Iowa Watershed Approach Phase II: North Raccoon Watershed

Project Evaluation

by

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- Members of the North Raccoon Watershed Management Authority
- Project Coordinators of the North Raccoon Watershed Management Authority
- Buena Vista County
- EOR, Inc
- Landowners and stakeholders of the North Raccoon Watershed
- City of Storm Lake
- RDG Planning & Design
- WHKS Engineering
- Northwest Iowa Planning & Development Commission

The success of the Iowa Watershed Approach (IWA) depends on collaborative partnerships among many statewide organizations and local stakeholders, who together will carry out the work necessary to achieve the goals of the IWA. Partners include, but are not limited to:

- U.S. Department of Housing and Urban Development (HUD)
- U.S. Army Corps of Engineers
- Iowa Silver Jackets Flood Risk Management Team
- Iowa Economic Development Authority
- Iowa Homeland Security and Emergency Management
- University of Iowa (IIHR—Hydroscience and Engineering, Iowa Flood Center, Center for Evaluation and Assessment)
- Iowa State University (Iowa Nutrient Research Center, Iowa Water Center, Daily Erosion Project, ISU Extension & Outreach)
- University of Northern Iowa (Tallgrass Prairie Center)
- Watershed Management Authorities and their member entities
- Iowa Department of Natural Resources
- Iowa Department of Transportation
- Iowa Association of Counties
- Iowa Department of Agriculture and Land Stewardship
- Iowa Soybean Association
- Iowa Natural Heritage Foundation
- Iowa Corn Growers Association
- Iowa Farm Bureau
- Iowa Agricultural Water Alliance
- Cities of Dubuque, Coralville, and Storm Lake
- The Nature Conservancy, Iowa Chapter
- Local Resource Conservation and Development Offices
- Benton, Buena Vista, Fremont, Iowa, Johnson, Mills, Winneshiek, and Howard counties

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1. Introduction

From 2011–2013, Iowa suffered eight Presidential Disaster Declarations encompassing 73 counties and more than 70% of the state. As devastating as these events were, this period is but a brief moment in Iowa's long history of enduring and recovering from major floods. Figure 1-1 shows just one example of the devastation caused by floods in Des Moines in 1993. Long-term data show that heavy precipitation and flood events are increasing in frequency across the Midwest, and Iowans need to be prepared for the economic, social, and environmental impacts of these changing trends.

Figure 1-1: Aerial view of flooding on the Raccoon River in Des Moines, July 1993 (photo by Des Moines Water Works).

In January 2016, the state of Iowa received a $97 million award for the Iowa Watershed Approach (IWA). The grant was part of the U.S. Department of Housing and Urban Development's (HUD) National Disaster Resilience Competition, which funds cutting-edge projects to address unmet needs from past natural disasters and to reduce Americans' vulnerability to future disasters. The project ends in September 2022. The IWA program takes a holistic approach to address flooding at the watershed scale, recognizing that upstream and downstream communities need to voluntarily work together to increase community flood resilience (Weber et al., 2018).

The IWA pursues six specific goals:

1) Reduce flood risk
2) Improve water quality
3) Increase community flood resilience
4) Engage stakeholders through collaboration, outreach, and education

5) Improve quality of life and health for Iowans, especially for vulnerable populations
6) Develop a program that is scalable and replicable throughout the Midwest and United States

The IWA brings Iowans together to address the factors that contribute to floods. Eight distinct watersheds were involved in the project, shown in Figure 1-2, including the Upper Iowa River, Upper Wapsipinicon River, Middle Cedar River, Clear Creek, English River, North Raccoon River, East Nishnabotna River, West Nishnabotna River, and Bee Branch Creek. In addition, urban projects in the cities of Dubuque, Coralville, and Storm Lake focused on infrastructure improvements to mitigate flood risk.

Figure 1-2: The Iowa Watershed Approach study areas include eight distinct watersheds and three urban areas.

Each watershed formed a Watershed Management Authority (WMA) that brings local stakeholders together to prioritize their watershed improvement needs, share resources, and foster new partnerships and collaborations. As part of Phase 1 of the IWA, IIHR—Hydroscience and Engineering (IIHR) and the Iowa Flood Center (IFC) developed a hydrologic assessment for each watershed that provided WMAs, local leaders, landowners, and residents with an understanding of the hydrology — the movement of water — within their watershed. This assessment delivered valuable information to stakeholders to help guide strategic decision-making to efficiently address flooding and water-quality concerns.

Figure 1-3: Flood mitigation oxbow and stream stabilization project (NR-001 Rob Smith) constructed as part of the IWA in the Outlet Creek HUC12, a sub-watershed of the North Raccoon HUC8.

The results of the Phase 1 efforts were used to determine future goals and strategies for best management practices (BMPs) and was integrated into the watershed management plan; a long-term vision for the watershed to reduce floods and improve water quality. IWA funds provided 90% cost-share assistance for BMP construction of ponds, wetlands, oxbow reconstructions, and more. IIHR and IFC have developed this Phase 2 report for the North Raccoon Watershed to detail the practices constructed and evaluate their individual and cumulative benefits.

Ultimately, 4 BMPs were completed in the North Raccoon River Watershed as part of the IWA:

- 2 oxbows
- 1 wetland
- 1 grade stabilization

Figure 1-3 and Figure 1-4 show examples of these projects. The total design and construction costs of these projects was just under $760,000. Chapter 6 provides details of all 4 practices, and Chapter 7 summarizes the results of the project evaluation.

Figure 1-4: Flood mitigation oxbow and stream stabilization project (NR-001 M&M Smith Family Farm) constructed as part of the IWA in the Outlet Creek HUC12, a sub-watershed of the North Raccoon HUC8.

2. Iowa's Hydrology and Water Quality

This chapter summarizes Iowa's water cycle, geology, land use, hydrology, and water quality across the state. The authors examined precipitation, streamflow, and shallow groundwater records to describe how much precipitation falls, how that water moves through the landscape, when storms typically produce river flooding, and how Iowa's hydrology, land use, and water quality have changed over the past decades and century. In addition, this chapter includes an overview of two novel web-based platforms that allow access to Iowa's flood and water-quality data. The information presented in this chapter is valid for the entire state, but some sub-sections place emphasis on the eight rural IWA watersheds shown in Figure 1-2.

a. Land Surface and Use

Iowa has a unique and diverse landscape that is the culmination of geologic processes occurring over millennia. Iowa has been subdivided into seven distinct landform regions, shown in Figure 2-1 (Prior, 1991). The Iowa Watershed Approach projects are primarily contained within four of these regions: the Paleozoic Plateau, the Iowan Surface, the Southern Iowa Drift Plain, and the Des Moines Lobe landform regions. Surficial materials are underlain by a host of sedimentary bedrock formations, including carbonate (limestone and dolomite), sandstone, and shale. Most of these rocks were deposited during the Paleozoic Era (541–299 million years ago), with others being deposited during the earlier Mesozoic Era (201–66 million years ago).

Following an extensive period of non-deposition and erosion, Iowa was glaciated numerous times during the Quaternary Period. At least seven episodes of glaciation occurred between 2.6 and 0.5 million years ago. These are collectively known as the Pre-Illinoian glacial advances. More recently, the Des Moines Lobe glacier advanced into north-central Iowa, reaching its maximum extent approximately 14,000 years ago. Subsequent loess (wind-blown silt) deposition occurred during and after this time, mantling much of the state. These glacial processes and erosional periods shaped the landform regions of Iowa.

The Southern Iowa Drift Plain encompasses the southern portion of the state and consists of several layers of Pre-Illinoian till deposits mantled by loess. Landscape development following the ice retreat eroded most of the features typically associated with glaciers and created the well-developed drainage network we see today. The Loess Hills landform region in the western part of the state has the same stratigraphic units as the Southern Iowa Drift Plain, but with thicker loess deposits because of its proximity to the source — the Missouri River alluvial plains.

In contrast, northeastern Iowa experienced a period of extreme cold (21,000 to 16,500 years ago) during the last glacial maximum, resulting in extensive erosion of the landscape and the formation of the Iowan Surface landform region. Characteristic features include gently rolling topography, common glacial "erratics" (rocks and boulders not native to Iowa transported here by glaciers), and loess-mantled paha (northwest to southeast trending uneroded upland remnants of the former landscape). The depth to bedrock is often shallow on this landform region. Surficial materials consist of poorly consolidated glacial deposits with the potential for extensive local sand bodies. In areas where the depth to bedrock is shallow, these materials provide limited protection from surface water infiltrating into bedrock.

The Paleozoic Plateau borders the Iowan Surface and experienced many of the same processes. The primary difference is that shallow bedrock dominates the Paleozoic Plateau. Characteristic features include steep sided, deeply entrenched valleys; abundant rock exposures; and common karst features. The unconsolidated materials consist of relatively thin glacial deposits with a loess mantle. Carbonate bedrock is susceptible to the formation of karst features, and numerous caves, springs, and sinkholes are identified throughout this landform region.

The younger Des Moines Lobe landform region exists in north-central Iowa. This region was glaciated between approximately 15,000 and 12,000 years ago, with several advances and retreats before the glacier finally receded. Because of the relative youth of this region, erosional processes have not erased the surficial features typical of glacial landscapes. Characteristic features include glacial moraines (arcuate ridges associated with stationary periods), ice contact features (knobs, kettles, and hummocky terrain), fine-grained lake and pond deposits, and outwash (coarse sand and gravel carried by rivers draining glaciers). Natural drainage on the Des Moines Lobe is typically very poor.

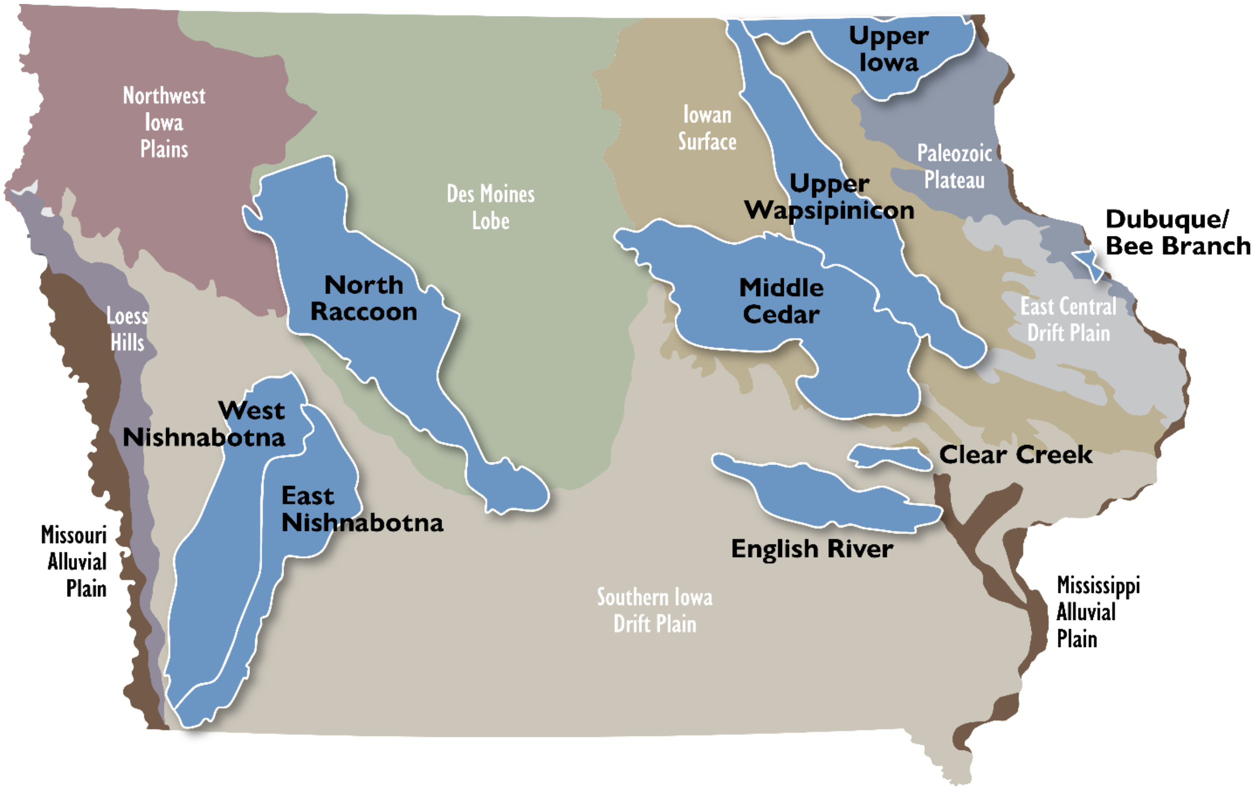


Figure 2-1: The IWA watersheds' positions within the landform regions of Iowa.

Prairies covered Iowa before the arrival of European settlers, as depicted in historical vegetation shown in Figure 2-2. Forests and wetlands created a diverse set of habitats for animals, and prairies contained up to 300 species of grasses and flowers. As settlers tilled the prairie and planted crops such as wheat, corn, and buckwheat, the land cover of Iowa shifted to a majority agricultural state (Schilling et al., 2008).

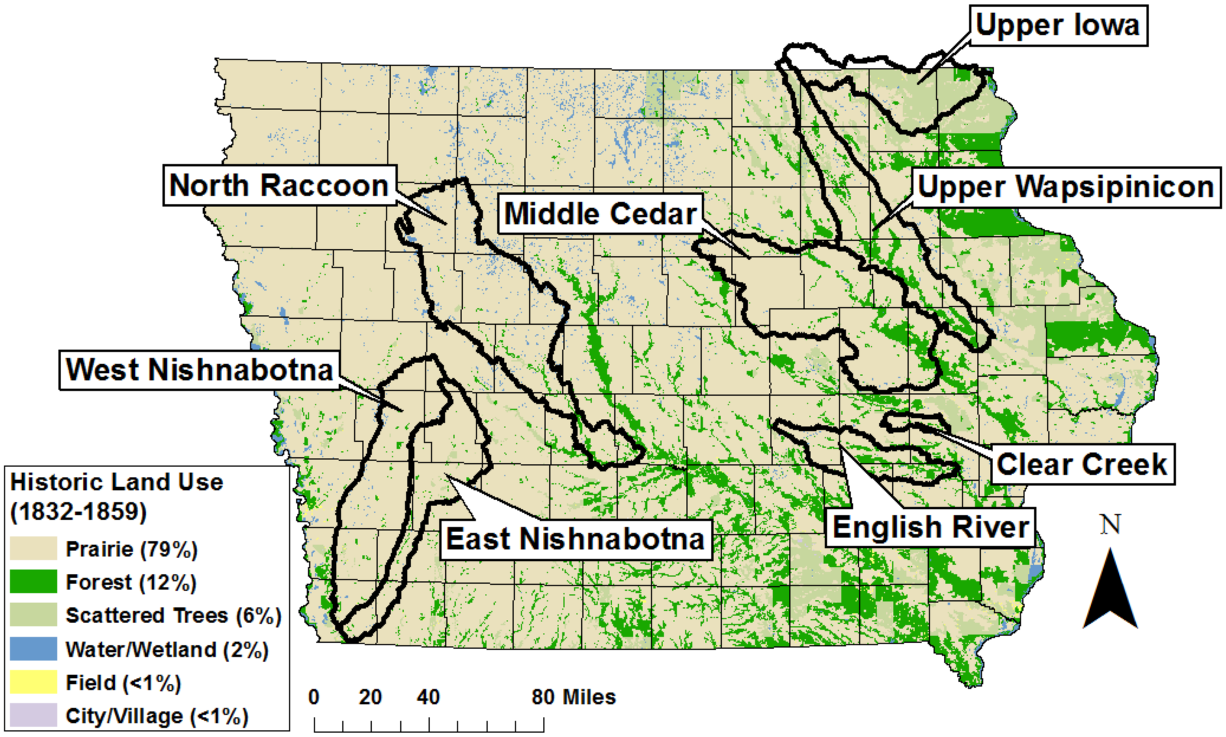


Figure 2-2: Historic vegetation of Iowa 1832–59. Raw data downloaded from the Iowa Geographic Map Server (https://ortho.gis.iastate.edu/).

Today, corn and soybeans cover 64% of Iowa (see Figure 2-3), with only small prairie remnants remaining. Several factors make Iowa an excellent place to sustain agricultural activities, including the rich topsoil left behind by the prairies; advances in farming technology including fertilizers, pesticides, and herbicides; and rainfall patterns, among others. Over the past 15 years, the percentage of Iowa's land used for growing corn and soybeans has stayed relatively stable at near 60%. The percentage of Iowa land area devoted to growing corn or soybeans is shown in Figure 2-4.

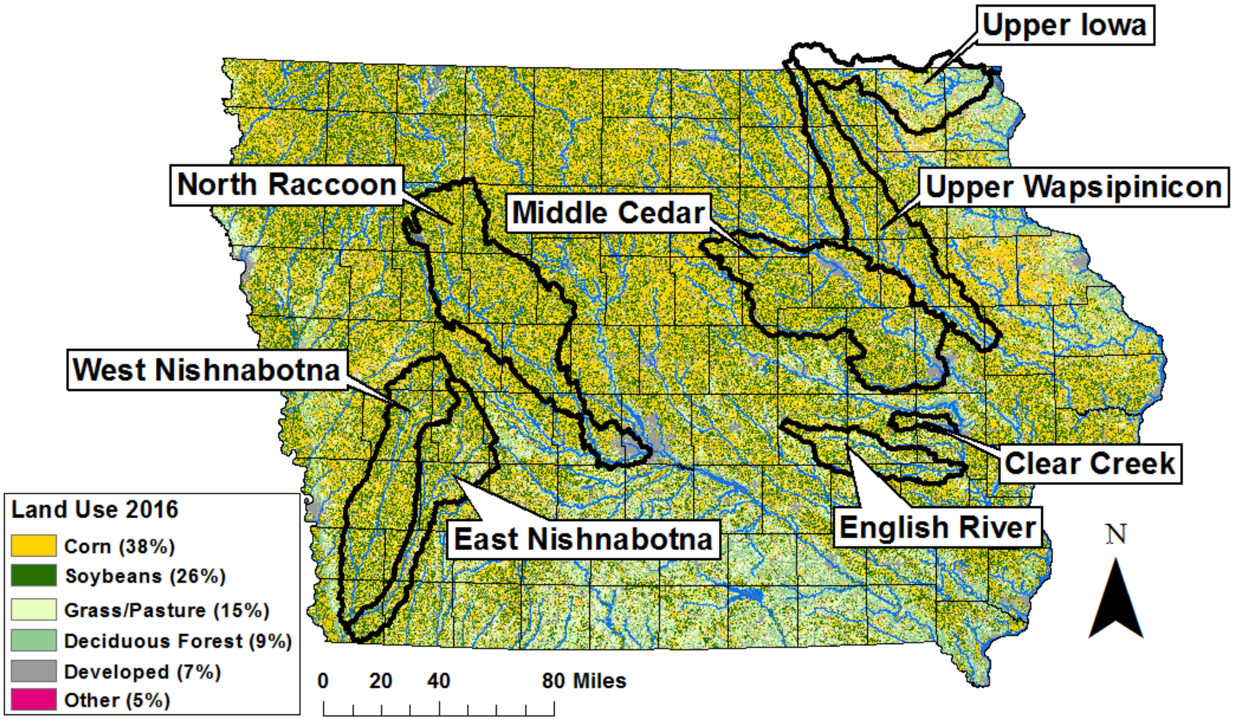


Figure 2-3: Land use composition in the state of Iowa 2016. Cropland Data Layer.

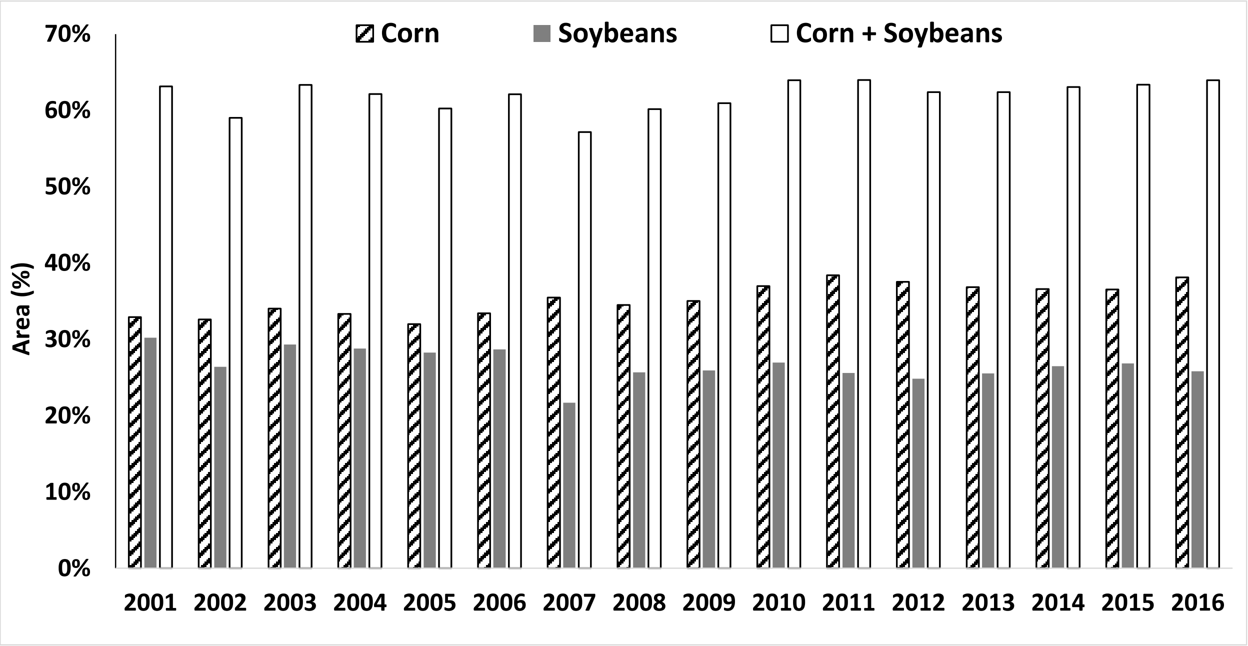


Figure 2-4: Percent of Iowa's total area planted with row crops between 2001 and 2016. Cropland Data Layer.

A significant portion of Iowa soils require sub-surface drainage to achieve optimal yields for row crops. Areas that likely require tile drainage are shown in Figure 2-5. It is estimated that installation of tile drainage peaked between the late 1800s and the mid-1900s, but today landowners continue to expand and upgrade drainage systems. In some areas (mostly in the Des Moines Lobe), public drainage districts were created to facilitate drainage over large areas. Drainage districts, also shown in Figure 2-5, have the power to tax and bond and are governed by trustees.

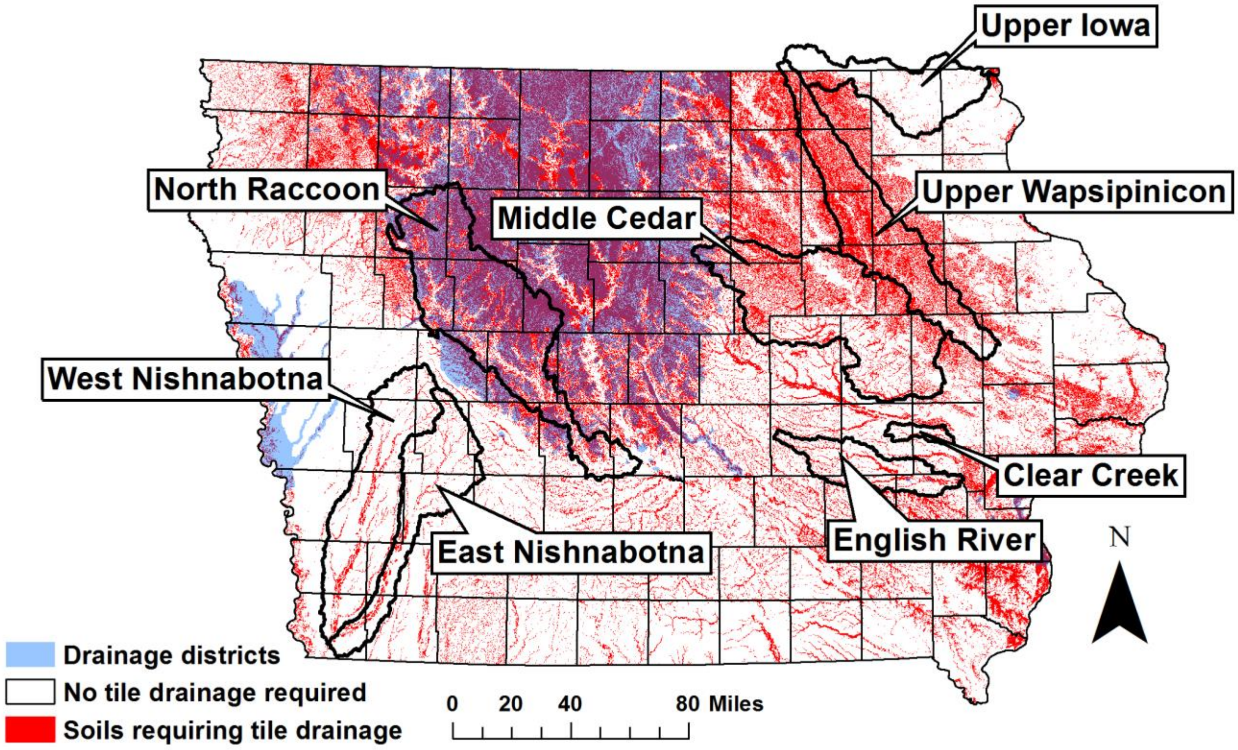


Figure 2-5: Soils requiring tile drainage for full productivity and drainage districts. Raw data source: DNR's NRGIS Library.

b. Climate and Water Cycle

Iowa is characterized by a humid continental climate with marked seasonal temperature variations, typically experiencing hot summers and cold winters. Annual average temperatures range between approximately 40°F and 60°F. The coldest and warmest months of the year are January and June, respectively. In January, the normal daily minimum temperatures range between 6°F and 17°F. In June, the normal daily maximum temperatures are in the 78–84°F range. Severe weather can impact regions of the state between the spring and fall; heavy rains and tornados are the most common of these events. Precipitation records show that Iowa typically receives the bulk of its annual precipitation in the spring and the summer.

i. Statewide Precipitation

Iowa's precipitation spatial patterns are marked by a smooth transition of annual precipitation across its landscape from the southeast to the northwest, as shown in Figure 2-6. The average annual precipitation reaches 40 inches in the southeast corner and decreases to 26 inches in the northwest corner.

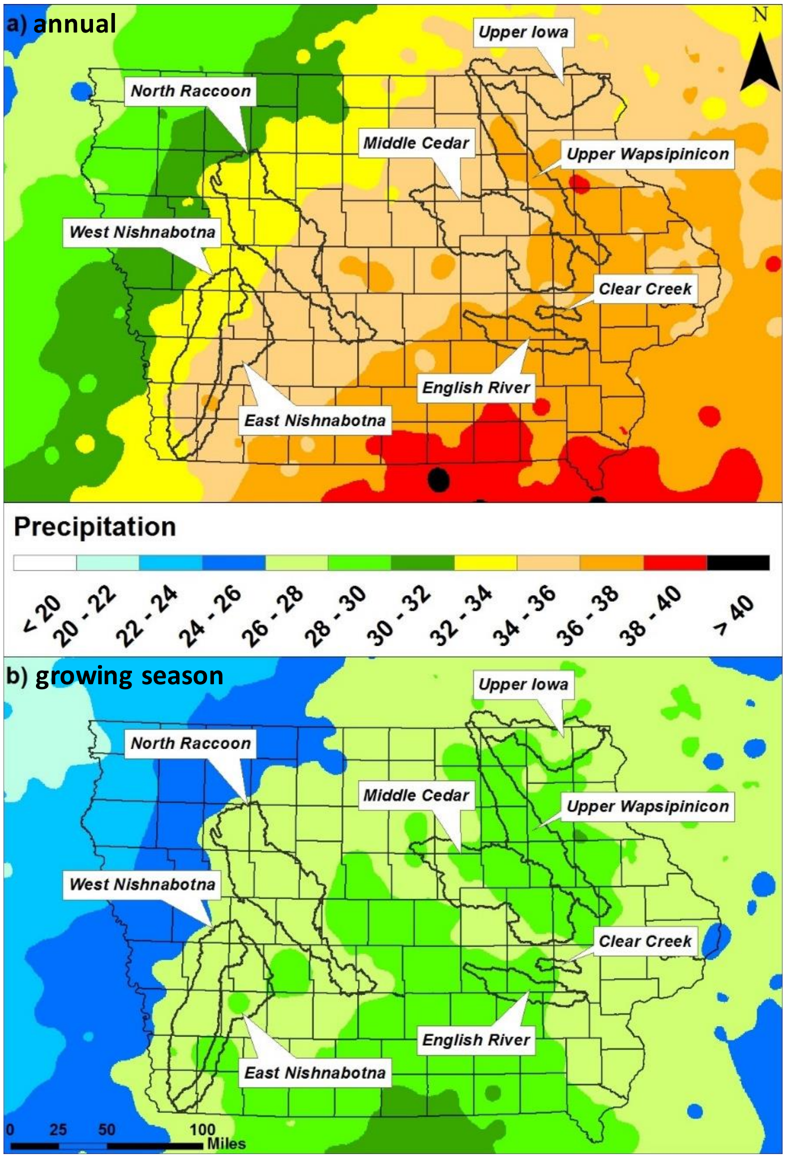


Figure 2-6: Average precipitation (inches): (a) annual; and (b) growing season (April–October). Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

Records show small variations in average annual precipitation among the eight IWA watersheds; the North Raccoon receives the least (33.8 inches), and the English River the most (36.6 inches). Historically, the quantity of annual precipitation presented in Figure 2-6b has been ideal for agricultural needs, such that Iowa has not required irrigation systems like other parts of the country. The state's average precipitation between April and October is approximately 27 inches, and the months with highest precipitation accumulations (May, June, and July) occur during the peak of the growing season. These climatological characteristics make Iowa an ideal place for agriculture.

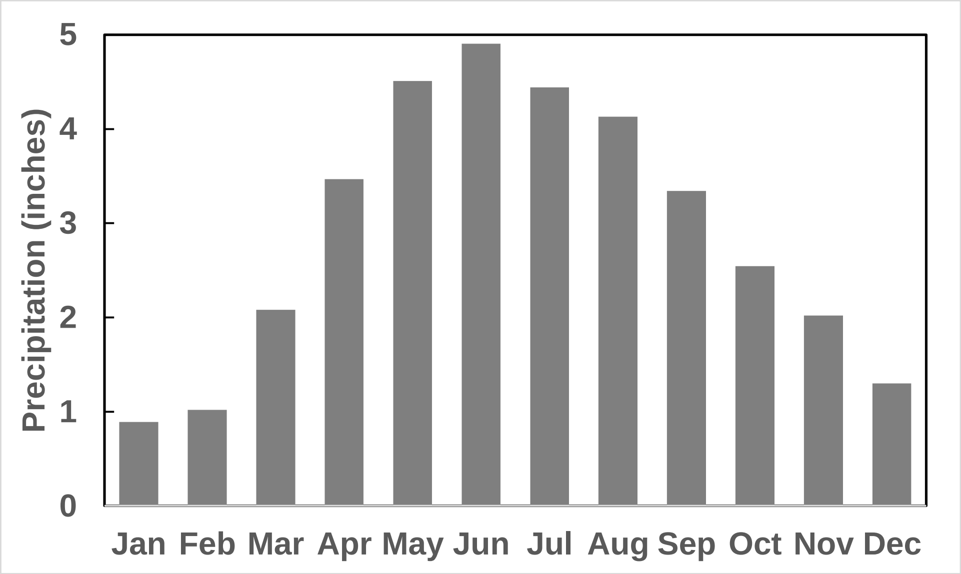


Figure 2-7: Statewide average monthly precipitation. Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

ii. The Water Cycle in Iowa

A large portion of Iowa's precipitation evaporates into the atmosphere — either directly from lakes and streams, or by transpiration from crops and vegetation. What doesn't evaporate drains into streams and rivers. The average annual partitioning of precipitation into evapotranspiration, surface flow, or base flow in each IWA watershed is shown in Figure 2-8.

Evapotranspiration

In Iowa, most precipitation leaves by evapotranspiration; for the IWA watersheds, evapotranspiration accounts for between 66% and 79% of precipitation. Moving westward in the state, a larger fraction of the precipitation evaporates.

Surface Flow

The precipitation that drains into streams and rivers can take two different paths. During rainy periods, some water quickly drains across the land surface, causing streams and rivers to rise in the hours and days following the storm. This portion of the flow is often called "surface flow," even though some of the water may soak into the ground and discharge later (e.g., through a tile drainage system).

Baseflow

The rest of the water that drains into streams and rivers takes a longer, slower path; first, it infiltrates into the ground and percolates down to the groundwater. Then it slowly moves toward a stream. The groundwater eventually reaches the stream, maintaining flows in a river even during extended dry periods. This portion of the flow is often called “baseflow.” In hydrologic analyses, subsurface drainage flows are typically lumped together with groundwater flows.

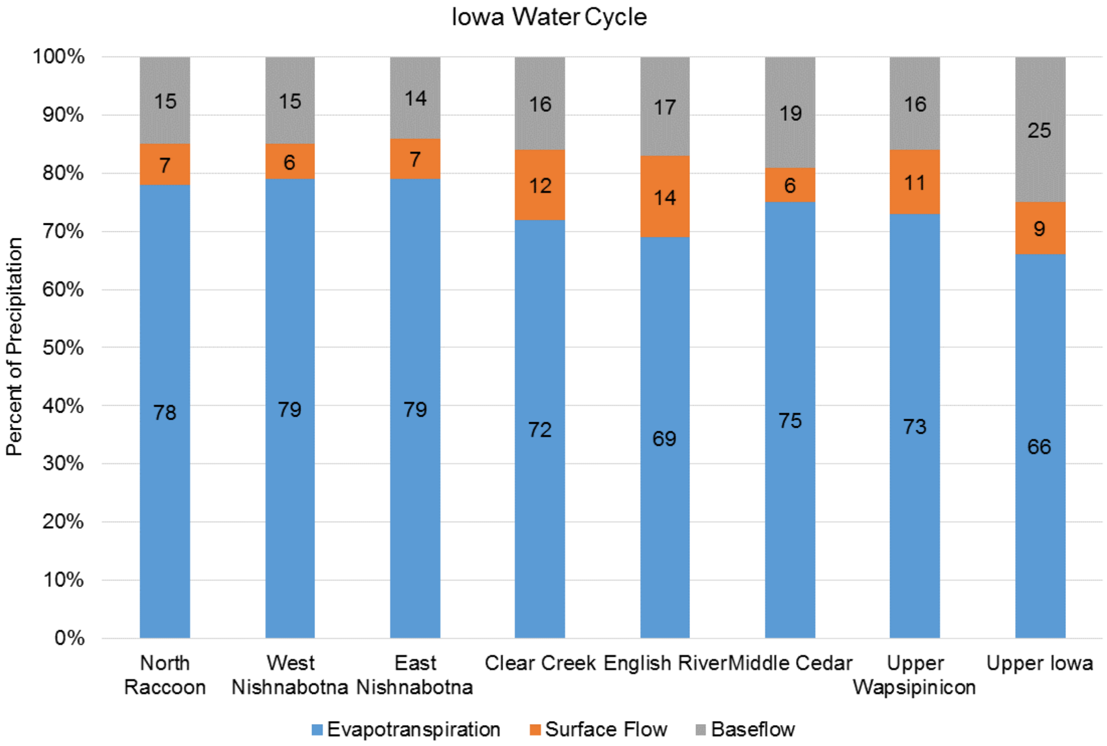


Figure 2-8: Iowa water cycle for the IWA watersheds. This shows the partitioning of average precipitation into evapotranspiration, surface flow, and baseflow components.

iii. Shallow Groundwater and Soil Moisture Trends

Shallow groundwater and soil moisture conditions can play an important role in the transformation of rainfall into runoff. For example, several studies have identified the occurrence of very wet winters and springs (and the subsequent high soil moisture and groundwater levels) as contributing factors to the major floods of 1993 and 2008 (Linhart and Eash, 2010; Mutel, 2010; Bradley, 2010; Smith et al., 2013). Across the state, almost 400 sensors continuously monitor the condition (e.g., streamflow and stage) of the Iowa rivers. In contrast, long-term continuous data on groundwater levels or soil moisture are sparse. Figure 2-9 displays shallow groundwater information from two United States Geological Survey (USGS) wells located in two different Iowa counties. The location of the water table is influenced by several factors, such as location on the landscape, land cover, soil type, etc. In Iowa, it is very common to find the water table within the first 25 feet of the soil column, except in the deep loess hills in western Iowa and incised bedrock valleys of northeast Iowa.

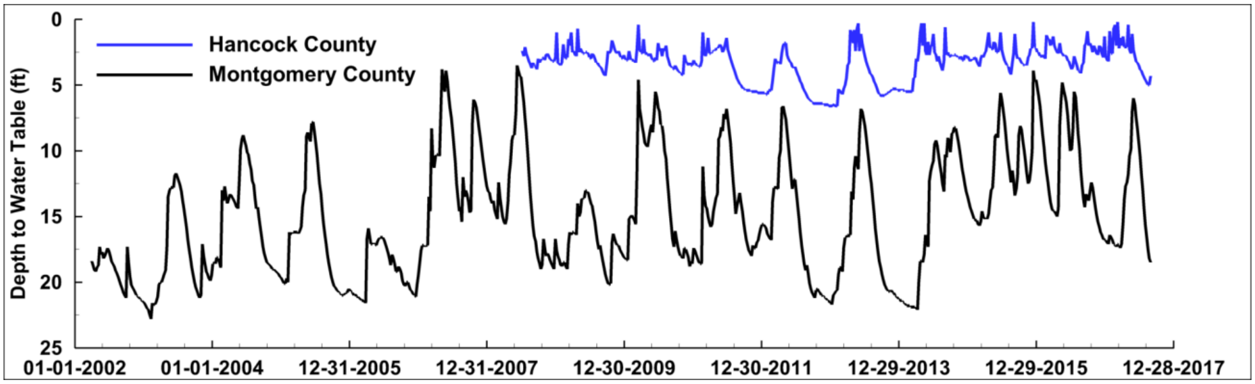


Figure 2-9: Shallow groundwater data (USGS wells).

iv. Floods

Rivers and streams have a finite capacity to convey water within their banks. When the amount of water surpasses that capacity, flooding occurs. Floods are typically related to large amounts of precipitation or snow melt and saturated or frozen soil. In Iowa, historic records show that the great majority (>90%) of floods occur in the spring and summer; the month of June shows the highest number of flood events. Precipitation records show that heavy rains occurred in the fall as well; however, Iowa soils have a larger capacity to infiltrate water late in the year, and therefore fall floods are less common. In Iowa's flood history, the events of 1993 and 2008 are on an entirely different scale than the others. These two events stand out from the rest when looking at the extent of the area impacted, recovery costs, precipitation amounts, and stream flows recorded (Bradley 2010; Smith et al., 2013). Figure 2-10 shows the extent of the flooding during the flood events of 1993 and 2008. In both years, flooding impacted the eight IWA watersheds.

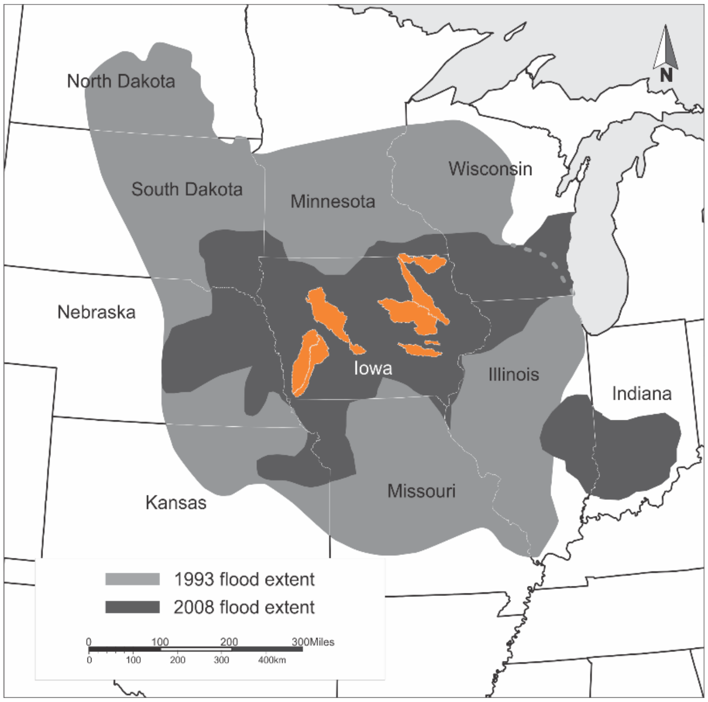


Figure 2-10: The extent of the flooding during the 1993 and 2008 floods (Bradley, 2010).

