Iowa Watershed Approach Phase II: Upper Wapsipinicon Watershed

Project Evaluation

October 2022

IIHR Technical Report No. # 534

Prepared by:
Iowa Flood Center | IIHR—Hydroscience and Engineering
The University of Iowa
C. Maxwell Stanley Hydraulics Laboratory
Iowa City, Iowa 52242

Table of Contents

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 Upper Wapsipinicon Watershed:

Members of the Upper Wapsipinicon Watershed Management Authority
Project Coordinators of the Upper Wapsipinicon Watershed Management Authority
Northeast Iowa RC&D
Shive-Hattery, Inc.
Landowners and stakeholders of the Upper Wapsipinicon Watershed
Howard County
Buchanan 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

List of Figures

List of Tables

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 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: Aerial view of flooding in Independence, September 2016

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.

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 Fig. 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 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 3: Flood mitigation pond (UW-023 Hoover) constructed as part of the IWA in the Dry Creek-Wapsipinicon River HUC12, a sub-watershed of the Upper Wapsipinicon 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 Upper Wapsipinicon Watershed to detail the practices constructed and evaluate their individual and cumulative benefits.

Ultimately, 28 BMPs were completed in the Upper Wapsipinicon Watershed as part of the IWA:

- 12 ponds
- 6 oxbows
- 4 wetlands
- 2 on-road structures
- 2 grass waterways
- 1 water and sediment control basin (WASCOB)
- 1 grade stabilization

Figures 3 and 4 show examples of these projects. The total design and construction costs of these projects was just over $1.8 million. Chapter 5 provides details of all 28 practices, and Chapter 6 summarizes the results of the project evaluation.

Figure 4: Flood mitigation pond (UW-027 Osborne) constructed as part of the IWA in the Smith Creek-Wapsipinicon River HUC12, a sub-watershed of the Upper Wapsipinicon HUC8.

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 Fig. 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 Fig. 1-1 (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.

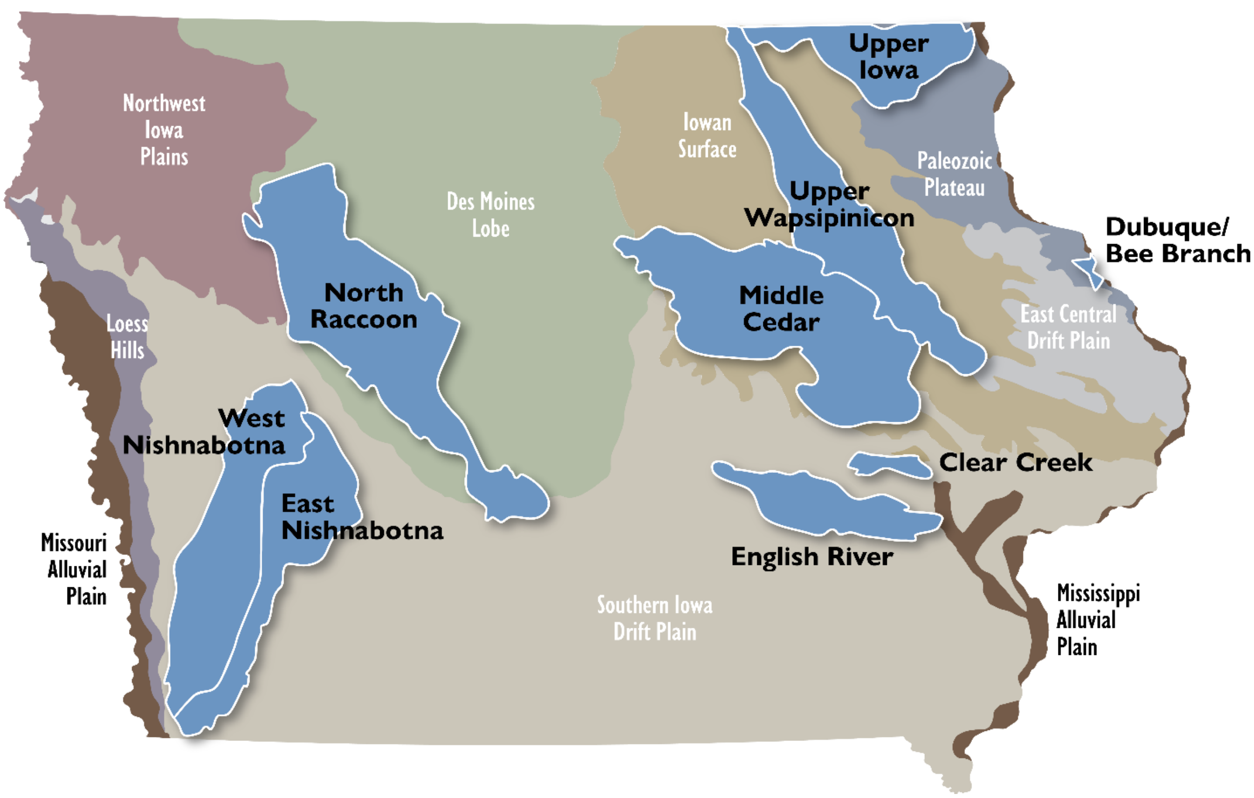

Figure 0-1: The IWA watersheds' positions within the landform regions of Iowa.

Prairies covered Iowa before the arrival of European settlers, as depicted in historical vegetation shown in Fig. 1-2. 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).

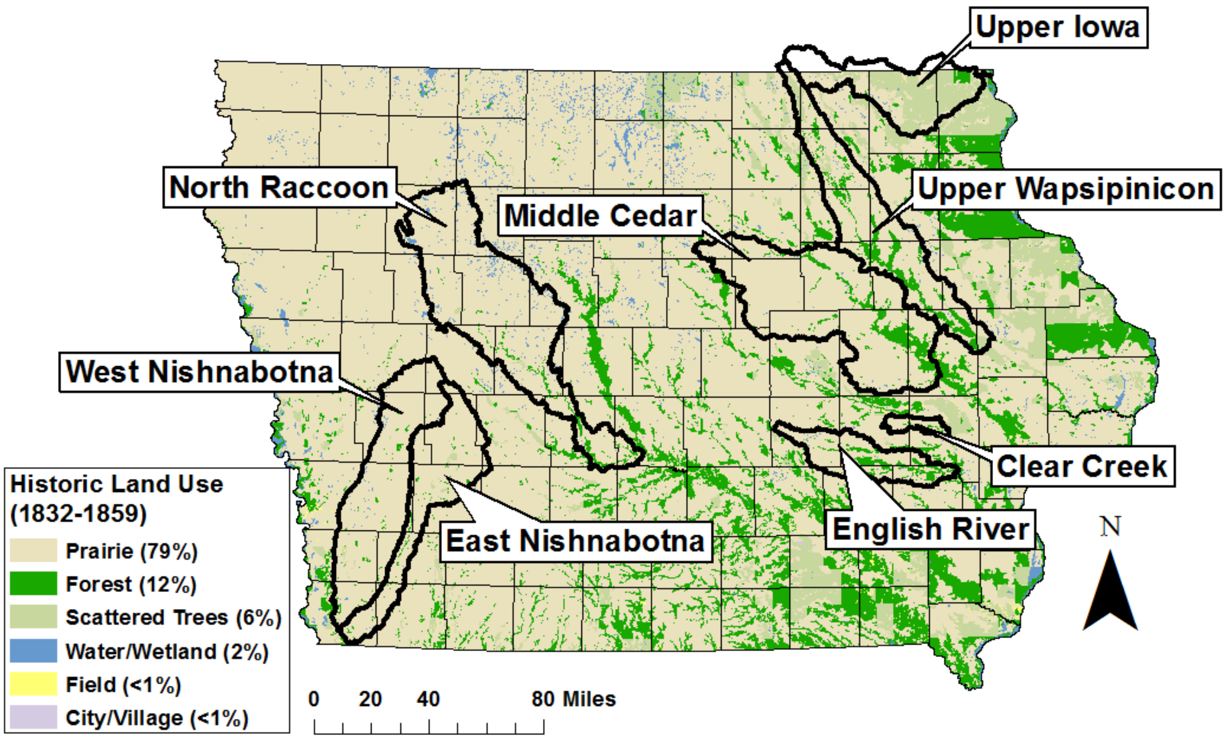

Figure 0-2: Historic vegetation of Iowa 1832–59. Raw data downloaded from the Iowa Geographic Map Server (https://ortho.gis.iastate.edu/).

Today, corn and soybeans cover 64% of Iowa (see Fig. 1-3), 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 Fig. 1-4.

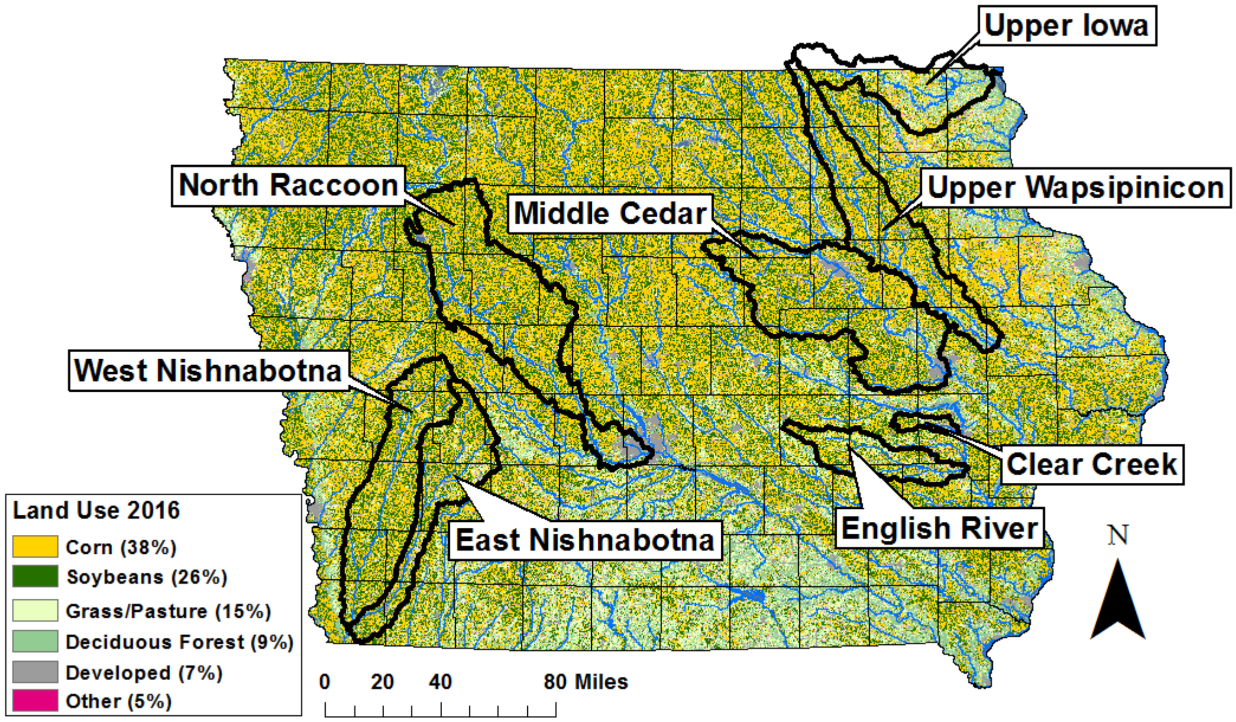

Figure 0-3: Land use composition in the state of Iowa 2016. Cropland Data Layer.

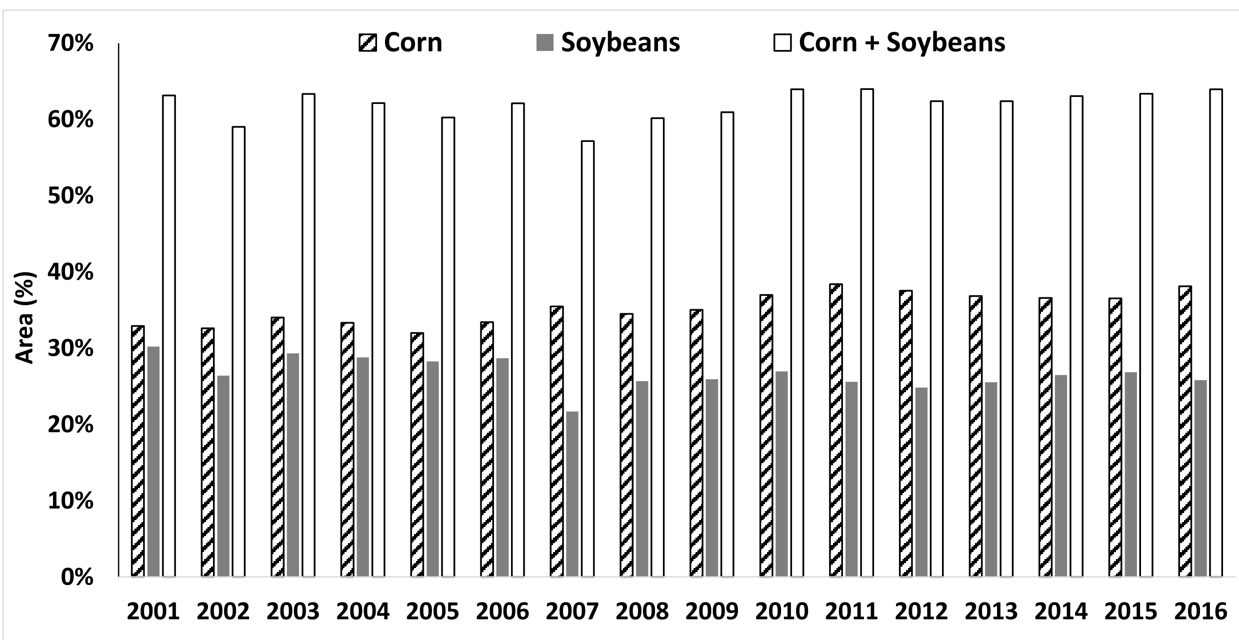

Figure 0-4: Percent of Iowa's total area planted with row crops between 2001 and 2016. Cropland Data Layer.

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 Fig. 1-5. 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 Fig. 1-5, have the power to tax and bond and are governed by trustees.

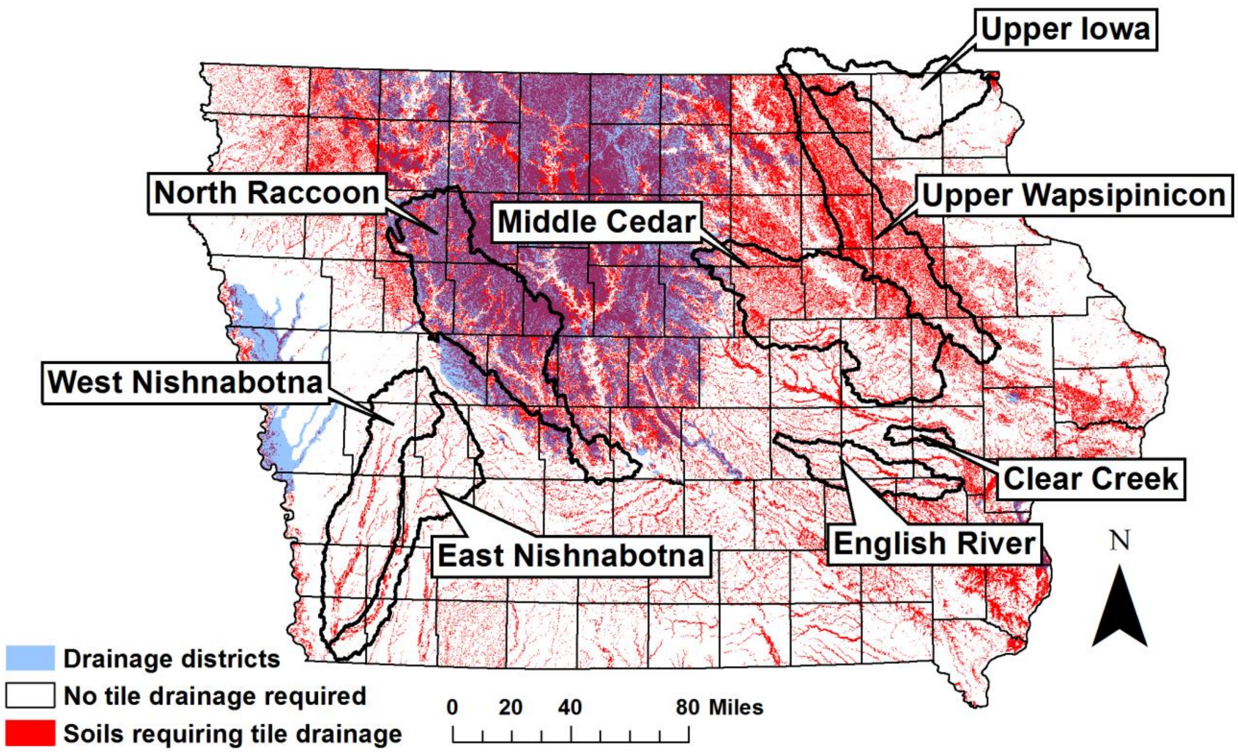

Figure 0-5: Soils requiring tile drainage for full productivity and drainage districts. Raw data source: DNR's NRGIS Library.

