

Iowa Watershed Approach Phase II: Middle Cedar Watershed Project Evaluation

by

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Sponsored by

The Iowa Watershed Approach

IOWA

**IIHR—Hydroscience
and Engineering**

IIHR Technical Report No. 536

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February 2023

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Acknowledgments

The Iowa Flood Center and IIHR—Hydroscience and Engineering would like to thank the following for participating in and contributing to the implementation of flood mitigation structures in the Middle Cedar Watershed:

Members of the Middle Cedar Watershed Management Authority
Project Coordinator of the Middle Cedar Watershed Management Authority
East Central Iowa Council of Governments (ECICOG)
WHKS, Inc
Landowners and stakeholders of the Middle Cedar Watershed
Benton County

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 Independence in the fall of 2016. 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 in Cedar Rapids, June 2008

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 wetland (MC-058 Jellison) constructed as part of the IWA in the Mud Creek HUC12, a sub-watershed of the Middle Cedar 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 Middle Cedar River Watershed to detail the practices constructed and evaluate their individual and cumulative benefits.

Ultimately, 88 BMPs were completed in the Middle Cedar River Watershed as part of the IWA:

- 28 ponds
- 25 WASCObS
- 12 grade stabilizations
- 10 wetlands
- 7 grass waterways
- 3 terraces
- 2 buffer strips
- 1 perennial cover

Figure 1-3 and Figure 1-4 show examples of these projects. The total design and construction costs of these projects was just over \$6.7 million. Chapter 6 provides details of all 88 practices, and Chapter 7 summarizes the results of the project evaluation.



Figure 1-4: Flood mitigation wetland (MC-007 Albert) constructed as part of the IWA in the Bear Creek HUC12, a sub-watershed of the Middle Cedar 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.

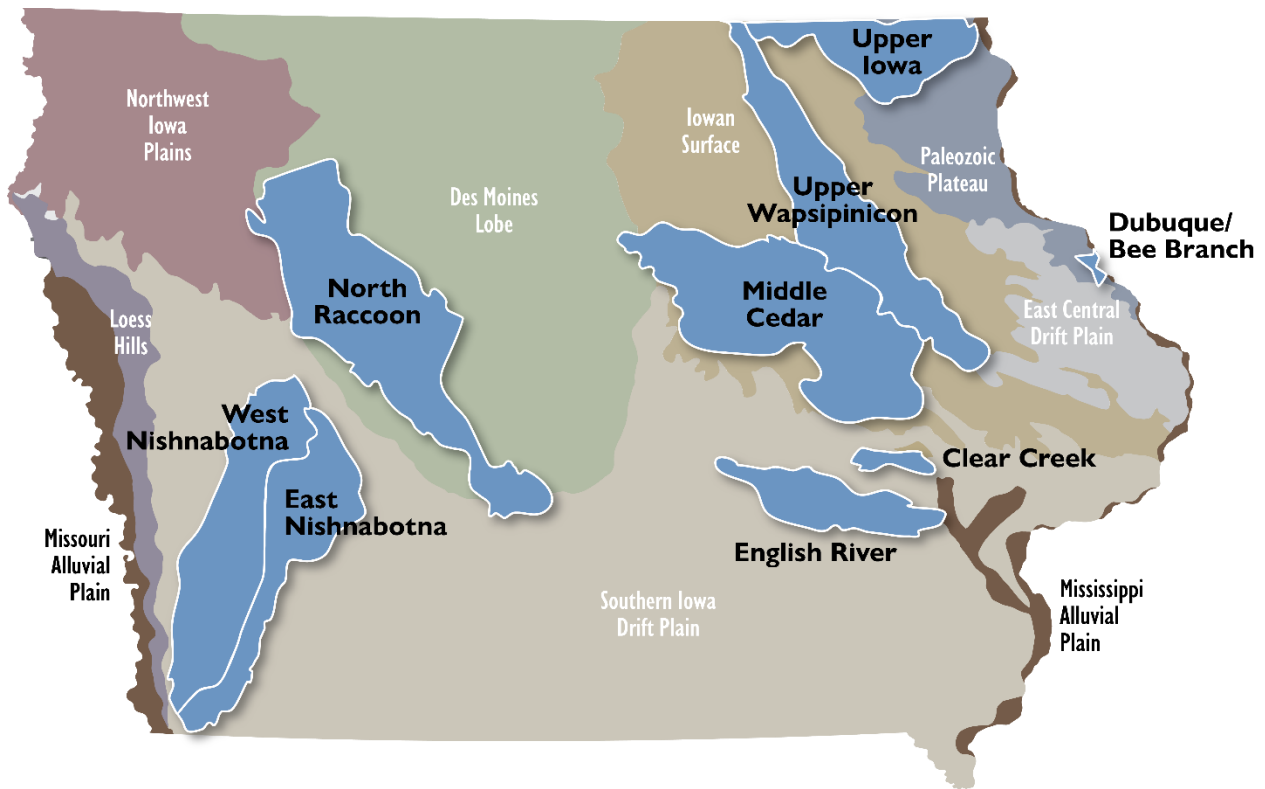


Figure 2-1: The IWA watersheds' positions within the landform regions of Iowa.

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).

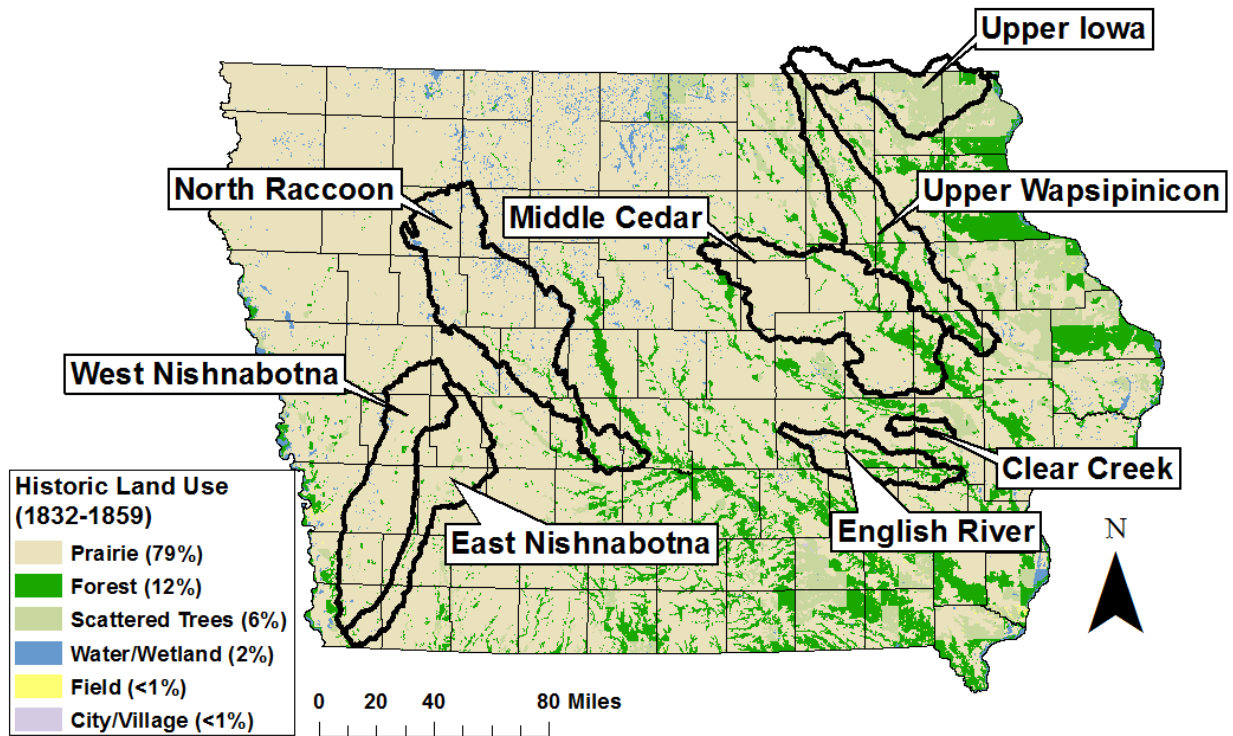


Figure 2-2: Historic vegetation of Iowa 1832–59. Raw data downloaded from the Iowa Geographic Map Server (<https://ortho.gis.iastate.edu/>).

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.

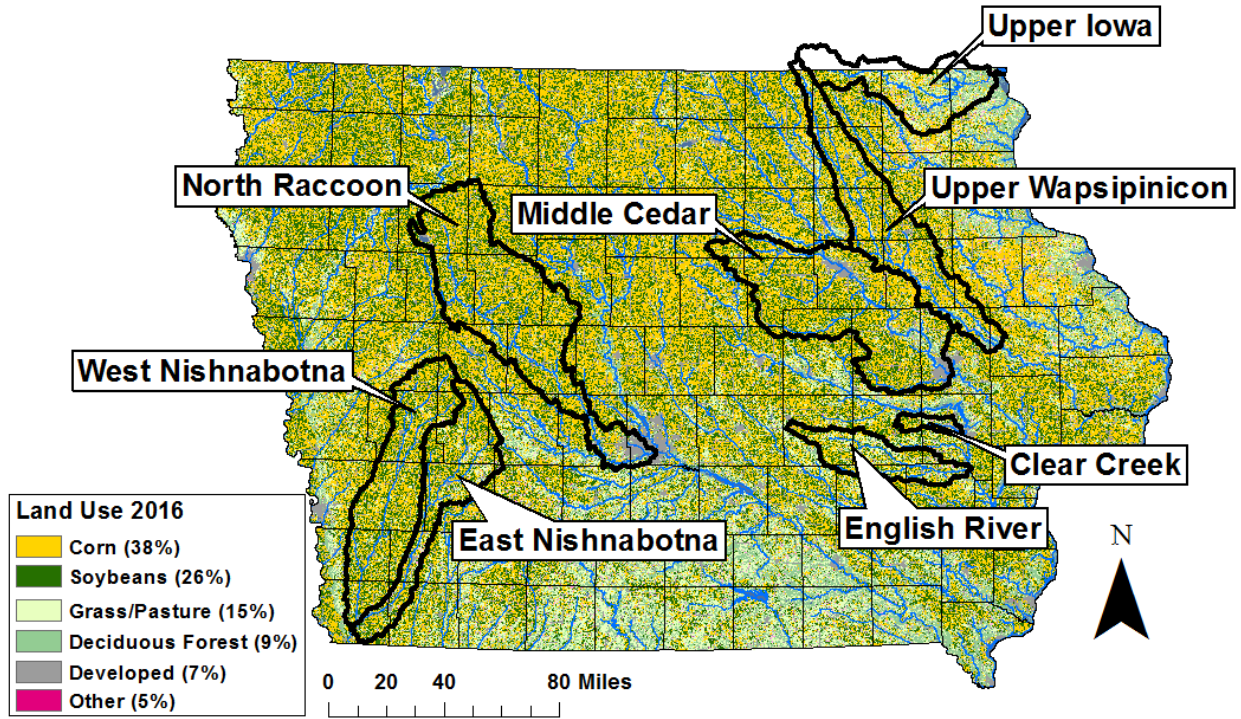


Figure 2-3: Land use composition in the state of Iowa 2016. Cropland Data Layer.

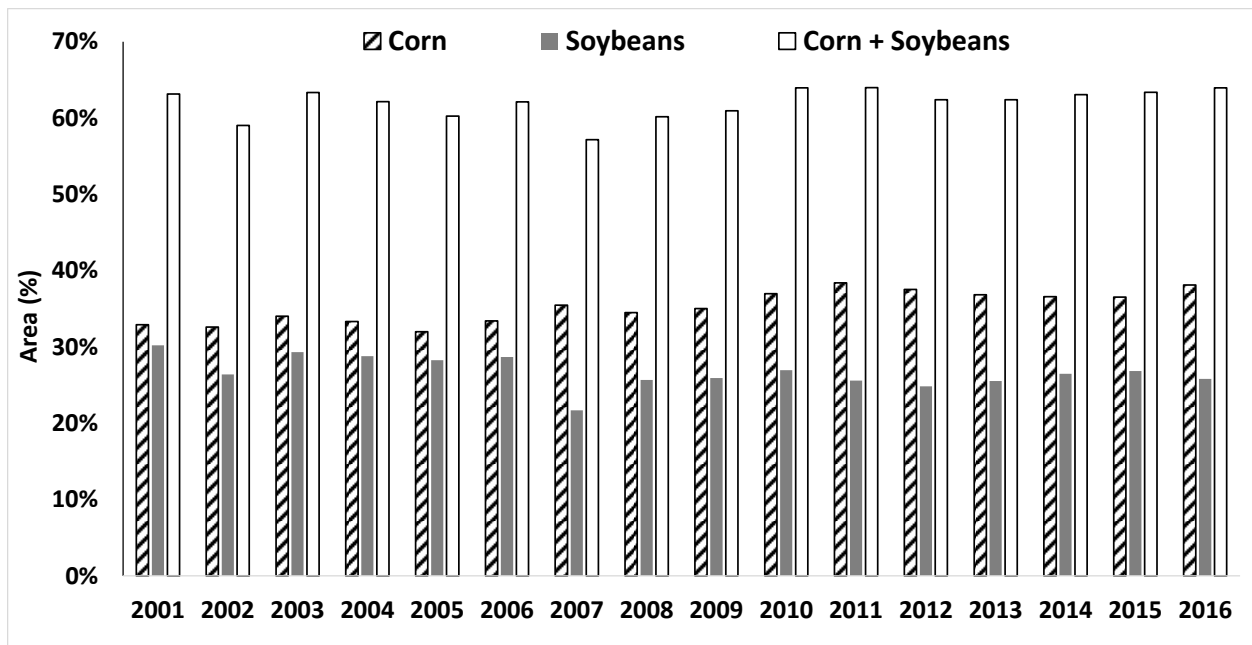


Figure 2-4: Percent of Iowa's total area planted with row crops between 2001 and 2016. Cropland Data Layer.

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.

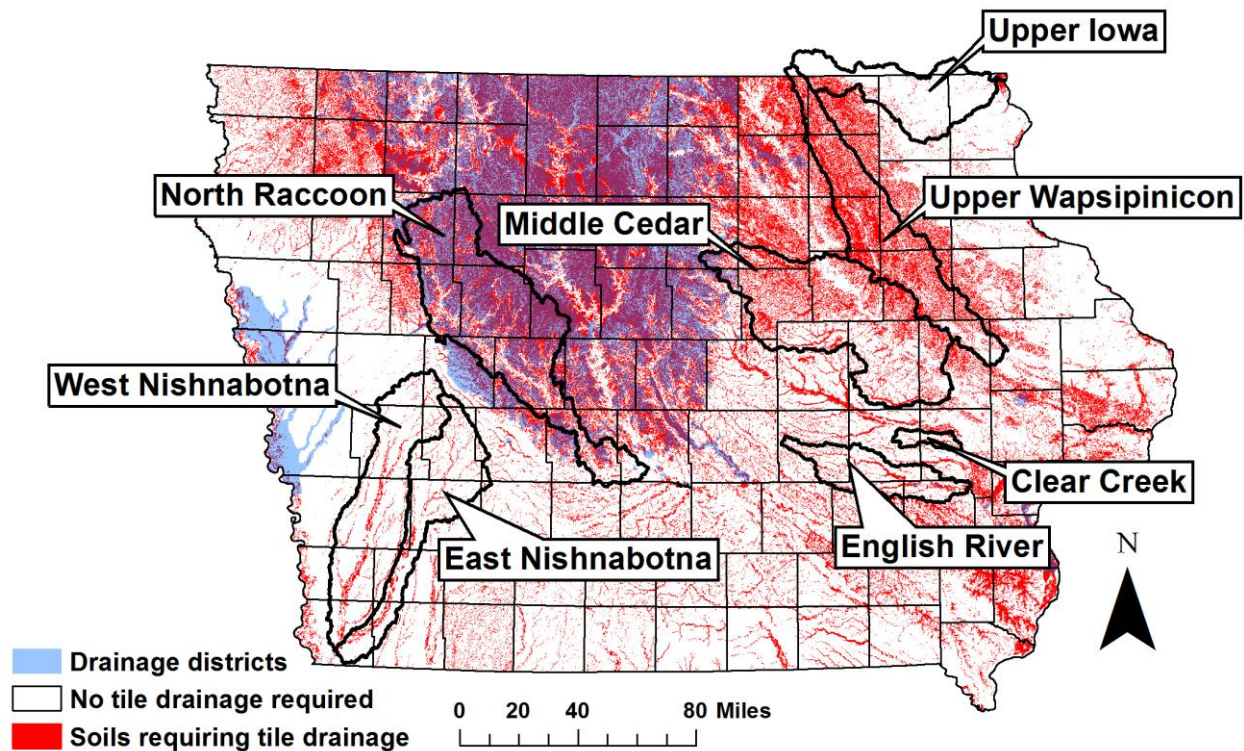


Figure 2-5: Soils requiring tile drainage for full productivity and drainage districts. Raw data source: DNR's NRGIS Library.

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 2-6a. The average

annual precipitation reaches 40 inches in the southeast corner and decreases to 26 inches in the northwest corner.

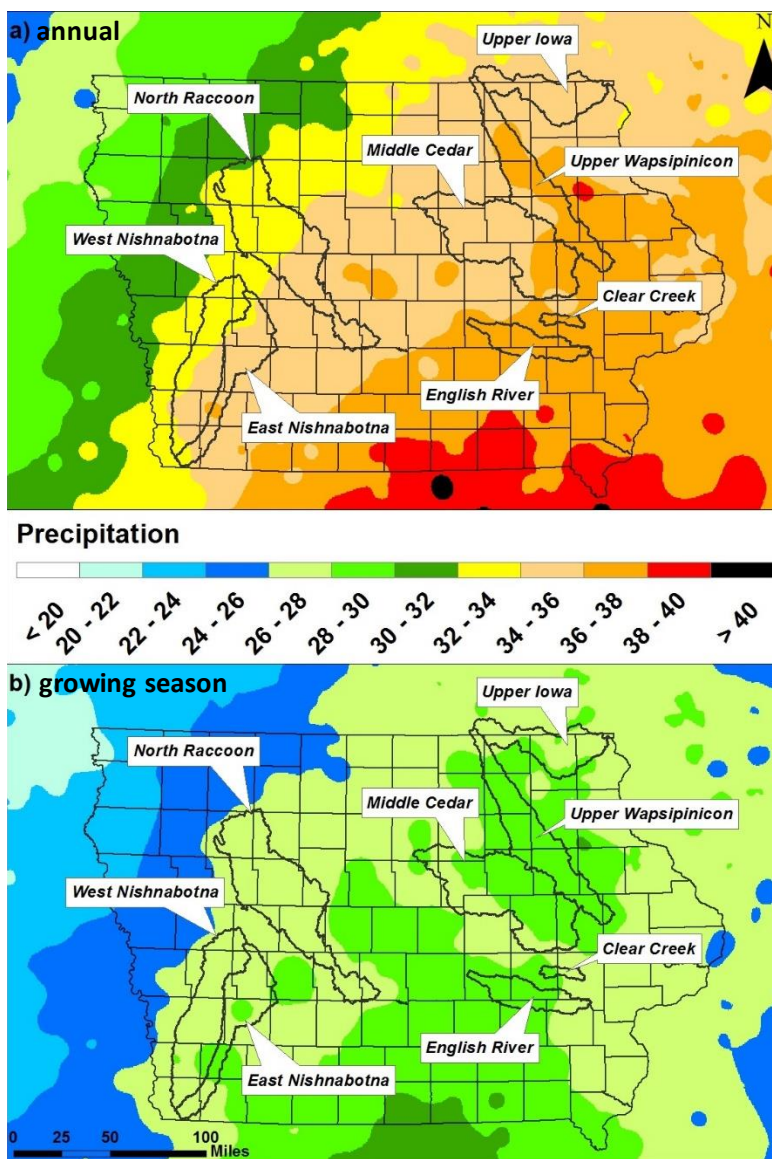


Figure 2-6: Average precipitation (inches): (a) annual; and (b) growing season (April–October). Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: <http://www.prism.oregonstate.edu/>).

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.

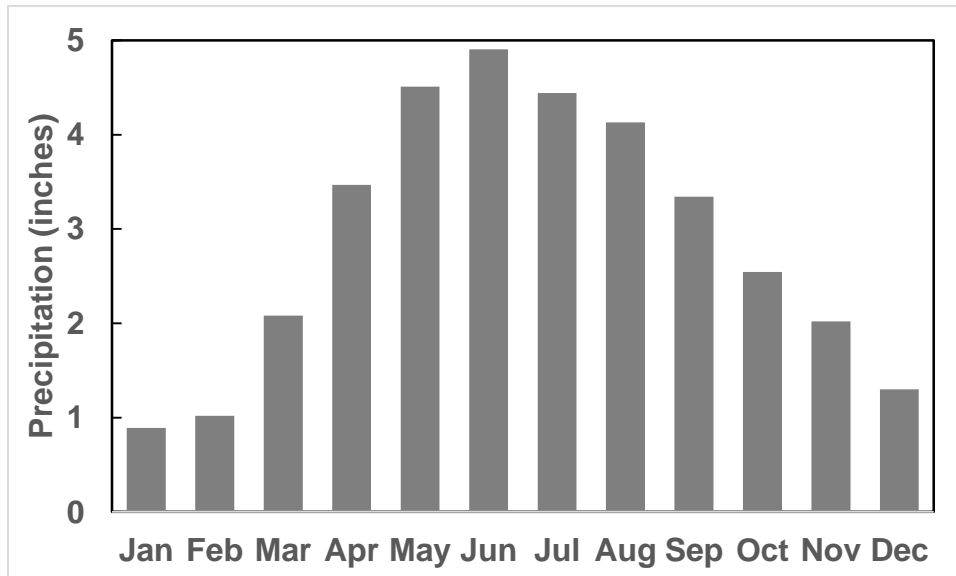


Figure 2-7: Statewide average monthly precipitation. Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: <http://www.prism.oregonstate.edu/>).

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 does not 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.

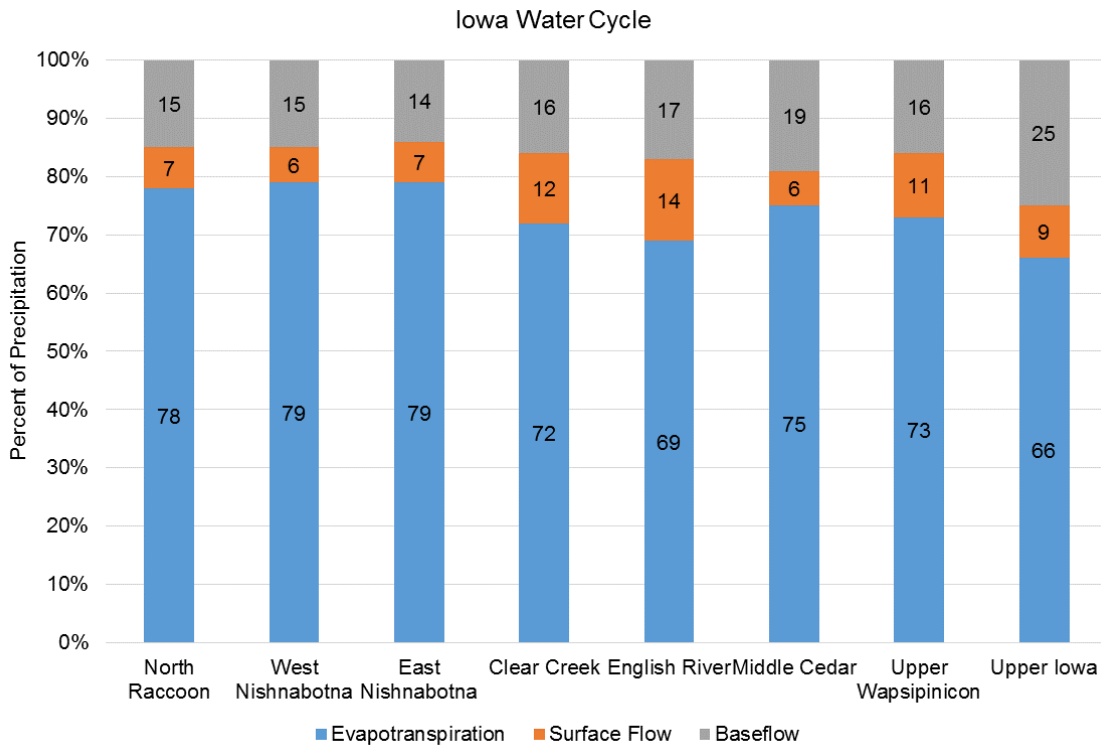


Figure 2-8: Iowa water cycle for the IWA watersheds. This shows the partitioning of average precipitation into evapotranspiration, surface flow, and baseflow components.

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.

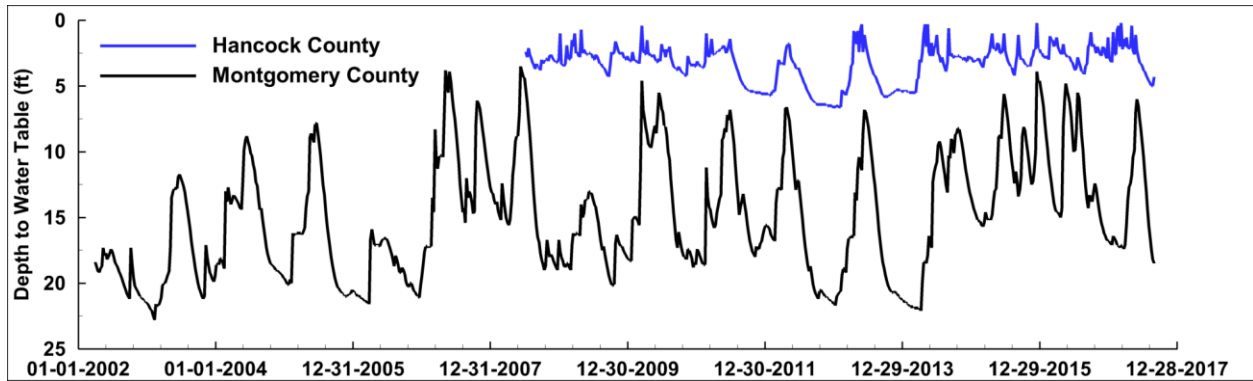


Figure 2-9: Shallow groundwater data (USGS wells).

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.

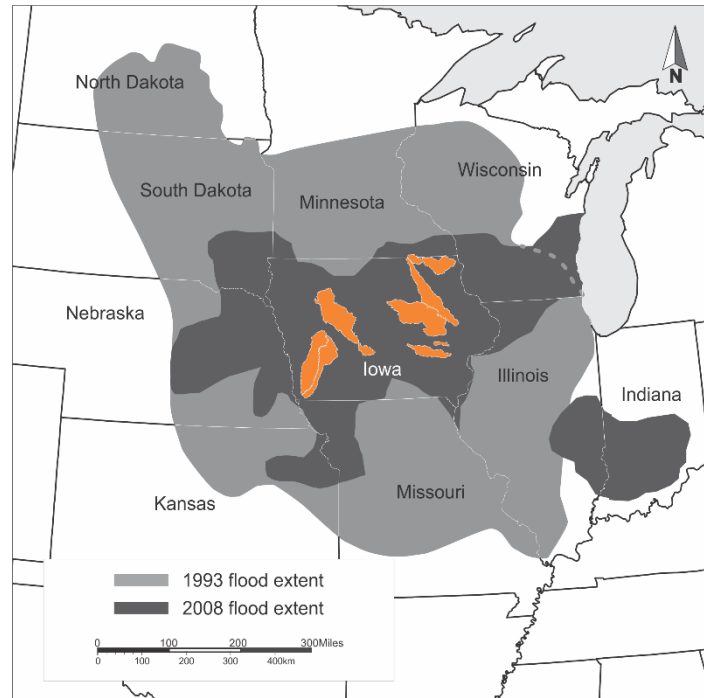


Figure 2-10: The extent of the flooding during the 1993 and 2008 floods (Bradley, 2010).