Federal disaster declarations give impacted regions access to federal recovery assistance. Current regulation permits two kinds of disaster declarations: emergency declarations and major disaster declarations (Stafford Act). Both are granted at the discretion of the president of the United States, after the governor of the impacted state makes the request. FEMA records on disaster declarations are open to the public and were used to write the text and create the figures below.

- FEMA records show 952 flood-related disaster declarations (FRDD) in Iowa between 1988 and 2016. Of these, 951 were reported for Iowa counties (Figure 2-11) and one for the Sac and Fox Tribe of the Mississippi in Iowa. All the FRDD in Iowa have been major disaster declarations, except for the 99 related to Hurricane Katrina evacuation (see Table 2-1), which were classified as emergency disaster declarations.

Table 2-1: FEMA disaster declarations in Iowa Counties (1988–2016). Data source: https://www.fema.gov/

DISASTER TITLE	COUNT 1988-2016
SEVERE STORMS, TORNADOES, AND ***FLOODING***	223
SEVERE STORMS & ***FLOODING***	195
SEVERE STORMS, TORNADOES AND ***FLOODING***	106
HURRICANE KATRINA EVACUATION	99
SEVERE STORMS AND ***FLOODING***	98
SEVERE STORMS, ***FLOODING*** , AND TORNADOES	97
SEVERE STORMS, TORNADOES, STRAIGHT-LINE WINDS, AND ***FLOODING***	79
SEVERE WINTER STORM	62
SEVERE WINTER STORMS	48
ICE STORM	44
SEVERE STORMS, STRAIGHT-LINE WINDS, AND ***FLOODING***	34
SNOW	30
SEVERE WINTER STORMS AND SNOWSTORM	27
SEVERE STORMS, AND ***FLOODING***	15
SEVERE SNOWSTORMS	13
FLOODING	6
SEVERE STORMS, TORNADOES, AND STRAIGHT-LINE WINDS	6
RAIN, WINDS, & TORNADOES	1
SEVERE STORM	1
	1184

In the last 30 years, every county in Iowa has experienced sufficiently large and severe flood events to warrant a presidential disaster declaration. The number of FRDDs for each Iowa county from 1988–2016 is shown in Figure 2-11.

- The eastern half of the state has received more FRDDs than the western part. In addition, most counties in Northeast Iowa have received at least 10 FRDDs in the last three decades. The two counties with the lowest and highest number of FRDDs are O’Brien (4) and Clayton (17), respectively.

- Since 1988, the longest period with no FRDDs in Iowa was two years, which can be seen in Figure 2-12. The years with the highest number of FRDDs were 1993, 2005, and 2008. Remarkably, the number of FRDDs in 1993 is higher than the number of counties in Iowa. In that year, 15 counties received two FRDDs, one in late April and the second in early July (Buchanan, Butler, Des Moines, Linn, Black Hawk, Muscatine, Benton, Cedar, Louisa, Tama, Webster, Floyd, Mitchell, Kossuth, and Scott counties).

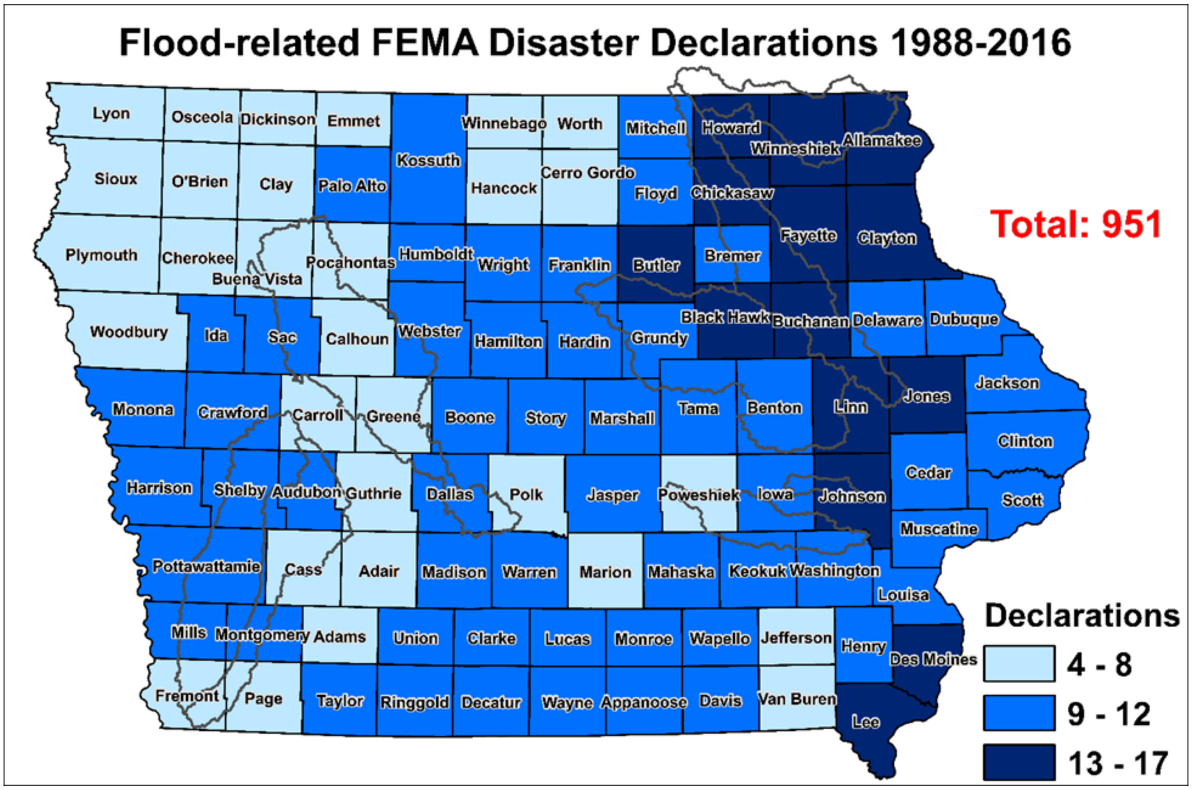


Figure 2-11: Number of flood-related federally declared disasters in Iowa counties (1988–2016). Data source: https://www.fema.gov/.

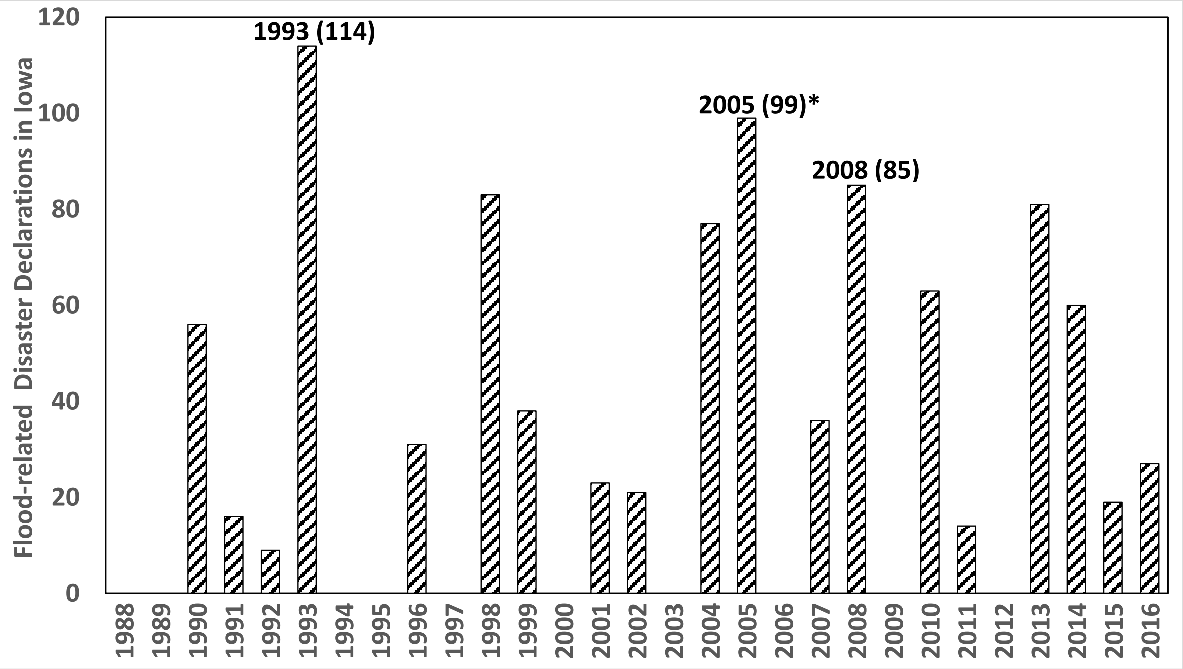


Figure 2-12: The number of flood-related federally declared disasters in Iowa (1988–2016). Data source: https://www.fema.gov/.

v. Droughts

Like floods, droughts are a recurrent phenomenon and part of the Earth’s climate. Droughts are characterized by periods with precipitation deficits; depending on their severity, these can also include very low streamflow, as well as reduced soil moisture and groundwater levels.

Unlike floods, droughts tend to progress slowly, and their onset is not easily identifiable. The extremely dry period of the 1930s (known as the “Dust Bowl”) is still considered the unsurpassable benchmark against which all other droughts will be measured. In Iowa’s recent history, both 1988 and 2012 stand out as drought years. Overall, comparisons of these two droughts reveal some similarities. In 1988, Iowa had its 4th hottest and 14th driest summer, whereas the 2012 summer was the 14th hottest and 5th driest in the observational record (Harry Hillaker, state climatologist).

Since 1999, several federal agencies and academic institutions partnered to create the U.S. Drought Monitor (USDM, http://droughtmonitor.unl.edu/), which releases a weekly map of drought conditions for the United States. Drought conditions are classified in five categories: Abnormally Dry (D0), Moderate Drought (D1), Severe Drought (D2), Extreme Drought (D3), and Exceptional Drought (D4). The map presented in Figure 2-13 shows the extent of 2012 drought in Iowa using data generated by the USDM.

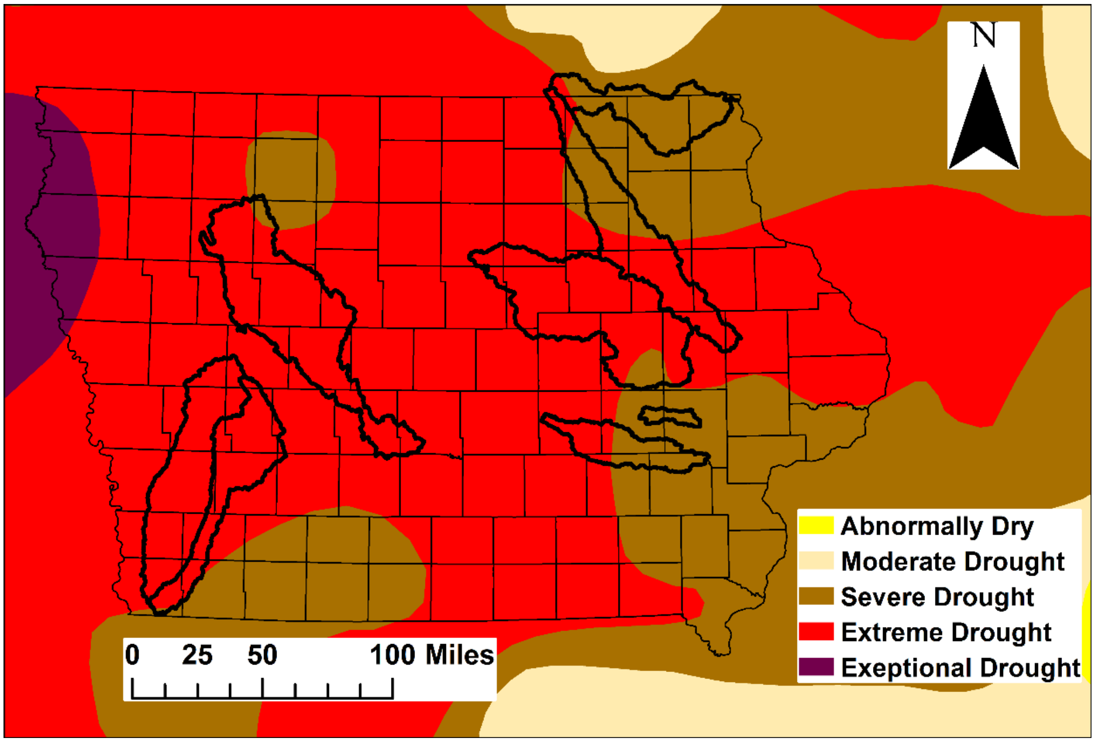


Figure 2-13. Drought conditions, October 09, 2012 (Source: http://droughtmonitor.unl.edu/).

c. Hydrological Alterations in Iowa and the Iowa Watershed Approach Study Areas

Although the hydrologic conditions presented for the Iowa Watershed Approach study areas illustrate the historical water cycle, the watersheds themselves are not static; historical changes have occurred that have altered the water cycle. In this section, we discuss the hydrological alterations of Iowa's watersheds.

i. Hydrological Alterations from Agricultural-Related Land Use Changes

The Midwest, with its low-relief, poorly-drained landscape, is one of the most intensively managed areas in the world (Schilling et al., 2008). With European-descendent settlement, most of the land was transformed from low-runoff prairie and forest to higher-runoff farmland (see Figure 2-2 and Figure 2-3). Within Iowa, the land cover changes in the first decades of settlement occurred at an astonishing rate (Wehmeyer et al., 2011). Using land cover information obtained from well-documented studies in 1859, 1875, and 2001, Wehmeyer et al. (2011) estimated that the increase in runoff potential in the first 30 years of settlement represents the majority of predicted change in the 1832 to 2001 study period.

Still, other transformations associated with an agricultural landscape have also impacted runoff potential (see Table 2-2). For example, the introduction of conservation practices in the second half of the 20th century tend to reduce runoff, as suggested by a recent study of an Iowa watershed (Papanicolaou et al., 2015). The Conservation Reserve Program (CRP) originally began in 1950s. The federal government established many programs in the 1970s to remove lands from agricultural production and establish native or alternative permanent vegetative cover; in an effort to reduce erosion and gully formation, government agencies also encouraged practices such as terraces, conservation tillage, and contour cropping. The Farm Bill of 1985 was the first act that officially established the CRP as we know it today; the Farm Bills of 1990, 1996, 2002, and 2008 expanded these activities. The 2014 Farm Bill gradually reduced the CRP cap from 32 million acres to 24 million acres, although the 2018 Farm Bill is expected to increase the CRP cap to 29 million acres. Table 2-2 summarizes the timeline of agriculture-driven land use changes and their impacts on local hydrology.

Table 2-2: Agricultural-Related Alterations and Hydrologic Impacts.

Timeline	Land use status, change, and interventions	Hydrologic effect(s)	Source
Pre-1830s	Native vegetation (tallgrass prairies and broad-leaved flowering plants) dominates the landscape	Baseflow dominated flows; slow response to precipitation events	Petersen (2010)
1830–1980	Continuous increase in agricultural production by replacement of perennial native vegetation with row crops 1940: <40% row crop (Raccoon) 1980: 75% row crop (statewide)	Elimination of water storage on the land; acceleration of the upland flow; expanded number of streams; increased stream velocity	Jones & Schilling (2011); Knox (2001)
1820–1930	Wetland drainage, stream channelization (straightening, deepening, relocation) leading to acceleration of the rate of change in channel positioning	Reduction of upland and in-stream water storage, acceleration of stream velocity	Winsor (1975); Thompson (2003); Urban & Rhoads (2003)
1890–1960 2000–present	Reduction of natural ponds, potholes, wetlands; development of large-scale artificial drainage system (tile drains)	Decrease of water storage capacity, groundwater level fluctuations, river widening	Burkart (2010); Schottler et al. (2013)
1940–1980	Construction of impoundments and levees in Upper Mississippi Valley	Increased storage upland	Sayre (2010)
1950–present	Modernization/intensification of the cropping systems	Increased streamflow, wider streams	Zhang & Schilling (2006); Schottler et al. (2013)
1970–present	Conservation practices implementation: Conservation Reserve Program (CRP); Conservation Reserve Enhancement	Reduction of runoff and flooding;	Castle (2010); Schilling (2000);

	Program (CREP); Wetland Reserve Program (WRP)	increase of upland water storage	Schilling et al. (2008);
2001–present	62% of Iowa’s land surface is intensively managed to grow crops (dominated by corn and soybeans up to 63% of total)	About 25% to 50% of precipitation converted to runoff (when tiling is present)	Burkart (2010)

ii. Hydrological Alterations Induced by Climate Change

The U.S. goverment recently released “The Climate Science Special Report” (Wuebbles et al., 2017), summarizing the state-of-the-art science on climate change and its physical effects. The CSSR writing team is comprised of three coordinating lead authors from the National Science Foundation and U.S. Global Change Research Program, NOAA Earth System Research Laboratory, and NASA Headquarters. In addition, more than 50 experts from federal agencies, departments, and universities are listed as lead authors, review editors, and contributing authors. CSSR is “designed to be an authoritative assessment of the science of climate change, with a focus on the United States, to serve as the foundation for efforts to assess climate-related risks and inform decision-making about responses.” The information below presents text and figures taken from the CSSR that are relevant to the IWA watersheds, Iowa, and the Midwest.

“Heavy rainfall is increasing in intensity and frequency across the United States (see Figure 2-14) and globally and is expected to continue to increase over the next few decades (2021–2050, see Figure 2-15), annual average temperatures are expected to rise by about 2.5°F for the United States, relative to the recent past (average from 1976–2005), under all plausible future climate scenarios.”

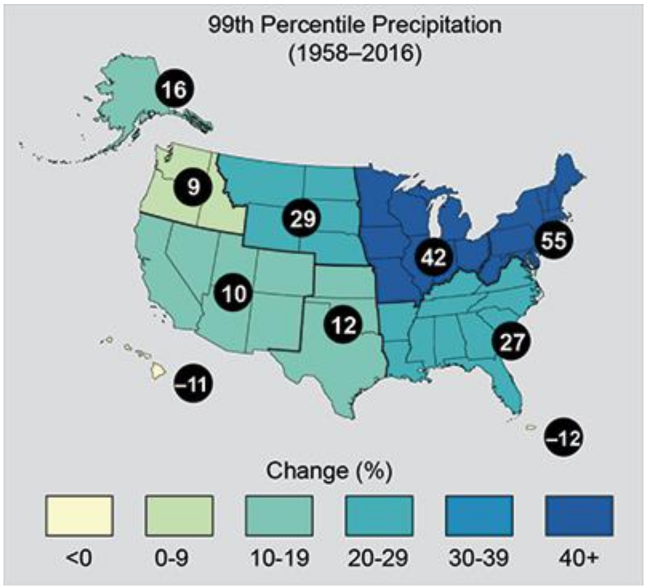


Figure 2-14: Observed change in heavy precipitation (the heaviest 1%) between 1958 and 2016. Figure taken from “The Climate Science Special Report” (Easterling et al. 2017) (https://science2017.globalchange.gov/).

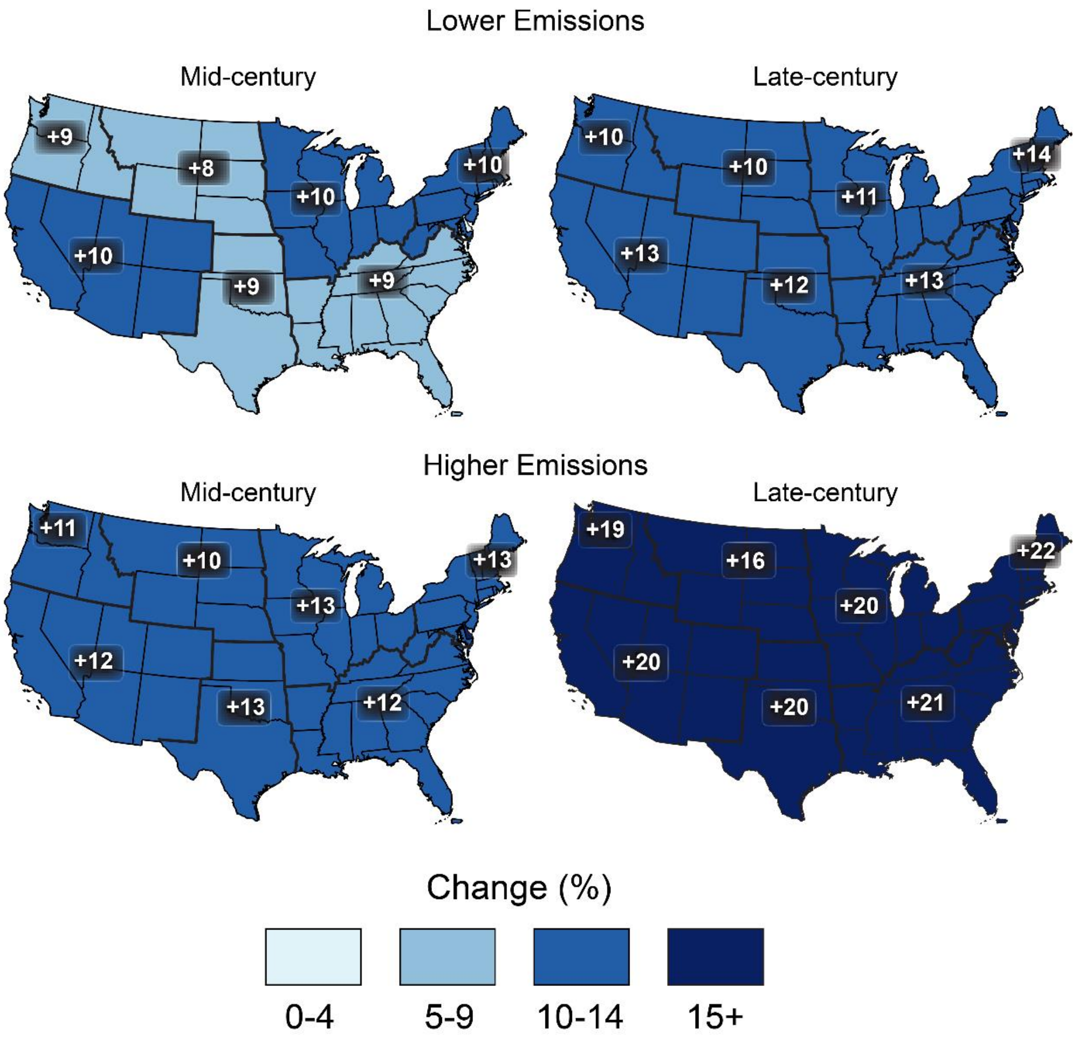


Figure 2-15: Projected change in heavy precipitation. Twenty-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps). Results are shown for a lower emissions scenario (top maps; RCP4.5) and for a higher emissions scenario (bottom maps, RCP8.5). Figure taken from "The Climate Science Special Report" (Easterling et al. 2017) (https://science2017.globalchange.gov/). RCP stands for Representative Concentration Pathway.

iii. Hydrological Alterations Induced by Urban Development

Although Iowa remains an agricultural state, a growing portion of its population resides in urban areas. The transition from agricultural to urban land uses has a profound impact on local hydrology, increasing the amount of runoff, the speed at which water moves through the landscape, and the magnitude of flood peaks. The factors that contribute to these increases (Meierdiercks et al., 2010) are the increase in the percentage of impervious areas within the drainage catchment and its location (Mejia et al., 2010), and the more efficient drainage of the landscape associated with the constructed drainage system — the surface, pipe, and roadway channels that add to the natural stream drainage system. Although traditional stormwater management practices aim to reduce increased flood peaks, urban areas have long periods of high flows that can erode stream channels and degrade aquatic habitat.

d. Assessment of Iowa's Water Quality

i. Iowa Water-Quality History

Prior to European settlement in the 19th century, Iowa was covered with prairies, oak savannahs, wetlands, and forests (see Figure 2-2). Much of the landscape was internally drained, meaning that rainfall and snowmelt drained to small depressional areas, rather than streams. Groundwater-fed streams meandered across the landscape and likely ran shallow and clear, carrying low levels of sediment and nutrients. Rivers easily spilled out into the floodplain after heavy rains, and riverbanks revegetated during drought, reducing streambank erosion.

Over several decades, the native prairie was broken and cultivated for corn, oats, and alfalfa, as well as a few other minor crops. Soil erosion was intense in the first years following a field's cultivation. From the period of 1880 to 1920, pervious clay pipes drained many of Iowa's wettest areas. This was most common in the recently-glaciated area of north-central Iowa known as the Des Moines Lobe, shown in Figure 2-1. Many new streams were constructed in ditches to drain water externally to the river network. Many existing streams were straightened to facilitate crop production.

The post-World War II era brought new developments to agriculture. The emergence of chemical fertilizers, soybeans, and continued drainage of the landscape with plastic drainage tiles helped Iowa become a world leader in crop and livestock production.

The loss of the native ecosystems, stream straightening and incision, artificial drainage, and discharges from industries and municipalities degraded water quality. Although the decline in water quality probably subsided in the early 1980s, Iowa's streams still carry more nutrients and sediment than most people find acceptable.

ii. Water Quality in the Post–Clean Water Act Era

The Federal Water Pollution Control Act of 1948 was the first major U.S. law to address water pollution. Growing public awareness and concern for controlling water pollution led to sweeping amendments in 1972. The amended law became commonly known as the Clean Water Act (CWA). The 1972 Amendments achieved the following: (1) established the basic structure for regulating pollutant discharges into the waters of the United States; (2) gave the EPA the authority to implement pollution control programs, such as setting wastewater standards for industry; (3) maintained existing requirements to set water-quality standards for all contaminants in surface waters; (4) made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions; (5) funded the construction of sewage treatment plants under the construction grants program; and (6) recognized the need for planning to address the critical problems posed by non-point source pollution.

After passage of the CWA, construction began on many new wastewater treatment facilities in Iowa, and upgrades were implemented on many existing treatment works. Undoubtedly these efforts improved water quality in several of Iowa's major interior rivers, in addition to the Missouri and Mississippi rivers on its borders. Improvements in the levels of ammonia, oxygen demand, Kjeldahl (organic) nitrogen, and dissolved oxygen were particularly important. These improvements made river water quality much more suitable for recreation and aquatic life, especially near Iowa's larger cities. However, the CWA provisions to address non-point source pollution (i.e., pollution from diffuse areas) proved relatively ineffective in reducing levels of nutrients and sediment in Iowa streams. The main CWA program designed to address non-point source pollution was the 319 Grant Program.

The Food Security Act of 1985 (Farm Bill) required farmers participating in most programs administered by the Farm Service Agency (FSA) and the Natural Resources Conservation Service (NRCS) to abide by certain conditions on any highly erodible land owned or farmed, or land considered a wetland. To comply with the highly erodible land conservation and wetland conservation provisions, farmers were required to certify that they would not: (1) produce an agricultural commodity on highly erodible land without a conservation system; (2) plant an agricultural commodity on a converted wetland; and (3) convert a wetland to produce an agricultural commodity. As result of these requirements, sediment levels in Iowa streams declined and water clarity improved (Jones and Schilling, 2011). Phosphorus levels also declined in unison with the improvements in sediment transport and water quality (Wang et al., 2016). However, conservation compliance, as these requirements are known, has not had a similar beneficial effect on stream nitrate levels (Sprague et al., 2011; Jones et al., 2017).

Iowa policy-makers and watershed stakeholders look to the Impaired Waters list, Section 303(d), as a common reference point to gauge statewide water quality. According to Section 303(d) of the CWA, from "time to time" states must submit a list of waters for which effluent limits will not be sufficient to meet all state water-quality standards. The EPA has defined "time to time" to mean April 1 of even numbered years. The failure to meet water-quality standards might be due to an individual pollutant, multiple pollutants, "pollution," or an unknown cause of impairment. The 303(d) listing process includes waters impaired by point sources and non-point sources of pollution. States must also establish a priority ranking for the listed waters, considering the severity of pollution and uses. In 2016, there were 608 category 5 Iowa waterbodies with 818 impairments. In 2014, there were 571 impaired waterbodies with 754 impairments. Category 5 waterbodies are those where a Total Maximum Daily Load assessment is required. About 58% of Iowa streams are considered "impaired"; 23% are considered "potentially impaired"; and 19% are considered to have "good" water quality. Indicator bacteria (i.e., *E. coli*) are the most common cause of impairment, causing about half of all such designations. Biological impairments are next, followed by fish kills. Figure 2-16 lists the main causes. Figure 2-17 shows historical numbers of impaired Iowa waters.

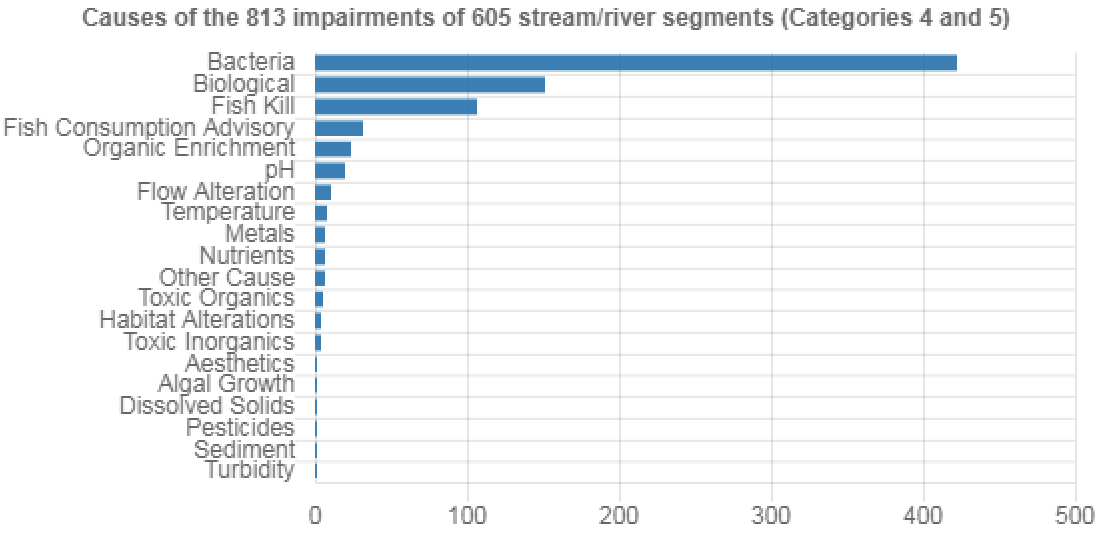


Figure 2-16: Causes of impairments in Iowa's impaired waters. (Iowa Department of Natural Resources, 2018).

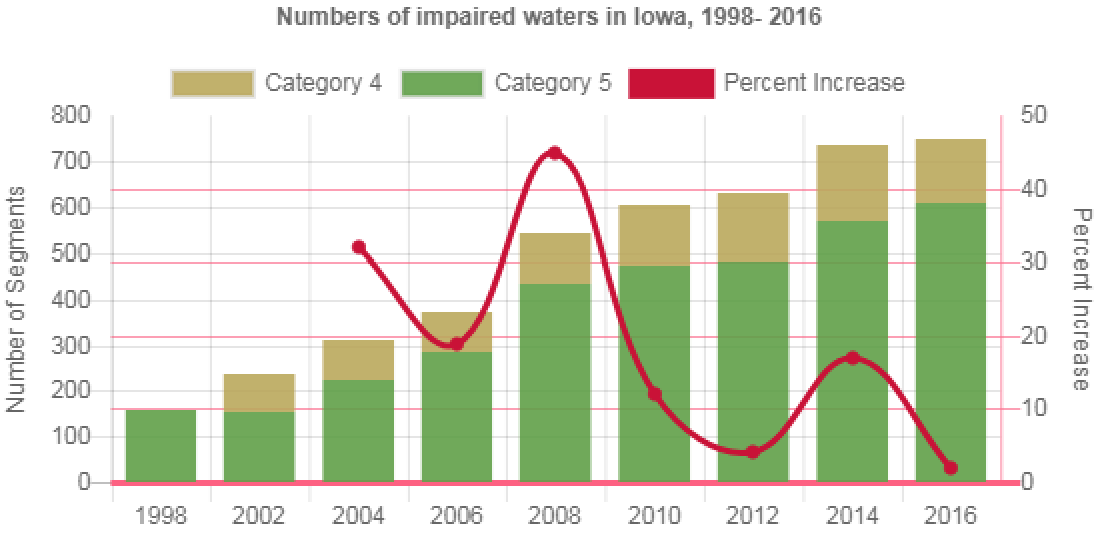


Figure 2-17: Numbers of impaired Iowa waters, 1998–2016. (Iowa Department of Natural Resources, 2018).

e. Web-Based Information Systems of Flood and Water-Quality Data

IIHR—Hydroscience and Engineering and the IFC at the University of Iowa have pioneered the creation of user-friendly, interactive, web-based information systems (WBIS) to communicate environmental information in Iowa and the United States. These two institutions also have expertise in the installation of real-time environmental monitoring systems and currently administer and maintain extensive networks that record flood and water-quality data in Iowa. WBIS displays this information, along with data collected by other federal institutions.

i. The Iowa Flood Information System (IFIS)

The Iowa Flood Information System (IFIS) is a one-stop web-platform to access community-based flood conditions, forecasts, visualizations, inundation maps, and flood-related information, visualizations, and applications. IFIS can be accessed using this URL: http://ifis.iowafloodcenter.org/ifis/. Below is an overview on some of the information available on IFIS.

Floodplain inundation maps

In partnership with the IDNR, the IFC has created statewide floodplain maps that estimate flood hazard extents and depths for every stream in the state of Iowa draining greater than one square mile. The maps depict flood boundaries and depths for eight different annual probabilities of occurrence: 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-%, allowing Iowans to better understand their flood risks and make informed land management decisions. The statewide floodplain maps can be accessed through IFIS or at http://www.iowafloodmaps.org/. Figure 2-18 shows an example of statewide floodplain map data for the city of Jefferson.

Community-based inundation maps

The IFC has also developed online inundation map libraries for more than 20 Iowa communities. These map libraries relate forecasted or observed flow conditions to flood extents and depths. They use detailed computer models that consider small-scale floodplain and channel features, bridges, and dams to better simulate the physics of flowing water. The maps allow a user to "translate" a forecasted river stage at a USGS gauge to flood extents and depths in the community, to better anticipate and respond to immediate flood hazards, and to consider "what-if" scenarios for long-term planning. Community inundation map libraries can be accessed on IFIS. Figure 2-19 shows the inundation map library interface for the city of Adel.

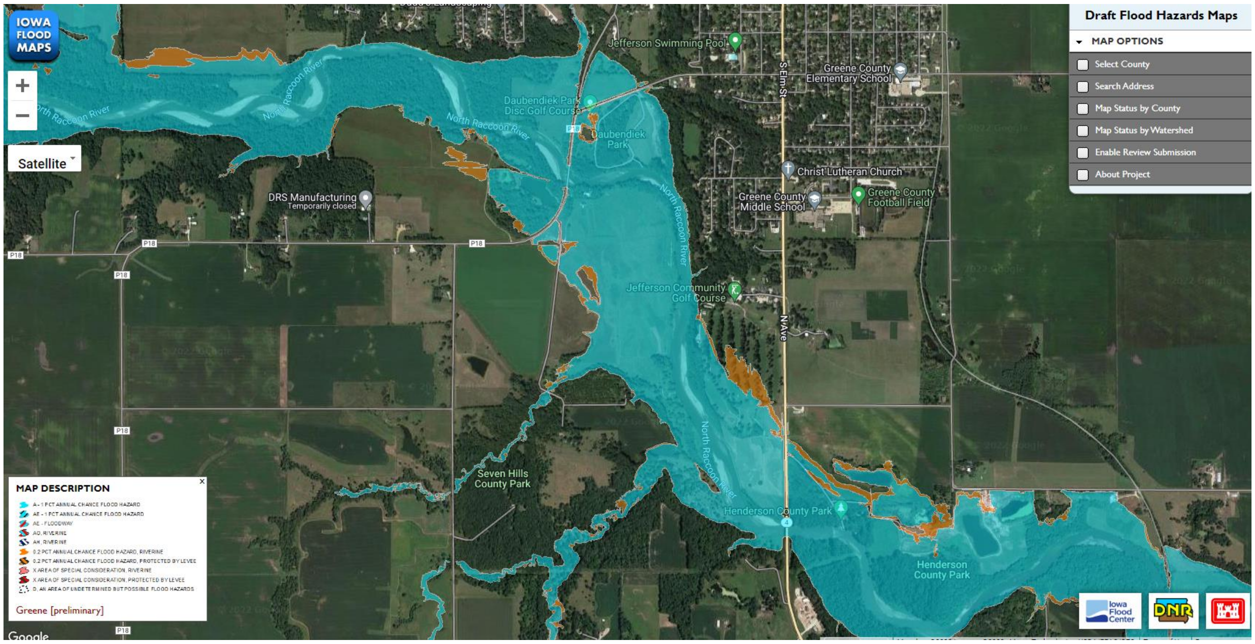
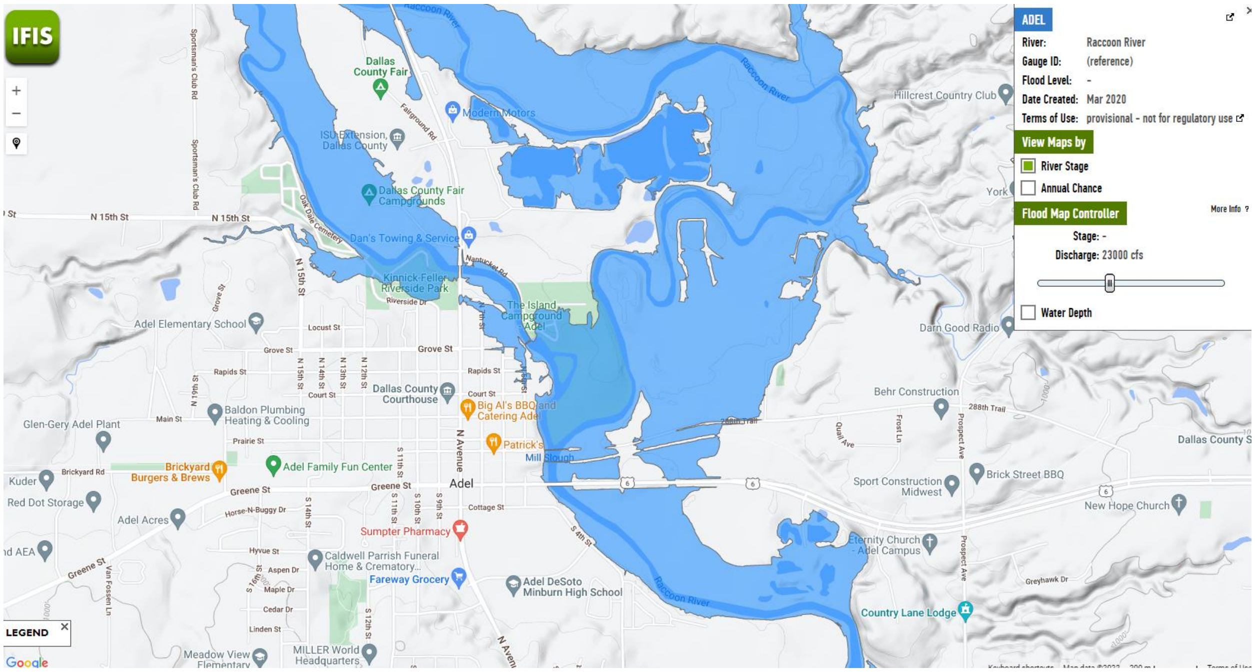


Figure 2-18. Statewide floodplain map data showing different levels of annual flood risk.