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 Fig. 1-6. The average annual precipitation reaches 40 inches in the southeast corner and decreases to 26 inches in the northwest corner.

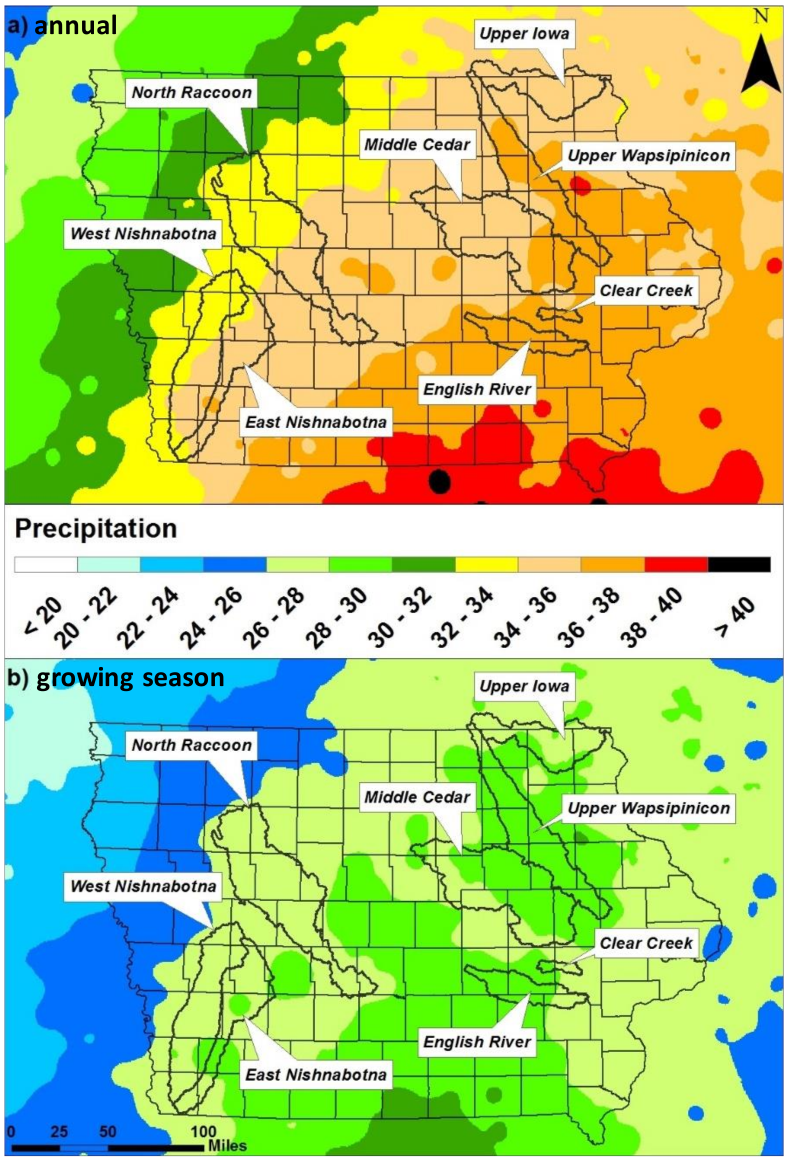

Figure 0-6: Average precipitation (inches): (a) annual; and (b) growing season (April–October). Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

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 Fig. 1-6b 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.

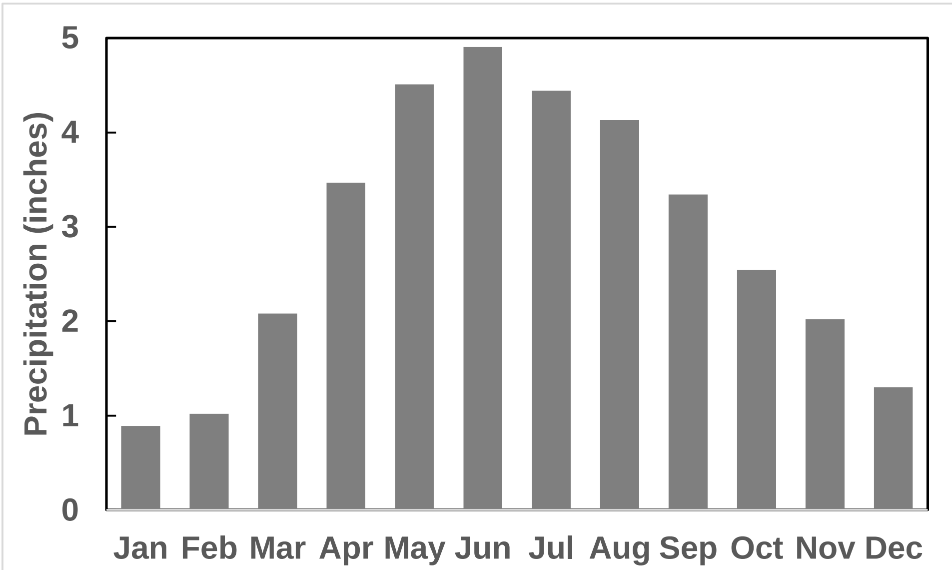

Figure 0-7: Statewide average monthly precipitation. Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

ii. The Water Cycle in Iowa

A large portion of Iowa's precipitation evaporates into the atmosphere — either directly from lakes and streams, or by transpiration from crops and vegetation. What doesn't evaporate drains into streams and rivers. The average annual partitioning of precipitation into evapotranspiration, surface flow, or base flow in each IWA watershed is shown in Fig. 1-8.

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.

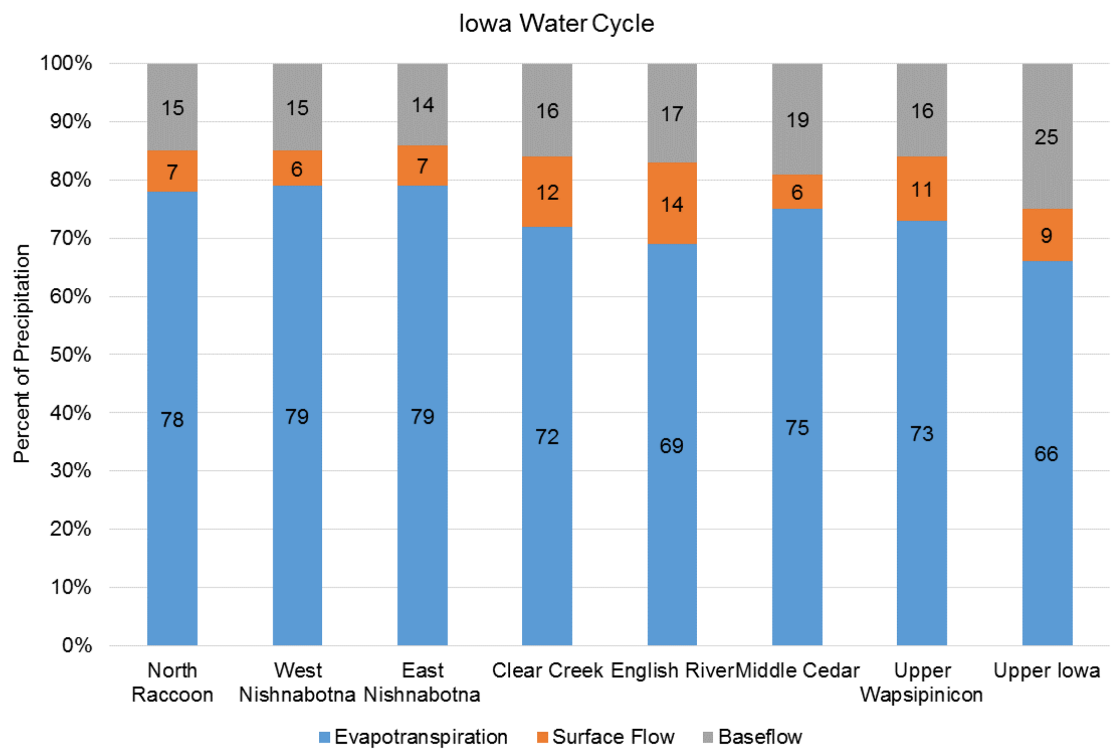

Figure 0-8: Iowa water cycle for the IWA watersheds. This shows the partitioning of average precipitation into evapotranspiration, surface flow, and baseflow components.

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 1-9 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.

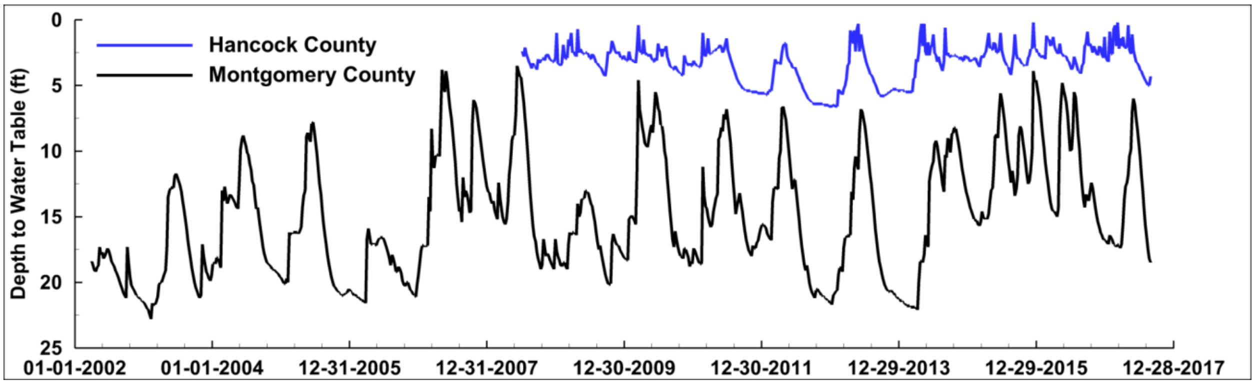

Figure 0-9: Shallow groundwater data (USGS wells).

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 1-10 shows the extent of the flooding during the flood events of 1993 and 2008. In both years, flooding impacted the eight IWA watersheds.

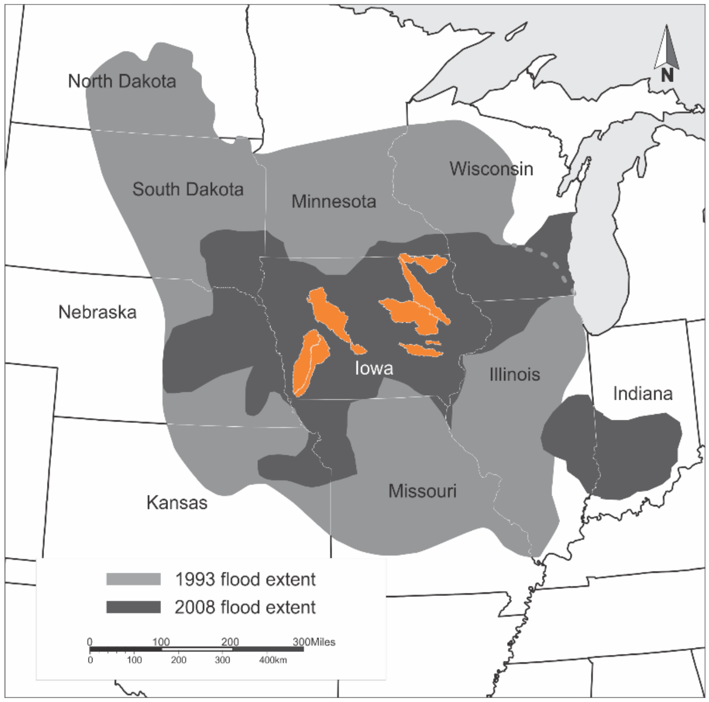

Figure 0-10: The extent of the flooding during the 1993 and 2008 floods (Bradley, 2010).

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 Fig. 1-11) 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 1-1), which were classified as emergency disaster declarations.

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

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

- In the last 30 years, every county in Iowa has experienced sufficiently large and severe flood events to warrant a presidential disaster declaration. The number of FRDDs for each Iowa county from 1988–2016 is shown in Fig. 1-11.

- 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 Fig. 1-12. 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).

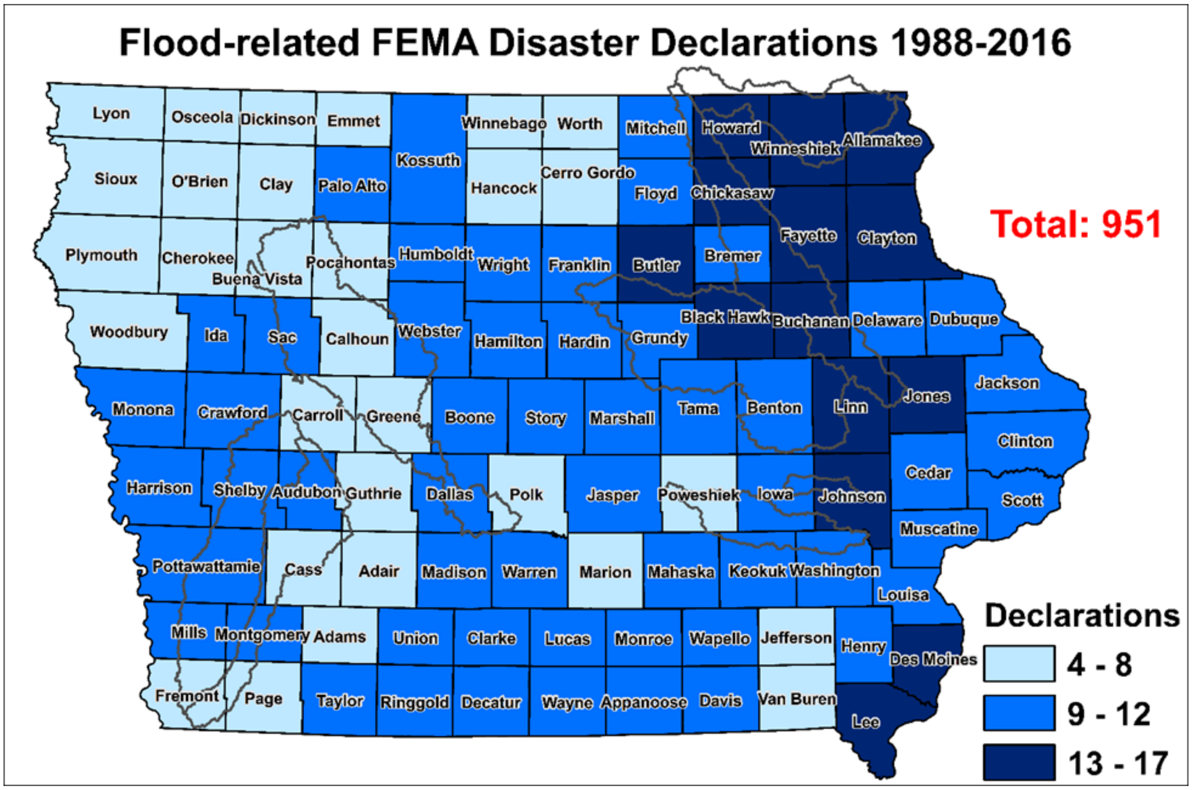

Figure 0-11: Number of flood-related federally declared disasters in Iowa counties (1988–2016). Data source: https://www.fema.gov/.