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 (see 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 <i>FLOODING</i>	223
SEVERE STORMS & <i>FLOODING</i>	195
SEVERE STORMS, TORNADOES AND <i>FLOODING</i>	106
<i>HURRICANE</i> KATRINA EVACUATION	99
SEVERE STORMS AND <i>FLOODING</i>	98
SEVERE STORMS, <i>FLOODING</i> , AND TORNADOES	97
SEVERE STORMS, TORNADOES, STRAIGHT-LINE WINDS, AND <i>FLOODING</i>	79
SEVERE WINTER STORM	62
SEVERE WINTER STORMS	48
ICE STORM	44
SEVERE STORMS, STRAIGHT-LINE WINDS, AND <i>FLOODING</i>	34
SNOW	30
SEVERE WINTER STORMS AND SNOWSTORM	27
SEVERE STORMS, AND <i>FLOODING</i>	15
SEVERE SNOWSTORMS	13
<i>FLOODING</i>	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).

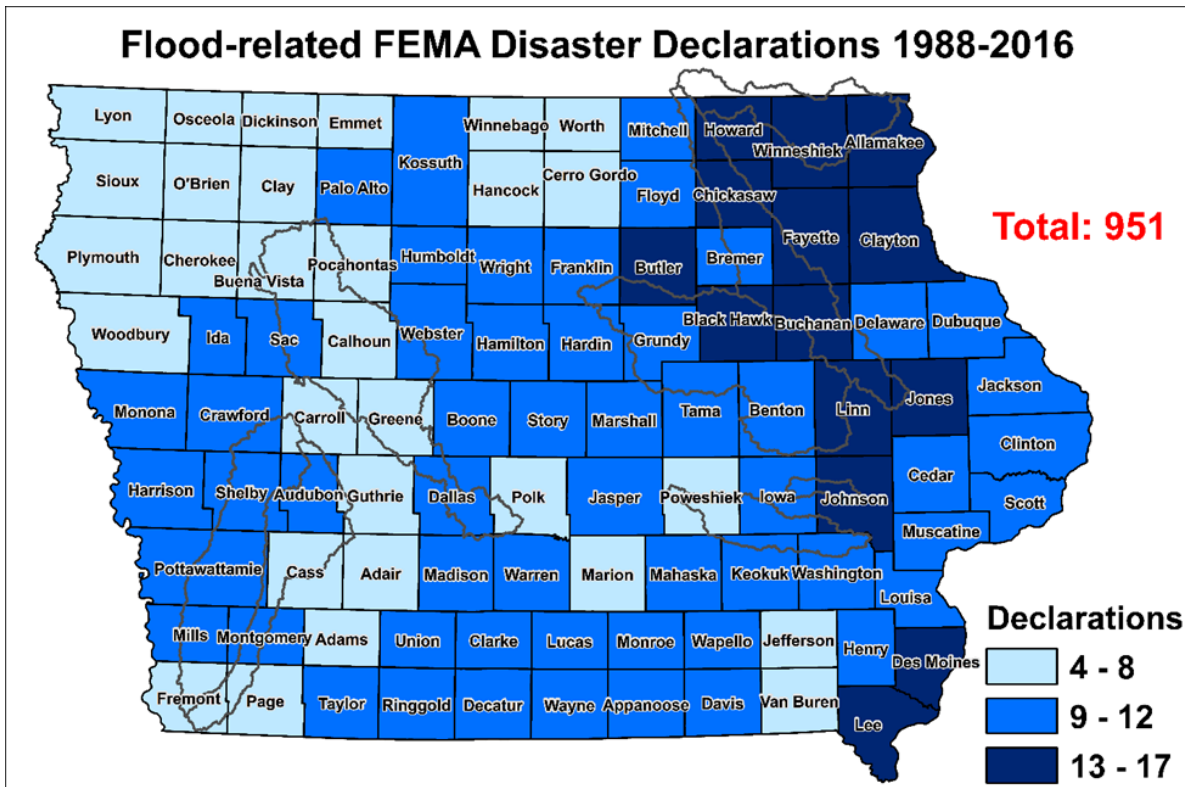


Figure 2-11: Number of flood-related federally declared disasters in Iowa counties (1988–2016).
Data source: <https://www.fema.gov/>.

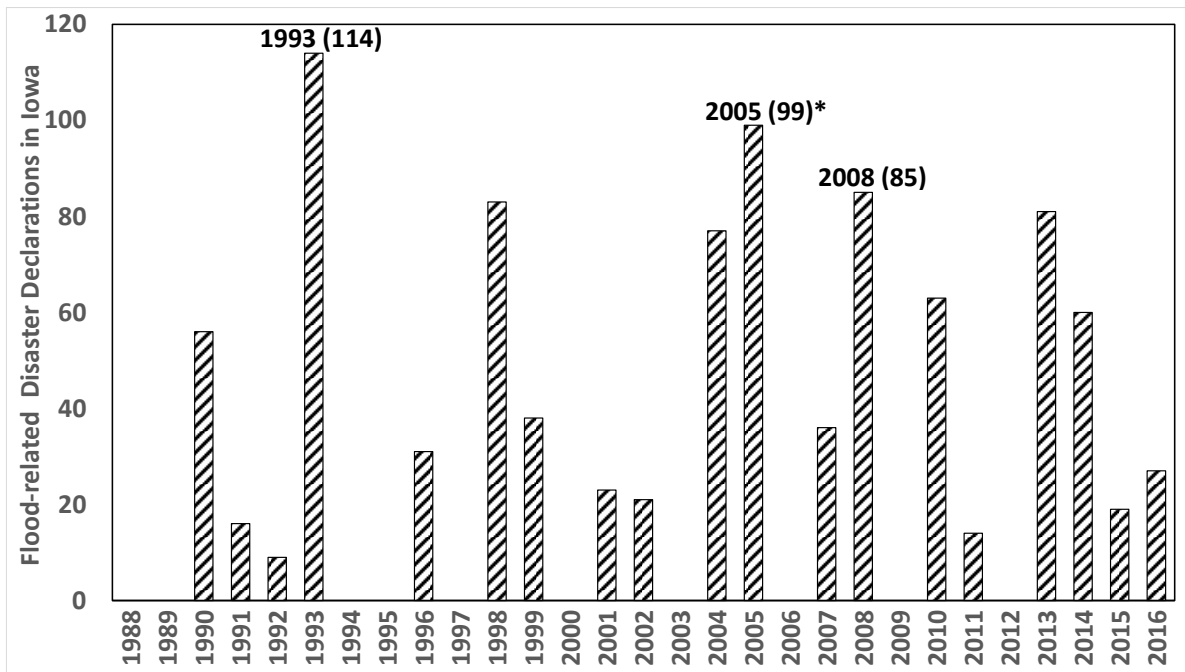


Figure 2-12: The number of flood-related federally declared disasters in Iowa (1988–2016). Data source: <https://www.fema.gov/>.

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.

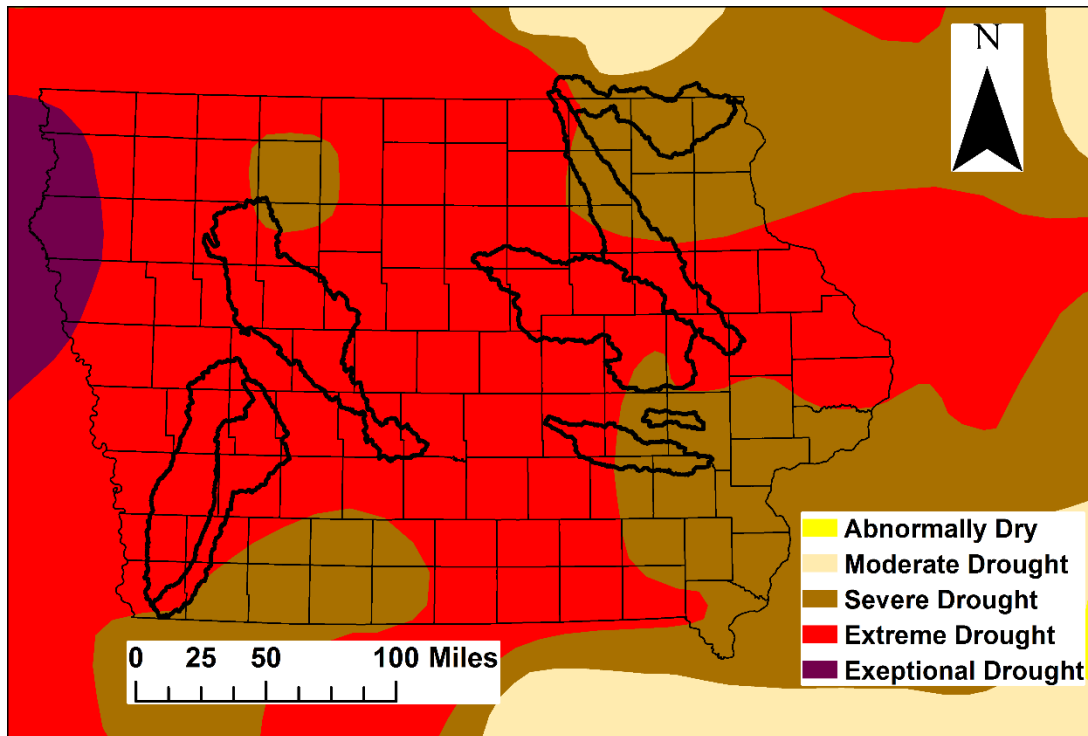


Figure 2-13. Drought conditions, October 09, 2012 (Source: <http://droughtmonitor.unl.edu/>).

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 Program (CREP); Wetland Reserve Program (WRP)	Reduction of runoff and flooding; increase of upland water storage	Castle (2010); Schilling (2000); 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. government 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, 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.”

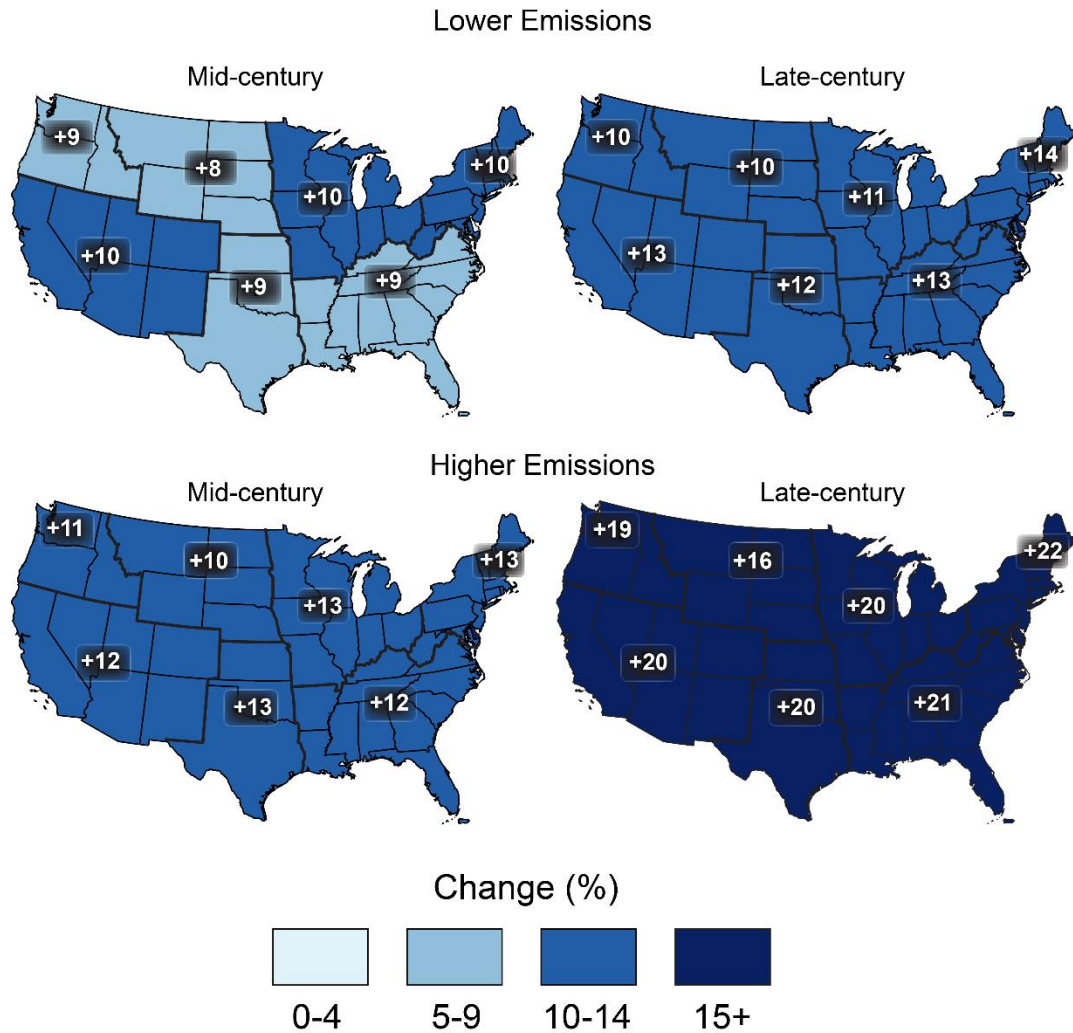


Figure 2-15: Projected change in heavy precipitation. Twenty-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps). Results are shown for a lower emissions scenario (top maps; RCP4.5) and for a higher emissions scenario (bottom maps, RCP8.5). Figure 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.

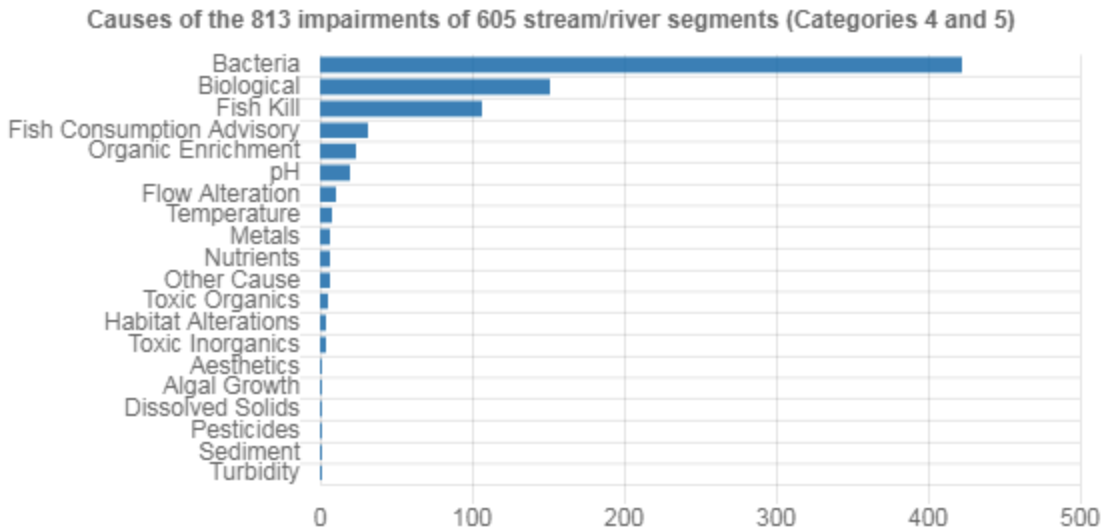


Figure 2-16: Causes of impairments in Iowa’s impaired waters. (Iowa Department of Natural Resources, 2018).

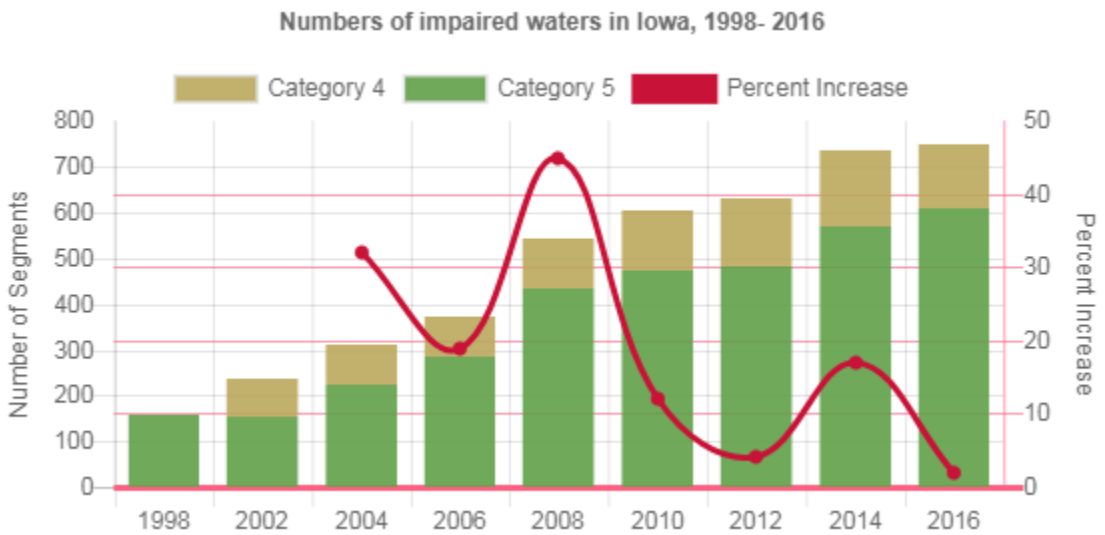


Figure 2-17: Numbers of impaired Iowa waters, 1998–2016. (Iowa Department of Natural Resources, 2018).

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 Shellsburg.

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 Cedar Rapids.

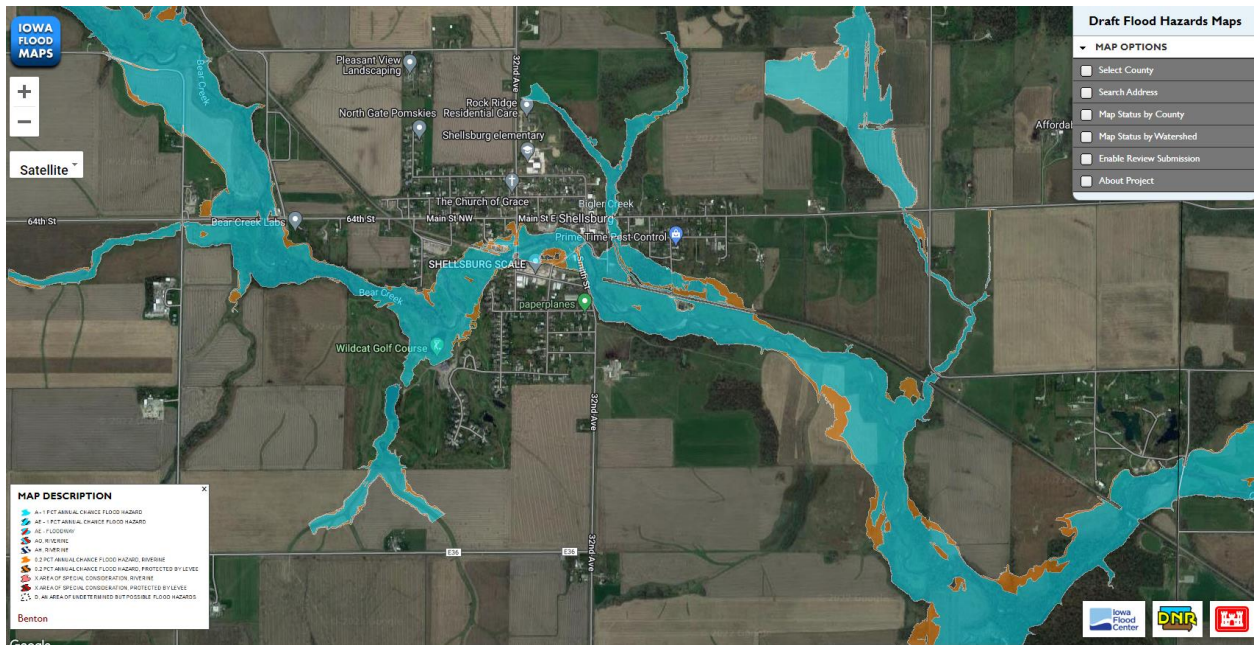


Figure 2-18. Statewide floodplain map data showing different levels of annual flood risk.

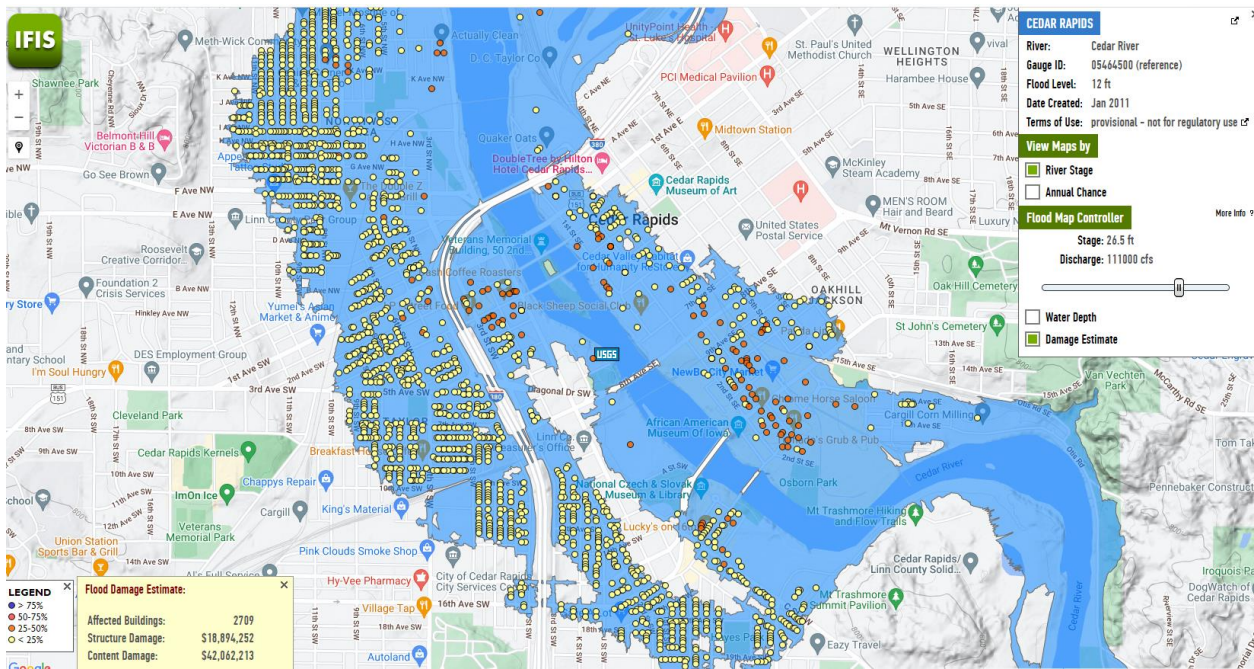


Figure 2-19. Flood inundation map library for the Cedar River in the city of Cedar Rapids.

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.

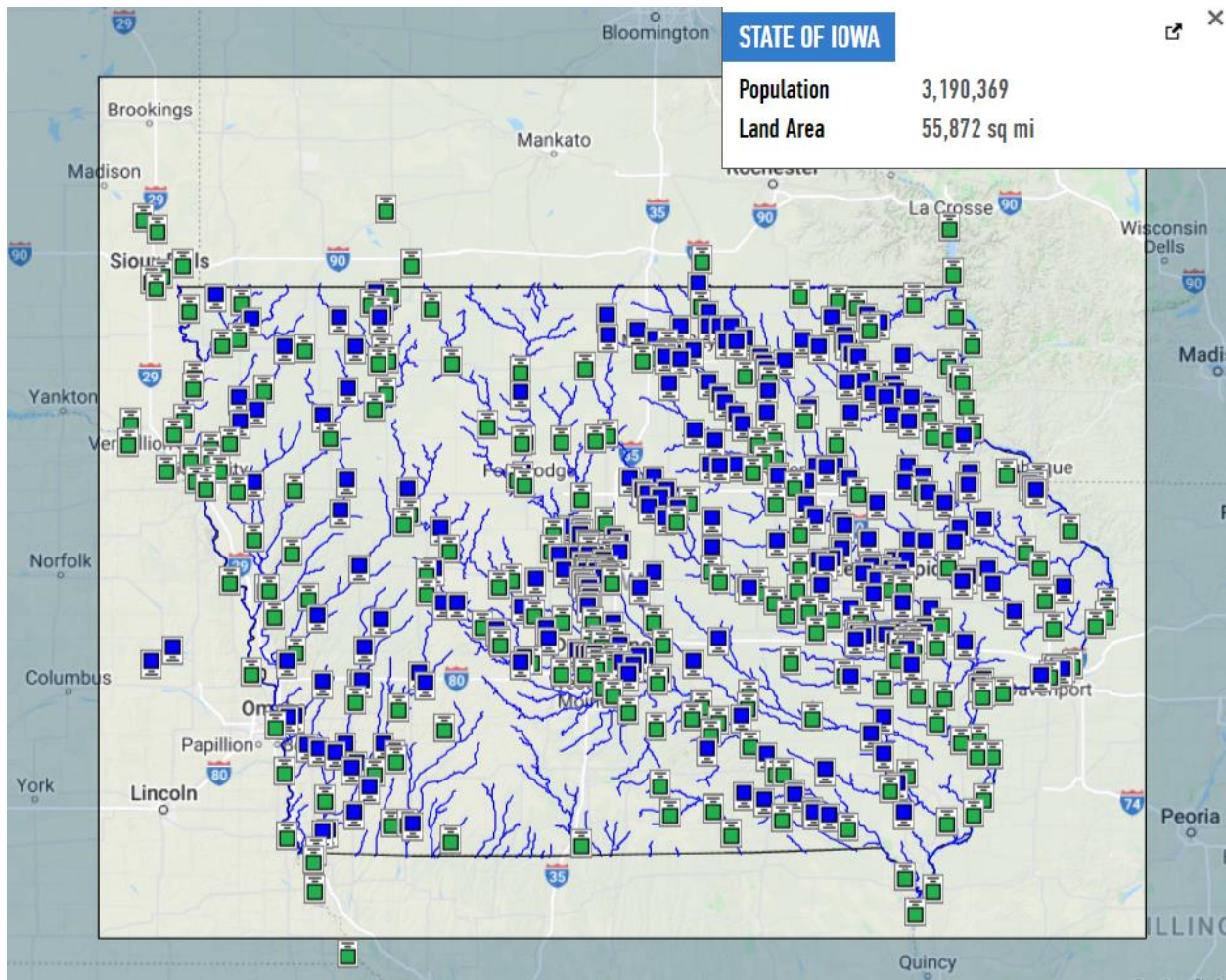


Figure 2-20. USGS (green) and Iowa Flood Center (blue) stream-stage monitoring locations displayed in the Iowa Flood Information System (IFIS).

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 is a screenshot of IWQIS displaying the WQ network (2022).

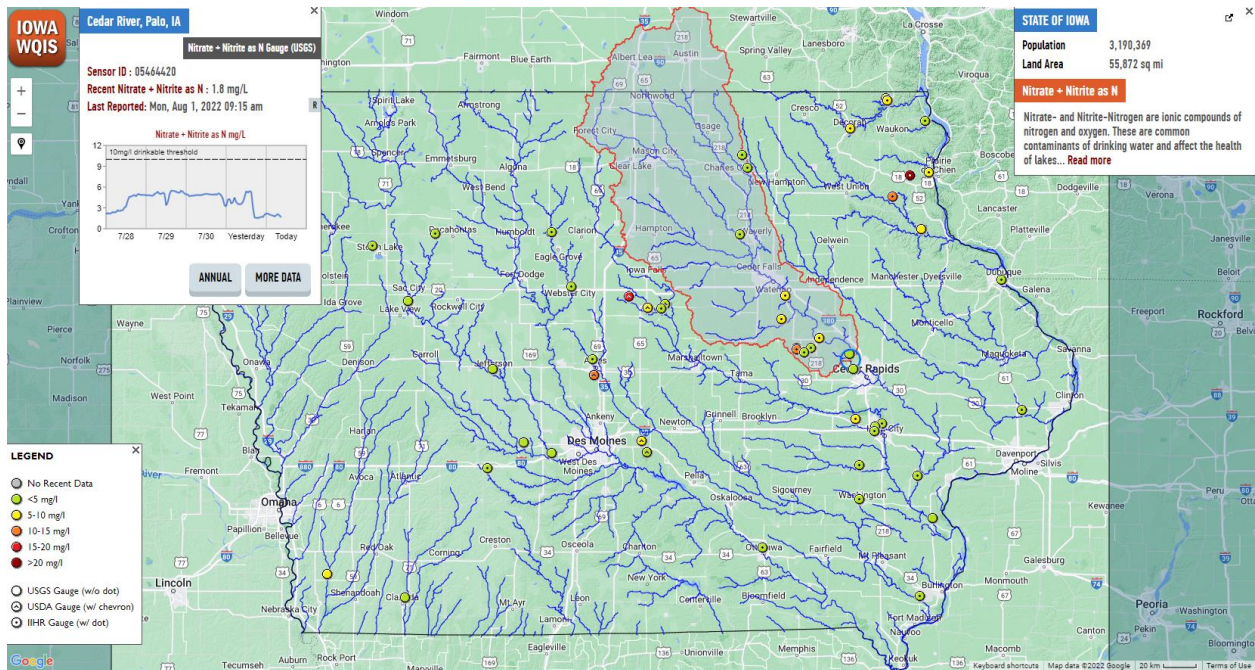


Figure 2-21. IIHR—Hydroscience and Engineering and USGS surface water-quality monitoring locations as displayed on the Iowa Water-Quality Information System (IWQIS).

