ | 0.669 |
| 2 | $b = -9.9 - 15.4 \cdot x_1 + 36.0 \cdot x_3$ | 0.683 |
| 3 | $b = 88.9 + 41.4 \cdot x_1 - 146.0 \cdot x_2 + 23.0 \cdot x_3$ | 0.198 |
| 4 | $b = -6.7 - 32.3 \cdot x_1 + 33.4 \cdot x_3$ | 0.920 |
| 5 | $b = -0.2 + 13.6 \cdot x_3$ | 0.558 |
| 6 | $b = -2.9 + 51.3 \cdot x_3$ | 0.872 |
| 7 | $b = -5.4 - 2.7 \cdot x_1 + 14.4 \cdot x_3$ | 0.945 |
| 8 | $b = -0.3 - 30.7 \cdot x_1 + 33.0 \cdot x_3$ | 0.865 |
| 9 | $b = -1.7 + 26.7 \cdot x_1 + 17.4 \cdot x_3$ | 0.970 |
| 10 | $b = 10.2 - 30.1 \cdot x_2 + 19.3 \cdot x_3$ | 0.399 |
| **Where $x_1$ = % manure, $x_2$ = % row crop, and $x_3$ = % tiled soils** | | |
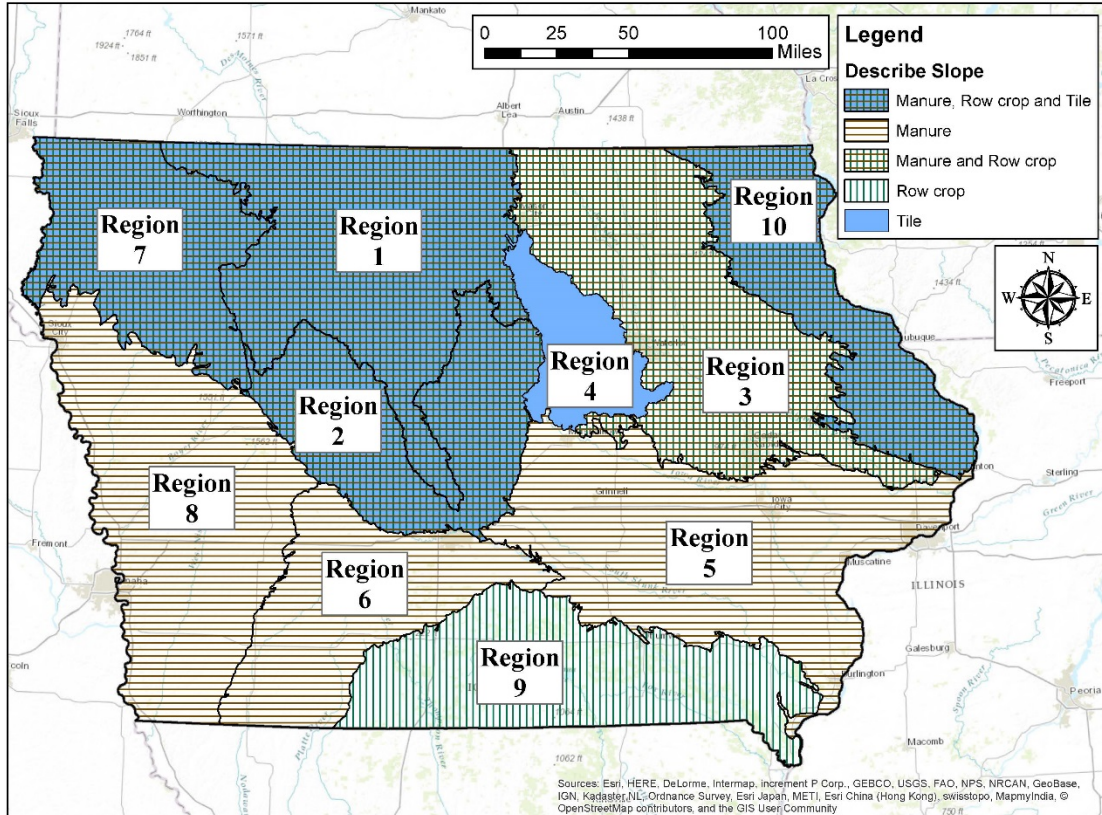
*Figure 19: Variables needed to predict water yield regression slope (m).*

*Table 7: MLRA regression equations for slope (m). With adjusted $R^2$.*

| MLRA Region # | Slope (m) Regression Equation | Adjusted $R^2$ |
|---|---|---|
| 1 | $m = -0.640 - 0.197*x_1 + 1.327*x_2 - 0.430*x_3$ | 0.578 |
| 2 | $m = -0.017 + 0.110*x_1 + 0.202*x_2 - 0.179*x_3$ | 0.912 |
| 3 | $m = -0.537 - 0.271*x_1 + 0.882*x_2$ | 0.511 |
| 4 | $m = 0.111 - 0.044*x_3$ | 0.538 |
| 5 | $m = 0.067 - 0.113*x_1$ | 0.651 |
| 6 | $m = 0.014 + 0.407*x_1$ | 1.000 |
| 7 | $m = -0.193 + 0.037*x_1 + 0.410*x_2 - 0.125*x_3$ | 0.892 |
| 8 | $m = 0.017 + 0.485*x_1$ | 0.914 |
| 9 | $m = -0.007 + 0.681*x_2$ | 0.985 |
| 10 | $m = -0.014 + 0.177*x_1 + 0.178*x_2 - 0.128*x_3$ | 0.979 |
| **Where $x_1$ = % manure, $x_2$= % row crop, and $x_3$ = % tiled soils** | | |

Figure 18 and Figure 19 show the significant increase in adjusted $R^2$ for

predicting both the regression intercept and slope after further subdividing the Des

Moines Lobe and Iowan Surface. Before the Des Moines Lobe was subdivided into north

and south subregions, the adjusted $R^2$ value to predict the regression intercept (b) was

0.235. This was improved to 0.669 in the north subregion and 0.683 in the south. The

adjusted $R^2$ value to predict the regression slope (m) was 0.365. This was improved to

0.578 in the north subregion and 0.912 in the south. Before the Iowan Surface was

subdivided into east and west subregions, the adjusted $R^2$ value to predict the regression

intercept (b) was 0.033. This was improved to 0.198 in the east subregion and 0.920 in

the west. The adjusted $R^2$ value to predict the regression slope (m) was 0.300. This was

improved to 0.511 in the east subregion and 0.538 in the west.

Some of the MLRA regions in the southwest corner of the state showed very high

adjusted $R^2$ values. Though the predictability of the regression equations is likely still

high, $R^2$ values of 0.99 or higher seem unrealistic. The MLRA regression equations in

these regions were each developed based on either three or four watersheds. The $R^2$

values were especially high in MLRAs with only three watersheds.

These MLRA equations may be useful in gaged locations with shorter water

quality records. Inputting the necessary land use variables, a watershed could be

delineated within an MLRA region and a regression equation could be developed to

predict annual nitrate yield by using water yield data. Necessary conversions would need

to be applied in order to convert the MLRA output nitrate yield (kg/ha) equation to a load

(Mg) equation. The regional MLRA regression equations could also be beneficial for

ungaged basins. In ungaged locations, regional streamflow regression equations from the

USGS could potentially be used to estimate water yield. However, further research would need to be performed to evaluate the accuracy of the nitrate load regressions at ungaged sites using water yield estimates from regional streamflow regression equations.

The MLRA regional regression equations were validated by comparing the regression yield and DNR ambient yield from the 23 main study basins. Rather than identifying how the MLRA performed each water year, the 17-year average water yield was input into each main study basin MLRA regression equation. This was then compared to the 17-year average nitrate yield from the DNR ambient data. Figure 20 shows how well the MLRA regression and DNR ambient yield compared from each of the 23 main study basins. Blue points on the red line correspond to the model agreeing with DNR ambient estimations.
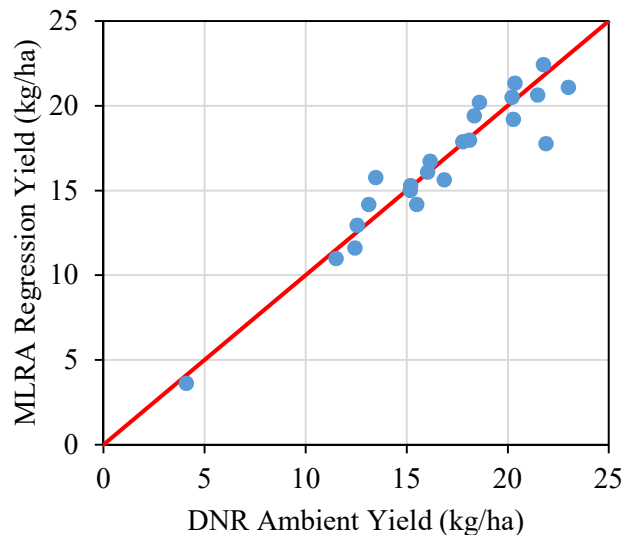


*Figure 20: MLRA regression validation plot.*

Figure 20 shows that the MLRA regression equations provide a reasonable estimate for predicting average nitrate yield. The MLRA regional equations cannot perfectly predict the developed temporal regression parameters, therefore the temporal

regression equations are the most reliable to provide accurate annual nitrate loads. For this reason annual statewide nitrate loads should be calculated using the temporal regression equations rather than the MLRA regional prediction of those equations.

The MLRA regional equations can be used to develop temporal equations to predict year-to-year variability in nitrate loads or yields for an individual watershed. Additionally, the long-term average water yield could be applied to the MLRA equations to predict the long-term average nitrate yield. The MLRA equations may provide a better long-term average nitrate yield estimate than the statewide spatial equation discussed earlier. This is because the MLRA equations better account for differences across the state in land description variables like percent row crop and tiled soils. The spatial statewide equation provided a general fit and assumed that the land was more uniform.

Summary

Statewide nitrate loads were calculated using DNR ambient nitrate data. The 10-year moving average through the annual statewide nitrate loads revealed that nitrate loads have been increasing at a steady rate from 2008 to 2015. A 10-year moving average for all subbasins studied showed that the nitrate loads in the southwest corner of Iowa have been increasing more rapidly than other areas throughout the state. Average nitrate yields were also calculated for all 62 subbasins. Regression equations were fit to DNR ambient nitrate data to formulate spatial and temporal regression equations. Percent row crop and water yield describe 78.4 percent of the variability in spatial average nitrate yield. Water yield was also selected as the preferred hydrologic variable to predict annual nitrate loads within each subbasin. On average, water yield accounts for 88 percent of the variability in annual nitrate loads. The water yield regression equations were used to estimate the

annual statewide nitrate loads. These regression estimates provide similar 10-year moving average loads as DNR ambient load calculations. The regression equations are important to both monitor and to quantify load reductions. Regional MLRA regression equations were also developed to predict parameters in the temporal water yield regression equations. These regional equations can be used to estimate annual or long-term nitrate yields or loads in ungaged basins.

# CHAPTER 5: DNR AMBIENT NETWORK COMPARED TO REAL-TIME CONTINUOUS DATA RESULTS AND DISCUSSION

Accurate nitrate concentration measurements are important to refine statewide nitrate load calculations to track the nutrient reductions corresponding to the INRS goals. Uncertainty in statewide nitrate load estimates from monthly nitrate grab samples introduces uncertainty in load reduction estimates. Collection of higher resolution nitrate concentrations provides more reliable data and leads to more accurate load reduction estimates.

<u>Background</u>

IIHR—Hydroscience and Engineering (IIHR) at the University of Iowa maintains a network of high-resolution continuous water quality sensors. The data is published through the Iowa Water Quality Information System (IWQIS), also maintained by IIHR. In addition to IIHR's sensor network, some USGS gaging stations record continuous water quality data, including nitrate concentrations. This data is also integrated into the IWQIS database. Most of the continuous sensors in the IWQIS network only report data collected from 2012 to present. Due to ice and other maintenance issues, including instrument calibration and cleaning, the water quality sensors are typically deployed from March to November. The USGS sensors evaluate water quality every fifteen minutes. The IIHR sensors evaluate water quality every five minutes and transmit data back to IIHR every fifteen minutes. The IIHR sensors detect nitrate concentrations using ultraviolet (UV) light. Increased UV absorption levels correspond to increased nitrate concentrations (Weber, Jones, & Davis, 2016).

The nitrate concentrations from IWQIS were downloaded to compare nitrate loads between the continuous sensor network and the DNR ambient network for the available time in which they overlapped. Figure 21 shows the location of comparable IWQIS and DNR ambient sites.
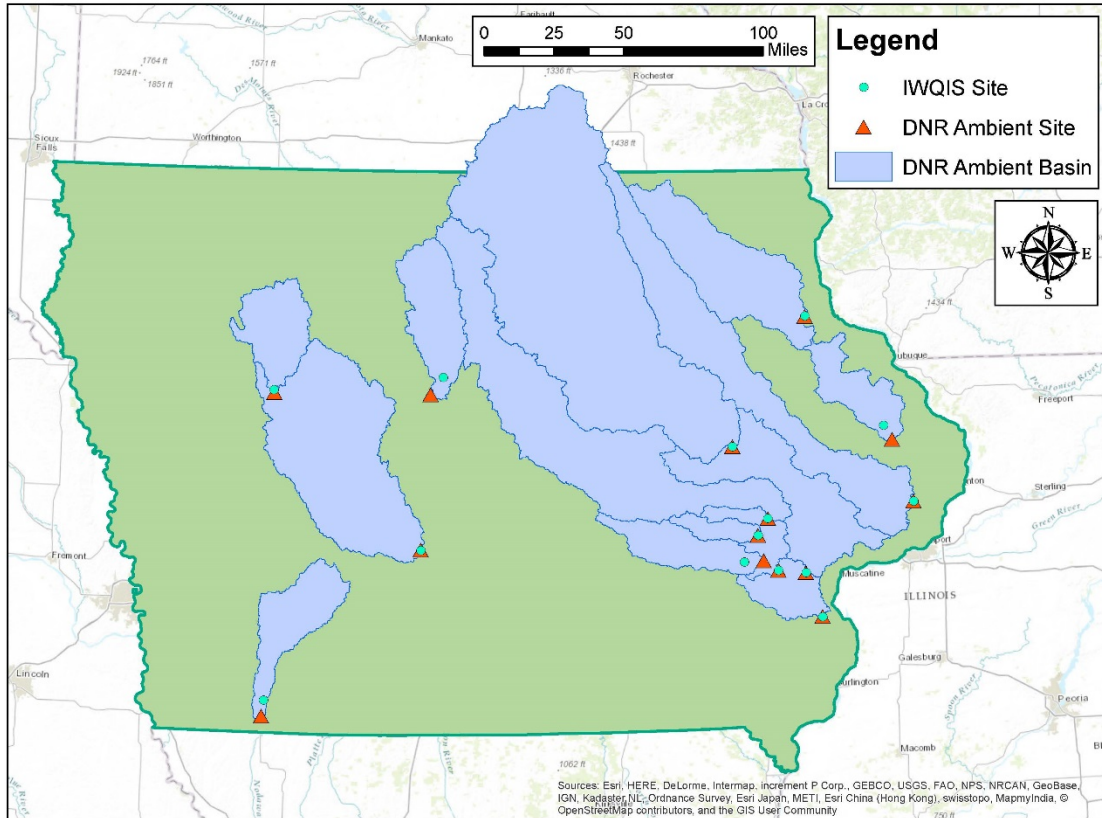


*Figure 21: IWQIS site comparison study area.*

The high-resolution continuous water quality sensors operated by IIHR and USGS better capture the day-to-day variability in nitrate levels. Monthly sampling from the DNR ambient network is unable to show day-to-day variability in nitrate levels because samples are collected at a much lower frequency. Figure 22 shows an example time series of the nitrate concentrations between the two networks. The resulting nitrate loads are

shown in Figure 23. These figures show how DNR ambient loads usually miss the peaks captured by IWQIS.
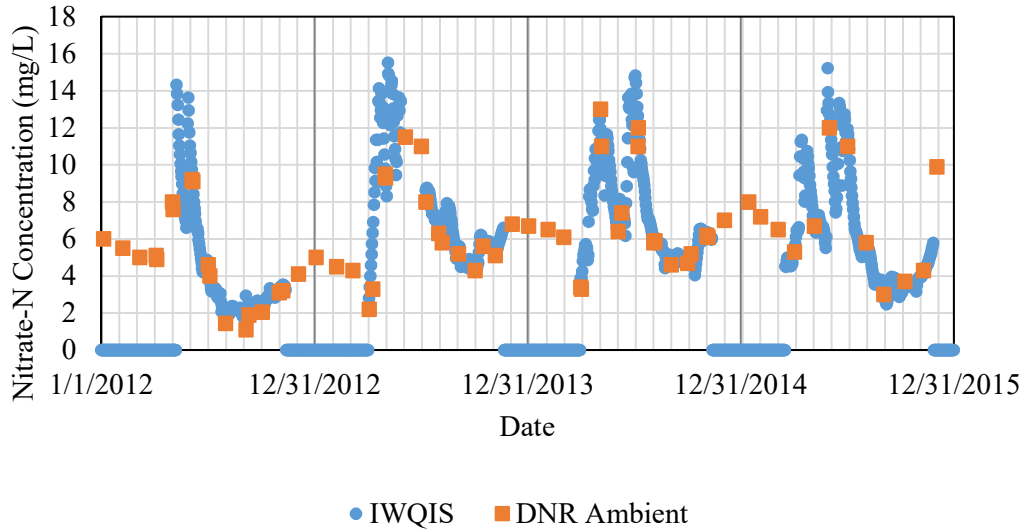


*Figure 22: Nitrate concentration time series for the Turkey River near Garber, IA.*
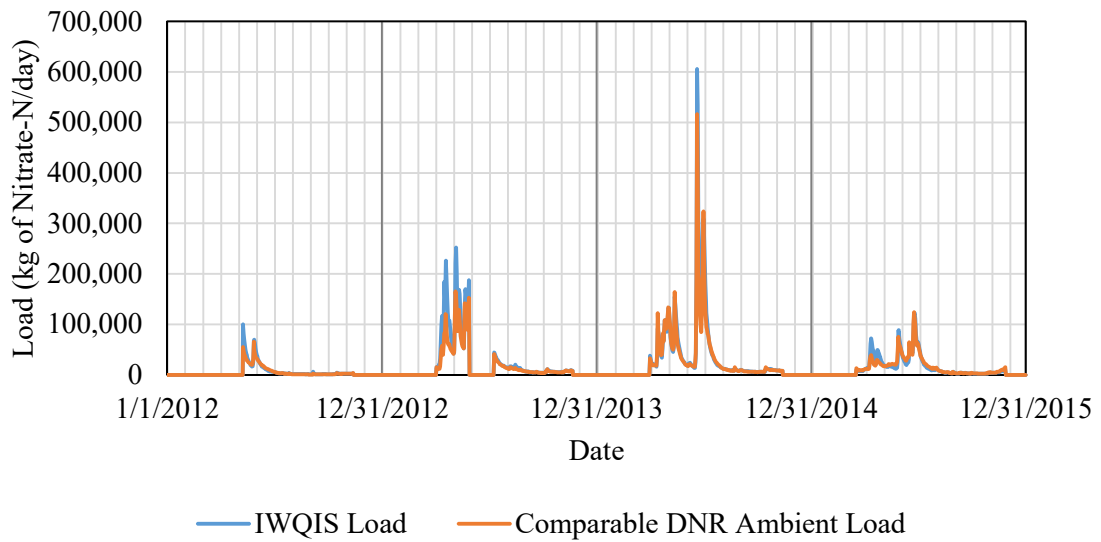


*Figure 23: Nitrate load time series for Turkey River near Garber, IA.*

From the analysis done in Chapter 4, the DNR ambient monthly data was linearly interpolated to a daily resolution. In order for the networks to be compared, they need to be at the same temporal scale. Nitrate concentrations collected every five to fifteen

minutes from the IWQIS network were averaged to obtain mean daily concentrations. Periodically the water quality sensors on the IWQIS network had data gaps ranging from a couple of days up to a month or more. Linear interpolation was used to interpolate the missing nitrate concentrations during these intermittent periods. The daily IWQIS average nitrate concentrations were then multiplied by the same USGS gage streamflow to obtain a daily nitrate load. The daily loads were then summed into monthly, annual, and period-of-record totals.