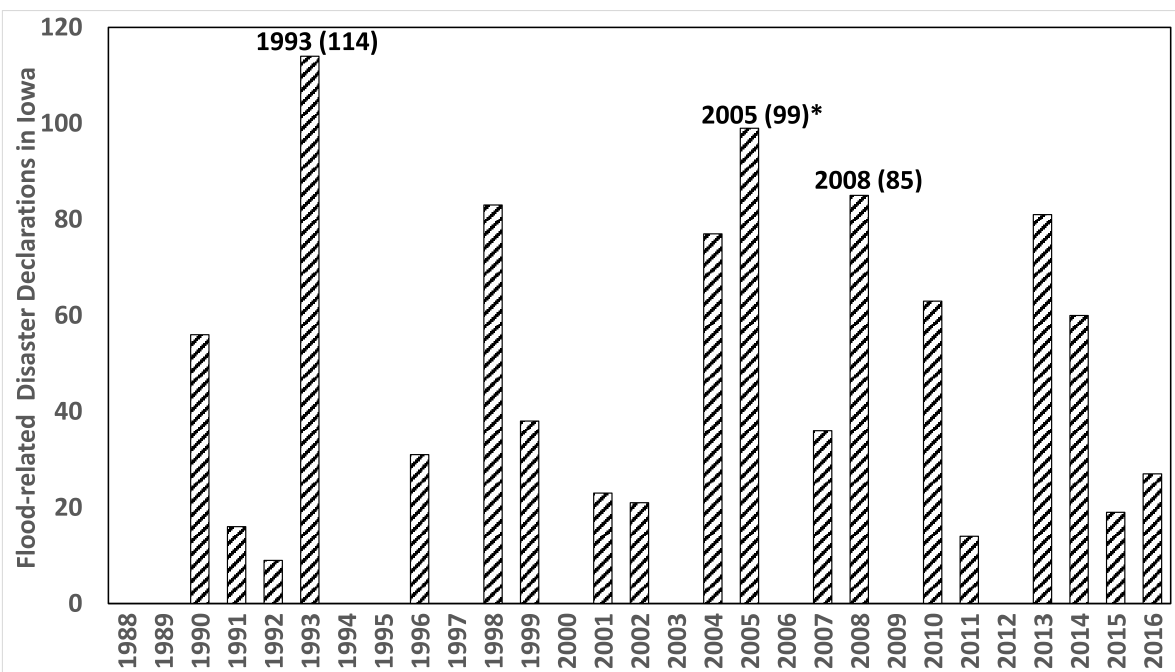

Figure 0-12: The number of flood-related federally declared disasters in Iowa (1988–2016). Data source: https://www.fema.gov/.

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 Fig. 1-13 shows the extent of 2012 drought in Iowa using data generated by the USDM.

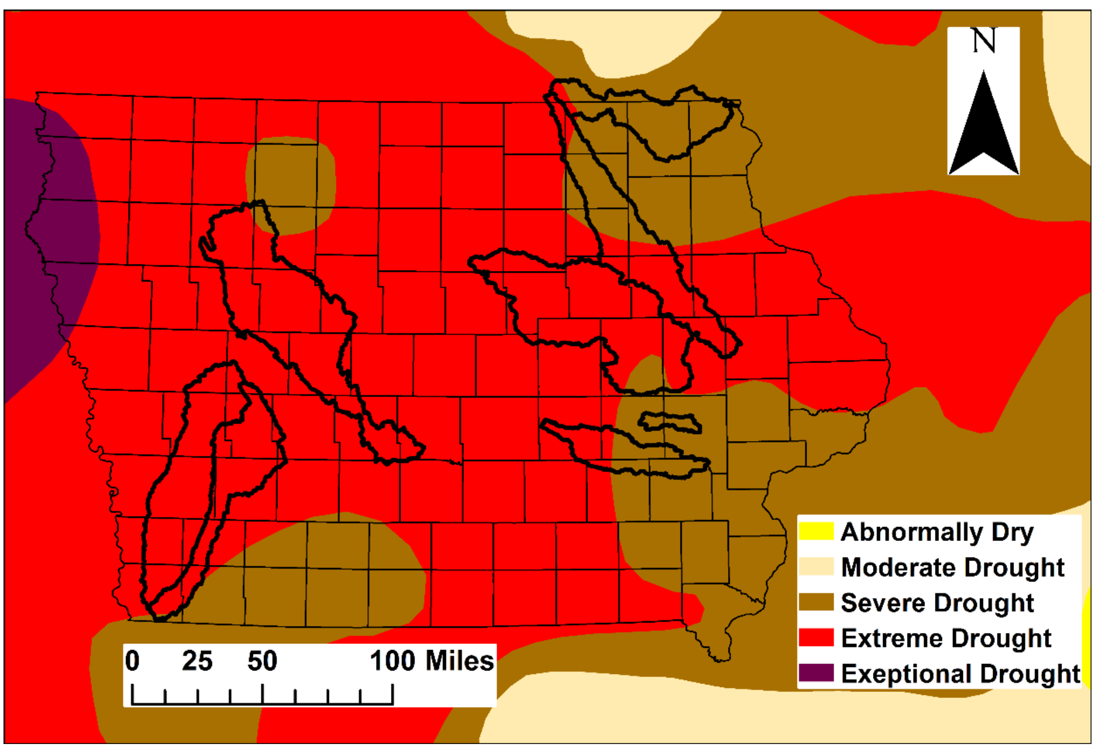

Figure 0-13. Drought conditions, October 09, 2012 (Source: http://droughtmonitor.unl.edu/).

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 Figs. 1-2 and 1-3). 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 1-2). 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 1-2 summarizes the timeline of agriculture-driven land use changes and their impacts on local hydrology.

Table 1-2: 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);	Reduction of runoff and flooding;	Castle (2010); Schilling (2000);

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

ii. Hydrological Alterations Induced by Climate Change

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

"Heavy rainfall is increasing in intensity and frequency across the United States (see Fig. 1-14) and globally and is expected to continue to increase over the next few decades (2021–2050, see Fig. 1-15), 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."

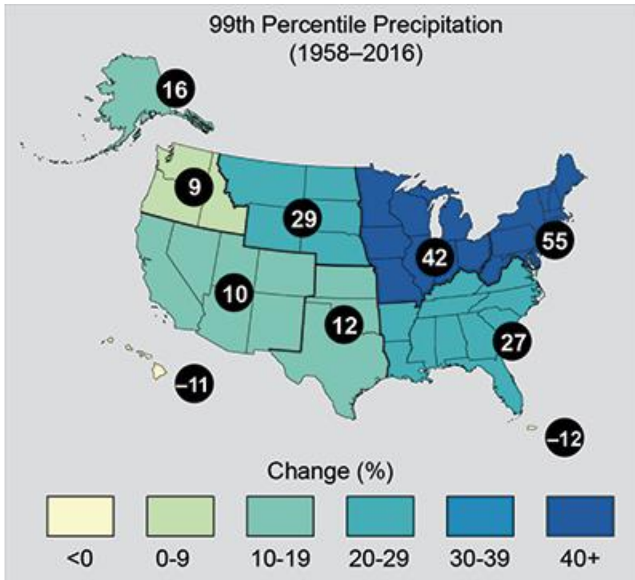

Figure 0-14: Observed change in heavy precipitation (the heaviest 1%) between 1958 and 2016. Figure taken from "The Climate Science Special Report" (Easterling et al. 2017) (https://science2017.globalchange.gov/).

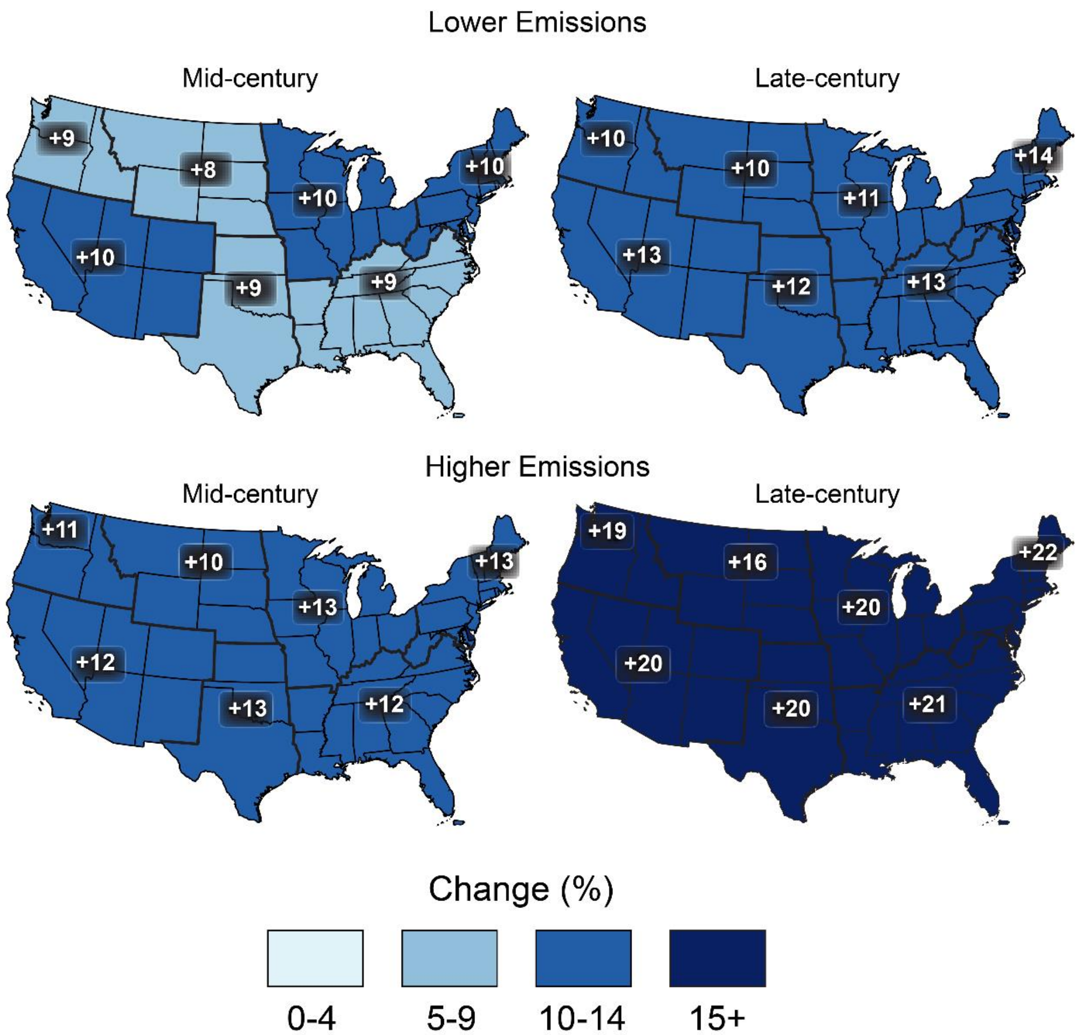

Figure 0-15: Projected change in heavy precipitation. Twenty-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps). Results are shown for a lower emissions scenario (top maps; RCP4.5) and for a higher emissions scenario (bottom maps, RCP8.5). Figure 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 Fig. 1-2). 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 Fig. 1-1. 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 1-16 lists the main causes. Figure 1-17 shows historical numbers of impaired Iowa waters.

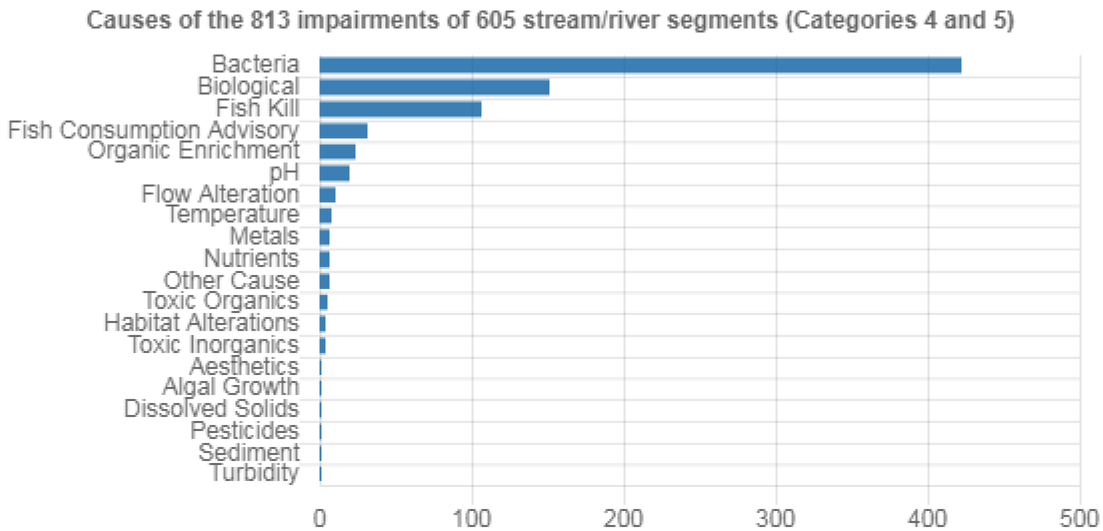

Figure 0-16: Causes of impairments in Iowa's impaired waters. (Iowa Department of Natural Resources, 2018).

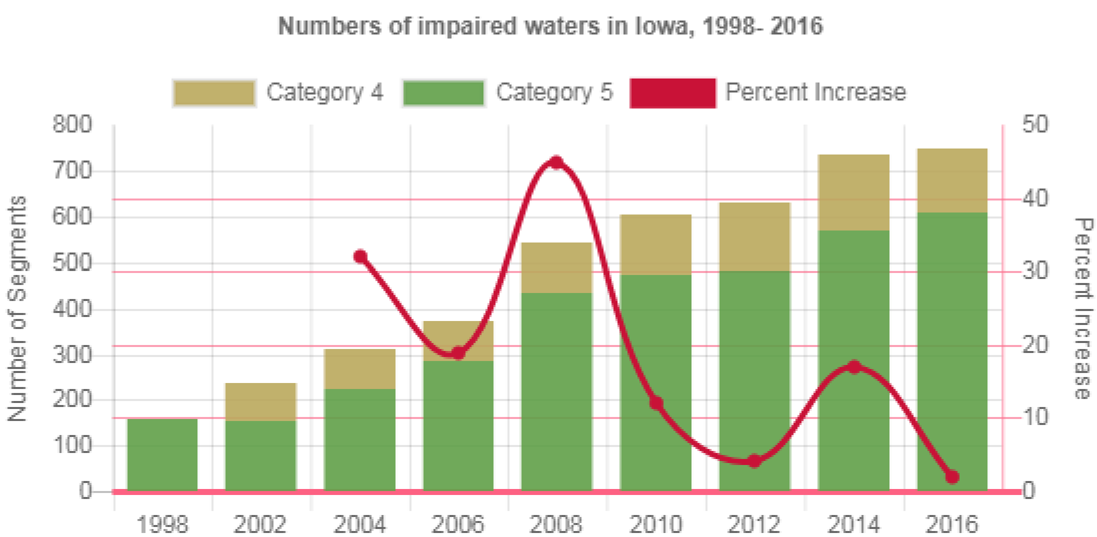

Figure 0-17: Numbers of impaired Iowa waters, 1998–2016. (Iowa Department of Natural Resources, 2018).

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 1-18 shows an example of statewide floodplain map data for the city of Quasqueton.

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 1-19 shows the inundation map library interface for the city of Independence.

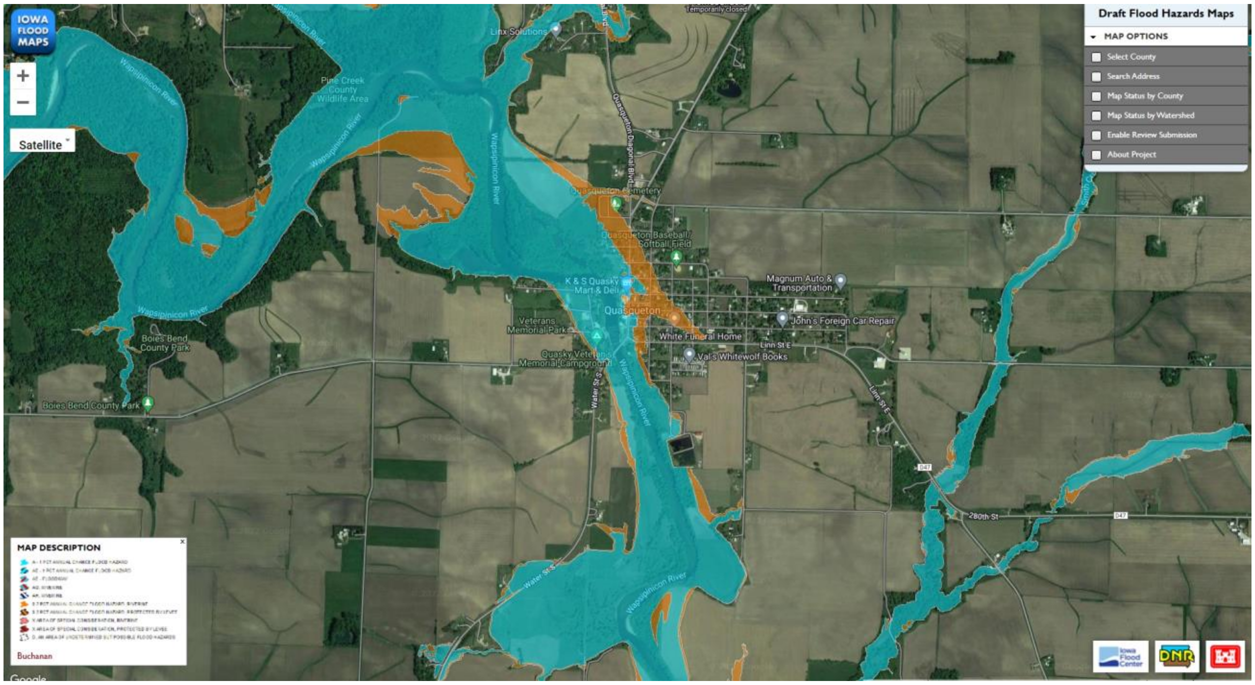

Figure 1-18: Statewide floodplain map data showing different levels of annual flood risk.