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 Middle Cedar River Watershed.

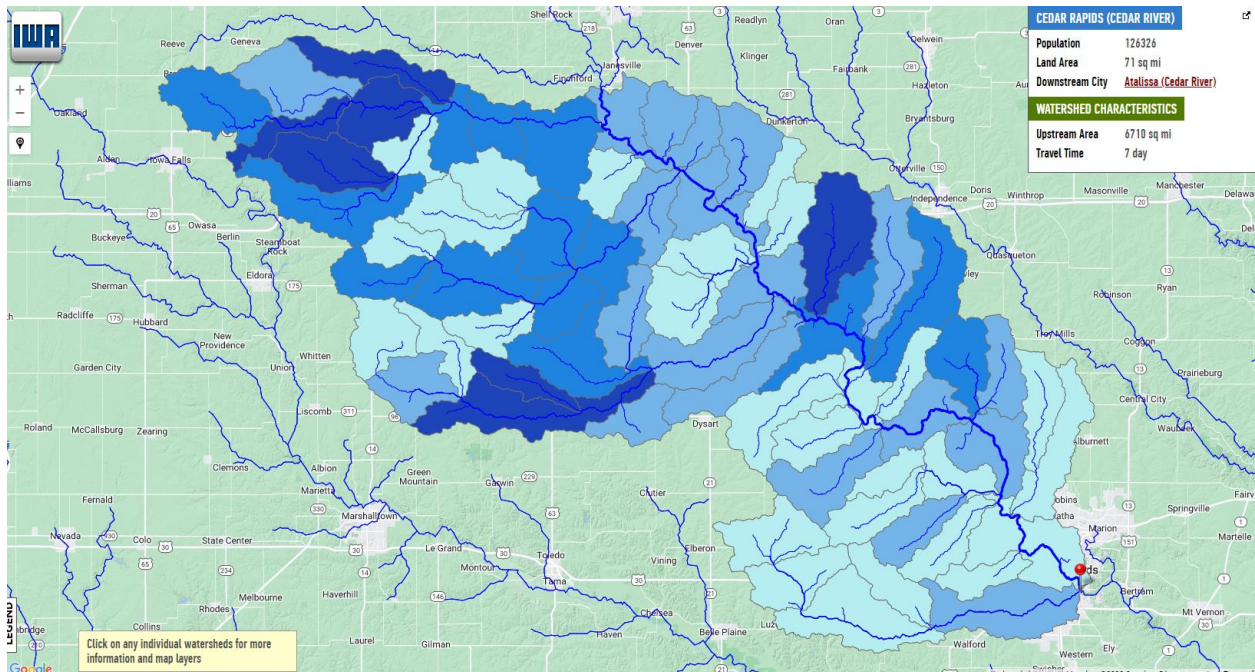


Figure 2-22. Example IWAIS interface view showing the number of existing water and sediment control basins within each HUC12 in the Middle Cedar Watershed.

3. Middle Cedar Watershed Description

This chapter provides an overview of the Upper Wapsipinicon Watershed, including hydrology, geology, topography, land use, and hydrologic/meteorologic instrumentation, as well as a summary of previous floods of record.

a. Hydrology

The Middle Cedar River Watershed as defined by the boundary of eight-digit Hydrologic Unit Code (HUC8) 07080205 and is located in East-Central Iowa and encompasses approximately 2,400 square miles (mi²). The watershed is part of the Cedar River Basin that expands from Minnesota to Southeast Iowa, where it joins the Iowa River at Columbus Junction. The total drainage area of the Cedar River basin at Cedar Rapids is approximately 6,710 mi². The Middle Cedar River watershed boundary falls within several counties, however, the majority of the watershed area lies within Grundy, Black Hawk, Benton and Linn counties.

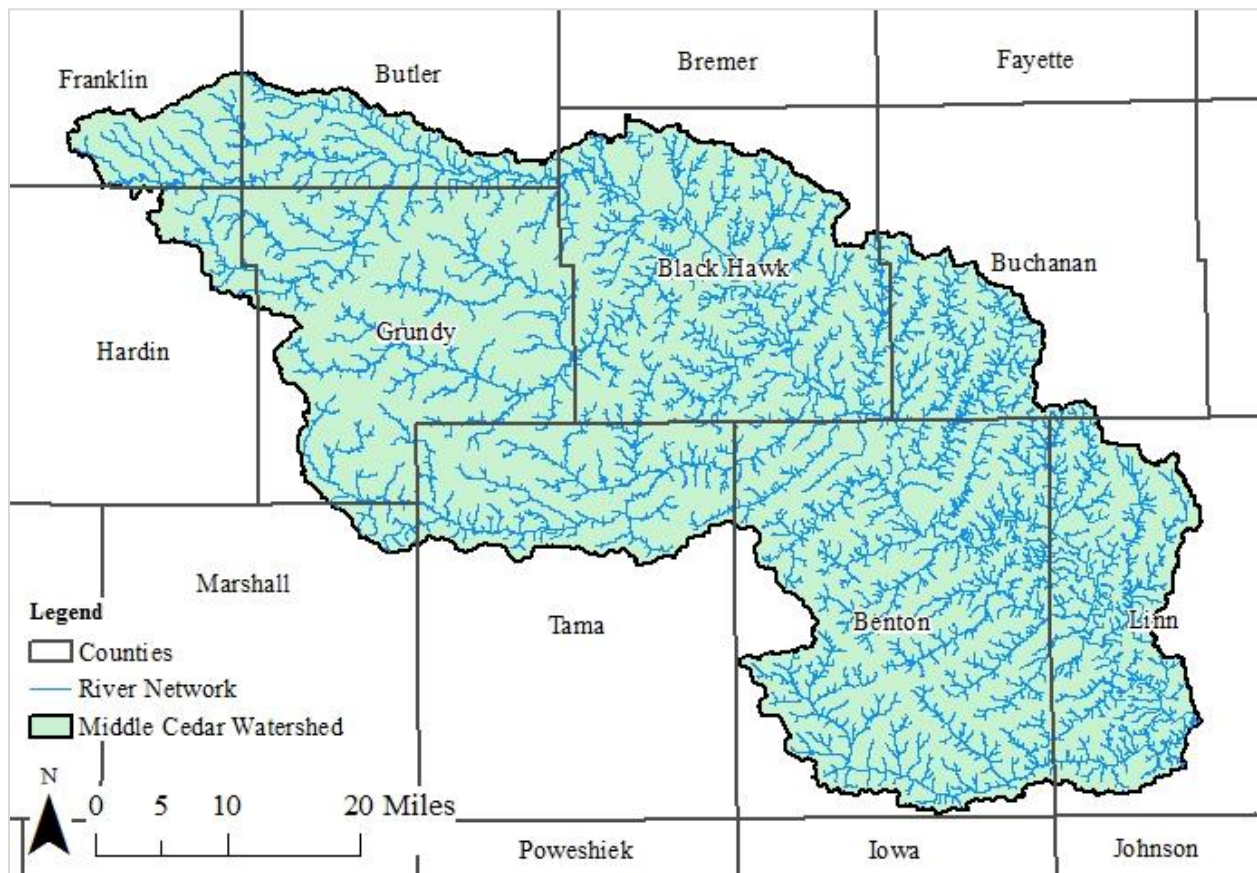


Figure 3-1: The Middle Cedar River Watershed (HUC8 07080205).

For the region of East-Central Iowa, the annual precipitation ranges from roughly 19 to 54 inches (Figure 3-2 and Figure 3-3). About 70% 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. The region has experienced increased variability in annual precipitation since 1975, along with a general increase in the

amount of spring rainfall. Analyses of streamflow records at the USGS stations Cedar River at Cedar Rapids and Wolf Creek near Dysart show that on an annual basis approximately 30% of the precipitation is transformed into streamflow (Figure 3-4) and 60% of the streamflow is derived from groundwater (Figure 3-5).

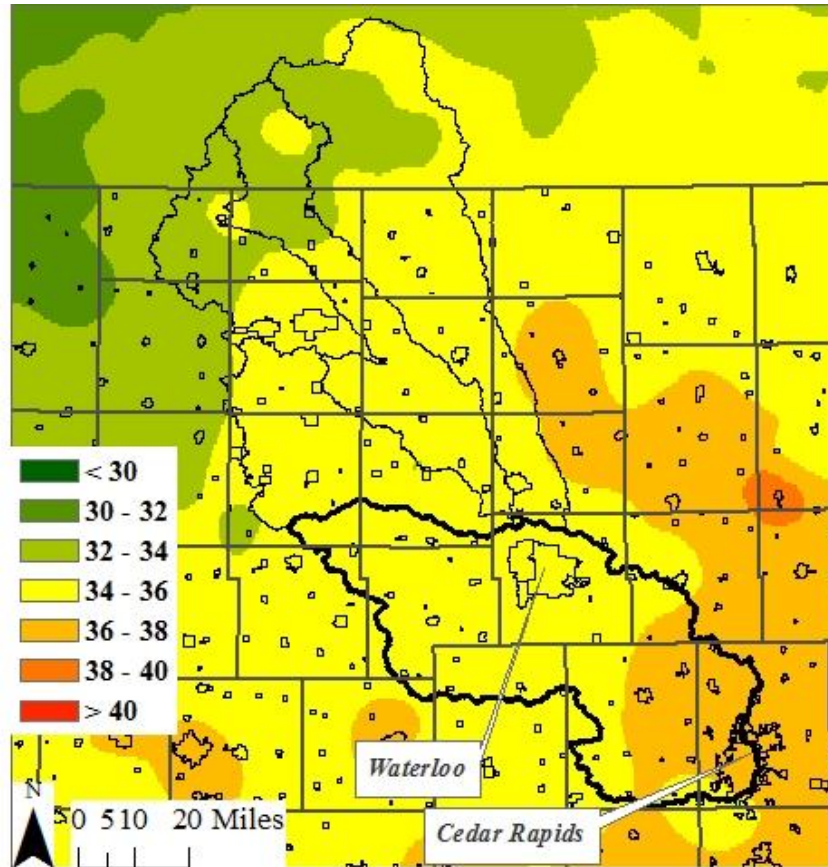


Figure 3-2: Average annual precipitation (inches). Estimates are based on the 30-year annual average (1981–2010).

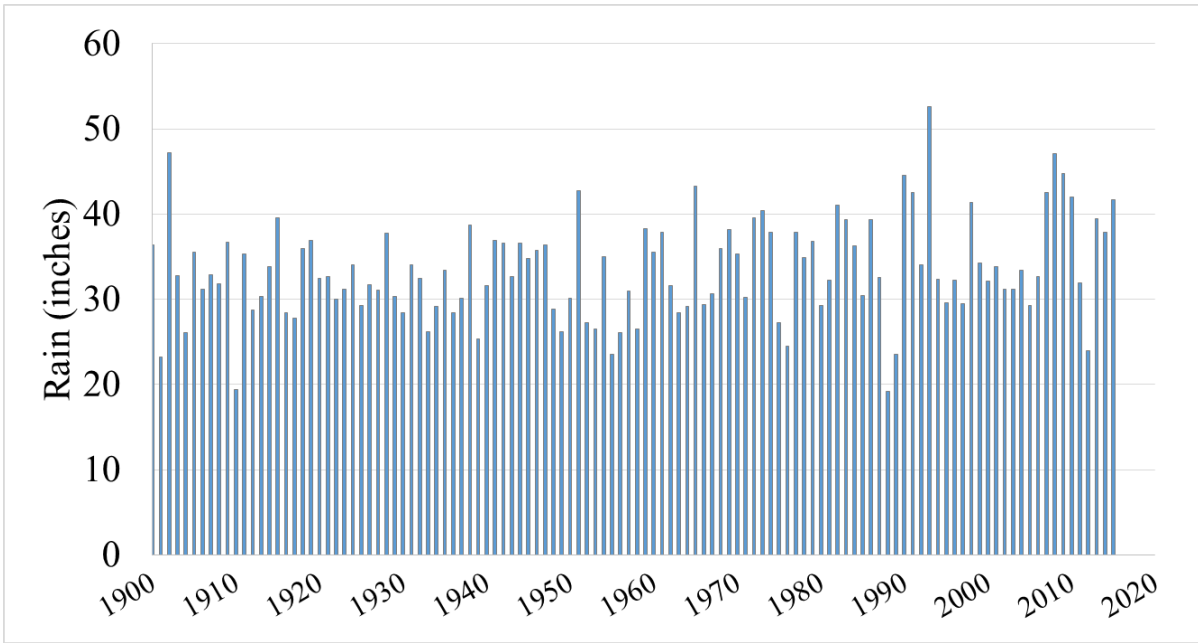


Figure 3-3: Bar graph of annual precipitation.

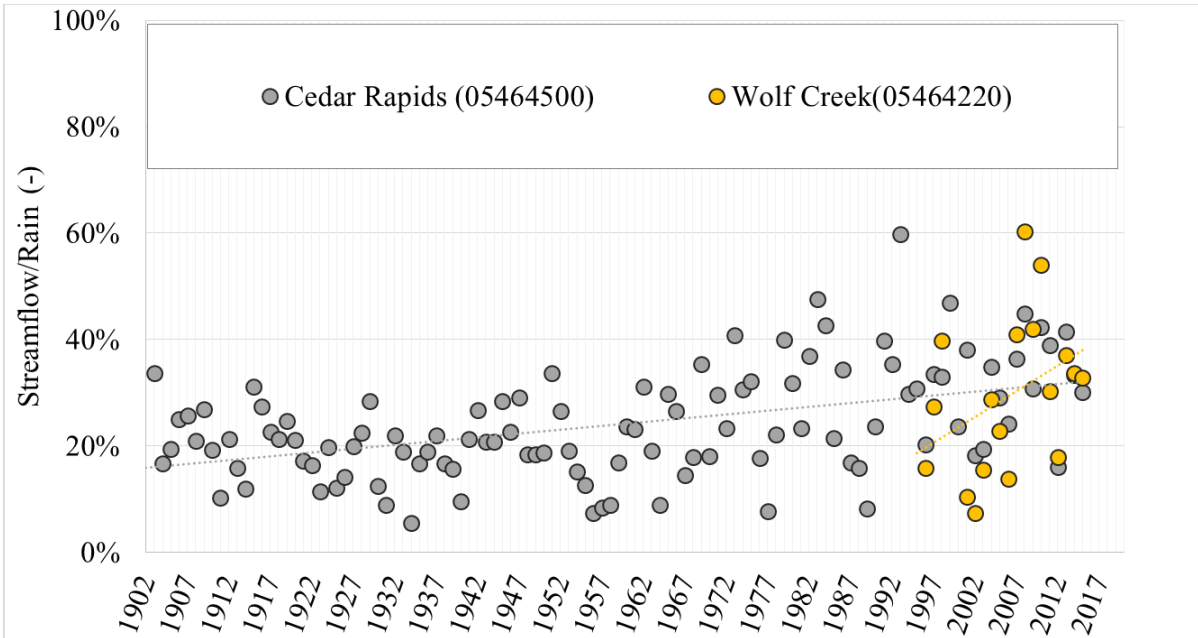


Figure 3-4: Annual ratio of streamflow to precipitation.

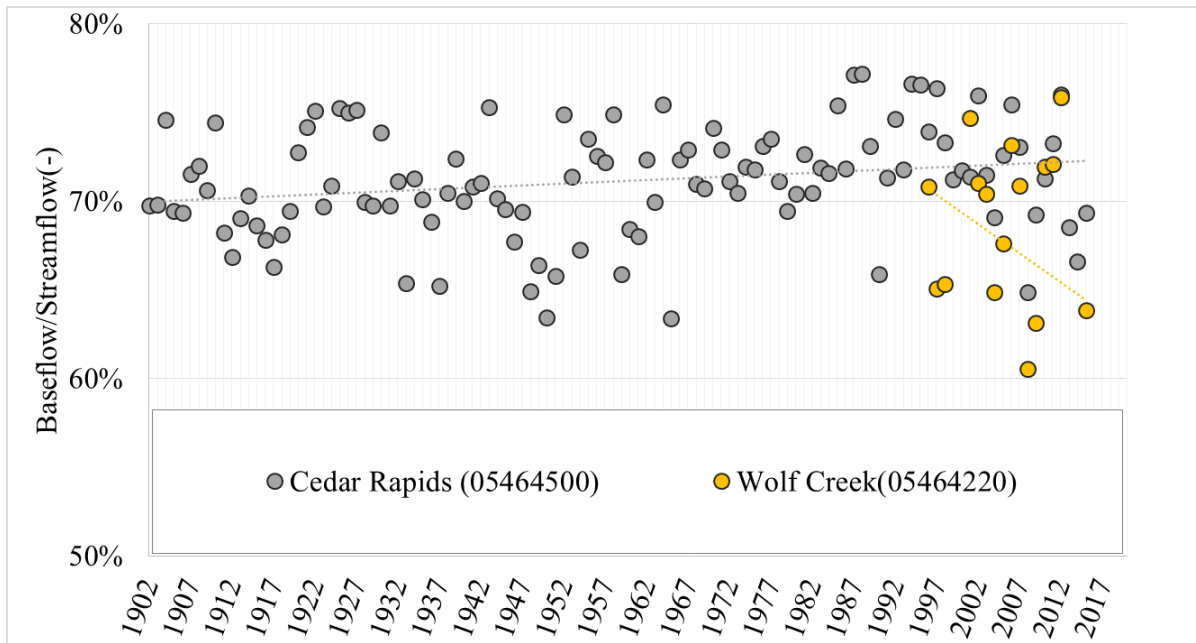


Figure 3-5: Annual ratio of baseflow to streamflow.

b. Geology and Soils

The Middle Cedar River Watershed is located almost entirely within the Iowan Surface landform region (Figure 2-1). There is a small area of the Des Moines Lobe landform region on the upstream end and another small area of Southern Iowa Drift Plain on the downstream edge. The characteristics of each landform region have an influence on the rainfall-runoff potential and hydrologic properties of the watershed.

The Iowan Surface encompasses much of northeast Iowa and formed as a result of this region being subjected to a period of intense cold between 21,000 to 16,500 years ago during the last glacial advance into Iowa. The close proximity to the Des Moines Lobe ice margin resulted in tundra and permafrost conditions, and as a result wind and water action significantly eroded the landscape. Characteristic features include gently rolling topography, common glacial ‘erratics’ (rocks and boulders not native to Iowa that have been transported here by glaciers), and loess-mantled paha (northwest to southeast trending uneroded upland remnants of the former landscape). Glacial materials at the surface 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. A limited number of sinkholes have been identified in the watershed.

Soils are classified into four Hydrologic Soil Groups (HSG) by the Natural Resources Conservation Service (NRCS) based on the soil’s runoff potential. The four HSG’s 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. In the case of 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 infiltration from occurring. 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. Complete descriptions of the Hydrologic Soil Groups can be found in the USDA-NRCS National Engineering Handbook, Part 630- Hydrology, Chapter 7.

The soil distribution of the Middle Cedar River watershed per digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WWS) is shown in Figure 3-6. Viewing the soil distribution at this map scale is difficult, but the map does illustrate the relative consistency of the HSG on the Iowan Surface landform region. Table 3-1 shows the approximate percentages by area of each HSG for the Iowan Surface in the Middle Cedar River Watershed. The Middle Cedar River Watershed consists primarily of HSG B type soils (65.6%), which have a moderate runoff potential when saturated. Smaller components of type B/D (27.1%) and type A (3.7%) soils are present. The remaining soil types comprise one percent or less of the total.

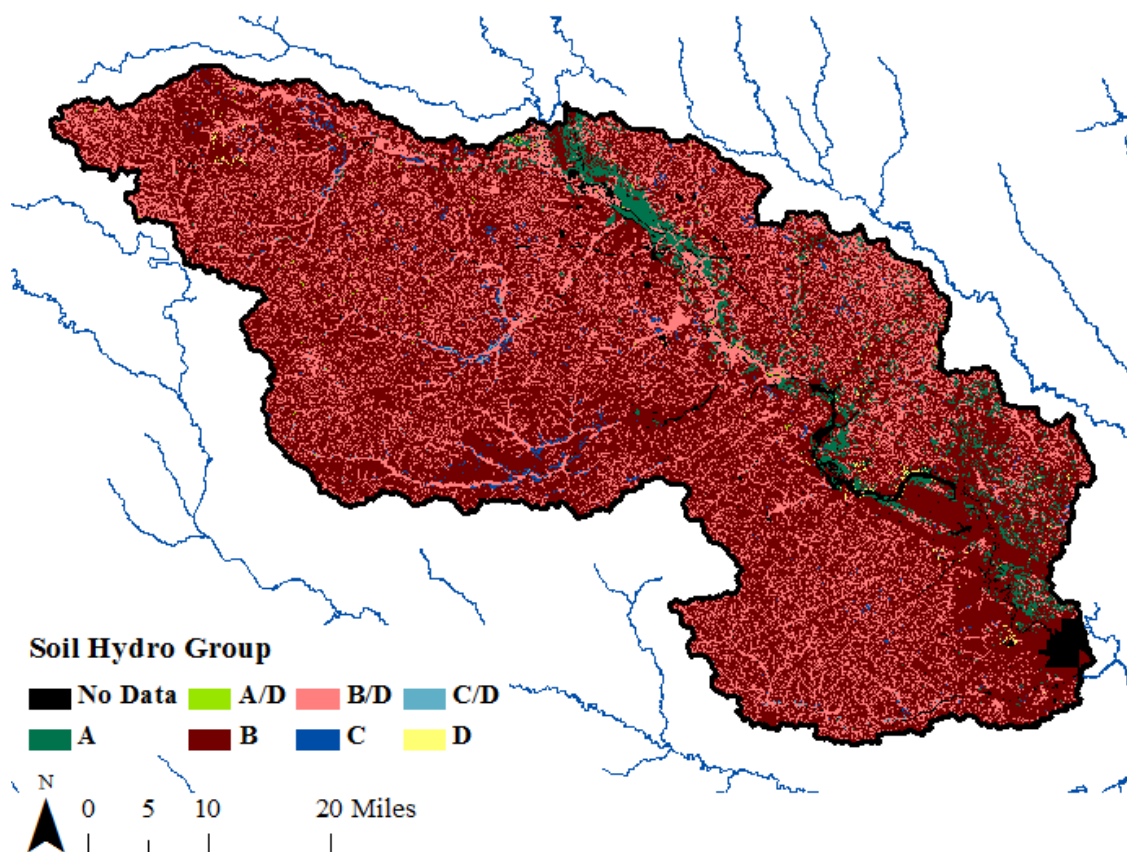


Figure 3-6. Distribution of Hydrologic Soil Groups in the Middle Cedar Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with Type A representing the lowest runoff potential and Type D representing the highest runoff potential.

Table 3-1. Approximate Hydrologic Soil Group Percentages by Area for the Middle Cedar Watershed.

Hydrologic Soil Group	Iowan Surface Approximate %
A	3.7
A/D	0.1
B	65.64
B/D	27.1
C	0.9
C/D	0.1
D	0.2

c. Topography

Figure 3-7 shows the topography of the Middle Cedar Watershed. Elevations range from approximately 1300 feet above sea level in the upstream and western part of the watershed to 550 feet above sea level in the downstream portion of the watershed in Cedar Rapids.

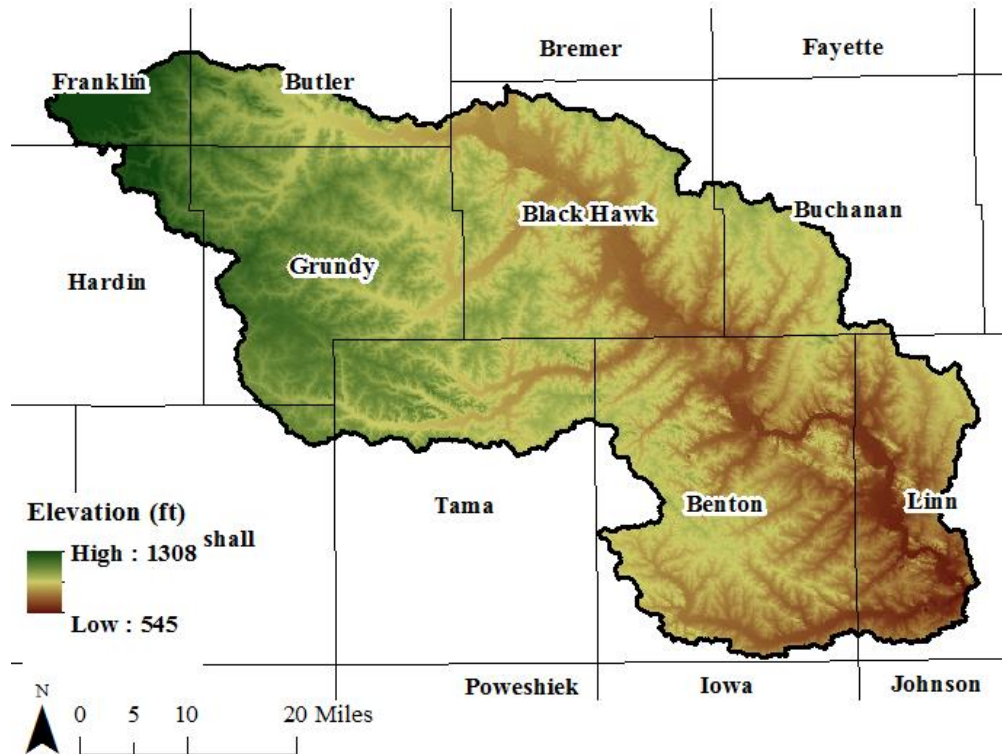


Figure 3-7. Topography of the Middle Cedar Watershed.

d. Land Use

Land use in the Middle Cedar Watershed is predominantly agricultural, dominated by cultivated crops (corn/soybeans) at approximately 74% of the acreage, followed by developed land at approximately 11%. The remaining acreage in the watershed is about 9% grassland and pasture, 3% forest, 1% crops other than corn/soy and 3% open water and/or wetlands, per the 2017 USDA/NASS Cropland Data Layer.