A percent difference was used to compare DNR ambient loads to IWQIS loads. The percent difference between DNR ambient data and IWQIS can be calculated using the appropriate equation below. Ideally, the percent difference would be around zero percent, indicating that both networks provide similar nitrate loads. The percent difference was calculated for seasonal, annual, and period-of-record (POR) loads.

*Equation 5: Active season (April – July) percent difference calculation.*

$$Active\ Season\ Percent\ Difference\ (\%) = \left| 100\% - \frac{\sum_{Month} DNR\ Ambient\ Load}{\sum_{Month} IWQIS\ Load} \right|$$

*Equation 6: Annual percent difference calculation.*

$$Annual\ Percent\ Difference\ (\%) = \left| 100\% - \frac{\sum_{Annual} DNR\ Ambient\ Load}{\sum_{Annual} IWQIS\ Load} \right|$$

*Equation 7: Period-of-record percent difference calculation.*

$$POR\ Percent\ Difference\ (\%) = \left| 100\% - \frac{\sum_{POR} DNR\ Ambient\ Load}{\sum_{POR} IWQIS\ Load} \right|$$

The daily scatterplot, shown in Figure 24, compares daily loads between IWQIS and DNR ambient data. Significant linear deviations, like those seen on either side of the red line in Figure 24, show the daily variability between the two networks. During a storm event DNR ambient nitrate loads could deviate from IWQIS loads by two to three times. As discussed earlier, this is a result of using low-resolution nitrate concentration data that typically does not capture the peak concentrations during a storm event.
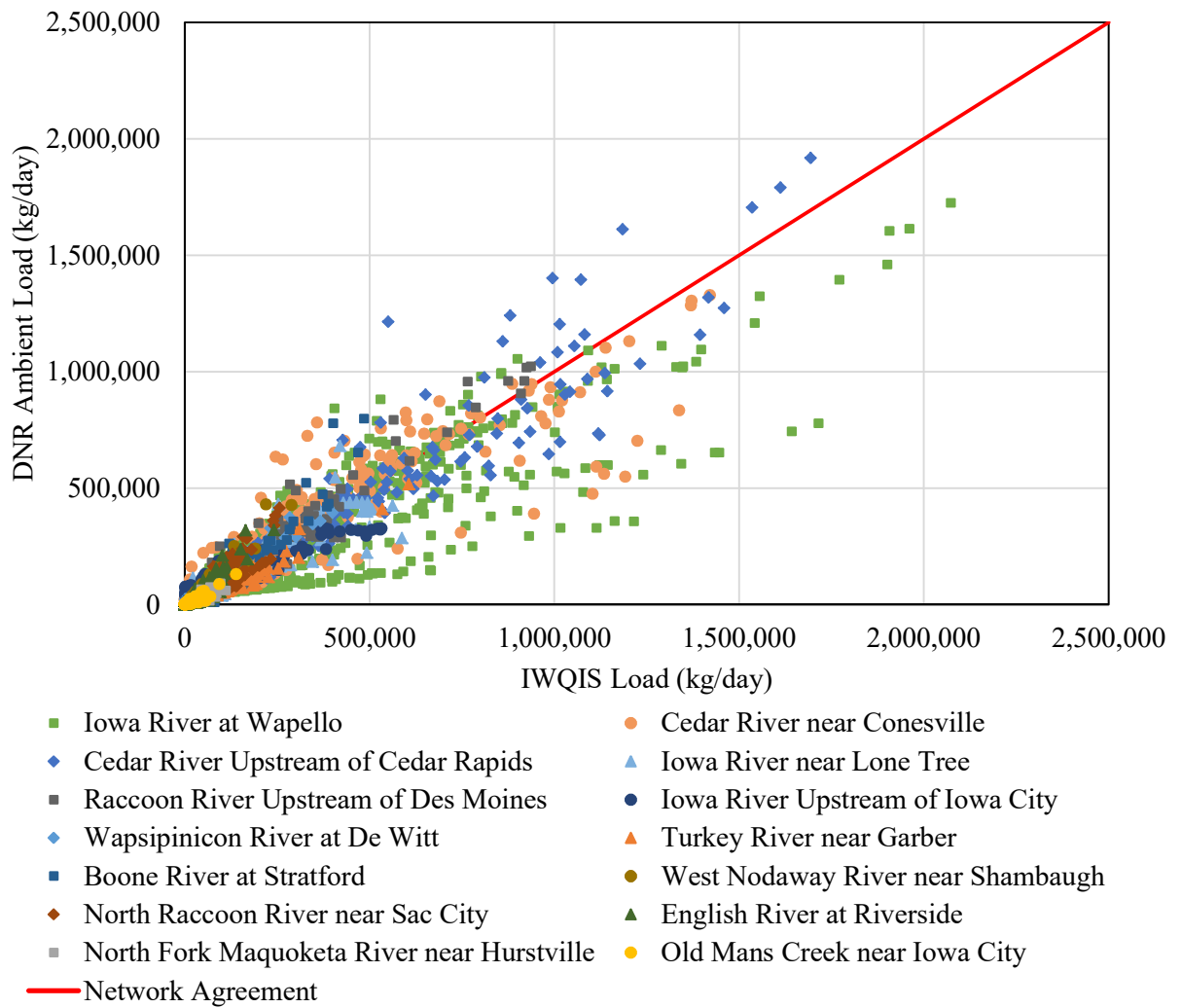


*Figure 24: Daily nitrate load comparison scatterplot.*

## Monthly and Seasonal Variability

The total monthly load graph, shown in Figure 25, shows that there is better agreement between the two networks on a monthly scale. The higher loads, and those that most deviate from the red line, generally occur during the active season. This shows the DNR ambient loads may not be reliable during the most important time of the year, from spring to early fall.



Legend:
- Iowa River at Wapello
- Cedar River Upstream of Cedar Rapids
- Raccoon River Upstream of Des Moines
- Wapsipinicon River at De Witt
- Boone River at Stratford
- North Raccoon River near Sac City
- North Fork Maquoketa River near Hurstville
- Cedar River near Conesville
- Iowa River near Lone Tree
- Iowa River Upstream of Iowa City
- Turkey River near Garber
- West Nodaway River near Shambaugh
- English River at Riverside
- Old Mans Creek near Iowa City
- Network Agreement

*Figure 25: Monthly nitrate load comparison scatterplot.*

When IWQIS data is available it provides more accurate load estimations, especially during the active season. From the remaining comparable data outside of the active season, the DNR ambient data produce similar nitrate loads to those calculated from IWQIS data.

Table 8 shows the seasonal average percent difference, calculated from Equation 5, between DNR ambient loads and IWQIS during the active season. The numbers in red indicate negative values, which represent the IWQIS load being less than the DNR ambient load during the active season. The absolute value for each site was averaged for each year to obtain an annual average active season percent difference.

*Table 8: Active season percent difference. Numbers in red indicate negative values. The average is the average of absolute values.*

| Site | 2012 | 2013 | 2014 | 2015 | Average |
|---|---|---|---|---|---|
| Turkey River near Garber | 12.9% | 29.2% | 9.4% | 4.6% | 14.0% |
| North Fork Maquoketa River near Hurstville | 0.5% | 8.5% | 47.9% | - | 19.0% |
| Wapsipinicon River at De Witt | - | - | - | 0.6% | 0.6% |
| Cedar River near Conesville | 85.8% | 9.1% | 33.4% | 13.1% | 35.4% |
| Cedar River Upstream of Cedar Rapids | - | 3.3% | 2.4% | - | 2.9% |
| Iowa River near Lone Tree | 9.2% | 1.6% | 27.3% | 0.8% | 9.7% |
| English River at Riverside | 8.3% | 24.6% | 11.7% | 1.2% | 11.5% |
| Old Mans Creek near Iowa City | 9.8% | 4.5% | 54.8% | 3.9% | 18.3% |
| Iowa River Upstream of Iowa City | - | 18.7% | 4.6% | - | 11.7% |
| Raccoon River Upstream of Des Moines | 21.4% | 9.4% | 24.0% | - | 18.3% |
| North Raccoon River near Sac City | 16.3% | 13.1% | 7.3% | 14.5% | 12.8% |
| Boone River at Stratford | 15.2% | 13.9% | 0.4% | 10.8% | 10.1% |
| West Nodaway River near Shambaugh | 32.2% | 14.6% | 3.9% | 0.8% | 12.9% |
| Iowa River at Wapello | 19.4% | - | - | 17.0% | 18.2% |
| **Annual Average Residual** | 21.0% | 12.5% | 18.9% | 6.7% | 14.8% |

The mean of each annual average indicated that DNR ambient loads were approximately 15 percent different than IWQIS during the active season. During 2012 to

2015 the minimum difference was 0.4 percent (Boone River at Stratford) and the maximum difference was as high as 85.8 percent (Cedar River near Conesville). This is a significant difference between the two networks.

Annual Variability

Table 9 shows the annual percent difference, calculated from Equation 6, between the total available nitrate loads from DNR ambient and IWQIS data during a comparable time frame for a given year. The comparable time frame was not a complete year because high-resolution sensors are not deployed during the winter. The comparable time frame was typically March through October. The numbers in red indicate negative values, which represent the IWQIS load being less than the DNR ambient load. The average is the average of absolute values for each site.

*Table 9: Annual percent difference. Numbers in red indicate negative values. The average is the average of absolute values.*

| Site | 2012 | 2013 | 2014 | 2015 | Average |
|---|---|---|---|---|---|
| Turkey River near Garber | 13.8% | 27.0% | 8.8% | 2.4% | 13.0% |
| North Fork Maquoketa River near Hurstville | 1.7% | 7.2% | 40.2% | | 16.4% |
| Wapsipinicon River at De Witt | | | | 1.2% | 1.2% |
| Cedar River near Conesville | | 9.9% | 28.4% | 14.6% | 17.6% |
| Cedar River Upstream of Cedar Rapids | | 4.0% | 1.8% | | 2.9% |
| Iowa River near Lone Tree | 8.1% | 1.8% | 22.5% | 1.3% | 8.4% |
| English River at Riverside | 7.9% | 24.6% | 3.0% | 2.7% | 9.5% |
| Old Mans Creek near Iowa City | 12.0% | 4.6% | 49.1% | 5.0% | 17.7% |
| Iowa River Upstream of Iowa City | 21.5% | 18.7% | 3.8% | | 14.6% |
| Raccoon River Upstream of Des Moines | 18.8% | 9.3% | 16.3% | | 14.8% |
| North Raccoon River near Sac City | 21.3% | 18.4% | 13.9% | 1.9% | 13.9% |
| Boone River at Stratford | 15.4% | 13.8% | 1.9% | 7.0% | 9.5% |
| West Nodaway River near Shambaugh | 31.6% | 13.7% | 3.8% | 1.5% | 12.7% |
| Iowa River at Wapello | 19.0% | | | 21.5% | 20.3% |
| **Annual Average Difference** | 15.6% | 12.7% | 16.1% | 5.9% | 12.6% |

The mean annual average percent difference between the two networks was 12.6 percent. During 2012 to 2015 the minimum was 1.2 percent (Wapsipinicon River at De Witt) and the maximum was 49.1 percent (Old Mans Creek near Iowa City). Though the percent difference improved from the active season, the prospect of DNR ambient data producing a load potentially 50 percent different from IWQIS is significant enough to merit the collection of nitrate data using continuous sensors.

Period-of-Record Variability

Table 10 shows the period-of-record percent difference, calculated from Equation 7, for each of the 14 sites studied. The numbers in red indicate negative values, which represent the IWQIS load being less than the DNR ambient load. The average is the average of absolute values for each site.

*Table 10: Period-of-record percent difference. Numbers in red indicate negative values. The average is the average of absolute values.*

| Site | Percent Difference |
|---|---|
| Turkey River near Garber | 13.6% |
| North Fork Maquoketa River near Hurstville | 21.6% |
| Wapsipinicon River at De Witt | 1.2% |
| Cedar River near Conesville | 4.2% |
| Cedar River Upstream of Cedar Rapids | 1.7% |
| Iowa River near Lone Tree | 5.5% |
| English River at Riverside | 9.9% |
| Old Mans Creek near Iowa City | 17.2% |
| Iowa River Upstream of Iowa City | 11.2% |
| Raccoon River Upstream of Des Moines | 1.3% |
| North Raccoon River near Sac City | 1.8% |
| Boone River at Stratford | 3.9% |
| West Nodaway River near Shambaugh | 5.1% |
| Iowa River at Wapello | 11.4% |
| **Period-of-Record Average** | 7.8% |

The absolute value percent difference for the period-of-record data set was 7.8 percent. During 2012 to 2015 the minimum was 1.2 percent (Wapsipinicon River at De Witt) and the maximum was 21.6 percent (North Fork Maquoketa River near Hurstville). This indicates that a long-term load export sum reduces the variability between the two networks. The nitrate load differences between the two networks at seasonal and annual scales underscores the utility of using more accurate data provided by high-resolution water quality sensors.

The absolute value of the data from Table 10 was plotted versus upstream area. Figure 26 shows that the percent difference between the two networks leveled out as watershed area increased, but it did not converge to a specific value. The wide range of percent difference for all the compared basins further justifies the use of continuous water quality sensors. This is especially true in smaller basins where DNR ambient data can largely deviate from IWQIS. Part of the wide range of percent difference among smaller basins can be explained by watershed hydrology. Streamflow in smaller watersheds is much more variable and flashy, whereas larger watersheds show much more smooth and gradual hydrographs.
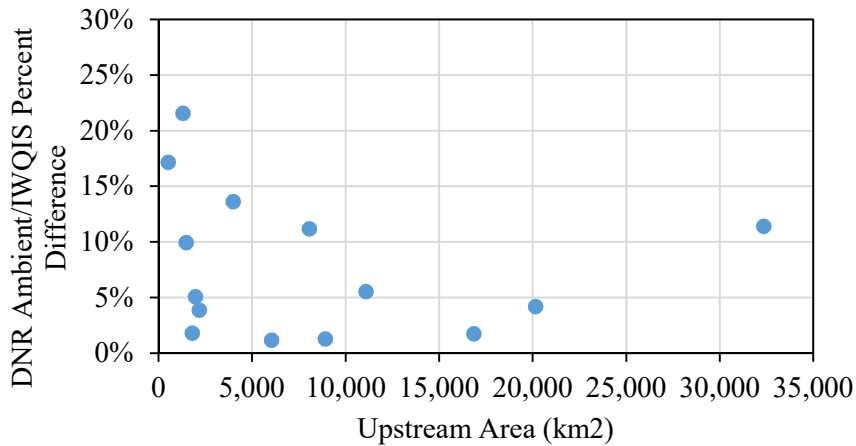
*Figure 26: Period-of-record percent difference vs. upstream area (km²).*

Calculation of statewide nitrate loads using DNR ambient data in large watersheds may not be substantially different than the loads calculated using IWQIS data. However, for basins smaller than a HUC 8, annual loads calculated using DNR ambient data have a greater risk of deviating significantly from loads calculated using IWQIS data. Statewide nitrate load estimates could be improved by replacing DNR ambient nitrate loads with IWQIS loads when data is available.

Summary

The figures and tables presented in this chapter show that interpolated DNR ambient data does not compare well to IWQIS on a daily time scale and significantly differs from IWQIS during the highest loading periods of April through July. DNR ambient data produces similar load estimates over a long-term, but has lower comparability to IWQIS at shorter temporal scales (i.e. seasonal/monthly scales). Accurate nitrate concentration collection or estimation is needed to better quantify statewide nitrate loads.

# CHAPTER 6: LIMITATIONS AND IMPLICATIONS

The regression models developed in Chapter 4 have weaknesses and limitations because they cannot perfectly replicate reality. The limitations of these models will be discussed. Possible ways to improve the models will also be considered. Despite model limitations, these developed regression equations have important implications that may simplify the process of tracking nutrient load reductions.

<u>Limitations</u>

The linear regression equations presented in this study were fit to annual nitrate load estimates. This limits regression load estimates to an annual scale, instead of daily, monthly, or seasonal nitrate load predictions. Additional regression analyses would need to be done to obtain load predictions at different temporal scales.

The study also assumed land use remained constant throughout the study period. Though this is relatively safe to assume, the regression equations are also limited by changing land use and especially implementation of conservation practices. For example, more widespread use of cover crops, saturated buffers, or wetlands could allow for more nitrate processing. This would cause nitrate loading patterns to change. The developed regression equations would not fit well if future land use or conservation practices deviate from historic conditions.

The spatial and temporal regression equations could be improved if they were generated using high-resolution nitrate data. The DNR ambient data was shown to vary widely from the high-resolution IWQIS data during spring to early fall which typically

corresponds to the highest nitrate loading period throughout the year. This could impact the integrity of the DNR ambient annual statewide nitrate export.

<u>Result Implications</u>

Despite the limitations of the spatial and temporal models, they provide insight into variables that most influence average nitrate yield and annual nitrate load. They can also be used to provide preliminary estimates of nitrate yields and loads in sampled basins.

Adequate land description coverages are available to obtain and process data to output percent row crop, percent manure, and percent tiled soils. A temporal nitrate yield equation from MLRA regional regression equations can be estimated using the generated land description variables. Additionally, USGS streamflow is collected at a high-resolution and aggregated into a daily mean streamflow available the next day. This provides an efficient way to calculate annual water yield in basins necessary to estimate statewide nitrate loads. The statewide nitrate load can then be extrapolated by January 1$^{st}$ of the following year of interest. Conversely, DNR ambient data may take until February or March before enough data is available to estimate a statewide nitrate load. Rapid calculation of the annual statewide load allows stakeholders more time to evaluate, make decisions, and set goals corresponding to nutrient reduction objectives for the upcoming year.

The spatial regression equations do not supply any information about yearly variability in nitrate yield. Yearly variability is provided by the temporal regression equations. Given land description and hydrologic variables, the spatial regression equations provide an estimate of the long-term average nitrate yield for a basin.

Row crop percentage was the most significant land description variable to predict spatial nitrate yield. Results indicate that changing the amount of row crop land use in a basin would have significant effects on nitrate loads.

Water yield was found to be the most significant hydrologic variable to predict temporal nitrate loads. At first glance, it may appear as though there is no way to control water yield. Though there may be some truth to this, water could be stored or detained to allow more in-stream processing. Since tile drainage is a subset of baseflow, and tile drains are commonly installed in row crop fields, best management practices (BMPs) could be implemented to customize tile drainage systems. One example is the installation and management of control structures that raise the water level on a field after harvest to allow more denitrification in the soil without harming the crop. Shortly before crops have been planted, the water level could be managed to avoid submerging crop root zones. Schilling and Libra (2000) pointed out that increases in baseflow have the potential to increase nitrate delivery to streams. The reverse may also be true. If baseflow contributions to streamflow could be reduced, then nitrate delivered to streams might decrease.