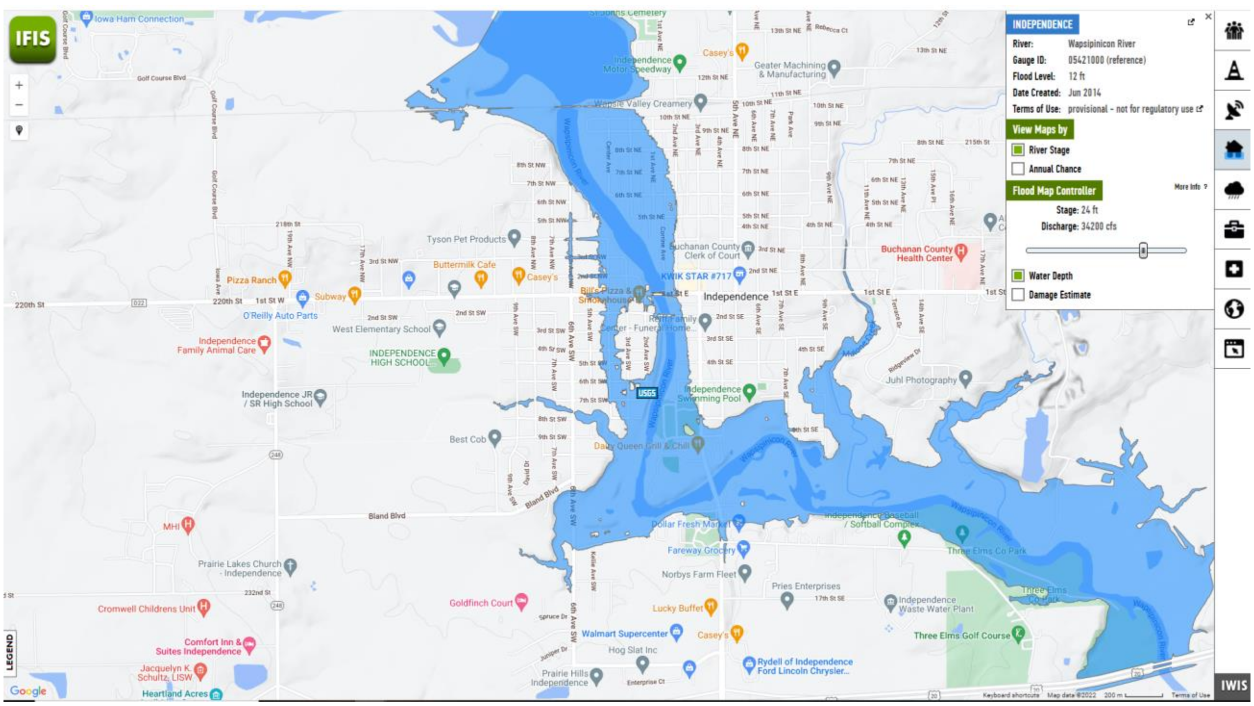

Figure 1-19: Flood inundation map library for the Wapsipinicon River in the city of Independence

Observed stream conditions

IFIS displays data from more than 400 sensors continuously monitoring Iowa stream conditions in real time, as shown in Fig. 1-20. 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.

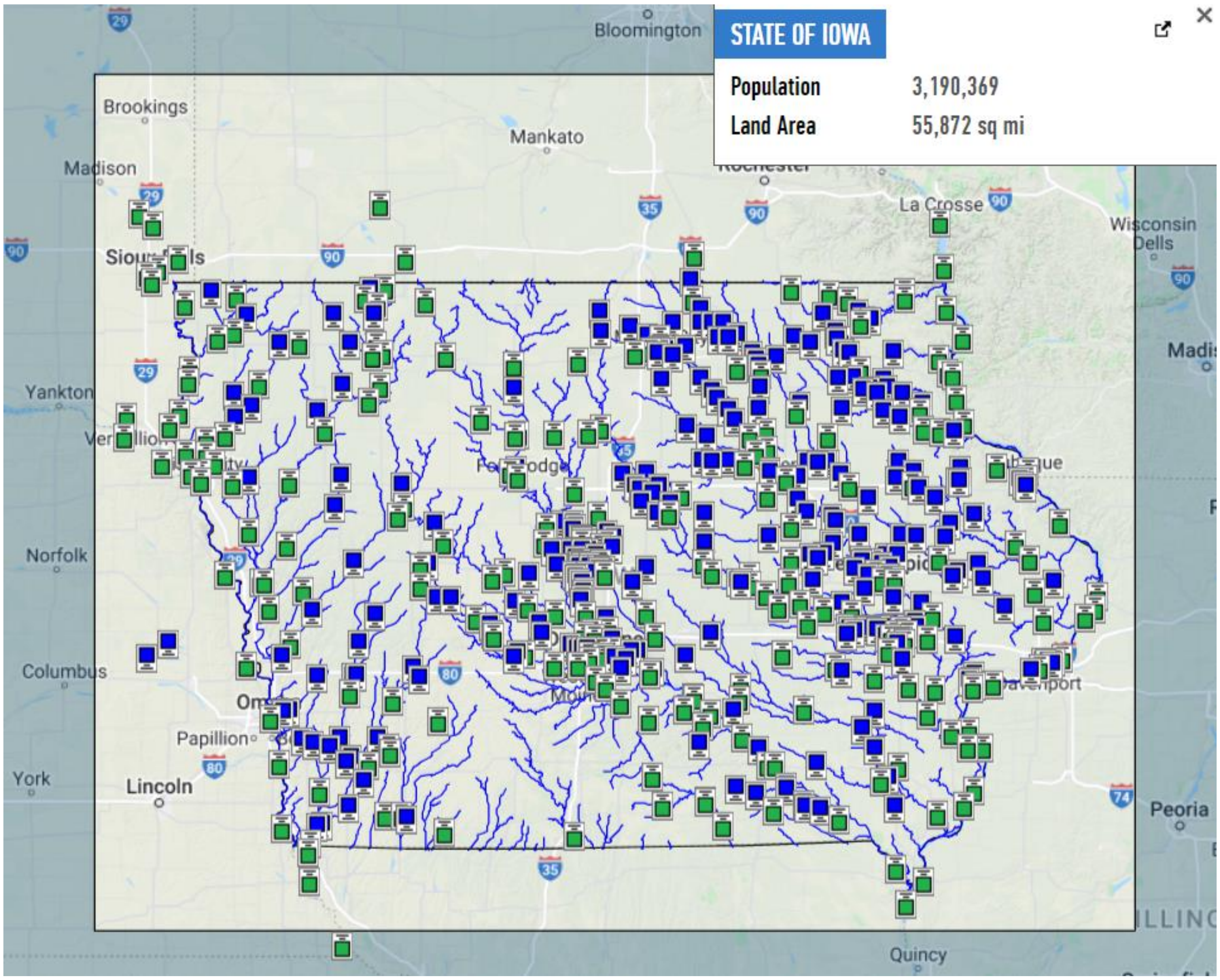

Figure 1-20: USGS (green) and Iowa Flood Center (blue) stream-stage monitoring locations displayed in the Iowa Flood Information System (IFIS).

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 1-21 is a screenshot of IWQIS displaying the WQ network (2022).

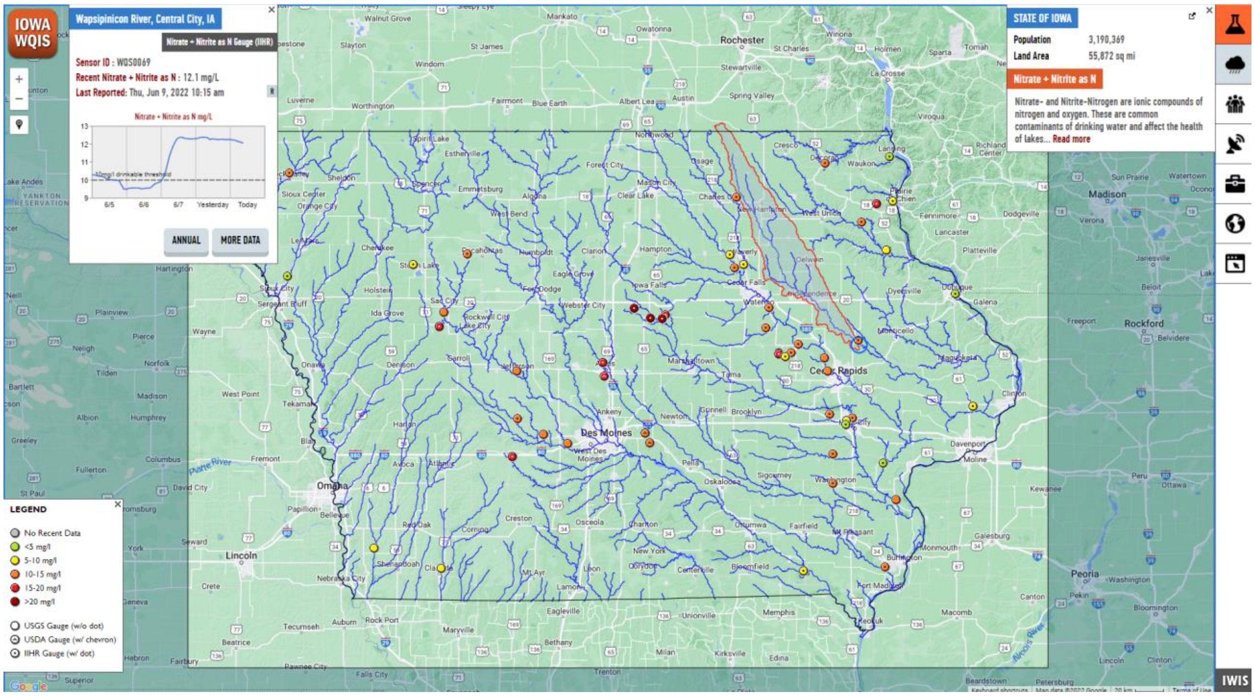

Figure 1-21: IIHR—Hydroscience and Engineering and USGS surface water-quality monitoring locations as displayed on the Iowa Water-Quality Information System (IWQIS).

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 1-22 shows an example view of the IWAIS interface, displaying the number of existing water and sediment control basins within each HUC12 in the Upper Wapsipinicon River Watershed.

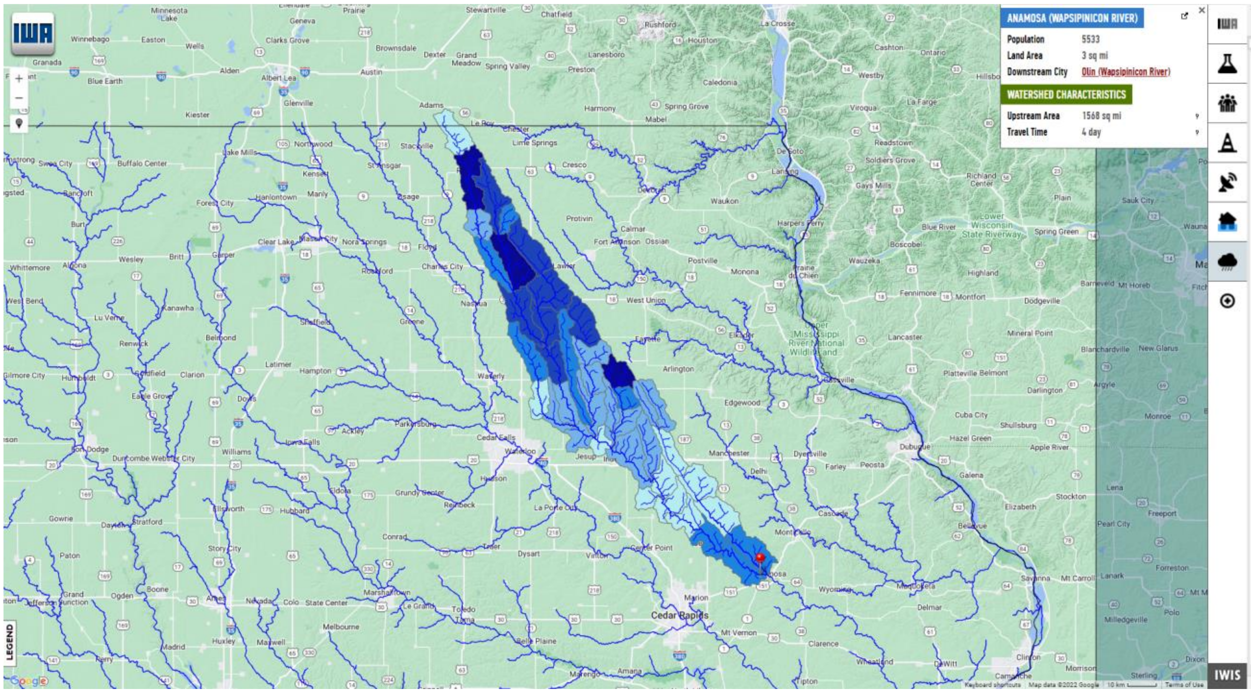

Figure 1-22: Example IWAIS interface view showing the number of existing water and sediment control basins within each HUC12 in the Upper Wapsipinicon Watershed.

Upper Wapsipinicon 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 Upper Wapsipinicon River Watershed, as defined by the boundary of eight-digit Hydrologic Unit Code (HUC8) 07080102, is located in east-central Iowa and encompasses approximately 1,568 square miles (mi^2). The Wapsipinicon River flows into the Mississippi River at the border of Iowa and Illinois. The total drainage area of the Wapsipinicon River at the border of Illinois and Iowa is approximately 2,549 mi^2. The Upper Wapsipinicon River Watershed boundary falls within 11 counties in total; however, the majority of the watershed area lies within Howard, Chickasaw, Bremer, Buchanan, and Linn counties.

Figure 0-1: The Upper Wapsipinicon River Watershed (HUC8 07080102).

Over the last 110 years, annual precipitation in the watershed has fallen between 20 and 46 inches (Fig. 2-3). Average annual precipitation ranges from roughly 33 inches in the upper part to 38 inches near Anamosa (Fig. 2-2). About 30% of the annual precipitation is transformed into streamflow (Fig. 2-4), and approximately 65% of the annual flow comes in the form of baseflow (Fig. 2-5).