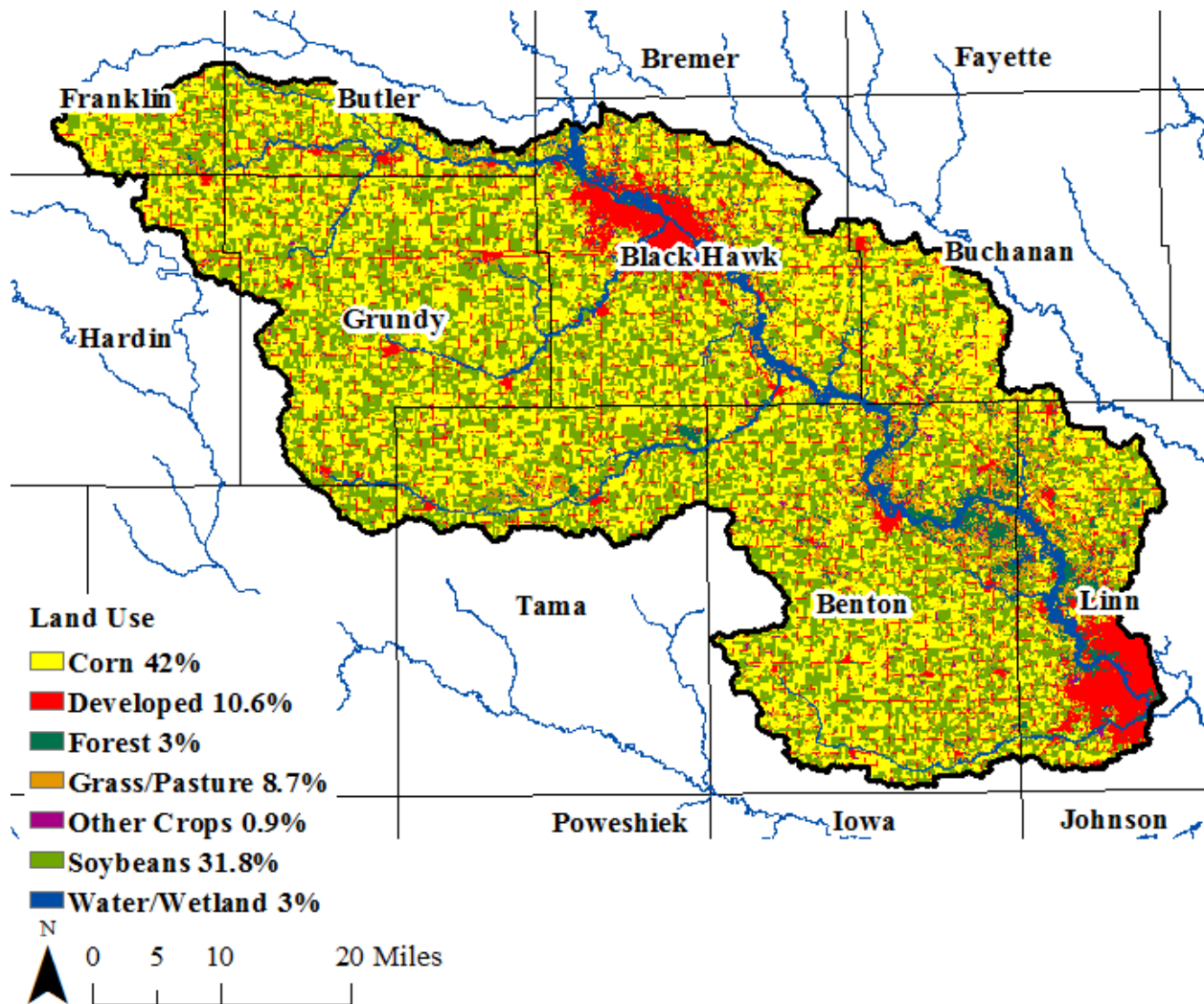


Figure 3-8. Land use composition in the Middle Cedar Watershed, per the 2017 USDA Cropland Data Layer.

e. BMP Mapping

Identifying existing conservation practices within a watershed serves as a benchmark for future implementation and provide information where more practices are needed. The Iowa Best Management Practices Mapping project (IBMP) identified existing conservation practices throughout the state of Iowa using data from the 2007 to 2010 timeframe. For the Middle Cedar watershed the total number of existing practices are 9921 acres of agricultural fields with contour buffer strips, 1809 acres of agricultural fields with strip cropping, 232 acres of grassed waterways, 5080 terraces, 668 pond dams, and 2858 water and sediment control basins. The spatial distribution of the conservation practices within the watershed is shown in Figure 3-9. Grassed waterways, contour buffer strips, and terraces are most prominent in the south central portion of the watershed. Pond dams are most prominent in the northeastern portion of the watershed while WASCOBs are more prominent in the western portion of the watershed. Fields using strip cropping methods are uncommon in the watershed.

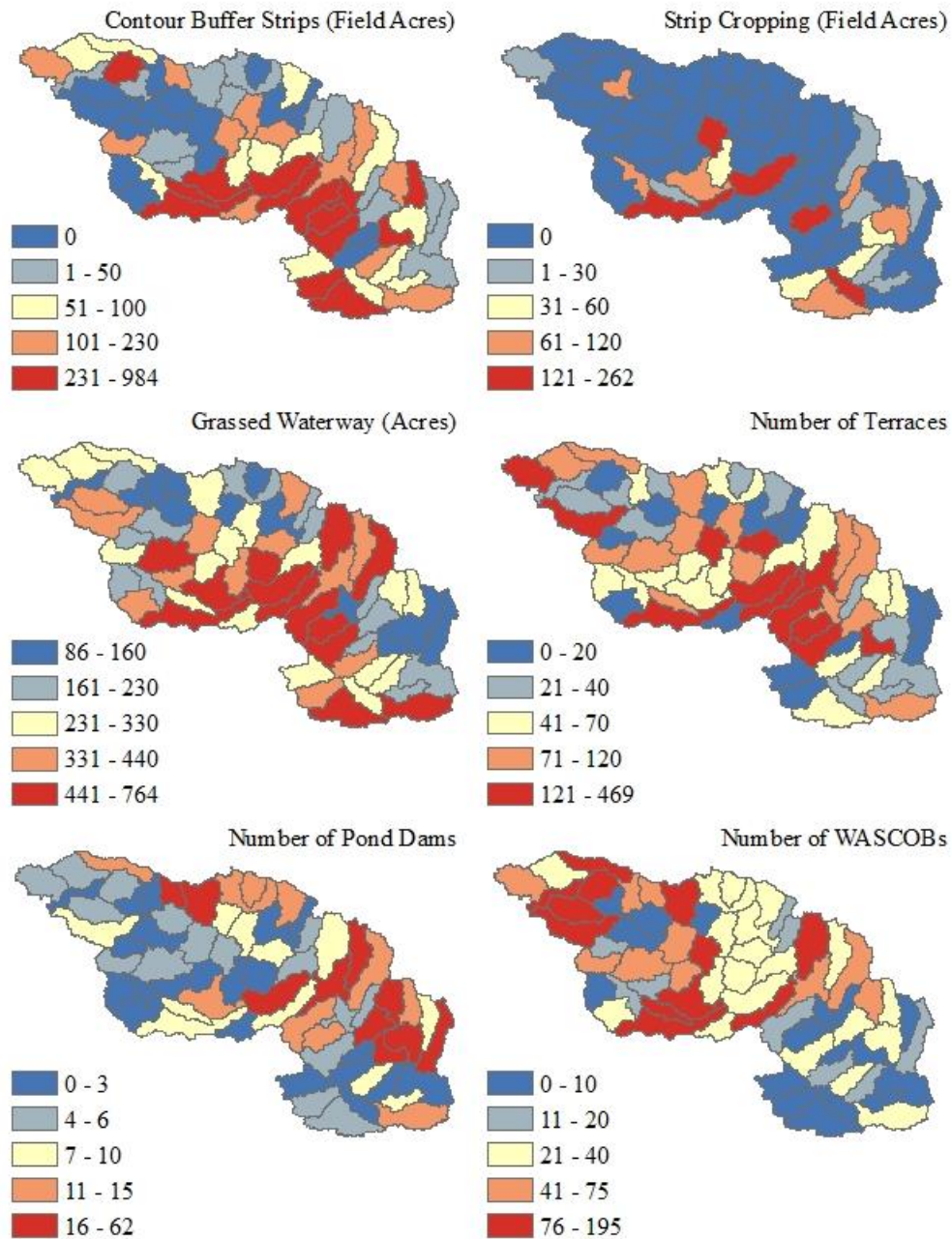


Figure 3-9. Iowa Best Management Practices Mapping Project.

f. 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 prepackaged 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 each of the HUC 12s in the Middle Cedar Watershed. Potential BMPs aggregations based on HUC 12 area are presented in Figure 3-10.

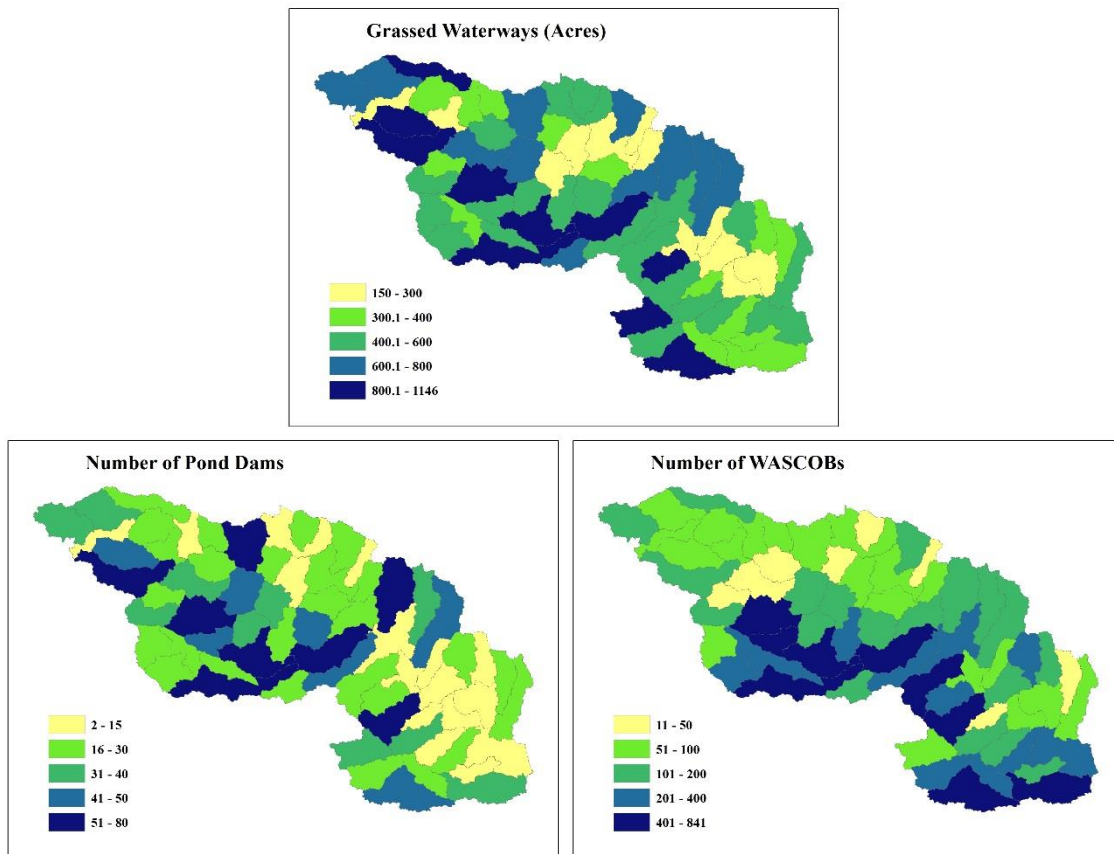


Figure 3-10. Potential BMPs. Ponds Dams represent nutrient removal wetlands.

g. Instrumentation/Data Records

The Middle Cedar Watershed has instrumentation installed to collect and record stream stage, discharge, and precipitation. There are eight United States Geological Survey (USGS) operated stage & discharge gages and twenty Iowa Flood Center stream stage sensors located within the watershed. There are also six Rain Gage/ Soil Moisture Sensors administered by IFC.

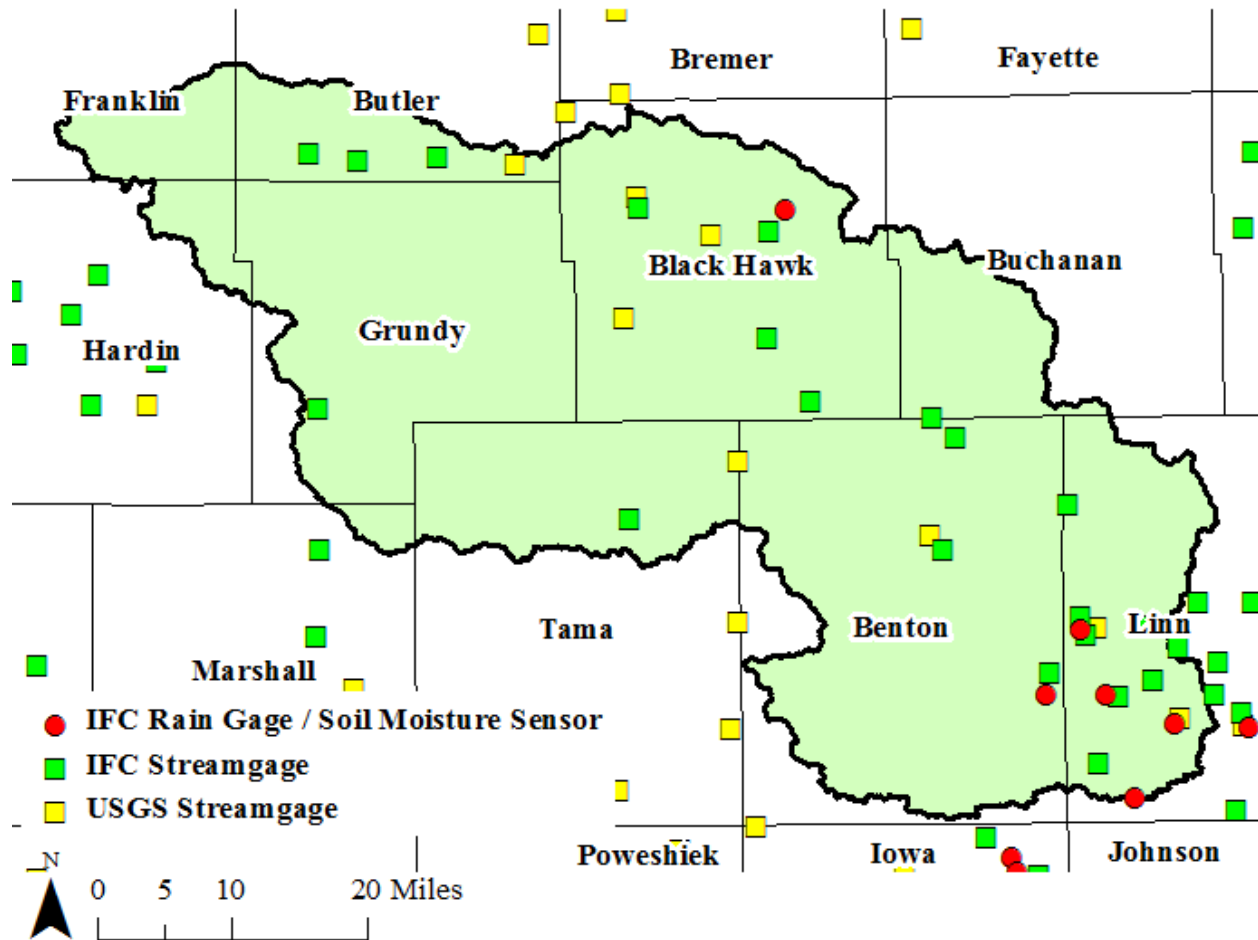


Figure 3-11. Hydrologic and meteorologic instrumentation in the Middle Cedar Watershed. Stage/discharge gages are shown in yellow or green while precipitation and soil moisture gages are shown in red.

h. Floods of Record

Six large flood events (discharge greater than 65,000 cfs) are recorded at the USGS Cedar River gaging station at Cedar Rapids since 1903. Three of these events have occurred since 1993 including: June 13, 2008 with 140,000 cfs, September 27, 2016 with 81,600 cfs, and April 4, 1993 with 71,000 cfs. Prior to 1993, there were two large flood events: March 31, 1961 with 73,000 cfs and April 10, 1965 with 66,800 cfs. Historically in June of 1851, there was one discharge measured at 65,000 cfs. These flood events may have been caused by heavy precipitation throughout the Cedar River watershed such as, the 2008 event where all five USGS gaging stations had record discharges or flooding could be caused by heavy precipitation upstream of the Middle Cedar watershed in tributaries of the Cedar River including: the West Fork Cedar River watershed, the Winnebago River watershed, Shell Rock River watershed, and the Upper Cedar River watershed. The 2016 flood event was one such event where record discharges occurred on the Cedar River at Cedar Rapids and at the inlet to the Middle Cedar watershed at Waterloo but, not in the tributaries located within the Middle Cedar watershed. Ultimately, the discharge from the Cedar River flows downstream, merging with the Iowa River, before entering the Mississippi River.

Table 3-2. Discharge from the Six Largest Flooding Events at USGS Gaging Stations in the Middle Cedar Watershed including; the Cedar River at Waterloo, Cedar River at Cedar Rapids, Black Hawk Creek at Hudson, Beaver Creek at New Hartford, and Wolf Creek near Dysart.

Cedar River at Waterloo USGS 05464000 (1929- Present)	6/11/2008 112,000 cfs	9/24/2016 83,700 cfs	3/29/1961 76,700 cfs	4/8/1965 69,500 cfs	7/23/1999 69,300 cfs	4/2/1993 68,100 cfs
Cedar River at Cedar Rapids USGS 05464000 (1851, 1903- Present)	6/13/2008 140,000 cfs	9/27/2016 81,600 cfs	3/31/1961 73,000 cfs	4/4/1993 71,000 cfs	4/10/1965 66,800 cfs	6/1851 65,000 cfs
Black Hawk Creek at Hudson USGS 05463500 (1952- Present)	4/25/2008 22,500 cfs	7/9/1969 19,300 cfs	5/30/2013 19,100 cfs	7/1/2014 16,900 cfs	6/17/1990 13,800 cfs	6/22/1974 10,500 cfs
Beaver Creek at New Hartford USGS 05463000 (1946- Present)	6/8/2008 25,900 cfs	6/25/2013 19,400 cfs	6/13/1947 18,000 cfs	7/9/1969 14,900 cfs	3/31/1993 14,700 cfs	6/1/1991 13,400 cfs
Wolf Creek near Dysart USGS 05464220 (1996- Present)	5/30/2008 15,700 cfs	5/23/2004 14,500 cfs	5/27/2013 10,300 cfs	4/27/2009 7,300 cfs	7/1/2014 7,290 cfs	6/12/1998 5,800 cfs

4. Water Quality Analysis

a. Data Availability

This analysis aimed to estimate riverine nutrient loads for the Middle Cedar 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 Middle Cedar 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.

The Middle Cedar is unique among the watersheds within the Iowa Watershed Approach in that it contains a significant upstream tributary area not included in the program's scope. When this occurs in a watershed of interest, estimating nutrients loads entering and exiting the watershed is standard practice. A mass balance is then performed, where the incoming loads are subtracted from those leaving the watershed. This process isolates the specific watershed of interest. Due to varying travel times between the watershed's upstream and downstream borders, it is helpful to aggregate the data at an annual level. Evaluating annual loads minimizes the uncertainty associated with dynamic flow values that can significantly alter the amount of time a chemical moves through the watershed's channel.

ii. Sources of Data

The headwaters of the Cedar River watershed originate in Minnesota, over 20 miles north above the state's border with Iowa. It flows across much of Eastern Iowa before draining into the Iowa river in Columbus Junction, IA. However, the Middle Cedar watershed only encompasses the river's stretch from Cedar Falls, IA, to Cedar Rapids, IA (shown in Figure 3-1). Any water quality analysis for the Middle Cedar needs to quantify the Cedar River's loads upstream of Cedar Falls and downstream of Cedar Rapids.

Significant nutrient data is present at a site just downstream of Cedar Rapids. This site has long been a part of the Iowa Department of Natural Resources (IDNR) ambient monitoring program. Nitrate, TP, OP, and turbidity are measured here every month. This Cedar Rapids site encompasses the entirety of Middle Cedar's total watershed. The USGS has also maintained a stream gauge slightly upstream in downtown Cedar Rapids—with streamflow measurements dating back to the early 1900s. All major tributaries enter the Cedar upstream of this gauge, so data from the IDNR site and the USGS gauge are often treated as coincident. The water quality data from Cedar Rapids is typically combined with the streamflow measurements, making this site an obvious choice for the downstream nutrient analyses conducted along the Middle Cedar.

Table 4-1. Summary of sites used in Middle Cedar analysis.

Site	River	IDNR ID	USGS ID	Area (mi ²)
Janesville	Cedar	10090001	5458500	1,661
Shell Rock	Shell Rock	10120001	5462000	1,746
West Fork	West Fork of Cedar	10070003	5458900	846
Beaver Creek	Beaver Creek	10070001	5463000	347
Cedar Rapids	Cedar	10570001	5464500	6,510
Middle Cedar	Cedar			1,910

Four rivers come together near the upstream boundary of the Middle Cedar—the Cedar River (main branch), the Shell Rock River, the West Fork of the Cedar River, and Beaver Creek. Each of these waterways has been monitored in a similar manner to the Cedar Rapids site. The IDNR has taken monthly measurements of the river's nutrients, while the USGS has continually recorded streamflow. Table 4-1 lists the specific IDNR reference numbers along with the USGS gauges and tributary areas used in this analysis, while Figure 4-1 displays the exact locations of the IDNR sites. The Middle Cedar site can be thought of as the difference between the Cedar Rapids watershed (which includes all areas within and upstream of the Middle Cedar) and the four upstream tributaries.

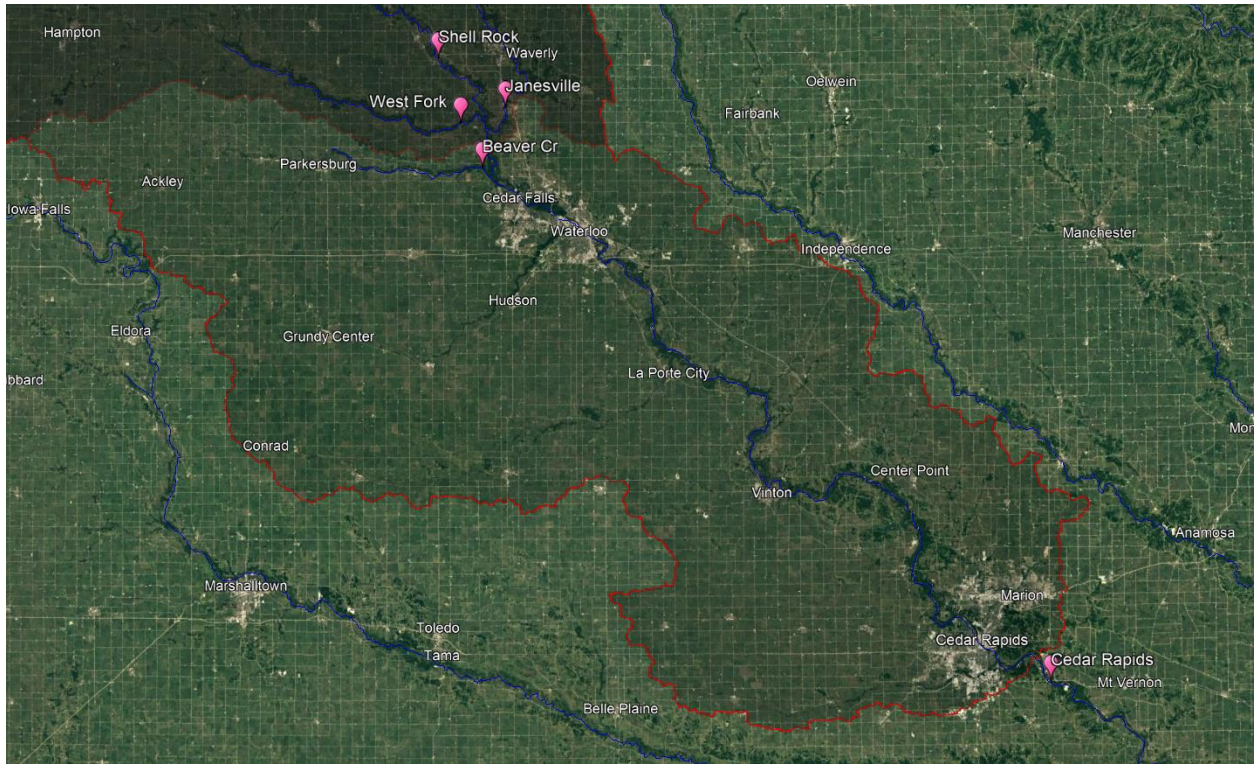


Figure 4-1. Data collection sites for the Middle Cedar watershed.

The IDNR began monitoring most of these sites in 1998 or 1999, and sampling for each continues to the present day. In the late 2000s, nitrate and turbidity sensors were deployed by the Iowa Water Quality Information System (IWQIS) and the USGS at several sites. These deployments resulted in more continuous records of these analytes in recent years. Figure 4-2 summarizes the number of days in each year containing nitrate, OP, Part P, and turbidity measurements at Cedar Rapids. This same overall pattern of data availability is present at the four upstream sites. The combination of data sources results in a very robust nutrient dataset, enabling the estimation of nitrate and phosphorus loads from 1998 to the present.

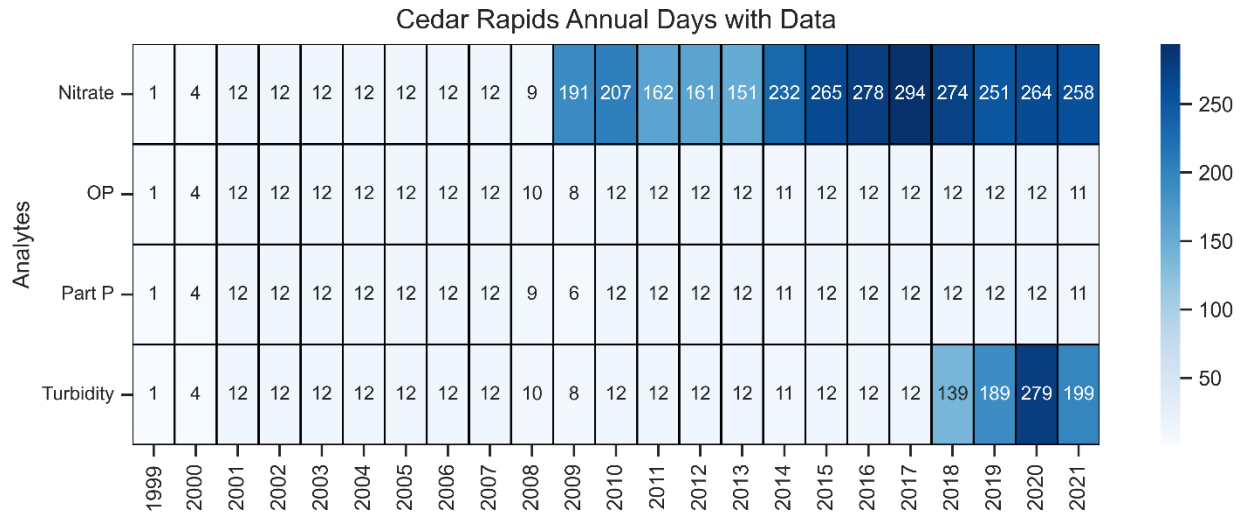


Figure 4-2. Annual days with data for the Cedar River at Cedar Rapids, IA.

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

b. Methods

Because there are numerous days on which nutrient data is 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 Middle Cedar, the goal was to estimate daily concentrations from 1998 to 2021—a timeframe commensurate with data availability and the Iowa Watershed Approach schedule.

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>).

Three separate models were constructed for all five sites associated with the Middle Cedar basin. Nitrate, OP, and Part P were modeled at each river from 1998 to 2021. The daily flow values utilized by these models are shown in Figure 4-3.

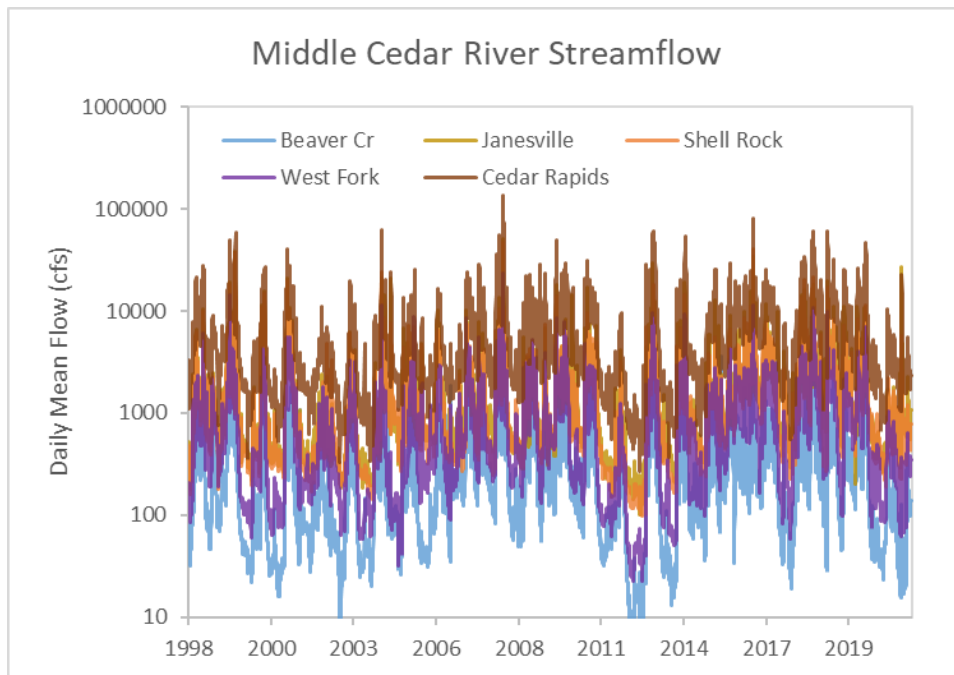


Figure 4-3. Daily flow values for the Middle Cedar streamflow gauges.

i. Nitrate

The WRTDSK nitrate models were successfully implemented, and no issues were found with the models' 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, each nitrate model performed exceptionally well.