The water yield regression equations may be used to validate nitrate load estimates and identify whether extreme nitrate loads differ from expected loads. They can also be used to calculate reasonable annual statewide nitrate loads and more precise 10-year moving average nitrate loads. The MLRA regional equations used to develop a water yield regression equation are ideal for locations that do not monitor water quality but have a USGS gage.

Due to the high resolution of IWQIS data, this data is recommended to be used when available, interpolating between small gaps where necessary, and supplementing the larger gaps (greater than 30 days) with interpolated DNR ambient loads. The main gap DNR ambient would be filling is the November through February gap.

Summary

The regression models discussed in Chapter 4 are limited to an annual scale. Nitrate load and yield estimates at a finer scale would require additional regression analysis. Because the models were based on current land cover data, the goodness of fit of the models will be limited to current land use and conservation practice implementation intensity. The models developed in this research provide a quick, easy, and inexpensive method to estimate and validate spatial and temporal nitrate loads and yields.

# CHAPTER 7: CONCLUSION

This research was conducted to calculate statewide nitrate load estimations based on DNR ambient nitrate data. Additional objectives were: identify patterns in the data, fit the data to linear regression models to generate spatial and temporal nitrate predictions, and compare low-resolution water quality data collected from the DNR ambient network with high-resolution water quality data collected from sensors on the IWQIS network.

To accomplish these objectives nitrate concentration, streamflow, and other hydraulic and land description data was obtained. Previous studies identified a strong link between nitrate concentrations and row crop percentage in Iowa watersheds. Monthly nitrate grab samples were interpolated to obtain daily nitrate concentrations. Daily mean streamflow was used to calculate daily nitrate loads. The daily nitrate loads were totaled each year and used to estimate the statewide load export. The statewide loads were aggregated into 10-year moving averages to compare the data to the INRS baseline nitrate load.

A 10-year moving average of the annual statewide nitrate load extrapolation shows that nitrate loads have been steadily increasing. There was a 30 percent nitrate load increase from 2008 to 2015. In addition, the 2015 statewide 10-year moving average nitrate load was 14 percent higher than the baseline load established by the INRS in 2010.

10-year moving averages were also calculated for each subbasin studied to identify areas with significant change in average nitrate export. Watersheds in the southwest corner of Iowa showed steeper trend lines through their annual nitrate loads. Additional research should be conducted to investigate what may be causing this region to have steeper trend lines indicating more rapid increase in annual average nitrate export.

The highest average nitrate yields are found in north central Iowa. This area generally comprises the landform regions described as the Des Moines Lobe and the Iowan Surface. These landforms have poor natural drainage, so tile drains have been installed to more quickly drain agricultural land. Efficiently and quickly routing water from agricultural land has the potential to increase nitrate concentrations, and subsequently nitrate loads and yields.

Regression equations were used to identify spatial and temporal trends. These equations were developed based on current conditions. Therefore, their future predictive power may be limited if conservation practices and land use substantially change. Row crop and water yield were found to be the best predictors of average spatial nitrate yields. In a majority of the watersheds studied, water yield by itself best replicated the temporal annual nitrate loads. The annual statewide nitrate load extrapolation using the water yield regression at each of the 23 main study basins was approximately 16 percent different than the extrapolation using DNR ambient data. Baseflow also performed well to predict temporal nitrate patterns, but due to the increased uncertainty and difficulty of measurement, water yield was used to predict temporal patterns.

Some of the watersheds appeared to display a logarithmic relationship between nitrate load and water yield, instead of the assumed linear relationship. Further research should be conducted to determine when or if a logarithmic relationship should be used instead of a linear relationship.

Using the water yield regression for each of the 23 main study basins and streamflow data from the past 50 years, a time series of annual statewide nitrate loads was estimated. The loads were then aggregated into a 10-year moving average. This was

compared to the 10-year moving average from available DNR ambient data. The 10-year

moving average from regression estimates follows the available DNR ambient 10-year

moving average well. The long-term 10-year moving average of statewide nitrate load

shows an increasing trend consistent with increasing trends in precipitation and

streamflow.

The temporal regression parameters were organized spatially by MLRA.

Geographic regression equations were generated to predict water yield regression

parameters from land use input variables. Temporal regression equations were then made

to estimate annual nitrate load and yield. These MLRA-based equations may be

especially useful in gaged locations with shorter water quality records or ungaged

regions. However, additional research would be needed to identify the accuracy of using

water yield estimates from ungaged locations to estimate nitrate loads.

Load estimates were compared between DNR ambient monthly grab samples and

high-resolution nitrate concentrations available from IWQIS. Loads were compared

during time periods when both IWQIS and DNR ambient networks had available data.

The mean annual average percent difference between DNR ambient data and IWQIS data

was 12.6 percent. This average represents an average of absolute values for each site.

DNR ambient data differed from IWQIS during the active season by an average of 14.8

percent. Based on the significant difference in calculated nitrate load exports between the

two networks during the active season, IWQIS sensor data should be used when it is

available. DNR ambient data could be used to fill data gaps in high-resolution data from

IWQIS.

Average statewide nitrate loads are on the rise. This study provided insights into nitrate collection techniques and potential methods to make quick and reliable annual nitrate load estimates. Study results indicate that consistent data collection and processing are needed to provide a better view to meet nitrate load reduction goals. Conservation practice implementation may cause challenges to load prediction using regression equations. This study identified the variables that have significant impacts on nitrate concentrations and yields. Applying this knowledge provides an opportunity to solve the environmental concerns brought about by high nitrate concentrations in rivers and streams.

# REFERENCES

Baker, J. L., David, M. B., Lemke, D., & Jaynes, D. B. (2008). *Understanding Nutrient Fate and Transport.* St. Joseph: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop. Upper Mississippi River Sub-basin Hypoxia Nutrient Committee.

Blesh, J., & Drinkwater, L. (2013, July). The impact of nitrogen source and crop rotation on nitrogen mass balances in the Mississippi River Basin. *Ecological Applications, 23*(5), 1017-1035.

Braker, G., Schwarz, J., & Conrad, R. (2010, July). Influence of temperature on the composition and activity of denitrifying soil communities. *FEMS Microbiology Ecology, 73*(1), 134-148.

Burkart, M. R., & James, D. E. (1999). Agricultural-Nitrogen Contributions to Hypoxia in the Gulf of Mexico. *Journal of Environmental Quality, 28*, 850-859.

Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., et al. (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology*.

David, M. B., Drinkwater, L. E., & McIsaac, G. F. (2010). Sources of Nitrate Yields in the Mississippi River Basin. *Journal of Environmental Quality, 39*, 1657-1667.

*Estuarine Science: What is Dissolved Oxygen?* (2001). Retrieved from University of Rhode Island Office of Marine Programs: http://omp.gso.uri.edu/ompweb/doee/science/physical/choxy1.htm

Goolsby, D. A., Battaglin, W. A., Aulenbach, B. T., & Hooper, R. P. (2001). Nitrogen

    Input to the Gulf of Mexico. *Journal of Environmental Quality, 30*(2), 329-336.

Hallberg, G. R. (1989). Pesticides pollution of ground water in the humid United States.

    *Agriculture, Ecosystems & Environment, 26*(3), 299-367.

Henriksen, G. H., Bloom, A. J., & Spanswick, R. M. (1990). Measurement of Net Fluxes

    of Ammonium and Nitrate at the Surface of Barley Roots Using Ion-Selective

    Microelectrodes. *Plant Physiology, 93*, 271-280.

Hill, R., Rinker, R., & Wilson, H. D. (1980). Atmospheric Nitrogen Fixation by

    Lightning. *Journal of Atmospheric Sciences, 37*, 179-192.

INRS. (2012). *A science and technology-based framework to assess and reduce nutrients*

    *to Iowa waters and the Gulf of Mexico.*

Iowa DNR. (2016). *Ambient Water Monitoring Strategy for Iowa 2016-2021.*

ISU Science Team. (2012). *Iowa Science Assessment of Nonpoint Source Practices to*

    *Reduce Nitrogen and Phosphorus Transport in the Mississippi River Basin.*

    Ames, IA: Iowa Department of Agriculture and Land Stewardship, Iowa

    Department of Natural Resources, and Iowa State University College of

    Agriculture and Life Sciences.

Jones, C., Kim, S.-W., & Schilling, K. (2017). Use of continuous monitoring to assess

    stream nitrate flux and transformation patterns. *Environmental Monitoring and*

    *Assessment, 189*(1), 35-46.

Libra, R. D. (1998). Nitrate Nitrogen: Iowa's Unintended Export. *Iowa Geology 1998, 23*,

    pp. 5-7.

Lim, K. J., Engel, B. A., Tang, Z., Choi, J., Kim, K.-S., Muthukrishnan, S., et al. (2005). Automated Web GIS Based Hydrograph Analysis Tool, WHAT. *Journal of the American Water Resources Association*, 1407-1416.

Minitab version 17.3.1. (2017). *[Computer software]*. Retrieved from Minitab 17: https://www.minitab.com/en-us/products/minitab/

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. (2001). *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico.* Washington, DC.

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. (2008). *Gulf Hypoxia Action Plan 2008 for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the Mississippi River Basin.* Washington, DC.

*Nitrification Primer*. (2004). Retrieved from Nitrification Network: http://nitrificationnetwork.org/Introduction.php#nitrification

Nova Scotia Agricultural College. (2007). *Factsheet: Ammonia Management From Manure Storage & Spreading.* Retrieved April 2017, from Soil & Crop Improvement Association of Nova Scotia: http://www.scians.org/factsheets/29/Ammonia%20Management%20From%20Manure%20Storage%20&%20Spreading

Osborne, L. L., & Kovacic, D. A. (1993). Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology, 29*(2), 243-258.

Plant & Soil Sciences eLibrary. (2017). *Forms of Nitrogen in the Soil*. Retrieved October

    2017, from

    http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=113044

    7042&topicorder=2&maxto=8

Power, J., & Schepers, J. (1989). Nitrate contamination of groundwater in North

    America. *Agriculture, Ecosystems & Environment, 26*(3), 165-187.

Rolston, D. (1981). *Nitrous oxide and nitrogen gas production in fertilizer loss.* New

    York: John Wiley & Sons.

Royer, T. V., David, M. B., & Gentry, L. E. (2006). Timing of Riverine Export of Nitrate

    and Phosphorus from Agricultural Watersheds in Illinois: Implications for

    Reducing Nutrient Loading to the Mississippi River. *Environmental Science &*

    *Technology, 40*(13), 4126-4131.

Royer, T. V., Tank, J. L., & David, M. B. (2004). Transport and Fate of Nitrate in

    Headwater Agricultural Streams in Illinois. *Journal of Environmental Quality, 33*,

    1296-1304.

Schilling, K. E. (2002). Chemical Transport from Paired Agricultural and Restored

    Prairie Watersheds. *Journal of Environmental Quality, 31*(4), 1184-1193.

Schilling, K. E. (2005). Relation of Baseflow to Row Crop Intensity in Iowa. *Agriculture,*

    *Ecosystems & Environment*, 433-438.

Schilling, K. E., & Libra, R. D. (2000). The Relationship of Nitrate Concentrations in

    Streams to Row Crop Land Use in Iowa. *Journal of Environmental Quality*, 1846-

    1851.

Schilling, K. E., & Libra, R. D. (2003). INCREASED BASEFLOW IN IOWA OVER

 THE SECOND HALF OF THE 20TH CENTURY. *Journal of the American*

 *Water Resources Association, 39*(4), 851-860.

Schilling, K. E., & Lutz, D. S. (2004). Relation of Nitrate Concentrations to Baseflow in

 the Raccoon River, Iowa. *Journal of the American Water Resources Association*,

 889-900.

Schilling, K. E., & Wolter, C. F. (2005). Estimation of Streamflow, Base flow, and

 Nitrate-Nitrogen Loads in Iowa Using Multiple Linear Regression Models.

 *Journal of the American Water Resources Association*, 1333-1346.

Schilling, K. E., & Zhang, Y.-K. (2004). Baseflow Contribution to Nitrate-Nitrogen

 Export From A Large, Agricultural Watershed. *Journal of Hydrology*, 305-316.

Schilling, K. E., Wolter, F. C., Liang, X., Zhang, Y.-K., Jones, C. S., Seaman, A., et al.

 (2017). Variability of Nitrate-N load estimation results will make quantifying load

 reduction strategies difficult in Iowa. *Journal of Soil and Water Conservation*.

Slater, L. J., & Villarini, G. (2016). Recent trends in U.S. flood risk. *Geophysical*

 *Research Letters*, 12,428-12,436.

Smakhtin, V. (2001). Low Flow Hydrology: A Review. *Journal of Hydrology, 240*(147-

 186).

United States Department of Agriculture. (n.d.). Retrieved October 17, 2017, from

 Census of Agriculture Historical Archive:

 http://agcensus.mannlib.cornell.edu/AgCensus/homepage.do

USEPA. (2000). *Nutrient criteria technical guidance manual: rivers and streams. EPA-*

 *822-B-00-002.* US Gov Printing Office, Washington D.C.

USEPA. (2008). *Hypoxia in the Northern Gulf of Mexico. An Update by the EPA Science Advisory Board. EPA-SAB-08-003.* Washington D.C.: EPA Science Advisory Board.

USEPA. (2015). *HTF 2015 Report to Congress.* Washington D.C.

USEPA. (2017, March 22). *STOrage and RETrieval and Water Quality eXchange*. Retrieved from USEPA: https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange

Weber, L., Jones, C., & Davis, C. (2016). *IIHR 2015 Water Monitoring Report.* Iowa City: IIHR-Hydroscience & Engineering.

Wortmann, C., Al-Kaisi, M., Helmers, M., Sawyer, J., Devlin, D., Barden, C., et al. (2013). *Agricultural Nitrogen Management for Water Quality Protection in the Midwest.*

Zhang, Y.-K., & Schilling, K. E. (2005). Temporal variations and scaling of streamflow and baseflow and their nitrate-nitrogen concentrations and loads. *Advances in Water Resources*, 701-710.

# APPENDIX A: STUDY AREA SITE INFORMATION

*Table A-1: Site information.*

| Watershed .shp # | DNR Ambient ID # | Site Name | DNR Ambient Drainage Area (km$^2$) | USGS Streamflow Gage # | Gage Drainage Area (km$^2$) | Drainage Ratio |
|---|---|---|---|---|---|---|
| 1 | 10030001 | Upper Iowa River at Dorchester | 1,987 | 05388250 | 1,994 | 0.997 |
| 2 | 10030002 | Yellow River Near Ion | 566 | 05389000 | 572 | 0.990 |
| 3 | 10220003 | Bloody Run Creek near Marquette | 89 | 05389400 | 88 | 1.005 |
| 4 | 10220001 | Turkey River near Garber | 4,023 | 05412500 | 4,002 | 1.005 |
| 4.1 | 10220002 | Volga River near Elkport | 1,042 | 05412400 | 901 | 1.156 |
| 5 | 10490001 | North Fork Maquoketa River near Hurstville | 1,528 | 05418400 | 1,308 | 1.168 |
| 6 | 10820001 | Wapsipinicon River near DeWitt | 6,045 | 05422000 | 6,050 | 0.999 |
| 6.1 | 10100001 | Wapsipinicon River at Independence | 2,381 | 05421000 | 2,714 | 0.877 |
| 7 | 10700001 | Cedar River near Conesville | 20,159 | 05465000 | 20,168 | 1.000 |
| 7.01 | 10570001 | Cedar River Downstream of Cedar Rapids | 18,002 | 05464500 | 16,861 | 1.068 |
| 7.02 | 10570002 | Cedar River Upstream of Cedar Rapids | 16,423 | 05464500 | 16,861 | 0.974 |
| 7.03 | 10070002 | Wolf Creek at Laporte City | 844 | 05464220 | 774 | 1.089 |
| 7.04 | 10070006 | Cedar River at Waterloo DS1 | 13,561 | 05464000 | 13,328 | 1.017 |
| 7.05 | 10070004 | Black Hawk Creek at Waterloo | 845 | 05463500 | 785 | 1.077 |

| Watershed .shp # | DNR Ambient ID # | Site Name | DNR Ambient Drainage Area (km$^2$) | USGS Streamflow Gage # | Gage Drainage Area (km$^2$) | Drainage Ratio |
|---|---|---|---|---|---|---|
| 7.06 | 10070005 | Cedar River at Waterloo US1 | 12,222 | 05464000 | 13,328 | 0.917 |
| 7.07 | 10070001 | Beaver Creek near Cedar Falls | 1,020 | 05463000 | 899 | 1.135 |
| 7.08 | 10090001 | Cedar River at Janesville | 4,329 | 05458500 | 4,302 | 1.006 |
| 7.09 | 10070003 | West Fork Cedar River at Finchford | 2,208 | 05458900 | 2,191 | 1.008 |
| 7.1 | 10120001 | Shell Rock River at Shell Rock | 4,481 | 05462000 | 4,522 | 0.991 |
| 7.11 | 10340001 | Cedar River near Charles City | 2,838 | 05457700 | 2,730 | 1.040 |
| 7.12 | 10170003 | Winnebago River Downstream of Mason City | 1,661 | 05459500 | 1,362 | 1.219 |
| 7.13 | 10170002 | Winnebago River Upstream of Mason City | 1,176 | 05459500 | 1,362 | 0.863 |
| 8 | 10580002 | Iowa River near Lone Tree | 11,101 | 05455700 | 11,119 | 0.998 |
| 8.1 | 10920001 | English River at Riverside | 1,623 | 05455500 | 1,487 | 1.092 |
| 8.2 | 10520003 | Iowa River Downstream of Iowa City | 8,588 | 05454500 | 8,472 | 1.014 |
| 8.3 | 10520001 | Old Mans Creek near Iowa City | 522 | 05455100 | 521 | 1.002 |
| 8.4 | 10520002 | Iowa River Upstream of Iowa City | 8,150 | 05453520 | 8,068 | 1.010 |
| 8.5 | 10640002 | Iowa River Downstream of Marshalltown | 4,230 | 05451500 | 3,968 | 1.066 |
| 8.6 | 10640003 | Iowa River Upstream of Marshalltown | 3,794 | 05451500 | 3,968 | 0.956 |
| 8.7 | 10990001 | Iowa River near Rowan | 1,104 | 05449500 | 1,103 | 1.001 |
| 9 | 10540001 | North Skunk River near Sigourney | 1,646 | 05472500 | 1,891 | 0.871 |