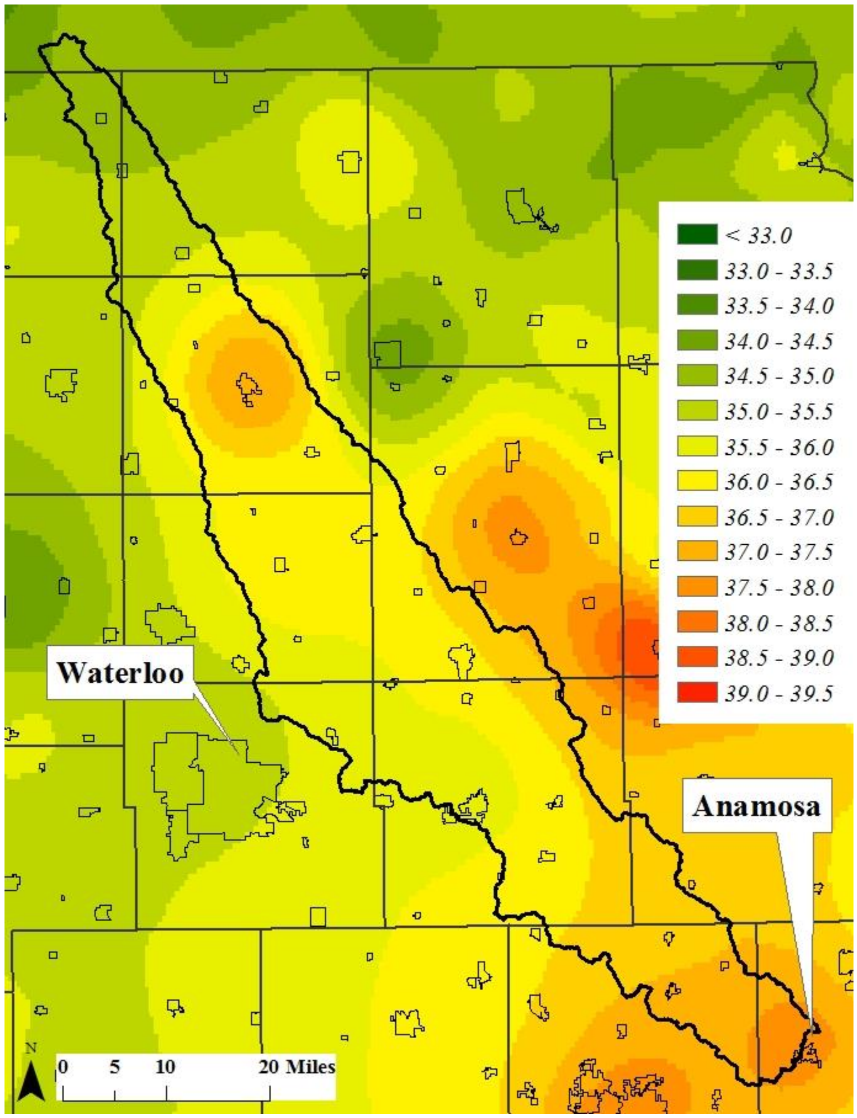

Figure 0-2: Average annual precipitation (inches). Estimates are based on the 30-year annual average (1981–2010).

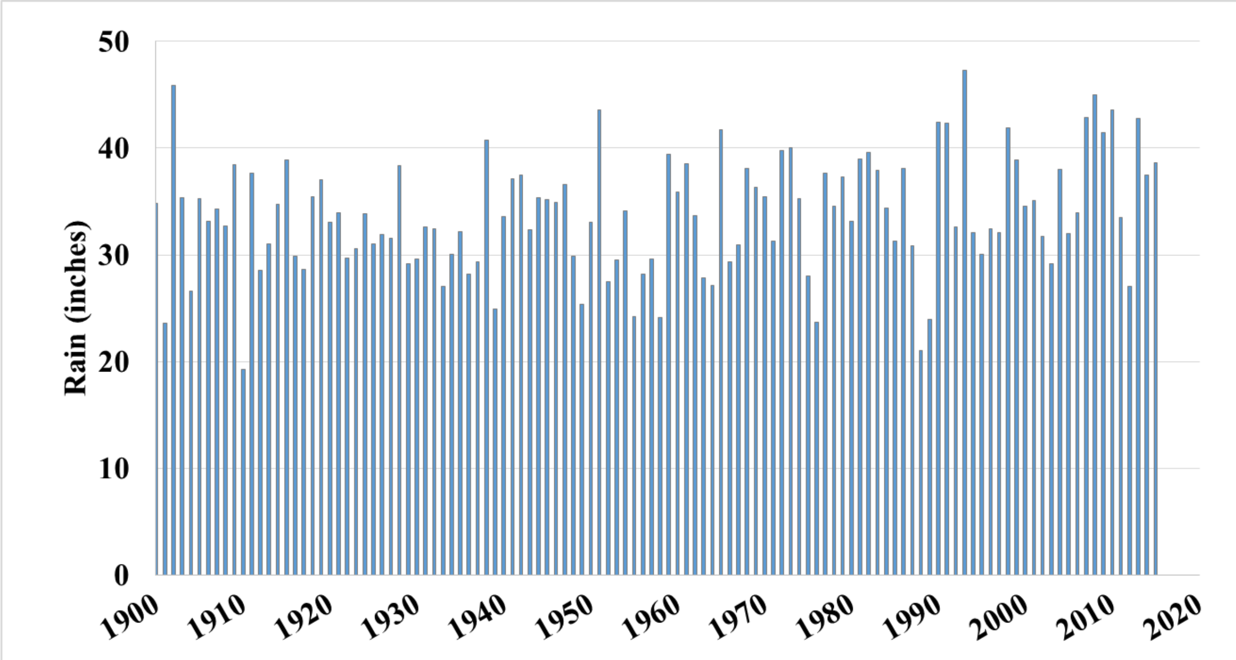

Figure 0-3: Bar graph of annual precipitation.

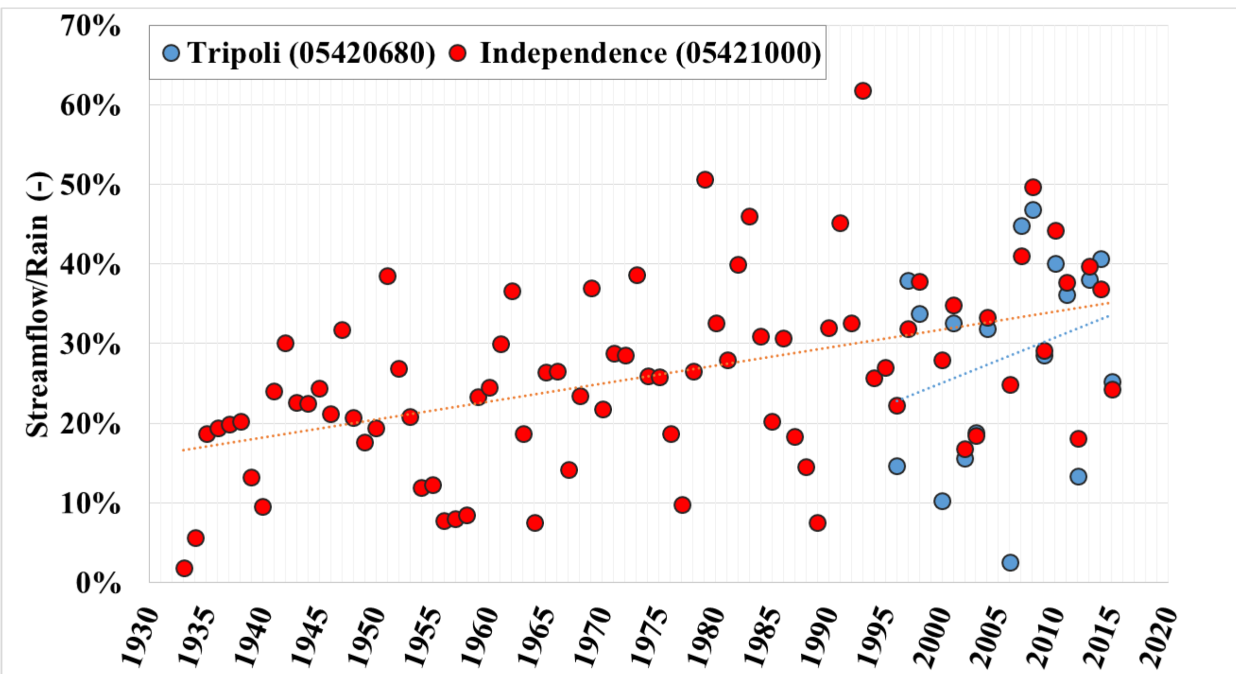

Figure 0-4: Annual ratio of streamflow to precipitation.

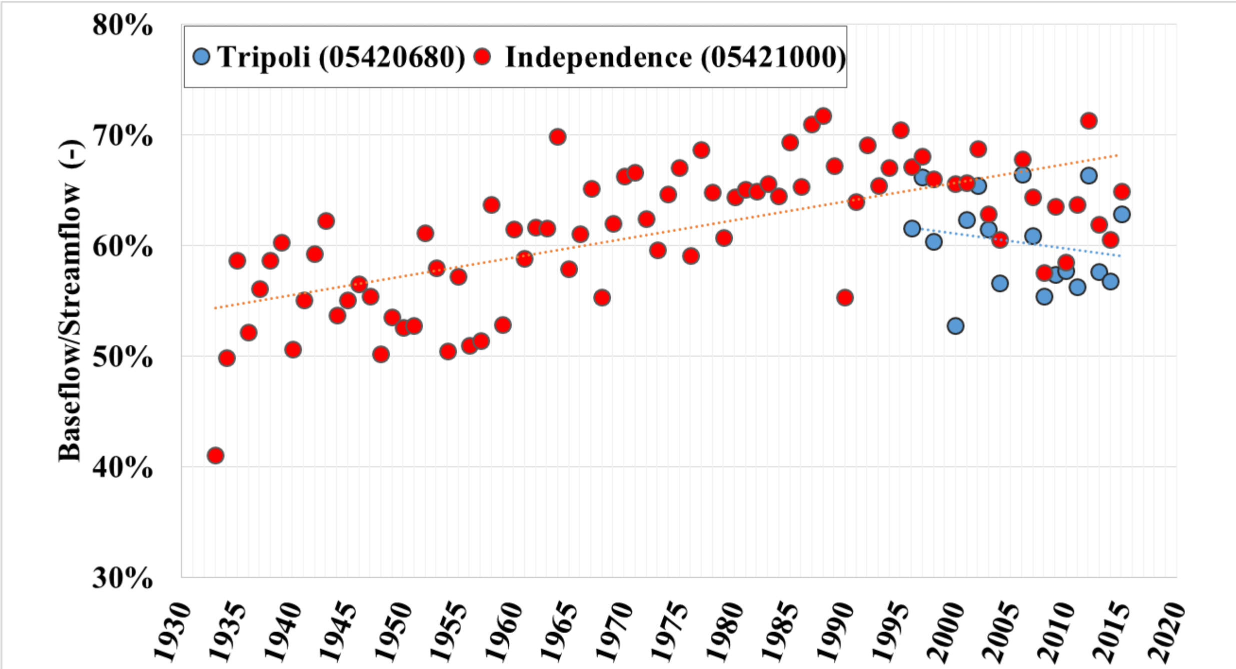

Figure 0-5: Annual ratio of baseflow to streamflow.

b. Geology and Soils

The Upper Wapsipinicon River Watershed is located almost entirely within the Iowan Surface landform region (Fig. 1-1), with a very small area of east-central Iowa Drift Plain on the downstream edge of the watershed. 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 is an area that was subjected to 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 transported 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 HSGs are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, there are dual code soil classes A/D, B/D, and C/D, which 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.

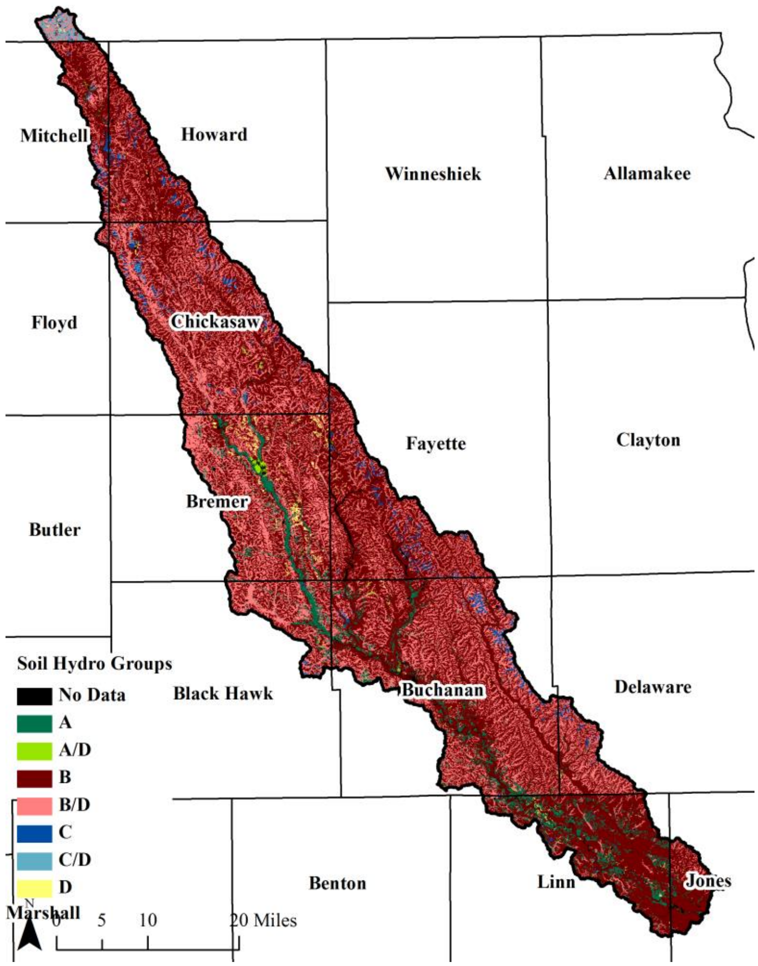

Figure 0-6: Distribution of Hydrologic Soil Groups in the Upper Wapsipinicon Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with Type A representing the lowest runoff potential, and Type D representing the highest runoff potential.

The soil distribution of the Upper Wapsipinicon River Watershed per digital soils data (SSURGO), available from the USDA-NRCS Web Soil Survey (WWS), is shown in Fig. 2-6. 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 2-1 shows the approximate percentages by area of each HSG for the Iowan Surface in the Upper Wapsipinicon River Watershed. The Upper Wapsipinicon River Watershed consists primarily of HSG B (60.6%) and B/D (30.1%) type soils, which have a moderate runoff potential when saturated. The remaining soil types each comprise 5% or less of the watershed.

Table 2-1: Approximate Hydrologic Soil Group Percentages by Area for the Upper Wapsipinicon Watershed.

Hydrologic Soil Group	Iowan Surface Approximate %
A	5.0
A/D	0.3
B	60.6
B/D	30.1
C	2.3
C/D	0.1
D	0.5

c. Topography

Figure 2-7 shows the topography of the Upper Wapsipinicon Watershed. Elevations range from approximately 1,400 feet above sea level in the upstream and western part of the watershed to 770 feet above sea level in the downstream portion of the watershed.

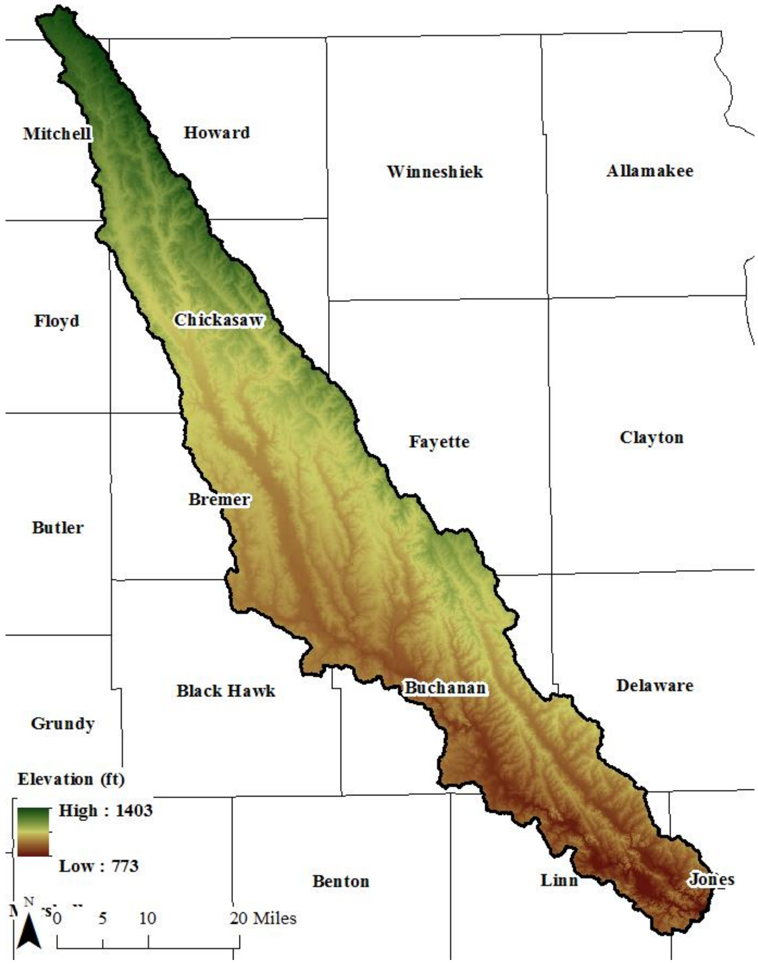

Figure 0-7: Topography of the Upper Wapsipinicon Watershed.

d. Land Use

Land use in the Upper Wapsipinicon Watershed is predominantly agricultural, dominated by cultivated crops (corn/soybeans) on approximately 71% of the acreage, followed by grass/pasture at approximately 11%. The remaining acreage in the watershed is about 7% developed land, 5% forest, 2% crops other than corn/soy, and 3% open water and/or wetlands, per the 2017 USDA/NASS Cropland Data Layer.