ADEL

River: Raccoon River
Gauge ID: (reference)
Flood Level: -
Date Created: Mar 2020
Terms of Use: provisional - not for regulatory use

☑ River Stage
☐ Annual Chance

Stage: -
Discharge: 23000 cfs

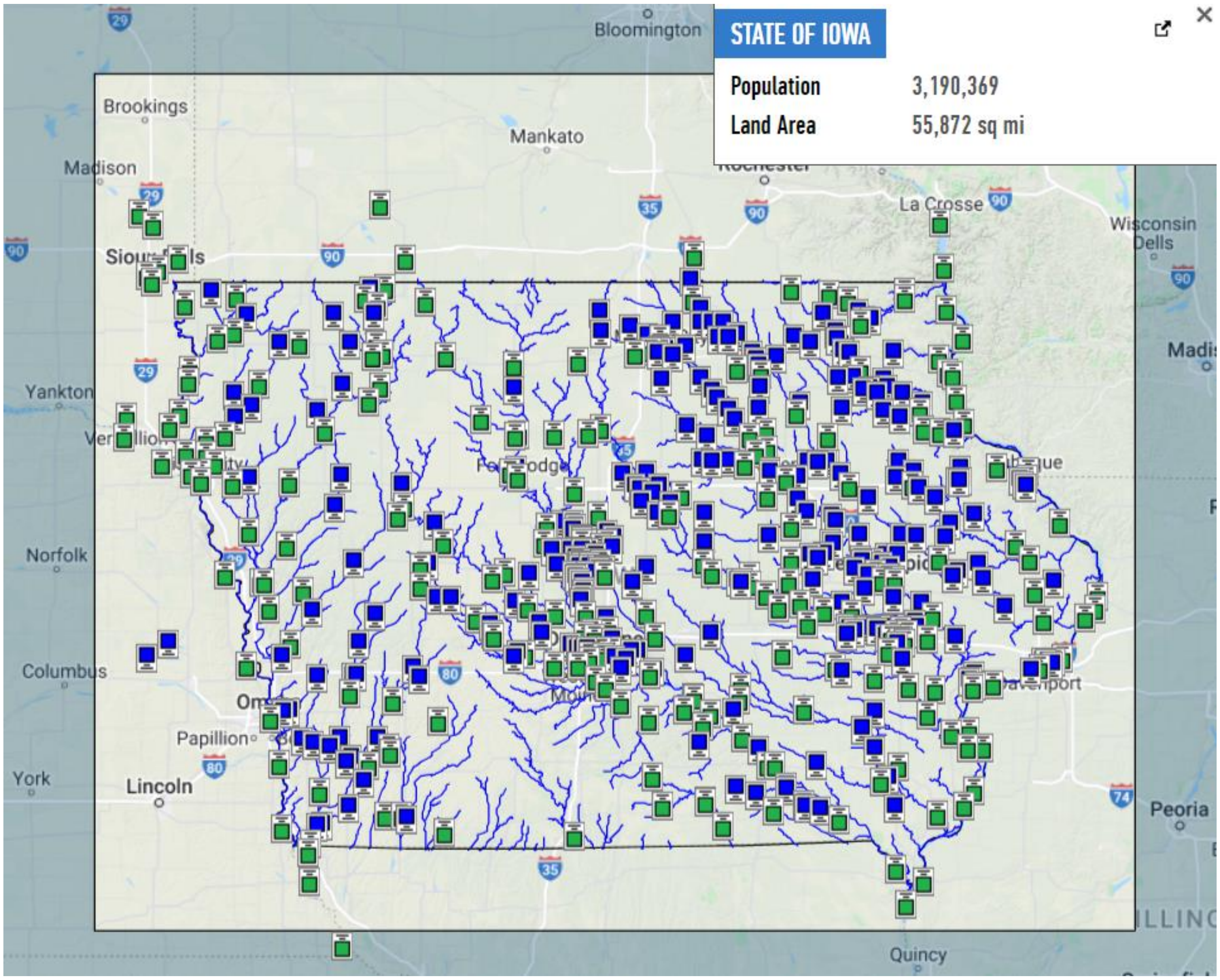
☐ Water Depth

Figure 2-19. Flood inundation map library for the North Raccoon River in the city of Adel.

Observed stream conditions

IFIS displays data from more than 400 sensors continuously monitoring Iowa stream conditions in real time, as shown in Figure 2-20. Currently, the USGS collects streamflow data at approximately

200 locations, and the IFC administers and maintains a growing network of more than 250 stream-stage sensors that record stage conditions.


STATE OF IOWA

Population 3,190,369

Land Area 55,872 sq mi

Figure 2-20. USGS (green) and Iowa Flood Center (blue) stream-stage monitoring locations displayed in the Iowa Flood Information System (IFIS).

Flood alerts, warnings, and forecasts

IFIS provides flood alerts for stream sensors with stage values higher than the threshold values for the four flood levels defined by National Weather Service (NWS) and the IFC. Different colors represent these four flood stage levels (action, flood, moderate flood, and major flood). The flood forecast products included in IFIS are the NWS six-hour forecast for 48 hours and the NWS seasonal forecast for 90 days. IFIS integrates short-term NWS forecasts into real-time data series and more-info views. The NWS shares a seasonal forecast probability for minor, moderate, and major flooding for a three-month period. The Iowa Flood Center has developed a real-time, high-performance, computing-based flood forecasting model that provides quantitative stage and discharge forecasts and a five-day flood risk outlook in IFIS for more than 1,500 locations (e.g., communities and stream gauges) in Iowa.

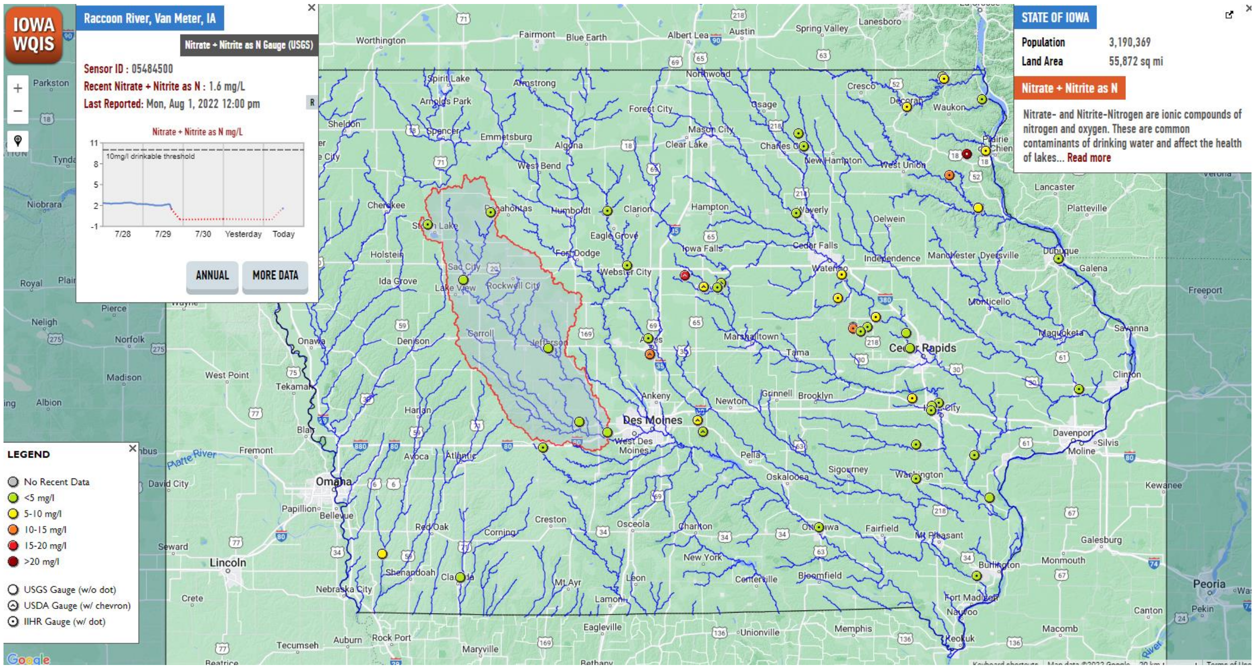
The IFC system complements the operational forecasts issued by the NWS and is based on sound scientific principles of flood genesis and spatial organization. At its core is a continuous rainfall-runoff model based on landscape decomposition into hillslopes and channel links. The input to the system comes from a radar-rainfall algorithm, developed in-house, that maps rainfall every 5 minutes with high spatial resolution.

ii. The Iowa Water-Quality Information System

The Iowa Water-Quality Information System (IWQIS) integrates real-time water-quality data collected by IIHR and the USGS, along with a variety of watershed-related information such as precipitation, stream flow and stage, soil moisture, and land use. IWQIS (https://iwqis.iowawis.org/) provides useful information for researchers, agencies, landowners, and other watershed stakeholders as they study, analyze, and work to better understand the fate and transport of nutrients in Iowa's waterways. IWQIS also helps Iowa monitor progress toward achieving the goals of the Iowa Nutrient Reduction Strategy. Iowa has the largest concentration of continuous nutrient and water-quality sensors in the United States; as of 2018, the state has a water-quality network comprised of:

- 74 nitrate sensors (14 operated by USGS)
- 27 hydrolabs (pH, SC, DO, temp)
- 26 turbidimeters
- 4 ortho-P sensors
- 4 ISCOs

This network generates data for science and policy-making, facilitates individual BMP performance assessments, and allows Iowans to quantify the nutrient loads leaving the state. Figure 2-21 shows a screenshot of IWQIS displaying the WQ network (2022).



IOWA WQIS

Raccoon River, Van Meter, IA

Nitrate + Nitrite as N Gauge (USGS)

Sensor ID : 05484500

Recent Nitrate + Nitrite as N : 1.6 mg/L

Last Reported: Mon, Aug 1, 2022 12:00 pm

STATE OF IOWA

Population	3,190,369
Land Area	55,872 sq mi

Nitrate + Nitrite as N

Nitrate- and Nitrite-Nitrogen are ionic compounds of nitrogen and oxygen. These are common contaminants of drinking water and affect the health of lakes... Read more

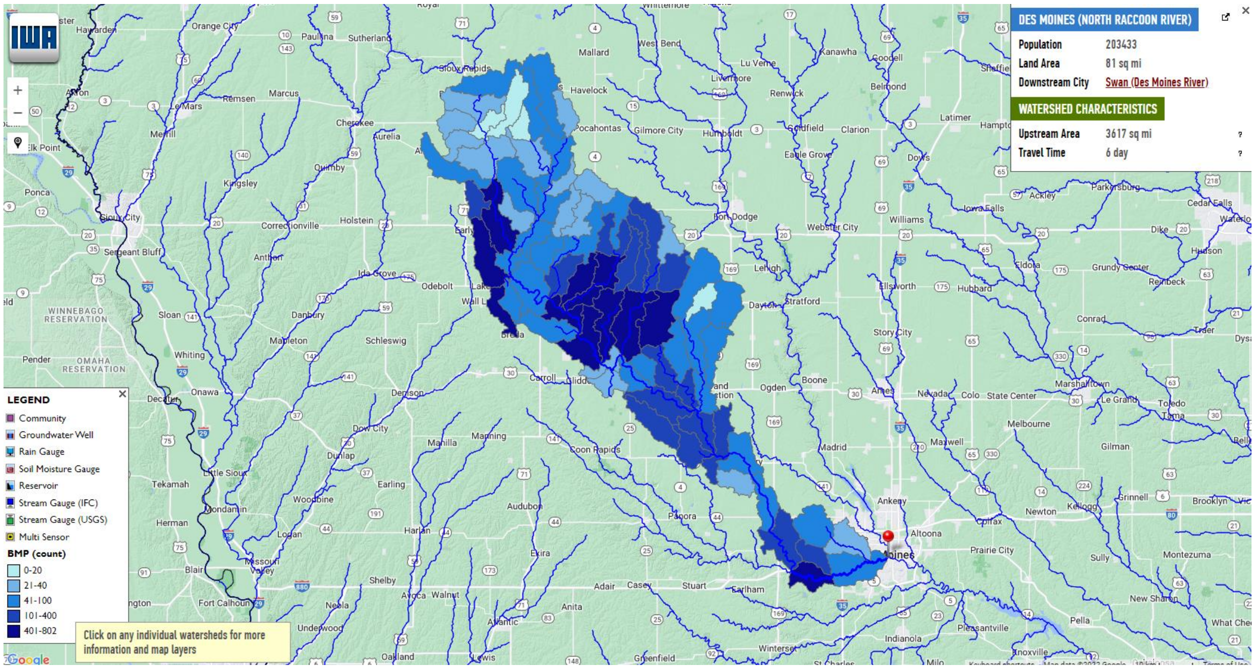
LEGEND

- ● No Recent Data
- ● <5 mg/l
- ● 5-10 mg/l
- ● 10-15 mg/l
- ● 15-20 mg/l
- ● >20 mg/l
- ○ USGS Gauge (w/o dot)
- ⊙ USDA Gauge (w/ chevron)
- ⊙ IIHR Gauge (w/ dot)

Figure 2-21. IIHR—Hydroscience and Engineering and USGS surface water-quality monitoring locations as displayed on the Iowa Water-Quality Information System (IWQIS).

iii. The Iowa Watershed Approach Information System (IWAIS)

IIHR and IFC are developing a web-based information system to provide public access to general information and updates on the IWA project, existing and potential BMPs in IWA watersheds, hydrologic and water-quality data collected in the IWA watersheds, and resources to improve flood resiliency. The website can be accessed at: http://iowawatershedapproach.org. Figure 2-22 shows an example view of the IWAIS interface, displaying the number of existing water and sediment control basins within each HUC12 in the North Raccoon River Watershed.



DES MOINES (NORTH RACCOON RIVER)

Population	203433
Land Area	81 sq mi
Downstream City	Swan (Des Moines River)

WATERSHED CHARACTERISTICS

Upstream Area	3617 sq mi	?
Travel Time	6 day	?

Figure 2-22. Example IWAIS interface view showing the number of existing water and sediment control basins within each HUC12 in the North Raccoon Watershed.

3. North Raccoon Watershed Description

This chapter provides an overview of current North Raccoon River Watershed conditions, including hydrology, geology, topography, land use, and hydrologic/meteorologic instrumentation, and historic water cycle, as well as a summary of previous floods of record.

a. Hydrology

The North Raccoon River Watershed as defined by the boundary of eight-digit Hydrologic Unit Code (HUC 8) 07100006 is in west-central Iowa and encompasses approximately 2471 square miles (mi^2). The North Raccoon River is joined by South Raccoon River (HUC 8) 07100007 near Van Meter, Iowa, forming the Raccoon River, flowing west to east into the Des Moines River at Des Moines, Iowa. The total drainage area of the Raccoon River at Des Moines is approximately 3608 mi^2. The North Raccoon River Watershed boundary falls within 15 counties in total, as shown in Figure 3-1; however, most of the watershed area lies within Buena Vista, Pocahontas, Sac, Calhoun, Webster, Carroll, Green, Dallas, and Polk Counties.

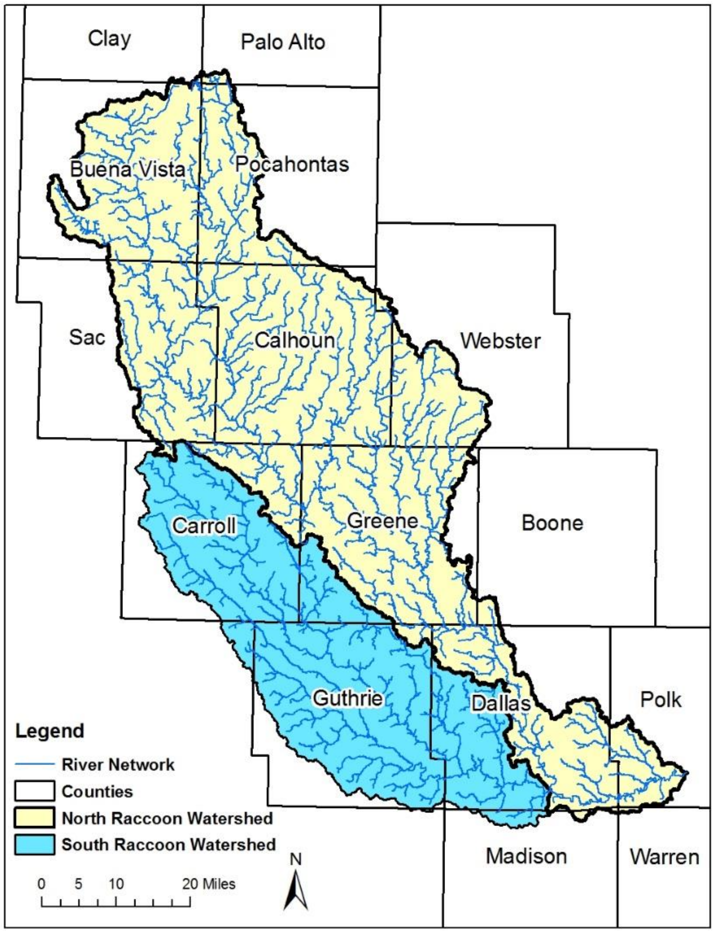


Figure 3-1. The North Raccoon River Watershed (HUC 8 07100006), drains 2471 mi^2. The North Raccoon River joins the South Raccoon River near Van Meter, Iowa.

Average annual precipitation in Iowa ranges from 26–40 inches, with the lowest precipitation in the northwest corner of the state and the highest in the southeast corner. The average annual precipitation ranges from roughly 33–36 inches in the North Raccoon River Watershed (PRISM, 1981–2010). About 75% of the annual precipitation falls as rain during the months of April–September. During this period, thunderstorms capable of producing torrential rains are possible, with the peak frequency of such storms occurring in June. Central Iowa has experienced increased variability in annual precipitation since 1975, along with a general increase in the amount of spring rainfall (U.S. Department of Agriculture — Iowa State University, 2011).

b. Geology and Soils

A landscape is a collection of terrain features or landforms (Iowa Geological & Water Survey, 2013). These combinations of surface features and underlying soils influence how water moves through the landscape.

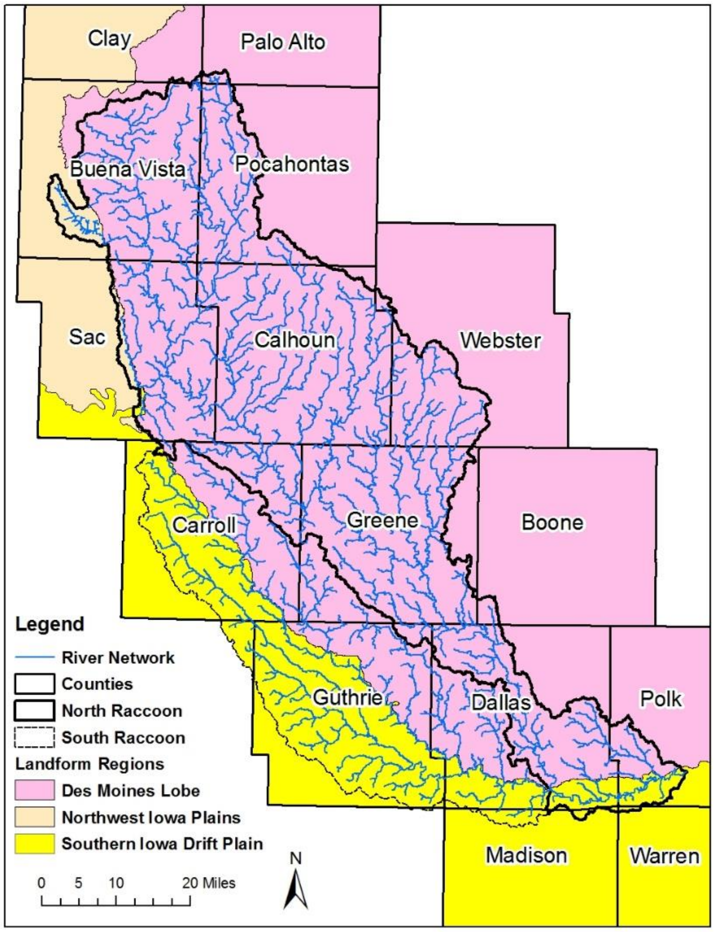


Figure 3-2. Defined Landform Regions of the North Raccoon River Watershed.

The North Raccoon River Watershed is located within three identified landform regions, the Des Moines Lobe, Northwest Iowa Plains, and Paleozoic Southern Iowa Drift Plain. While each landform region has a unique influence on the rainfall-runoff characterization, the North Raccoon River watershed is dominated by the Des Moines Lobe.

The Des Moines Lobe was shaped by the last glacier to enter Iowa. The glacier entered Iowa in a series of surges beginning 15,000 years ago. By 12,000 years ago, the slowly decaying ice sheet was gone, leaving behind a poorly drained landscape underlain by pebbly clay and areas of sands and gravels from swift meltwater streams. Today, broadly curved bands of ridges and knobby hills called moraines, mark the position of stationary ice fronts (Iowa Geological & Water Survey, 2017). Natural lakes have formed in large, scoured depressions. Abundant smaller depressions dot the landscape and are characterized as wetlands known as potholes. These depressions may hold water year-round, however many do not and only intermittently fill during heavy rainfall events or with snowmelt in the spring of the year. Many have been drained through the use of intakes and piping networks. Figure 3-3 shows a typical Des Moines Lobe cross-section.

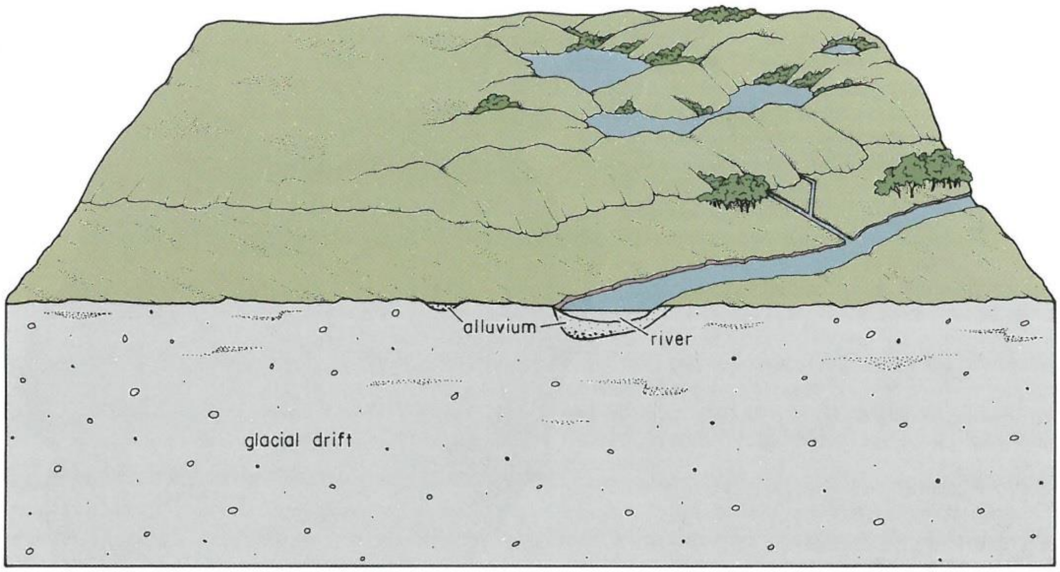


Figure 3-3. Typical Des Moines Lobe cross-section (Prior 1991).

The southern portion of the watershed, primarily the Raccoon River downstream of the confluence of the North and South Raccoon Rivers, lies in the Southern Iowa Drift Plain. This region is dominated by glacial deposits left by ice sheets that extended south into Missouri over 500,000 years ago. The deposits were carved by deepening episodes of stream erosion so that only a horizon line of hill summits marks the once-continuous glacial plain. Numerous rills, creeks, and rivers branch out across the landscape shaping the old glacial deposits into steeply rolling hills and valleys. A mantle of loess drapes the uplands and upper hill slopes (Iowa Geological & Water Survey, 2017). Figure 3-4 shows a typical Southern Iowa Drift Plain cross-section.

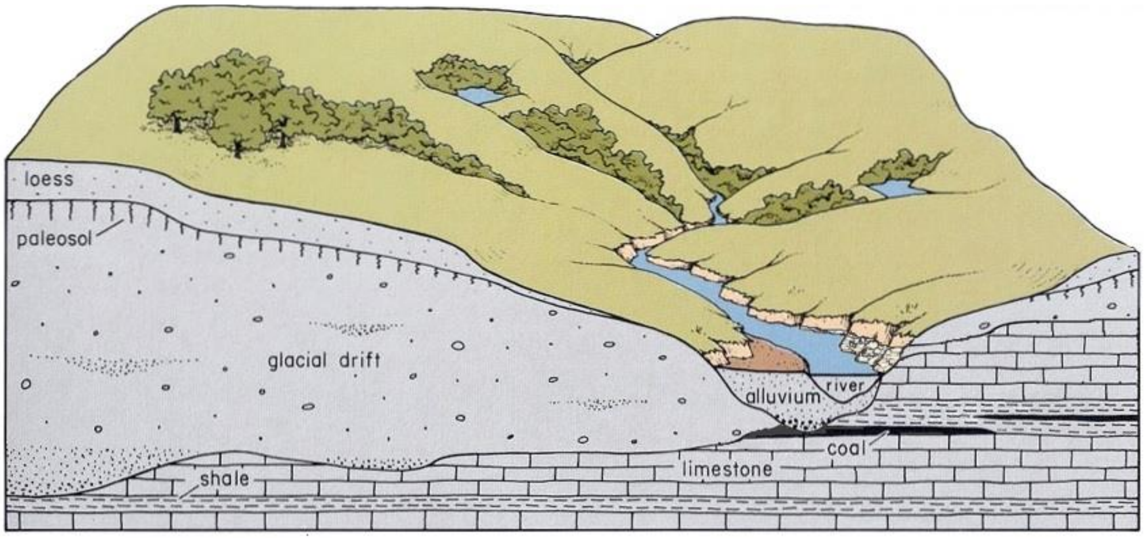


Figure 3-4. Typical Southern Iowa Drift Plain cross-section (Prior 1991).

Depth to bedrock varies from 0–500 feet throughout the watershed, as shown in Figure 3-5. Isolated areas of shallow depth to bedrock are found in southern Dallas and Polk counties A shapefile developed by IGS showing likely locations of bedrock exposed or within 30 inches of the surface shows isolated exposures through Dallas and Polk counties, and is shown in the inset of Figure 3-5.

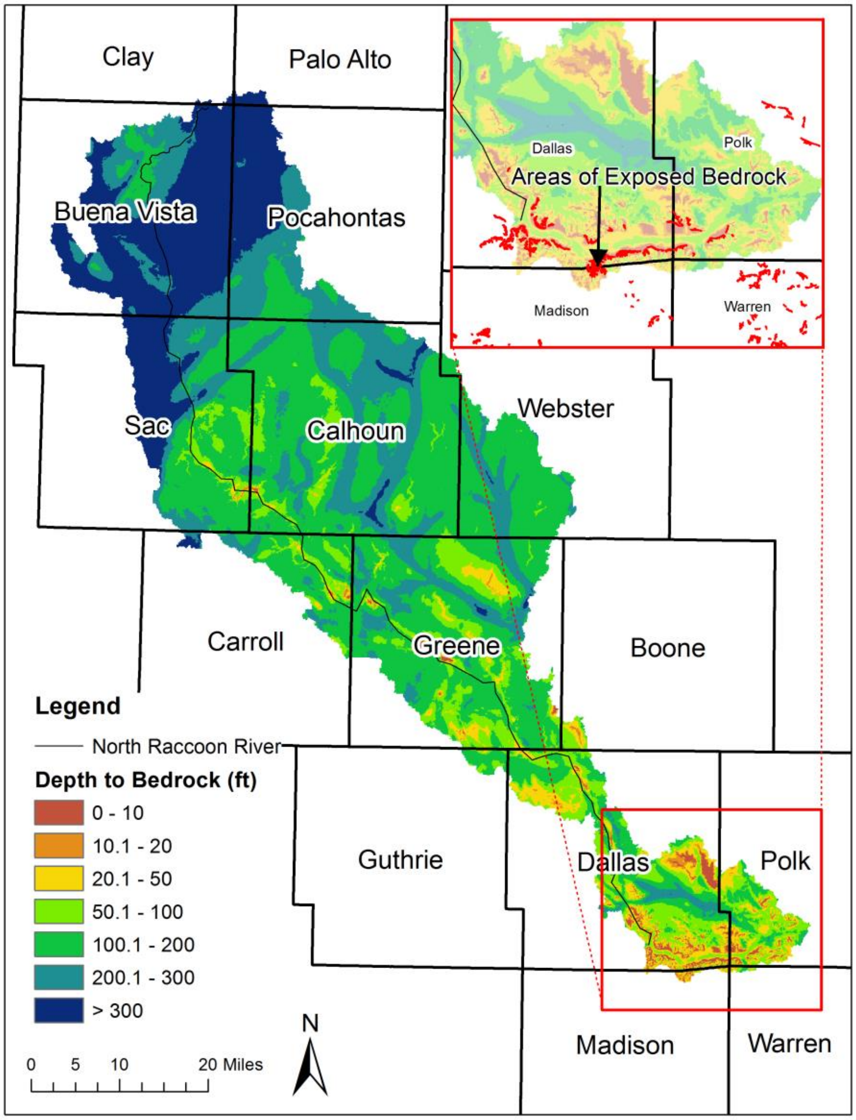


Figure 3-5. Depth to bedrock in the North Raccoon River Watershed.

The Natural Resources Conservation Service (NRCS) classifies soils into four hydrologic soil groups (HSG) based on the soil's runoff potential. The four HSGs are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, there are dual code soil classes A/D, B/D, and C/D that are assigned to certain wet soils. For these soil groups, even though the soil properties may be favorable to allow infiltration (water passing from the surface into the ground), a shallow groundwater table (within 24 inches of the surface) typically prevents much from doing so. For example, a B/D soil will have the runoff potential of a B-type soil if the shallow water table were to be drained away, but the higher runoff potential of a D-type soil if it is not. Table 3-1 summarizes some of the properties generally true for each HSG (A-D). This table is meant to provide a general description of each HSG and is not all-inclusive. Complete descriptions of the HSGs can be found in USDA-NRCS National Engineering Handbook, Part 630 – Hydrology, Chapter 7.

Table 3-1. Soil properties and characteristics generally true for hydrologic soil groups A-D.

Hydrologic Soil Group	Runoff Potential	Soil Texture	Composition	Minimum Infiltration Rate[1] (in/hr)
A	Low	Sand, gravel	< 10% clay > 90% sand/gravel	>5.67
B	Moderately low	Loamy sand, sandy loam	10–20% clay 50–90% sand	1.42-5.67
C	Moderately high	Loam containing silt and/or clay	20–40% clay <50% sand	0.14–1.42
D	High	Clay	>40% clay <50% sand	<0.14

[1] For HSG A-C, infiltration rates based on a minimum depth to any water impermeable layer and the ground water table of 20 and 24 inches, respectively.

The Des Moines Lobe consists of a mix of HSG B and B/D type soils. The area closer to the North Raccoon River is generally B type soils, resulting in moderate runoff potential. The soil in the area north and east of the main river channel as one moves further into the Des Moines Lobe is primarily classified as B/D. Dual code HSGs, such as B/D, indicate a shallow groundwater table would inhibit infiltration, creating type D soil behavior; however, if drained, the soil would behave as type B. Much of this area has had tiling placed to drain away this shallow groundwater. The soil distribution of the North Raccoon River Watershed per digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WSS) is shown in Figure 3-6. Viewing the soil distribution at this map scale is difficult, but the map does illustrate how much soils vary in space and the noticeable difference in soil types of the main river channel area versus moving further inward toward the center of the Des Moines Lobe. Table 3-2 shows the approximate percentages by area of each soil type for the North Raccoon River Watershed within the Des Moines Lobe.

Table 3-2. Approximate Hydrologic Soil Group percentages by area of the North Raccoon River Watershed within the Des Moines Lobe.

Hydrologic Soil Group	Des Moines Lobe Approximate %
A	0.3
A/D	0.1
B	48.8

B/D	44.9
C	1.0
C/D	4.1
D	0.8

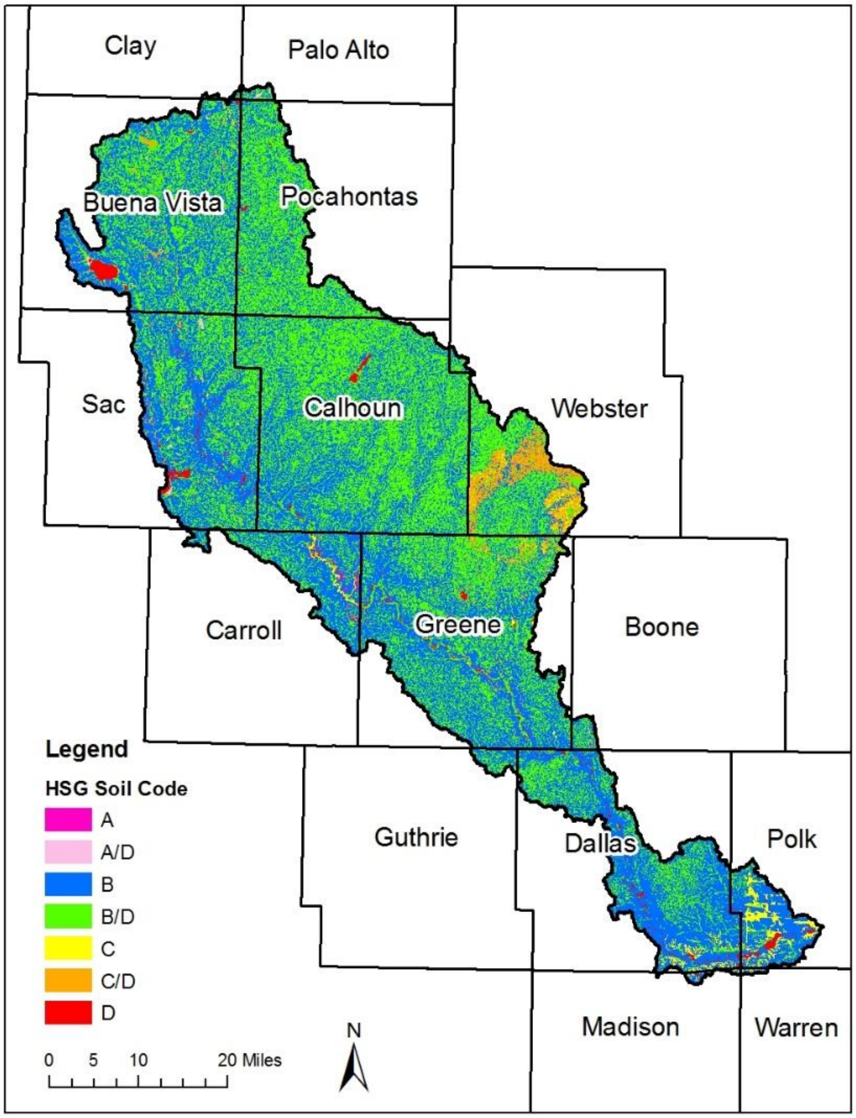


Figure 3-6. Distribution of Hydrologic Soil Groups in the North Raccoon River Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with Type A representing the lowest runoff potential and Type D representing the highest runoff potential.

c. Topography

The topography of the North Raccoon River Watershed reflects its geologic past. As previously mentioned, much of the watershed lies within the Des Moines Lobe, which characterized as minimally sloping ground, interrupted by many isolated potholes. To facilitate drainage of the region, much of the drainage network is comprised of constructed channels. Figure 3-7 shows topography provided by Iowa DNR in the form of bare-earth light detection and ranging (LiDAR) data. Elevations range from approximately 1510 feet above sea level in the uppermost part of the watershed upstream of Storm Lake to 785 feet at the Des Moines River outlet at Des Moines. Typical land slopes are between 0.3 and 1.4% (25th and 75th percentiles), with the steepest areas occurring in along the major stream valleys throughout watershed, as shown in Figure 3-9.

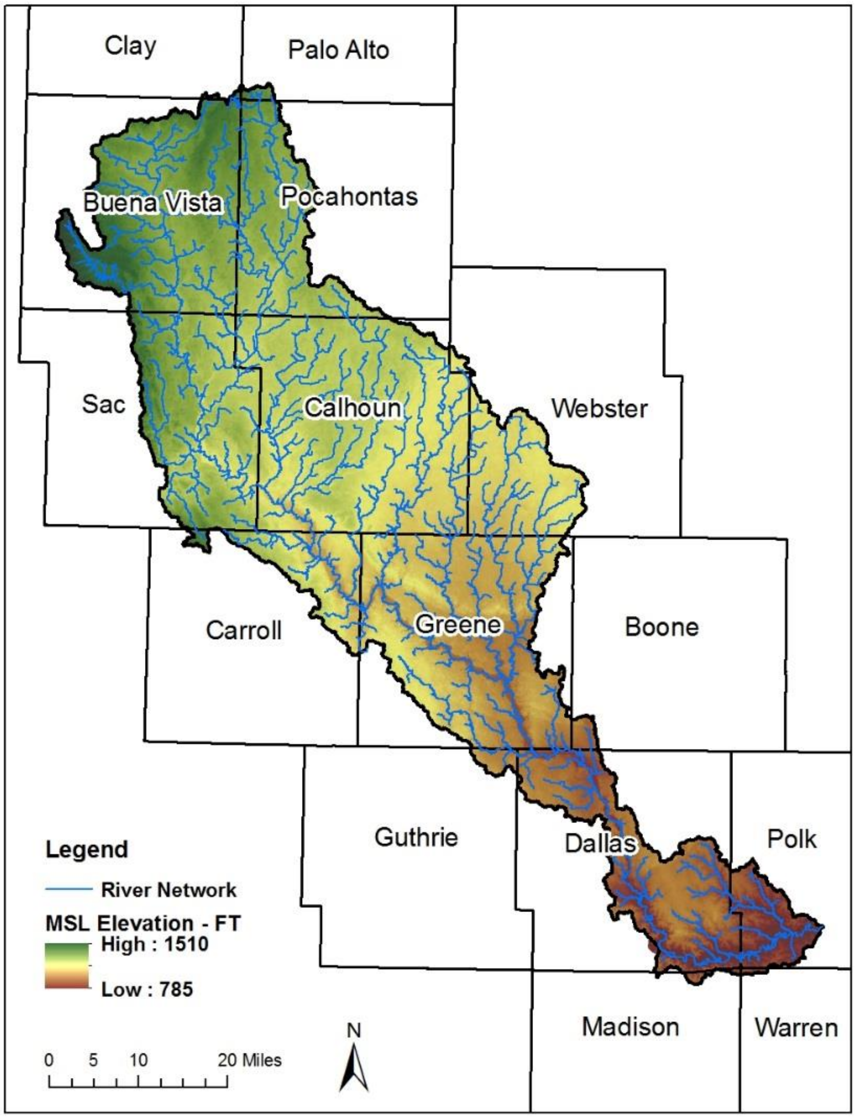


Figure 3-7. Topography of the North Raccoon River Watershed.

Potholes were identified using Geographic Information System (GIS) tools. Identifying the location of these isolated depressions is an important consideration in replicating the rainfall-runoff process of the region. These isolated pockets do not lead directly to runoff, rather they will store water until it either fills completely and spills over onto the adjacent draining land surface, evaporates, infiltrates naturally into the ground, or infiltration is aided by drainage inlets and pipe networks. In addition to identifying these isolated potholes, the area draining to each depression was also identified. These drainage areas were incorporated into the hydrologic modeling conducted for this hydrologic assessment as areas that do not contribute directly to surface runoff. Figure 3-8 shows an example of delineated potholes and their respective drainage area. A constructed/maintained channel can also be observed to the east of the potholes.

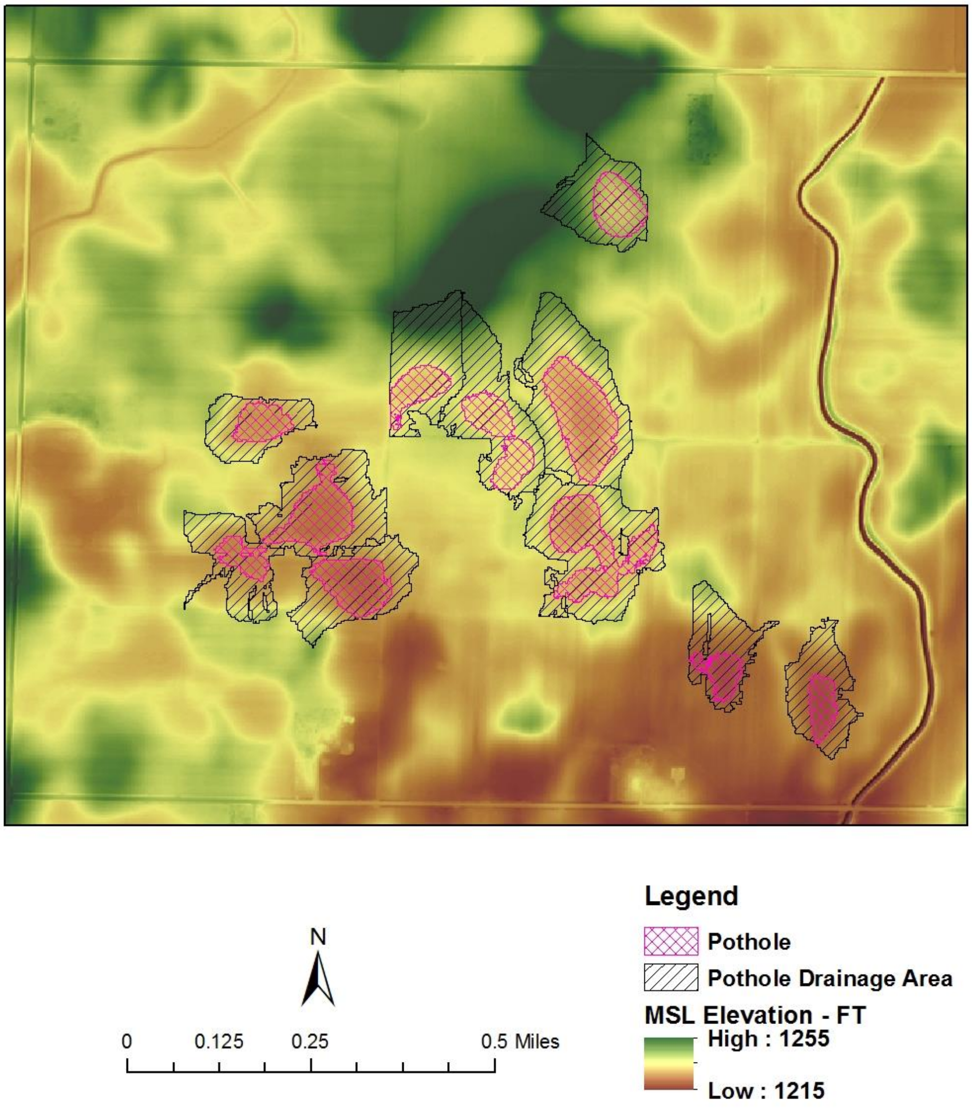


Figure 3-8. Delineated potholes and the land area that drains to them within the Des Moines Lobe in the North Raccoon River Watershed.