| Watershed .shp # | DNR Ambient ID # | Site Name | DNR Ambient Drainage Area (km²) | USGS Streamflow Gage # | Gage Drainage Area (km²) | Drainage Ratio |
|---|---|---|---|---|---|---|
| 10 | 10620001 | South Skunk River near Oskaloosa | 4,247 | 05471500 | 4,235 | 1.003 |
| 10.1 | 10500001 | Indian Creek Near Colfax | 1,027 | 05471200 | 715 | 1.437 |
| 10.2 | 10850002 | South Skunk River Downstream of Ames | 1,518 | 05471000 | 1,440 | 1.054 |
| 11 | 10440001 | Cedar Creek near Oakland Mills | 1,379 | 05473400 | 1,373 | 1.005 |
| 12 | 10900002 | Des Moines River Downstream of Ottumwa | 34,751 | 05489500 | 34,639 | 1.003 |
| 12.01 | 10900003 | Des Moines River Upstream of Ottumwa | 34,294 | 05489500 | 34,639 | 0.990 |
| 12.02 | 10630002 | Cedar Creek near Bussey | 964 | 05489000 | 969 | 0.995 |
| 12.03 | 10910003 | South River near Ackworth | 1,228 | 05487470 | 1,191 | 1.031 |
| 12.04 | 10910001 | Middle River near Indianola | 1,267 | 05486490 | 1,303 | 0.973 |
| 12.05 | 10910002 | North River near Norwalk | 905 | 05486000 | 904 | 1.001 |
| 12.06 | 10250002 | Raccoon River upstream of Des Moines | 8,871 | 05484500 | 8,912 | 0.995 |
| 12.07 | 10250001 | South Raccoon River at Redfield | 2,538 | 05484000 | 2,574 | 0.986 |
| 12.08 | 10770002 | Des Moines River Upstream of Des Moines | 15,135 | 05481650 | 15,128 | 1.000 |
| 12.09 | 10770001 | Beaver Creek near Grimes | 957 | 05481950 | 927 | 1.032 |
| 12.1 | 10810001 | North Raccoon River near Sac City | 1,840 | 05482300 | 1,813 | 1.015 |
| 12.11 | 10940003 | Des Moines River Downstream of Fort Dodge | 11,030 | 05480500 | 10,852 | 1.016 |

| Watershed .shp # | DNR Ambient ID # | Site Name | DNR Ambient Drainage Area (km$^2$) | USGS Streamflow Gage # | Gage Drainage Area (km$^2$) | Drainage Ratio |
|---|---|---|---|---|---|---|
| 12.12 | 10400001 | Boone River at Stratford | 2,298 | 05481000 | 2,186 | 1.051 |
| 12.13 | 10460001 | West Fork Des Moines near Humbolt | 6,013 | 05476750 | 5,843 | 1.029 |
| 13 | 10270001 | Thompson Fork-Grand River at Davis City | 1,801 | 06898000 | 1,816 | 0.992 |
| 14 | 10730001 | West Nodaway River near Shambaugh | 2,046 | 06817000 | 1,974 | 1.037 |
| 15 | 10360001 | East Nishnabotna River near Shenandoah | 2,645 | 06809500 | 2,315 | 1.142 |
| 16 | 10650001 | West Nishnabotna River near Malvern | 2,508 | 06807410 | 1,577 | 1.590 |
| 17 | 10430001 | Boyer River near Missouri Valley | 2,357 | 06609500 | 2,256 | 1.045 |
| 18 | 10430002 | Soldier River at Pisgah | 1,058 | 06608500 | 1,054 | 1.003 |
| 19 | 10670002 | Maple River at Mapleton | 1,668 | 06607200 | 1,733 | 0.963 |
| 20 | 10970001 | Little Sioux River near Smithland | 6,958 | 06606600 | 6,475 | 1.075 |
| 20.1 | 10180001 | Little Sioux River at Larrabee | 4,814 | 06605850 | 4,009 | 1.201 |
| 20.2 | 10210001 | Ocheyden River near Spencer | 1,139 | 06605000 | 1,103 | 1.032 |
| 21 | 10970002 | West Fork Ditch at Hornick | 1,042 | 06602020 | 1,044 | 0.998 |
| 22 | 10750001 | Floyd River near Sioux City | 2,295 | 06600500 | 2,295 | 1.000 |
| 23 | 10840001 | Rock River near Hawarden | 4,351 | 06483500 | 4,123 | 1.055 |

# APPENDIX B: VBA INTERPOLATION CODE

<u>Main Code Body</u>

---

```
Private Sub CommandButton2_Click()

    Dim count As Long

    'Filepath at HOME
    If OptionButton1_Home.Value = True Then FILEPATH =
        Sheets("Sites").Range("C7").Value
    'Filepath at WORK
    If OptionButton1_Work.Value = True Then FILEPATH =
        Sheets("Sites").Range("C8").Value

    Filename = ActiveCell.Value
    SummaryRow = ActiveCell.Offset(, -1).Value
    DischargeName = ActiveCell.Offset(, 1).Value
    DrainageRatio = ActiveCell.Offset(, 4).Value

    '***Copy and past nitrate concentrations and discharge data***
    Workbooks.Open Filename:=FILEPATH & Filename

    Windows(Filename & ".xlsx").Activate

    'Clear any existing nitrate or streamflow data
    Sheets("Daily Interpolation").Range("A3:E1000").ClearContents
    Sheets("Daily Interpolation").Range("A3:E1000").ClearFormats
    Sheets("Discharge").Activate
    Sheets("Discharge").Range("A2:C2").Select
    Sheets("Discharge").Range(Selection, Selection.End(xlDown)).Select
    Selection.ClearContents
    Selection.ClearFormats

    'Copy, paste and round date down to midnight
    Sheets("Raw Data").Activate
    Sheets("Raw Data").Range("D1").Select
    Sheets("Raw Data").Range(Selection, Selection.End(xlDown)).Select
    Selection.Copy
    Sheets("Daily Interpolation").Select
    Sheets("Daily Interpolation").Range("B2").Select
    ActiveSheet.Paste
    Columns("B:B").EntireColumn.AutoFit
    Sheets("Daily Interpolation").Range("C2").Select
    Application.CutCopyMode = False
```

```
ActiveCell.FormulaR1C1 = "Date Rounded"
Sheets("Daily Interpolation").Range("C3").Select
'Round date down to remove time of day to midnight
ActiveCell.FormulaR1C1 = "=ROUNDDOWN(RC[-1],0)"

'Copy and paste nitrate concentrations
Sheets("Raw Data").Select
Sheets("Raw Data").Range("G1").Select
Sheets("Raw Data").Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("Daily Interpolation").Select
Sheets("Daily Interpolation").Range("D2").Select
ActiveSheet.Paste
Sheets("Raw Data").Select
Sheets("Raw Data").Range("A1").Select
'Set "Result" number format to "General"
Sheets("Daily Interpolation").Select
Sheets("Daily Interpolation").Range("D2").Select
Sheets("Daily Interpolation").Range(Selection, Selection.End(xlDown)).Select
With Selection
    Selection.NumberFormat = "General"
    .Value = .Value
End With

'External macro is necessary because the code won't execute here properly
'Drag "RoundDown" equation down through all dates
Call Round              'Code is under "Module 1"
'Check for multiple readings on one day
Call CheckForMultiples    'Code is under "Module 1"

'***INTERPOLATE NITRATE TO DAILY CONCENTRATION***

'Clear existing data in interpolation zone
Sheets("Daily Interpolation").Range("F3:O3").Select
Sheets("Daily Interpolation").Range(Selection, Selection.End(xlDown)).Select
Selection.ClearContents

'Add headings
Sheets("Daily Interpolation").Range("B1") = "Drainage Ratio:"
Sheets("Daily Interpolation").Range("C1") = DrainageRatio
Sheets("Daily Interpolation").Range("F2") = "Interpolated Date"
Sheets("Daily Interpolation").Range("G2") = "Month"
Sheets("Daily Interpolation").Range("H2") = "Day"
Sheets("Daily Interpolation").Range("I2") = "Year"
Sheets("Daily Interpolation").Range("J2") = "Interpolated Result (mg/L)"
Sheets("Daily Interpolation").Range("K2") = "Scaled Discharge (L/day)"
```

```vba
Sheets("Daily Interpolation").Range("L2") = "Scaled Load (Mg/day)"
Sheets("Daily Interpolation").Range("M2") = "Comments"
Sheets("Daily Interpolation").Range("N2") = "DNR Ambient Dates"
Sheets("Daily Interpolation").Range("O2") = "USGS Dates"

Call Interpolate        'Code is under "Module 2"

Call SeparateDates      'Code is under "Module 1"

'***Copy, paste and convert streamflow***

'Copy Discharge to site
Workbooks.Open Filename:=FILEPATH & "Discharge Textfiles\" & DischargeName
Windows(DischargeName & ".xlsx").Activate
Sheets("Raw Discharge").Activate
Sheets("Raw Discharge").Range("C2:D2").Select
Sheets("Raw Discharge").Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Windows(Filename & ".xlsx").Activate
Sheets("Discharge").Activate
Sheets("Discharge").Range("A2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, transpose:=False

Sheets("Discharge").Range("A1") = "Date"
Sheets("Discharge").Range("B1") = "Discharge (cfs)"
Sheets("Discharge").Range("C1") = "Discharge (L/day)"

Call ConvertDischarge       'Code is under "Module 1"

Sheets("Discharge").Range("A1:C1").Select
Sheets("Discharge").Range(Selection, Selection.End(xlDown)).Select
With Selection
    .HorizontalAlignment = xlCenter
    .VerticalAlignment = xlCenter
    .WrapText = True
    .Orientation = 0
    .AddIndent = False
    .IndentLevel = 0
    .ShrinkToFit = False
    .ReadingOrder = xlContext
    .MergeCells = False
End With
```

```vba
'Format cells to proper type
Sheets("Discharge").Range("A2").Select
Sheets("Discharge").Range(Selection, Selection.End(xlDown)).Select
Selection.NumberFormat = "m/d/yyyy"
Sheets("Discharge").Range("B2:C2").Select
Sheets("Discharge").Range(Selection, Selection.End(xlDown)).Select
Selection.NumberFormat = "0"
Sheets("Discharge").Range("A1").Select

'Format column width
Sheets("Discharge").Columns("A:A").ColumnWidth = 11
Sheets("Discharge").Columns("B:B").ColumnWidth = 11
Sheets("Discharge").Columns("C:C").ColumnWidth = 13.5

Windows(DischargeName & ".xlsx").Activate
ActiveWorkbook.Save
ActiveWorkbook.Close

'***Calculate nitrate load***

Windows(Filename & ".xlsx").Activate

'Vlookup discharge and scale it by multiplying by drainage ratio
Call Vlookup        'Code is under "Module 1"

Call CalcLoad       'Code is under "Module 1"

'***Format and prepare data to be pasted in summary spreadsheet***

'Format column headers
Sheets("Daily Interpolation").Range("B2:O2").Select
    With Selection
    .HorizontalAlignment = xlCenter
    .VerticalAlignment = xlCenter
    .WrapText = True
    .Orientation = 0
    .AddIndent = False
    .IndentLevel = 0
    .ShrinkToFit = False
    .ReadingOrder = xlContext
    .MergeCells = False
End With
Sheets("Daily Interpolation").Columns("A:A").ColumnWidth = 8.3
Sheets("Daily Interpolation").Columns("B:B").ColumnWidth = 20.75
Sheets("Daily Interpolation").Columns("C:C").ColumnWidth = 21.15
Sheets("Daily Interpolation").Columns("D:D").ColumnWidth = 5.75
```

```
Sheets("Daily Interpolation").Columns("E:E").ColumnWidth = 8.6
Sheets("Daily Interpolation").Columns("F:F").ColumnWidth = 10
Sheets("Daily Interpolation").Columns("G:G").ColumnWidth = 5.75
Sheets("Daily Interpolation").Columns("H:H").ColumnWidth = 4
Sheets("Daily Interpolation").Columns("I:I").ColumnWidth = 5
Sheets("Daily Interpolation").Columns("J:J").ColumnWidth = 15.75
Sheets("Daily Interpolation").Columns("K:K").ColumnWidth = 11.45
Sheets("Daily Interpolation").Columns("L:L").ColumnWidth = 7.9
Sheets("Daily Interpolation").Columns("M:M").ColumnWidth = 18.6
Sheets("Daily Interpolation").Columns("N:N").ColumnWidth = 10
Sheets("Daily Interpolation").Columns("O:O").ColumnWidth = 10

Call ToFromDate     'Code is under "Module 1"

'Add Start and End dates to the Summary Page
Sheets("Daily Interpolation").Range("N3").Select
AmbientStart = ActiveCell.Value
AmbientEnd = ActiveCell.Offset(1, 0).Value
USGSStart = ActiveCell.Offset(0, 1).Value
USGSEnd = ActiveCell.Offset(1, 1).Value

Windows("Date Interpolater.xlsm").Activate
Sheets("Summary").Activate
Sheets("Summary").Select
Sheets("Summary").Range("C" & SummaryRow).Select
ActiveCell.Value = AmbientStart & " - " & AmbientEnd
Sheets("Summary").Range("D" & SummaryRow).Select
ActiveCell.Value = USGSStart & " - " & USGSEnd

'If "Pivot" tab exists, delete "Pivot" Tab
'If no "Pivot" tab, move to "Add Pivot Tab"
Windows(Filename & ".xlsx").Activate
Sheets("Pivot").Select
ActiveWindow.SelectedSheets.Delete

'Add Pivot Tab
Windows(Filename & ".xlsx").Activate
Sheets("Daily Interpolation").Activate
Sheets.Add After:=ActiveSheet
Sheets("Sheet1").Select
Sheets("Sheet1").Name = "Pivot"

Call AddPivot     'Code is under "Module 1"

Call Year_Pivot   'Code is under "Module 1"
```

```
'***Paste annual loads in summary spreadsheet***

'Vlookup of ANNUAL LOAD in pivot table
Windows("Date Interpolater.xlsm").Activate
Sheets("Summary").Activate
Sheets("Summary").Select
Sheets("Summary").Range("F" & SummaryRow).Select
ActiveCell.FormulaR1C1 = "=VLOOKUP(R[-" & SummaryRow - 3 & "]C,'" &
    Filename & ".xlsx'!YearTable,2,FALSE)"
'copy equation across row
Sheets("Summary").Range("F" & SummaryRow).Select
Selection.AutoFill Destination:=Sheets("Summary").Range("F" & SummaryRow &
    ":W" & SummaryRow)
Sheets("Summary").Range("F" & SummaryRow & ":W" & SummaryRow).Select
Selection.NumberFormat = "0.00"


'Vlookup of AVERAGE CONCENTRATION in pivot table
Windows("Date Interpolater.xlsm").Activate
Sheets("Summary").Activate
Sheets("Summary").Select
Sheets("Summary").Range("F" & SummaryRow + 69).Select
ActiveCell.FormulaR1C1 = "=VLOOKUP(R[-" & SummaryRow - 3 & "]C,'" &
    Filename & ".xlsx'!YearTable,4,FALSE)"
'copy equation across row
Sheets("Summary").Range("F" & SummaryRow + 69).Select
Selection.AutoFill Destination:=Sheets("Summary").Range("F" & SummaryRow + 69
    & ":W" & SummaryRow + 69)
Sheets("Summary").Range("F" & SummaryRow + 69 & ":W" & SummaryRow +
    69).Select
Selection.NumberFormat = "0.00"

Windows(Filename & ".xlsx").Activate
ActiveWorkbook.Save
ActiveWorkbook.Close

Windows("Date Interpolater.xlsm").Activate
Sheets("Sites").Activate


End Sub
```