Table 4-2. WRTDSK model performance metrics.

River	Type	R2	RMSE	R2.In	RMSE.In	FluxBias
Cedar Janesville	Nitrate	0.59	1.75	0.48	0.47	0.02
	OP	0.14	0.07	0.45	0.73	0.34
	PartP	0.06	0.12	0.38	1.01	0.23
Shell Rock	Nitrate	0.68	1.35	0.61	0.51	0.01
	OP	0.20	0.08	0.46	0.80	0.20
	PartP	0.18	0.13	0.40	0.90	-0.03
West Fork	Nitrate	0.78	1.63	0.74	0.48	-0.01
	OP	0.30	0.05	0.51	0.57	-0.02
	PartP	0.21	0.09	0.40	1.13	0.00
Beaver Creek	Nitrate	0.70	2.04	0.86	0.32	0.04
	OP	0.16	0.06	0.42	0.58	-0.01
	PartP	0.15	0.14	0.52	1.08	0.11
Cedar Rapids	Nitrate	0.73	1.59	0.87	0.30	-0.04
	OP	0.30	0.11	0.51	0.77	0.17
	PartP	0.21	0.09	0.40	0.71	0.05

The observed (black dots) and estimated (solid line) nitrate concentrations at the Cedar Rapids site are shown in Figure 4-4. The nitrate concentrations ranged from 0.01 to 18 mg/L. The predicted concentrations largely remained within the range of observed values and were consistently below 15.0 mg/L. Many more observed values have been available in recent years due to sensor deployment. All model performance metrics are shown in Table 4-2.

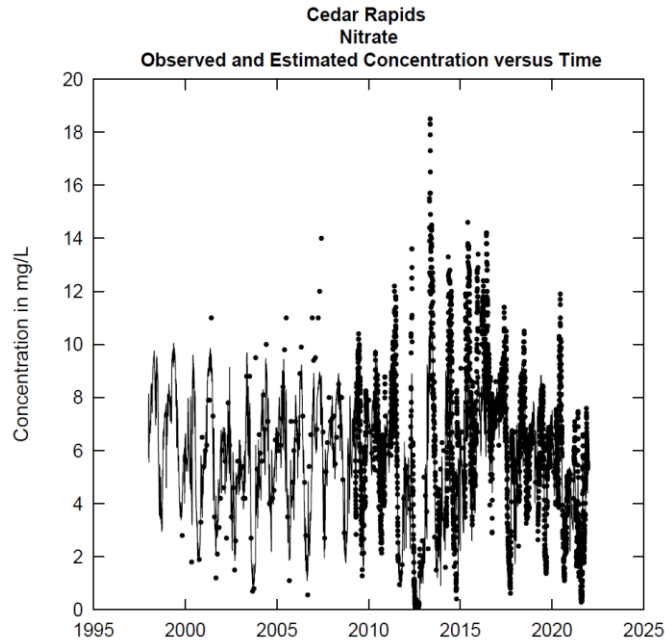


Figure 4-4. WRTDSK nitrate model results at Cedar Rapids.

ii. Orthophosphate

The WRTDSK OP models were successfully implemented. In many cases, OP can be difficult to predict based on flow, as it is a dissolved constituent. The models' performances here were adequate for all sites. The model concentrations typically remained near 0.05 – 0.2 mg/L, with values occasionally extending above 0.5 mg/L.

Figure 4-5 contains an example of the Kalman filter being applied to the OP estimates at Cedar Rapids. The black lines show the original WRTDS concentrations, and the red points are the observed samples—the exact OP measurements at the Cedar Rapids 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.

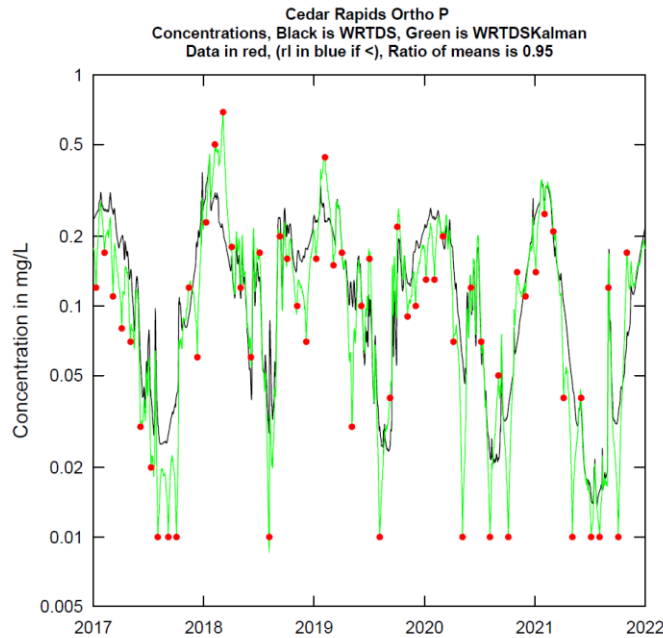


Figure 4-5. WRTDSK orthophosphate model results at Cedar Rapids.

iii. Particulate Phosphorus

The WRTDSK models were 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. Still, because turbidity data were available, its potential use as a surrogate for Part P was also investigated.

Figure 4-6 plots the relationship between the log-transformed values of Part P and turbidity collected at the Janesville site. The literature generally suggests that a linear model for the log-transformed variables is ideal. This relationship may also be referred to as the power regression model since the untransformed equation follows a power-law framework.

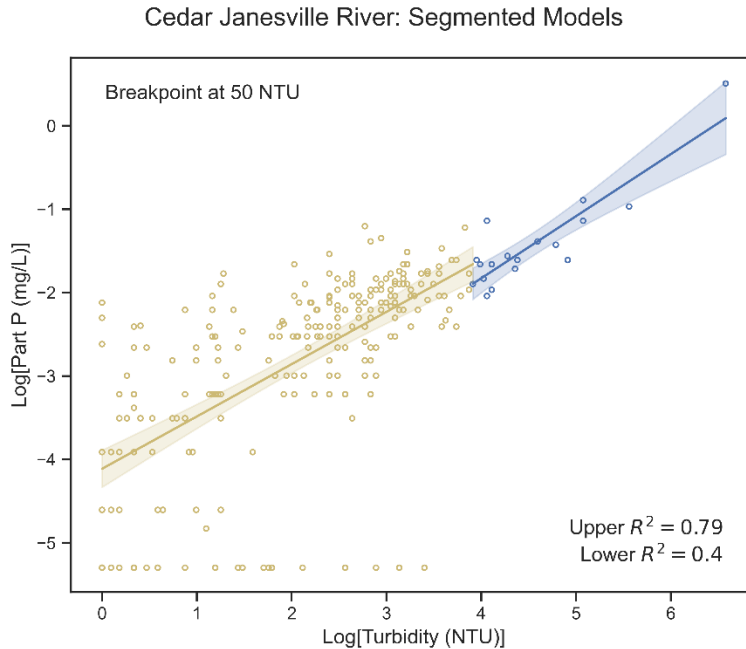


Figure 4-6. Turbidity-based surrogate model for Part P at Janesville.

It has been observed that numerous models have issues with heteroskedasticity on the transformed data. This is seen in Figure 4-6, where the variance of residuals is more prominent for smaller turbidity values than for larger ones. This issue was addressed by splitting the model using piecewise regression around a breakpoint of 50 NTU. The resulting surrogacy models contained two equations for predicting Part P—one for turbidity values less than 50 NTU and one for values above this threshold. Using two equations resolved issues with heteroskedasticity, as the residual variance largely remained constant above and below this threshold.

Part P concentrations were then predicted on any days where turbidity data were available, and these estimates were given higher priority over the WRTDSK model. The surrogacy-based concentrations were used to calculate loads instead of the WRTDSK concentrations when turbidity data were present. This observed value was used as the ultimate Part P concentration on any days that contained observed Part P data.

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. With nitrate and TP loads compiled for the five locations, daily loads were estimated for the Middle Cedar by subtracting the combined values for the four upstream sites from those at Cedar Rapids. This resulting timeseries was used to isolate the Middle Cedar region.

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 Middle Cedar, 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 Middle Cedar’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. Yields are a valuable metric for normalizing loads by tributary area so that different watersheds can be compared more appropriately. 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 WRTDSK and turbidity-based surrogacy 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. Negative values are possible for the Middle Cedar; these are days on which the upstream values are larger than those at Cedar Rapids.

Table 4-3. Descriptive statistics for the Middle Cedar flows and nutrients.

Stat	Cedar Rapids					Middle Cedar		
	Flow (cfs)	TP (mg/L)	P Load (lbs)	Nitrate (mg/L)	N Load (lbs)	Flow (cfs)	P Load (lbs)	N Load (lbs)
count	8766	8766	8766	8766	8766	8766	8766	8766
mean	6364	0.32	11249	5.93	253724	1965	4509	71957
std	7739	0.13	16860	2.62	357615	4428	15727	187535
min	268	0.06	601	0.10	295	-67783	-483830	-2220875
0.1	1260	0.20	1973	2.35	19045	137	871	-9823
0.25	1990	0.24	2967	4.18	44003	563	1586	4734
0.5	3680	0.28	5594	6.00	110611	1186	2864	30870
0.75	7955	0.37	12546	7.59	316342	2514	6039	94205
0.9	14500	0.49	26012	9.23	686884	4984	12836	232147
0.99	36434	0.74	79990	12.60	1679417	16930	41877	784840
max	138000	1.41	351047	18.50	4289536	85580	181475	2034281

i. Nitrate Estimates

Figure 4-7 shows the Middle Cedar’s yearly nitrate and water yields, plotted on the secondary axis. These are calculated by dividing the summation of daily loads within a year by the Middle Cedar’s tributary area. The yearly yields varied considerably from 0.1 to 48 lbs/ac, with a mean near 21.5 lbs/ac. There may be a gradual increase in nitrate occurring across the period of analysis. The water yields correlated strongly with nitrate yields, resulting in larger nitrate loads due to the increased water volume. The wettest years occurred in 2008 and 2010.

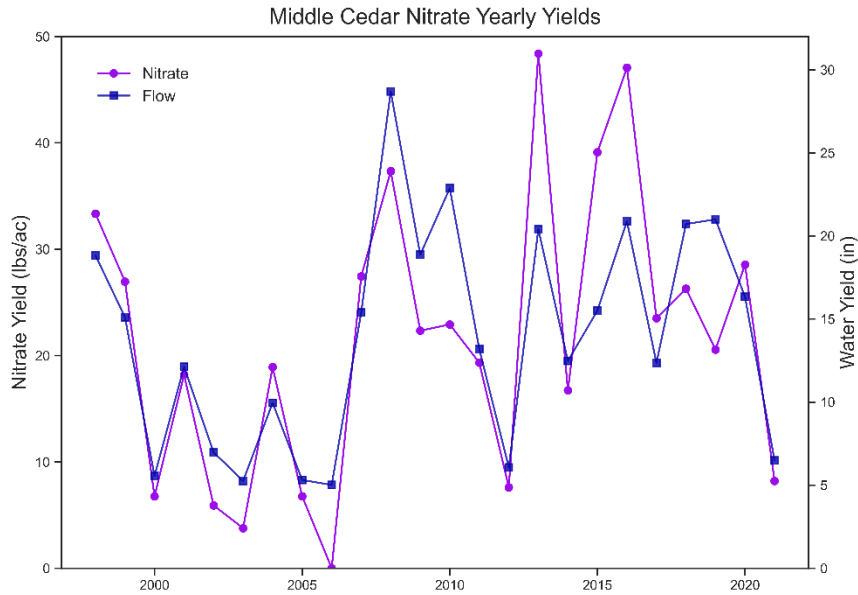


Figure 4-7. Average annual nitrate yields in the Middle Cedar.

Figure 4-8 contains the boxplots for nitrate concentrations at Cedar Rapids 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 occurred during May and June, while the lowest concentrations were seen in August, September, and October.

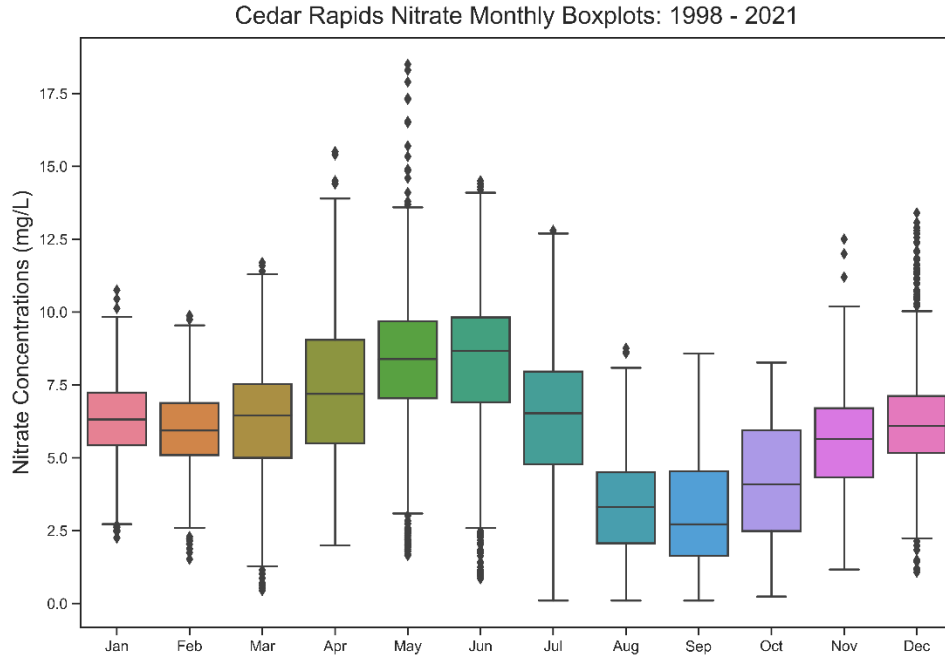


Figure 4-8. Boxplots of monthly nitrate concentrations at Cedar Rapids.

Figure 4-9 shows the yearly nitrate yields for the five analyzed sites and the Middle Cedar watershed. This plot helps compare the presence of nitrate across the sites of interest. Yields among the six locations are correlated, meaning that locations' highest and lowest yields tend to take place concurrently. Beaver Creek produced the largest yields, but there was tremendous variability across the rivers, with no location being repeatedly larger or smaller than the others. Yields were typically in the range of 5.0 to 50 lbs/ac.

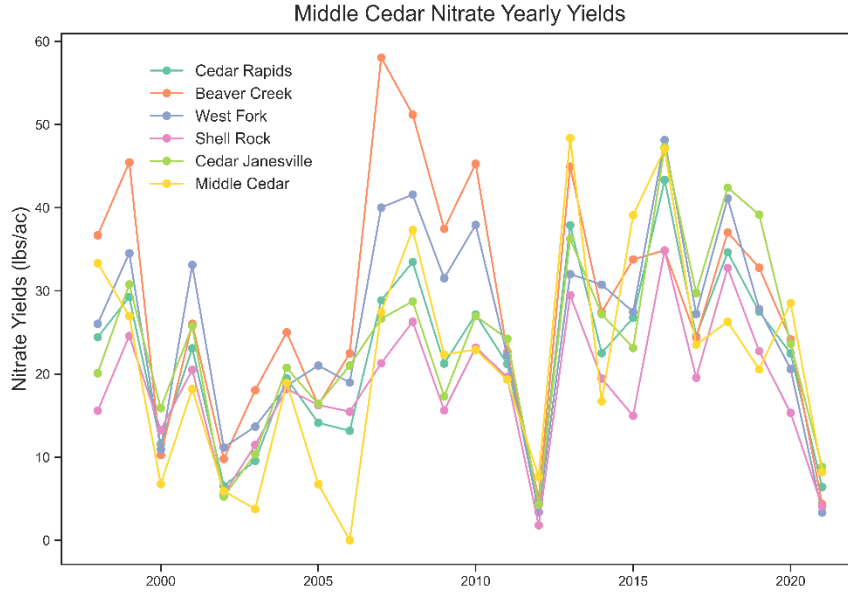


Figure 4-9. Yearly nitrate and water yields.

Table 4-4 summarizes the nitrate and TP yields at all locations. The yields for the entire analysis period and the corresponding means and medians are provided. Beaver Creek had the highest mean yield, followed closely by West Fork. The Shell Rock River had the lowest, while the Middle Cedar also tended to be on the lower end. Typical mean annual yields ranged from 18.4 to 28.9 lbs/ac.

Table 4-4. Summary of nitrate and TP yields for the Middle Cedar sites.

Site	Yearly Nitrate Yields (lbs/ac)		1998 - 2021 Nitrate Yield	Yearly TP Yields (lbs/ac)		1998 - 2021 TP Yield
	Mean	Median		Mean	Median	
Cedar Rapids	22.2	22.8	533.9	0.99	0.87	23.67
Beaver Creek	28.9	26.7	693.4	0.92	0.79	21.98
West Fork	26.0	27.3	623.2	0.65	0.61	15.67
Shell Rock	18.4	18.8	442.0	0.83	0.71	20.02
Cedar Janesville	23.8	23.9	572.2	0.92	0.82	21.96
Upstream	22.6	21.8	541.3	0.84	0.72	20.07
Middle Cedar	21.5	21.5	516.0	1.35	1.39	32.34

ii. Phosphorus Estimates

Figure 4-10 shows the annual TP and water yields for the Middle Cedar. These were calculated in a similar fashion to the nitrate yields. Yearly yields spanned from 0.0 to 3.4 lbs/ac. The highest yields were found in the late 1990s and decreased shortly after. No clear trend was evident in recent years.

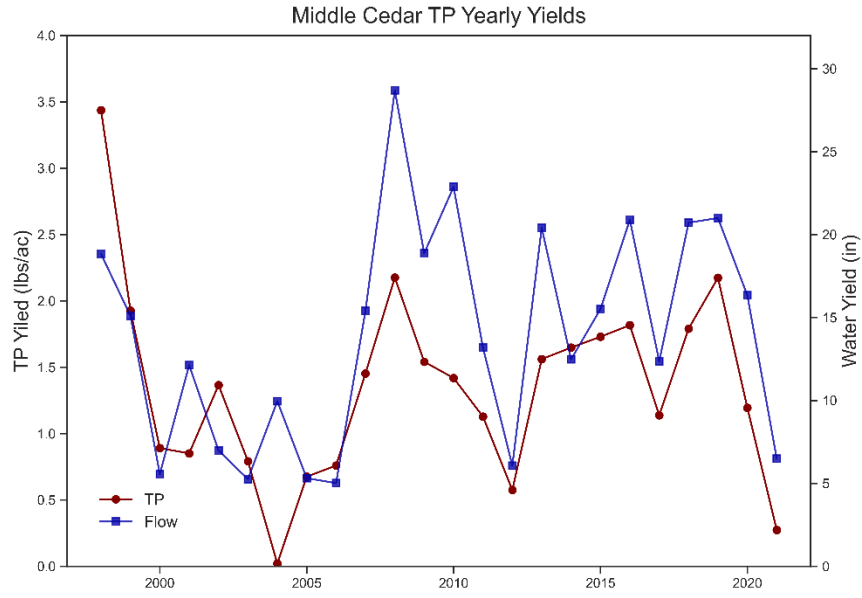


Figure 4-10. Annual average TP concentrations.

Similarly, the concentrations were separated by month for TP. Boxplots of these monthly concentrations at Cedar Rapids are shown in Figure 4-11. These boxplots are more positively skewed, and each month contains many potential outliers. The medians varied slightly by month, with the highest values occurring during the winter and early spring months. The medians were mainly near 0.2 to 0.3 mg/L.

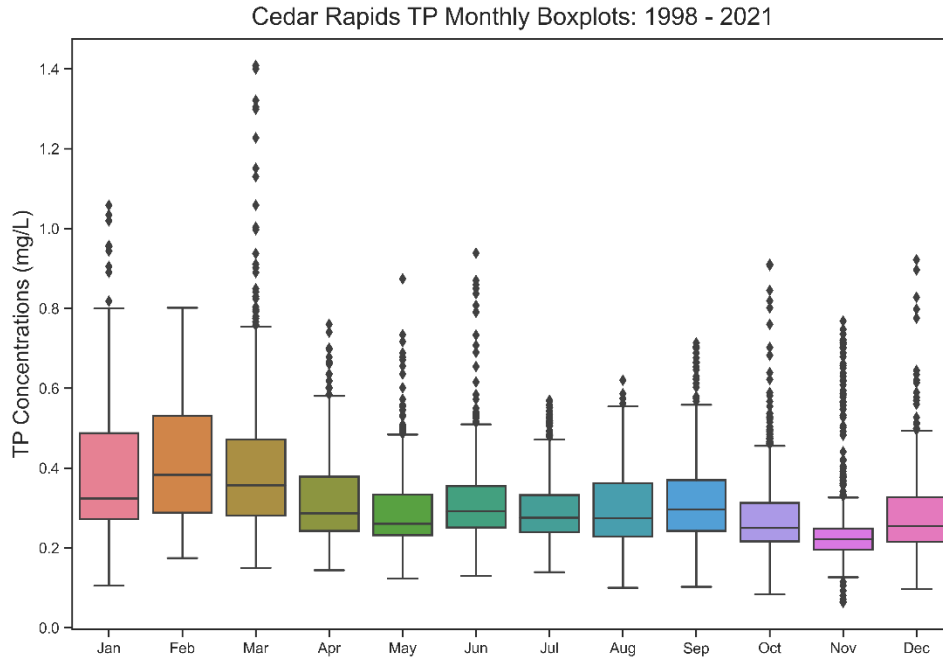


Figure 4-11. Boxplots of monthly TP concentrations.

Figure 4-12 shows the annual TP yields for all Middle Cedar locations. There was again variation among yearly yields, with the lowest value near 0.1 lbs/ac, the highest value near 3.5 lbs/ac, and an average near 0.9 lbs/ac. In this instance, the Middle Cedar seemed to stand out as containing consistently larger TP yields than the other rivers. 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 20 times smaller than those of nitrate.

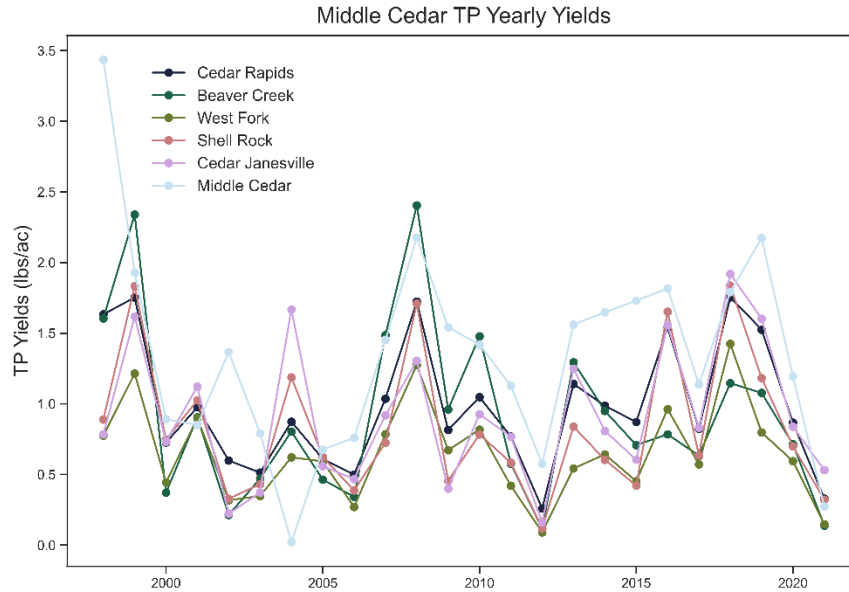


Figure 4-12. Yearly TP and water yields.

These averaged yields are also included in Table 4-4. The Middle Cedar had the highest mean yield value of 1.35 lbs/ac. The upstream sites had yields closer to 0.9 lbs/ac, apart from the West Fork site, which had the lowest yield of 0.65 lbs/ac. The Middle Cedar is a higher source of TP than its upstream neighbors.

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. 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 4-5 summarizes the findings for each site. P-values were used to determine whether the test was statistically significant, and values lower than 0.05 indicated a significant trend.

While daily nitrate concentrations generally decreased, nitrate loads increased at nearly every site. The daily streamflow values were also increasing, so the growing water volume is likely offsetting any decreases seen in riverine nitrate concentrations. TP behavior was slightly more complicated. Daily concentrations decreased at a few areas, but loads increased in others. Notably, TP loads increased in all the upstream sites but decreased at the Middle Cedar. This may imply that while yields are high in the Middle Cedar, some progress has been made in reducing them over the past 20 years. Very few trends were present in the annual timeseries.

Table 4-5. Trend analysis results ($p < 0.05$).

Variable	Property	Cedar Janesville	Shell Rock	West Fork	Beaver Creek	Cedar Rapids	Middle Cedar
Nitrate	Daily Concentrations	increasing	decreasing	decreasing	decreasing	decreasing	
	Daily Loads	increasing	increasing	increasing	no trend	increasing	increasing
	Annual Concentrations	no trend	no trend	no trend	decreasing	no trend	
	Annual Loads	no trend	no trend	no trend	no trend	no trend	no trend
Total Phosphorus	Daily Concentrations	decreasing	decreasing	no trend	no trend	decreasing	
	Daily Loads	increasing	increasing	increasing	increasing	decreasing	decreasing
	Annual Concentrations	no trend	no trend	no trend	no trend	decreasing	
	Annual Loads	no trend	no trend	no trend	no trend	no trend	no trend
Flow	Daily Flows	increasing	increasing	increasing	increasing	increasing	increasing
	Annual Flows	no trend	no trend	no trend	no trend	no trend	no trend

d. Conclusions

The historical nutrient data at Cedar Rapids and four of the Cedar River’s upstream tributaries (Janesville, Shell Rock, West Fork, and Beaver Creek) made it possible to estimate nitrate and TP loads for the Middle Cedar River. The data at these five sites were excellent, containing a solid record of nutrient data spanning over 20 years. The IDNR has sampled each site every month since the late 1990s, and the USGS operates nearby gauges in Kalona that have monitored streamflow for many decades. In recent years, IWQIS and the USGS have installed nitrate sensors and turbidimeters that can continuously monitor these analytes at numerous sites. Data from these three sources were assembled for this analysis.

Daily nutrient loads were estimated from 1998 to 2021 at all five locations. WRTDSK models were successfully implemented for nitrate, OP, and Part P. The Part P models were further supplemented with a turbidity-based surrogacy model. 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. Loads for the Middle Cedar were then calculated by subtracting combined loads from the upstream tributaries from those estimated at Cedar Rapids.

The Middle Cedar nitrate concentrations tended to be normally distributed, while the TP concentrations were more positively skewed. Annual nitrate yields ranged from 0.1 to 48, with an average of 21.5 lbs/ac. Annual TP yields ranged from 0.0 and 3.4, with an average of 1.35 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 Middle Cedar are greater than the rest of Iowa, while the TP yields are smaller. Nitrate was highest in the Beaver Creek and West Fork tributaries while lowest in the Shell Rock. The Middle Cedar had comparatively lower nitrate yields. TP yields in the Middle Cedar were higher than all other tributaries, and the lowest TP was found in the West Fork. All annual water yields strongly correlated with yearly nutrient yields. Both the Mann-Kendall and Spearman trend detection tests indicated that daily loads were increasing for nitrate and TP in the upstream tributaries. In the Middle Cedar, however, only nitrate loads were increasing, with TP found to be on the decline.

Mean daily streamflow was also increasing at all locations, and this likely has a major impact on offsetting potential nutrient reduction efforts.

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 – Hydrosience 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).