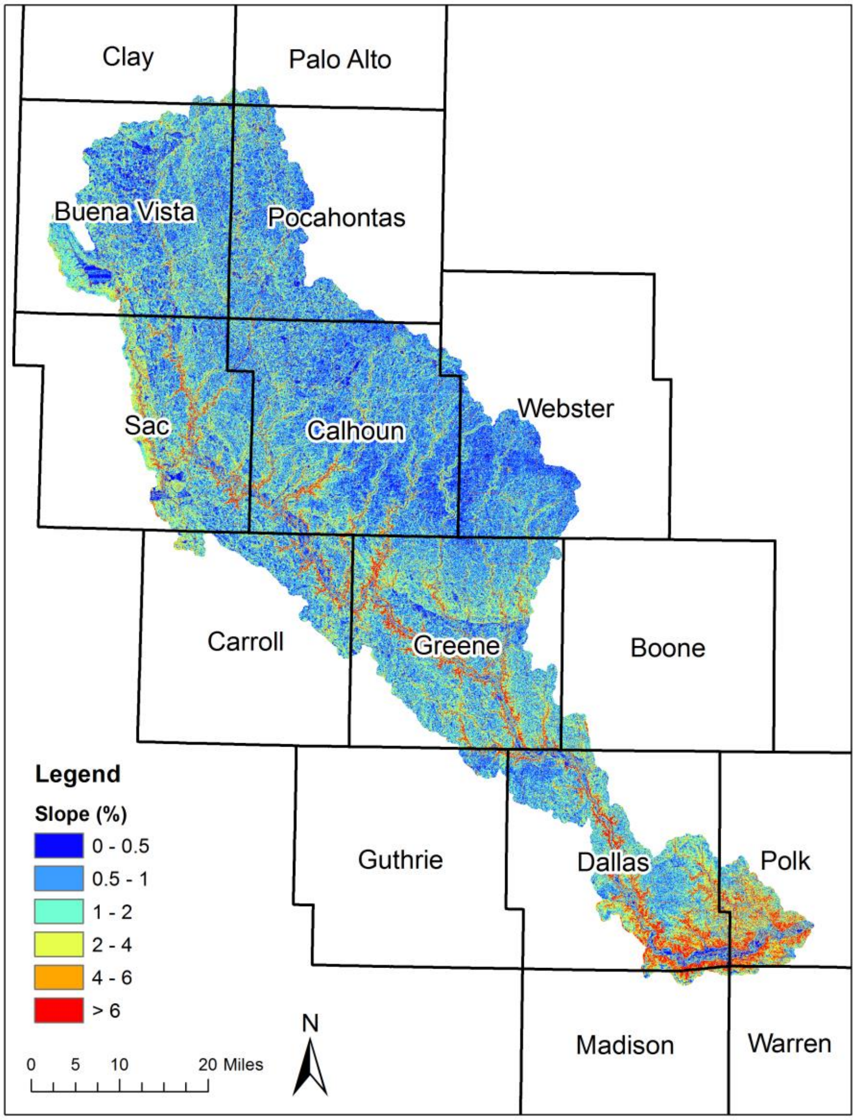


Figure 3-9. Terrain slopes derived from LiDAR data.

d. Land Use and BMP Mapping Project

Land use in the North Raccoon River Watershed is predominantly agricultural, dominated by cultivated crops (corn/soy beans) on approximately 77.7% of the acreage (approximately 1,228,250 acres), followed by grass/hay/pasture at approximately 11.9%. The remaining acreage in the watershed is about 4.6% forest (primarily deciduous forest), 3.2% developed land, and 2.6% open water and/or wetlands, per the 2009 High Resolution Land Cover (HRLC) dataset provided by Iowa DNR. Figure 3-10 shows the spatial distribution of land cover in the watershed.

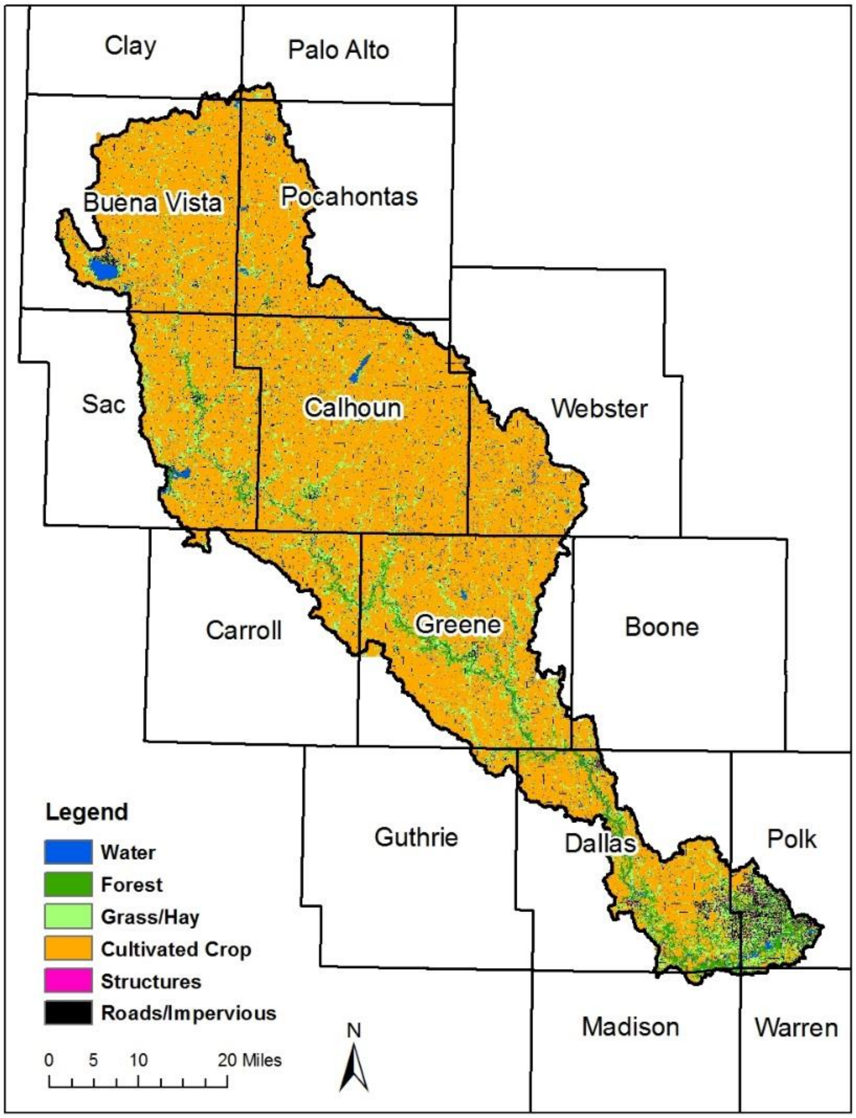


Figure 3-10. Land use composition in the North Raccoon River Watershed, according to the 2009 HRLC dataset provided by Iowa DNR.

The Iowa Best Management Practices (BMP) Mapping Project is a collaborative effort led by the Iowa State University Geographic Information Systems (GIS) Facility, in association with the Iowa DNR, Iowa Flood Center, Iowa Department of Agriculture and Land Stewardship, Iowa Nutrient Research Center, National Laboratory for Agriculture and the Environment, and the Iowa Nutrient Research and Education Council. The goal of the project is to provide a complete baseline set of BMPs during the 2007–10 timeframe for use in watershed modeling, historic documentation, and future practice tracking. These practices include terraces, water and sediment control basins (WASCOBs), grassed waterways, pond dams, contour strip cropping, and contour buffer strips. The data has been manually digitized for each HUC 12 using LiDAR products, color-infrared (CIR) imagery, National Agriculture Imagery Program imagery, and historic aerial photography.

The densities of several types of BMPs in the North Raccoon River Watershed are shown in Figure 3-11.

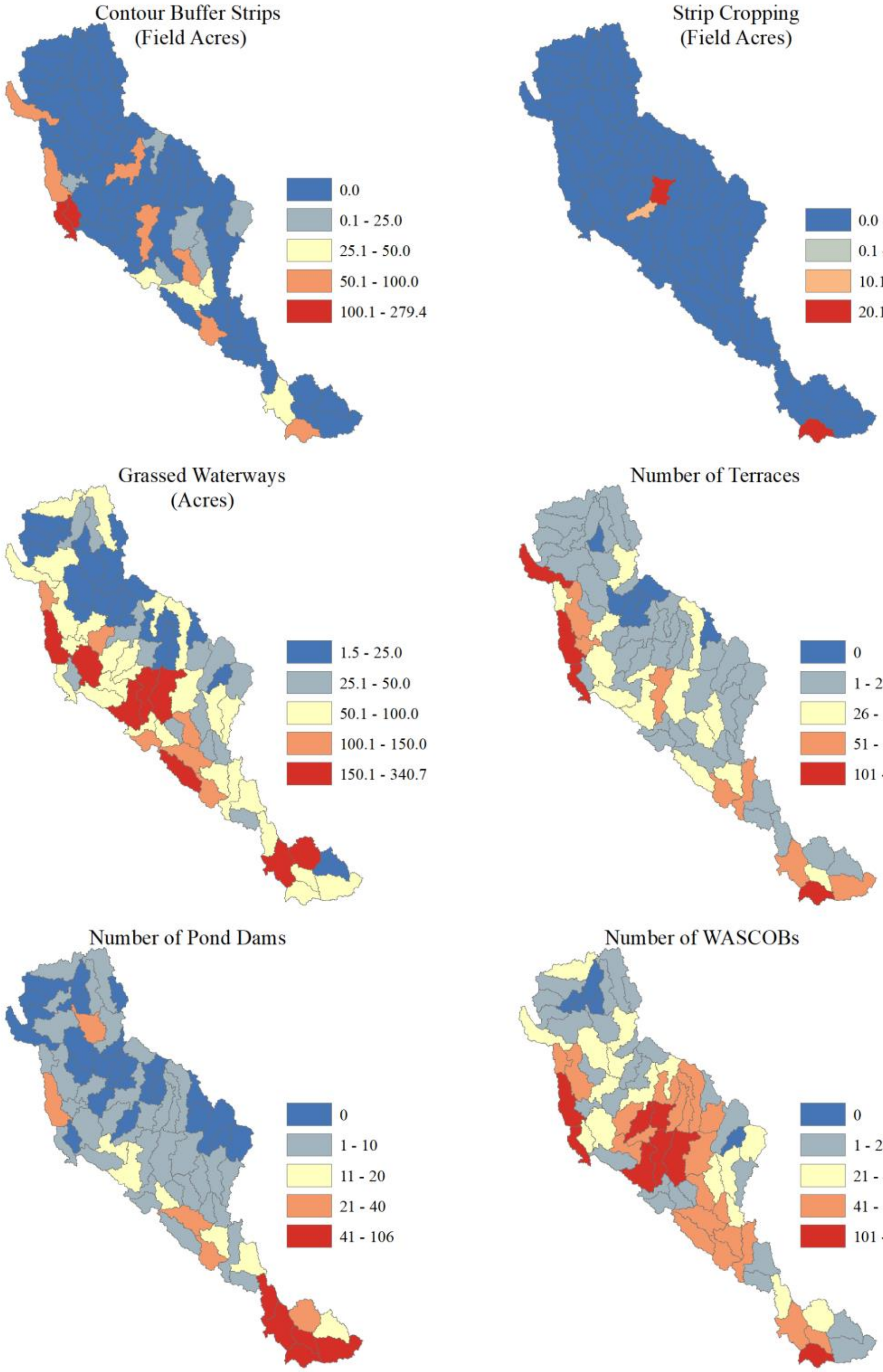


Figure 3-11. Iowa Best Management Practices Mapping project data.

e. Potential BMPs – Agricultural Conservation Planning Framework

Development of an effective watershed planning document will require identification of potential conservation practices and viable locations to implement them. One cutting-edge tool available for practical conservation planning is the Agricultural Conservation Planning Framework (ACPF) watershed planning toolbox, developed by Mark Tomer and his research team at the USDA-ARS in Ames, Iowa (Tomer et al., 2013). ACPF is a watershed approach to conservation planning facilitated with a set of semi-automated tools within ArcGIS software. Freely available and pre-packaged GIS data can be used for terrain analyses to determine which fields within the watershed are most prone to runoff into streams. Users can apply the ACPF toolbox to identify locations where field-scale and edge-of-field practices could be installed based on general design criteria. These practices include controlled drainage, surface intake filters or restored wetlands, grassed waterways, contour buffer strips, WASCOBs, nutrient removal wetlands (NRWs), or edge-of-field bioreactors (North Central Region Water Network 2018).

Using the ACPF toolbox, IFC has generated potential BMPs for 20 of the most northern HUC 12s in the North Raccoon River Watershed. Figure 3-12 shows potential BMPs and aggregated based on HUC 12 area.

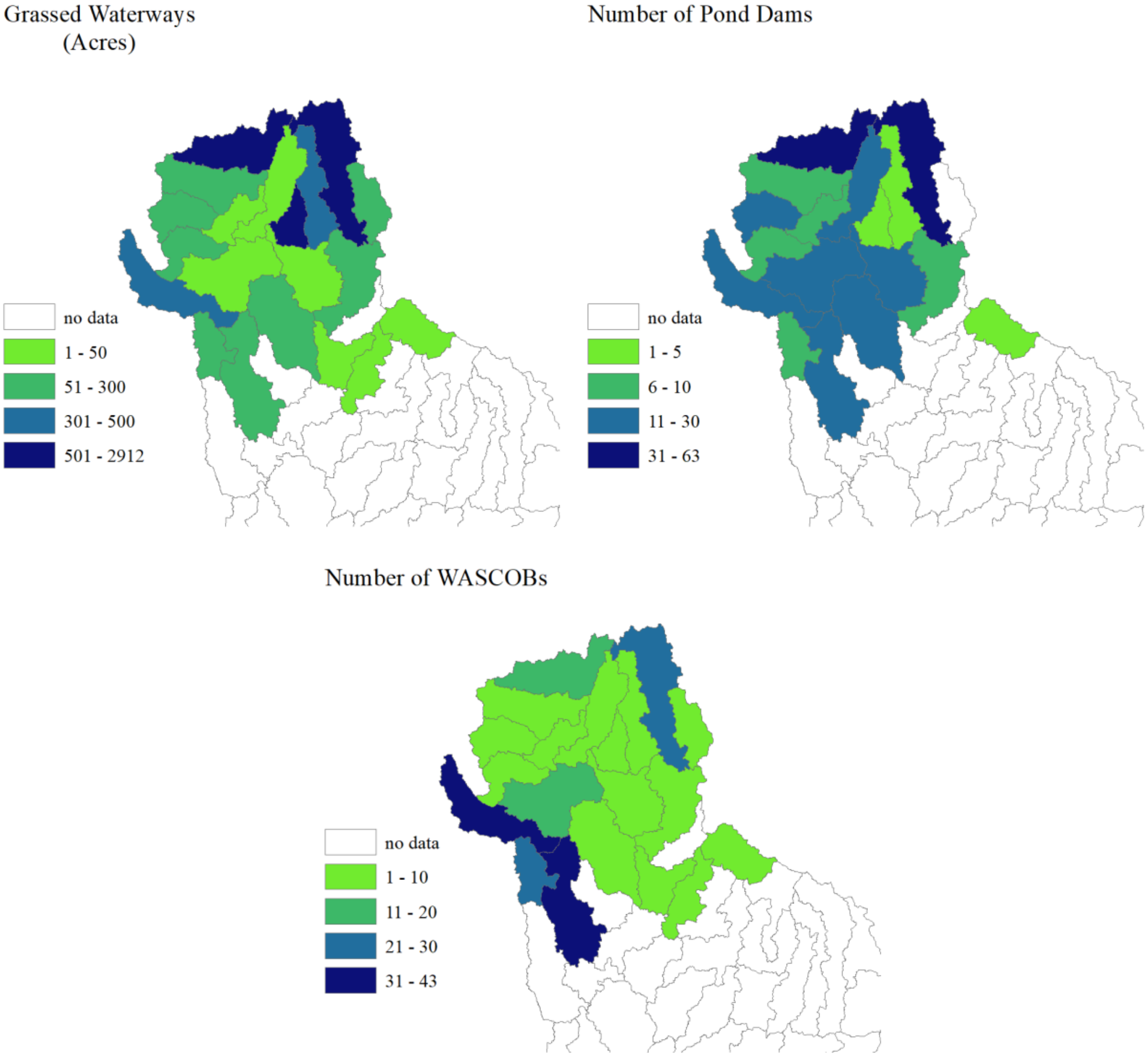


Figure 3-12. Potential BMPs in the upper North Raccoon River Watershed.

f. Instrumentation/Data Records

The North Raccoon River Watershed has instrumentation installed to collect and record stream stage, discharge, and precipitation measurements. Nine USGS-operated stage and discharge gauges and nine IFC stream-stage sensors are located within the watershed. There are seven National Oceanic and Atmospheric Administration (NOAA) 15-minute/hourly precipitation gages within or near the watershed and an additional thirty-one NOAA-partnered daily-measuring precipitation gages within or near the watershed. The operational period of record varies for each of these gages. The following figure and tables detail the instrumentation and its period of record. Only the NOAA-partnered daily-measuring precipitation gauges that fall within the watershed boundary are listed in Table 3-3.

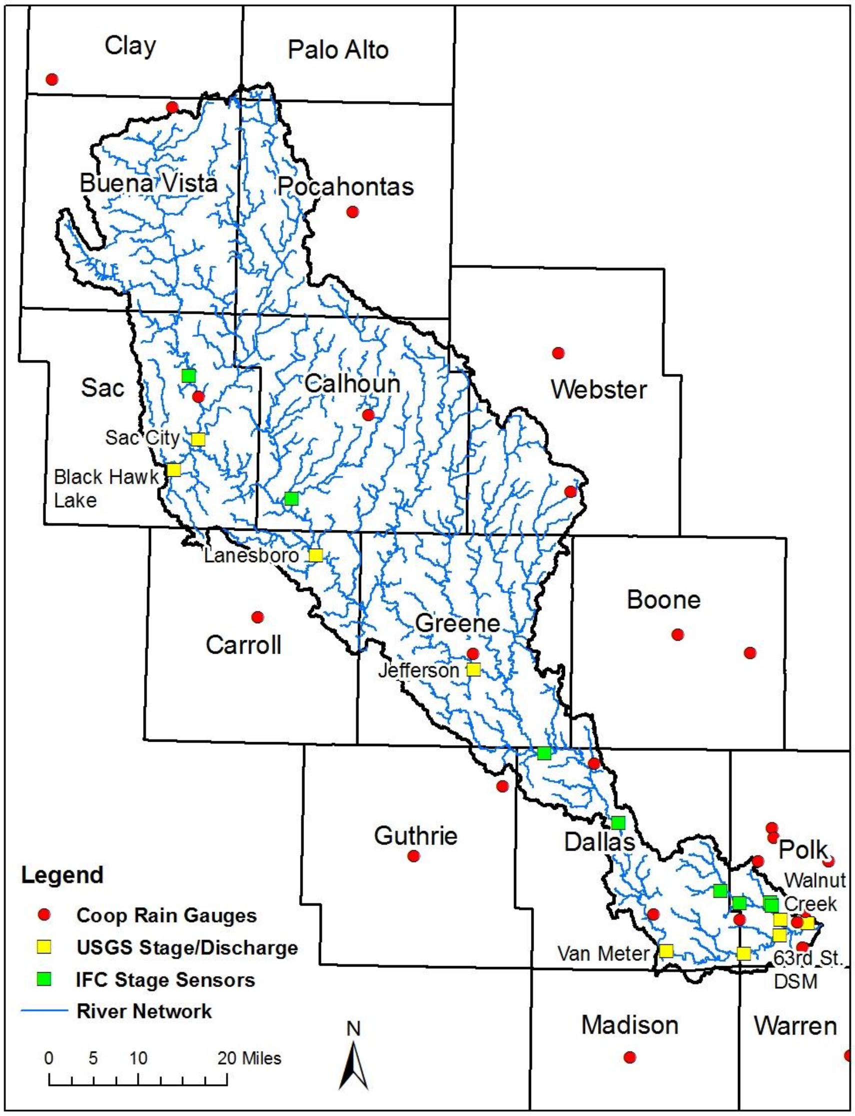


Figure 3-13. Hydrologic and meteorologic instrumentation in the North Raccoon River Watershed. Stage/discharge gages (18) are shown in yellow or green while NOAA-partnered daily-measuring precipitation gages (31) are shown in red.

Table 3-3. Stage/Discharge Gauges and Precipitation Gauges in the North Raccoon River Watershed.

Gage Type	Location	Period of Record
USGS Stage/Discharge	N. Raccoon River near Sac City, IA 05482300	1958 – present
USGS Stage Only	Black Hawk Lake at Lake View, IA 05482315	1970 – 1975 1978 – 1992 1994 – present
USGS Stage Only	N. Raccoon River near Lanesboro, IA 05482430	2009 – present

USGS Stage/Discharge	N. Raccoon River near Jefferson, IA 05482500	1940 – present
USGS Stage/Discharge	Raccoon River at Van Meter, IA 05484500	1915 – present
USGS Stage Only	Raccoon River near West Des Moines, IA 05484600	2000 – present
USGS Stage/Discharge	Raccoon River at 63rd St. Des Moines, IA 05484650	1991 – present
USGS Stage/Discharge	Raccoon River at Fleur Dr. Des Moines, IA 05484900	1995 – present
USGS Stage/Discharge	Walnut Creek at Des Moines, IA 05484800	1971 – present
IFC Stream Sensor (stage)	N. Raccoon River, 230th St., North of Sac City, IA NRCCNRV03	2011 – present
IFC Stream Sensor (stage)	Lake Creek, 365th St./HWY 165, North of Lanesboro, IA LAKECR01	2010 – present
IFC Stream Sensor (stage)	N. Raccoon River, P46/D Ave., Near Dallas/Greene County Line NRCCNRV02	2014 – present
IFC Stream Sensor (stage)	N. Raccoon River, Milburn Road., Dallas County, IA NRCCNRV01	2014 – present
IFC Stream Sensor (stage)	Raccoon River, R16/R Ave., Near Van Meter, IA RCCNRV01	2014 – present
IFC Stream Sensor (stage)	Little Walnut Creek, NW 156th St., Dallas County, IA LTLWLNT01	2010 – present
IFC Stream Sensor (stage)	Walnut Creek, South of Hickman Rd./HWY 6, Polk County, IA WLNTCR01	2016 – present
IFC Stream Sensor (stage)	North Walnut Creek, Hickman Rd./HWY 6, Polk County, IA NWLNTCR02	2010 – present
IFC Stream Sensor (stage)	North Walnut Creek, West of 75th St., Polk County, IA NWLNTCR01	2011 – present
NOAA 15min/1hr Precip	Rockwell City #1	1948 – 1968
NOAA 15min/1hr Precip	Rockwell City #2	1968 – 2012
NOAA 15min/1hr Precip	Beaver, IA	1948 – 1953
NOAA 15min/1hr Precip	Ogden, IA	1953 – 2012
NOAA 15min/1hr Precip	Johnston, IA	1998 – 2006
NOAA 15min/1hr Precip	Des Moines, SE 6th St.	1948 – 1975
NOAA 15min/1hr Precip	Des Moines Airport	1948 – 2013
NOAA-partnered Daily Precip	Sac City, IA	2008 – present
NOAA-partnered Daily Precip	Rockwell City, IA	2008 – present

NOAA-partnered Daily Precip	Hartcourt 2 N	2008 – present
NOAA-partnered Daily Precip	Jefferson 2 NW	2008 – present
NOAA-partnered Daily Precip	Perry, IA	2008 – present
NOAA-partnered Daily Precip	Adel, IA	2009 – present
NOAA-partnered Daily Precip	West Des Moines, IA	2008 – present
NOAA-partnered Daily Precip	Des Moines Waveland	2008 – present
NOAA-partnered Daily Precip	Des Moines NWS (Snow)	2012 – present

g. Baseflow and Runoff Historic Trends

We estimated annual precipitation volumes for each water year (October 1–September 30) from 1950 to 2017 using daily precipitation records near the watershed areas upstream of Jefferson and Van Meter. Total annual discharge for each water year was also calculated at Jefferson and Van Meter, using daily discharge observations from USGS gauging stations 05482500 and 05484500. Using these historical precipitation and discharge records, it is possible to estimate partitioning of precipitation into baseflow and direct runoff on an annual basis. Using the local minimum method, we separated daily discharge into baseflow and runoff. Figure 3-14 shows plots of annual precipitation, streamflow, baseflow, and runoff at Jefferson, Iowa. All datasets have a slight positive trend, with low correlation values. Similar datasets are shown in Figure 3-15 for Van Meter, Iowa.

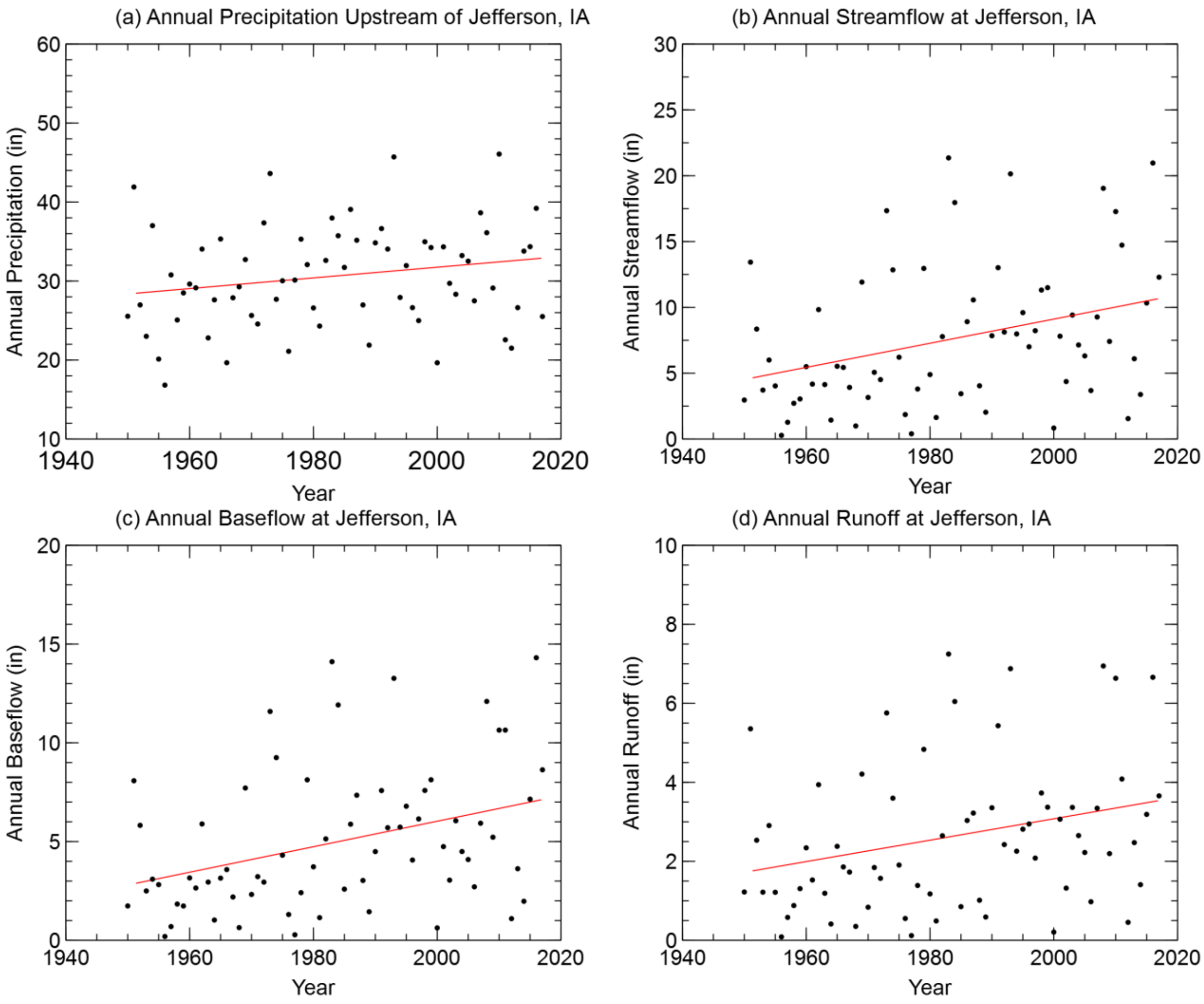


Figure 3-14. Annual totals for: (a) precipitation; (b) streamflow; (c) baseflow; and (d) runoff at Jefferson, IA.

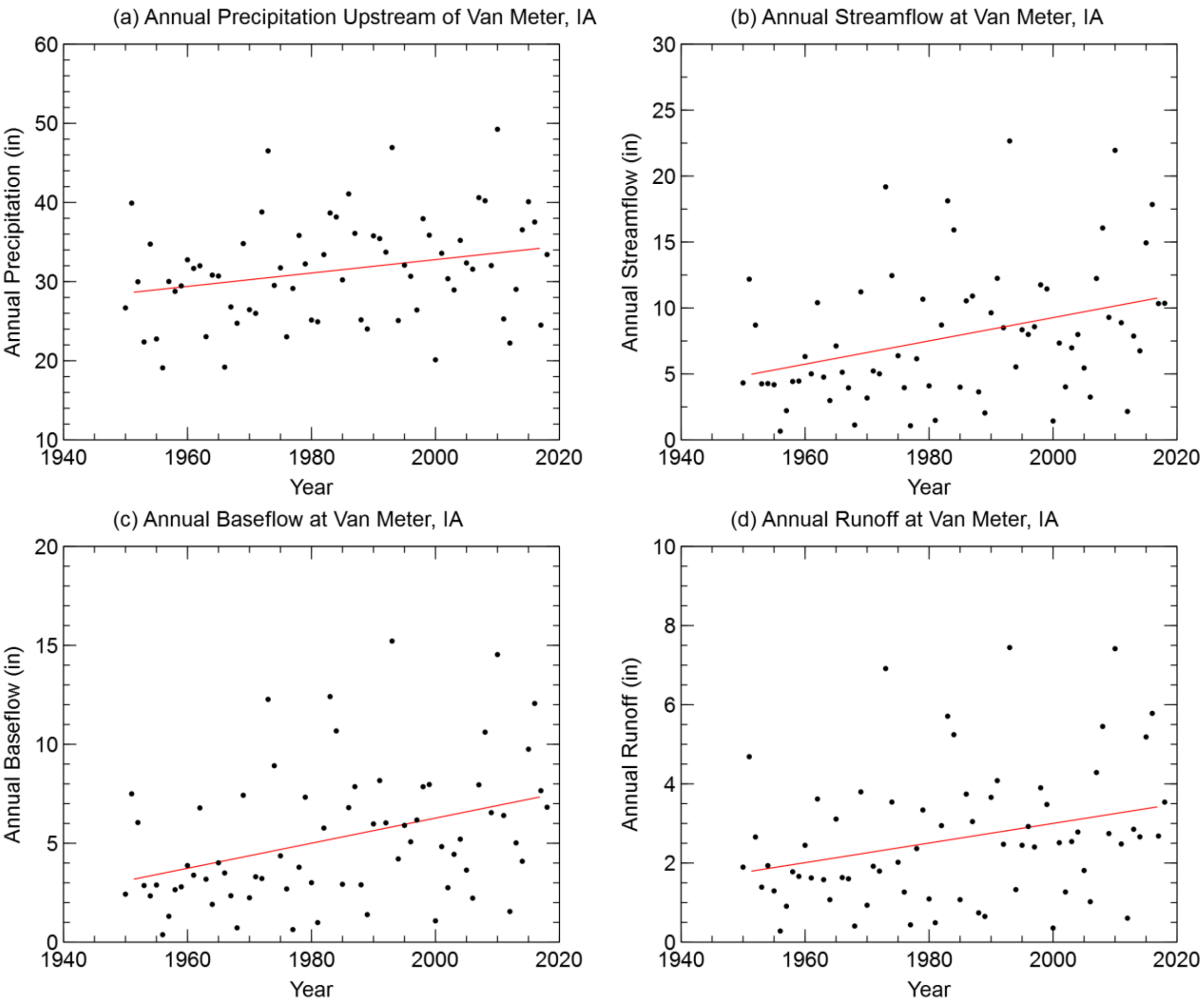


Figure 3-15. Annual totals for: (a) precipitation; (b) streamflow; (c) baseflow; and (d) runoff at Van Meter, IA.

We developed cumulative mass curves to further visualize and investigate any historic trends associated with these data. Cumulative mass curves allow visualization of long-term discharge or precipitation trends, with changes in slope indicating possible historical change points. Cumulative mass curves at Jefferson and Van Meter were created for precipitation, streamflow, baseflow, and runoff by summing each consecutive annual total volume (inches), and are shown in Figure 3-16 and Figure 3-17. Cumulative annual precipitation closely follows a linear trend, with little deviation from the fitted trend line. This indicates no significant change in long-term total precipitation upstream of both Jefferson and Van Meter. Beginning in the 1980s, cumulative annual streamflow totals at both locations indicate a departure from the historical trend, with the largest departures beginning in the mid-1990s and continuing to the present. This change appears to be a result of increased baseflow, which shows more noticeable departures from the historic trend than does cumulative annual runoff. It is worth noting that the 1993 water year appears to contribute to an abrupt departure from the historic trend.

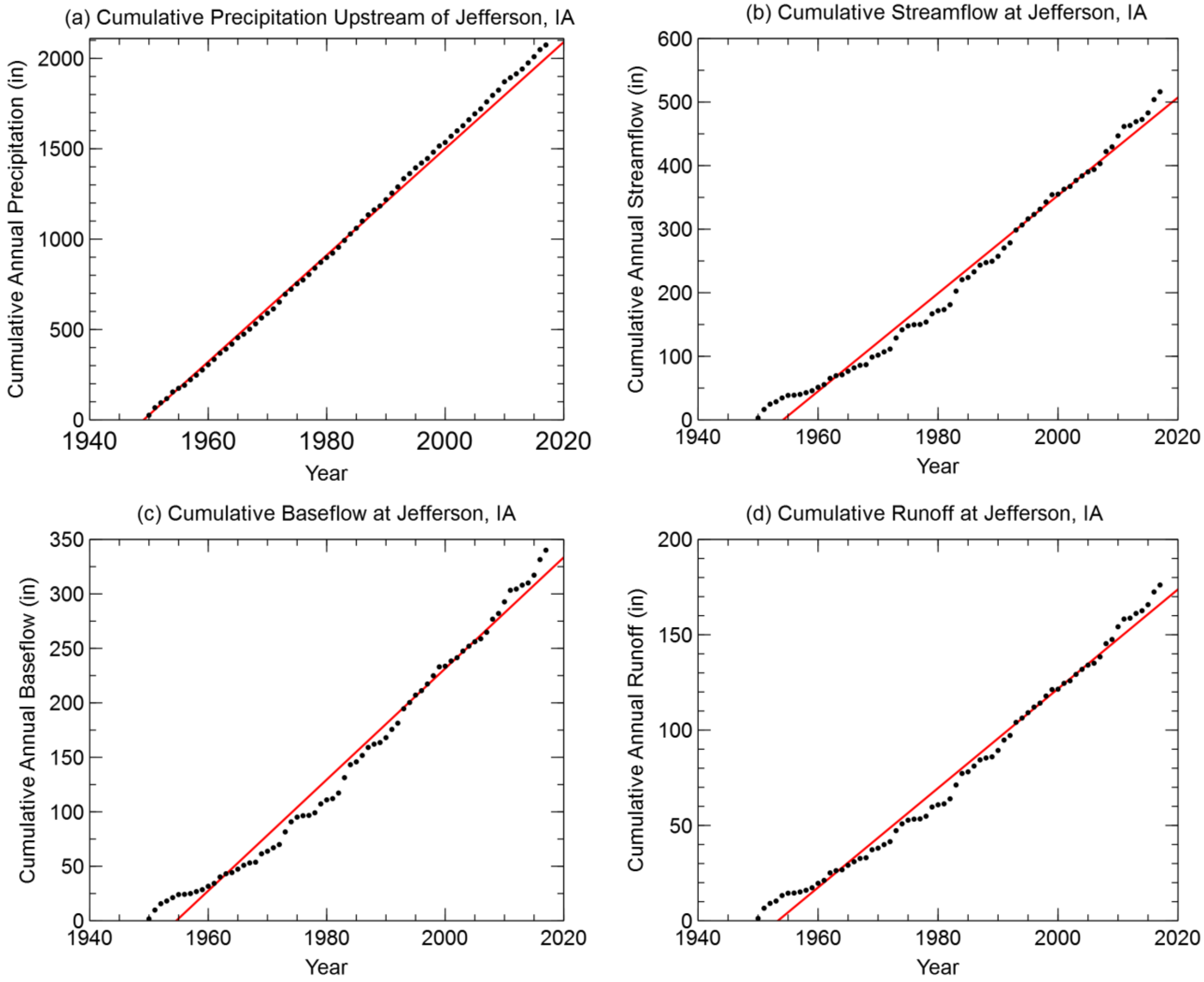


Figure 3-16. Cumulative annual totals for: (a) precipitation; (b) streamflow; (c) baseflow; and (d) runoff at Jefferson, Iowa.

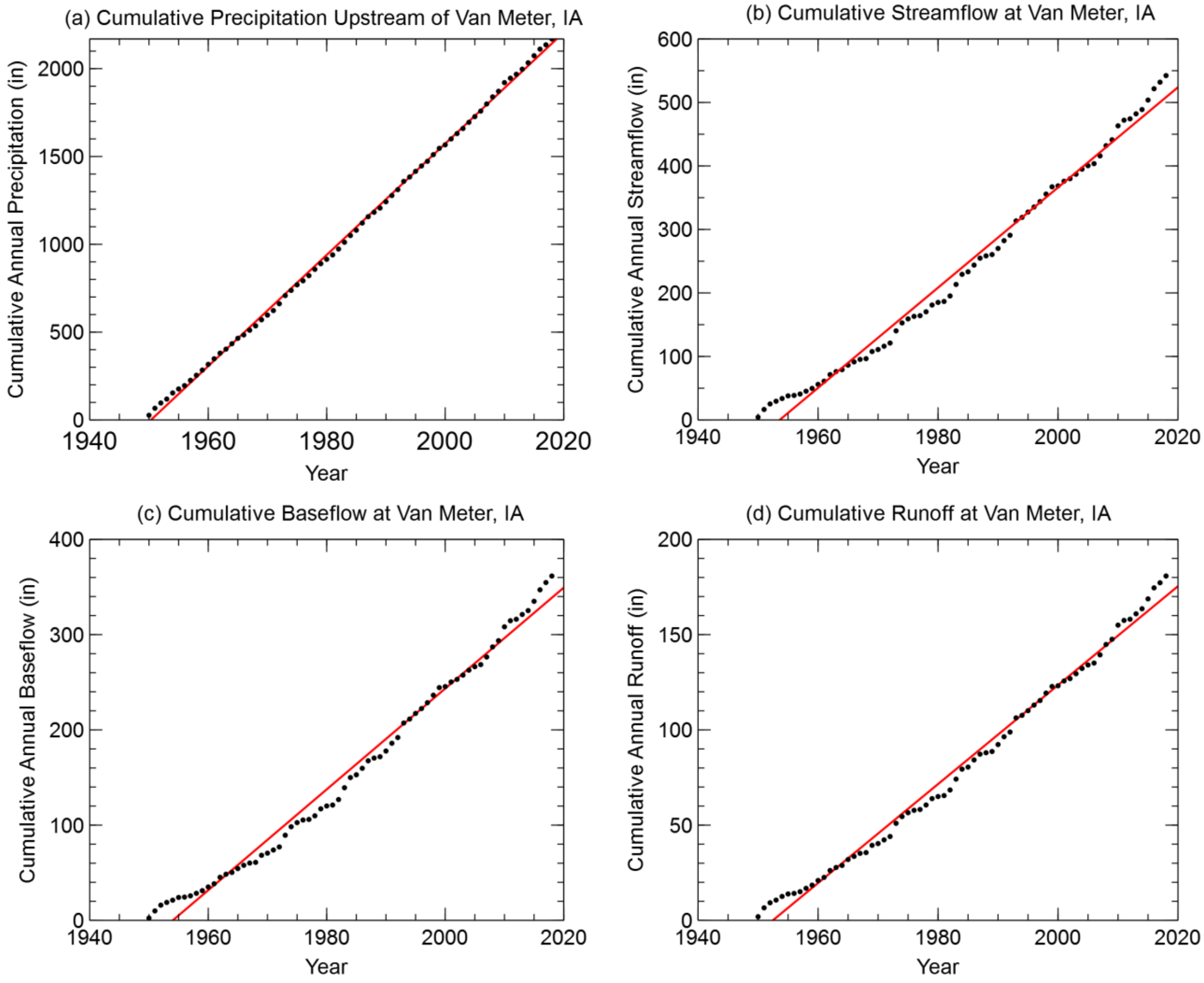
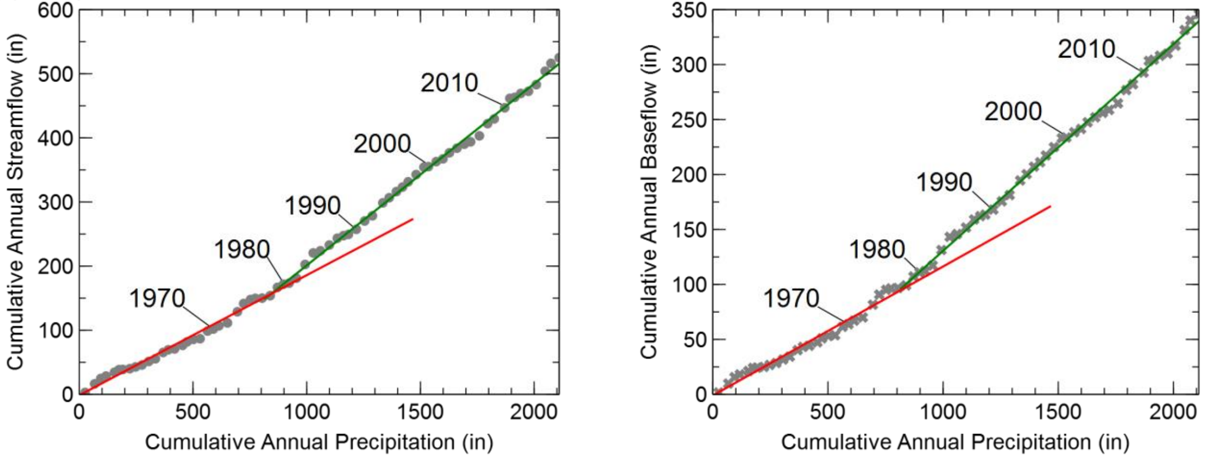


Figure 3-17. Cumulative annual totals for: (a) precipitation; (b) streamflow; (c) baseflow; and (d) runoff at Van Meter, Iowa.