Module 1: Sub-routine Code

```vba
Sub Round()

col = 3     'Column 3 = C

'  Copy "RoundDown" formula down through all dates
    Sheets("Daily Interpolation").Range("B3").Select
    count = Sheets("Daily Interpolation").Range(Selection,
Selection.End(xlDown)).Rows.count

    Sheets("Daily Interpolation").Range("C3").Select      'The column must match
where "Date Rounded" is located
    Selection.AutoFill Destination:=Sheets("Daily Interpolation").Range(Cells(3,
col), Cells(count + 2, col))

    End Sub
```

```vba
Sub CheckForMultiples()

col = 5     'Column 5 = E

'  Copy formula down to check for multiple readings on the same day
    Sheets("Daily Interpolation").Range("B3").Select
    count = Sheets("Daily Interpolation").Range(Selection,
Selection.End(xlDown)).Rows.count

    Sheets("Daily Interpolation").Range("E2").Value = "Check for Multiple
Readings"
    Sheets("Daily Interpolation").Range("E3").Select
    ActiveCell.FormulaR1C1 = "=IF(RC[-2]=R[1]C[-2],1,0)"
    Sheets("Daily Interpolation").Range("E3").Select
    Selection.AutoFill Destination:=Sheets("Daily Interpolation").Range(Cells(3,
col), Cells(count + 2, col))

    End Sub
```

```vba
Sub SeparateDates()

month_col = 7     'Column 7 = G
day_col = 8       'Column 8 = H
year_col = 9      'Column 9 = I

'  Copy formula down to separate date into Year, Month, and Day
    Sheets("Daily Interpolation").Range("J3").Select
    count = Sheets("Daily Interpolation").Range(Selection,
Selection.End(xlDown)).Rows.count
```

```vba
        Sheets("Daily Interpolation").Range("G3").Select
        ActiveCell.FormulaR1C1 = "=MONTH(RC[-1])"
        Sheets("Daily Interpolation").Range("H3").Select
        ActiveCell.FormulaR1C1 = "=DAY(RC[-2])"
        Sheets("Daily Interpolation").Range("I3").Select
        ActiveCell.FormulaR1C1 = "=YEAR(RC[-3])"
        Sheets("Daily Interpolation").Range("G3:I3").Select
        Selection.AutoFill Destination:=Sheets("Daily Interpolation").Range(Cells(3,
month_col), Cells(count + 2, year_col))

        Sheets("Daily Interpolation").Range("G3:I3").Select
        Range(Selection, Selection.End(xlDown)).Select
        Selection.NumberFormat = "0"

    End Sub

    Sub ConvertDischarge()

        Sheets("Discharge").Range("A2").Select
        count = Sheets("Discharge").Range(Selection,
Selection.End(xlDown)).Rows.count

        Sheets("Discharge").Range("C2").Select
        'Convert cfs to L/day
        ActiveCell.FormulaR1C1 = "=RC[-1]*28.3168*3600*24"
        Sheets("Discharge").Range("C2").Select
        Selection.AutoFill Destination:=Sheets("Discharge").Range(Cells(2, 3),
Cells(count + 1, 3))

    End Sub

    Sub Vlookup()

    col = 11        'Column 11 = K

        Sheets("Daily Interpolation").Activate
        Sheets("Daily Interpolation").Range("J3").Select
        count = Sheets("Daily Interpolation").Range(Selection,
Selection.End(xlDown)).Rows.count

        Sheets("Discharge").Activate
        Sheets("Discharge").Range("A2").Select
        dis_count = Sheets("Discharge").Range(Selection,
Selection.End(xlDown)).Rows.count

        'Name the table so the Vlookup function will recognize the table
        Sheets("Discharge").Range("A2:C2").Select
        Sheets("Discharge").Range(Selection, Selection.End(xlDown)).Select
```

```vba
        ActiveWorkbook.Names.Add Name:="DisTable",
RefersTo:=Sheets("Discharge").Range(Cells(2, 1), Cells(dis_count + 1, 3))

        Sheets("Daily Interpolation").Activate
        Sheets("Daily Interpolation").Range("K3").Select
        ActiveCell.FormulaR1C1 = "=VLOOKUP(RC[-5],DisTable,3,FALSE)*R1C3"
        Sheets("Daily Interpolation").Range("K3").Select
        Selection.AutoFill Destination:=Sheets("Daily Interpolation").Range(Cells(3,
col), Cells(count + 2, col))

        Sheets("Daily Interpolation").Range("K3").Select
        Sheets("Daily Interpolation").Range(Selection, Selection.End(xlDown)).Select
        Selection.NumberFormat = "0"

    End Sub
```

```vba
    Sub CalcLoad()

    col = 12        'Column 12 = L

        Sheets("Daily Interpolation").Range("J3").Select
        count = Sheets("Daily Interpolation").Range(Selection,
Selection.End(xlDown)).Rows.count
        Sheets("Daily Interpolation").Range("L3").Select
        ActiveCell.FormulaR1C1 = "=RC[-2]*RC[-1]/1000000000"
        Sheets("Daily Interpolation").Range("L3").Select
        Selection.AutoFill Destination:=Sheets("Daily Interpolation").Range(Cells(3,
col), Cells(count + 2, col))

        Sheets("Daily Interpolation").Range("L3").Select
        Sheets("Daily Interpolation").Range(Selection, Selection.End(xlDown)).Select
        Selection.NumberFormat = "0.00"

    End Sub
```

```vba
    Sub ToFromDate()

    col = 6         'Column 6 = F
    ambient = 14
    USGS = 15

        'Copy and paste "DNR Ambient" dates
        Sheets("Daily Interpolation").Activate
        Sheets("Daily Interpolation").Range("F3").Select
        count = Sheets("Daily Interpolation").Range(Selection,
Selection.End(xlDown)).Rows.count

        Sheets("Daily Interpolation").Range("F3").Select
```

```vba
        StartDate = ActiveCell.Value
        EndDate = ActiveCell.Offset(count - 1, 0).Value

        Sheets("Daily Interpolation").Range("N3") = StartDate
        Sheets("Daily Interpolation").Range("N4") = EndDate

        'Copy and paste "USGS" dates
        Sheets("Discharge").Activate
        Sheets("Discharge").Range("A2").Select
        count = Sheets("Discharge").Range(Selection,
Selection.End(xlDown)).Rows.count

        StartDate = ActiveCell.Value
        EndDate = ActiveCell.Offset(count - 1, 0).Value

        Sheets("Daily Interpolation").Activate
        Sheets("Daily Interpolation").Range("O3") = StartDate
        Sheets("Daily Interpolation").Range("O4") = EndDate

    End Sub
    Sub AddPivot()

        Sheets("Daily Interpolation").Activate
        Sheets("Daily Interpolation").Range("J3").Select
        count = Sheets("Daily Interpolation").Range(Selection,
Selection.End(xlDown)).Rows.count

        ActiveWorkbook.PivotCaches.Create(SourceType:=xlDatabase, SourceData:=
_
        "Daily Interpolation!R2C6:R" & count + 2 & "C12",
Version:=xlPivotTableVersion14). _
            CreatePivotTable TableDestination:="Pivot!R3C1",
TableName:="PivotTable1", _
            DefaultVersion:=xlPivotTableVersion14

        Sheets("Pivot").Select
        Cells(3, 1).Select

        'Check on "Load"
        ActiveSheet.PivotTables("PivotTable1").AddDataField
ActiveSheet.PivotTables( _
            "PivotTable1").PivotFields("Scaled Load (Mg/day)"), "Sum of Load
(Mg/day)", xlSum

        'Check on "Year"
        With ActiveSheet.PivotTables("PivotTable1").PivotFields("Year")
```

```vba
        .Orientation = xlRowField
        .Position = 1
      End With

      'Check on Discharge
      ActiveSheet.PivotTables("PivotTable1").AddDataField
ActiveSheet.PivotTables( _
         "PivotTable1").PivotFields("Scaled Discharge (L/day)"), "Sum of Discharge
(L/day)", _
         xlSum

      'Check on Interpolated concentration
      ActiveSheet.PivotTables("PivotTable1").AddDataField
ActiveSheet.PivotTables( _
         "PivotTable1").PivotFields("Interpolated Result (mg/L)"), _
         "Average of Interpolated Result (mg/L)", xlAverage

   End Sub
   Sub Year_Pivot()

      Sheets("Pivot").Activate
      Sheets("Pivot").Range("A4").Select
      pivot_count = Sheets("Pivot").Range(Selection,
Selection.End(xlDown)).Rows.count

      'Name the table so the Vlookup function will recognize the table
      Sheets("Pivot").Range("A4:D4").Select
      Sheets("Pivot").Range(Selection, Selection.End(xlDown)).Select
      ActiveWorkbook.Names.Add Name:="YearTable",
RefersTo:=Sheets("Pivot").Range(Cells(4, 1), Cells(pivot_count + 2, 4))

   End Sub
```

```vba
Sub Interpolate()

Dim date_col, res_col, row As Double
Dim int_date_col, int_res_col, int_row, comments_col, comment_num As Double
Dim dx, dy, slope As Double
Dim int_date_current As Date
Dim int_res_current As Double
Dim count, del, sum As Double
Dim numb_dup, Ave As Double

date_col = 3        'Date Column: 3 = C
res_col = 4         'Result Column: 4 = D
row = 3             'Start Row
int_date_col = 6    'Interpolated Date Column: 6 = F
int_res_col = 10    'Interpolated Result Column: 10 = J
int_row = 3         'Interpolated Start Row
comments_col = 13   'Comments Column: 13 = M

'Clear existing interpolated data
Range(Cells(row, int_date_col), Cells(row, int_res_col)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.ClearContents
Selection.ClearFormats

'Replace "Not Detected" with half of detectable limit (0.1)
Cells(row, res_col).Select
Range(Selection, Selection.End(xlDown)).Select
Cells.Replace What:="Not Detected", Replacement:="0.05", LookAt:=xlPart, _
    SearchOrder:=xlByRows, MatchCase:=False, SearchFormat:=False, _
    ReplaceFormat:=False

'How to deal with duplicates
Cells(row, res_col).Select
count = Range(Selection, Selection.End(xlDown)).Rows.count

'Sum the column of "Multiple Readings" to determine how many rows of
duplicates will be deleted
Cells(row, 5).Select
Range(Selection, Selection.End(xlDown)).Select
del = Application.WorksheetFunction.sum(Selection)

count = count - del
```

```vba
'Average multiple readings on one day and delete extra rows
For row = 3 To count + 1

    If Cells(row, date_col) = Cells(row + 1, date_col) Then

        numb_dup = 1        'Number of duplicates or "Multiple Readings" there are
for one date
        sum = Cells(row, res_col)

        Do Until Cells(row, date_col) <> Cells(row + 1, date_col)

            numb_dup = numb_dup + 1        'Advance number of duplicates
            sum = sum + Cells(row + 1, res_col)
            row = row + 1

        Loop

        Cells(row - numb_dup + 1, 1) = numb_dup
        Ave = sum / numb_dup
        Cells(row - numb_dup + 1, res_col) = Ave
        Range(Cells(row - numb_dup + 2, 2), Cells(row, 5)).Select
        Selection.Delete Shift:=xlUp
        row = row - numb_dup

    End If

Next row

row = 3

'Interpolation algorithm
For row = 3 To count + 1

    dx = Cells(row + 1, date_col) - Cells(row, date_col)
    dy = Cells(row + 1, res_col) - Cells(row, res_col)
    slope = dy / dx

    int_date_current = Cells(row, date_col)
    int_res_current = Cells(row, res_col)

    'Add comment indicating number of samples being averaged
    If Application.WorksheetFunction.IsNumber(Cells(row, 1)) = True Then
        comment_num = Cells(row, 1).Value
        Cells(int_row, comments_col) = "Average of " & comment_num & "
samples"
    End If
```

```vba
        Do Until int_date_current = Cells(row + 1, date_col)

            Cells(int_row, int_date_col) = int_date_current
            Cells(int_row, int_res_col) = int_res_current
            int_date_current = int_date_current + 1          'Advance date by one day
            int_res_current = int_res_current + slope         'Advance result by one time
step
            int_row = int_row + 1                            'Advance interpolation row

        Loop

    Next row

    Cells(int_row, int_date_col) = int_date_current          'Print last value in loop
    Cells(int_row, int_res_col) = int_res_current            'Print last value in loop

    'Format Interpolated Data
    Cells(3, int_date_col).Select
        Range(Selection, Selection.End(xlDown)).Select
        Selection.NumberFormat = "m/d/yyyy"
    Cells(3, int_res_col).Select
        Range(Selection, Selection.End(xlDown)).Select
        Selection.NumberFormat = "0.00"
    Range(Cells(3, int_date_col), Cells(3, comments_col)).Select
    Range(Selection, Selection.End(xlDown)).Select
        With Selection
            .HorizontalAlignment = xlCenter
            .VerticalAlignment = xlBottom
            .WrapText = False
            .Orientation = 0
            .AddIndent = False
            .IndentLevel = 0
            .ShrinkToFit = False
            .ReadingOrder = xlContext
            .MergeCells = False
        End With

    Cells(3, int_res_col + 1).Select

    End Sub
```

# APPENDIX C: GIS DATA PROCESSING TIPS

How to clip and re-project PRISM data sets from .asc to UTM

- Download 4km PRISM .asc
- Pull into GIS and zoom to desired clipping extent
- Right click .asc file in Table Of Contents, click Data, click Export data:
  - Extent: Data Frame (Current)
  - Spatial Reference: Raster Dataset (Original)
  - Update Location
  - Update Name
  - Format: TIFF
  - Click "Save"
- Search Catalog: Project Raster (Data Management)
  - Input Raster: Recently exported .tif
  - Output Raster Dataset: Update location and name
  - Output Coordinate System: NAD 1983 UTM Zone 15N
  - Click "OK"

How to increase raster resolution (4 km grid to 30 m grid)

- Make sure data set has been projected to project coordinate system
- Search Catalog: Resample (Data Management)
  - Input Raster: 4 km grid
  - Output Raster Dataset: Update location and name
  - Update X: 30
  - Update Y: 30

How to process land use raster to get row crop percentages

- Search Catalog: Polygon to Raster
  - Input Features: .shp file (i.e. watershed polygon)
  - Value Field: DNR Ambient ID
  - Output Raster Dataset: Update location and name
  - Cellsize: Select land use raster
  - Click "OK"
- Search Catalog: Times
  - Input Raster or Constant Value 1: Recently exported watershed raster
  - Input Raster or Constant Value 2: Land use raster
  - Output Raster: Update location and name
  - Click "OK"

<u>How to obtain precipitation, % tiled soils, % manure and average slope</u>
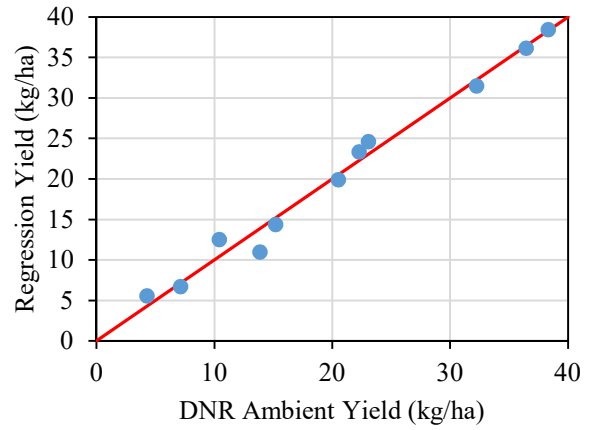
- Search Catalog: Zonal Statistics as Table (Spatial Analyst)
    - <u>Input Raster or Feature Zone Data:</u> .shp file (i.e. watershed polygon)
    - <u>Zone Field:</u> .shp field to calculate statistics on (i.e. DNR Ambient ID)
    - <u>Input Value Raster:</u> Raster to find stats for (i.e. Precipitation grid)
    - <u>Output Table:</u> Update location and name
    - <u>Statistics Type:</u>
        - PRISM Precipitation: Sum
        - Tiled Soils: Sum
        - Manure: Sum
        - Slope: Average
    - Click "OK"

# APPENDIX D: ADDITIONAL GRAPHS

*Figure D-1: Water yield regression scatterplots for 23 main study basins.*
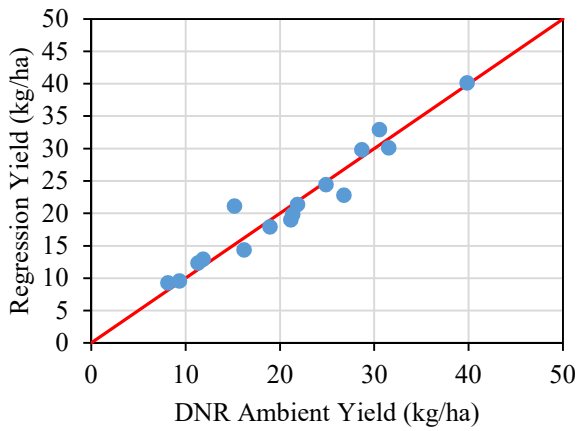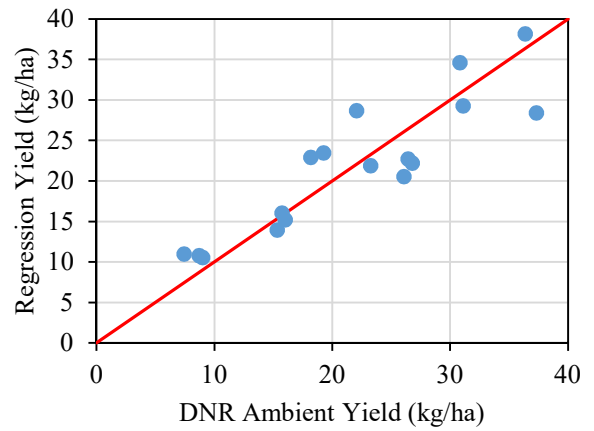
*Figure D-1 (Cont.)*