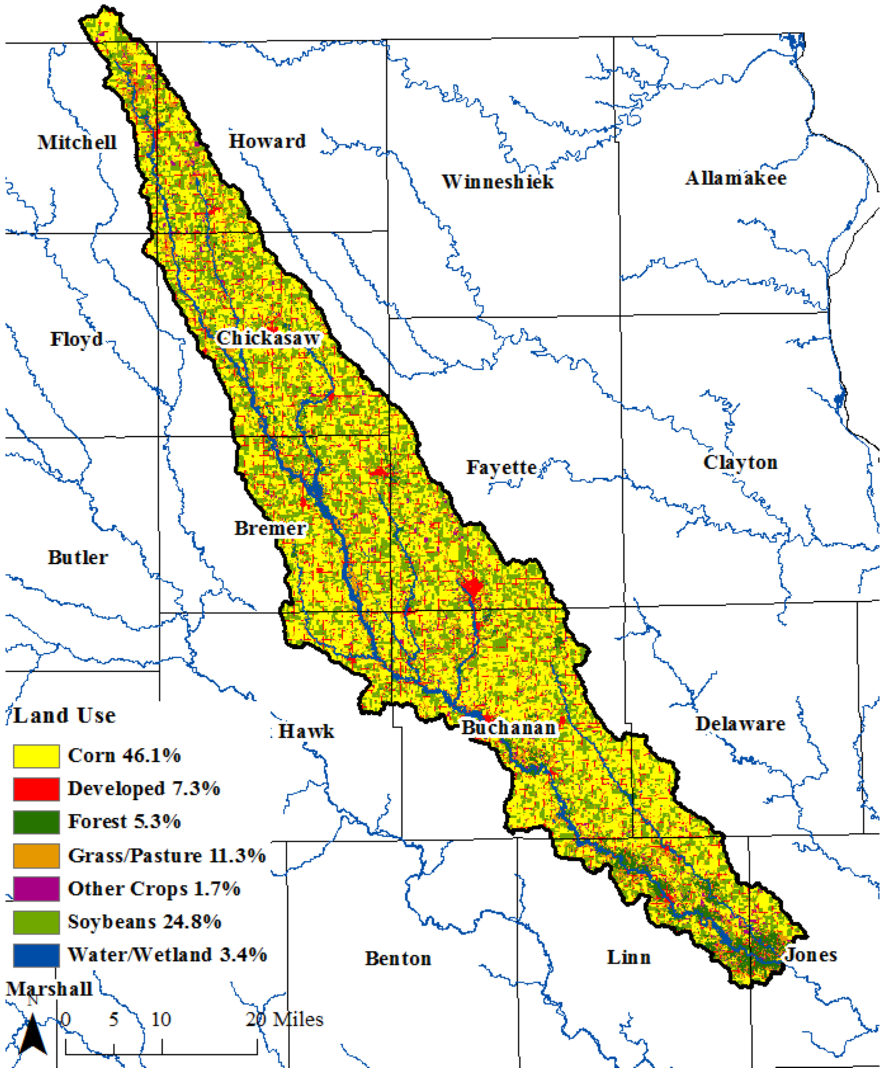

Figure 0-8: Land use composition in the Upper Wapsipinicon Watershed, per the 2017 USDA Cropland Data Layer.

e. BMP Mapping

Identifying existing conservation practices within a watershed serves as a benchmark for future implementation and provides information about 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 Upper Wapsipinicon Watershed, the total number of existing practices comprises 6,712 acres of agricultural fields with contour buffer strips, 1,309 acres of agricultural fields with strip cropping, 10,477 acres of grassed waterways, 1,350 terraces, 486 pond dams, and 2,116 water and sediment control basins (WASCOBs). The spatial distribution of the conservation practices within the watershed is shown in Fig. 2-9. Grassed waterways, terraces, pond dams, and WASCOBs, are most prevalent near the headwaters and outlet, with less prevalence within the central portion of the watershed. Strip cropping and contour buffer strips are not common in portions of the watershed.

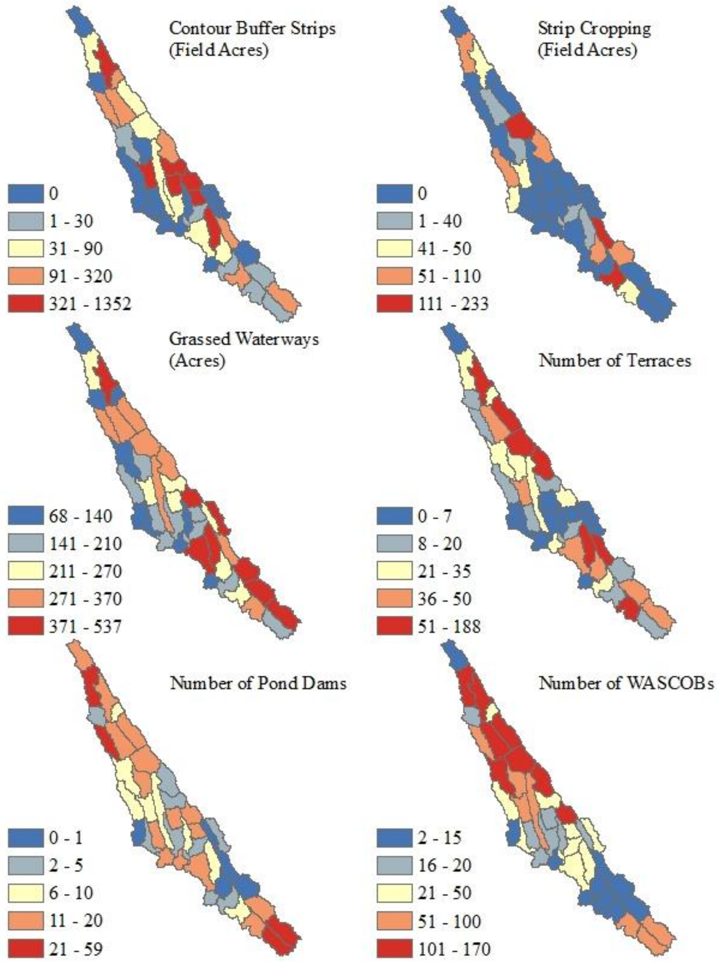

Figure 0-9: Iowa Best Management Practices Mapping Project.

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 HUC12s in the Upper Wapsipinicon Watershed. Potential BMP aggregations based on HUC12 area are presented in Fig. 2-10.

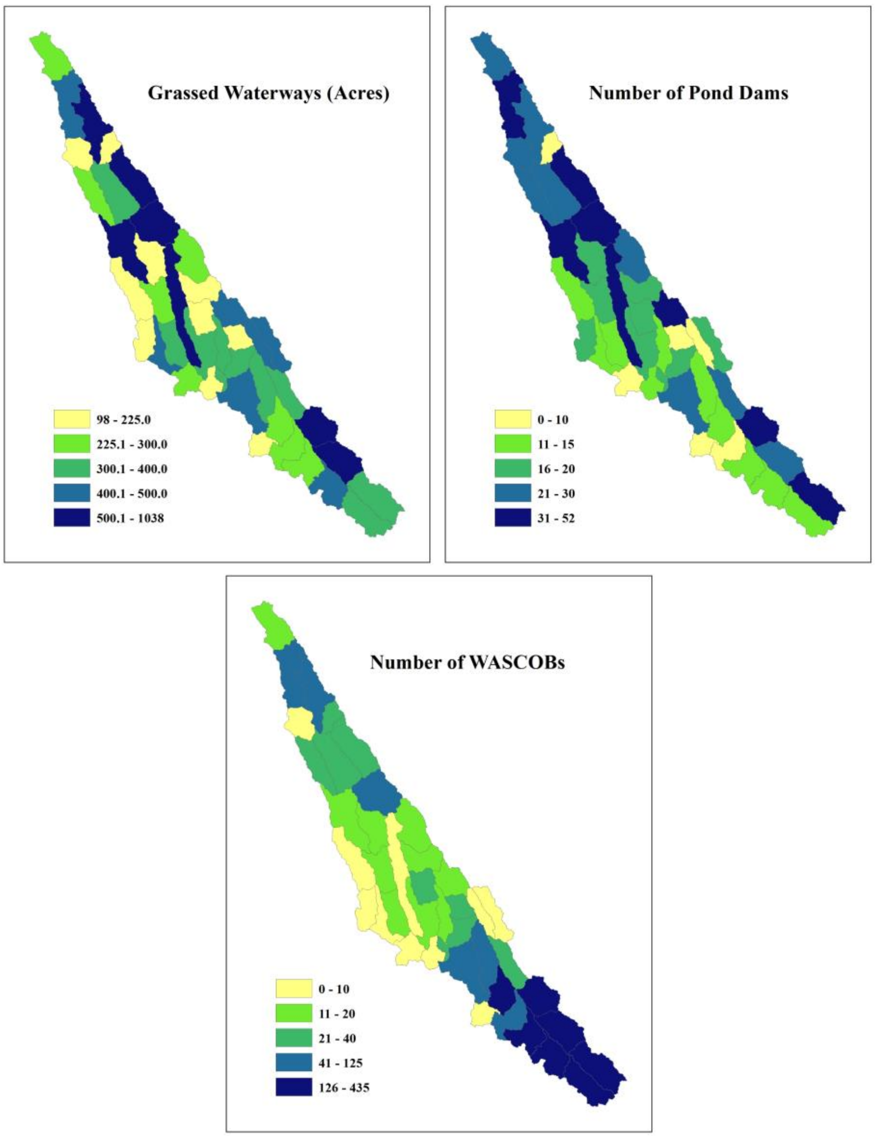

Figure 0-10: Potential BMPs. Ponds dams represent nutrient removal wetlands.

g. Instrumentation/Data Records

The Upper Wapsipinicon Watershed has instrumentation installed to collect and record stream stage, discharge, precipitation, groundwater, and soil moisture measurements. There are two active United States Geological Survey (USGS) operated stage and discharge gauges located within the watershed: 05421000 at Independence and 05420680 at Tripoli. USGS gauge 05421740 at Anamosa is technically not located within the Upper Wapsipinicon Watershed, which ends at the confluence of the Wapsipinicon River and Buffalo Creek, but it is less than three river miles downstream of the boundary and therefore the most suitable for capturing the entire Upper Wapsipinicon. Ten Iowa Flood Center (IFC) stream-stage sensors are also located within the watershed, 15 rain gauges that measure precipitation, and two hydrostations that measure precipitation, wind speed, depth to water table, and soil moisture and temperature. Figure 2-11 shows the location of these instruments throughout the Upper Wapsipinicon Watershed. Specific data records from these various gauges can be found on IFIS: https://ifis.iowafloodcenter.org/ifis/app/.

Figure 0-11: Location of instrumentation gauges within the Upper Wapsipinicon Watershed.

h. Floods of Record

Nine large flood events (greater than 20,000 cfs) are recorded at the Wapsipinicon River USGS gauging station at Independence. The six largest events are shown in Table 2-2. Of the six events, five have occurred since 1990, including: May 18, 1999, at 31,100 cfs; September 25, 2016, at 25,200 cfs; August 26, 1990, at 24,400 cfs; June 11, 2008, at 23,700 cfs; and July 24, 2010, at 22,800 cfs. The floods of 2008 and 2016 were also major flood events upstream near Tripoli and especially downstream near Anamosa. Before 1990, two large flood events occurred. On July 18, 1968, the Wapsipinicon River discharge at Independence was 26,800 cfs; downstream near Anamosa three days later, a discharge of 20,000 cfs was recorded. Then, on July 1, 1969, near Tripoli, discharge of 18,900 cfs was recorded. However, as Table 2-2 shows, the majority of top flood events have occurred in the last couple of decades, and all of the top-six floods in Anamosa have occurred since 2004.

Table 2-2: Discharge from the Six Largest Flood Events at USGS Gauging Stations in the Wapsipinicon River Watershed, Including: the Wapsipinicon River near Tripoli, Wapsipinicon River at Independence, and the Wapsipinicon River near Anamosa

Wapsipinicon River near Tripoli USGS 05420680 (1969, 1997–Present)	7/21/1999 19,400 cfs	7/1/1969 18,900 cfs	6/9/2008 18,300 cfs	8/29/2021 17,200 cfs	9/23/2016 14,000 cfs	5/23/2004 9,680 cfs
Wapsipinicon River at Independence USGS 05421000 (1934–Present)	5/18/1999 31,100 cfs	7/18/1968 26,800 cfs	9/25/2016 25,200 cfs	8/26/1990 24,400 cfs	6/11/2008 23,700 cfs	7/24/2010 22,800 cfs
Wapsipinicon River near Anamosa USGS 05421740 (1968, 1999, 2003–Present)	6/13/2008 31,800 cfs	7/26/2010 25,700 cfs	9/7/2018 23,200 cfs	9/27/2016 23,100 cfs	5/26/2004 22,000 cfs	5/31/2013 20,500 cfs

Water Quality Analysis

a. Data Availability

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

i. Data Requirements

Historic nutrient data are needed to estimate riverine loads at a site of interest. It was necessary to identify which locations within the Upper Wapsipinicon contained nitrate and TP data. Several programs monitor nutrient data on a routine basis by collecting grab samples that are brought to a laboratory for analysis. This protocol creates a record of discrete data points of nitrate and TP concentrations. In the past decade, it has become possible to deploy *in-situ* sensors along a river that continuously measure nitrate. These sensors greatly enhance the discrete nitrate data by creating a more complete record. 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 measure of water clarity and it can be measured continuously on-site. Its values can then be used to predict Part P concentrations. 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) maintains 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 available record of nutrient concentrations and streamflow measurements. When these two data records are both available, it is possible to estimate loads. Streamflow can also act as a useful surrogate. Because the USGS measures it routinely, streamflow is a reliable tool for estimating nutrient concentrations. The USGS calculates mean daily streamflow values, which make it possible to estimate nutrient loads on a daily basis.

ii. Sources of Data

The headwaters of the Upper Wapsipinicon Watershed are set in Minnesota, slightly beyond Iowa's northern border. The watershed's outlet is located in Central City, Iowa. Unfortunately, historical data is relatively sparse at this location. No routine sampling has taken place within at least 30 miles of Central City. As part of the Iowa Watershed Approach, staff installed a sensor to measure nitrate at Central City. This sensor began operating in 2017, resulting in quite a short period of available data.

There are two other sites along the Wapsipinicon River that have much more robust data records. The first is located at Independence, Iowa, about 35 miles upstream of Central City. The second is located near DeWitt, Iowa, about 70 miles downstream of Central City. These sites are part of the Iowa Department of Natural Resources (IDNR) ambient monitoring program. Nitrate and TP are measured every month at these locations. The DeWitt site is downstream of Central City and includes the entire Upper Wapsipinicon watershed within its tributary area. Because of its downstream location, DeWitt was selected as the site for the entirety of the Upper Wapsipinicon's nutrient analysis. It contains approximately 1,000 square miles of tributary area in addition to the Upper Wapsipinicon's watershed. Even though this extra area is not part of the Upper Wapsipinicon, DeWitt is an ideal choice for nutrient evaluation because the data available there is comprehensive. Geologic regions and land use conditions are also relatively consistent in this portion of the Wapsipinicon basin, meaning that observations at DeWitt are likely applicable for the Upper Wapsipinicon as well. The exact location of the DeWitt site is shown below; the southeastern most pink pin in Fig. 3-1 corresponds to IDNR site 10820001. The Independence and Central City locations are also shown, along with the Upper Wapsipinicon watershed.