The influence of extremely wet years, such as 1993, on the linear trend can be accounted for using a double-mass curve. A double-mass curve based on a plot of two cumulative quantities during the same period will follow a straight line if the proportionality between the qualities remains unchanged (Gao et al. 2010). Figure 3-18 and Figure 3-19 show double mass curves of cumulative precipitation with cumulative streamflow, baseflow, and runoff at Jefferson and Van Meter, respectively. These plots indicate that changes in historic streamflow totals are likely a result of historic increases in baseflow beginning in the 1980s, with the largest changes occurring in the last two decades. The reason for changes in streamflow continues to be intensely investigated (Mora et al. 2013, Frans et al. 2013, Yiping et al. 2013); likely drivers include improved conservation practices promoting infiltration, greater artificial drainage, increasing row crop production, and channel incision (Schilling and Libra, 2003).

(a) Precipitation-Streamflow Double-Mass Curve at Jefferson, IA (b) Precipitation-Baseflow Double-Mass Curve at Jefferson, IA



(c) Precipitation-Runoff Double-Mass Curve at Jefferson, IA (d) All Double-Mass Curves

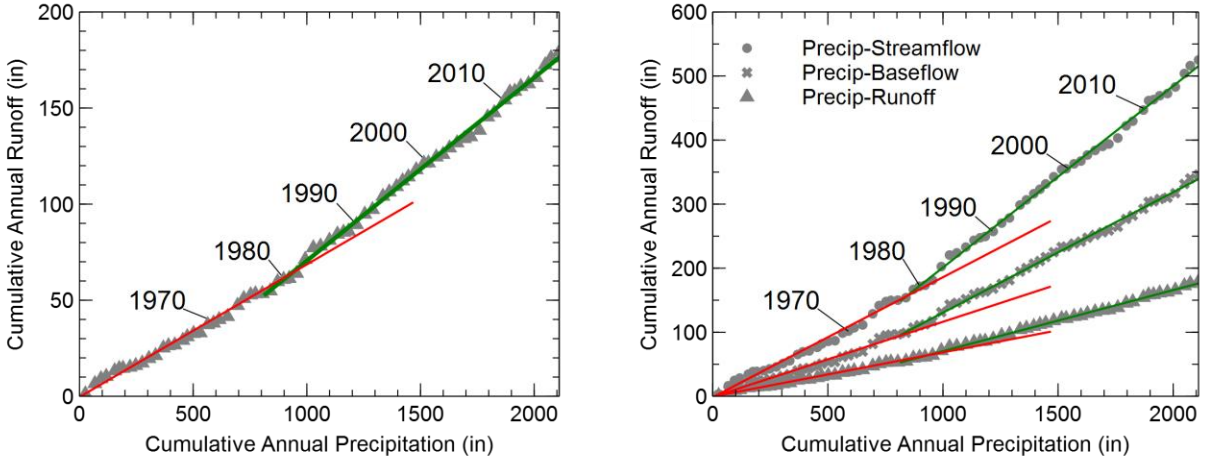
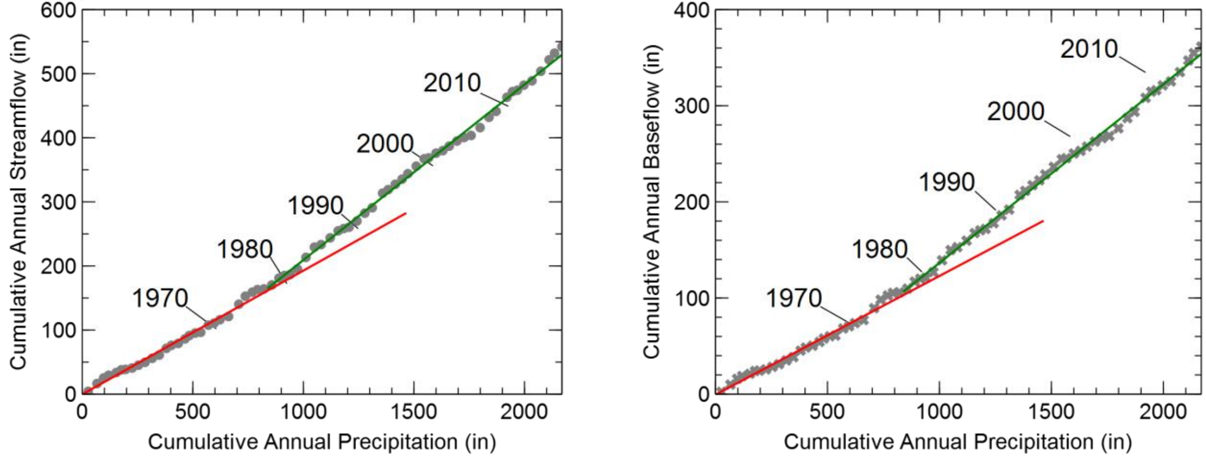
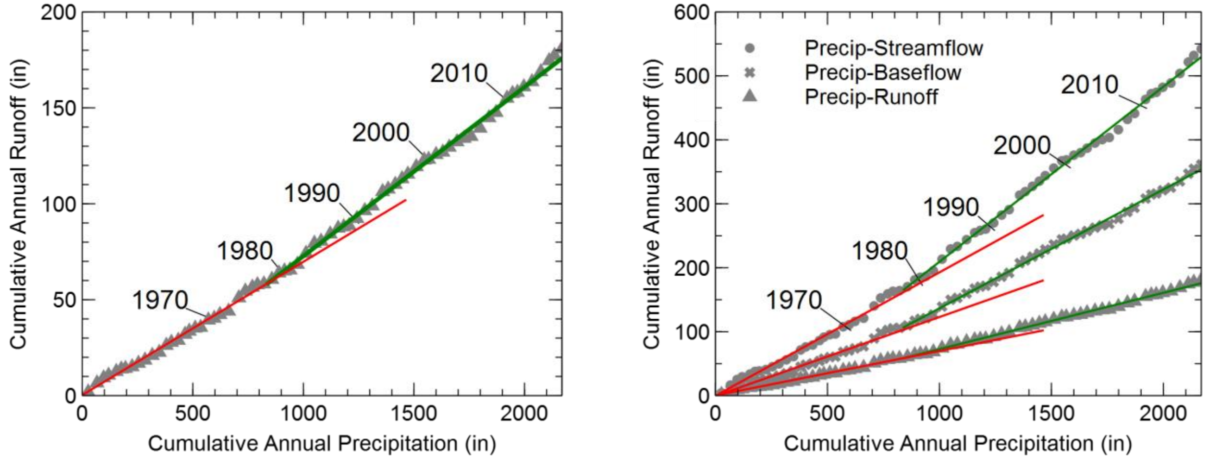


Figure 3-18. Double-mass curves using cumulative annual precipitation with cumulative annual (a) streamflow, (b) baseflow, and (c) runoff at Jefferson, Iowa. Fitted lines show segments have different slopes beginning around 1980.


(a) Precipitation-Streamflow Double-Mass Curve at Van Meter, IA

(b) Precipitation-Baseflow Double-Mass Curve at Van Meter, I


(c) Precipitation-Runoff Double-Mass Curve at Van Meter, IA

(d) All Double-Mass Curves

Figure 3-19. Double-mass curves using cumulative annual precipitation with cumulative annual (a) streamflow, (b) baseflow, and (c) runoff at Van Meter, Iowa. Fitted lines show segments have different slopes beginning around 1980.

h. Monthly Water Cycle

Using historic USGS streamflow and precipitation records, we calculated the average monthly stream flow and upstream precipitation at Jefferson and Van Meter for the period 1950-2017. Monthly averages for Van Meter and Jefferson are shown in Figure 3-20 and Figure 3-21, respectively. The monthly trends are very similar at both locations. Precipitation amounts are lowest during the winter months. However, this precipitation is likely snowfall, which accumulates before melting in the warmer spring temperatures. A large increase in the average precipitation occurs in the spring months, before peaking in the months of May and June. Streamflow follows a similar trend; the largest monthly average streamflow occurs in May and June. Precipitation slowly decreases through late summer and early fall, while streamflow drops significantly after the summer months.

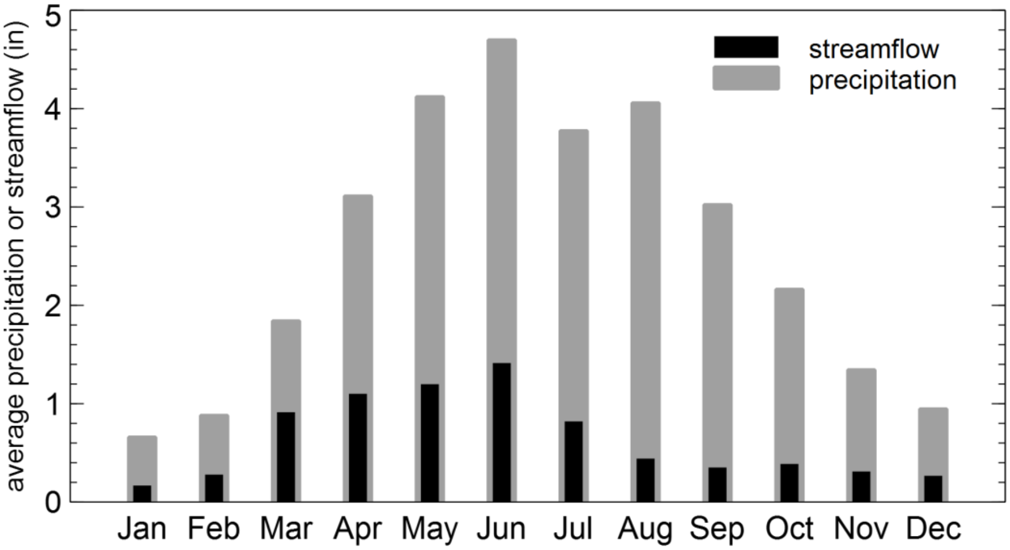


Figure 3-20. Monthly water cycle for the North Raccoon River Watershed at Jefferson, Iowa. The plots show the average monthly precipitation (inches) and the average monthly streamflow (inches). The average monthly estimates for precipitation and streamflow are based on the period 1950–2017.

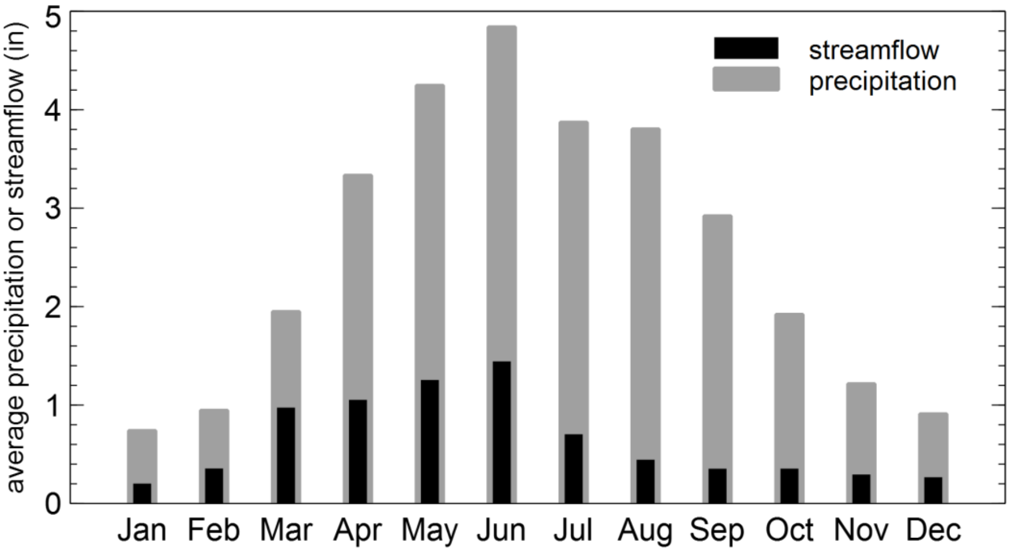


Figure 3-21. Monthly water cycle for the North Raccoon River Watershed at Van Meter, Iowa. The plots show the average monthly precipitation (inches) and the average monthly streamflow (inches). The average monthly estimates for precipitation and streamflow are based

i. Floods of Record

Figure 3-22 shows the annual maximum peak discharges observed at the Jefferson and Van Meter USGS gauging stations. While these are annual maximum, many were not flood events. Calculating the mean annual peak discharge by averaging all annual peak observations can serve as a reasonable threshold for flooding occurrences. Of the 103 annual maximum peak discharges at Jefferson, Iowa, 42 peaks were greater than the mean annual peak discharge. Of the 78 annual maximum peak discharges at Van Meter, Iowa, 35 peak were greater than the mean annual peak discharge. It is important to note the Van Meter gauging station is downstream of the confluence with the South Raccoon River.

Further analyses of these annual maximum peak discharges reveal the seasonal flood pattern for the North Raccoon Watershed. Figure 3-23 shows the calendar day of occurrence for each of the annual maximum peak discharges at Jefferson and Van Meter. There is an abrupt drop in annual maximum in the month of July for both locations. This is further visualized in Figure 3-24 with the number of flood occurrences for each calendar month. Most flooding events occur during the months of May and June. A secondary peak occurs in March, likely caused by snowmelt and spring rains. Late summer and early fall see a small increase in the occurrence of flood events.

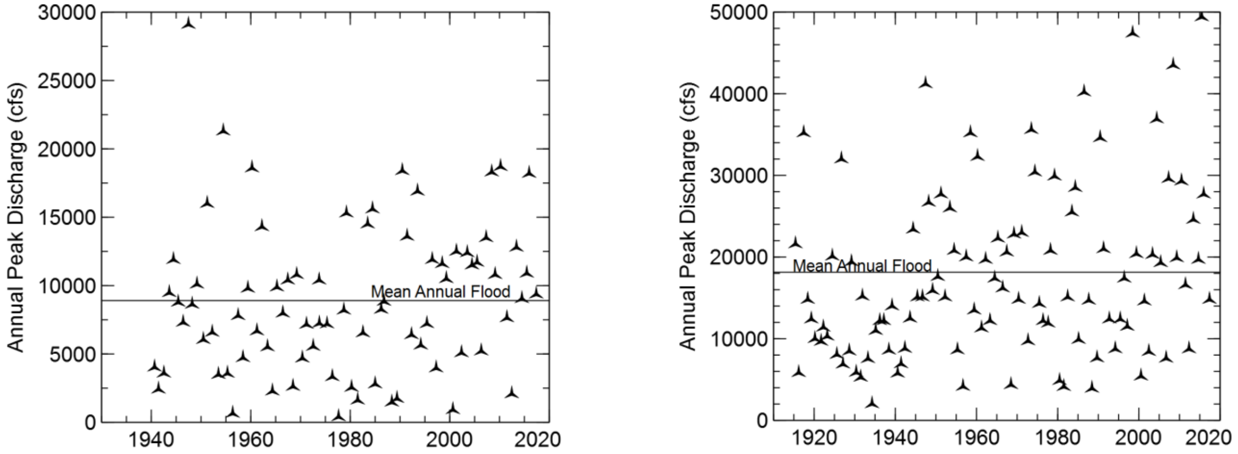


Figure 3-22. Annual maximum peak discharges observed at the Jefferson (left) and Van Meter (right) USGS stream gauge stations.

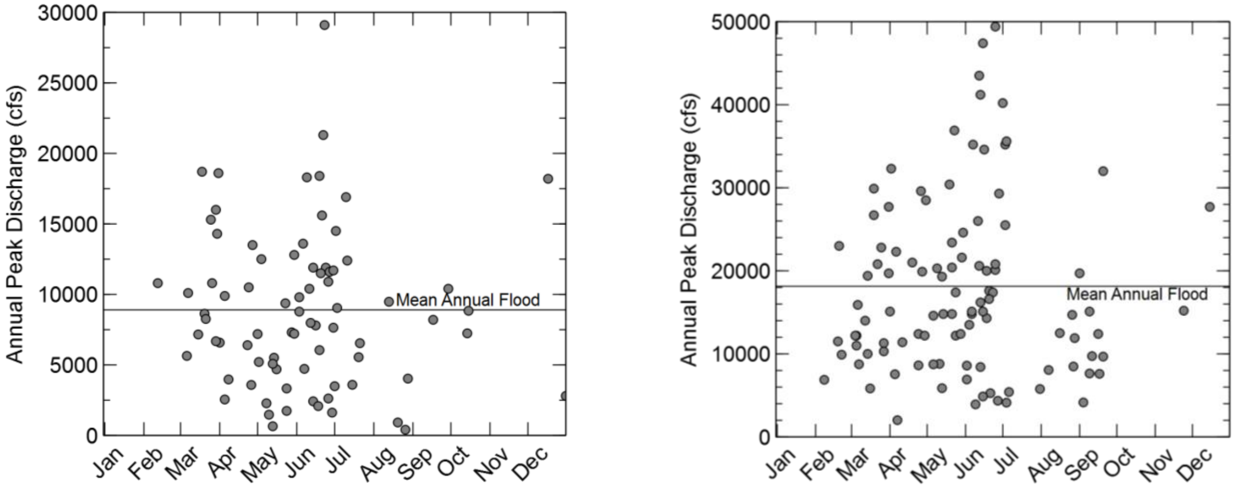


Figure 3-23. Annual maximum peak discharge and the calendar day of occurrence at the Jefferson (left) and Van Meter (right) USGS stream gauge stations.

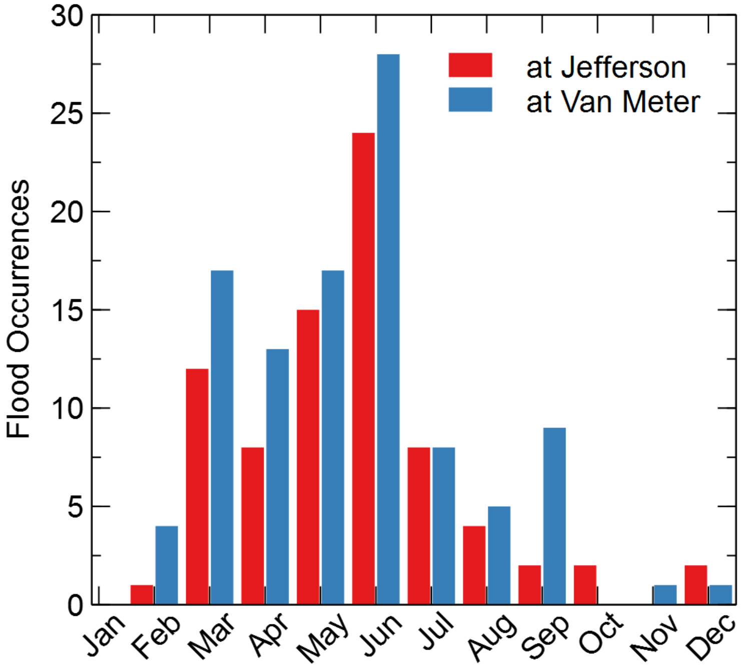


Figure 3-24. Flood occurrence frequency by month at both the Jefferson and Van Meter USGS stream gauge stations.

Six large flood events (discharge greater than 40,000 cfs) have been recorded at the USGS Raccoon River gaging station at Van Meter, Iowa since 1947. The four largest of these flood peaks have occurred since 1993: July 10, 1993 – 70,100 cubic feet per second (cfs); June 25, 2015 - 49,400 cfs; June 15, 1998 – 47,400 cfs; June 12, 2008 – 43,500 cfs. The fifth and sixth largest peak discharges since 1915 at this gage were 41,200 cfs on June 13, 1947 and 40,200 cfs on July 1, 1986. Large discharges at this location may develop in the North Raccoon River Watershed upstream of the confluence with the South Raccoon River near Van Meter, may develop in the South Raccoon River Watershed, or may develop as a combination of discharges from both rivers from widespread rain events. Ultimately, the discharge that is observed here continues downstream on the Raccoon River and into Des Moines.

Table 3-4 shows the six largest discharges at two USGS gaging stations on the North Raccoon River, the USGS gaging station on the South Raccoon River near Redfield, the USGS gaging station on the Raccoon River near Van Meter (downstream of the confluence of the North and South Raccoon Rivers) and at 63rd Street in Des Moines. Table 3-4 also shows the USGS gaging station on Walnut Creek at Des Moines.

Table 3-4. Discharges from the Six Largest Flooding Events at USGS Gaging Stations in the North Raccoon River Watershed, the South Raccoon River at Redfield, IA, the Gaging Stations on the Raccoon River Downstream of the Confluence of the North and South Raccoon Rivers, and Walnut Creek at Des Moines.

N. Raccoon Sac City (1958 - Present)	3/23/1979 13,100 cfs	9/01/1962 10,800 cfs	6/17/1990 9,930 cfs	3/16/2010 9,820 cfs	6/21/1983 9,390 cfs	3/30/1960 9,020 cfs
N. Raccoon Jefferson (1940 - Present)	6/23/1974 29,100 cfs	6/22/1954 21,300 cfs	3/18/2010 18,700 cfs	3/31/1960 18,600 cfs	6/19/1990 18,400 cfs	6/09/2008 18,300 cfs
S. Raccoon Redfield (1940 - Present)	7/10/1993 44,000 cfs	6/25/2015 38,000 cfs	7/28/2008 37,100 cfs	6/15/1998 35,100 cfs	7/02/1958 35,000 cfs	5/23/2004 28,300 cfs
Raccoon Van Meter (1915 - Present)	7/10/1993 70,100 cfs	6/25/2015 49,400 cfs	6/15/1998 47,400 cfs	6/12/2008 43,500 cfs	6/13/1947 41,200 cfs	7/01/1986 40,200 cfs
Raccoon DSM 63rd (1991 - Present) *estimated by USGS	7/11/1993 66,000 cfs*	6/13/2008 52,000 cfs	6/26/2015 46,600 cfs	6/16/1998 40,300 cfs	4/26/2007 33,500 cfs	5/24/2004 30,800 cfs
Walnut Creek DSM (1971 - Present)	5/10/1986 12,500 cfs	8/09/2010 11,700 cfs	6/25/2015 9,720 cfs	7/01/1973 9,000 cfs	6/09/1974 8,160 cfs	6/16/1990 7,780 cfs

At the Raccoon River USGS gaging station near Van Meter, the largest discharge was experienced on July 10, 1993 (70,100 cfs), roughly 70 percent of the discharge was observed passing the USGS gaging station on the South Raccoon River near Redfield. The peak discharge observed at the North Raccoon USGS gaging station near Jefferson was 16,900 cfs on July 10, 1993 as well. With travel time factored in, the peak observed on the North Raccoon River would have passed the Raccoon River gaging station at Van Meter on July 12th. For the 2008 event at Van Meter on June 12, 2008 (43,500 cfs), both the North and South Raccoon Watersheds contributed equally to the development of the peak discharge, with the observed peak discharge of 18,300 cfs for the North Raccoon near Jefferson on June 9th and an observed discharge of 26,300 cfs for the South Raccoon on June 12th. It is worth nothing the South Raccoon's largest peak discharge in 2008 was actually from another storm event (July 28, 2008).

Further analysis of annual peak discharges reveals a strong correlation between dates of peak annual discharges on the South Raccoon River near Redfield and the Raccoon River at Van Meter, as shown in Table 3-5. Of the largest 10 annual peak discharges observed at Van Meter, nine of the annual peaks observed on the South Raccoon River at Redfield occurred during the same event. The correlation between the dates of annual peak events at Van Meter and Jefferson are much lower – only 4 of the largest 10 annual peaks at Van Meter coincided with the annual peaks at Jefferson.

Table 3-5. The dates of the 10 largest peak annual discharges observed at Van Meter, IA, compared to the dates of peak annual discharges on South Raccoon River at Redfield, IA, and the North Raccoon River at Jefferson, IA.

Water Year	Rank	Date of Annual Peak at Van Meter (Confluence of N. and S. Raccoon)	Date of Annual Peak at Redfield (S. Raccoon)	Coincident Peak at Redfield (S. Raccoon)	Date of Annual Peak at Jefferson (N. Raccoon)	Coincident Peak at Jefferson (N. Raccoon)
1993	1	7/10/1993	7/10/1993	Yes	7/10/1993	Yes
2015	2	6/25/2015	6/25/2015	Yes	6/26/2015	Yes
1998	3	6/15/1998	6/15/1998	Yes	6/27/1998	no
2008	4	6/12/2008	7/28/2008	no	6/9/2008	Yes
1947	5	6/13/1947	6/12/1947	Yes	6/23/1947	no
1986	6	7/1/1986	7/1/1986	Yes	3/21/1986	no
2004	7	5/23/2004	5/23/2004	Yes	6/20/2004	no
1973	8	7/4/1973	7/4/1973	Yes	9/29/1973	no
1958	9	7/3/1958	7/2/1958	Yes	6/7/1958	Yes
1990	10	6/16/1990	6/16/1990	Yes	6/19/1990	no

j. Flood Frequency Estimates

Flood frequency estimates for Jefferson and Van Meter were generated using a Bulletin 17C Analysis of observed annual peak discharges at Jefferson and Van Meter, IA, and are shown in Table 3-6. These estimates represent the percent annual chance exceedance probability of the discharge occurring in any given year. For example, the 1-percent annual chance exceedance event has a probability of 1 out of 100 chance of occurring in any given year, hence it has been frequently referred to as the “100 Year Flood”. However, when you consider longer periods, like a typical 30 year home mortgage, the 1-percent annual chance exceedance event has a 26% chance of occurring at least once over that 30 year period.

Table 3-6. Flood frequency estimates generated using a Bulletin 17C Analysis of observed annual peak discharges at Jefferson and Van Meter, IA.

Percent Annual Chance Exceedance	Return Period	Estimated Flowrate at Jefferson, IA, cfs	Estimated Flowrate at Van Meter, IA, cfs
0.2	500	32670	79948
0.5	200	28969	68335
1	100	26125	59863
2	50	23235	51648
5	20	19320	41148
10	10	16253	33423
20	5	13032	25786
50	2	8239	15332

The magnitude of peak annual exceedance estimates are highly correlated with upstream drainage area. Logically, more area draining to a point would result in higher flood flowrates. Drainage areas throughout the stream networks of the North and South Raccoon River Watersheds are shown in Figure 3-25.

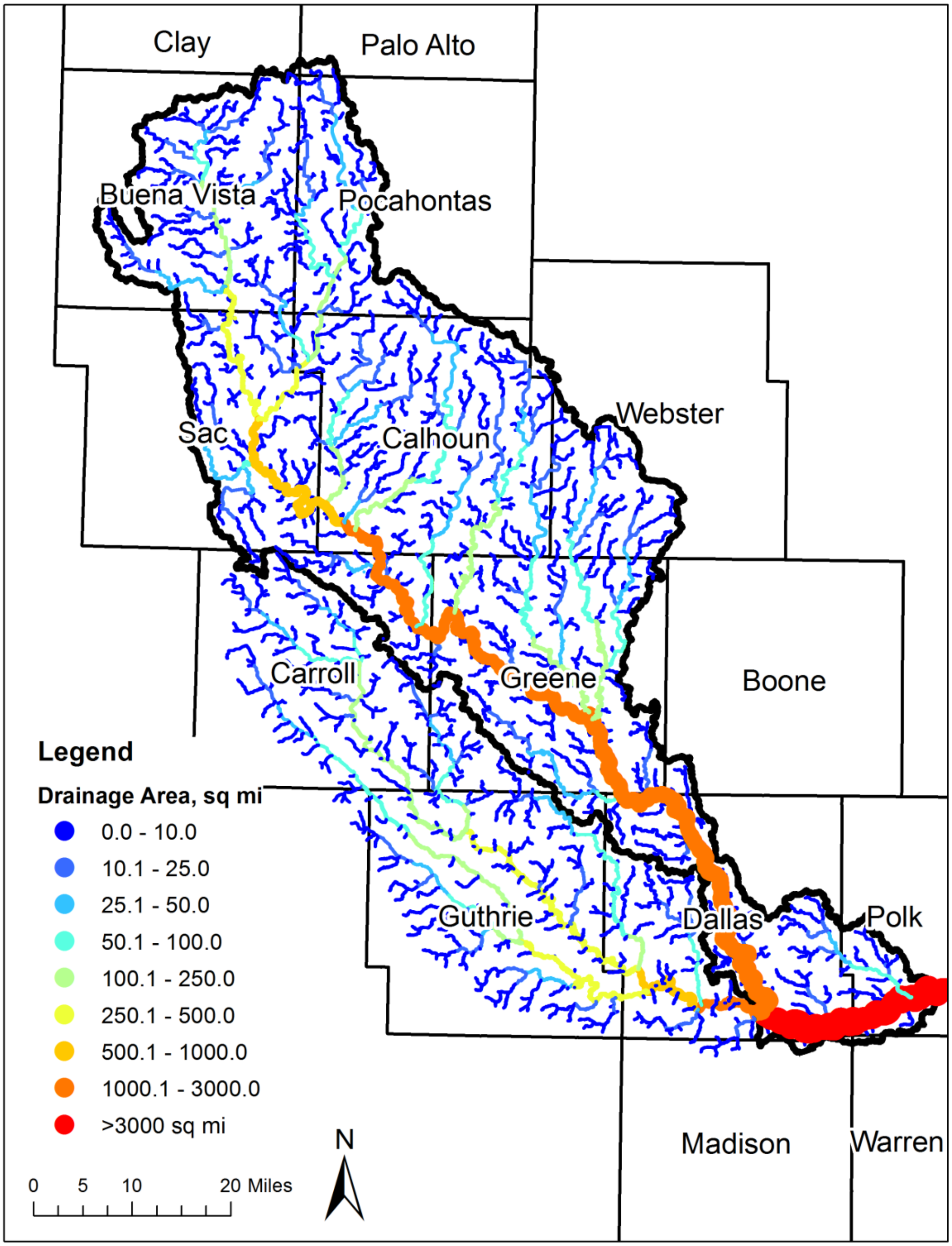


Figure 3-25. Upstream drainage area throughout the stream network in the North and South Raccoon River Watersheds.

4. Water Quality Analysis

a. Data Availability

This analysis aimed to estimate riverine nutrient loads for the North Raccoon River watershed. The primary nutrients of concern traveling through Iowa's rivers are nitrate and phosphorus. Phosphorus is comprised of two forms, a dissolved form called orthophosphate (OP) and a suspended form called particulate phosphorus (Part P). The combination of these two is called total phosphorus (TP). Reducing these nutrients in Iowa waters is a central goal of the Iowa Watershed Approach and water quality improvement efforts more generally.

i. Data Requirements

Historical nutrient data are needed to estimate riverine loads for any site of interest, so identifying which locations along the North Raccoon contained previously collected nitrate and TP data was necessary. Several programs monitor nutrient data every month by collecting grab samples that are brought to a laboratory for analysis. This protocol has created a record of discrete data points of nitrate and TP concentrations. It has become possible in the past decade to deploy in-situ sensors along a river that continuously measure nitrate. These sensors have greatly enhanced the discrete nitrate data by creating a more complete record for recent years. Measuring TP on-site is currently infeasible, and grab samples remain the only way to measure TP concentrations directly. However, recent research has demonstrated that turbidity is an effective surrogate for Part P. Turbidity is a quantitative indicator of water clarity and can be measured continuously on-site. Continuous turbidity values can then be used to predict Part P concentrations. Therefore, turbidity is another helpful analyte to identify when evaluating data availability.

Finally, measurements of the river's flow are also needed to estimate nutrient loads. The United States Geological Survey (USGS) operates numerous gauges that measure streamflow throughout Iowa. A USGS gauge needs to be located near a site where nutrient data are collected to assess that site's loads accurately. The potential timeframe for nutrient analysis is determined by the historical record of nutrient concentrations and streamflow measurements. It is possible to estimate loads when these two data records are both available. Streamflow can also act as a useful surrogate. Since it is measured routinely by the USGS, it can often be a valuable tool for estimating nutrient concentrations. The USGS typically calculates mean daily streamflow values, making it possible to estimate nutrient loads at a daily timescale.

ii. Sources of Data

The headwaters of the North Raccoon watershed originate near Rembrandt, IA, approximately 110 miles northwest of Des Moines, IA. The North Raccoon's outlet occurs at the river's confluence with the South Raccoon River—in the town of Van Meter, IA. While historical sampling has been sparse on the downstream reaches of the North Raccoon, two sites further upstream have monitored nutrient data. The more upstream of these two is located just south of Sac City, IA. This site has long been a part of the Iowa Department of Natural Resource's (IDNR) ambient monitoring program. Nitrate, TP, OP, and turbidity are measured here every month. Additionally, the USGS has monitored daily nitrate concentrations at this location using an in-stream sensor. The second site is located at Jefferson, IA, and the USGS has similarly monitored daily nitrate at this site. Discrete grab samples have been collected by the IDNR here but on a sporadic basis.

The Sac City site contains 30% of the North Raccoon's total watershed. The USGS has maintained a stream gauge at this same location—with streamflow measurements dating back to 1958. Although this is a minority of the North Raccoon's overall area, this portion of the watershed contains many projects directly related to the Iowa Watershed Approach initiatives, making it a location of great interest for water quality. The Jefferson site includes 70% of the North Raccoon, and the USGS has measured streamflow here since 1940. The Jefferson site is pertinent as it is the most downstream location within the North Raccoon, where long-term nutrient data has been collected. Water quality analyses conducted at this site will be the most representative of the overall watershed.

The exact locations of the Sac City and Jefferson sites within the North Raccoon watershed are shown below. The Sac City pin in Figure 4-1 corresponds to IDNR site 10810001 and USGS streamflow gauge 05482300; the Jefferson pin corresponds to IDNR site 10370001 and USGS streamflow gauge 05482500.

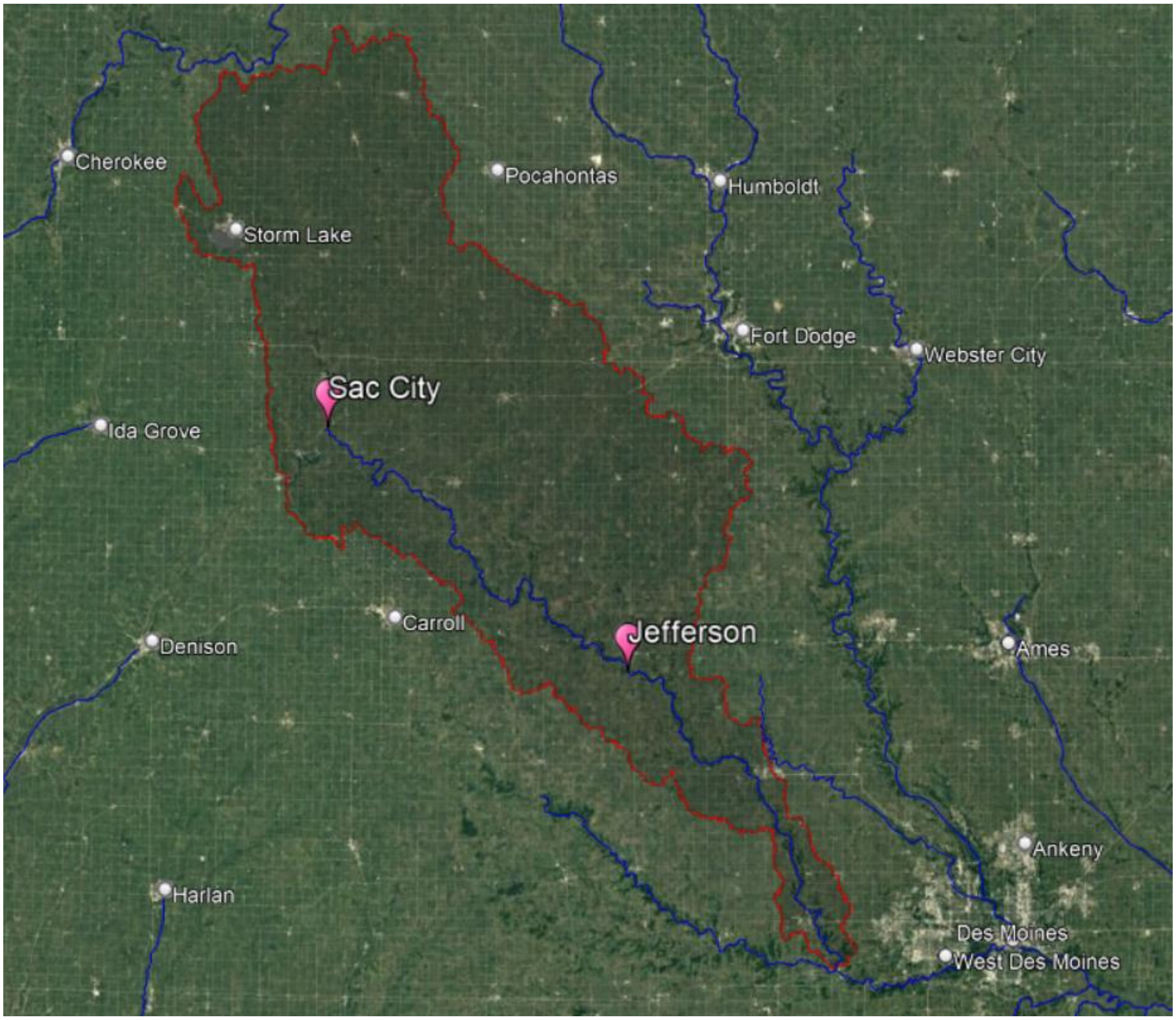


Figure 4-1. Data collection sites for the North Raccoon watershed.

The IDNR began monthly monitoring at Sac City in 1998, and sampling continues to the present day. In 2008, nitrate sensors were deployed by the USGS, resulting in more continuous records of nitrate data in the past 15 years. Figure 4-2 summarizes the number of days each year containing nitrate, OP, Part P, and turbidity measurements. This combination of data sources results in a very robust nutrient dataset, enabling the estimation of nitrate and phosphorus loads from 1998 to the present.

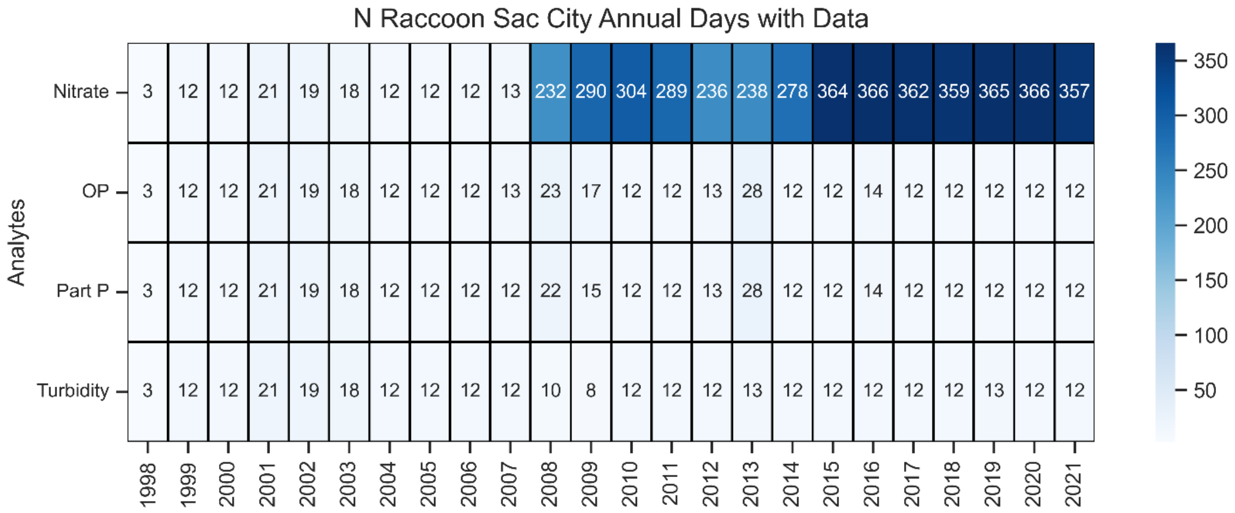


Figure 4-2. Annual days with data for the North Raccoon River at Sac City, IA.