99

19 ——— Regression-Ambient Agreement

20 ——— Regression-Ambient Agreement
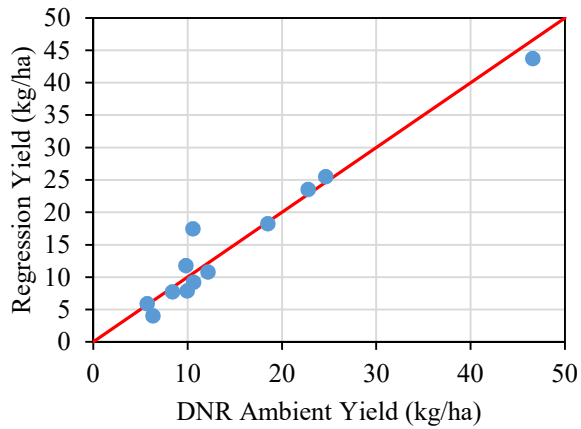
21 ——— Regression-Ambient Agreement
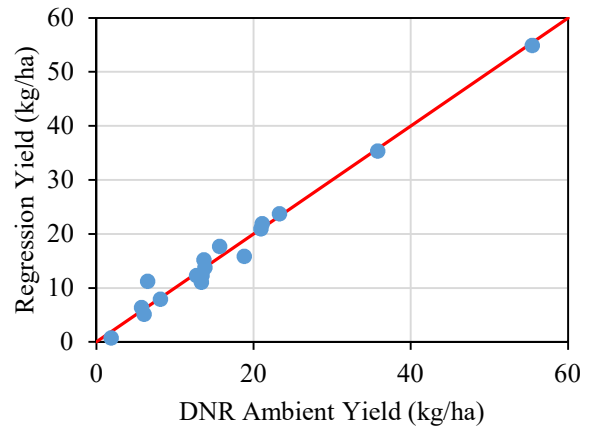
22 ——— Regression-Ambient Agreement
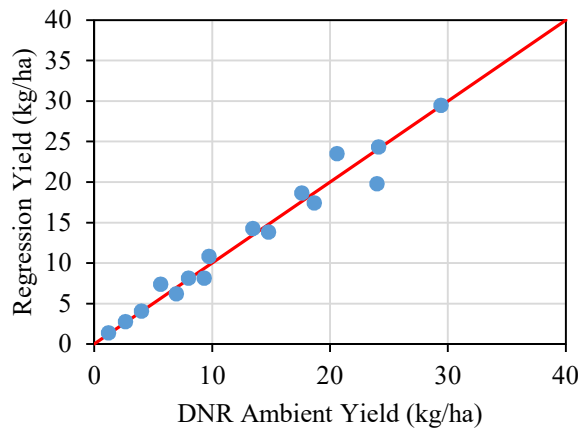
23 ——— Regression-Ambient Agreement
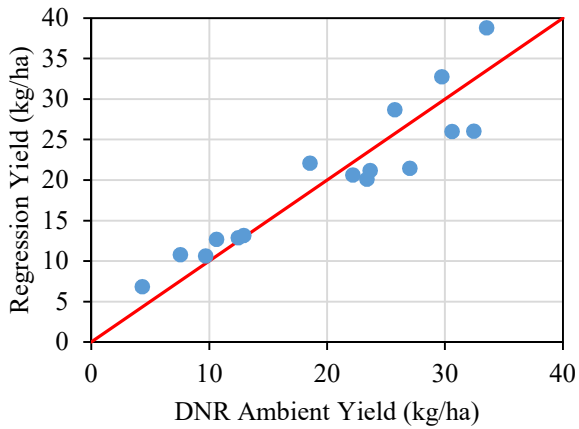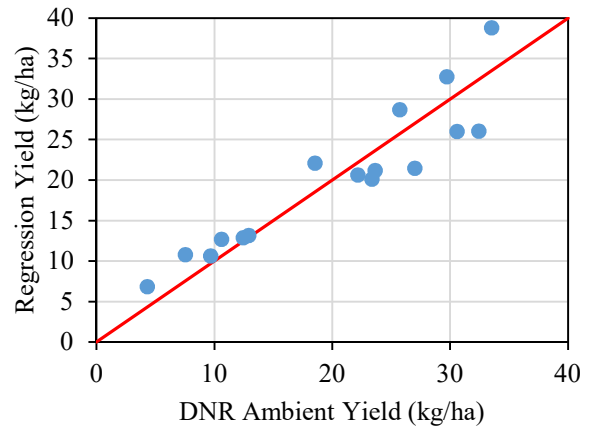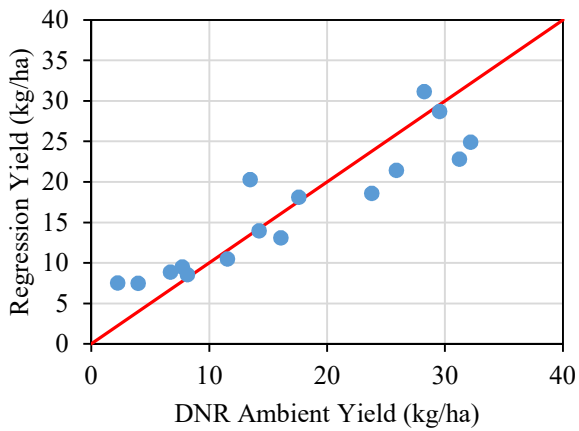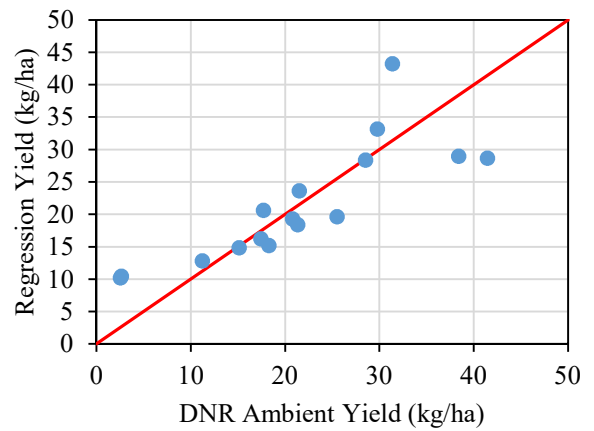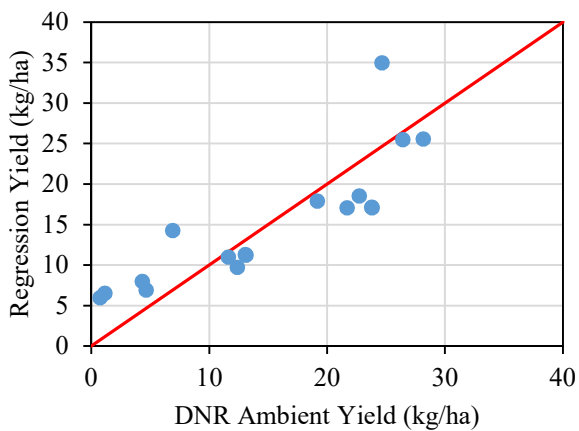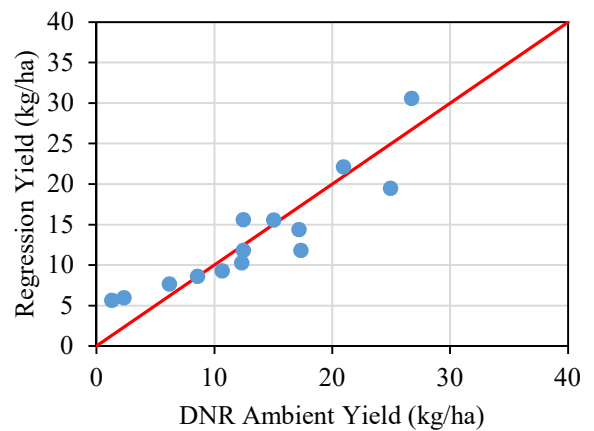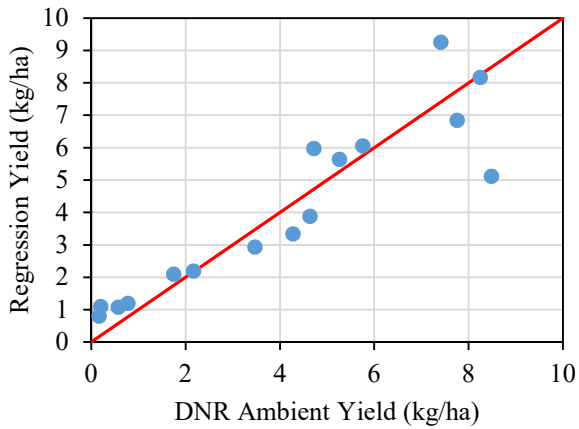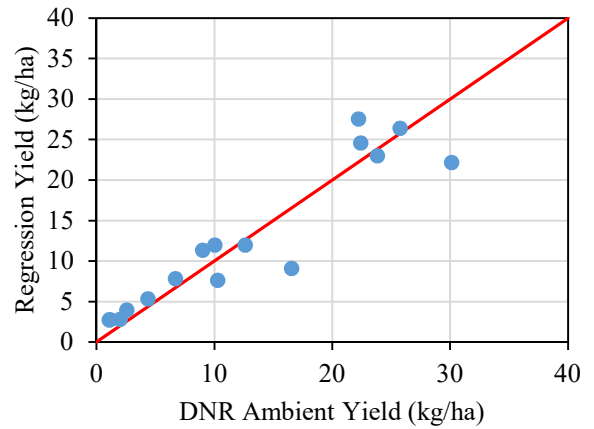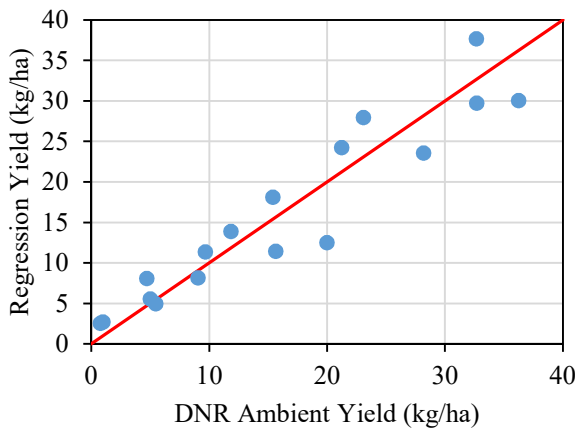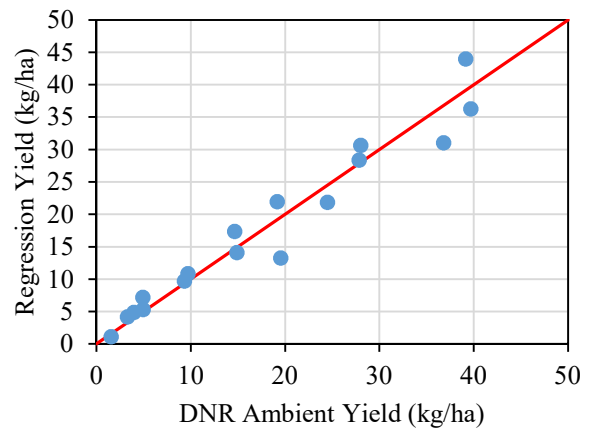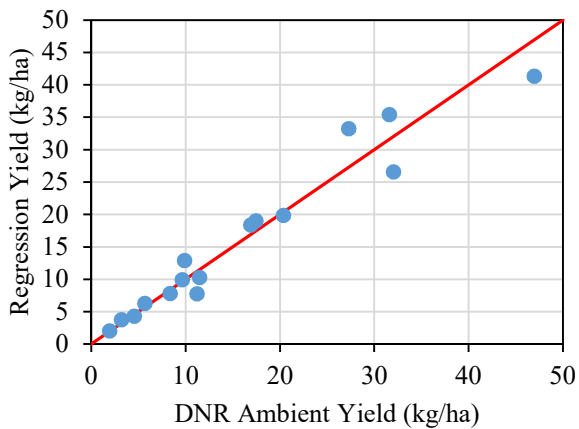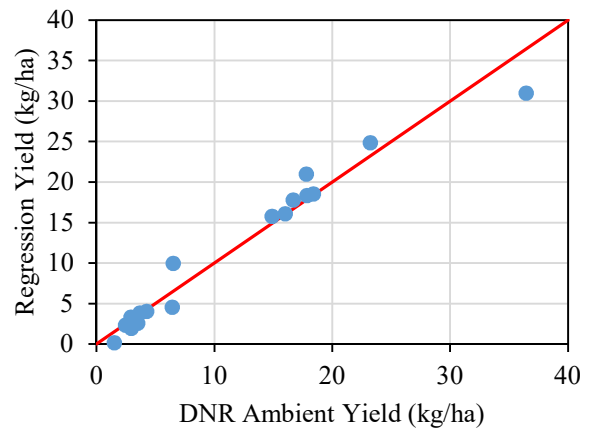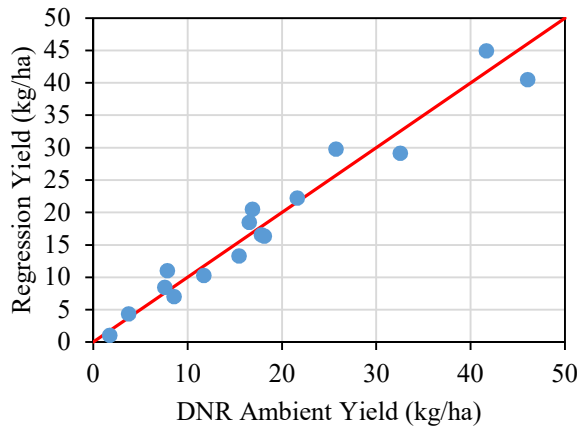
# APPENDIX E: ADDITIONAL LINEAR REGRESSION MODELS

Temporal Simulation 2: Precipitation Yield Regression

*Equation E-1: Precipitation yield temporal regression.*

$$Load\ [Mg/year](or\ Yield\ [kg/ha/year]) = m * Precipitation\ [mm] + b$$

*Table E-1: Precipitation yield regression parameters.*

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | R² |
|---|---|---|---|---|---|
| 1 | -4735 | 9.39 | -23.82 | 0.0472 | 0.586 |
| 2 | -2296 | 3.71 | -40.53 | 0.0655 | 0.808 |
| 3 | -82 | 0.25 | -9.21 | 0.0278 | 0.365 |
| 4 | -15486 | 25.61 | -38.49 | 0.0637 | 0.743 |
| 4.1 | -3327 | 5.22 | -31.93 | 0.0501 | 0.756 |
| 5 | -4612 | 8.60 | -30.19 | 0.0563 | 0.662 |
| 6 | -20347 | 35.73 | -33.66 | 0.0591 | 0.788 |
| 6.1 | -8202 | 15.15 | -34.45 | 0.0636 | 0.715 |
| 7 | -72396 | 124.81 | -35.91 | 0.0619 | 0.773 |
| 7.01 | -74670 | 125.50 | -41.48 | 0.0697 | 0.711 |
| 7.02 | -63948 | 109.84 | -38.94 | 0.0669 | 0.701 |
| 7.03 | -5170 | 8.54 | -61.29 | 0.1012 | 0.754 |
| 7.04 | -45819 | 85.57 | -33.79 | 0.0631 | 0.571 |
| 7.05 | -4596 | 7.87 | -54.40 | 0.0931 | 0.779 |
| 7.06 | -37291 | 69.47 | -30.51 | 0.0568 | 0.571 |
| 7.07 | -5453 | 9.27 | -53.46 | 0.0908 | 0.750 |
| 7.08 | -13183 | 26.02 | -30.45 | 0.0601 | 0.539 |
| 7.09 | -7567 | 15.06 | -34.27 | 0.0682 | 0.695 |
| 7.1 | -6575 | 16.80 | -14.67 | 0.0375 | 0.430 |
| 7.11 | -8232 | 17.69 | -29.00 | 0.0623 | 0.498 |
| 7.12 | -2469 | 6.39 | -14.86 | 0.0385 | 0.476 |
| 7.13 | -1327 | 3.85 | -11.29 | 0.0327 | 0.425 |
| 8 | -22517 | 47.18 | -20.28 | 0.0425 | 0.711 |
| 8.1 | -4892 | 8.37 | -30.14 | 0.0515 | 0.665 |
| 8.2 | -25023 | 45.12 | -29.14 | 0.0525 | 0.760 |
| 8.3 | -1967 | 3.31 | -37.69 | 0.0634 | 0.663 |
| 8.4 | -23381 | 42.37 | -28.69 | 0.0520 | 0.754 |
| 8.5 | -17583 | 32.26 | -41.57 | 0.0763 | 0.797 |
| 8.6 | -15997 | 29.07 | -42.16 | 0.0766 | 0.777 |
| 8.7 | 400 | 2.58 | 3.62 | 0.0234 | 0.134 |
| 9 | -3561 | 7.09 | -21.63 | 0.0431 | 0.657 |
| 10 | -8851 | 19.77 | -20.84 | 0.0466 | 0.706 |
| 10.1 | -2033 | 4.66 | -19.80 | 0.0454 | 0.632 |
| 10.2 | -4232 | 9.37 | -27.88 | 0.0617 | 0.672 |

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | $R^2$ |
|---|---|---|---|---|---|
| 11 | -2490 | 4.72 | -18.05 | 0.0342 | 0.586 |
| 12 | -89111 | 166.20 | -25.64 | 0.0478 | 0.800 |
| 12.01 | -87457 | 164.27 | -25.50 | 0.0479 | 0.791 |
| 12.02 | -316 | 0.55 | -3.28 | 0.0057 | 0.737 |
| 12.03 | -613 | 1.04 | -4.99 | 0.0085 | 0.725 |
| 12.04 | -1301 | 2.59 | -10.27 | 0.0204 | 0.618 |
| 12.05 | -1154 | 2.70 | -12.75 | 0.0298 | 0.503 |
| 12.06 | -28461 | 57.33 | -32.08 | 0.0646 | 0.732 |
| 12.07 | -9522 | 16.54 | -37.51 | 0.0652 | 0.753 |
| 12.08 | -28518 | 67.28 | -18.84 | 0.0445 | 0.429 |
| 12.09 | -3472 | 6.86 | -36.28 | 0.0717 | 0.762 |
| 12.1 | -5807 | 13.72 | -31.55 | 0.0745 | 0.619 |
| 12.11 | -12989 | 39.27 | -11.78 | 0.0356 | 0.307 |
| 12.12 | -6887 | 16.26 | -29.97 | 0.0708 | 0.551 |
| 12.13 | -5317 | 16.73 | -8.84 | 0.0278 | 0.327 |
| 13 | -1400 | 2.26 | -7.78 | 0.0125 | 0.822 |
| 14 | -5929 | 9.30 | -28.97 | 0.0455 | 0.858 |
| 15 | -8907 | 14.97 | -33.68 | 0.0566 | 0.821 |
| 16 | -10561 | 17.59 | -42.10 | 0.0701 | 0.882 |
| 17 | -7836 | 13.96 | -33.24 | 0.0592 | 0.823 |
| 18 | -2520 | 4.58 | -23.82 | 0.0433 | 0.713 |
| 19 | -5183 | 10.07 | -31.07 | 0.0603 | 0.601 |
| 20 | -10691 | 25.49 | -15.36 | 0.0366 | 0.385 |
| 20.1 | -8804 | 18.90 | -18.29 | 0.0393 | 0.435 |
| 20.2 | -2555 | 5.64 | -22.44 | 0.0495 | 0.480 |
| 21 | -3802 | 6.67 | -36.48 | 0.0640 | 0.582 |
| 22 | -7423 | 15.32 | -32.34 | 0.0668 | 0.387 |
| 23 | -9072 | 19.98 | -20.85 | 0.0459 | 0.339 |

Temporal Simulation 3: Runoff Coefficient Regression

*Equation E-2: Runoff coefficient temporal regression.*

$$Load\ [Mg/year](or\ Yield\ [kg/ha/year]) = m * Runoff\ Coefficient + b$$

*Table E-2: Runoff coefficient regression parameters.*

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | $R^2$ |
|---|---|---|---|---|---|
| 1 | -2000 | 17377.75 | -10.06 | 87.44 | 0.833 |
| 2 | -701 | 5759.95 | -12.38 | 101.69 | 0.916 |
| 3 | -55 | 701.09 | -6.16 | 78.95 | 0.801 |
| 4 | -3802 | 39473.11 | -9.45 | 98.12 | 0.891 |
| 4.1 | -603 | 7769.92 | -5.79 | 74.57 | 0.817 |
| 5 | -2008 | 17178.63 | -13.14 | 112.46 | 0.860 |
| 6 | -4216 | 50767.40 | -6.97 | 83.98 | 0.767 |
| 6.1 | -319 | 19152.58 | -1.34 | 80.45 | 0.684 |
| 7 | -12091 | 165290.29 | -6.00 | 81.99 | 0.808 |
| 7.01 | -18322 | 178766.81 | -10.18 | 99.30 | 0.792 |
| 7.02 | -12287 | 143049.14 | -7.48 | 87.10 | 0.732 |
| 7.03 | -657 | 10158.17 | -7.78 | 120.42 | 0.847 |
| 7.04 | -14179 | 136418.83 | -10.46 | 100.6 | 0.745 |
| 7.05 | -603 | 10202.12 | -7.13 | 120.75 | 0.865 |
| 7.06 | -8503 | 100714.34 | -6.96 | 82.40 | 0.642 |
| 7.07 | -899 | 12448.44 | -8.81 | 122.04 | 0.825 |
| 7.08 | -2580 | 40089.14 | -5.96 | 92.61 | 0.665 |
| 7.09 | -757 | 20875.05 | -3.43 | 94.54 | 0.764 |
| 7.1 | -1200 | 31324.94 | -2.68 | 69.90 | 0.659 |
| 7.11 | -2179 | 30087.06 | -7.68 | 106.01 | 0.604 |
| 7.12 | -510 | 11310.36 | -3.07 | 68.08 | 0.668 |
| 7.13 | -211 | 7133.64 | -1.79 | 60.66 | 0.648 |
| 8 | -206 | 65620.02 | -0.19 | 59.11 | 0.700 |
| 8.1 | -392 | 10747.95 | -2.42 | 66.22 | 0.865 |
| 8.2 | -1528 | 53424.46 | -1.78 | 62.20 | 0.840 |
| 8.3 | -210 | 4371.74 | -4.02 | 83.77 | 0.755 |
| 8.4 | -1855 | 51923.80 | -2.28 | 63.71 | 0.842 |
| 8.5 | -1502 | 42248.79 | -3.55 | 99.88 | 0.742 |
| 8.6 | -1608 | 36030.21 | -4.24 | 94.96 | 0.799 |
| 8.7 | -284 | 9816.01 | -2.57 | 88.91 | 0.912 |
| 9 | -314 | 10941.30 | -1.91 | 66.46 | 0.858 |
| 10 | 596 | 28439.79 | 1.40 | 66.97 | 0.725 |
| 10.1 | 118 | 7133.94 | 1.15 | 69.47 | 0.728 |
| 10.2 | 854 | 12405.72 | 5.63 | 81.72 | 0.642 |
| 11 | 45 | 7229.59 | 0.33 | 52.41 | 0.825 |
| 12 | -2182 | 188744.63 | -0.63 | 54.31 | 0.833 |
| 12.01 | -1933 | 186459.08 | -0.56 | 54.37 | 0.838 |

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | $R^2$ |
|---|---|---|---|---|---|
| 12.02 | -4 | 776.27 | -0.05 | 8.06 | 0.829 |
| 12.03 | -36 | 1640.08 | -0.29 | 13.35 | 0.853 |
| 12.04 | -14 | 4072.04 | -0.11 | 32.14 | 0.783 |
| 12.05 | 59 | 4617.62 | 0.65 | 51.05 | 0.750 |
| 12.06 | -1596 | 75249.86 | -1.80 | 84.82 | 0.792 |
| 12.07 | -2183 | 27303.21 | -8.60 | 107.56 | 0.697 |
| 12.08 | -577 | 98154.13 | -0.38 | 64.85 | 0.839 |
| 12.09 | 23 | 8974.55 | 0.24 | 93.78 | 0.683 |
| 12.1 | 311 | 17696.76 | 1.69 | 96.16 | 0.613 |
| 12.11 | 2668 | 59734.16 | 2.42 | 54.15 | 0.730 |
| 12.12 | 1476 | 18895.66 | 6.42 | 82.24 | 0.531 |
| 12.13 | 1280 | 25274.10 | 2.13 | 42.03 | 0.722 |
| 13 | -23 | 3452.94 | -0.13 | 19.17 | 0.836 |
| 14 | -536 | 13071.99 | -2.62 | 63.88 | 0.855 |
| 15 | -1455 | 21813.18 | -5.50 | 82.47 | 0.863 |
| 16 | -1901 | 25742.72 | -7.58 | 102.63 | 0.873 |
| 17 | -1325 | 24027.51 | -5.62 | 101.92 | 0.785 |
| 18 | -722 | 9951.91 | -6.83 | 94.08 | 0.733 |
| 19 | -917 | 18413.08 | -5.50 | 110.38 | 0.785 |
| 20 | -530 | 40966.10 | -0.76 | 58.87 | 0.834 |
| 20.1 | 159 | 25097.69 | 0.33 | 52.13 | 0.891 |
| 20.2 | 29 | 7395.08 | 0.26 | 64.94 | 0.877 |
| 21 | -727 | 13010.96 | -6.98 | 124.85 | 0.743 |
| 22 | -1404 | 28542.98 | -6.12 | 124.35 | 0.860 |
| 23 | -1153 | 35219.32 | -2.65 | 80.94 | 0.889 |