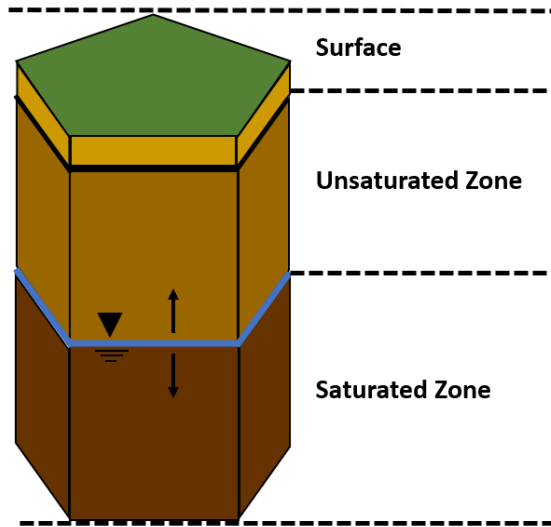


Figure 5-1. Vertical zones of a Voronoi element in GHOST: surface, unsaturated, and saturated zones.

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 Boussinesq equation. For a full documentation of GHOST’s mathematical model, please refer to Politano (2019).

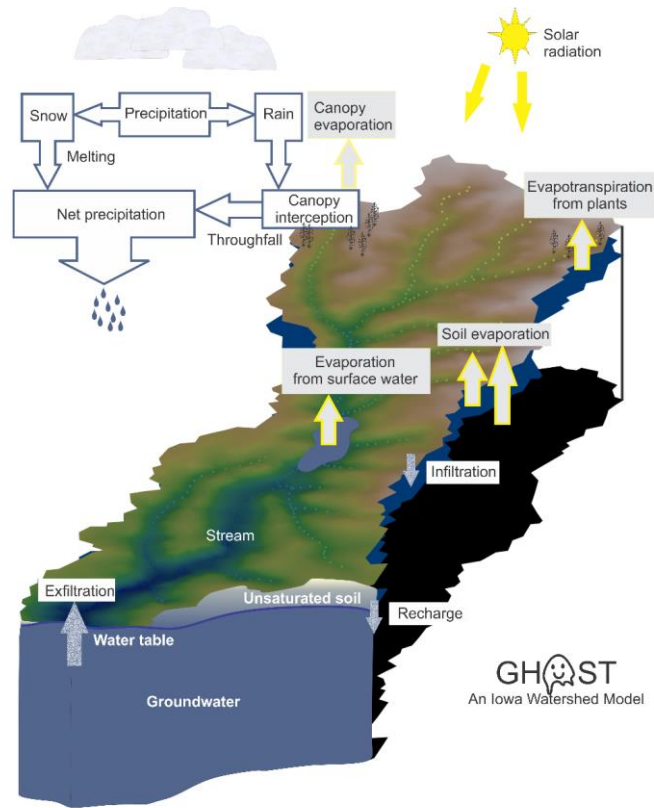


Figure 5-2. The hydrologic cycle calculated by GHOST (Politano, 2019).

b. Middle Cedar Model Construction

The GHOST model for the Middle Cedar Watershed consists of a computational mesh of Voronoi elements and a network of connected linear stream segments, shown in Figure 5-3. 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.

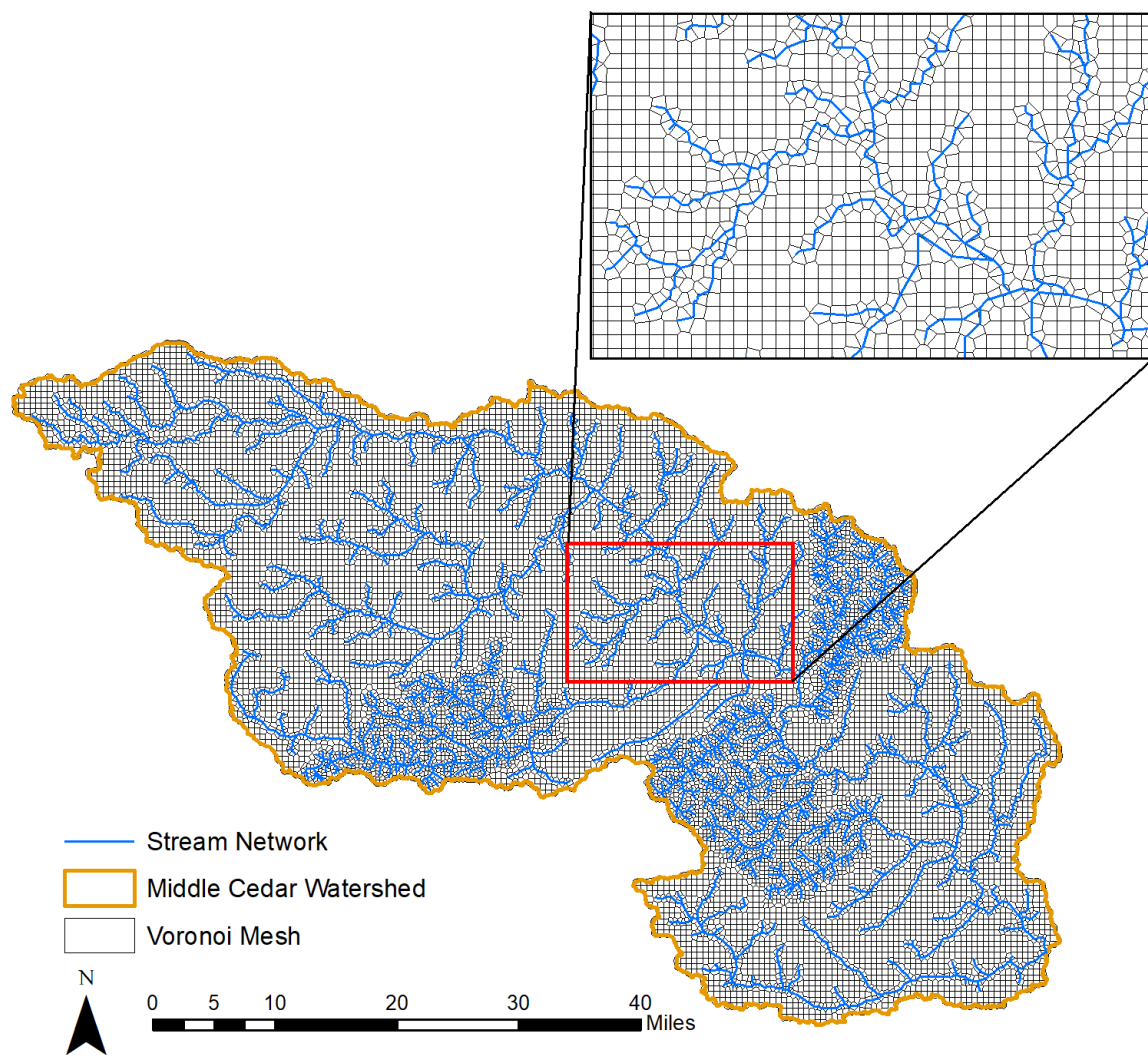


Figure 5-3. The Voronoi mesh and stream network used in the Middle Cedar GHOST model.

The model for the Middle Cedar contains 15,723 elements, with an average size of 0.41 km² (100.1 acres), the largest at 1.09 km² (269.2 acres), and the smallest only 0.12 km² (29.6 acres). There are 5,128 river segments with a total length of 2,615 km (1634 miles) and average, maximum, and minimum lengths of 510 m, 1,897 m, and 95 m, respectively. In addition, 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 0.26 km² (66 acres); the largest was only 0.70 km² (173 acres).

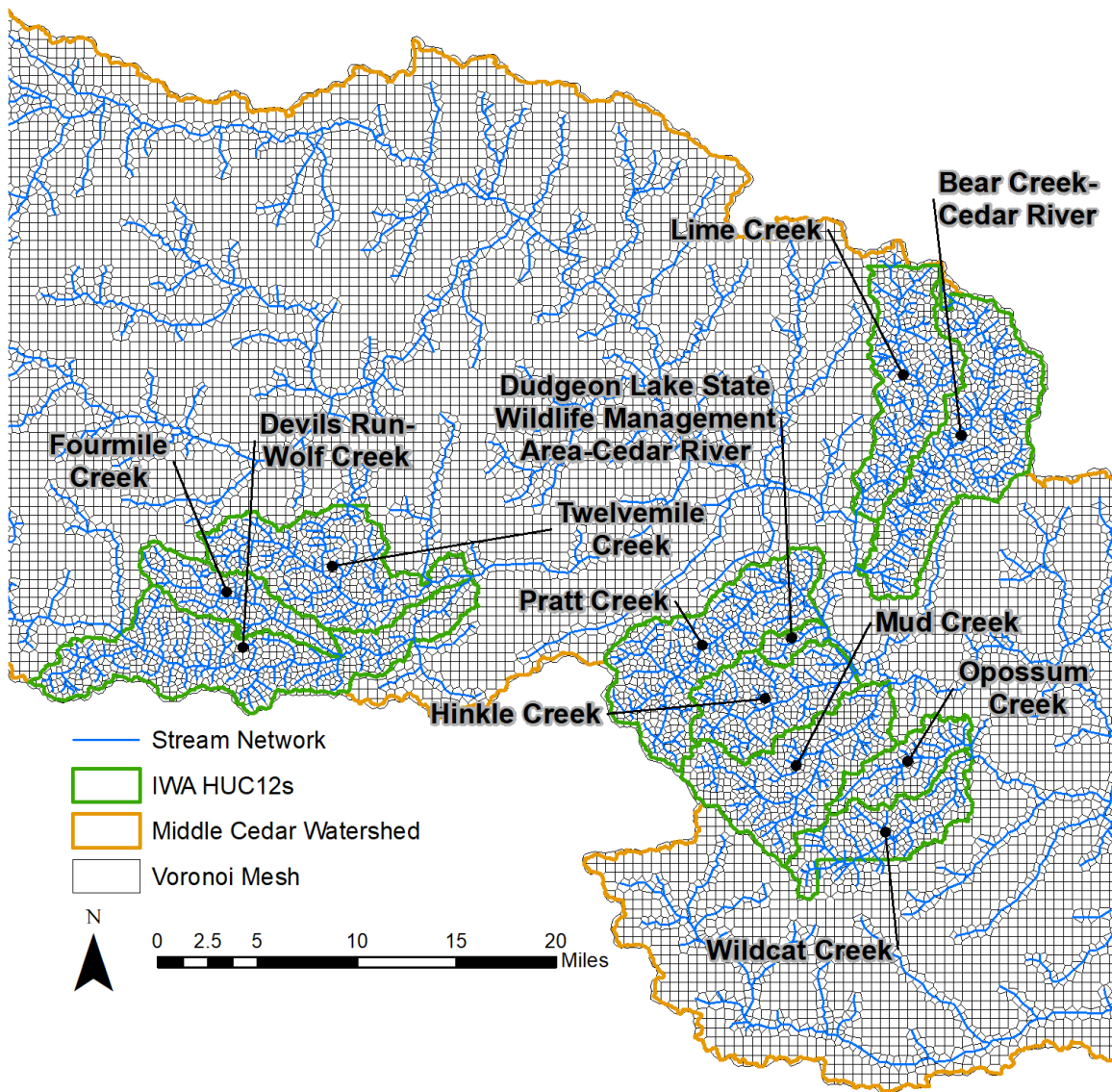


Figure 5-4. The mesh within IWA focus areas was constructed with a finer resolution than the rest of the watershed.

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, 88% are assigned to row crop, 1% to forest, 6% to grass/pasture, and just 4% to urban, as shown in Figure 5-5.

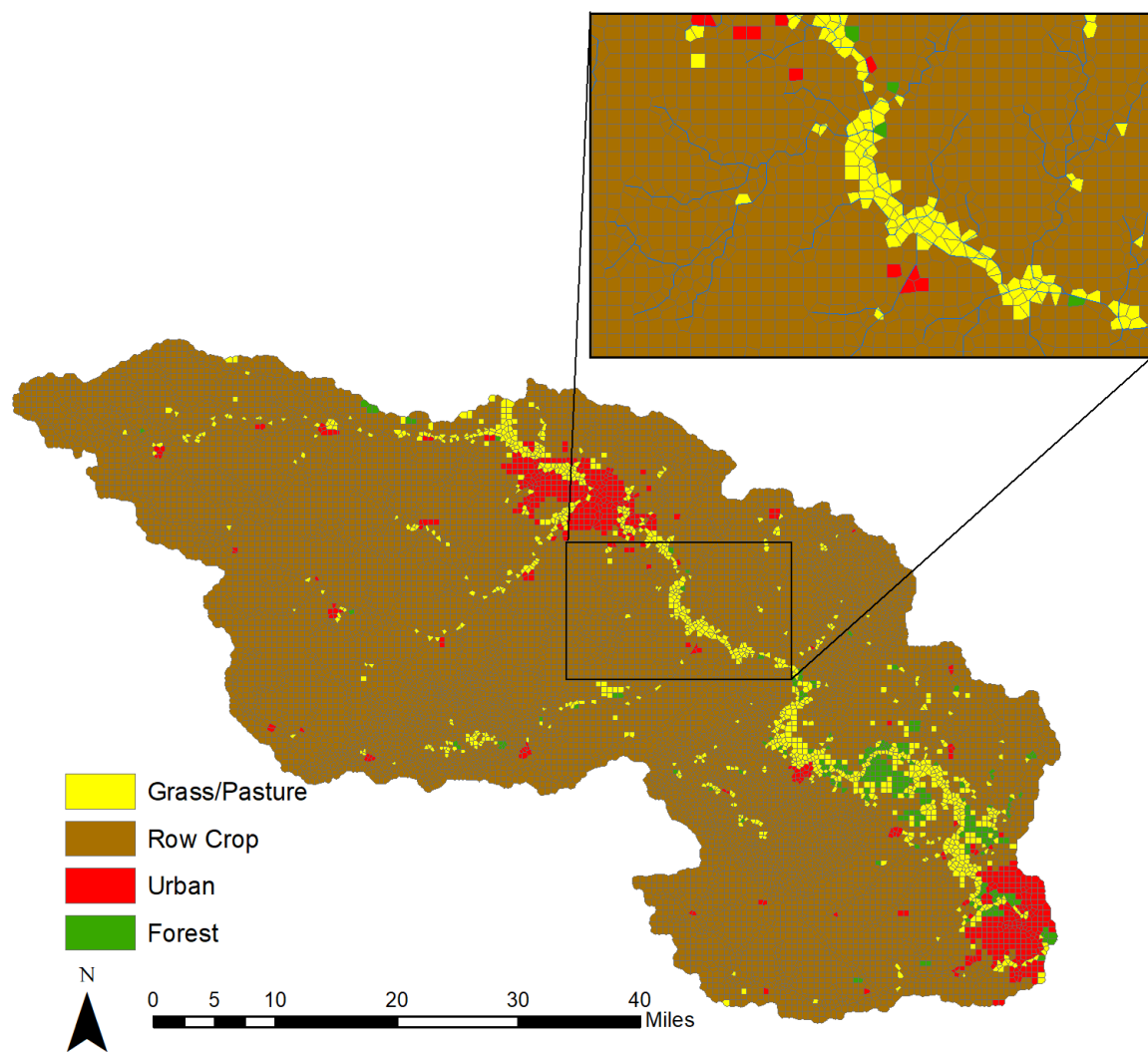


Figure 5-5. GHOST mesh with elements' land use classifications.

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 64 NLDAS pixels shown in Figure 5-6.

Four USGS streamflow gauges provided references to calibrate the GHOST model: Cedar River at Cedar Rapids (05464500), Wolf Creek near Dysart (05464220), Black Hawk Creek at Hudson (05463500) and Beaver Creek at New Hartford (05463000) (see Figure 5-6 and Figure 5-7). The next section describes the process and results of model calibration.

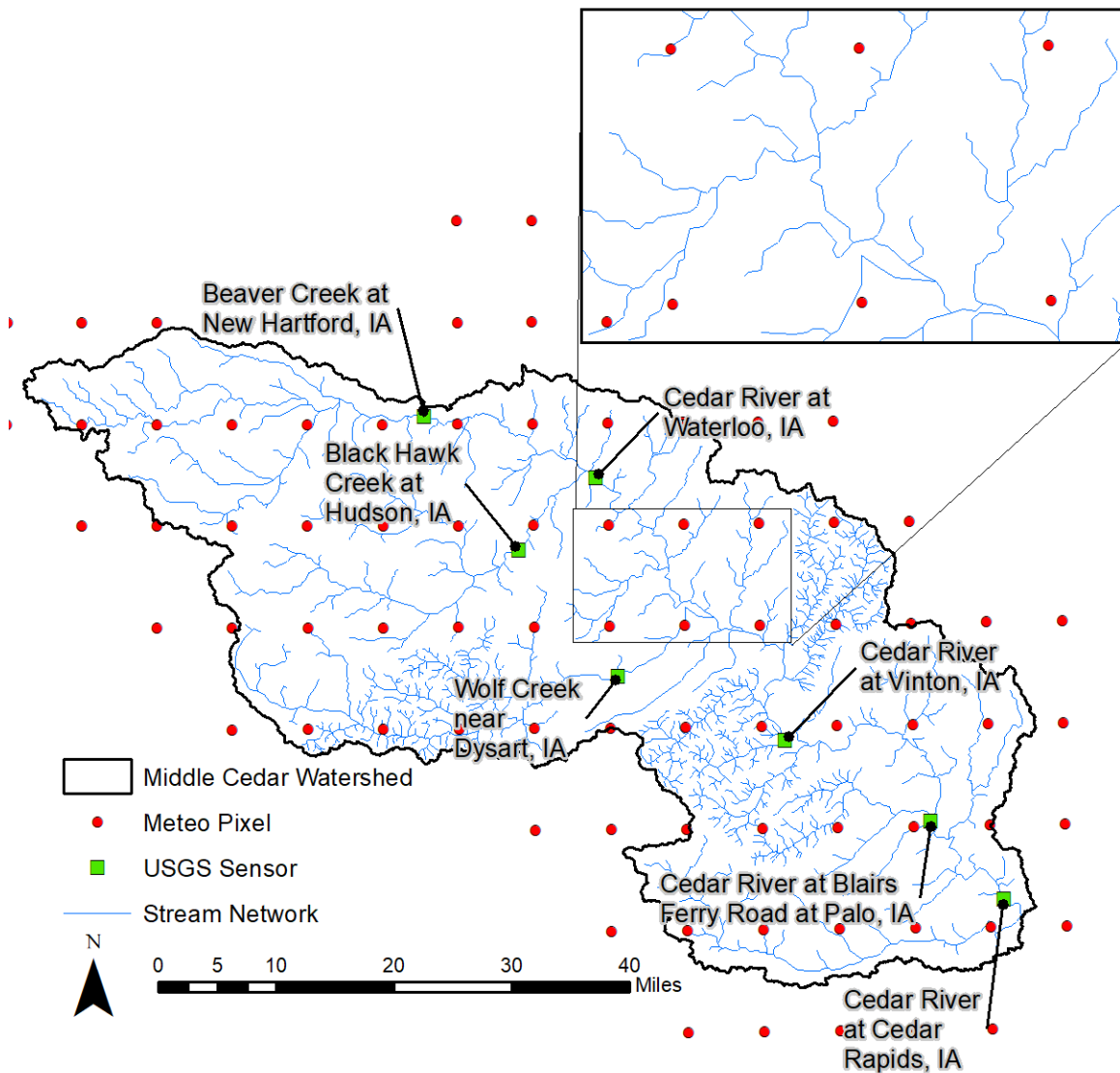


Figure 5-6. The location of the meteorological forcing data pixels and USGS gauges used in the Middle Cedar Watershed model.

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. The comparison of observed and simulated average daily discharges for the four gauges is shown in Figure 5-7. In general, GHOST did a good job of capturing low-flow periods as well as flood events, 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 are shown in Table 5-1. For PBIAS and R^2 , the modeled results at Cedar Rapids, Wolf Creek, Black Hawk Creek, and Beaver Creek exceed these thresholds. NSE values at Black Hawk Creek and Beaver Creek are slightly below the recommended values.

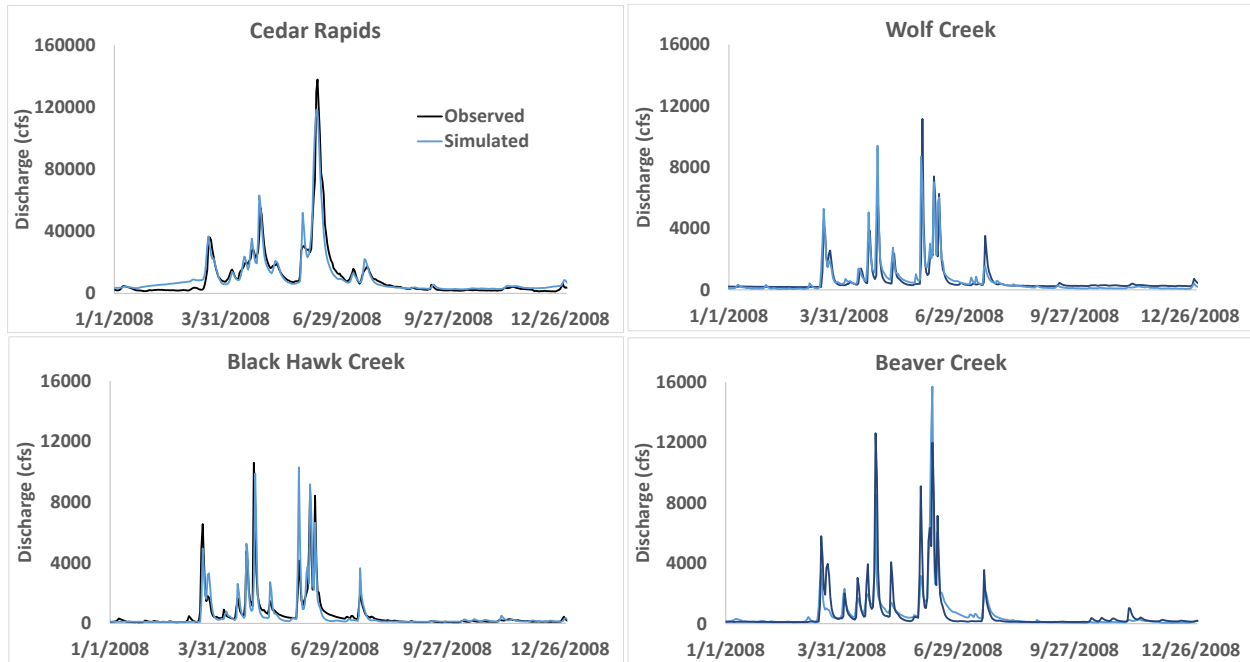


Figure 5-7. Comparison of simulated (blue) and observed (black) daily average discharge for 2008. The location of the stations is presented in Figure 5-6.

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

Metric	Cedar Rapids	Wolf Creek	Black Hawk	Beaver Creek
NSE	0.87	0.65	0.59	0.51
R^2	0.76	0.56	0.59	0.63
PBIAS	4.21	-7.56	9.38	0.91

The Middle Cedar 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. As shown in Figure 5-8, the model captures this pattern well, with slight tendencies to over-predict winter months and under predict June and July. Overall, the GHOST model's performance matched observed average monthly runoff depths closely, with R^2 values greater than 0.85.

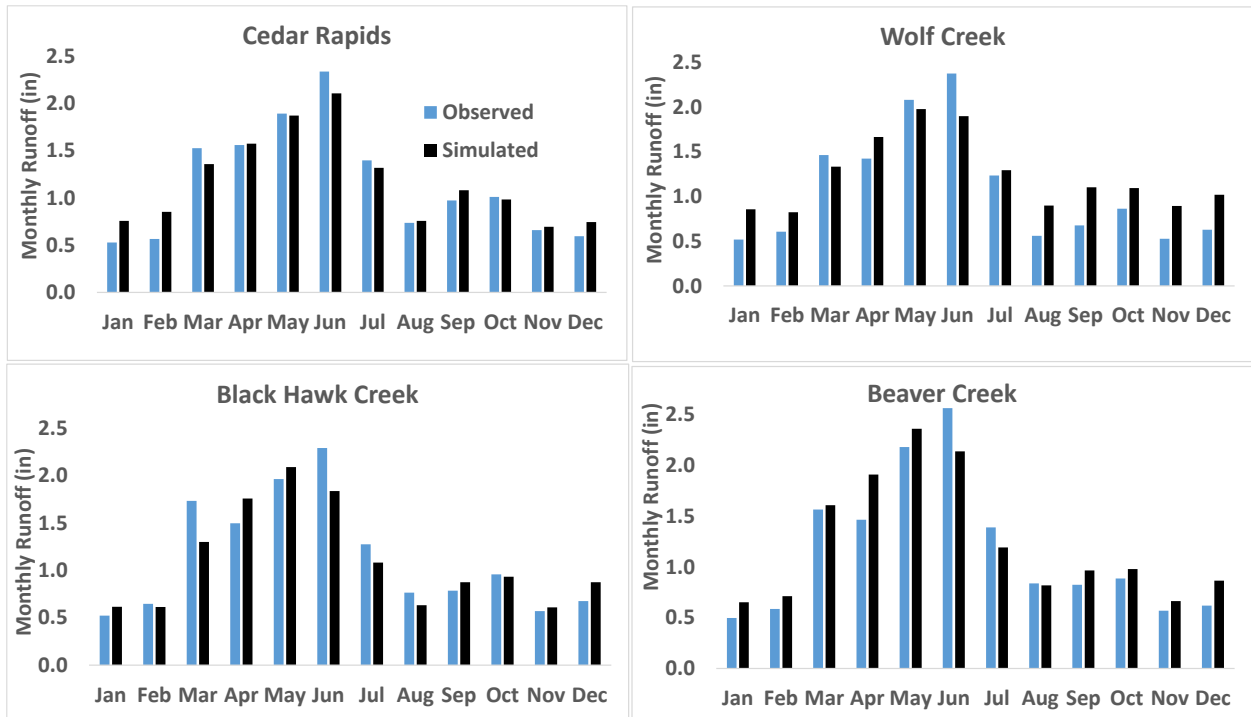


Figure 5-8. Observed and simulated average monthly runoff depths from 2003–2018.

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.

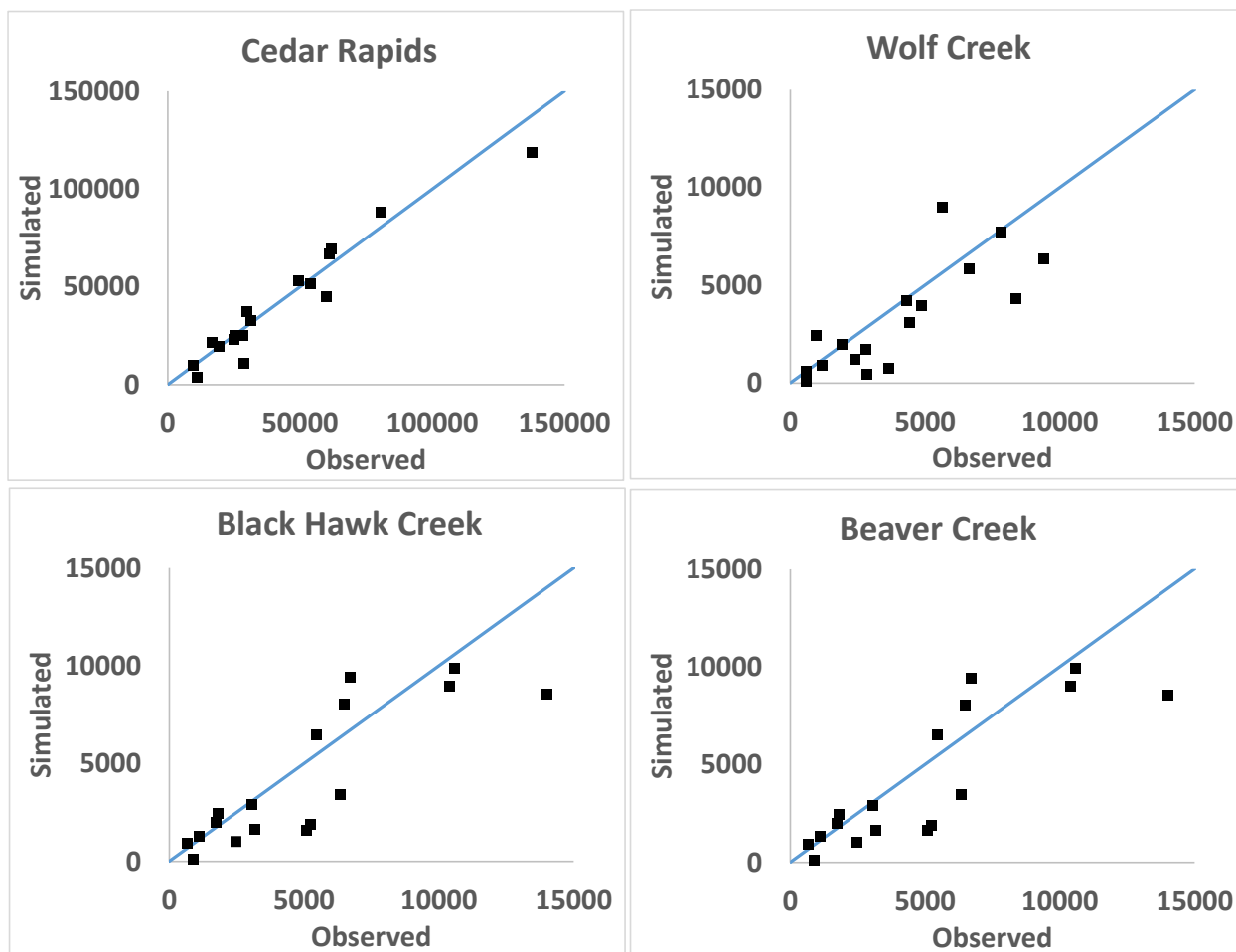


Figure 5-9. Annual peak discharge (in cfs) plotted against a 1:1 line, showing how well modeled peaks matched observed values.