The IDNR began monthly sampling at the Jefferson site in 1999, but this was discontinued in 2009. Daily nitrate measurement started in 2008 and continues to the present day. Figure 4-3 summarizes the number of days in each year containing nitrate, OP, Part P, and turbidity measurements. While the nitrate record is relatively strong, phosphorus data after 2009 is limited. Consequently, only nitrate behavior could be analyzed at Jefferson—data collection in recent years is too sparse to quantify phosphorus adequately.

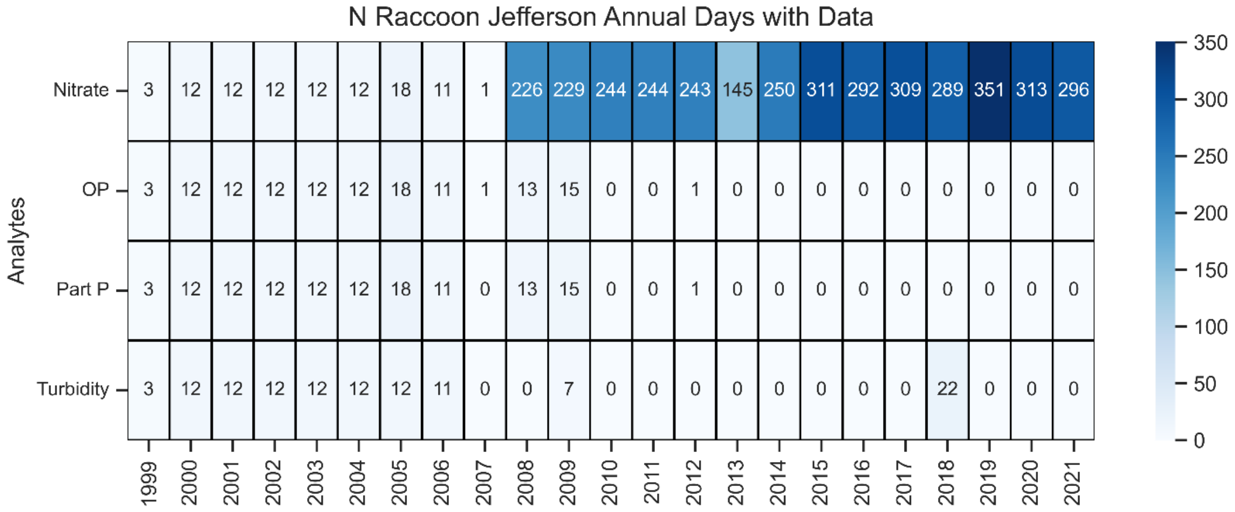


Figure 4-3. Annual days with data for the North Raccoon River at Jefferson, IA.

In preparation for daily load estimates, the nutrient data were assembled from these three sources: the IDNR and the USGS. Any further inquiries about data availability at this location may be directed toward Elliot Anderson (elliot-anderson@uiowa.edu) at the University of Iowa.

b. Methods

Because there are numerous days on which nutrient data are unavailable, it is necessary to estimate nitrate and TP concentrations on these days without data. If nutrient concentrations can be accurately estimated over the period of available data, it is possible to calculate nutrient loads comprehensively. In the case of the North Raccoon, the goal was to estimate daily concentrations from 1998 to 2021—a timeframe commensurate with data availability and the Iowa Watershed Approach schedule. Both nitrate and TP could be estimated at Sac City, while only nitrate could be estimated at Jefferson.

The simplest way to estimate the missing data is to interpolate between actual measurements. Studies have indicated that this may be sufficient for nitrate in some Iowa streams. However, uncertainty associated with TP concentrations is too great for interpolation to be viable. Surrogacy-based models are more commonly used when interpolation is not practical. Turbidity is useful as a surrogate to estimate Part P, but there are also many days on which turbidity data is unavailable. Several models have been developed that use flow and seasonal factors to predict water-borne constituents. These models are almost always possible to implement, as the USGS constantly measures streamflow, and seasonal metrics are always present.

Over the past several years, the industry standard has moved to the Weighted Regression on Time Discharge and Season (WRTDS) model. These models couple historical water quality measurements with daily flow values to produce estimated daily concentrations over the entire streamflow period. WRTDS uses several flow-related metrics and seasonal variables to predict these concentrations. Recently, the WRTDS model framework has been supplemented with a Kalman filter. This Kalman filter adjusts the concentrations of the original WRTDS model based on their proximity to the measured values. This model version is referred to as WRTDSK and has been made available by the USGS as an open-source R package. The WRTDSK model produces the best possible estimates of loads. Documentation for the WRTDSK package is available on the following GitHub page (https://usgs-r.github.io/EGRET/articles/WRTDSK.html).

Four separate models were constructed for the North Raccoon basin. Nitrate, OP, and Part P were each modeled from 1998 to 2021 at Sac City, and nitrate was modeled at Jefferson for this same period. The daily flow values utilized by these models are shown in Figure 4-4.

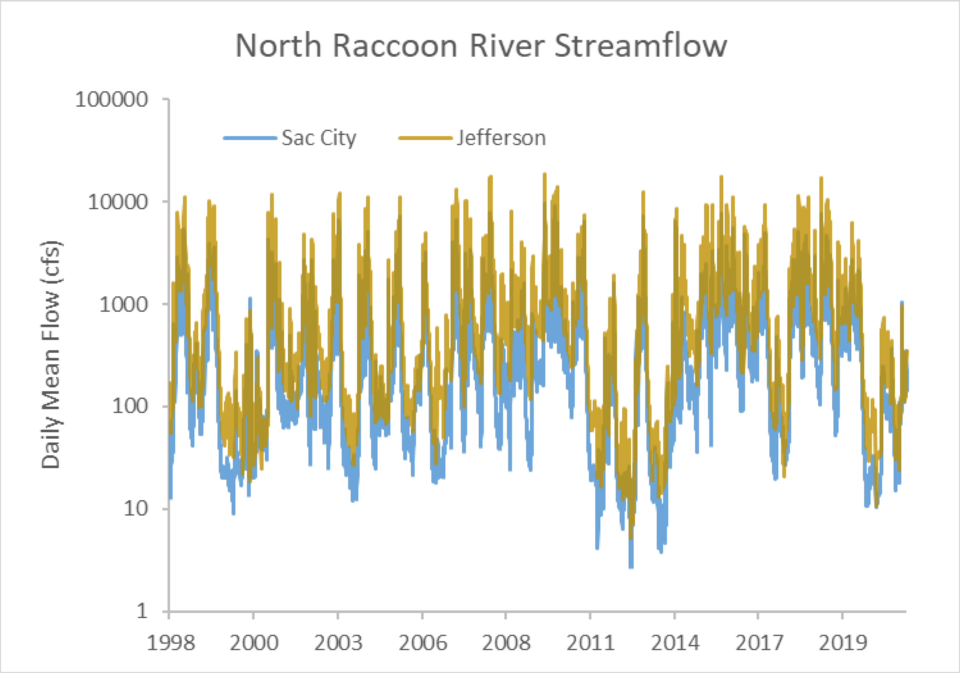


Figure 4-4. Daily flow values for the North Raccoon River sites.

i. Nitrate

The WRTDSK nitrate models were successfully implemented, and no issues were found with the model's residuals. While it is possible to simply interpolate nitrate concentrations, the WRTDSK models significantly improved upon linear interpolation. Therefore, the values produced by the WRTDSK models are the most accurate estimates currently available. Overall, the model performance was quite good.

Table 4-1. WRTDSK model performance metrics.

River	Type	R2	RMSE	R2.ln	RMSE.ln	FluxBias
N Raccoon Sac City	Nitrate	0.62	2.79	0.69	0.35	-0.05
	OP	0.76	0.36	0.58	0.66	0.00
	PartP	-0.02	0.38	0.32	1.56	0.04
N Raccoon Jefferson	Nitrate	0.71	3.02	0.82	0.64	-0.06

The observed (black dots) and estimated (solid line) nitrate concentrations at Sac City are shown in Figure 4-5. The nitrate concentrations ranged from 0.01 to 40 mg/L. The predicted concentrations largely remained within the range of observed values, but they did reach higher concentrations in a few instances. Sensor deployment has made many more observed values available in recent years. All model performance metrics are shown in Table 4-1. Model performance at Jefferson was slightly stronger, but the overall implementation was much the same as at Sac City.

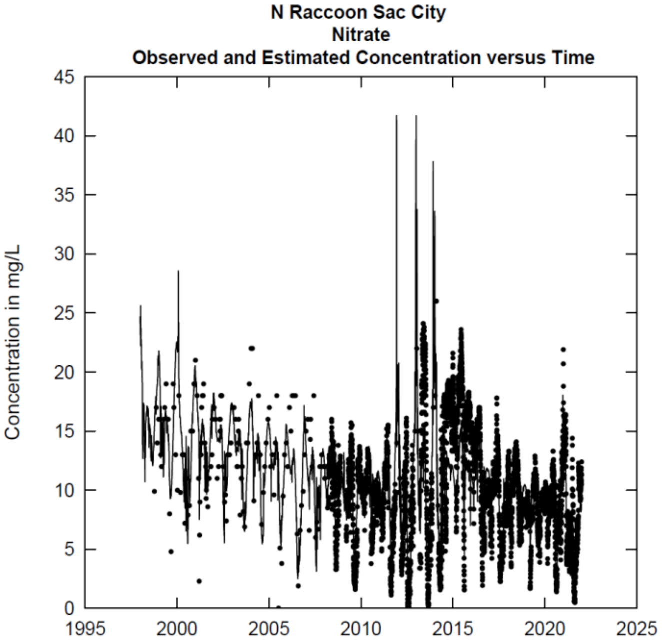


Figure 4-5. WRTDSK nitrate model results at Sac City.

ii. Orthophosphate

The WRTDSK OP model was successfully implemented. In many cases, OP can be difficult to predict based on flow, as it is a dissolved constituent. The model performance here was marginal. The model concentrations typically remained near 0.05 – 2.0 mg/L, with values occasionally extending above 5.0 mg/L.

Figure 4-6 contains an example of the Kalman filter being applied to the OP estimates. The black lines show the original WRTDS concentrations, and the red points are the observed samples—the exact OP measurements at the Sac City site. The green lines show the new concentrations made by implementing the Kalman filter. The closer the concentrations are to the actual measurements, the more they get adjusted to match these measurements.

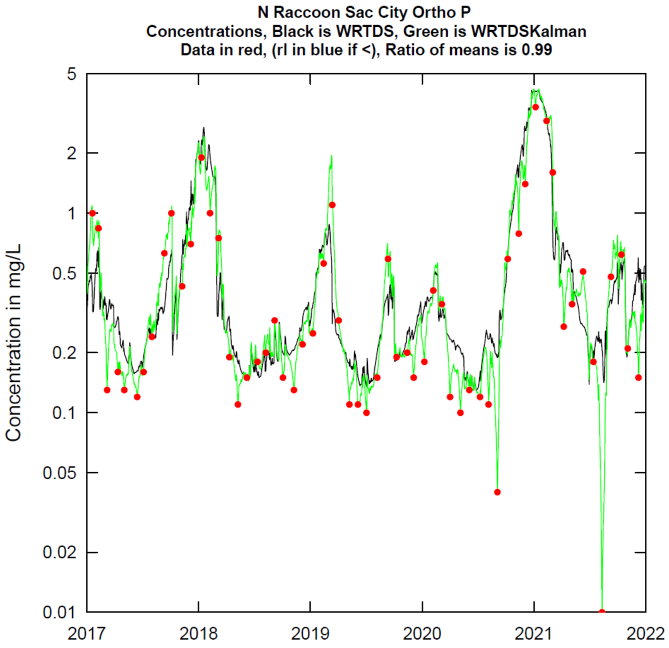


Figure 4-6. WRTDSK orthophosphate model results.

iii. Particulate Phosphorus

The WRTDSK model was similarly implemented for Part P. Part P is typically driven by erosion. Much of the Part P found in Iowa streams is sorbed to sediment originating from fields or streambanks. Because runoff can trigger this erosion, flow-based models often perform well for Part P, and the WRTDSK model proved adequate. At Sa City, continuous turbidity data have never been collected, so its potential use as a surrogate for Part P was not investigated. Part P estimates were confined to the WRTDSK model.

While model performance for Part P was notably weaker than the nitrates or OP models, the model was still viable. It was used to estimate daily Part P concentrations, ranging from 0.01 to 5.0 mg/L. Finally, the OP and Part P concentrations were summed to produce an overall TP concentration. This final TP value was used to estimate the timeseries of phosphorus loads from 1998 to 2021.

iv. Trend Detection

An additional aspect of this project was determining the presence of any temporal trends in the nutrient data. A trend analysis could be conducted once the concentrations and loads were assembled. Significant effort has gone into reducing nutrient loads in the North Raccoon, so it is natural to investigate any potential trends that may be present.

Two statistical tests were performed on the loads and concentrations for both nitrate and TP for the entire 1998 – 2021 period. The first was the Mann-Kendall Trend test, a standard tool for evaluating monotonic trends. This test determines if the timeseries data are consistently increasing or decreasing. This test can be performed on data that are not normally distributed, which is often the case for riverine loads. The second test evaluated Spearman’s rank correlation coefficient. This test calculated the correlation between the ranks of the analyte values and the ranks of the dates. This test also investigates if a monotonic relationship is present between two variables, in this case, a nutrient metric and a date. Data may also be non-normal when calculating the Spearman correlation coefficient.

As a final step, the daily values were aggregated for every year. For concentrations, this involved taking the average of all the daily concentrations within a given year. For loads, this involved summing the daily fluxes. Loads were further converted to yields by dividing their annual values by the North Raccoon’s watershed area. A similar process was conducted using the daily flow values. The daily flows were likewise assembled on a yearly basis into an annual volume of water and a water yield. The yearly timeseries benefit from removing any seasonal effects in the daily values. Their plots are also more intuitive than the daily values due to the reduced number of data points. Both the Mann-Kendall test and Spearman Rank Test were run on the yearly values as well.

c. Results

A summary of the descriptive statistics for each pertinent variable is shown below. The flows are the daily mean streamflow values measured by the USGS. TP is the phosphorus concentration estimated using the WRTDSK models. These concentrations were then coupled with the daily flows to calculate phosphorus loads (P Load). Nitrate concentrations were estimated using WRTDSK models, and nitrate loads (N Load) were similarly calculated using these concentrations and the daily flow values.

Table 4-2. Descriptive statistics for the North Raccoon flows and nutrients.

Stat	Sac City					Jefferson		
	Flow (cfs)	TP (mg/L)	P Load (lbs)	Nitrate (mg/L)	N Load (lbs)	Flow (cfs)	Nitrate (mg/L)	N Load (lbs)
count	8766	8766	8766	8766	8766	8766	8766	8766
mean	477	0.76	1199	11.49	30415	1131	8.91	66801
std	823	0.95	3270	4.68	50156	1858	5.95	104334
min	3	0.09	11	0.03	8	5	0.00	0
0.1	22	0.24	108	5.36	940	55	0.97	283
0.25	50	0.30	227	8.35	2335	128	4.37	2839
0.5	171	0.44	411	11.40	10385	441	8.80	24362
0.75	567	0.73	948	14.75	36266	1340	12.30	87714
0.9	1200	1.56	2351	17.44	84161	2850	16.20	188116
0.99	4127	5.37	14180	22.37	248243	9647	26.40	500963
max	9630	12.24	88581	40.08	533730	18500	38.68	999206

i. Nitrate Estimates

Figure 4-7 contains the final daily nitrate concentrations at Sac City and Jefferson. These concentrations generally appear normally distributed, and these values appear relatively constant over the entire record. Seasonality and autocorrelation are present throughout the timeseries, with higher concentrations occurring nearby one another and the concentrations generally being cyclic.

Concentrations were almost always greater at the upstream Sac City site. The highest single nitrate concentration was a modeled value of 40 mg/L; the lowest concentrations of 0.01 mg/L occurred in numerous instances throughout the years at both sites.

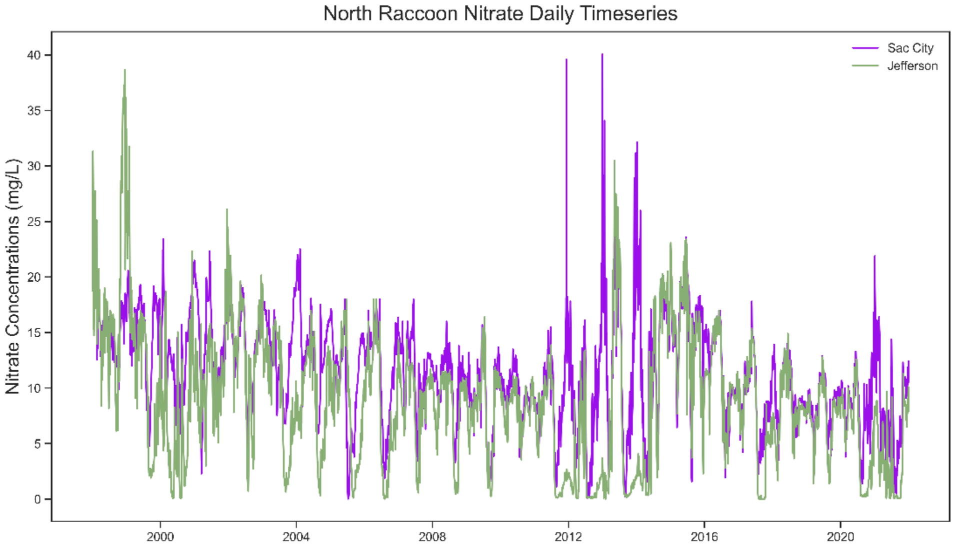


Figure 4-7. Daily nitrate concentrations.

Average yearly concentrations are shown in Figure 4-8. These averages are simply the arithmetic mean of all daily concentrations within a given year. The annual averages range from about 2.5 to 17.5 mg/L, with a typical year near 11.5 mg/L. Again, values were consistently higher at Sac City. A downward trend appears more evident when examining the yearly averages, with values decreasing at both sites across the modeled timeframe. The total flows for each year are shown on the secondary axis. Typical flows for the North Raccoon are on the order of hundreds of billions of gallons per year. As the Jefferson site is downstream of Sac City, its flow values were always the larger of the two. The wettest year occurred in 2010.

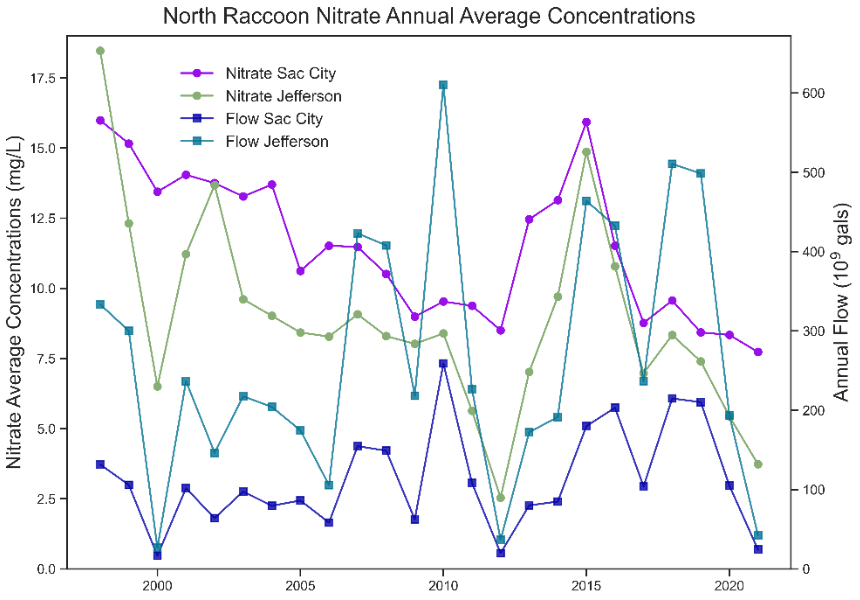


Figure 4-8. Average annual nitrate concentrations.

Figure 4-9 contains the boxplots for nitrate concentrations at Sac City separated by month. The boxplots show the variation of concentrations within each month, along with the median, interquartile range, and potential outliers. The monthly distributions seem mostly symmetric. The highest medians occur during the May and June months as well as the December and January months. There appear to be two distinct peaks in nitrate concentrations in the winter and summer. The lowest concentrations occur in August and September. Similar seasonal patterns were present at Jefferson.

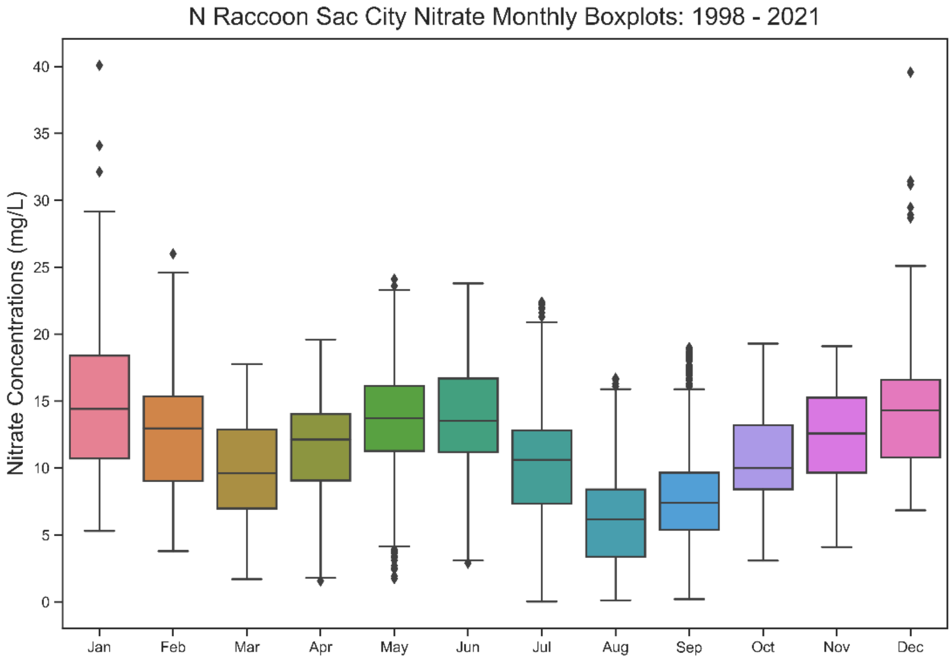


Figure 4-9. Boxplots of Sac City monthly nitrate concentrations.

Figure 4-10 shows each site's daily nitrate loads. These were calculated by multiplying the daily concentrations by their corresponding mean flow values. Flows values are generally positively skewed, often following a lognormal distribution. Due to the skewness of the flows, the nitrate loads also tend to be positively skewed. The highest loads tend to be near 1.0 million lbs of nitrate per day. There were also periods of low flow that resulted in minimal nitrate loads. Nitrate loads were larger at Jefferson due to the larger water volume at that site.

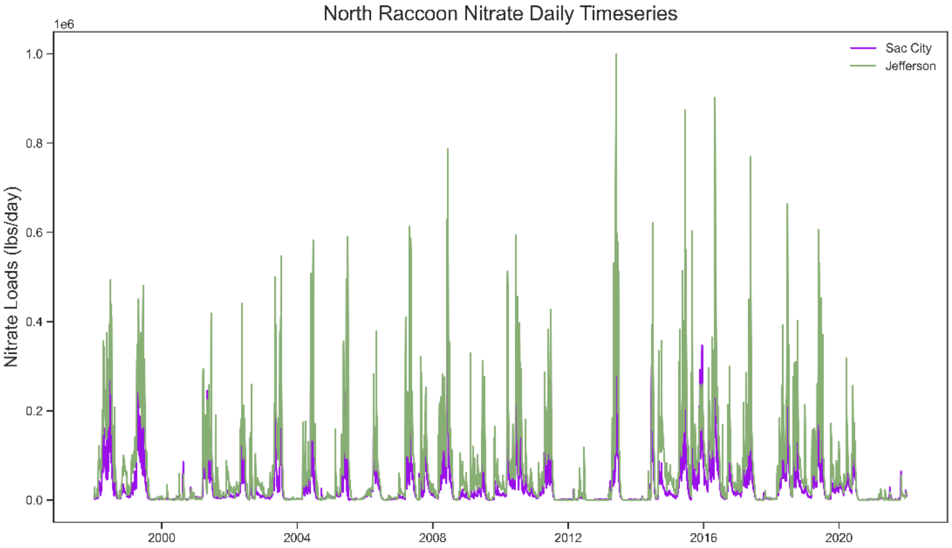


Figure 4-10. Daily nitrate loads.

Figure 4-11 shows the yearly nitrate and water yields. These are calculated by dividing the summation of daily loads within a year by the tributary area. For the Sac City site, this is 700 square miles, and for the Jefferson site, this is 1619 square miles. The yearly yields varied considerably from 5.0 to 56 lbs/ac, with a mean near 24 lbs/ac. Water yields correlate with nitrate yields, and higher water yields result in larger nitrate loads due to the increased water volume. Both nitrate and water yields were similar between Sac City and Jefferson.

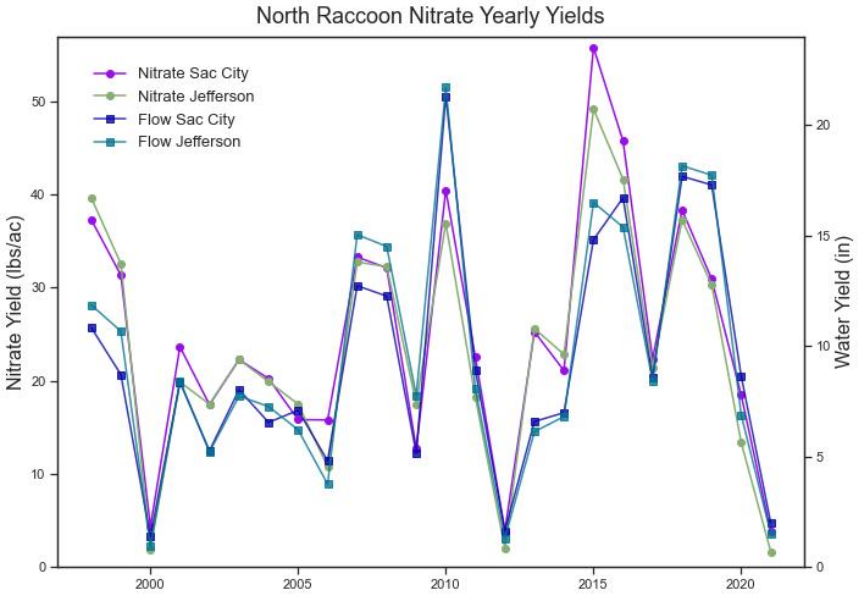


Figure 4-11. Yearly nitrate and water yields.

ii. Phosphorus Estimates

Figure 4-12 shows the daily TP concentrations. It was only possible to estimate TP at Sac City. The TP concentrations are much more positively skewed than the nitrate concentrations. There is no clear trend in the daily TP concentrations, and values typically range between 0.01 to 5.0 mg/L. A single modeled value of nearly 12 mg/L far exceeded the other TP concentrations in the North Raccoon. Seasonality may also be present, with higher concentrations occurring in winter.

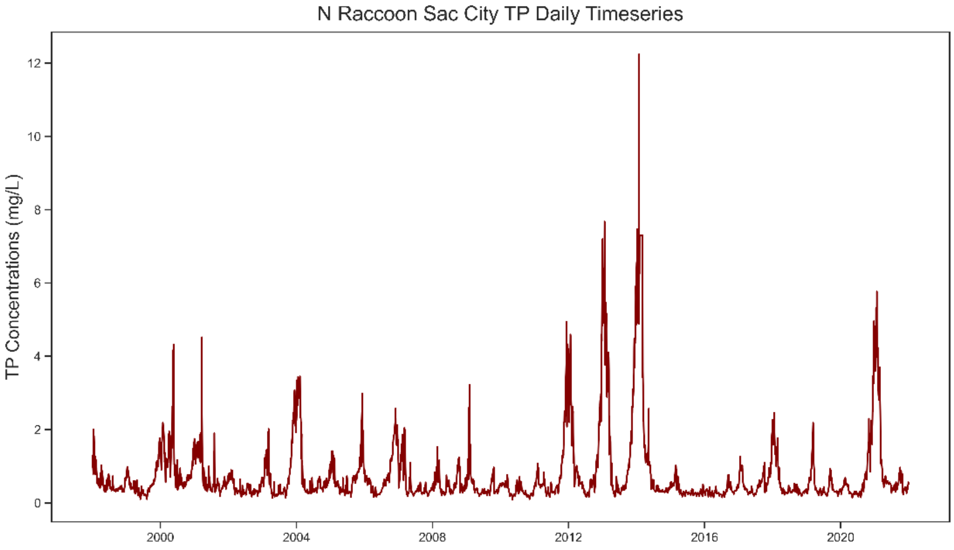


Figure 4-12. Daily TP concentrations.

Figure 4-13 shows the annual average TP concentrations and the annual water volume. The average concentrations appear to be marginally decreasing across the timeframe. The typical yearly concentrations were generally near 1.0 mg/L, and these concentrations generally were not related to the annual water volumes of the North Raccoon.

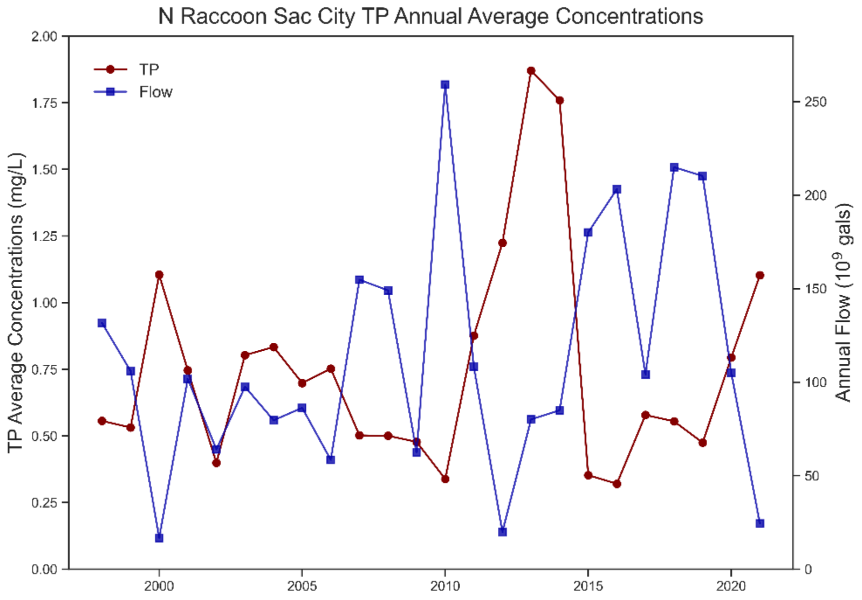


Figure 4-13. Annual average TP concentrations.

Similarly, the concentrations were separated by month for TP. Boxplots of these monthly concentrations are shown in Figure 4-14. These boxplots are quite positively skewed, and each month contains many potential outliers. The medians varied slightly by month, with the highest values occurring during the winter months. The medians were mainly near 0.4 mg/L.

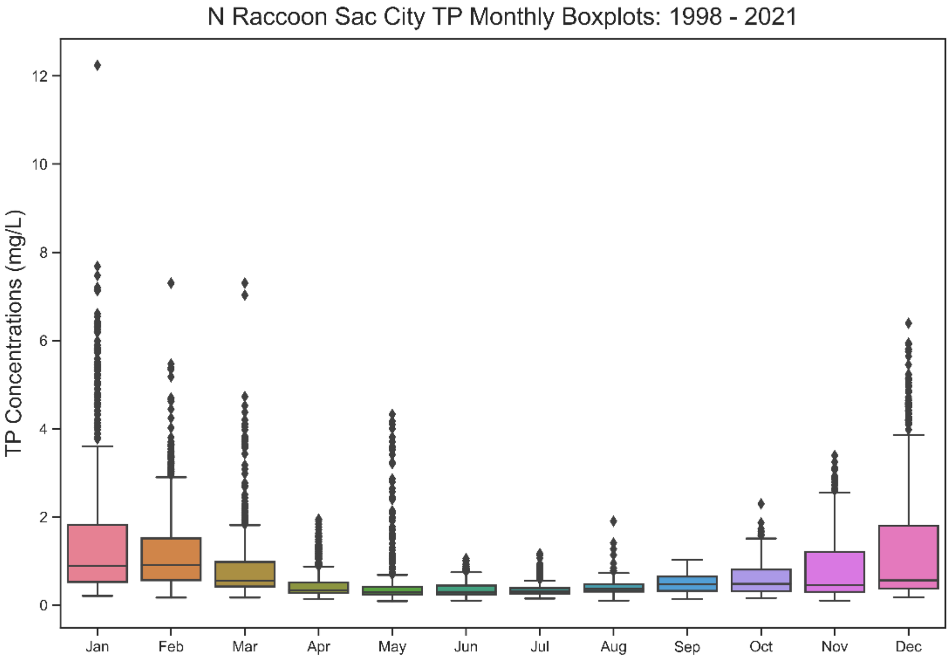


Figure 4-14. Boxplots of monthly TP concentrations.

Figure 4-15 displays the daily TP loads for the North Raccoon. These loads are very positively skewed. High TP concentrations tend to occur on days with high flows, i.e., streamflow is correlated with TP. Since these two factors tend to occur coincidently, the resulting loads can become extremely skewed. The maximum loads were over 20,000 lbs per day.

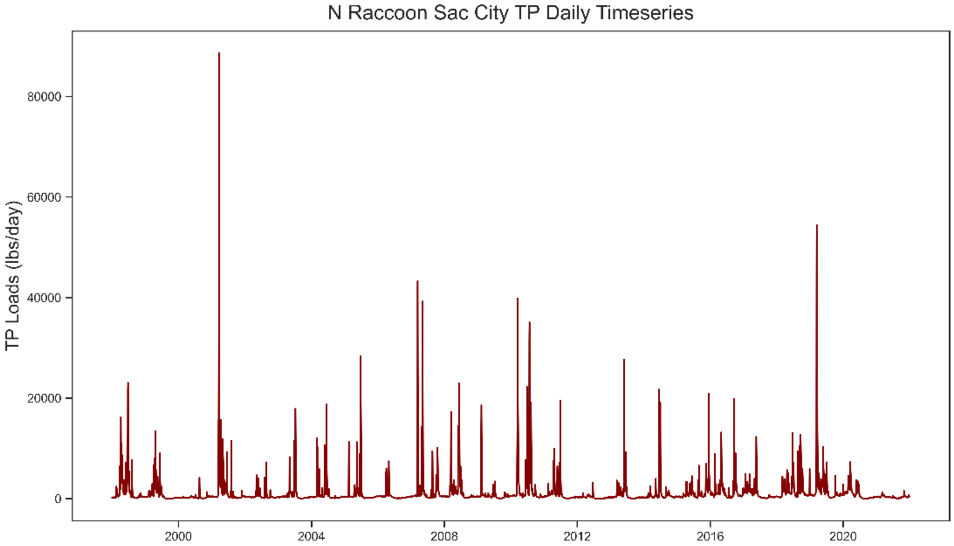


Figure 4-15. Daily TP loads.

Figure 4-16 shows the annual TP yields and water yields. There was considerable variation among yearly yields, with the lowest value near 0.2 lbs/ac, the highest value near 2.2 lbs/ac, and an average near 1.0 lbs/ac. These yearly yields were closely linked to the annual water yields, and higher water yields are directly related to higher TP yields. The yields for TP are approximately ten times smaller than those of nitrate.

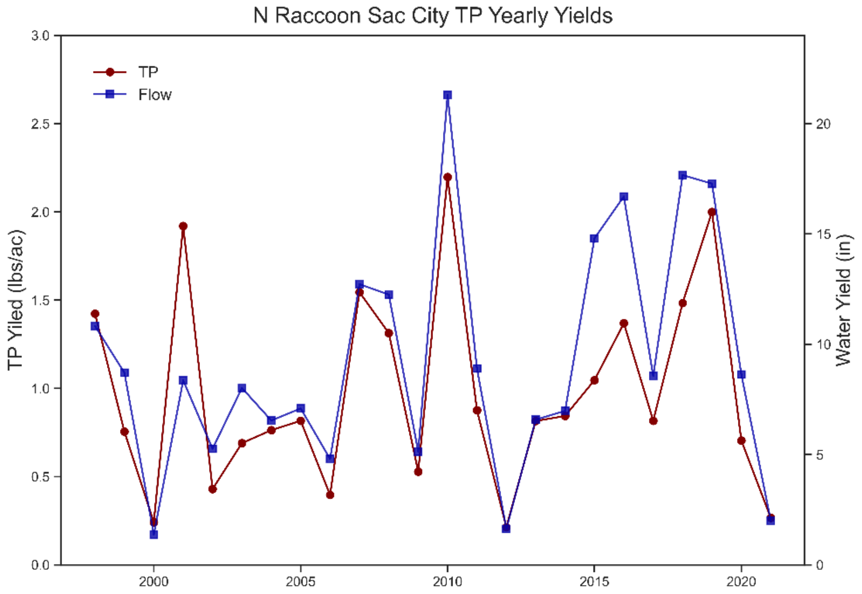


Figure 4-16. Yearly TP and water yields.

iii. Trend Detection

The Mann-Kendall trend test and the Spearman's rank correlation coefficient were conducted on the daily concentrations and loads and the annual concentrations and loads. These tests were done for both nitrate and TP. The tests were also performed for the daily and yearly flow timeseries. Table 4-3 summarizes the findings for each of the tests. The p-values relate to the statistical significance of each test. Values lower than 0.05 indicate that a statistically significant trend is present. The slope indicates the change in value per unit (either day or year) found by the Mann-Kendall test.

At Sac City, daily concentrations were found to be decreasing for both nitrate and TP. However, daily loads increased for TP, while no statistically significant trend was present for daily nitrate loads. Daily flows were also increasing, so this likely offset the decrease in nitrate and TP concentrations, resulting in an increase for TP loads and no appreciable trend for nitrate loads. At Jefferson, both the nitrate concentrations and loads were decreasing. Notably, loads fell even though daily flows had a positive trend, suggesting that nitrate reduction is more significant than increasing streamflow. In terms of the annual timeseries, annual concentrations nitrate concentrations were similarly decreasing. There was perfect agreement between the Mann-Kendall and Spearman tests. Both produced the same results, suggesting the trend detection test results are viable.

Table 4-3. Trend analysis results.

Site	Variable	Property	Mann-Kendall			Spearman	
			trend	p-value	slope	trend	p-value
Sac City	Nitrate	Daily Concentrations	**decreasing**	<0.001	-7.70E-04	**decreasing**	<0.001
		Daily Loads	no trend	0.497	0.0235	no trend	0.658
		Annual Concentrations	**decreasing**	<0.001	-0.2961	**decreasing**	<0.001
		Annual Loads	no trend	0.941	1.93E+04	no trend	0.747
	Total Phosphorus	Daily Concentrations	**decreasing**	<0.001	-9.60E-06	**decreasing**	<0.001
		Daily Loads	**increasing**	<0.001	0.0215	**increasing**	<0.001
		Annual Concentrations	no trend	0.941	-9.69E-05	no trend	0.977
		Annual Loads	no trend	0.472	3.86E+03	no trend	0.557
	Flow	Daily Flows	**increasing**	<0.001	0.0079	**increasing**	<0.001
		Annual Flows	no trend	0.264	2.46E+09	no trend	0.225
Jefferson	Nitrate	Daily Concentrations	**decreasing**	<0.001	-6.90E-04	**decreasing**	<0.001
		Daily Loads	**decreasing**	0.007	-0.0985	**decreasing**	0.004
		Annual Concentrations	**decreasing**	0.005	-0.2458	**decreasing**	0.011
		Annual Loads	no trend	0.823	-1.52E+04	no trend	0.828
	Flow	Daily Flows	**increasing**	<0.001	0.0162	**increasing**	<0.001
		Annual Flows	no trend	0.442	2.72E+09	no trend	0.409

d. Conclusions

The historical nutrient data at Sac City, IA, and Jefferson, IA, made it possible to estimate nitrate and TP loads for the North Raccoon River. The data at the Sac City site was excellent, containing a solid record of nutrient data spanning over 20 years. The IDNR has sampled the site every month since 1998, and the USGS operates a co-located gauge that has monitored streamflow since 1958. In 2008, the USGS also installed nitrate sensors that have continuously monitored this location. At Jefferson, routine phosphorus sampling was discontinued in 2009, but the USGS began consistently measuring nitrate, which (along with a co-located stream gauge) enabled long-term nitrate estimates at this location. Data from these two sources were assembled for this analysis.