Temporal Simulation 4: Baseflow Yield Regression

*Equation E-3: Baseflow yield temporal regression.*

$$Load\ [Mg/year](or\ Yield\ [kg/ha/year]) = m * Baseflow[mm] + b$$

*Table E-3: Baseflow yield regression parameters.*

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | $R^2$ |
|---|---|---|---|---|---|
| 1 | -1461 | 23.68 | -7.35 | 0.1192 | 0.967 |
| 2 | -325 | 6.78 | -5.75 | 0.1197 | 0.975 |
| 3 | -39 | 0.98 | -4.37 | 0.1102 | 0.962 |
| 4 | -1776 | 49.62 | -4.41 | 0.1233 | 0.938 |
| 4.1 | -230 | 9.91 | -2.20 | 0.0951 | 0.859 |
| 5 | -761 | 19.26 | -4.98 | 0.1261 | 0.953 |
| 6 | -443 | 59.67 | -0.73 | 0.0987 | 0.813 |
| 6.1 | 303 | 28.80 | 1.27 | 0.1210 | 0.789 |
| 7 | -2679 | 202.27 | -1.33 | 0.1003 | 0.863 |
| 7.01 | -9768 | 232.62 | -5.43 | 0.1292 | 0.867 |
| 7.02 | -6592 | 193.32 | -4.01 | 0.1177 | 0.836 |
| 7.03 | -11 | 12.87 | -0.13 | 0.1526 | 0.881 |
| 7.04 | -8808 | 187.83 | -6.50 | 0.1385 | 0.828 |
| 7.05 | 35 | 13.19 | 0.42 | 0.1561 | 0.909 |
| 7.06 | -6267 | 147.45 | -5.13 | 0.1206 | 0.771 |
| 7.07 | -111 | 16.12 | -1.09 | 0.1580 | 0.851 |
| 7.08 | -2312 | 62.91 | -5.34 | 0.1453 | 0.787 |
| 7.09 | 365 | 27.55 | 1.65 | 0.1248 | 0.827 |
| 7.1 | -1046 | 49.62 | -2.33 | 0.1107 | 0.780 |
| 7.11 | -2824 | 53.16 | -9.95 | 0.1873 | 0.778 |
| 7.12 | -380 | 18.36 | -2.29 | 0.1105 | 0.806 |
| 7.13 | -111 | 11.41 | -0.94 | 0.0970 | 0.760 |
| 8 | 5519 | 68.48 | 4.97 | 0.0617 | 0.719 |
| 8.1 | 71 | 16.96 | 0.44 | 0.1045 | 0.879 |
| 8.2 | 2822 | 59.89 | 3.29 | 0.0697 | 0.810 |
| 8.3 | -27 | 6.56 | -0.52 | 0.1258 | 0.823 |
| 8.4 | 2457 | 58.50 | 3.01 | 0.0718 | 0.805 |
| 8.5 | 1200 | 52.43 | 2.84 | 0.1240 | 0.755 |
| 8.6 | 786 | 44.92 | 2.07 | 0.1184 | 0.797 |
| 8.7 | -219 | 17.90 | -1.98 | 0.1621 | 0.970 |
| 9 | 491 | 13.90 | 2.98 | 0.0844 | 0.824 |
| 10 | 3180 | 30.09 | 7.49 | 0.0709 | 0.676 |
| 10.1 | 716 | 8.57 | 6.97 | 0.0834 | 0.648 |
| 10.2 | 1523 | 16.44 | 10.03 | 0.1083 | 0.635 |
| 11 | 755 | 9.76 | 5.47 | 0.0708 | 0.660 |
| 12 | 12409 | 214.24 | 3.57 | 0.0616 | 0.815 |
| 12.01 | 12596 | 211.68 | 3.67 | 0.0617 | 0.813 |

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | $R^2$ |
|---|---|---|---|---|---|
| 12.02 | 48 | 1.55 | 0.49 | 0.0160 | 0.756 |
| 12.03 | 32 | 3.35 | 0.26 | 0.0272 | 0.845 |
| 12.04 | 189 | 6.28 | 1.49 | 0.0496 | 0.746 |
| 12.05 | 328 | 6.47 | 3.63 | 0.0716 | 0.685 |
| 12.06 | 3632 | 95.22 | 4.09 | 0.1073 | 0.734 |
| 12.07 | -634 | 35.81 | -2.50 | 0.1411 | 0.761 |
| 12.08 | 4723 | 133.35 | 3.12 | 0.0881 | 0.814 |
| 12.09 | 530 | 11.91 | 5.54 | 0.1245 | 0.725 |
| 12.1 | 978 | 29.13 | 5.31 | 0.1583 | 0.746 |
| 12.11 | 4642 | 90.56 | 4.21 | 0.0821 | 0.739 |
| 12.12 | 1978 | 32.01 | 8.61 | 0.1393 | 0.601 |
| 12.13 | 1765 | 41.25 | 2.94 | 0.0686 | 0.793 |
| 13 | 108 | 5.55 | 0.60 | 0.0308 | 0.816 |
| 14 | -27 | 18.78 | -0.13 | 0.0918 | 0.834 |
| 15 | -356 | 27.32 | -1.35 | 0.1033 | 0.870 |
| 16 | -663 | 30.66 | -2.64 | 0.1222 | 0.941 |
| 17 | -495 | 31.36 | -2.10 | 0.1330 | 0.949 |
| 18 | -457 | 13.95 | -4.32 | 0.1319 | 0.960 |
| 19 | -472 | 26.49 | -2.83 | 0.1588 | 0.951 |
| 20 | 486 | 65.04 | 0.70 | 0.0935 | 0.891 |
| 20.1 | 702 | 41.49 | 1.46 | 0.0862 | 0.925 |
| 20.2 | 170 | 12.90 | 1.50 | 0.1132 | 0.906 |
| 21 | -520 | 19.92 | -4.99 | 0.1911 | 0.971 |
| 22 | -907 | 47.44 | -3.95 | 0.2067 | 0.984 |
| 23 | -896 | 66.91 | -2.06 | 0.1538 | 0.970 |

Temporal Simulation 5: Water Yield Regression

*Equation E-4: Water yield temporal regression.*

$$Load\ [Mg/year](or\ Yield\ [kg/ha/year]) = m * Streamflow[mm] + b$$

*Table E-4: Water yield regression parameters.*

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | $R^2$ |
|---|---|---|---|---|---|
| 1 | -1038 | 15.69 | -5.22 | 0.0790 | 0.973 |
| 2 | -236 | 4.46 | -4.17 | 0.0787 | 0.985 |
| 3 | -34 | 0.70 | -3.80 | 0.0792 | 0.968 |
| 4 | -985 | 31.69 | -2.45 | 0.0788 | 0.949 |
| 4.1 | -14 | 5.81 | -0.14 | 0.0558 | 0.856 |
| 5 | -388 | 12.46 | -2.54 | 0.0816 | 0.965 |
| 6 | 796 | 37.24 | 1.32 | 0.0616 | 0.799 |
| 6.1 | 993 | 15.77 | 4.17 | 0.0662 | 0.744 |
| 7 | -189 | 136.50 | -0.09 | 0.0677 | 0.858 |
| 7.01 | -6651 | 152.70 | -3.69 | 0.0848 | 0.866 |
| 7.02 | -3326 | 125.36 | -2.03 | 0.0763 | 0.811 |
| 7.03 | 23 | 8.26 | 0.27 | 0.0979 | 0.899 |
| 7.04 | -6356 | 123.41 | -4.69 | 0.0910 | 0.838 |
| 7.05 | 179 | 7.83 | 2.12 | 0.0926 | 0.889 |
| 7.06 | -4363 | 96.95 | -3.57 | 0.0793 | 0.782 |
| 7.07 | 32 | 9.73 | 0.32 | 0.0954 | 0.872 |
| 7.08 | -1311 | 39.01 | -3.03 | 0.0901 | 0.787 |
| 7.09 | 411 | 18.52 | 1.86 | 0.0839 | 0.844 |
| 7.1 | -585 | 32.92 | -1.31 | 0.0735 | 0.787 |
| 7.11 | -1982 | 32.36 | -6.98 | 0.1140 | 0.804 |
| 7.12 | -226 | 11.89 | -1.36 | 0.0716 | 0.805 |
| 7.13 | -13 | 7.38 | -0.11 | 0.0628 | 0.758 |
| 8 | 4888 | 50.31 | 4.40 | 0.0453 | 0.729 |
| 8.1 | 280 | 8.47 | 1.73 | 0.0522 | 0.878 |
| 8.2 | 2810 | 41.58 | 3.27 | 0.0484 | 0.811 |
| 8.3 | 56 | 3.48 | 1.07 | 0.0666 | 0.810 |
| 8.4 | 2433 | 40.27 | 2.99 | 0.0494 | 0.809 |
| 8.5 | 1385 | 34.80 | 3.27 | 0.0823 | 0.788 |
| 8.6 | 1073 | 29.53 | 2.83 | 0.0778 | 0.814 |
| 8.7 | 24 | 10.66 | 0.22 | 0.0965 | 0.971 |
| 9 | 623 | 7.84 | 3.78 | 0.0476 | 0.820 |
| 10 | 3251 | 19.86 | 7.66 | 0.0468 | 0.672 |
| 10.1 | 769 | 4.99 | 7.49 | 0.0485 | 0.651 |
| 10.2 | 1738 | 9.31 | 11.45 | 0.0613 | 0.598 |
| 11 | 647 | 4.79 | 4.69 | 0.0347 | 0.719 |
| 12 | 10562 | 159.68 | 3.04 | 0.0460 | 0.821 |
| 12.01 | 10744 | 157.90 | 3.13 | 0.0460 | 0.820 |

| Watershed .shp # | LOAD Intercept (b) | LOAD Slope (m) | YIELD Intercept (b) | YIELD Slope (m) | $R^2$ |
|---|---|---|---|---|---|
| 12.02 | 46 | 0.56 | 0.48 | 0.0058 | 0.801 |
| 12.03 | 52 | 1.21 | 0.42 | 0.0099 | 0.816 |
| 12.04 | 234 | 3.12 | 1.85 | 0.0246 | 0.738 |
| 12.05 | 348 | 3.57 | 3.85 | 0.0395 | 0.669 |
| 12.06 | 3443 | 64.35 | 3.88 | 0.0725 | 0.763 |
| 12.07 | -435 | 21.82 | -1.71 | 0.0860 | 0.786 |
| 12.08 | 4394 | 96.14 | 2.90 | 0.0635 | 0.812 |
| 12.09 | 598 | 7.18 | 6.25 | 0.0750 | 0.726 |
| 12.1 | 1058 | 18.17 | 5.75 | 0.0987 | 0.727 |
| 12.11 | 4728 | 64.35 | 4.29 | 0.0583 | 0.739 |
| 12.12 | 2370 | 17.84 | 10.32 | 0.0776 | 0.591 |
| 12.13 | 1658 | 30.55 | 2.76 | 0.0508 | 0.805 |
| 13 | 107 | 2.70 | 0.59 | 0.0150 | 0.839 |
| 14 | 113 | 10.19 | 0.55 | 0.0498 | 0.873 |
| 15 | -155 | 17.65 | -0.59 | 0.0667 | 0.891 |
| 16 | -562 | 22.09 | -2.24 | 0.0880 | 0.946 |
| 17 | -379 | 21.75 | -1.61 | 0.0923 | 0.941 |
| 18 | -483 | 10.14 | -4.57 | 0.0958 | 0.957 |
| 19 | -444 | 18.94 | -2.66 | 0.1136 | 0.954 |
| 20 | 744 | 45.15 | 1.07 | 0.0649 | 0.877 |
| 20.1 | 726 | 28.50 | 1.51 | 0.0592 | 0.920 |
| 20.2 | 251 | 8.18 | 2.20 | 0.0718 | 0.896 |
| 21 | -474 | 13.85 | -4.54 | 0.1329 | 0.949 |
| 22 | -857 | 33.70 | -3.73 | 0.1468 | 0.982 |
| 23 | -873 | 44.59 | -2.01 | 0.1025 | 0.966 |

# APPENDIX F: ADDITIONAL MLRA INFORMATION

*Table F-1: Subbasins used to formulate MLRA regression equations.*

| | Region # | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **Subbasin #** | 7.13 | 8.5 | 6 | 7.03 | 8 | 12.04 | 19 | 15 | 11 | 1 |
| | 8.7 | 8.6 | 6.1 | 7.05 | 8.1 | 12.05 | 20 | 16 | 12.02 | 2 |
| | 12.08 | 10.1 | 7 | 7.07 | 8.2 | 14 | 20.1 | 17 | 12.03 | 3 |
| | 12.1 | 10.2 | 7.01 | 7.09 | 8.3 | | 20.2 | 18 | 13 | 4 |
| | 12.11 | 12 | 7.02 | | 8.4 | | 21 | | | 4.1 |
| | 12.12 | 12.01 | 7.04 | | 9 | | 22 | | | 5 |
| | 12.13 | 12.06 | 7.06 | | 10 | | 23 | | | |
| | | 12.07 | 7.08 | | | | | | | |
| | | 12.09 | 7.1 | | | | | | | |
| | | | 7.11 | | | | | | | |
| | | | 7.12 | | | | | | | |
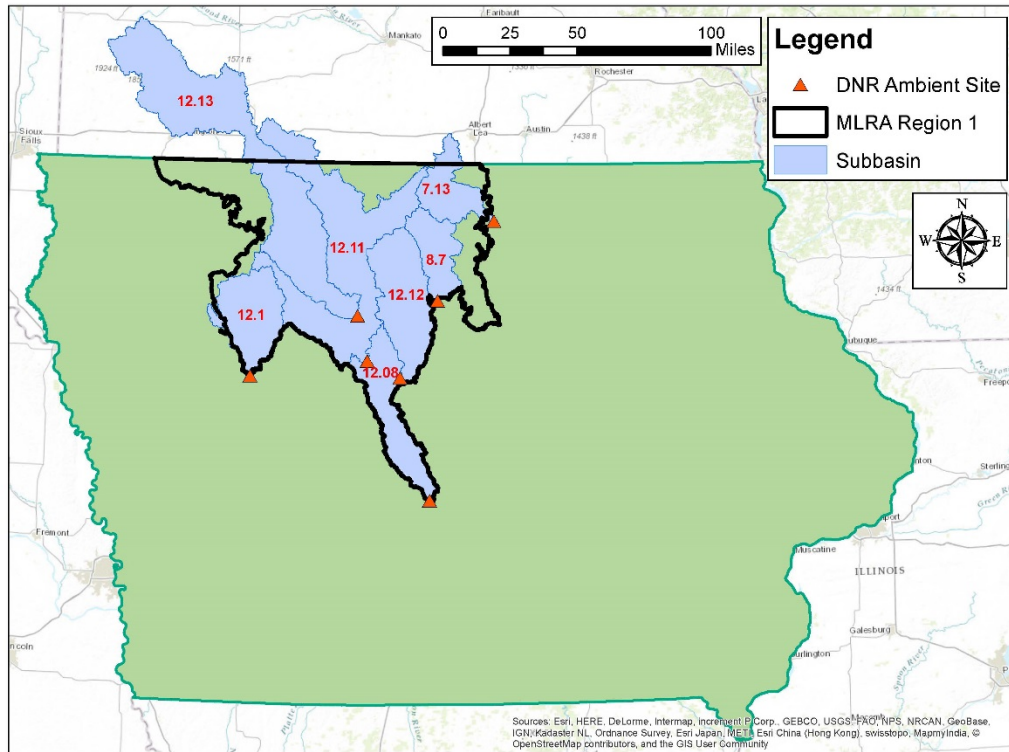


*Figure F-1: Subbasins used to formulate MLRA Region 1 regression equation.*
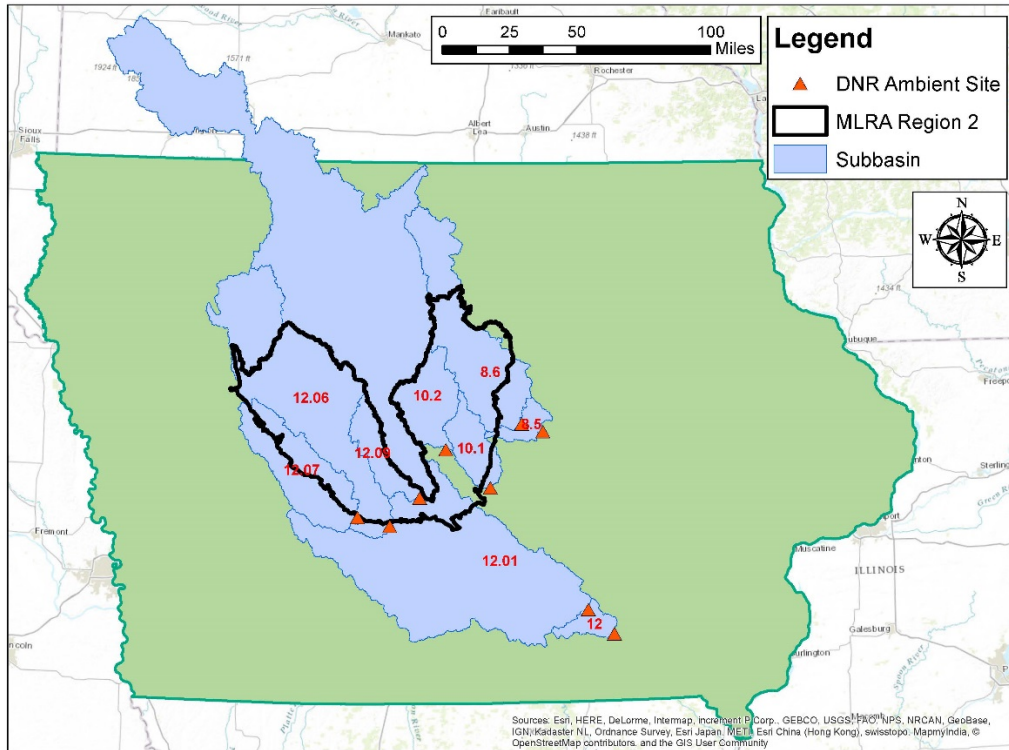
*Figure F-2: Subbasins used to formulate MLRA Region 2 regression equation.*
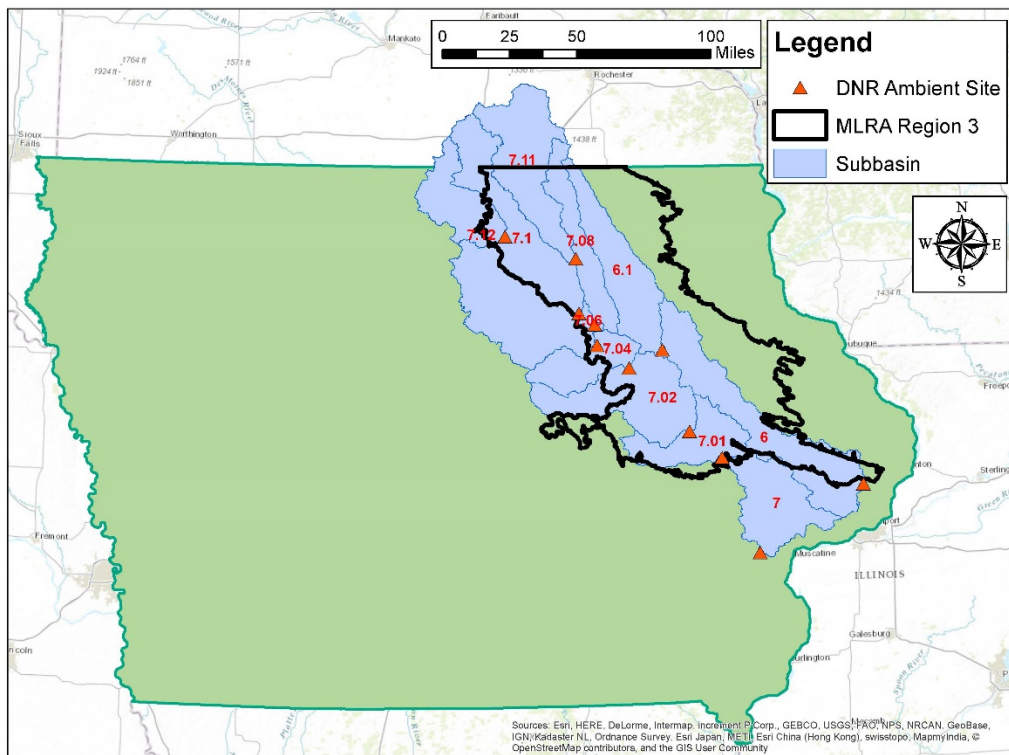