The largest peaks were simulated well at Cedar Rapids and Wolf Creek but under-predicted at Black Hawk Creek and Beaver Creek. Based on the performance metrics, hydrographs, and auxiliary figures presented in this section, the GHOST model was deemed to be well-calibrated for the Middle Cedar Watershed. It is therefore deemed suitable for use as a helpful tool for the IWA.

d. Implementation of IWA Projects in the Model

The calibrated GHOST model for the Upper Wapsipinicon 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 6 provides a full catalogue of the 88 projects constructed in the Middle Cedar Watershed, as well as in-depth details on several samples. This section describes how the effects of the projects were incorporated in the hydrologic model.

The majority of the projects provide significant flood mitigation benefits, with the exception of several grass waterways, grade stabilization projects, and oxbows. Design engineers provided

stage-discharge curves for those projects that could store water. These curves detail 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 5-10 shows this set-up for several of the IWA projects.

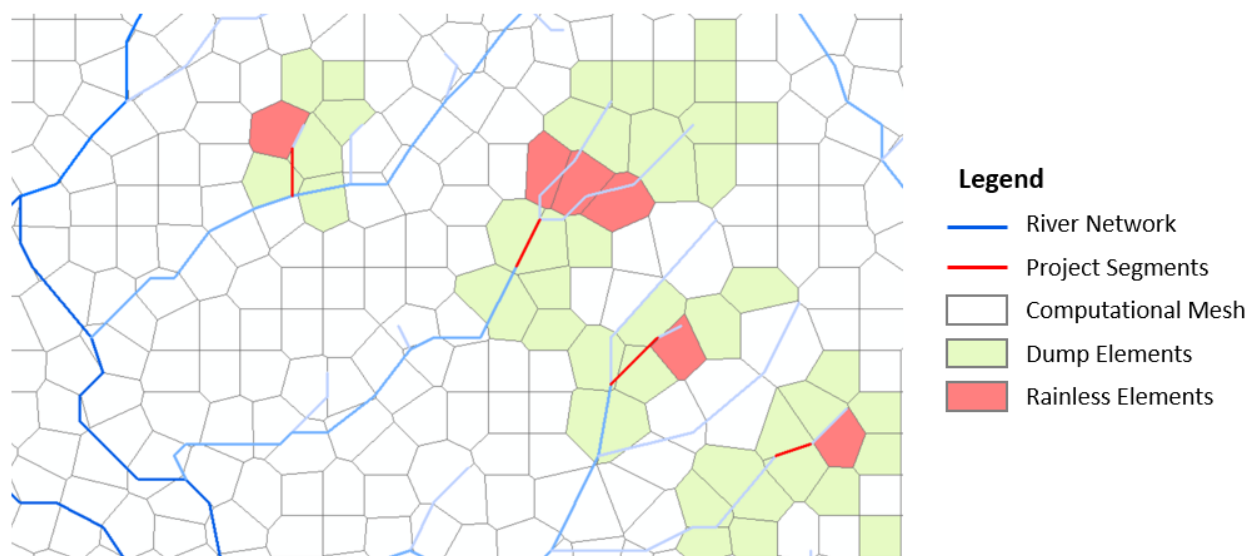


Figure 5-10. A portion of the GHOST model that shows how project effects are simulated by dumping the attenuated outflow hydrograph calculated for each project while eliminating rainfall upstream, which would produce the original, unaltered streamflow.

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 Middle Cedar Watershed

The Iowa Watershed Approach helped fund the design and construction of 88 new BMPs across the Middle Cedar Watershed, providing 90% cost-share assistance to volunteer landowners. A summary of the 88 projects is given in Table 6-1.

BMPs were constructed in eight of the ten HUC12s selected to be part of the IWA; no projects were built in the Opossum Creek or Wildcat Creek subwatersheds. Figure 6-1 shows the location of the 88 projects in the Middle Cedar Watershed. One HUC12 subwatershed, Devils Run – Wolf Creek, is a “pass-through” HUC12s, implying that a high-order stream enters and exits the HUC12, this can limit the impact of projects, which will be covered in further detail in Chapter 7.

Table 6-1: Project Summary Table.

PROJECT	PRACTICE	WATERSHED	COST	DRAINAGE AREA (ac)	Flood Storage (ac-ft)	Berm Storage (ac-ft)
MC-001-BEECHER	POND	HINKLE CREEK	\$39,140.00	65	17.8	25
MC-005-ALBERT	WETLAND	BEAR CREEK	\$137,942.00	112	9.4	21.8
MC-006-ALBERT	WETLAND	BEAR CREEK		n/a	minimal	minimal
MC-007-ALBERT	WATERWAY	BEAR CREEK		n/a	minimal	minimal
MC-008-PALMER	WATERWAY	LIME CREEK	\$16,285.00	n/a	minimal	minimal
MC-009-LEE	WATERWAY	BEAR CREEK	\$19,045.00	n/a	minimal	minimal
MC-010-LEE	GRADE STABILIZATION	BEAR CREEK		n/a	minimal	minimal
MC-011-LEE	POND	LIME CREEK	\$107,755.00	49	18.9	28.7
MC-021-LEE	WETLAND	LIME CREEK	\$46,950.00	20	6.5	7.8
MC-013-COULTER	TERRACE	HINKLE CREEK	\$78,476.00	n/a	minimal	minimal
MC-014-COULTER	TERRACE	HINKLE CREEK		n/a	minimal	minimal
MC-015-COULTER	TERRACE	HINKLE CREEK		n/a	minimal	minimal

MC-016-COULTER	WATERWAY	HINKLE CREEK		n/a	minimal	minimal
MC-017-COULTER	WATERWAY	HINKLE CREEK		n/a	minimal	minimal
MC-018-COULTER	WASCOB	HINKLE CREEK		n/a	minimal	minimal
MC-019-COULTER	WASCOB	HINKLE CREEK		n/a	minimal	minimal
MC-020-COULTER	WASCOB	HINKLE CREEK		n/a	minimal	minimal
MC-030-PRIEBE	WATERWAY	LIME CREEK	\$27,520.00	n/a	minimal	minimal
MC-032-SEDA	POND	TWELVEMILE	\$58,134.00	30	8.5	13.3
MC-033-SEDA	PERENNIAL COVER	TWELVEMILE		n/a	minimal	minimal
MC-034-WILSON	POND	DEVILS RUN	\$50,300.00	24	4.3	6.3
MC-035-WILSON	POND	DEVILS RUN	\$60,956.00	30	22.1	26.7
MC-038-MCMILLAN	WETLAND	DEVILS RUN	\$108,891.00	78.2	21.2	26.5
MC-043-GEATER	POND	BEAR CREEK	\$140,098.00	53	24.4	28.8
MC-044-SEDA	GRADE STABILIZATION	DEVILS RUN	\$72,000.00	n/a	minimal	minimal
MC-045-SEDA	GRADE STABILIZATION	DEVILS RUN		n/a	minimal	minimal

MC-046-SEDA	GRADE STABILIZATION	DEVILS RUN		n/a	minimal	minimal
MC-047-SEDA	GRADE STABILIZATION	DEVILS RUN		n/a	minimal	minimal
MC-048-SEDA	GRADE STABILIZATION	DEVILS RUN		n/a	minimal	minimal
MC-049-KOESTER	BUFFER STRIP	DEVILS RUN	\$44,100.00	n/a	minimal	minimal
MC-053-WOLFGRAM	WETLAND	DEVILS RUN	\$441,640.00	1124	50.2	74.2
MC-054-CLAUSEN	BUFFER STRIP	DEVILS RUN		n/a	minimal	minimal
MC-055-ARP	POND	DEVILS RUN	\$154,803.00	211	53.2	80.6
MC-058-JELLISON	WETLAND	MUD CREEK	\$702,400.00	1336	105.3	130.4
MC-059-CALDERWOOD	POND	FOURMILE CREEK	\$60,298.00	23.7	8.84	12.2
MC-060-HARRISON	POND	PRATT CREEK	\$223,000.00	110	40.5	97
MC-063-KOOP	POND	DEVILS RUN	\$208,210.00	90.3	32.8	49.9
MC-064-HEINEMAN	POND	HINKLE CREEK	\$134,611.00	37	13.4	24.5
MC-068-BALDRIDGE	WASCOB	RODGERS PARK	\$57,000.00	n/a	minimal	minimal

MC-069-BALDRIDGE	POND	RODGERS PARK		23.4	3.5	6.1
MC-070-BALDRIDGE	WASCOB	RODGERS PARK		n/a	minimal	minimal
MC-071-BALDRIDGE	WASCOB	RODGERS PARK		n/a	minimal	minimal
MC-072-BENTONCCB	WETLAND	RODGERS PARK		14.6	3.7	3.8
MC-075-BENTONCCB	WASCOB	RODGERS PARK	\$25,000.00	n/a	minimal	minimal
MC-076-BENTONCCB	POND	RODGERS PARK	\$60,000.00	18.3	1.5	1.5
MC-083-GRIMM	GRADE STABILIZATION (outlet)	HINKLE CREEK	\$19,201.00	n/a	minimal	minimal
MC-121-GRIMM	GRADE STABILIZATION (outlet)	PRATT CREEK	\$23,625.00	n/a	minimal	minimal
MC-077-GRIMM	POND	HINKLE CREEK	\$76,313.00	12.3	2.8	4.7
MC-078-GRIMM	POND	PRATT CREEK	\$65,200.00	39.1	13.6	22.6
MC-080-GRIMM	GRADE STABILIZATION	HINKLE CREEK	\$23,625.00	n/a	minimal	minimal

MC-081-GRIMM	GRADE STABILIZATION	HINKLE CREEK	\$23,625.00	n/a	minimal	minimal
MC-082-HUNTCLUBFARMS	POND	DEVILS RUN	\$250,000.00	208	69.5	96.2
MC-084-MEYER	WETLAND	HINKLE CREEK	\$25,130.00	n/a	0	0
MC-087-NOE	WATERWAY	MUD CREEK	\$101,478.00	n/a	minimal	minimal
MC-088-HENKLE	WETLAND	MUD CREEK	\$339,489.00	193	18.5	27.4
MC-091-CRAWFORD	POND	FOURMILE CREEK	\$54,568.00	7.4	1	1.8
MC-092-CRAWFORD	POND	FOURMILE CREEK	\$173,109.00	89	25.7	41.3
MC-093-CRAWFORD	WASCOB	FOURMILE CREEK	\$44,423.00	n/a	minimal	minimal
MC-094-CRAWFORD	WASCOB	FOURMILE CREEK		n/a	minimal	minimal
MC-095-CRAWFORD	WASCOB	FOURMILE CREEK		n/a	minimal	minimal
MC-098-HENNINGS	POND	PRATT CREEK	\$40,573.00	21.5	5.5	8.8
MC-099-HENNINGS	WASCOB	PRATT CREEK	\$12,000.00	n/a	minimal	minimal
MC-107-KOTOUC	WASCOB	PRATT CREEK	\$118,057.00	n/a	minimal	minimal

MC-108-KOTOUC	WASCOB	PRATT CREEK		n/a	minimal	minimal
MC-109-KOTOUC	WASCOB	PRATT CREEK		n/a	minimal	minimal
MC-110-KOTOUC	WASCOB	PRATT CREEK		n/a	minimal	minimal
MC-111-KOTOUC	WASCOB	PRATT CREEK		n/a	minimal	minimal
MC-112-KOTOUC	GRADE STABILIZATION	PRATT CREEK		n/a	minimal	minimal
MC-113-KOTOUC	WASCOB	PRATT CREEK		n/a	minimal	minimal
MC-114-KOTOUC	GRADE STABILIZATION	PRATT CREEK		n/a	minimal	minimal
MC-115-KNAACK	WASCOB	DEVILS RUN	\$62,853.00	n/a	minimal	minimal
MC-116-KNAACK	WASCOB	DEVILS RUN		n/a	minimal	minimal
MC-117-KNAACK	WASCOB	DEVILS RUN		n/a	minimal	minimal
MC-118-KNAACK	WASCOB	DEVILS RUN		n/a	minimal	minimal
MC-119-KNAACK	WASCOB	DEVILS RUN		n/a	minimal	minimal
MC-120-KNAACK	WASCOB	DEVILS RUN		n/a	minimal	minimal
MC-152-THEDE	POND	FOURMILE CREEK	\$215,000.00	46.6	12.6	23.8
MC-160-JORGENSEN	POND	MUD CREEK	\$167,950.00	99	27.2	48.4
MC-139-HART	POND	PRATT CREEK	\$270,738.00	350	11.4	45.9

MC-158-HICKS	POND	MUD CREEK	\$263,280.00	155.5	54.9	77.3
MC-158-HICKS	WASCOB	MUD CREEK	\$11,845.00	n/a	minimal	minimal
MC-153-156 GIESKING	POND	TWELVEMILE	\$283,850.00	138	38.2	77.3
MC-016-VINTON	WETLAND	MUD CREEK	\$283,274.00	504	29	39.7
MC-141-WAYSON	POND	PRATT CREEK	\$165,610.00	121.4	22	39.1
MC-144-145- GREINER	POND	DEVILS RUN	\$186,730.00	81	23.7	40.9
MC-159-BLOHM	POND	DEVILS RUN	\$141,786.00	55	24.7	42.4
MC-066-FLEMING	POND	PRATT CREEK	\$200,860.00	46	16.2	24.9
MC-067-FLEMING	WASCOB	PRATT CREEK		n/a	minimal	minimal
Total			\$6,718,746.00	5,616	843	1328

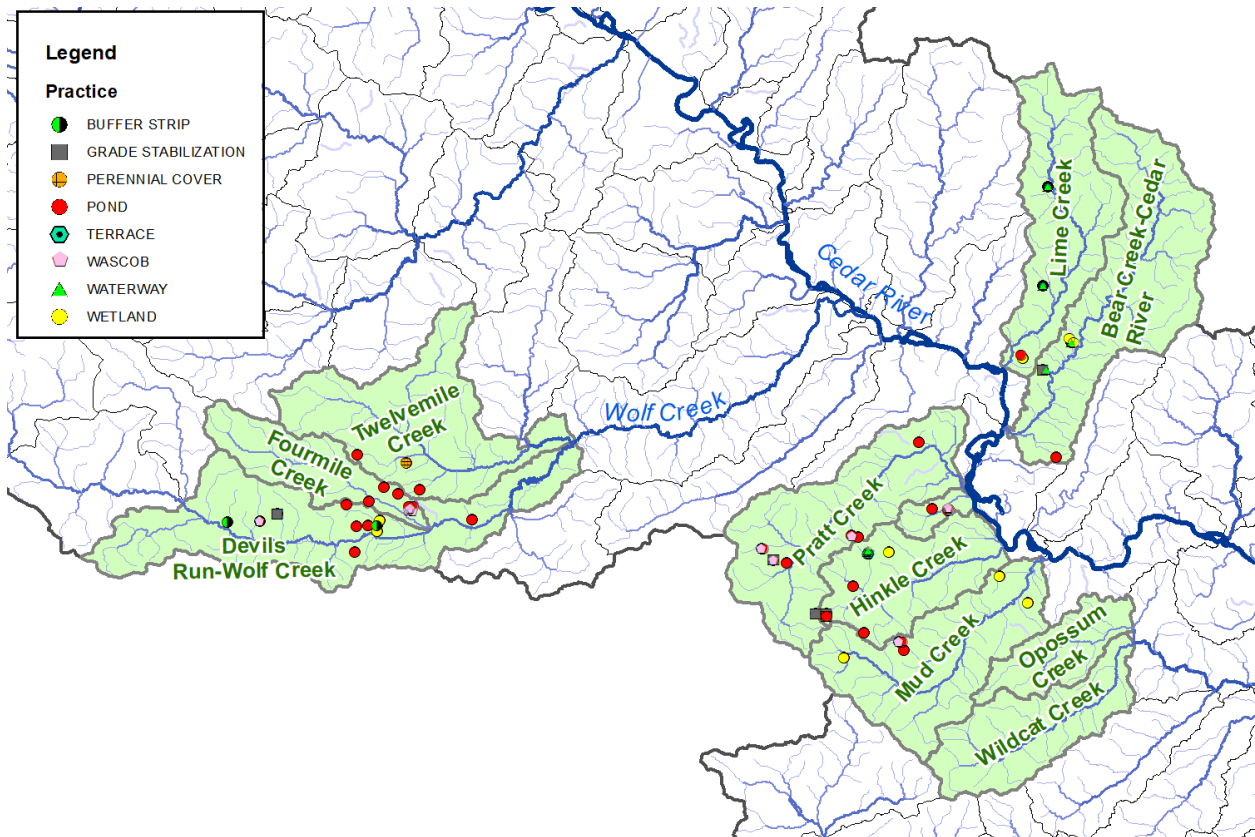


Figure 6-1: Location and type of the 88 IWA projects in the Middle Cedar River Watershed. Note that in several instances, two projects are too close together to appear separate.

b. Hydraulics of Flood Mitigation Projects

Eight different types of BMPs were constructed in the Middle Cedar Watershed: 28 ponds, 25 WASCOBs, 12 grade stabilizations, 10 wetlands, 7 grass waterways, 3 terraces, 2 buffer strips, and 1 perennial cover project. Aside from grass waterways, most projects provide at least some runoff attenuation. However, 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 large 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.

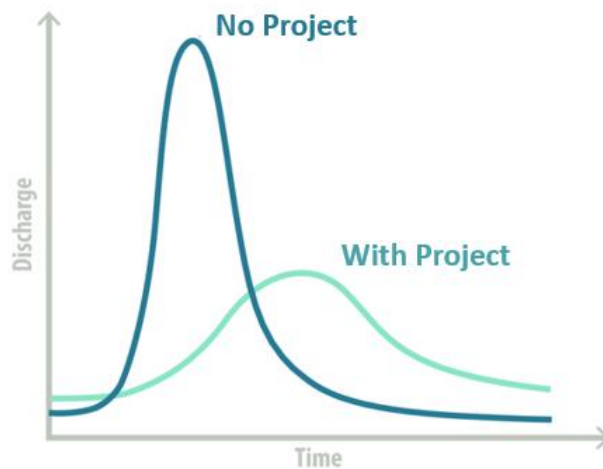


Figure 6-2: A classic comparison of a streamflow hydrograph with and without a flood mitigation project. The addition of the project does not change the volume of water moved but lowers the peak flow passed and gradually releases the water at lower rates.

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.

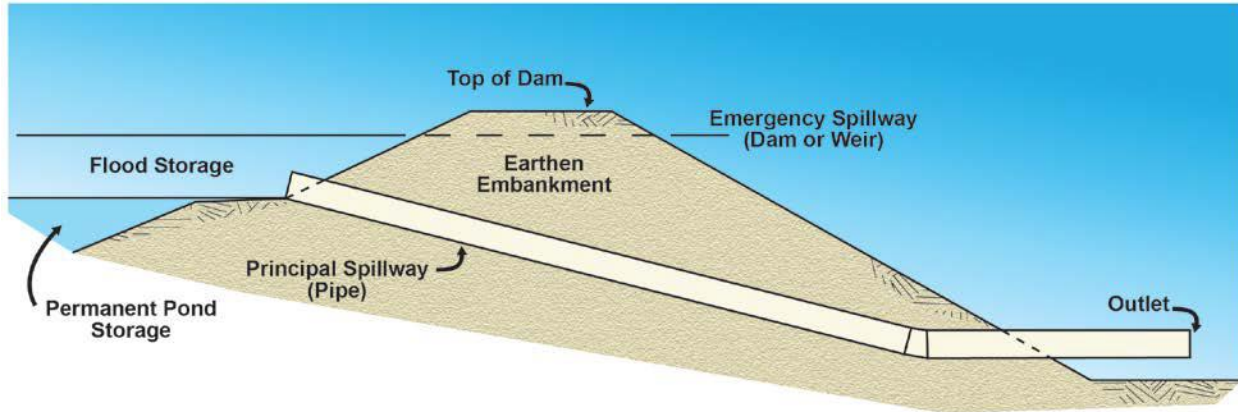


Figure 6-3: Schematic of a pond constructed to provide flood storage.

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, 88 new BMPs were constructed in the Middle Cedar River Watershed:

- 28 Ponds
- 25 WASCObS
- 12 Grade Stabilizations
- 10 Wetlands
- 7 Grass Waterways
- 3 Terraces
- 2 Buffer Strips
- 1 Perennial Cover

Most of these projects will provide meaningful storage and flood reduction benefits for the watershed, and all will help improve water quality. Ponds, wetlands, on-road structures, 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., grass waterways), their size, or their location. However, the hydrologic model was able to simulate the benefits that constructing many 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 Middle Cedar Watershed.

7. Middle Cedar Hydrologic Assessment

a. Individual Impacts of IWA Projects

In order to assess the flood reduction impacts of IWA projects in the Middle Cedar Watershed, a design storm was imposed on GHOST. The storm generated 6.2 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.

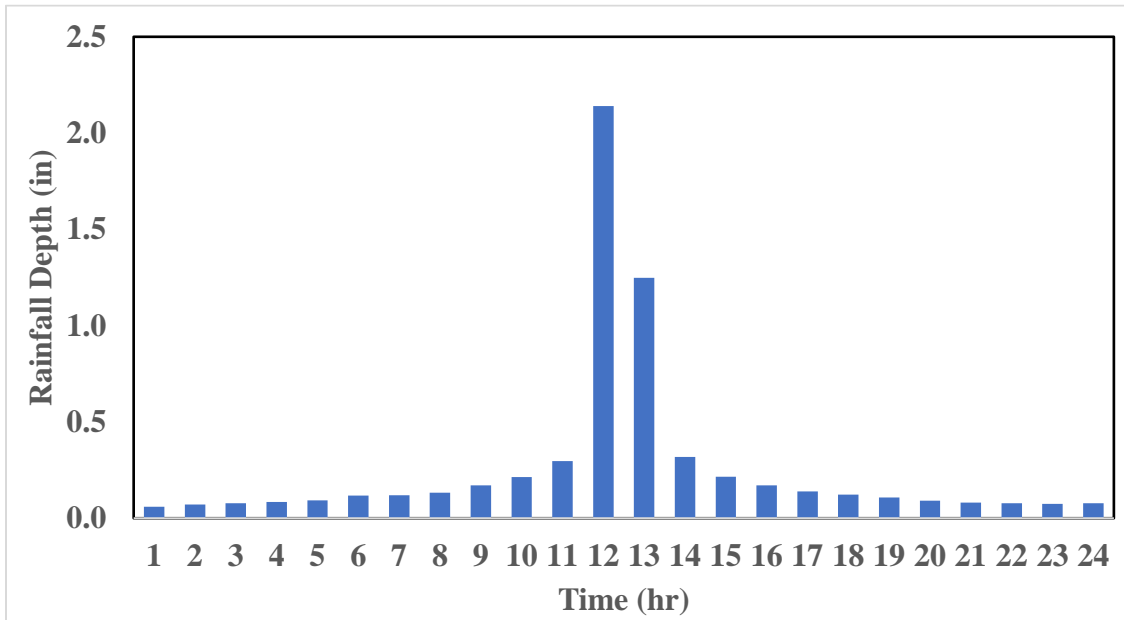


Figure 7-1. Rainfall hyetograph from the design storm used in GHOST to test the effects of projects on flood peak reductions.

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 include examples of the primary types of flood mitigation projects (ponds and wetlands) and represent streamflow responses to project implementation on a local scale.

For the Mud Creek HUC12, Figure 7-2 shows the location of projects MC-158, MC-160, and MC-058 as well as four index points (A, B, C, and D) where the flood-reduction benefits of the projects were assessed. The modeled flow hydrographs (with and without projects) at the selected index points are shown in the lower panel.

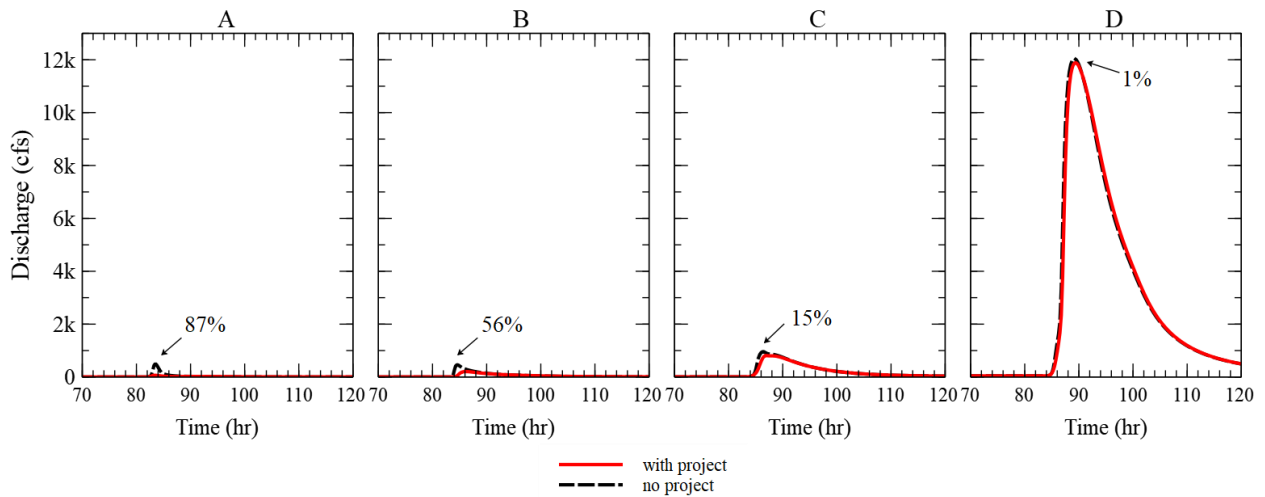
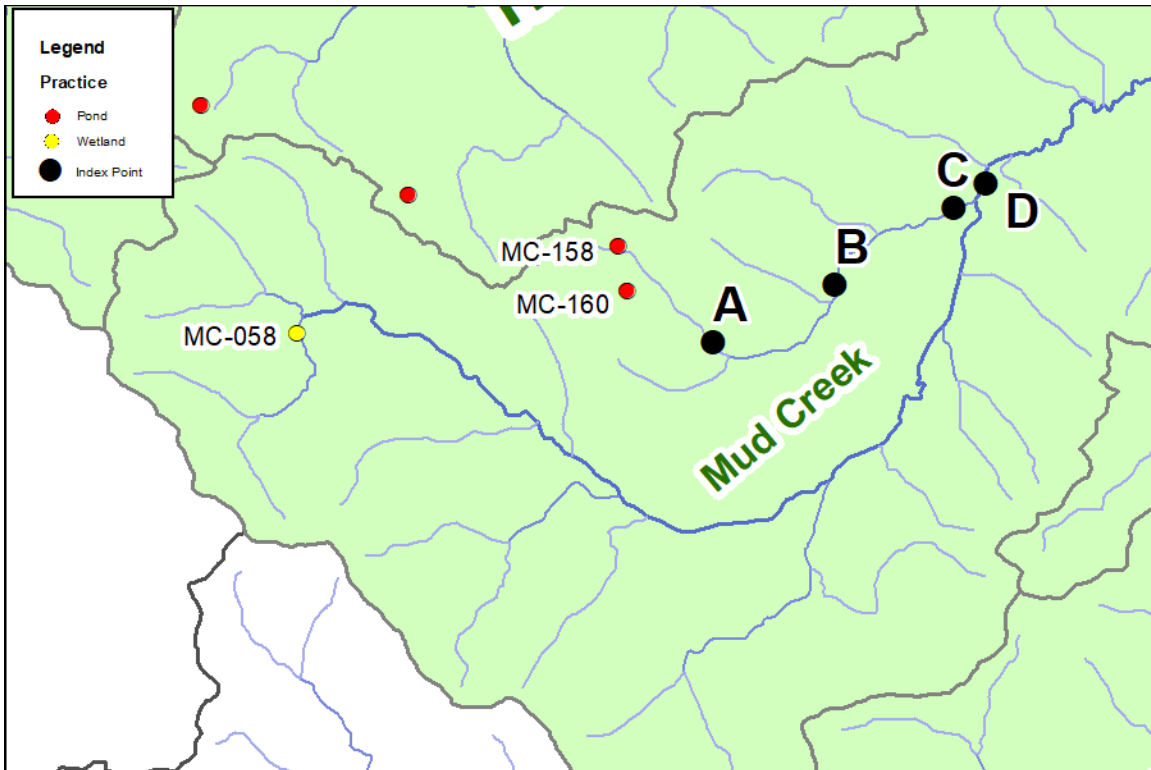


Figure 7-2. The location of projects MC-058, MC-158, MC-160, along with hydrographs comparing the streamflow with (solid red) and without (dashed black) projects at points A, B, C, and D.