Daily nutrient loads were estimated from 1998 to 2021. WRTDSK models were successfully implemented for nitrate, OP, and Part P at Sac City, while nitrate was successfully modeled at Jefferson. The final Part P concentrations were added to the OP concentrations that form TP concentrations. The estimated nitrate and TP concentrations were then coupled with daily mean flows monitored by the USGS to create daily nutrient loads.

The nitrate concentrations tended to be normally distributed, while the TP concentrations were more positively skewed. Nitrate concentrations ranged from 0.01 mg/L and 40 mg/L with an average of 11.5 mg/L. TP concentrations ranged from 0.1 mg/L and 12.2 mg/L with an average of 0.76 mg/L. Yearly nitrate yields ranged from 1.7 lbs/ac to 55.8 lbs/ac, with an average of 24 lbs/ac. Yearly TP yields ranged from 0.2 lbs/ac to 2.2 lbs/ac, with an average of 1.0 lbs /ac. Previous studies have estimated Iowa’s statewide yields for nitrate and TP across similar timeframes as 16 lbs/ac and 1.8 lbs/ac, respectively. The nitrate yields from the North Raccoon are greater than the rest of Iowa, while the TP yields are smaller. Annual water yields strongly correlated with annual nutrient yields. Both the Mann-Kendall and Spearman trend detection tests indicated that daily concentrations were decreasing for nitrate and TP. However, daily TP loads were increasing, and no trend was present for daily nitrate loads. Because mean daily streamflow was also increasing, the increased flow in the North Raccoon likely offset any reductions in nitrate and TP concentrations.

5. Model Development

The modeling activities described in this report were performed using the Generic Hydrologic Overland-Subsurface Toolkit (GHOST), a physically-based integrated model developed at IIHR – Hydroscience and Engineering to run decades-long simulations for entire Iowa watersheds. The model represents hydrologic processes using physical laws and empirical correlations parameterized with actual watershed characteristics, such as soil types, land use, topography, and hydrologic connections (Politano, 2019). This allows it to predict streamflow during normal and extreme rainfall and snowmelt. The model incorporates best management practices (BMPs) to enable a comparison of streamflow and watershed characteristics before and after the construction of IWA projects.

a. Hydrologic Model Description

GHOST is based on MM-PIHM (Multi-Modular Penn State Integrated Hydrologic Model), an open-source code developed by Qu and Duffy (2007) that specializes in coupling surface and subsurface flows. Modifications of the original model in GHOST include: “1) capturing main hydrological processes to predict observed multi-year hydrographs and annual water budgets; 2) increasing accuracy using a Voronoi-based discretization; and 3) improving computational efficiency through multithread parallel computing” (Politano, 2019). In addition, Razmand (2020) added tile drainage to GHOST to capture this important component of Iowa’s hydrology.

Watersheds in GHOST are discretized horizontally by a mesh of Voronoi (a.k.a., Thiessen) polygons, which improve the accuracy of gradient computations and calculated fluxes between these elements. Vertically, the elements are defined by three different zones: the surface zone, as well as two subsurface zones (unsaturated and saturated soil), separated by a dynamic water table (Figure 5-1) (Politano, 2019).

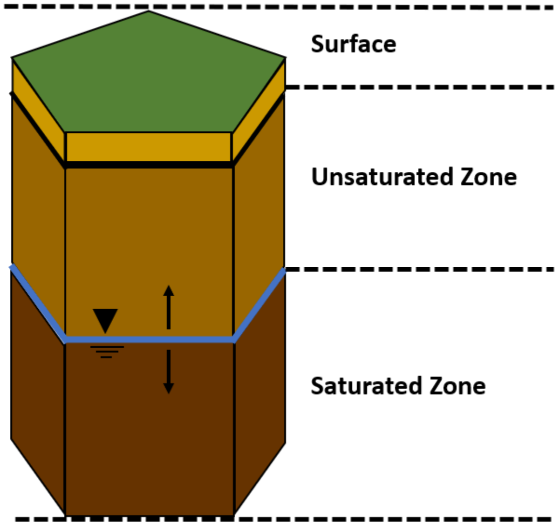


Figure 5-1. Vertical zones of a Voronoi element in GHOST: surface, unsaturated, and saturated zones.

GHOST computes all the major components of the water cycle, as shown by Figure 5-2. Rain (or snow) is intercepted by the vegetation canopy before it reaches the surface. Water on the surface either evaporates, runs off, or infiltrates the soil. Infiltrated water transpires, evaporates, exfiltrates, or recharges the groundwater, which can then either be evaporated or discharged to streams through natural movement or tile drainage. GHOST calculates surface flow using the two-dimensional diffusive wave approximation of the Saint Venant equations, where water depth is computed using a one-dimensional approximation to capture the channel geometry. Flow in the unsaturated zone is assumed to be primarily vertical and is governed by the Darcy equation, while groundwater (the saturated zone) moves horizontally via the non-linear Bousinnesq equation. For a full documentation of GHOST's mathematical model, please refer to Politano (2019).

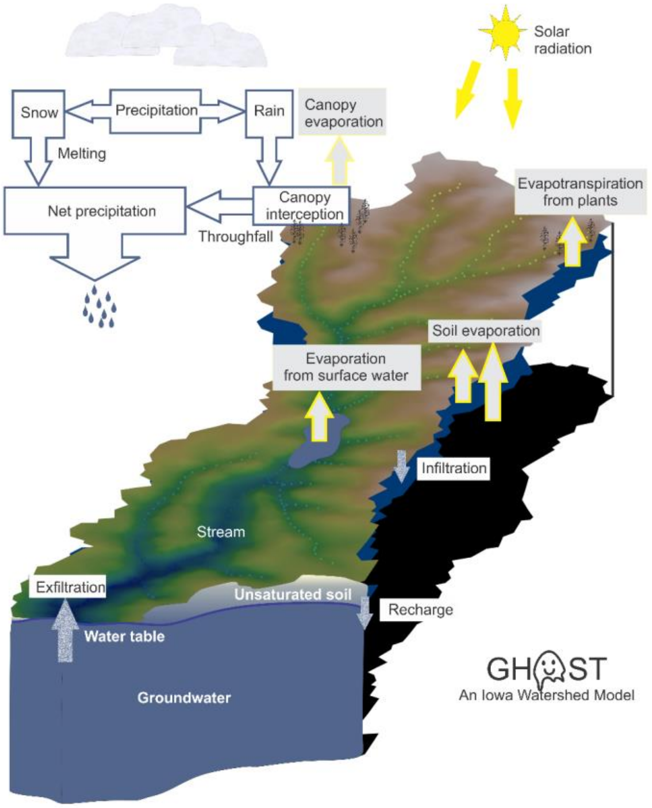


Figure 5-2. The hydrologic cycle calculated by GHOST (Politano, 2019).

b. North Raccoon Model Construction

The GHOST model for the North Raccoon River Watershed consists of a computational mesh of Voronoi elements and a network of connected linear stream segments, shown in **Error! Reference source not found.**. Modelers delineated the stream network using a 10-meter resolution digital elevation model (DEM) procured from the National Elevation Dataset (NED). Within each element, water fluxes are calculated and communicated to neighboring elements and stream segments. Each element contains information about its location, minimum and maximum elevation, area, soil, and land use type. The stream network is detailed by each segment’s location, length, minimum and maximum elevation, and stream order, with corresponding parameters including depth, width, roughness, and connection to the surface and subsurface of its neighboring elements.

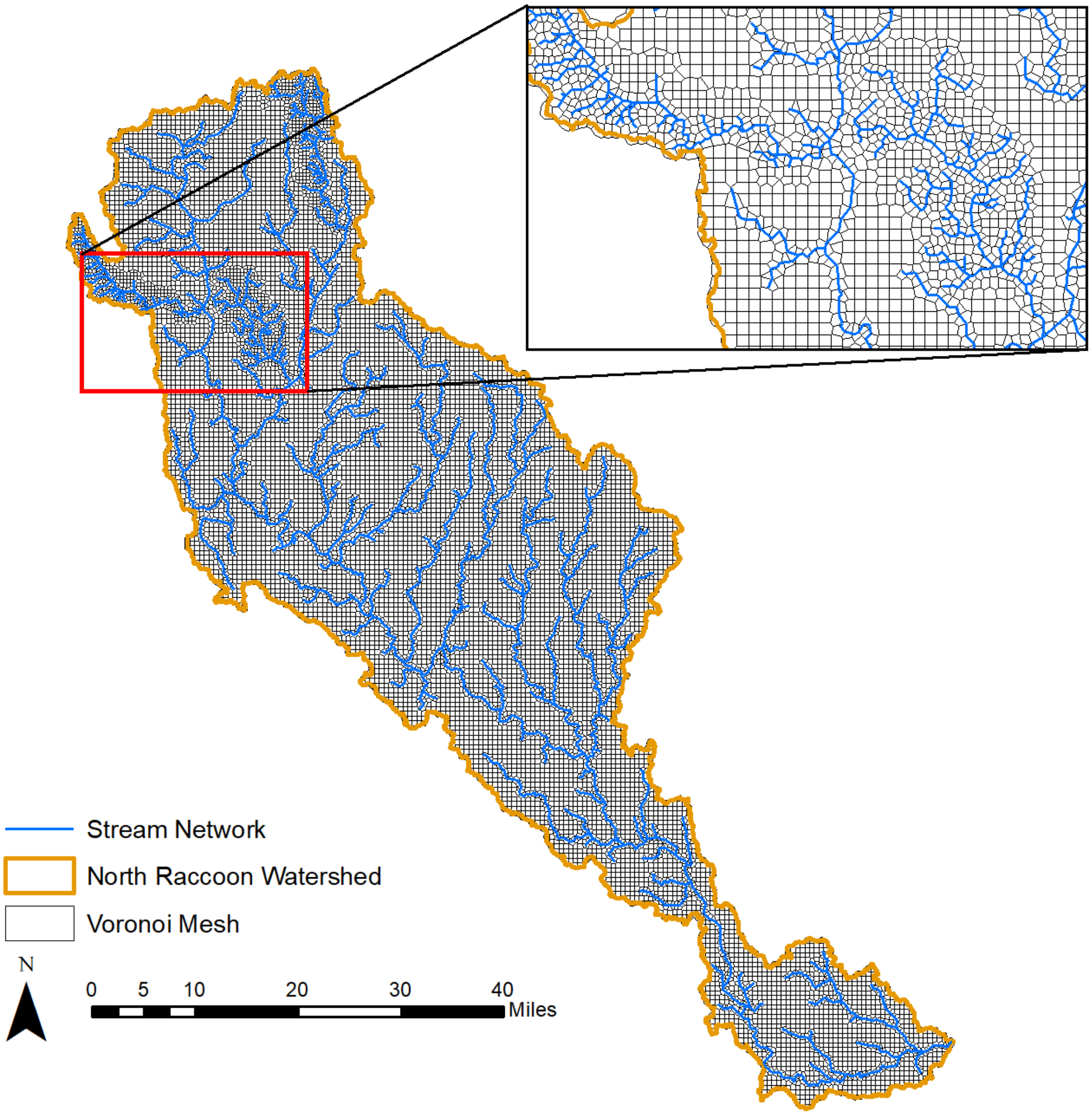


Figure 5-3. The Voronoi mesh and stream network used in the North Raccoon GHOST model.

The model for North Raccoon River Watershed contains 14551 elements, with an average size of 0.45 km^2 (111 acres), the largest at 1.18 km^2 (293 acres), and the smallest only 0.12 km^2 (29 acres). There are 3330 river segments with a total length of 1910 km (1189 miles) and average, maximum, and minimum lengths of 570 m, 1870 m, and 100 m, respectively. Many segment lengths were increased by a multiplier to account for real-life sinuosity that was not captured in the coarsely resolved stream network.

HUC12 sub-watersheds within the IWA focus area were constructed with a finer resolution mesh and denser stream network to enhance the model's performance surrounding IWA projects. This can be seen in Figure 5-4. Elements within these HUC12s were smaller than the rest of the watershed, with an average area of just 0.29 km^2 (71 acres); the largest was only 0.76 km^2 (187 acres).

GHOST assigns each computational element to one of four land use types, based on the type that is predominant in that element. Different land use types result in different characteristics within the model, including evapotranspiration parameters such as leaf area index, vegetation height, root depth, and crop coefficient, as well as albedo, surface roughness, and surface water storage capabilities. Landcover data were collected from the USDA 2018 Crop Data Layer (USDA, 2021). Though elements vary slightly in area, 87% are assigned to row crop, 4% to forest, 5% to grass/pasture, and 3% to urban, as shown in Figure 5-5.

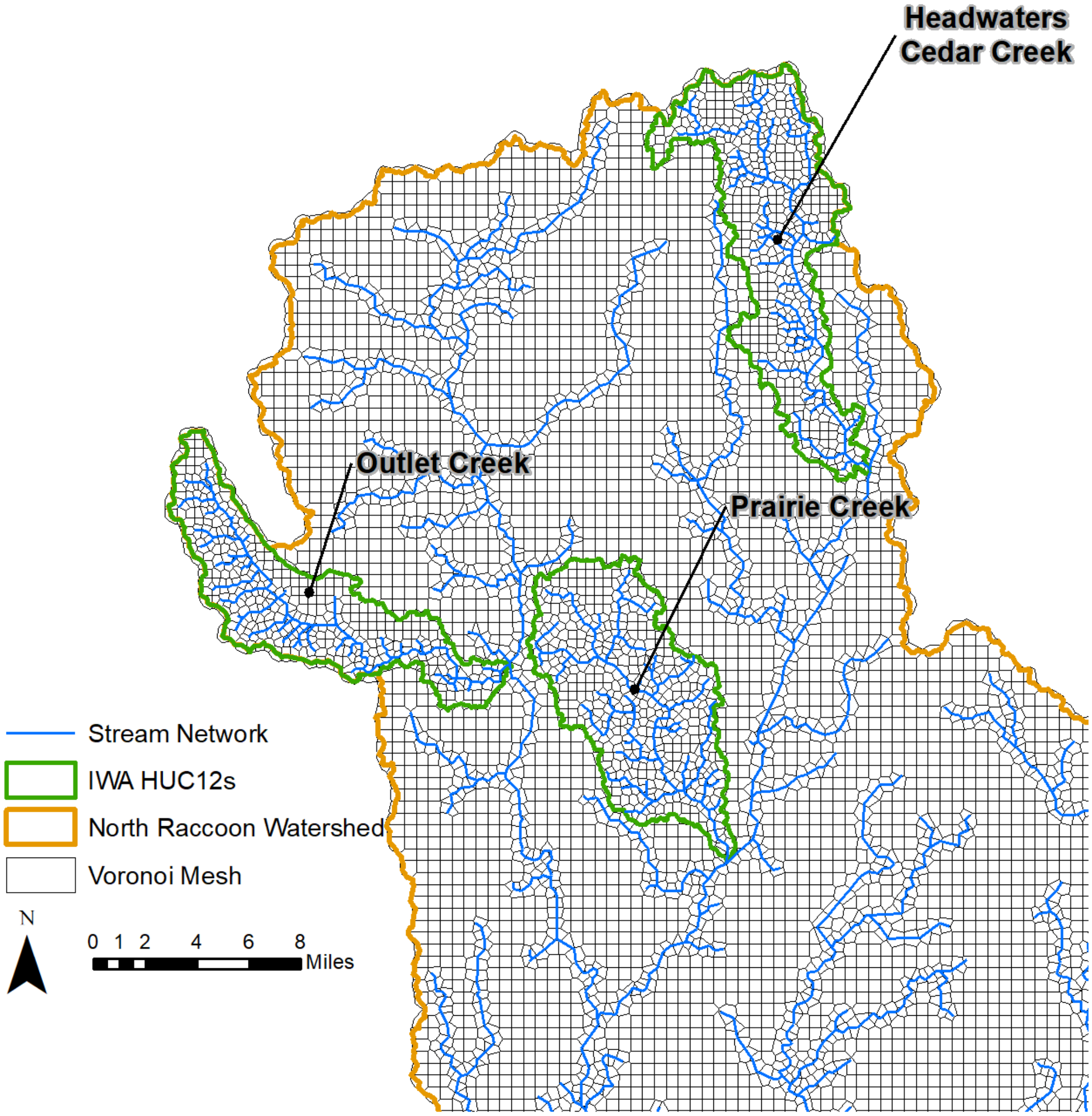


Figure 5-4. The mesh within IWA focus areas was constructed with a finer resolution than the rest of the watershed.

GHOST requires five different weather parameters as forcing data: precipitation, temperature, wind speed, surface pressure, and potential evapotranspiration. Modelers obtained meteorological data from the North American Land Data Assimilation System Phase 2 (NLDAS-2). The model used the 83 NLDAS pixels shown in Figure 5-6Figure 5-5.

Three USGS streamflow gauges on the North Raccoon River were used to calibrate the GHOST model (all shown in Figure 5-6): gauge 05482300 at Sac City, gauge 05482500 at Jefferson, and gauge 05484900 at Fleur Drive (Des Moines). The next section describes the process and results of model calibration.

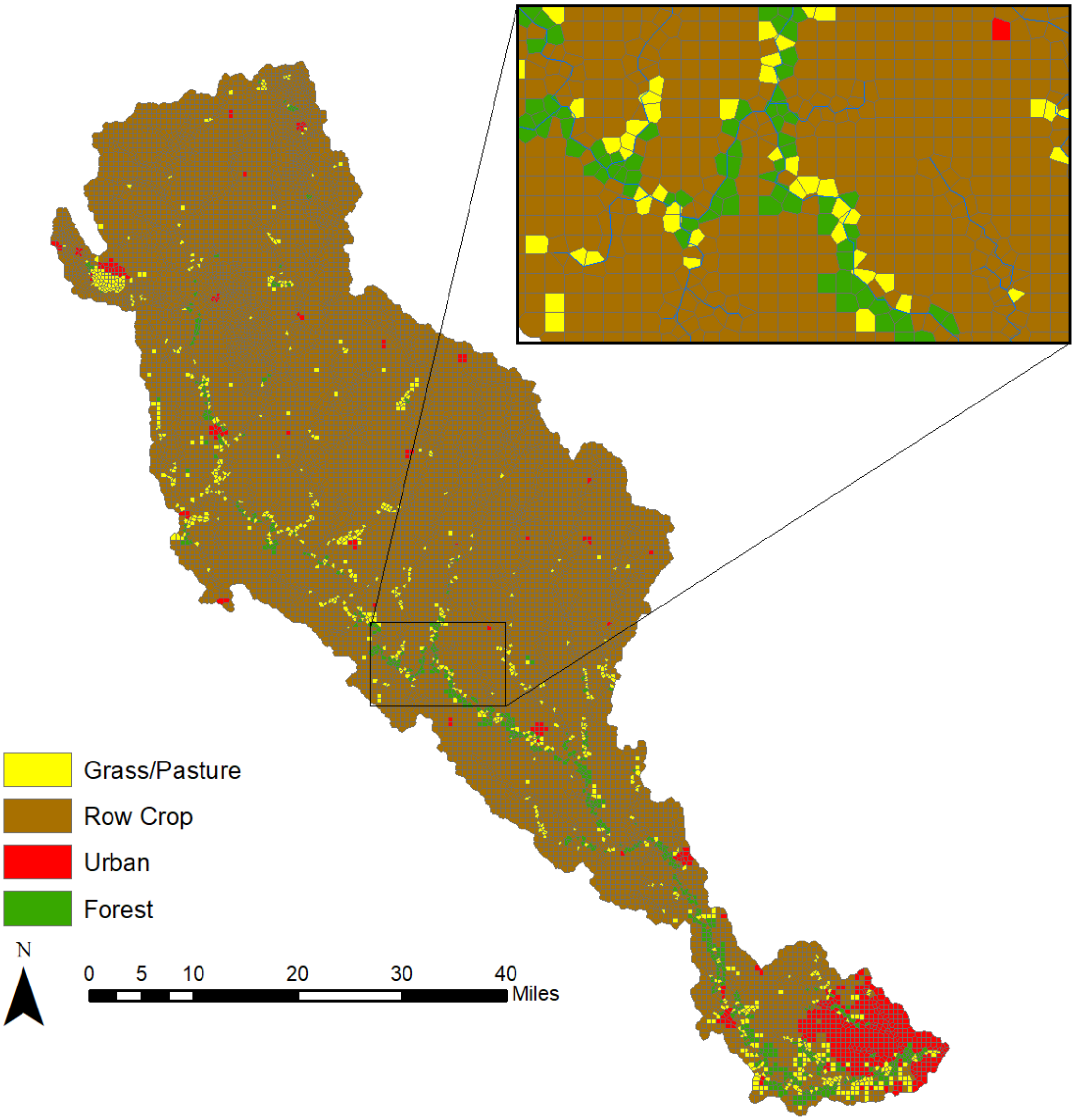


Figure 5-5. GHOST mesh with elements' land use classifications.

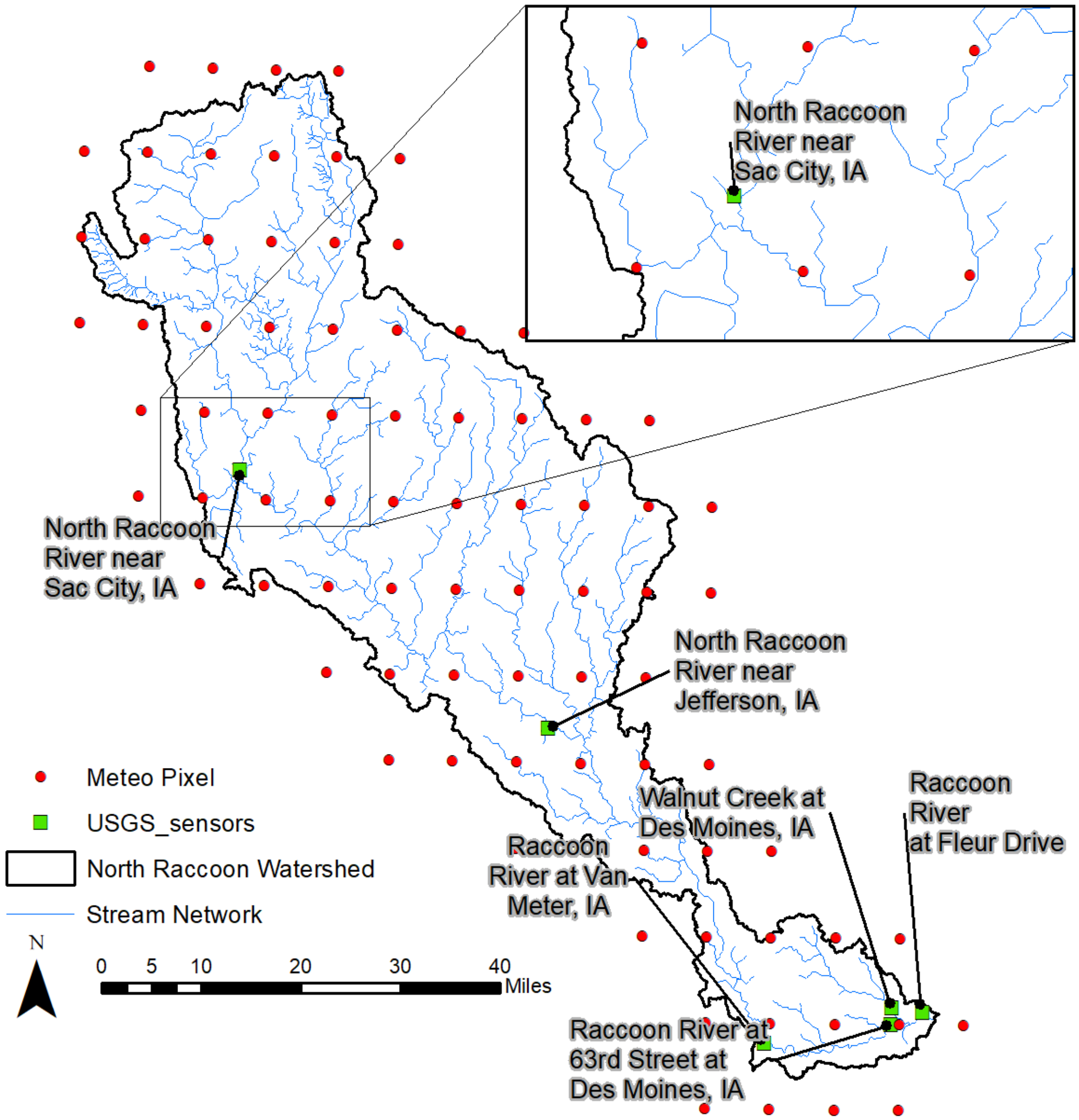


Figure 5-6. The location of the meteorological forcing data pixels and USGS gauges used in the North Raccoon Watershed model.

c. Model Calibration

Calibration is the process of adjusting model parameters until simulated results match observed time series as closely as possible, typically stream discharge at a gauging station. Analyses based upon the model can therefore be assumed to reflect reality to a reasonable degree. Researchers performed model calibration for an 18-year period from 2003–2020. Simulated flows were compared to observed flows at the USGS stream-gauge stations 05482300 at Sac City, gauge 05482500 at Jefferson, and gauge 05484900 at Fleur Drive (Des Moines), as shown in Figure 5-6. The comparison of observed and simulated average daily discharges for all gauges is shown in

Figure 5-7. In general, GHOST did a good job of capturing the watershed behavior, albeit with some mismatches inherent in all hydrologic modeling.

We can use several performance metrics to evaluate how well a model matches observed discharges. Based on Moriasi et al., 2007, model simulations can be judged as satisfactory if Nash-Sutcliffe efficiency (NSE) > 0.60, Percent bias (PBIAS) < ±15%, and the coefficient of determination (R^2) > 0.50. The metrics for this model's daily average discharges are shown in Table 5-1. The NSE is above the recommended minimum threshold at Jefferson and Fleur Drive, and slightly below the threshold at Sac City. PBIAS is greater than the maximum recommended threshold at all three sites, particularly at Sac City and Jefferson. A bias toward over prediction is apparent in Figure 5-7. The R^2 is well above the recommended minimum threshold at all three locations. It's important to note that these values were calculated on daily values over an 18-year period, which is more stringent than common practice.

The North Raccoon River Watershed displays a monthly pattern typical in Iowa, with the highest runoff depths from March through July and relatively drier conditions during the rest of the year. The model captures this pattern well at all three locations, with a tendency to overpredict runoff volumes throughout the year, as seen in Figure 5-8. Overall, the GHOST model's performance matched trends in observed average monthly runoff depths closely, with R^2 values of 0.92 for Sac City, 0.92 for Jefferson, and 0.96 for Fleur Drive.

Researchers compared the peak annual discharge for each year to assess the model's ability to capture the largest flood events. Figure 5-9 plots each annual peak with observed discharge on the x-axis and simulated on the y-axis to show how closely the two values match — that is, how close each point is to the one-to-one line. There is significant scatter about the one-to-one line at Sac City, resulting in a lower R^2 value. However, the data are roughly equally distributed above and below the line, suggesting the model is capturing the average behavior at this location. At Jefferson and Fleur Drive, R^2 values are relatively high. Simulations reproduce the general watershed behavior at the three sites.

The accuracy of the model at different scales of discharge can be assessed using the flow duration curves in Figure 5-10. For the entire record (2003–2020), we ranked daily flows from largest to smallest and then plotted against the probability that a given flow will be equaled or exceeded. The flow duration curves for all three locations exhibit very similar patterns. The observed and simulated curves show good agreement for lower frequency events with somewhat decreased performance at frequency increases.

Based on the performance metrics, hydrographs, and auxiliary figures presented in this section, the GHOST model was deemed to be well-calibrated for the North Raccoon River Watershed. It is therefore deemed suitable for use as a helpful tool for the IWA.

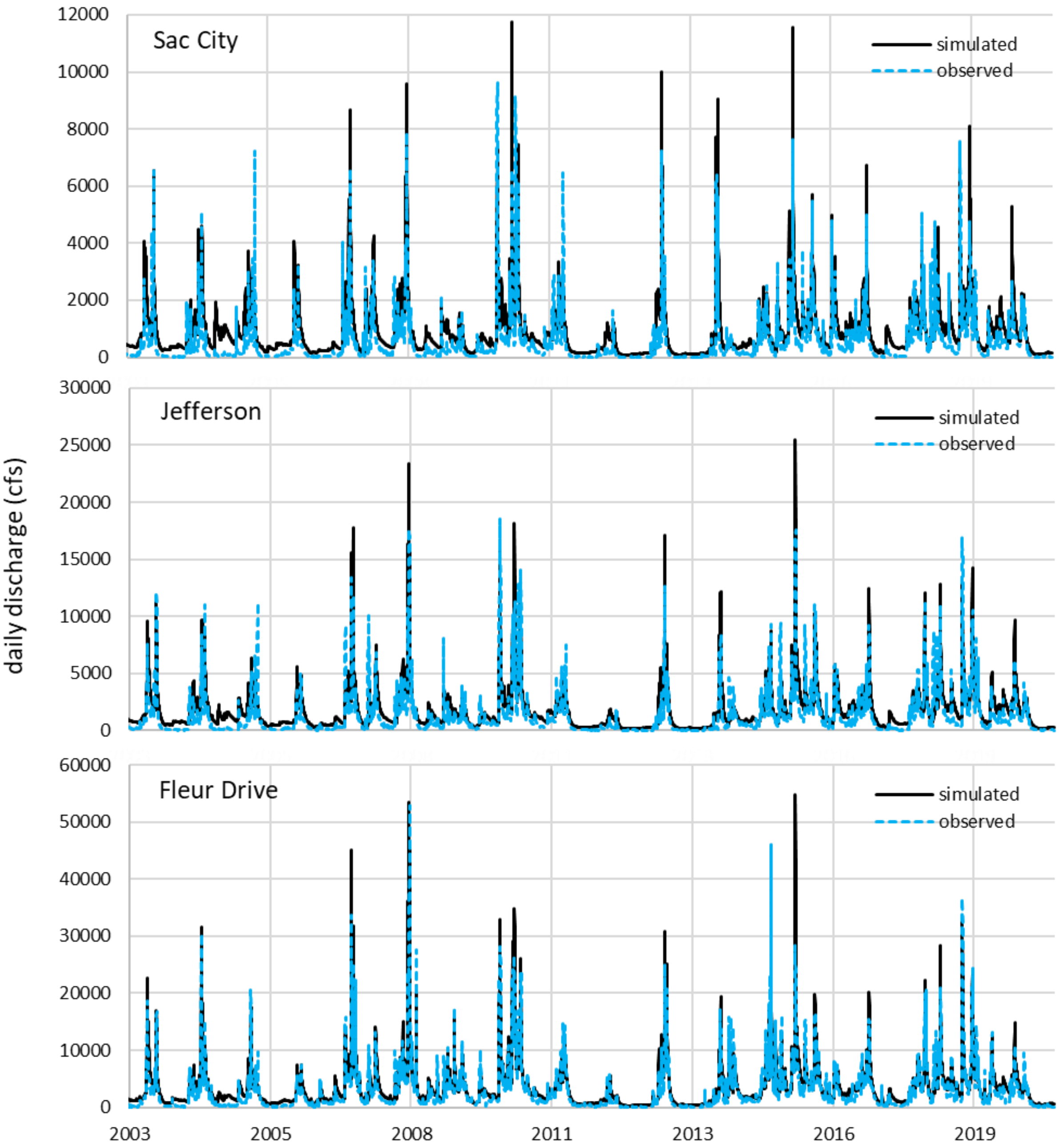


Figure 5-7. Comparison of simulated (black) and observed (blue) daily average discharge at Sac City (top), Jefferson (middle), and Fleur Drive (bottom).

Table 5-1. Performance parameters for the calibrated GHOST model.

metric	Sac City	Jefferson	Fleur Drive
NSE	0.49	0.68	0.84
R^2	0.71	0.75	0.85
PBIAS	68%	41%	18%

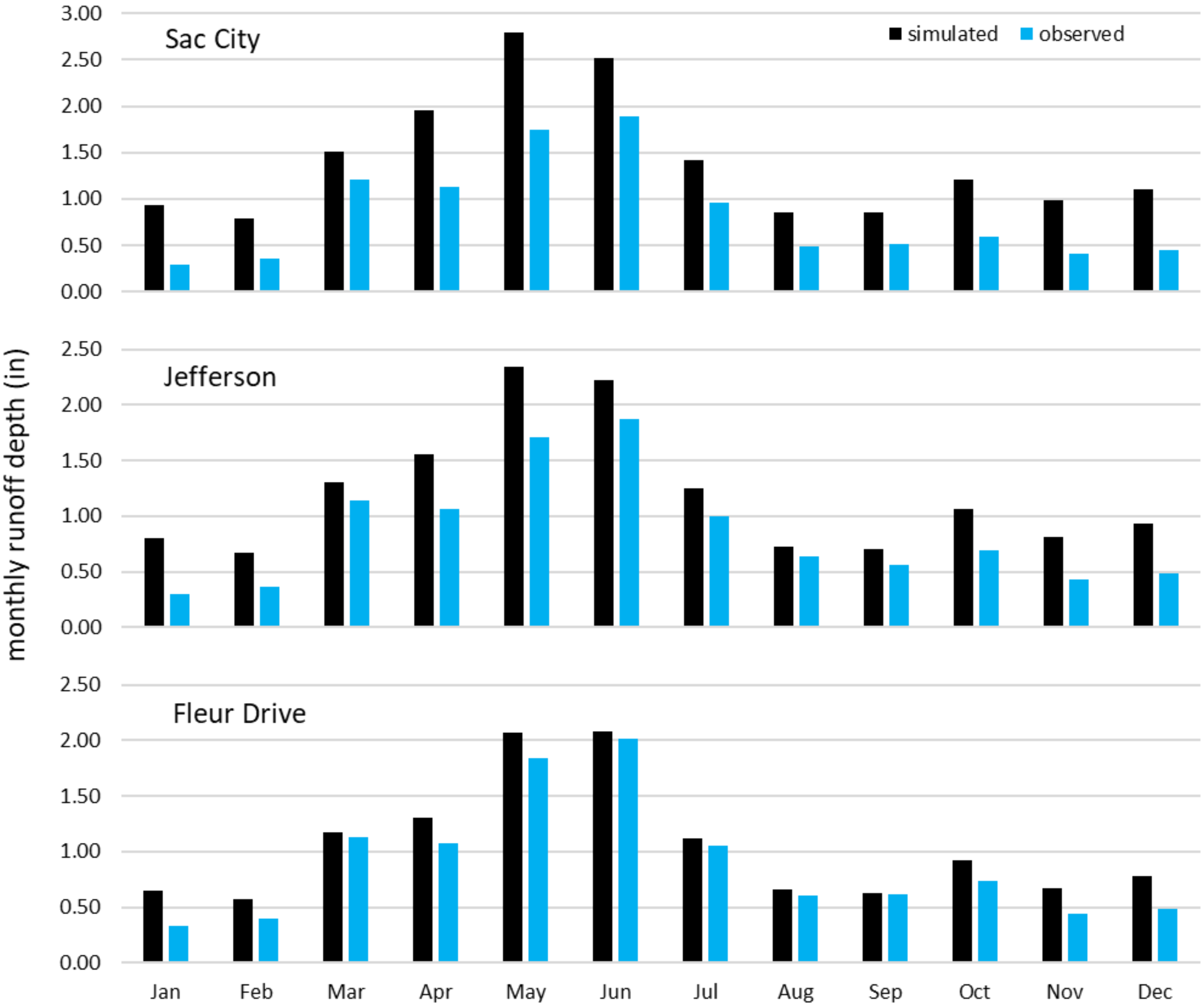


Figure 5-8. Observed and simulated average monthly runoff depths from 2003–2020 at Sac City (top), Jefferson (middle), and Fleur Drive (bottom).

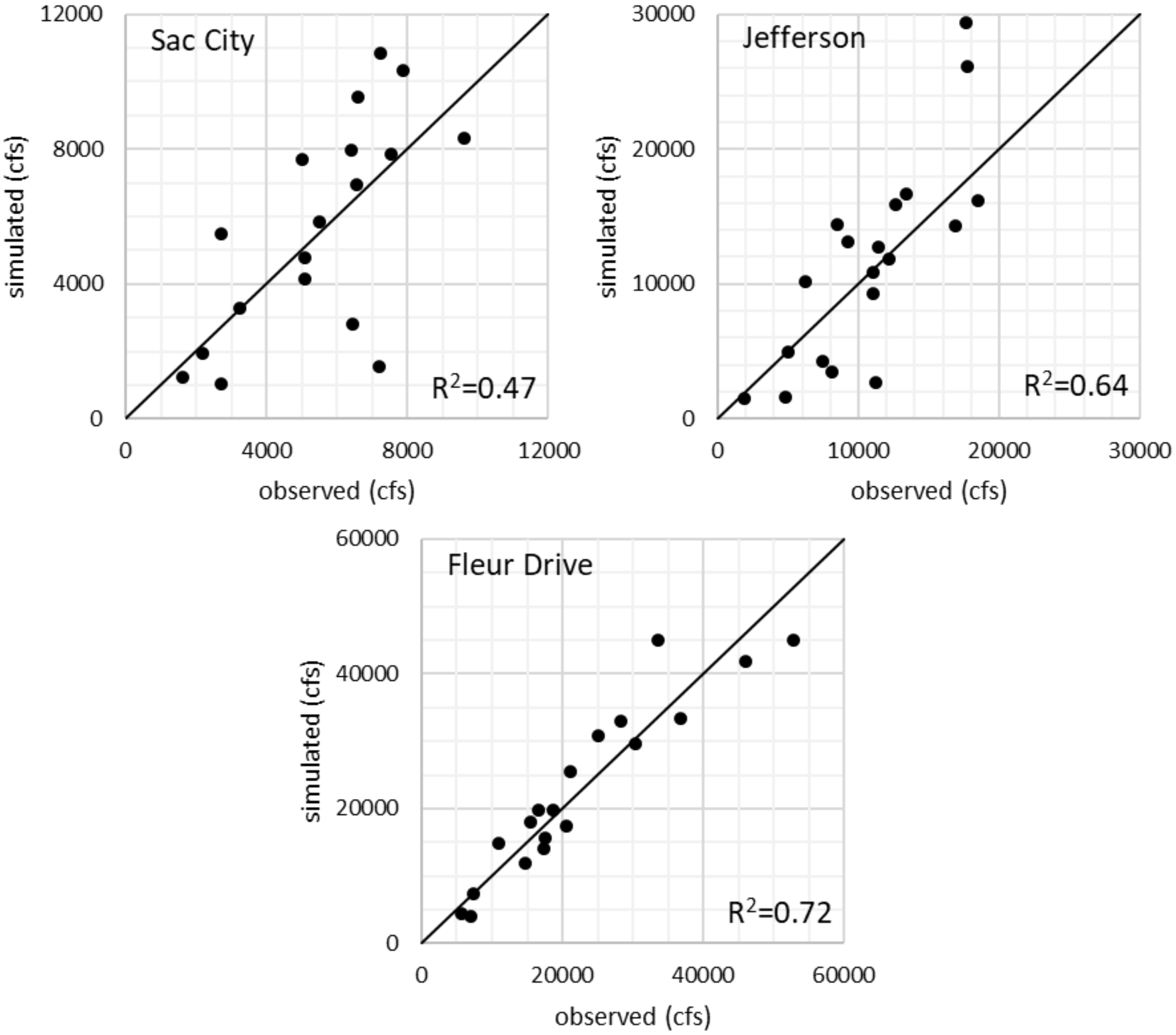


Figure 5-9. Annual peak discharge plotted against a 1:1 line, showing how well modeled peaks matched observed values at Sac City (top right), Jefferson (top left), and Fleur Drive (bottom).