*Figure F-3: Subbasins used to formulate MLRA Region 3 regression equation.*
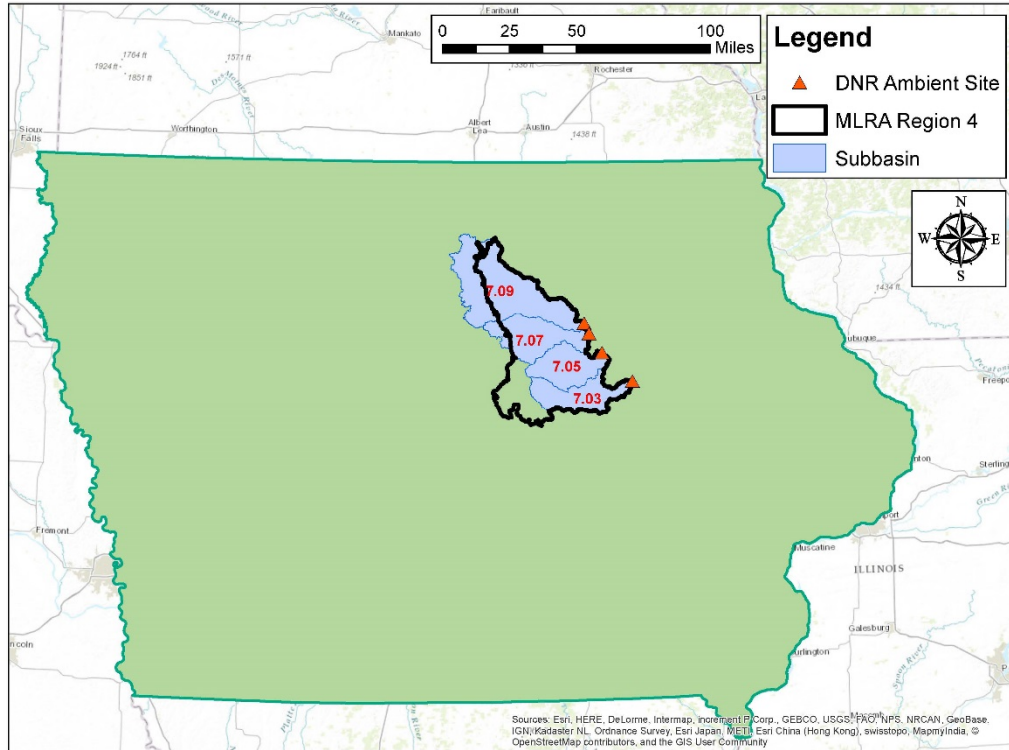
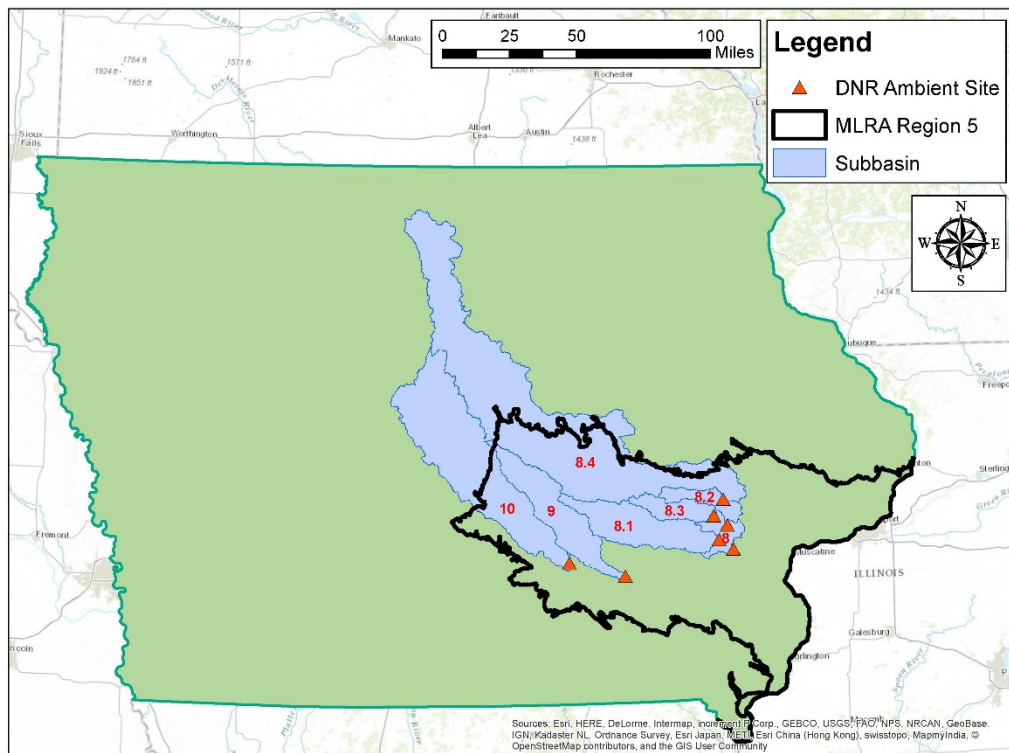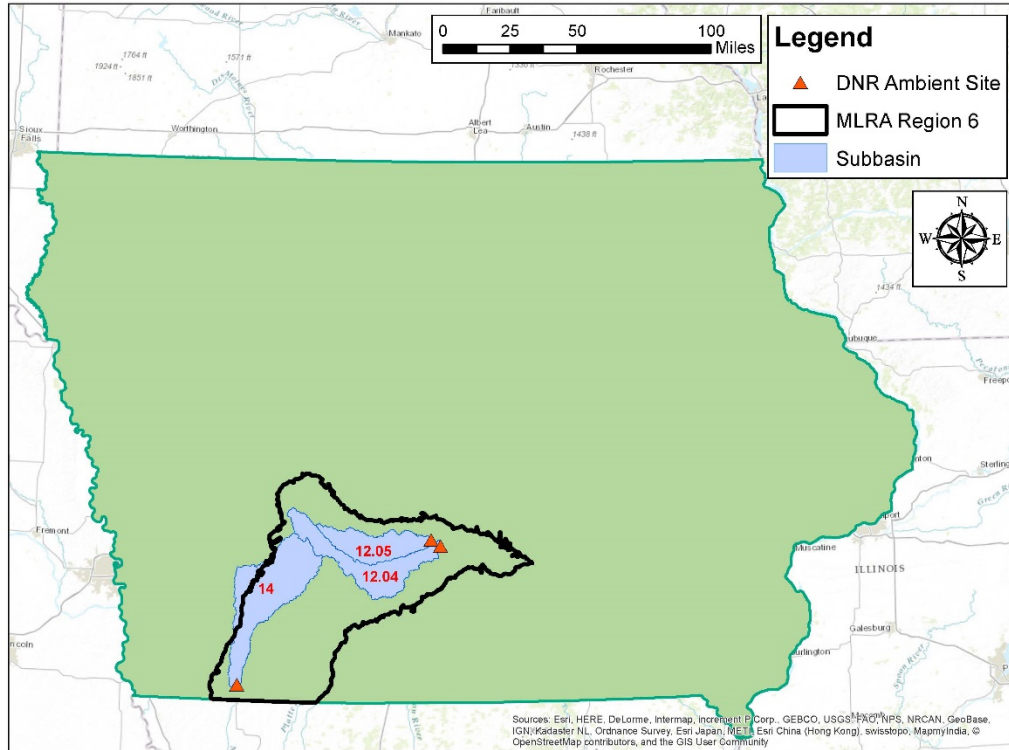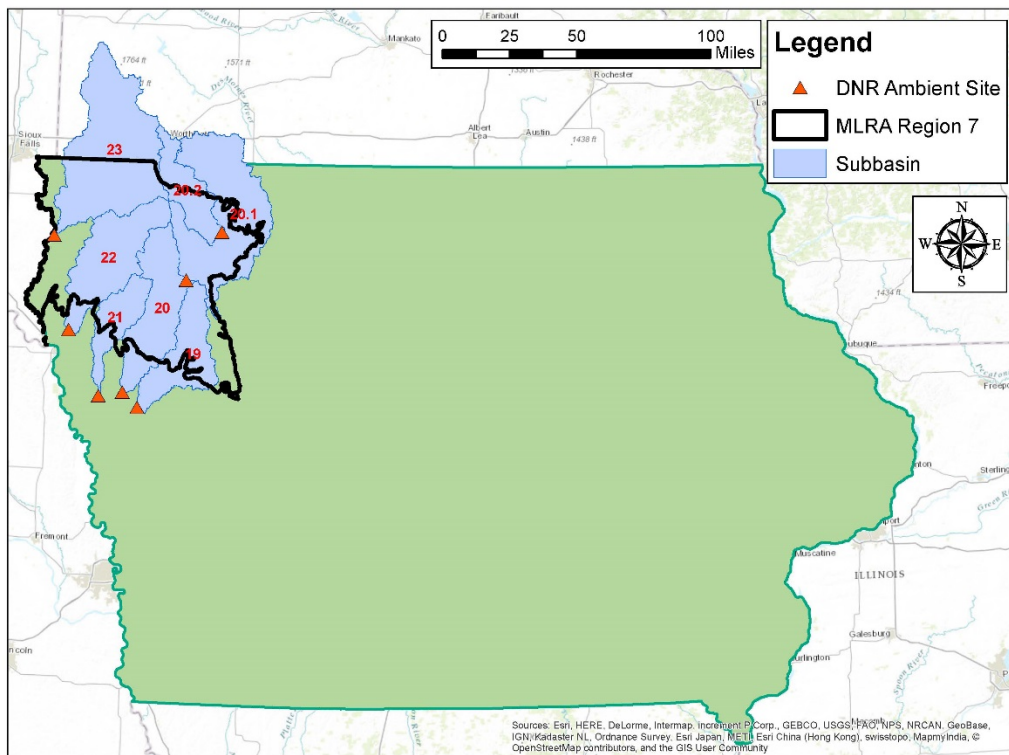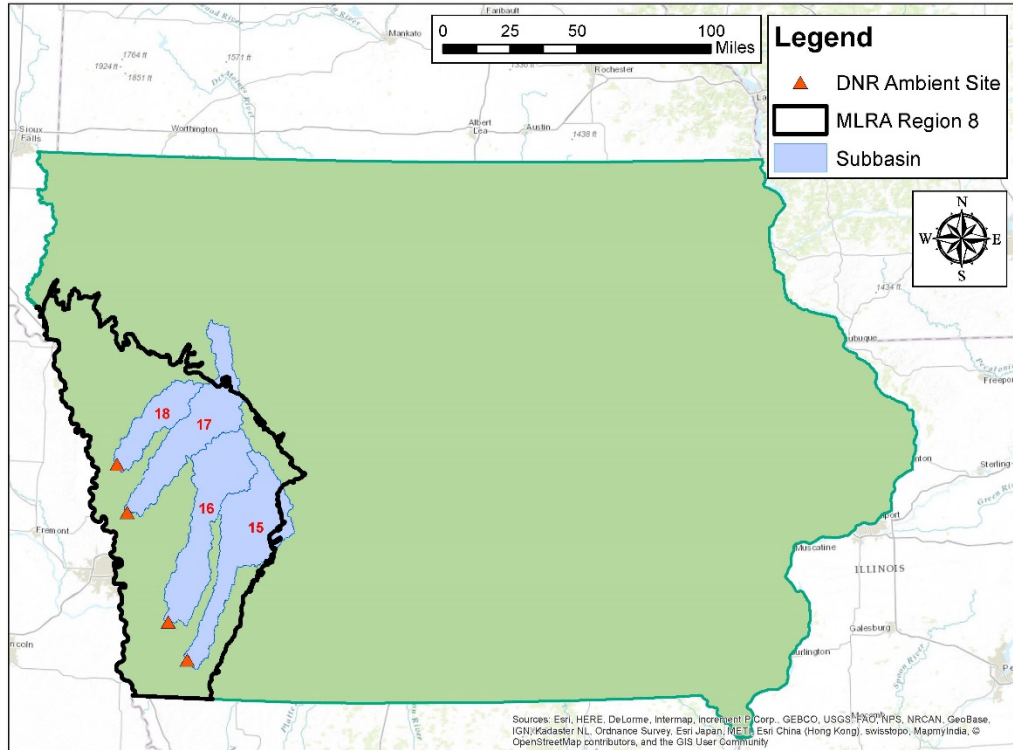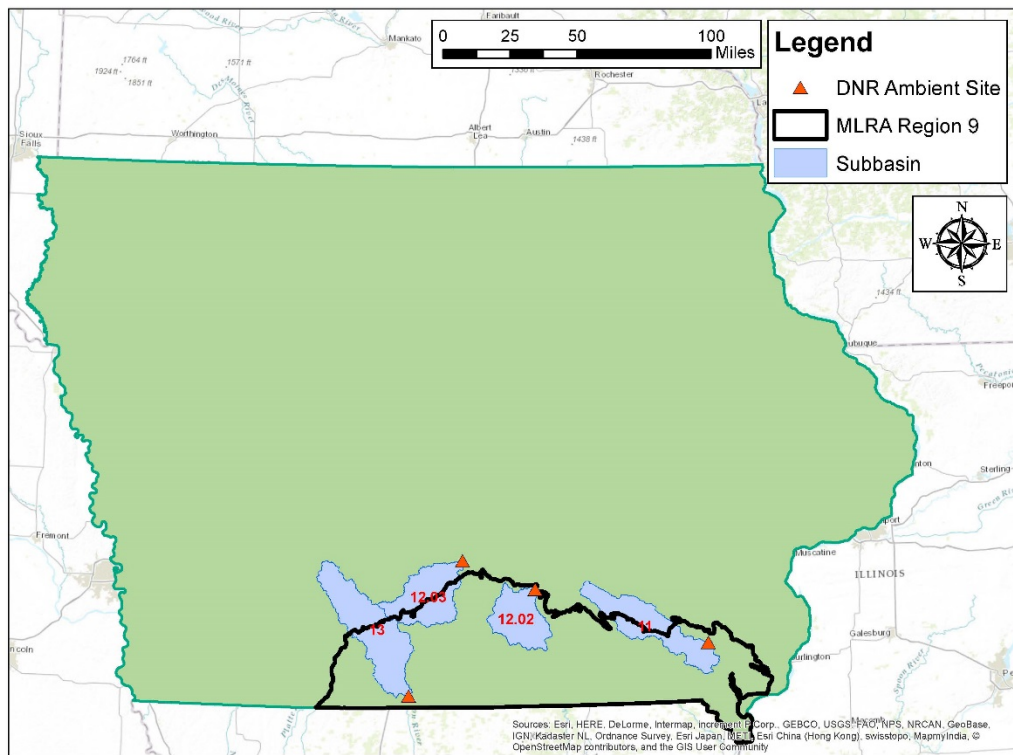*Figure F-4: Subbasins used to formulate MLRA Region 4 regression equation.*



*Figure F-5: Subbasins used to formulate MLRA Region 5 regression equation.*

*Figure F-6: Subbasins used to formulate MLRA Region 6 regression equation.*



*Figure F-7: Subbasins used to formulate MLRA Region 7 regression equation.*

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*Figure F-8: Subbasins used to formulate MLRA Region 8 regression equation.*



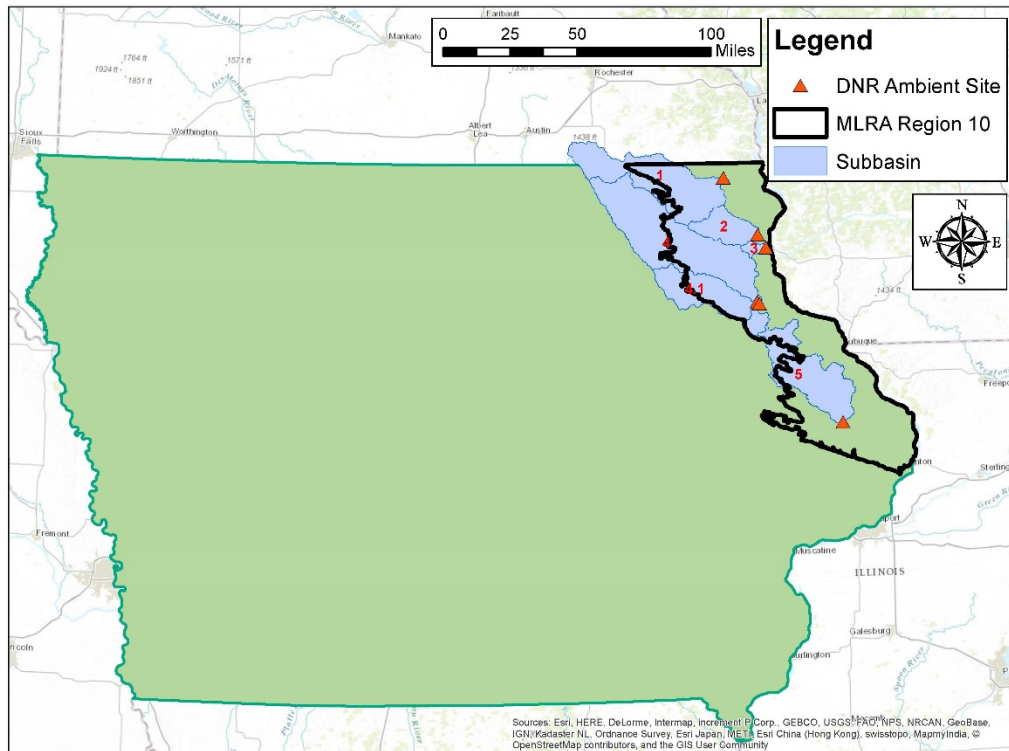*Figure F-9: Subbasins used to formulate MLRA Region 9 regression equation.*

*Figure F-10: Subbasins used to formulate MLRA Region 10 regression equation.*