Points A, B, and C are located on a tributary of Mud Creek whereas point D is on Mud Creek itself. Modeled hydrographs for these four points show the expected behavior of reduced peak flow attenuation as downstream distance from the project location increases and fraction of the watershed affected by the projects decreases.

At point A, downstream of the projects MC-158 and MC-160, peak streamflow is significantly attenuated by the projects; the corresponding hydrographs show 87% peak flow reduction. Point

B, with a larger upstream drainage area, shows higher peak flows for both simulations (with and without project), but the peak flow reduction at this point is decreased to 56%. Moving further downstream, at point C the peak flow reduction is reduced to 15%. At point D (located on Mud Creek) the flow is regulated by three projects (MC-058, MC-158, and MC-160). However, peak flow reduction at this point is only 1% because a significant portion of the area that drains to this point is not influenced by the projects.

Watershed-Scale Effects

Although most of the projects produced considerable local flood reduction benefits, these impacts are drastically reduced at larger spatial scales. Figure 7-3 shows peak reductions at several large-scale index points for the design storm (Figure 7-1) used to generate the hydrographs in the previous section. The four index points in Figure 7-3 are located at points that receive water from areas greater than 13,000 acres downstream from multiple IWA projects. Peak flow reductions for these areas range from 0.3 to 3.1%.

Figure 7-4 summarizes peak flow reductions associated with the design storm (Figure 7-1) at the outlets of HUC12 watersheds containing constructed management practices. Peak flow reductions are variable among the HUC12s, ranging from less than 0.1 to 3.1%. 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 7-1 compares the drainage areas of the Middle Cedar watershed, the HUC12 watersheds in which practices were constructed, and those influenced by the practices themselves.

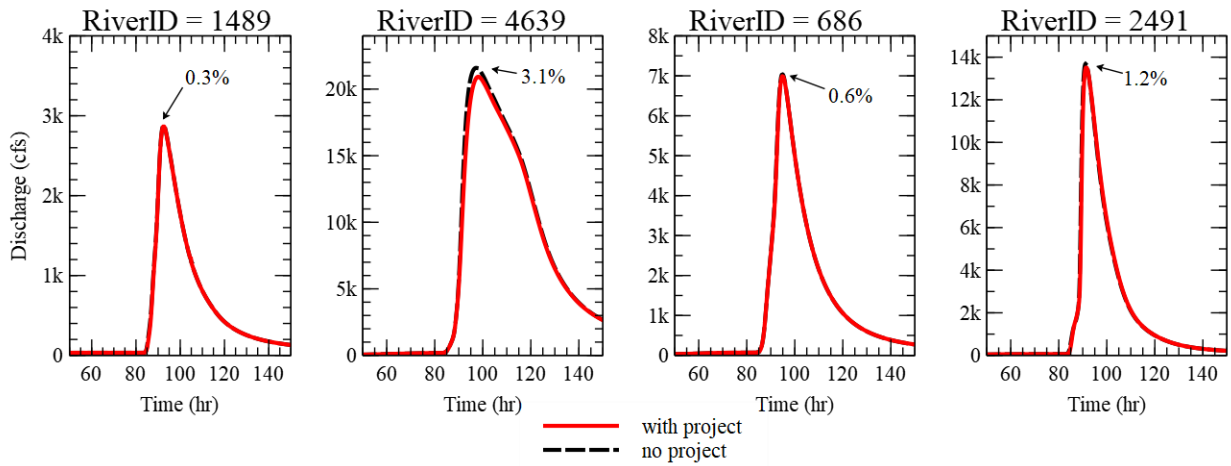
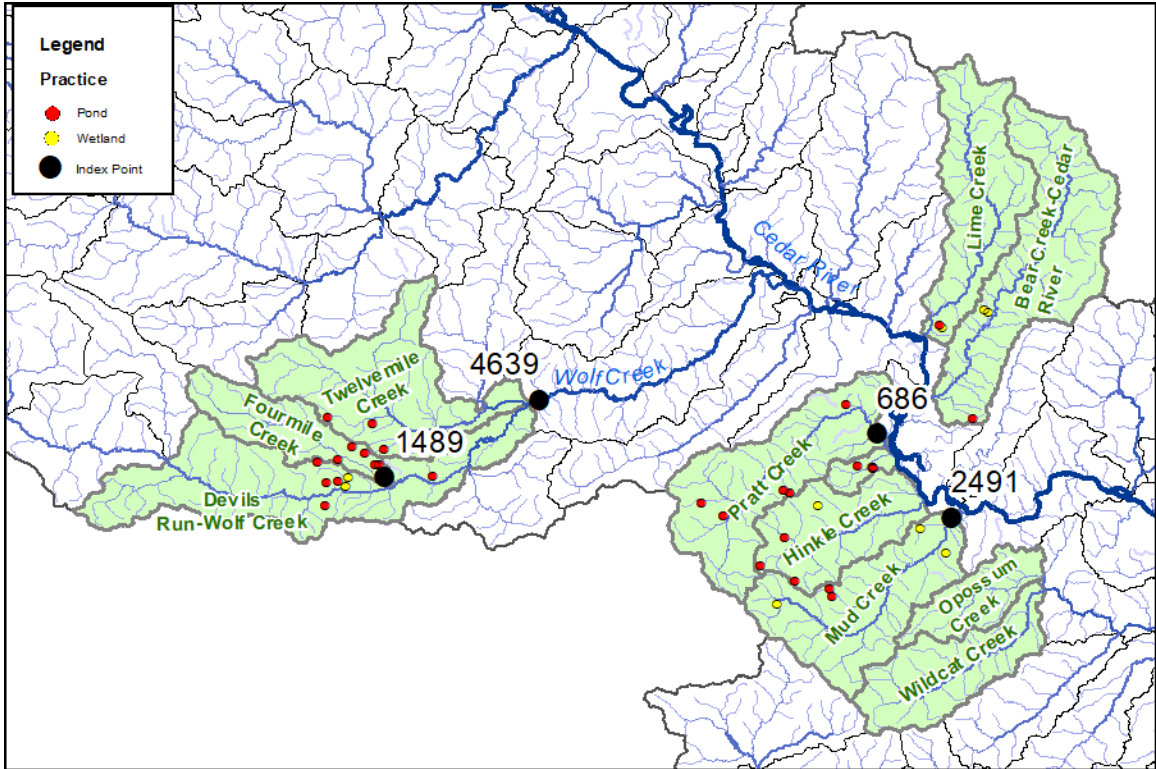


Figure 7-3. Flood peak reduction at four watershed-scale index points: Fourmile Creek outlet (RiverID=1489), Wolf Creek near Dysart (RiverID=4639), Pratt Creek outlet (RiverID=686) and Mud Creek outlet (RiverID=2491).

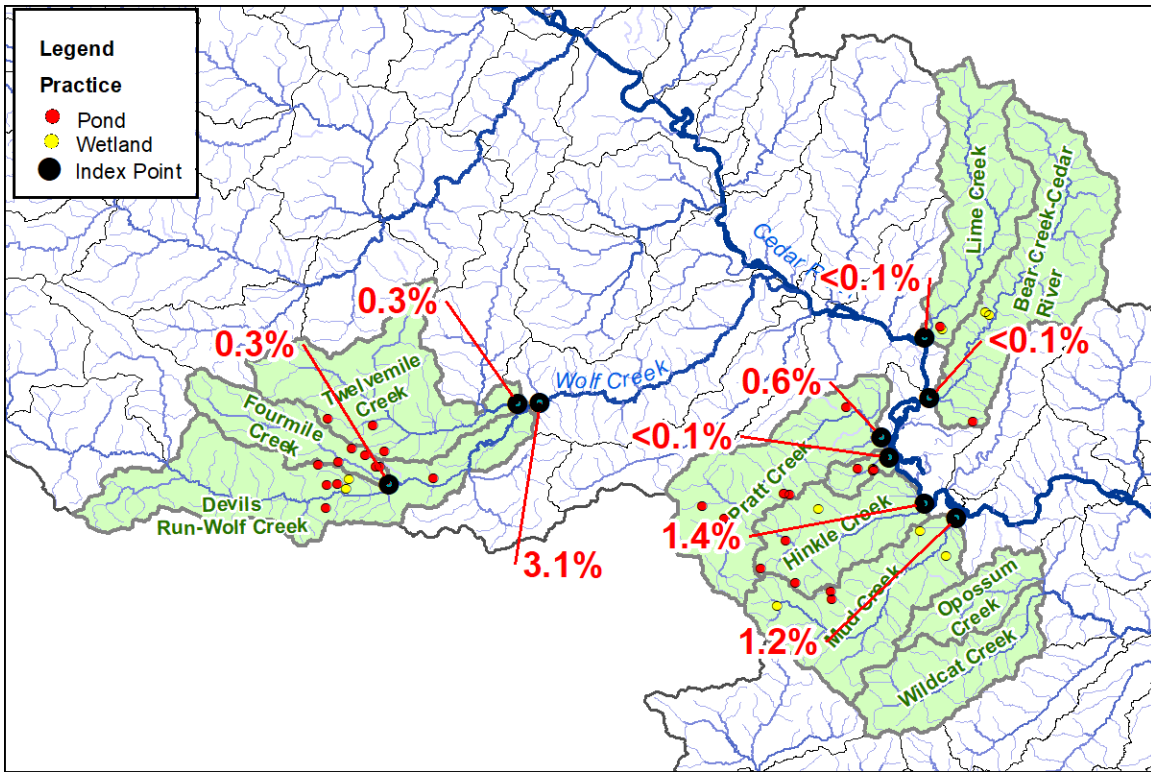


Figure 7-4. Flood peak reduction (red text) at the outlets of HUC12s with projects.

Table 7-1. Drainage area and storage capacity of IWA Projects relative to their HUC12 and the Middle Cedar River Watershed (MC).

HUC12 Watershed	HUC12 Watershed Area (ac)	HUC12 % of Middle Cedar Watershed Area	IWA Project Drainage Area (ac)	IWA Project % of HUC12 Area	IWA Project % of Middle Cedar Watershed Area	IWA Project Flood Storage (ac-ft)	IWA Project Total Storage (ac-ft)
Hinkle Creek	19,611	1.3%	141.1	0.7%	0.01%	45	72
Bear Creek-Cedar River	38,410	2.5%	165	0.4%	0.01%	34	51
Lime Creek	29,790	1.9%	69	0.2%	0.00%	25	37
Mud Creek	28,502	1.8%	2287.5	8.0%	0.15%	235	323
Twelvemile Creek	32,239	2.1%	376	1.2%	0.02%	116	187

Devils Run-Wolf Creek	39,724	2.6%	1612.5	4.1%	0.10%	209	307
Fourmile Creek	13,639	0.9%	247.7	1.8%	0.02%	72	120
Pratt Creek	31,696	2.1%	539.8	1.7%	0.03%	76	181
Dudgeon Lake State Wildlife Management Area-Cedar River	2,788	0.2%	177.7	6.4%	0.01%	31	51
Opossum Creek	10,422	0.7%	0	0	0	0	0
Wildcat Creek	19,688	1.3%	0	0	0	0	0
Total	266,509	17.24%	5,616	2.11%	0.36%	843	1328

b. Limitations of the IWA Projects

While impactful on a local scale, the limited flood reduction benefits of the 88 IWA projects for downstream communities is 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 affected by the IWA projects is 5,616 acres, only 0.36% of the entire Middle Cedar Watershed. It is not surprising, therefore, that peak reductions are negligible at Cedar Rapids, when <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 flood storage of the IWA projects is 843 ac-ft, which may be a difficult number to comprehend without some context.

During the flood of June 2008, the record flood in Cedar Rapids, over 2,600,000 ac-ft of water flowed through the city between June 1 and June 30. If the IWA projects had been in place during this harrowing event, they would have been able to hold back only about 0.03% of the floodwaters.

c. Future Implications

The impact of the 88 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 7-5 shows the approximate cost to achieve a 20% peak reduction in the top-10 floods from 2002-2020, extrapolating from the cost of total storage of the IWA. 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 to billions of dollars.

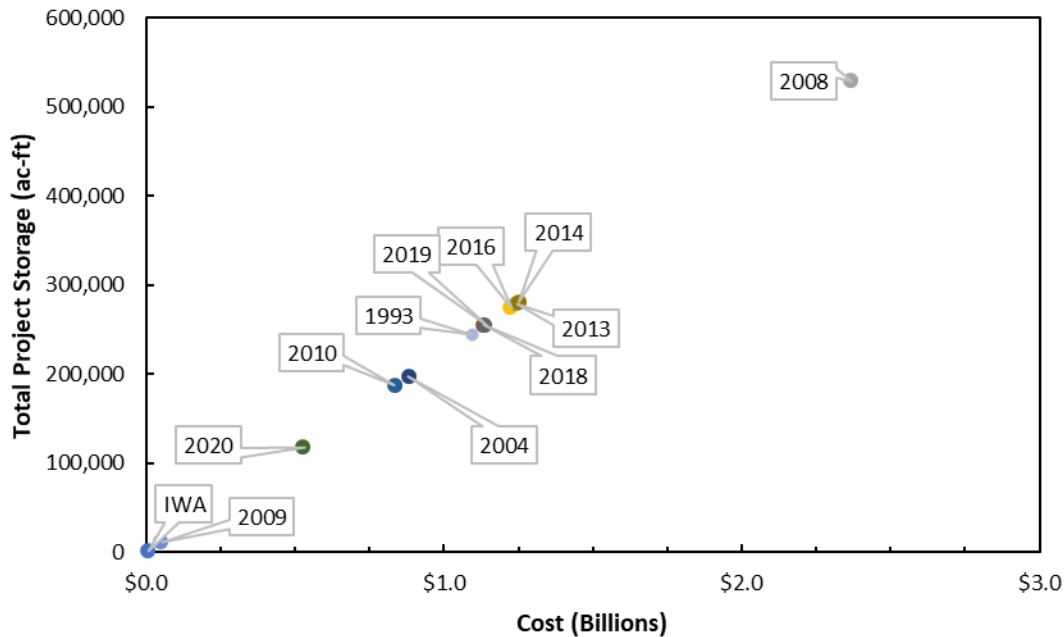


Figure 7-5. Approximate flood storage and cost required to achieve a 20% peak reduction in the top-10 flood events between 2002–2020, compared to the IWA. The 1993 Flood is also included for reference.

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 7-5 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. There are 191 HUC12s (68 in the Middle Cedar Watershed alone) upstream of Cedar Rapids, Iowa. We estimate that more than \$1.2B would be required to make a dent in flooding upstream of Cedar Rapids; this agrees well with Figure 7-5.

8. Summary and Conclusions

The Middle Cedar 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 Middle Cedar River Watershed a catalogue of projects constructed, the model used to assess them, and the results of that evaluation.

a. Watershed Characteristics

The Middle Cedar River Watershed is a 2,400-square-mile HUC8 located in east-central Iowa. The watershed is part of the Cedar River basin, which extends from southern Minnesota into southeast Iowa. At the city of Cedar Rapids, the most downstream point of the Middle Cedar River Watershed, the total drainage area is 6,710 square miles. The watershed lies primarily on the Iowan Surface. Over 70% of the watershed's land area is used for agriculture. Average annual precipitation ranges from roughly 34 inches in the upper part of the watershed to 38 inches near Cedar Rapids. Based upon USGS stream gauge records on Wolf Creek near Dysart and the Cedar River at Cedar Rapids, approximately 30% of the watershed's precipitation becomes streamflow. Flooding is common in the Middle Cedar, much like the rest of Iowa. Record flooding occurred throughout the watershed in 2008.

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 for using data from several monitored locations within and immediately upstream of the Middle Cedar River Watershed. At Cedar Rapids, nitrate concentrations ranged from 0.01 mg/L to 18.5 mg/L, with an average of 5.93mg/L. Total phosphorus (TP) concentrations ranged from 0.01 mg/L to 1.4 mg/L, with an average of 0.32 mg/L. Within the Middle Cedar River Watershed, yearly nitrate yields ranged from 0.1 lbs/ac to 48 lbs/ac, and TP yields were between 0.0 lbs/ac and 3.4 lbs/ac. Annual water yields strongly correlated to annual nutrient yields. Trend detection tests suggested that daily concentrations for nitrate and TP were decreasing in the Middle Cedar River Watershed. Daily nitrate loads were generally increasing, as mean daily flows were also found to be increasing. However, daily TP load trends were decreasing on the main stem of the Middle Cedar but increasing in its tributaries.

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 in Cedar Rapids, Dysart, Hudson, and New Hartford, and could therefore be used with confidence to assess watershed response to IWA projects. 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 88 BMPs across the Middle Cedar Watershed: 28 ponds, 25 WASCOBs, 12 grade stabilizations, 10 wetlands, 7 grass waterways, 3 terraces, 2 buffer strips, and 1 perennial cover project. More than half of the projects are 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 IWA projects. Significant flood reduction benefits were realized immediately downstream of constructed projects. However, benefits decreased rapidly further downstream, as total watershed area increased and proportion of the watershed affected by projects decreased. In the Mud Creek HUC12, an 87% peak flow reduction was stimulated immediately downstream of two pond project sites. This reduction gradually diminished as streamflow increased downstream from the sites until the peak flow reduction was 1% in Mud Creek.

Because of the limited number and size of projects, cumulative impacts on the watershed-scale were small. Peak flows were reduced by 0.6% or less below the Fourmile Creek, Twelvemile Creek, Lime Creek, Bear Creek, Pratt Creek, and Dudgeon Lake HUC12s. The outlet of the Devil's Run, Hinkle Creek, and Mud Creek HUC12s saw 3.1% or lower peak flow reductions due to the IWA projects. No projects were constructed in the Opossum Creek or Wildcat Creek HUC12s.

The 88 IWA projects regulate drainage from over 5,600 acres and can store more than 840 ac-ft of flood water. However, these capacities are dwarfed by the size of the entire Middle Cedar Watershed. Less than 0.4% of the entire drainage area is regulated by these projects. And if the projects had been in place during the flood of 2008, they would have been able to store just 0.03% of the flood waters that passed through Cedar Rapids. An incredible investment in upstream flood mitigation infrastructure and land management would be required in both the Middle Cedar and upstream watersheds to begin to address flooding large scale flooding on the main stem of the Cedar River. Based on the storage achieved by the \$6.7 million spent in the Middle Cedar during Phase II of IWA, hundreds of millions to billions of dollars would be required to reduce the top-10 floods by 20% between 2002 and 2020. 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 Middle Cedar 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, 88 best management practices were constructed within eight of the ten Middle Cedar River study sub-watersheds. The IWA project team used the GHOST hydrologic model to evaluate the flood mitigation performance of constructed practices. 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 88 constructed projects do not have significant flood mitigation benefits at sub-watershed and Middle Cedar River Watershed scales. Realization of watershed-scale benefits will require substantial additional investments in best management practices throughout the Middle Cedar River and upstream. 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

- Bradley, A.A. (2010). “What Causes Floods in Iowa?” A Watershed Year: Anatomy of the Iowa Floods of 2008, C. Mutel (editor), University of Iowa Press, Iowa City, Iowa. 7 - 17.
- Burkart, M. (2010). “The Hydrologic Footprint of Annual Crops,” A Watershed Year: Anatomy of the Iowa Floods of 2008, C. Mutel (editor), University of Iowa Press, Iowa City, Iowa. 77 – 85.
- Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, (2017). Precipitation change in the United States. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 207-230, doi: 10.7930/JoH993CC.
- Iowa Department of Natural Resources (2018). *2018 305(b) assessment summary*. ADBNet - 2018 305(b) Assessment Summary. Retrieved February 8, 2020, from <https://programs.iowadnr.gov/adbnet/Assessments/Summary/2018>.
- Jones, C.S. and Schilling, K.E. (2011). “From Agricultural Intensification to Conservation: Sediment Transport in the Raccoon River, Iowa, 1916-2009,” *Journal of Environmental Quality*, 40.
- Knox, J.C. (2001). “Agricultural Influence on Landscape Sensitivity in the Upper Mississippi River Valley,” *Catena* 42, 193-224.
- Linhart, S.M., and Eash, D.A. (2010). Floods of May 30 to June 15, 2008, in the Iowa and Cedar River basins, eastern Iowa, Open-File Report 2010-1190, 99. U.S. Geological Survey.
- Meierdiercks, K.L., Smith, J.A., Baeck, M.L., and Miller, A.J. (2010). “Analyses of Urban Drainage Network Structure and its Impacts on Hydrologic Response,” *Journal of American Water Resources Research*, 14(4), 416-424.
- Mejia, A.I., Moglen, G.E. (2010). “Impact of the Spatial Distribution of Imperviousness on the Hydrologic Response of an Urbanizing Basin,” *Hydrologic Processes*, 24, 3353-3373.
- Mora, C., Abby G. Frazier, A.G., Longman, R.J., Dacks, R.S., Walton, M.M., Tong, E.J., Sanchez, J.J., Kaiser, L.R., Stender, Y.O., Anderson, J.M., Ambrosino, C.M., Fernandez-Silva, I., Giuseffi, L.M. and Giambelluca, T.M. (2013). The projected timing of climate departure from recent variability, *Nature*, 502(7470).
- Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, 50(3), pp.885-900.
- Mutel, C.M. (2010). A Watershed Year: Anatomy of the Iowa Floods of 2008, C. Mutel (editor), University of Iowa Press, Iowa City, Iowa. 74.
- North Central Region Water Network (2018). About the Agricultural Conservation Planning Framework (ACPF). <https://northcentralwater.org/acpf/>. Accessed July 01, 2018.

- Papanicolaou, A.N., Wacha, K.M., Abban, B.K., Wilson, C.G., Hatfield, J.L., Stanier, C.O., Filley, T.R. (2015). "From soils to landscapes: A landscape oriented approach to simulate soil organic carbon dynamics in intensively managed landscapes," *Journal of Geophysical Research: Biogeosciences*, 120, 2375-2401, doi:10.1002/2015JG003078.
- Politano, M. (2019). GHOST - Generic Hydrologic Overland-Subsurface Toolkit. Iowa City: IIHR - Hydroscience & Engineering.
- Prior, Jean Cutler. *Landforms of Iowa*. University of Iowa Press, 1991.
- PRISM Climate Group. (2018). Oregon State University, <http://prism.oregonstate.edu>, created March 2018.
- Razmand, M. (2020). Development of a Tile Module for GHOST and its Application. Iowa City: University of Iowa.
- Sayre, R. (2010). "The Dam and the Flood: Cause of Cure," *A Watershed Year: Anatomy of the Iowa Floods of 2008*, C. Mutel (editor), University of Iowa Press, Iowa City, Iowa. 103 – 109.
- Schilling, K. (2000). "Patterns of Discharge and Suspended Sediment Transport in the Walnut and Squaw Creek Watersheds, Jasper County, Iowa: Water Years 1996-1998," Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, Iowa.
- Schilling, K.E., Chan, K-S., Jha, M.K., Zhang, Y-K., and Gassman, P.W. (2008). "Impact of Land Use and Land Cover Change on the Water Balance of a Large Agricultural Watershed: Historical Effects and Future Directions," *Water Resources Research*, 44, doi: 10.1029/2007WE006644.
- Schilling, K.E., Chan, K-S., Liu, K-S., and Zhang, Y-K., Gassman, P.W. (2008). "Quantifying the Effect of Land Use Land Cover Change on Increasing Discharge in the Upper Mississippi River," *Journal of Hydrology* 387, pp. 343-345.
- Schottler, S.P., Ulrich, J., Belmont P., Moore, R., Lauer, J.W., Engstrom, D.R., Almendinger, J.E. (2013). "Twentieth Century Agricultural Drainage Creates More Erosive Rivers," *Hydrological Processes*, doi:10.1002/hyp.9738.
- Sprague, L.A., Hirsch, R.M., Aulenbach, B.T. (2011). "Nitrate in the Mississippi River and its tributaries, 1980 to 2008: Are we making progress?" *Environmental Science & Technology*. 2011. August 9;45(17):7209–16.
- Thompson, J. (2003). "Wetlands Drainage, River Modification, and Sectoral Conflict in the Lower Illinois Valley," Southern Illinois University, Carbondale, IL.
- Tomer, M.D., Porter, S.A., James, D.E., Boomer, K.M.B., Kostel, J.A., and McLellan, E. (2013). "Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning" *Journal of Soil & Water Conservation*. 68:113A-120A.

Urban, M.A. and Rhoads, B.L. (2003). "Catastrophic Human-Induced Change in Stream-Channel Planform and Geometry in an Agricultural Watershed, Illinois, USA", *Annals of the Association of American Geographers*, 93(4), 783-796.

Wang, C., Chan, K., Schilling, K.E. (2016). "Total Phosphorus Concentration Trends in 40 Iowa Rivers, 1999 to 2013." *Journal of Environmental Quality*. Madison, WI. doi: 10.2134/jeq2015.07.0365.

Weber, L.J., Muste, M., Bradley A.A., Amado Arenas, A., Demir, I., Drake, C.W., Krajewski, W.F., Loeser, T.J., Politano, M.S., Shea, B.R., Thomas, N.W. (2018). "The Iowa Watershed Project: Iowa's prototype for engaging communities and professionals in watershed hazard mitigation." *International Journal of River Basin Management*, 16:3, 315-328, doi: 10.1080/15715127.2017.1387127.

Wehmeyer, L.L., Weirich, F.H., and Cuffney, T.F. (2011). "Effect of Land Cover Change on Runoff Curve Number Estimation in Iowa, 1832–2001," *Ecohydrol.* 4, 315–321.

Winsor, R. (1975). "Artificial Drainage of East Central Illinois 1820-1920," PhD Thesis, Department of Geography, University of Illinois, Urbana-Champaign, Illinois.

Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B. DeAngelo, S. Doherty, K. Hayhoe, R. Horton, J.P. Kossin, P.C. Taylor, A.M. Waple, and C.P. Weaver, (2017). Executive summary. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 12-34, doi: 10.7930/JoDJ5CTG

Zhang, Y. K. and Schilling, K.E. (2006). "Effects of Land Cover on Water Table, Soil Moisture, Evapotranspiration, and Groundwater Recharge: a Field Observation and Analysis," *Journal of Hydrology*, 319(1-4), 328-338.

Zhang, Y-K. and Schilling, K.E. (2006). "Increasing Streamflow and Baseflow in the Mississippi River since the 1940s: Effects of Land-use Change," *Journal of Hydrology* 325, doi:10.1016/j.jhydrol.200509.033, 412-42.