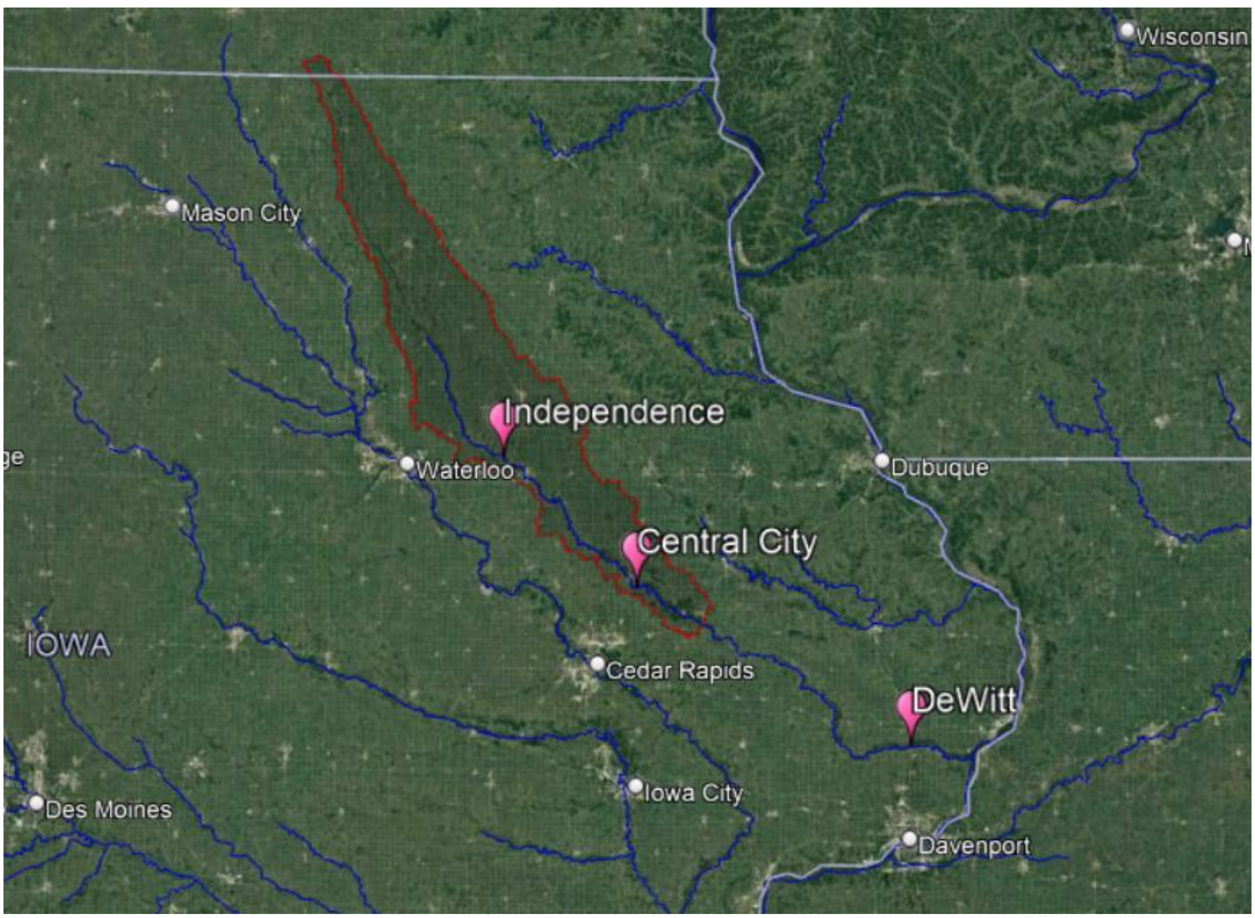

Figure 0-1: Data collection sites for the Wapsipinicon watershed.

The IDNR began monthly monitoring at this site in 1998, and monitoring continues to the present day. The USGS also included the DeWitt site as part of the Big River Study project. In this project, additional nutrient sampling occurred between 2004 and 2014. Starting in 2015, nitrate and turbidity sensors provided more continuous measurements of these analytes in recent years. Figure 3-2 summarizes the number of days in each year with measures of nitrate OP, Part P, and turbidity. This combination of data sources results in one of the best nutrient records for any location in Iowa. The site at Independence contains only the monthly IDNR samples, further suggesting that DeWitt was the ideal site to investigate the Upper Wapsipinicon. USGS gauge 05422000 measures streamflow at DeWitt and is co-located with the nutrient collection site. The flow record at DeWitt extends from 1934 to the present.

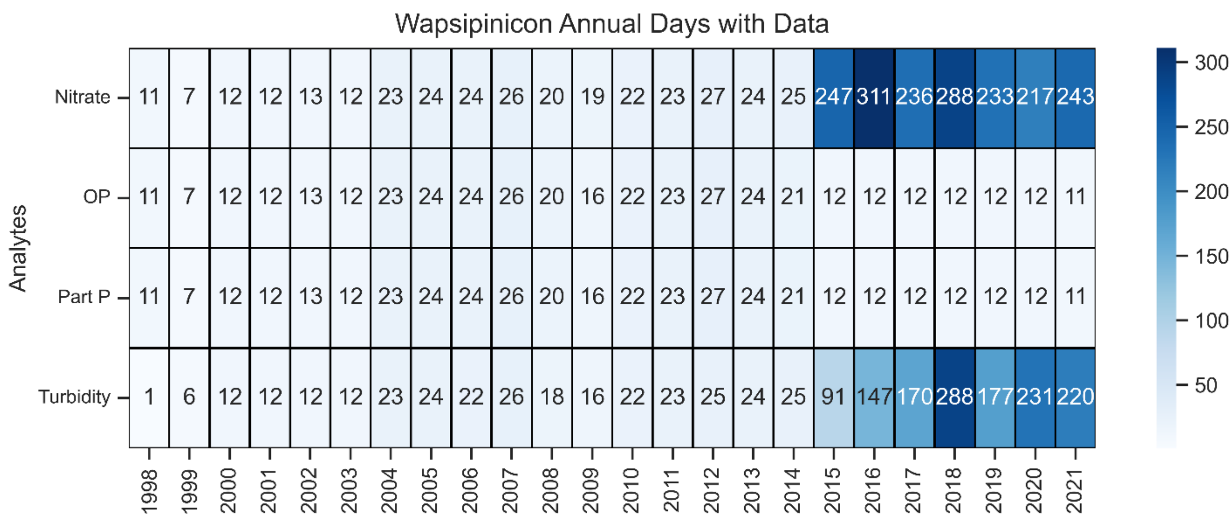

Figure 0-2: Annual days with data for the Wapsipinicon River at DeWitt, Iowa.

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 to Elliot Anderson (elliot-anderson@uiowa.edu) at the University of Iowa.

b. Methods

Because there are numerous days for which nutrient data is not available, it is necessary to estimate nitrate and TP concentrations. If nutrient concentrations can be accurately estimated for the period of available data, it is then possible to fully calculate nutrient loads. In the case of the Upper Wapsipinicon, the aim was to estimate concentrations from 1998 to 2021.

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 turbidity data is unavailable for many days. Several models use flow and seasonal factors to predict waterborne constituents; these have the benefit of almost always being feasible to implement. The USGS consistently measured 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. This model couples historical water-quality measurements with daily flow values to produce estimated daily concentrations for the entire streamflow period. WRTDS uses several flow-related predictors and seasonal variables to predict the concentrations. Recently, the WRTDS model framework has been supplemented with a Kalman filter. This filter adjusts the concentrations of the original WRTDS model based on their proximity to the measured values. The USGS has made this model version, referred to as WRTDSK, available by as an open-source R package. The WRTDSK model produces the best possible load estimates. Details of the WRTDSK package are available on the following GitHub page (https://usgs-r.github.io/EGRET/articles/WRTDSK.html).

Three separate models were implemented for the Upper Wapsipinicon basin from 1998 to 2021: nitrate, OP, and Part P. The daily flow data used by each of these models are shown in Fig. 3-3.

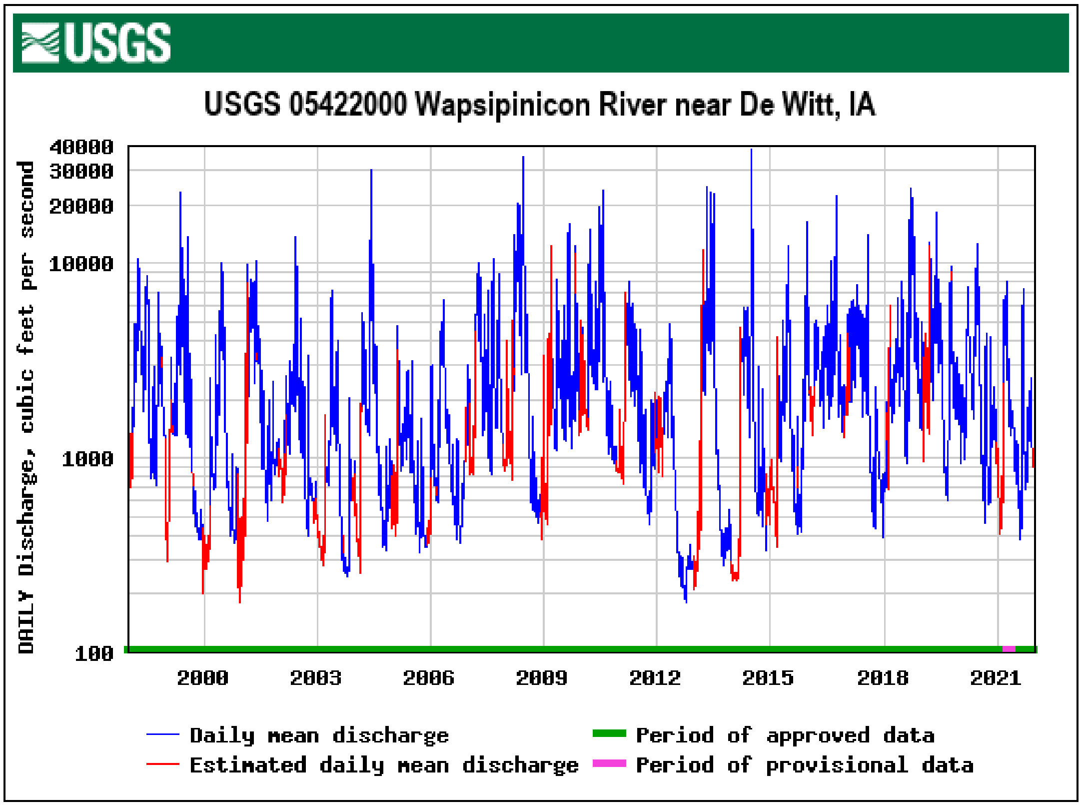

Figure 0-3: Daily flow values for the Wapsipinicon River at DeWitt, Iowa.

i. Nitrate

Researchers successfully implemented the WRTDSK nitrate model and found no issues with its residuals. While it is possible to simply interpolate nitrate concentrations, the WRTDSK model greatly improved upon linear interpolation. Therefore, the values produced by the WRTDSK model are the most accurate estimates currently available. Overall, the model performed well.

Table 3-1: WRTDS Model Performance Metrics.

River	Type	R2	RMSE	R2.ln	RMSE.ln	FluxBias
Wapsipinicon	Nitrate	0.733607	1.629488	0.747	0.497	-0.01198
	OP	0.25357	0.07872	0.611	0.707	0.048819
	PartP	0.212576	0.117795	0.412	0.604	-0.05034

The observed and estimated concentrations are shown in Fig. 3-4. The nitrate concentrations ranged from 0.01 to 20 mg/L. The predicted concentrations were relatively conservative and remained consistently below 10 mg/L. More observed values have become available in recent years because of additional sensor deployment. The model performance metrics are shown in Table 3-1.

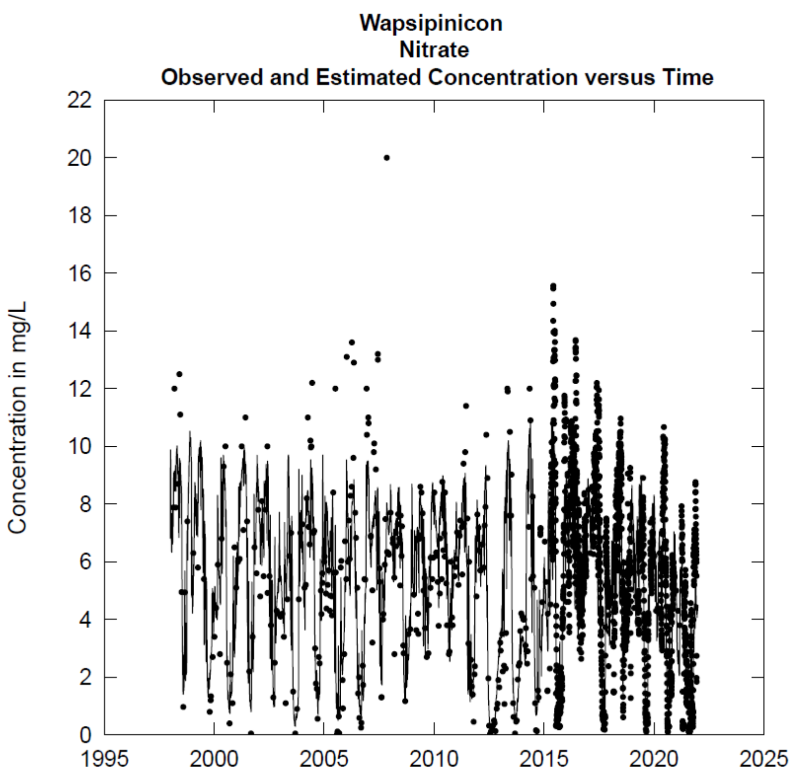

Figure 0-4: WRTDSK nitrate model results.

ii. Orthophosphate

Researchers successfully implemented the WRTDSK OP model. As a dissolved constituent, OP can be difficult to predict based on flow in many cases. However, this model performed quite well with the performance metrics shown in Table 3-1. The model concentrations typically remained near 0.1 mg/L, and occasionally, values would extend to 1 mg/L.

Figure 3-5 shows an example of the Kalman filter as applied to the OP estimates. The black lines show the original WRTDS concentrations, and the red points are the observed samples—the exact OP measurements at the DeWitt site. The green lines show the new concentrations generated by implementing the Kalman filter. The closer the concentrations are the actual measurements, the more they are adjusted to match these measurements.

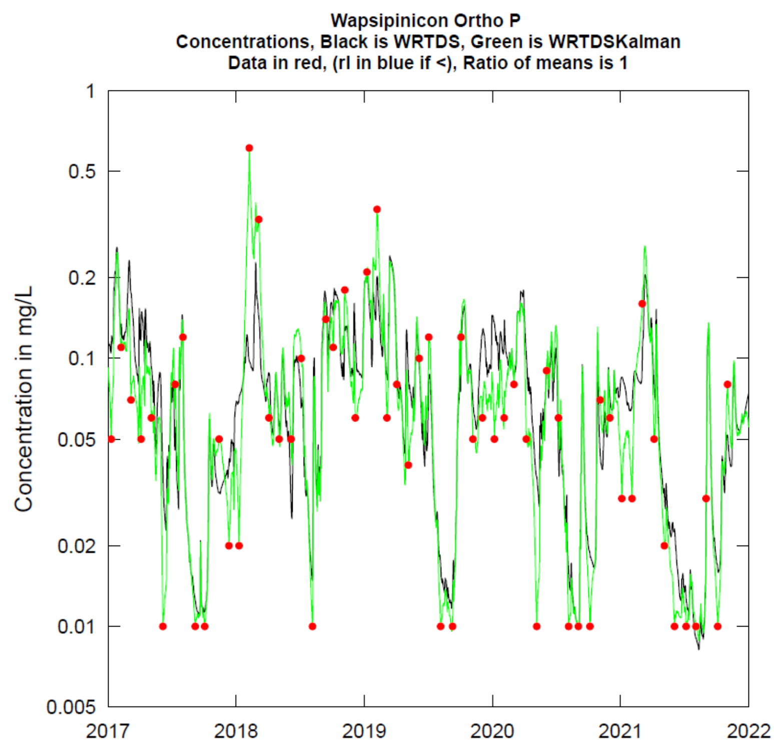

Figure 0-5: WRTDSK orthophosphate model results.

iii. Particulate Phosphorus

We similarly implemented the WRTDSK model for Part P. Erosion typically drives Part P. Much of the Part P found in 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. Part P concentrations were estimated via WRTDSK for 1998 to 2021. Still, because turbidity data were available, its potential use as a surrogate for Part P was also investigated.

Figure 3-6 plots the relationship between the log-transformed values of Part P and turbidity collected at the DeWitt site. The literature has generally suggested that a linear model for the log-transformed variables is ideal. This relationship may also be referred to as the power-regression model because the untransformed equation follows a power-law framework.