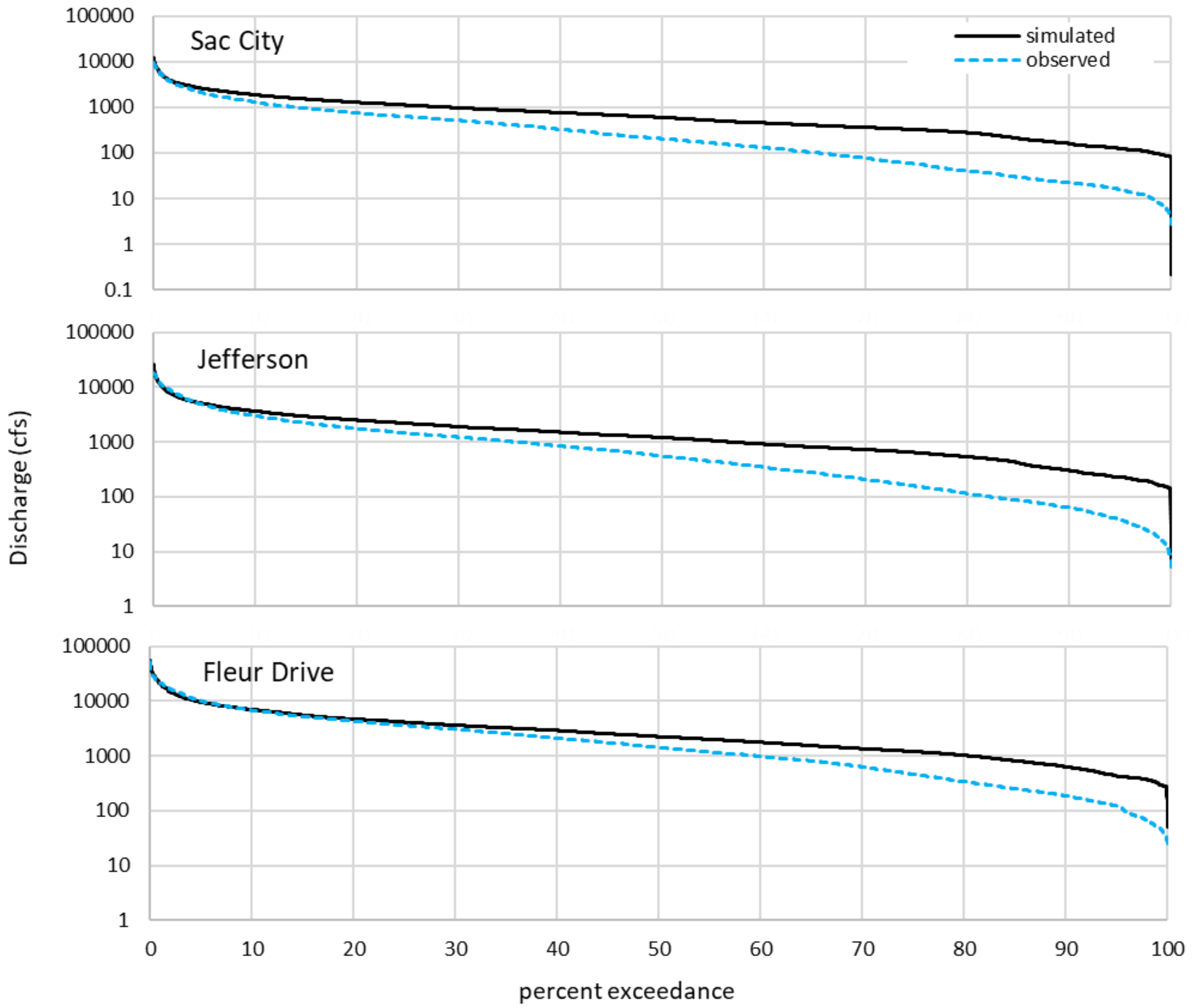


Figure 5-10. Daily flow duration curves at Sac City (top), Jefferson (middle), and Fleur Drive (bottom).

d. Implementation of IWA Projects in the Model

The calibrated GHOST model for the North Raccoon River Watershed described in the preceding sections was used to evaluate the individual and cumulative hydrologic effects of the BMPs constructed as part of the IWA, with a particular focus on flood events. Chapter **Error! Reference source not found.** provides a full catalogue of the 4 projects constructed in the North Raccoon River Watershed. This section describes how the effects of the projects were incorporated in the hydrologic model.

Ponds, wetlands, and similar projects provide significant flood mitigation benefits. Design engineers provided a stage-discharge curve for the North Raccoon River Watershed project that could store water. This curve details how much water is discharged by the project based on the depth (stage) of water within the project's retention basin. Therefore, discharge during an event can be calculated by using the inflow hydrograph to determine how much water is entering the project; using the total volume of water to calculate the depth; and using that depth with the stage-discharge curve to determine the outflow and volume of water leaving. This process is repeated iteratively at each timestep to generate the outflow hydrograph.

Inflow hydrographs are upstream of projects and therefore unaltered by the project; they can be retrieved from GHOST and/or design storms — flood events that produce pre-determined inflow hydrographs. These conditions serve as the "control" for comparison with the simulations with projects. Once outflow hydrographs are calculated by routing the inflow hydrographs through the stage-discharge curves, they replace the previous control hydrograph immediately downstream of each project. In GHOST, we introduce the outflow hydrographs onto elements adjacent to river segments. Rain is removed from the upstream drainage because the flow it would have produced is being replaced by the flow imposed by the outflow hydrograph. Figure 5-11 shows an example of the configuration used for several of the IWA projects.

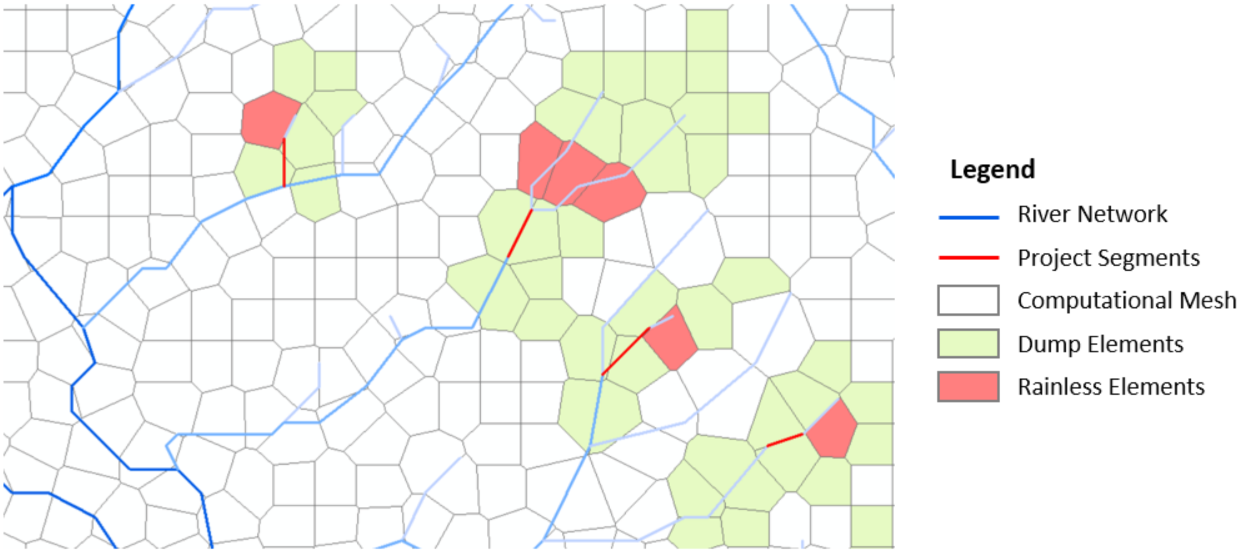


Figure 5-11. A portion of the GHOST model that shows how project effects are simulated by dumping the attenuated outflow hydrograph calculated for each project while eliminating rainfall upstream, which would produce the original, unaltered streamflow.

From the project locations, water continues downstream, whether it be from rainfall/groundwater (as is the case in the control version) or is introduced to the system based on the outflow hydrograph that the projects produce. Therefore, the effect of the project can be analyzed at any point downstream, and cumulative effects of multiple projects are merged when their respective streams converge. Chapter 7 presents the results from testing the individual and cumulative impacts of the IWA projects during flooding.

6. Project Inventory

a. IWA Projects in the North Raccoon Watersheds

The Iowa Watershed Approach helped fund the design and construction of 4 new BMPs within the North Raccoon Watershed, providing 90% cost-share assistance to volunteer landowners. A summary of the 4 projects is given in Table 6-1.

Table 6-1: Project Summary Table.

PROJECT	PRACTICE	WATERSHED	COST	DRAINAGE AREA (ac)	Berm Storage (ac-ft)
NR-001-WHITEFAMILYTRUST	Wetland	Outlet Creek	$303,620.00	304	57
NR-001-JSMITH	Grade Stabilization	Outlet Creek	$26,110.00	n/a	minimal
NR-001-RSMITH	Oxbows & Stream Restoration	Outlet Creek	$130,085.00	n/a	minimal
NR-001-TSMITH	Oxbows & Stream Restoration	Outlet Creek	$298,178.00	n/a	minimal
		TOTAL	$757,993.00	304	57

BMPs were constructed in one of the three HUC12s selected to be part of the IWA; no projects were built in Headwaters Cedar Creek or Prairie Creek sub-watersheds. Figure 5-1 shows the locations of the 4 projects in the North Raccoon Watershed.

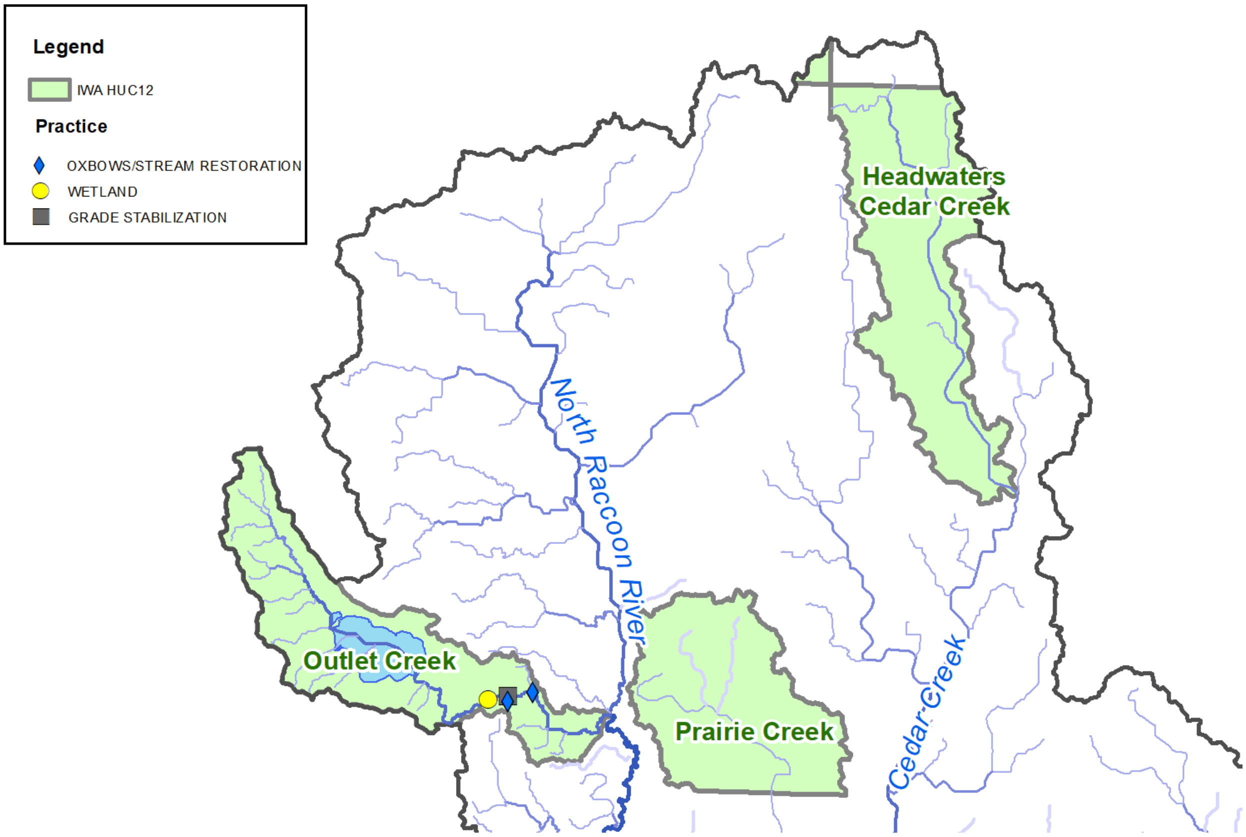


Figure 6-1: Location and type of the 4 IWA projects in the North Raccoon River Watershed.

b. Hydraulics of Flood Mitigation Projects

Three different types of BMPs were constructed in the North Raccoon Watershed: 1 wetland, 2 oxbow and stream restoration projects, and 1 grade stabilization. Some smaller types of projects are difficult to implement in the GHOST model due to the difference in project size versus mesh resolution. Therefore, only relatively larger projects with relatively large upstream drainage area and flood storage such as ponds, wetlands, and on-road structures were incorporated into GHOST modeling. All these practices were assumed to follow the same hydraulic principle for flood attenuation.

Storage structures (ponds, wetlands, on-road structures) hold floodwater temporarily and gradually release it at a lower rate later. While the same volume of water ultimately enters and exits the project, the peak flow is reduced, which can have minor to significant flood reduction benefits.

Most flood damage is usually attributed to the peak flow, and not necessarily a prolonged moderate flow. Figure 6-2 illustrates a classic difference in streamflow with and without a storage project.

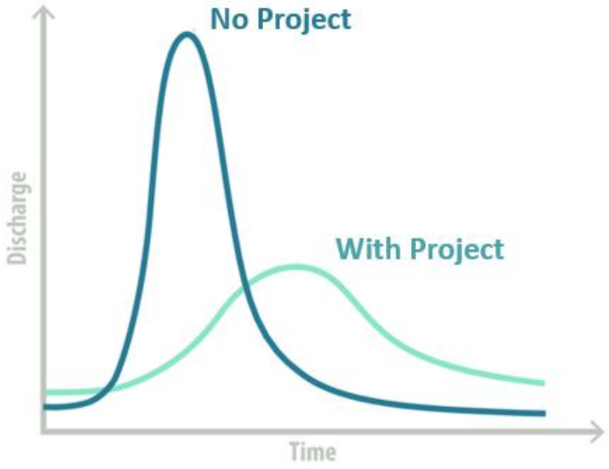


Figure 6-2: A classic comparison of a streamflow hydrograph with and without a flood mitigation project. The addition of the project does not change the volume of water moved but rather lowers the peak flow passed and gradually releases the water at slower rates.

A basic storage structure design (Figure 6-3) consists of an embankment that holds water back to fill up a storage pool. The pool might be a pond or a wetland, and in the case of on-road structures, the embankment is the roadway itself and the ditch area serves as the pool. A principal spillway (usually a pipe) allows water passage through the embankment, albeit with a maximum discharge — hence the streamflow reduction. During a flood event, water enters the pool and the principal spillway discharges its maximum flow downstream, while water begins to fill up the storage pool. As inflows decrease, the storage pool begins to empty out through the pipe, producing a delayed, gradual outflow. To avoid structural damage, an auxiliary/emergency spillway is constructed at a higher elevation than the pipe; this allows a high rate of discharge to prevent water from overtopping the embankment. Most principal spillways are also built above the bottom of the pool to allow a permanent / "dead" storage of water (ponds and wetlands avoid drying out). The storage volume between the principal and auxiliary spillways is referred to as "active" storage because this water level can fluctuate rapidly to attenuate flood events.

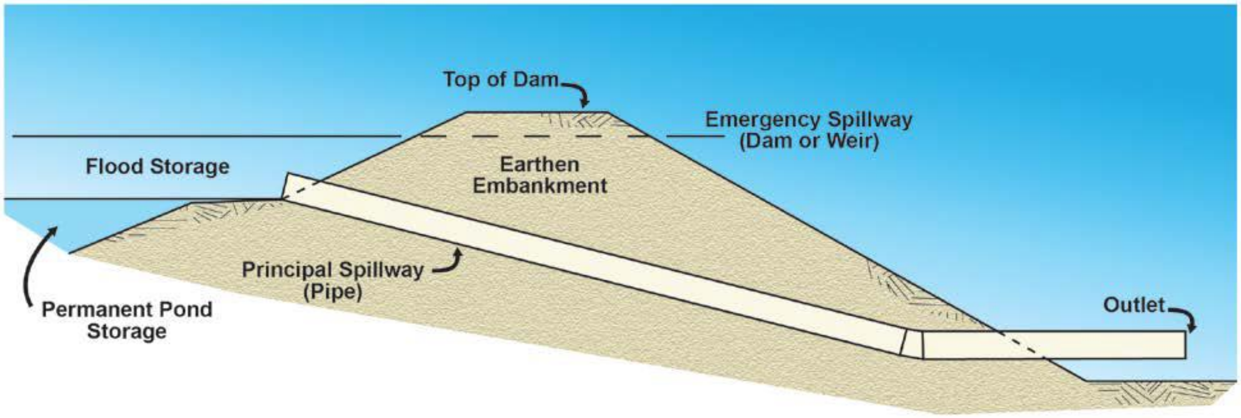


Figure 6-3: Schematic of a pond constructed to provide flood storage.

The effectiveness of any flood mitigation project depends on its storage volume and outlets — how quickly the water is released. A project with a properly sized principal spillway but an active volume that is too small would rapidly fill up and activate its auxiliary spillway, providing little-to-no peak reduction. On the other hand, a project with adequate volume but too large a principal spillway would pass most large inflows unchanged through the principal spillway, never holding water in its active volume.

c. Project Summary

As a result of the Iowa Watershed Approach, 4 new BMPs were constructed in North Raccoon Watershed:

- 1 Wetland
- 2 Oxbow & Stream Restoration Projects
- 1 Grade Stabilization

Some project types can provide meaningful storage and flood reduction benefits for the watershed, and most will help improve water quality. Ponds, wetlands, terraces, and WASCOBs all help to reduce peak flows and slow down the movement of water, allowing greater attenuation and removal of sediment, nutrients, and other pollutants. Oxbows help rivers and streams spread out over their old paths during floods, holding water and removing pollutants. And while grass waterways generally don’t affect flow much, they help to prevent runoff from carrying sediment and pollutants into streams. We were not able to model all these projects because of the nature of the practice (e.g., oxbows), their size, or their location. However, the hydrologic model was able to simulate the benefit that constructing one of these BMPs will likely have on the watershed going forward. The next chapter details the project-modeling process and summarizes the individual and cumulative benefits for the hydrology of the North Raccoon Watershed.

7. North Raccoon Hydrologic Assessment

a. Individual Impacts of IWA Projects

In order to assess the flood reduction impacts of IWA projects in the North Raccoon Watershed, a design storm was imposed on GHOST. The storm generated 6.3 inches of rain within a 24-hour period, as shown in Figure 7-1. The watershed response to this storm was measured first in a "control" version without projects to ensure that streamflow at the future project sites was consistent with expectations provided by the design engineers. For some projects, a different streamflow had to be introduced at the future project site, using the method described in Section 5.d, to more accurately match the inflow hydrographs that the projects were designed for.

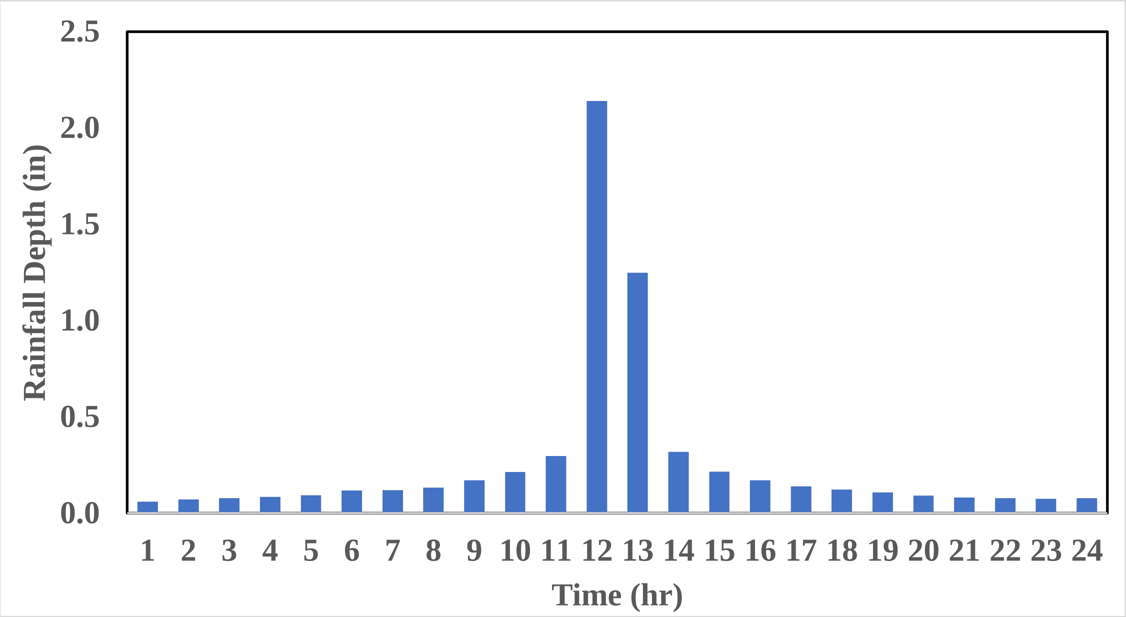


Figure 7-1. Rainfall hyetograph from the design storm used in GHOST to test the effects of projects on flood peak reductions.

This first run provides a baseline comparison of how the watershed would react to a storm like this while no projects are present. Next, modelers added projects by imposing the outflow hydrographs at their respective locations (see Section 5.d for the full methodology). In these cases, streamflow immediately downstream of each project reflects the conditions with projects in place and can be compared to the control. The following analysis focuses on the single wetland (NR-001 White Family Trust) constructed on a small tributary of Outlet Creek and its streamflow responses on a local scale.

For the Outlet Creek HUC12, Figure 7-2 shows the location of the constructed wetland (NR-001 White Family Trust) as well as three index points (A, B, and C) where the flood-reduction benefits of the projects were assessed. In addition, this figure presents modeled hydrographs (with and without projects) at the selected index points.

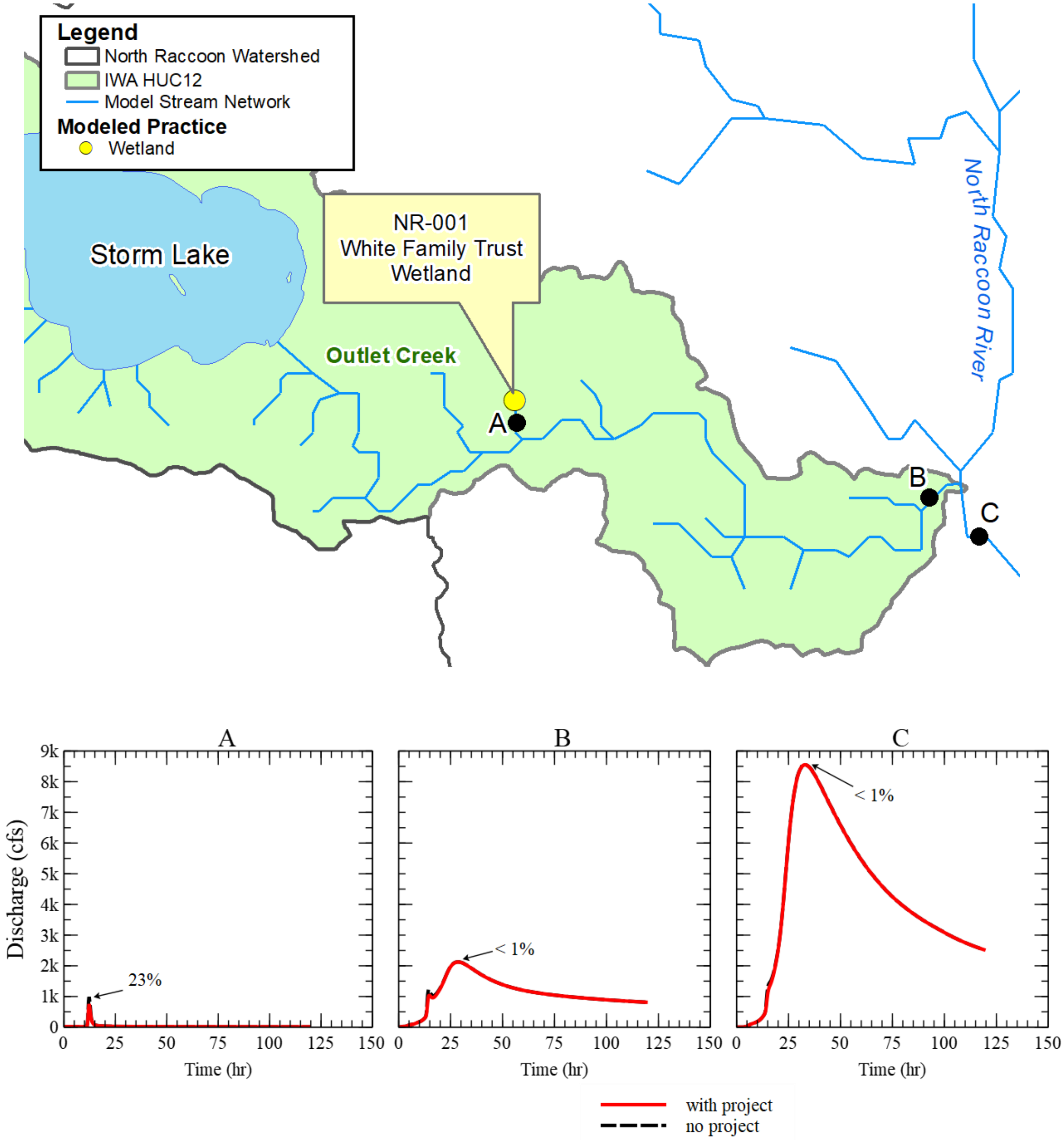


Figure 7-2. The location of wetland project NR-001, along with hydrographs comparing the streamflow with (solid red) and without (dashed black) projects at points A, B, and C.

Point A is located just downstream of the project location on a small tributary of Outlet Creek, whereas point B is on Outlet Creek and point C is on the North Raccoon River. Modeled hydrographs for these three points show the expected behavior of having less peak flow attenuation as downstream distance from the project location increases.

At point A, downstream of the NR-001 wetland, peak streamflow is attenuated by the project and the corresponding hydrographs show 23% peak flow reduction. Point B shows higher peak flows for both simulations (with and without project) but the peak flow reduction at this point is far lower than that at point A. Peak flow reduction at point B is less than 1%. Moving downstream, at point C the peak flow reduction decreases further, and is nearly zero. As drainage area increases, a smaller proportion of the total drainage area and runoff volume is captured and attenuated by the wetland.

b. Watershed-Scale Effects

Figure 7-3 summarizes peak flow reductions associated with the design storm (Figure 7-1) at the outlets of IWA HUC12 watersheds. At the HUC12 watershed scale, the influence of constructed practices is minimal. The proportion of HUC12 area affected by practices, the position of practices within the HUC12, and the practices' storage volumes all contribute to variability in peak reductions. Table 6-1 shows the area draining to the NR-001 wetland and its total storage capacity.

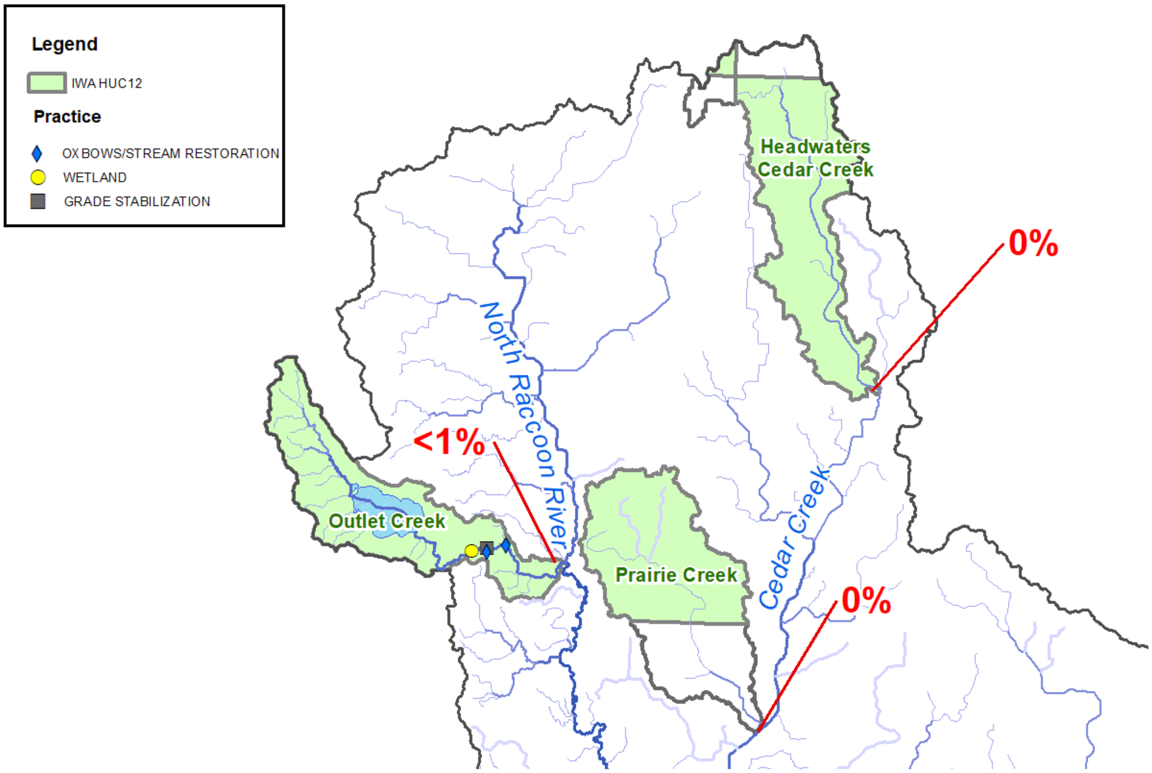


Figure 7-3. Flood peak reduction (red text) at the outlets of HUC12s with projects.

c. Limitations of the IWA Projects

While impactful on a local scale, the limited flood reduction benefits of IWA projects for downstream communities are not surprising when scrutinized from a broader perspective. Streamflow is ultimately related to a river's drainage area; the larger the proportion of total drainage affected by flood mitigation projects, the more flood flows will be attenuated in the river.

The total drainage area regulated by the IWA constructed wetland is 304 acres, only 1.1% of the Outlet Creek HUC12 and 0.02% of the entire North Raccoon Watershed. It is not surprising, therefore, that peaks are reduced at about less than 1% at the outlet of Outlet Creek HUC12, when 1.1% of the basin's drainage area is captured by projects.

In addition to drainage area, the storage capacity provided by these projects is crucial in understanding their flood reduction capabilities. Storage is essentially the volume of water a project can hold back during a flood event. The total storage of the IWA wetland project is 57 ac-ft, which may be a difficult number to comprehend without some context.

During the flood of June 2010, the largest recent flood at Jefferson, over 360,000 ac-ft of water flowed past Jefferson. If the IWA projects had been in place during this event, they would have been able to hold back only about 0.02% of the floodwaters.

d. Future Implications

The impact of the 4 IWA projects is still significant, providing local flood reduction, water-quality, and wildlife habitat benefits. However, improvements on a watershed-scale would require significant additional investment and effort. To get an idea of the investment needed to produce watershed-scale flood-reduction benefits, Figure 7-4 shows the approximate cost to achieve a 20% peak reduction in the top-12 floods from 2001-2020, extrapolating from the total cost of North Raccoon and other IWA storage projects. For many floods, a 20% peak reduction would make a significant difference in damages and costs incurred, and lives affected. The price tag to achieve this, however, is in the hundreds of millions of dollars.

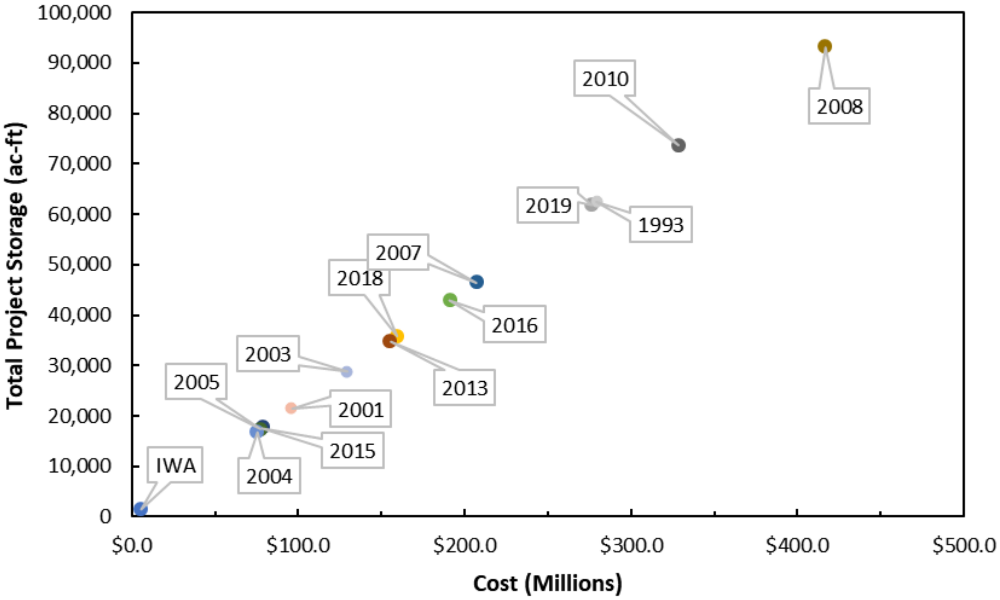


Figure 7-4. Approximate flood storage and cost required to achieve a 20% peak reduction in the top-12 flood events between 2001–2020, compared to the IWA. The 1993 Flood is also included for reference.

While the estimated price tags may seem astronomical, we can quickly put them in perspective when considering the costs of serious flood events. According to the National Weather Service, The Great Flood of 1993 resulted in 17 fatalities, the evacuation of over 10,000 people, and $5.4 billion in damages (adjusted for inflation). The 2008 flood affected 85 of Iowa's 99 counties, impacting over 40,000 people and killing one, and resulting in $12B in damages (adjusted for inflation). The human and financial costs of those floods may make the large investments depicted in Figure 7-4 seem more appropriate. Iowa has a tremendous need to reduce flooding and improve water quality. IIHR estimates that it would cost about $3M for each HUC12 to begin to address flooding and another $3M to address water quality. With 75 HUC12s in the North Raccoon Watershed, we estimate that more than $225M would be required to make a dent in flooding; this agrees well with Figure 7-4.

8. Summary and Conclusions

The North Raccoon River Watershed was one of eight distinct Iowa rural watersheds that participated in the IWA program. The goals of the IWA were: (1) reduce flood risk; (2) improve water quality; (3) increase flood resilience; (4) engage stakeholders through collaboration and outreach/education; (5) improve quality of life and health, especially for susceptible populations; and (6) develop a program that is scalable and replicable throughout the Midwest and the United States. The Phase I hydrologic assessment report provided an understanding of the watershed hydrology and the potential of various hypothetical flood mitigation strategies that may be leveraged to accomplish goals of the IWA. This process helped inform the location and construction of BMPs (ponds, wetlands, etc.) across the watershed, as part of Phase II. This report has presented a summary of water-quality conditions in the North Raccoon, a catalogue of projects constructed, the model used to assess them, and the results of that evaluation.

a. Watershed Characteristics

The North Raccoon River Watershed is a HUC8 located in west-central Iowa, lying mostly on the Des Moines Lobe. It receives drainage from the South Raccoon Watershed just upstream of Van Meter, where the North and South branches become the Raccoon River. The entire Raccoon River Watershed is 3608 mi^2, with the North Raccoon measuring approximately 2471 mi^2. Over 78% of the watershed's land area is used for agriculture. Average annual precipitation in the North Raccoon River Watershed ranges from roughly 33 to 36 inches. About 75% of the annual precipitation falls as rain during the months of April–September. During this period, thunderstorms capable of producing torrential rains are possible, with the peak frequency of such storms occurring in June.

b. Water-Quality Conditions

Water-quality conditions are generally poor throughout the state of Iowa. One of the main goals of the IWA was to help address this problem. The water-quality analysis detailed in this report was conducted at sampling locations on the North Raccoon River at Sac City (nitrate and phosphorous) and Jefferson (nitrate only). Nitrate concentrations ranged from 0.01 mg/L and 40 mg/L with an average of 11.5 mg/L. TP concentrations ranged from 0.1 mg/L and 12.2 mg/L with an average of 0.76 mg/L. Yearly nitrate yields ranged from 1.7 lbs/ac to 55.8 lbs/ac, with an average of 24 lbs/ac. Yearly TP yields ranged from 0.2 lbs/ac to 2.2 lbs/ac, with an average of 1.0 lbs /ac. The nitrate yields from the North Raccoon are greater than the rest of Iowa, while the TP yields are smaller. Both the Mann-Kendall and Spearman trend detection tests indicated that daily concentrations were decreasing for nitrate and TP. However, mean daily streamflow was also increasing and likely offset any reductions in nitrate and TP concentrations when considering nutrient loads.

c. Hydrologic Model

The modeling activities described in this report were performed using the physically based, integrated GHOST model developed at IIHR to simulate the hydrologic responses over time periods on the order of decades. GHOST stands for Generic Hydrologic Overland-Subsurface Toolkit. GHOST is based on the open-source hydrologic code MM-PIHM (Qu and Duffy 2007, Yu et al. 2013), which fully couples surface and subsurface domains to predict streamflow as well as groundwater movement for normal and extreme rainfall and snowmelt events. Model simulations were forced using 19 years (2002–2020) of hourly climatological data obtained from NLDAS. The simulations provided information not only on flood events, but also on the watershed's hydrology during medium and low flows. The calibrated baseline model accurately predicted discharges relative to observations made at USGS stream gauges at Sac City, Jefferson, and Fleur Drive, and could therefore be used with confidence to assess watershed response to IWA projects (see Chapter 5). The effect of the projects was tested using a design storm imposed on the GHOST model.

d. IWA Project Summary

The Iowa Watershed Approach resulted in the construction of 4 BMPs across the North Raccoon Watershed: 1 wetland, 2 oxbow and stream restorations, and 1 grade stabilization. Table 6-1 lists the 4 projects and their details, and Figure 6-1 shows a map of the projects. Projects were constructed in only one of the three IWA sub-watersheds in the North Raccoon (Outlet Creek). Only one of the projects is expected to provide a reasonable degree of flood storage capability, mainly through the attenuation and delayed release of peak flood flows.

e. Evaluation of the IWA Projects

The hydrologic model constructed in Phase II of the IWA was used to evaluate the individual and cumulative flood reduction impacts of the NR-001 White Family Trust project, constructed in the Outlet Creek HUC12. A peak flow reduction of 23% was predicted immediately downstream of the project site. This reduction diminished as streamflow increased downstream from the site until the peak flow reduction was <1% on Outlet Creek immediately upstream of its confluence with the North Raccoon River. No projects were constructed in the other two IWA HUC12 watersheds: Prairie Creek and the Headwaters of Cedar Creek.

The NR-001 White Family Trust wetland receives drainage from 304 acres and can store 57 acre-ft of water. Only 1.1% of the Outlet Creek HUC12 and 0.02% of the North Raccoon River Watershed drain through the wetland. Therefore, the wetland has little to no impact on flood flows at these scales. An incredible investment in upstream flood mitigation infrastructure would be required to begin to address flooding on a watershed scale.

IWA Phase I report estimated that approximately 25,000 acre-ft of distributed detention storage could be constructed in the North Raccoon River Watershed, assuming a typical project storage capacity of 49 acre-ft. The number of potential storage project sites is limited by the watershed's low topographic relief. The 25,000 acre-ft scenario resulted in local flood peak reductions along tributary streams for several historical and hypothetical storm events, it did not result in significant benefit along the main stem of the North Raccoon River. Broad use of cover crops and/or substantially larger storage projects would be necessary to achieve 5% decrease in peak streamflow at the North Raccoon Watershed outlet for the precipitation events studied in IWA Phase I.

Based on the storage achieved by a portion of the $760,000 spent in the North Raccoon during IWA Phase II, hundreds of millions of dollars would be required to reduce the top-10 floods between 2002 and 2020 by 20%. However, that price tag seems less daunting when compared to the damages and costs associated with major floods of the past: over $5 billion and 17 lives lost in 1993, and over $12 billion, one life lost, and thousands of Iowans impacted in 2008.

f. Conclusion

A review of available data demonstrates the urgent need to mitigate flood hazards and poor water quality in the North Raccoon River Watershed. The Iowa Nutrient Reduction Strategy identifies a suite of best management practices to address poor water quality in Iowa streams, many of which have secondary flood mitigation benefits. Based on guidance provided by IWA Phase I and expressed interest from watershed stakeholders, 4 best management practices were constructed within the four North Raccoon River study sub-watersheds. The IWA project team used the GHOST hydrologic model to evaluate the flood mitigation performance of one constructed practice. Project evaluations demonstrated significant localized flood mitigation benefits. The magnitudes and downstream extents of local flood mitigation benefits are dependent upon the type of practice, its size relative to its upstream drainage, and the influences of downstream tributaries and receiving streams. Unfortunately, the constructed project does not have significant flood mitigation benefits at sub-watershed and North Racoon River Watershed scales. Realization of watershed-scale benefits will require substantial additional investments in best management practices throughout the North Raccoon River Watershed. The Iowa Watershed Approach, through establishment of Watershed Management Authorities, watershed hydrologic assessments, and construction and evaluation of best management practices, has created a framework from which management efforts can continue and watershed-scale benefits can ultimately be achieved.

Appendix A – References

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