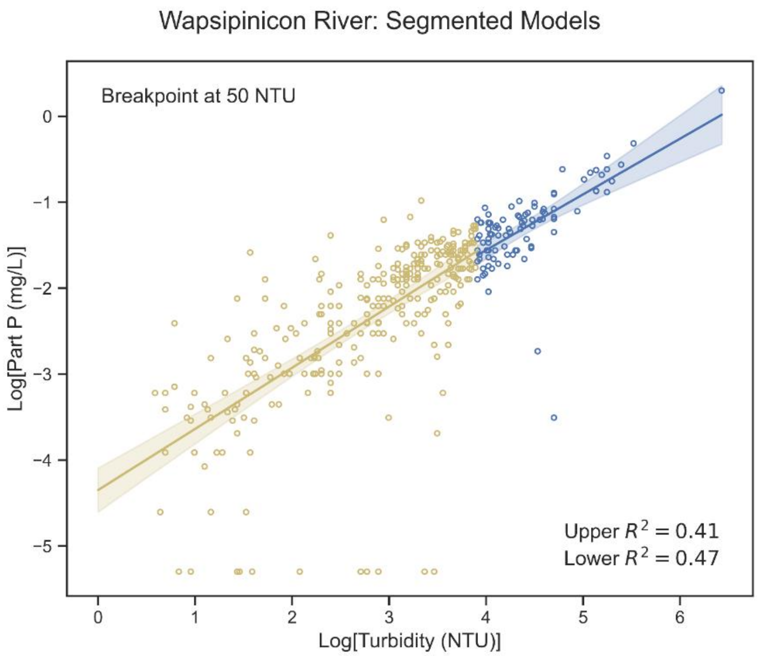

Figure 0-6: Turbidity-based surrogate model for Part P.

Observations show that numerous models have issues with heteroskedasticity on the transformed data. This can be seen in Fig. 3-6, 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 model contained two equations for predicting Part P—one for turbidity values of 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 days where turbidity data were available, and these estimates were given higher priority over the WRTDSK model. When turbidity data were present, researchers used the surrogacy-based concentrations to calculate loads instead of the WRTDSK concentrations. This observed value became the ultimate Part P concentration on days with observed Part P data.

Finally, the researcher added the OP and Part P concentrations together to produce an overall TP concentration. With this final TP value, the team estimated a timeseries of phosphorus loads from 1998 to 2021.

iv. Trend Detection

In addition, researchers looked for temporal trends in the nutrient data by conducting a trend analysis after the concentrations were loads assembled. Significant effort has gone into reducing nutrient loads in the Upper Wapsipinicon, so it is natural to investigate any potential trends that may be present.

The team performed two statistical tests 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. It 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 calculates the correlation between the ranks of the analyte values and the ranks of the dates. It also determines 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, they aggregated the daily values for every year. For concentrations, this involved taking the average of all the daily concentrations within a given year. For loads, it required summing the daily fluxes. Loads were further converted to yields by dividing their annual values by the Wapsipinicon's watershed area. The team conducted a similar process using the daily flow values, which were likewise assembled on a yearly basis into an annual volume of water and a water yield. The yearly timeseries benefit from removing any seasonal effects present in the daily values. Their plots are also more intuitive than the daily values because of the reduced number of data points. Both the Mann-Kendall test and Spearman Rank Test were run on the yearly values as well.

c. Water-Quality Results

Table 3-2 shows a summary of the descriptive statistics for each pertinent variable. The flows are the daily mean streamflow values as measured by the USGS. TP is the phosphorus concentration estimated using WRTDSK and turbidity-based surrogacy models. Researchers then coupled these concentrations with the daily flows to calculate phosphorus loads (P Load). Nitrate concentrations were estimated using WRTDSK models, and nitrate loads (N Load) were similarly calculated using these concentrations and the daily flow values.

Table 3-2: Descriptive statistics for the Wapsipinicon flows and nutrients.

Stat	Flow (cfs)	TP (mg/L)	P Load (lbs)	Nitrate (mg/L)	N Load (lbs)
count	8776	8776	8776	8776	8776
mean	2452	0.24	3963	5.46	90310
std	2932	0.13	6008	2.95	119753
min	179	0.01	28	0.03	74
0.1	420	0.11	300	1.17	3428
0.25	707	0.15	584	3.26	11998
0.5	1480	0.22	1711	5.69	43324
0.75	3110	0.29	4775	7.45	122025
0.9	5610	0.37	10538	9.33	246353
0.99	14700	0.68	29066	11.99	535370
max	38400	1.49	73455	20.00	1308001

i. Nitrate Estimates

Figure 3-7 contains the final daily nitrate concentrations. These concentrations generally appear to be normally distributed. The values also appear to be relatively constant over the entire record, though there may be a decrease within the past five years. Seasonality is present throughout the timeseries, with higher concentrations occurring during the summer and lower ones in the winter. The highest single nitrate concentration was 20 mg/L; the lowest concentrations was 0.1 mg/L, which occurred several times throughout the years.

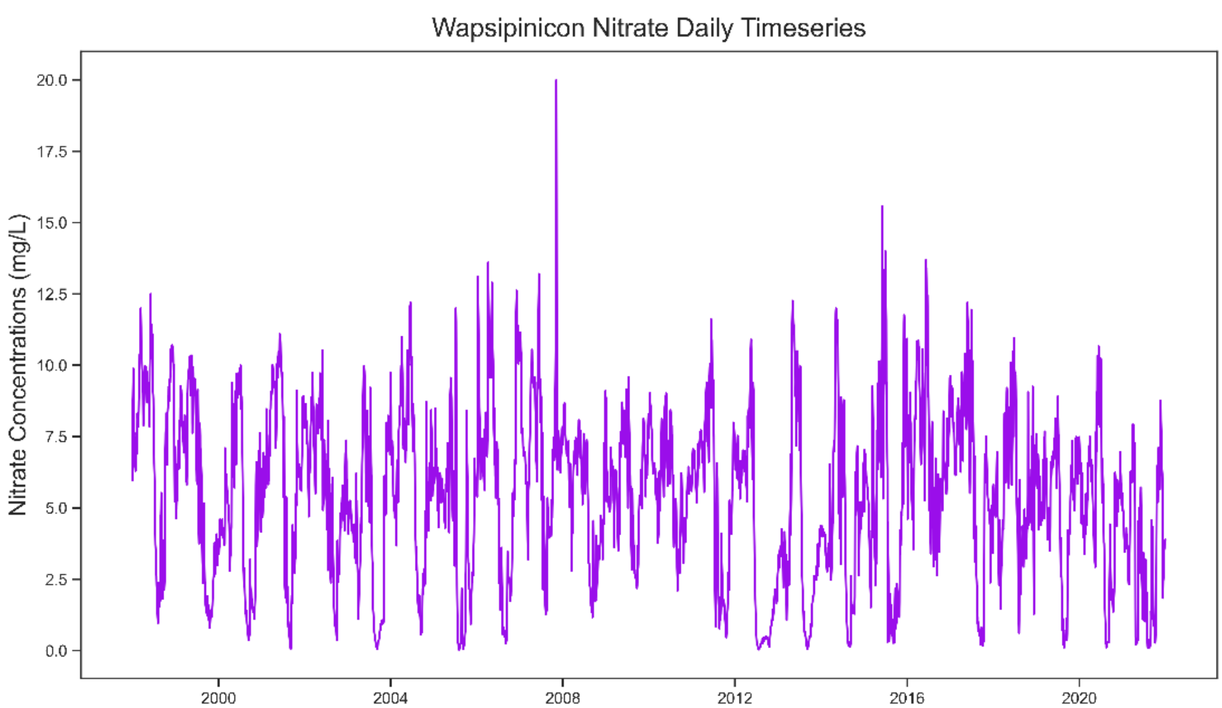

Figure 0-7: Daily nitrate concentrations.

Average yearly concentrations are shown in Fig. 3-8. These averages are simply the arithmetic mean of all daily concentrations within a given year. The annual averages range from about 3.5 to 7.5 mg/L, with a typical year near 5 mg/L. The decline in concentrations is more evident when observing the yearly data points. The total flows for each year are shown on the secondary axis. Typical flows for the Wapsipinicon are on the order of magnitude of hundreds of billions of gallons each year. The wettest years occurred in 2008 and 2018.

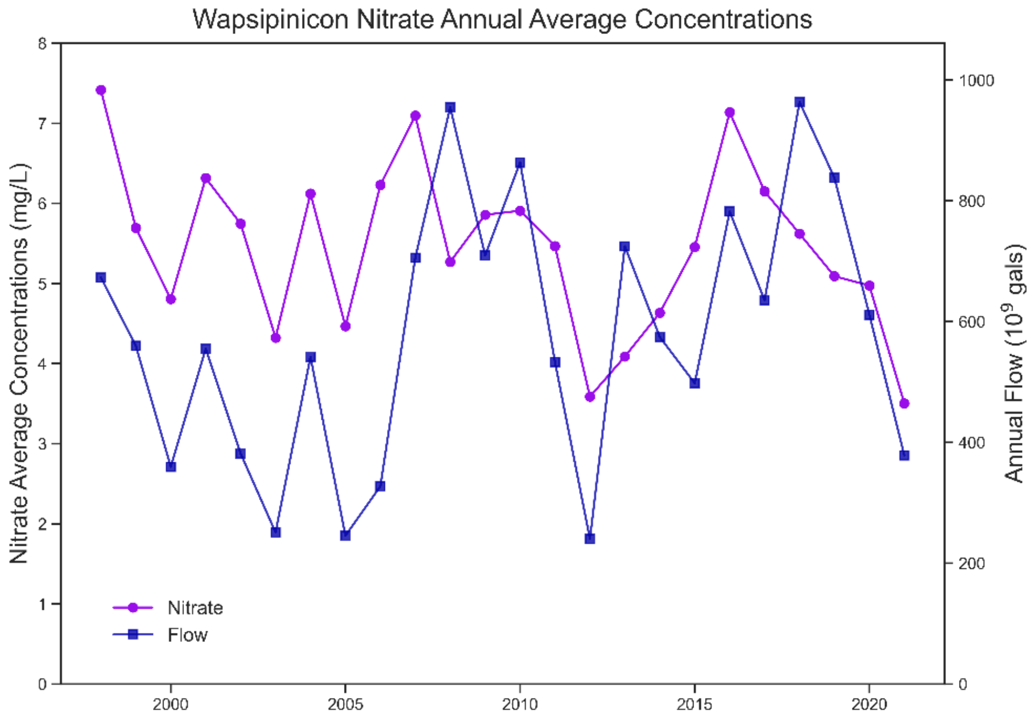

Figure 0-8: Average annual nitrate concentrations.

Figure 3-9 displays boxplots for nitrate concentrations separated by month. The boxplots show the variation of concentrations within each month, along with the median, interquartile range, and outliers. The monthly distributions seem primarily symmetric. The highest medians occurred during the months of May and June, while the lowest concentrations occurred in August and September.

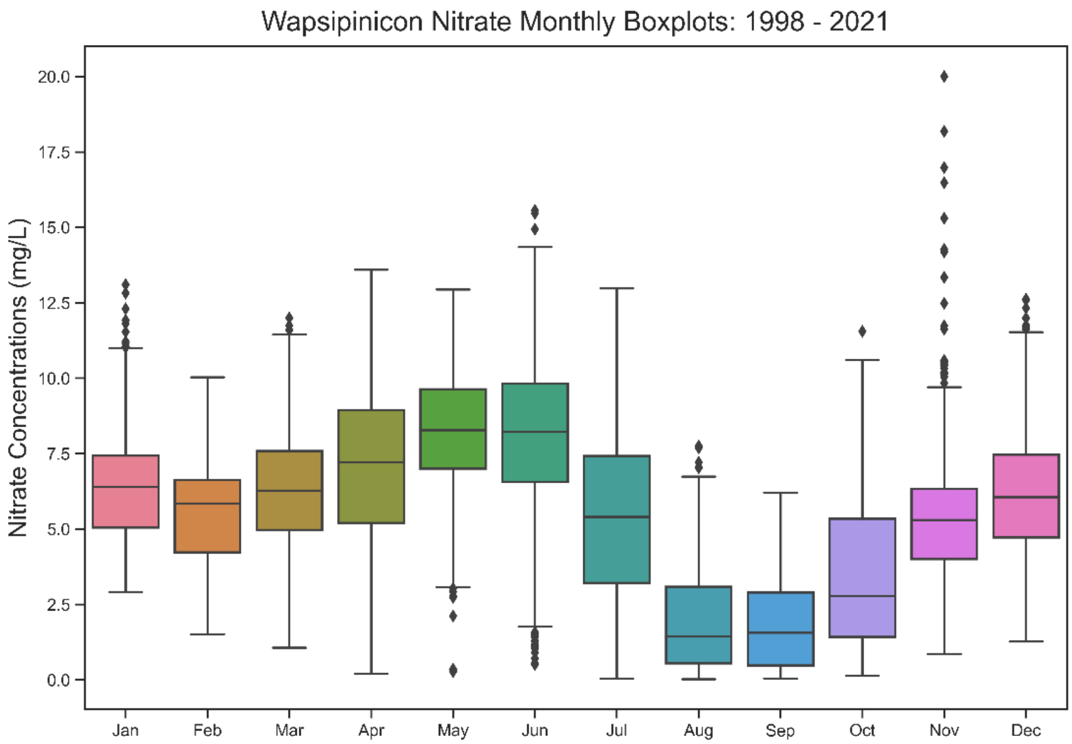

Figure 0-9: Boxplots of monthly nitrate concentrations.

Figure 3-10 shows the daily nitrate loads. These were calculated by multiplying the daily concentrations by their corresponding mean flow values. Flow values are generally positively skewed, often following a lognormal distribution. Because of the skewness of the flows, the nitrate loads also tend to be positively skewed. The highest values tend to be near 1 million lbs of nitrate per day. Periods of low flow also occur and result in very minimal nitrate loads.

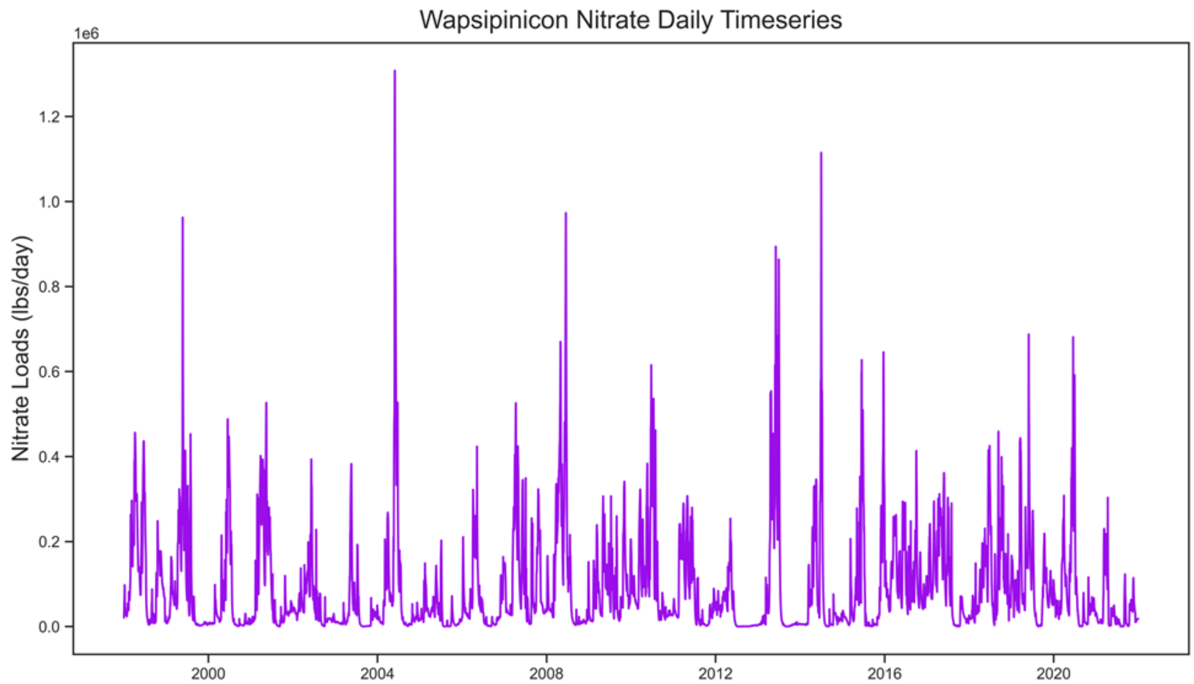

Figure 0-10: Daily nitrate loads.

Figure 3-11 shows the yearly nitrate and water yields. These are calculated by dividing the summation of daily loads within a year by the tributary area of the DeWitt site, which is 2,336 square miles. The yearly yields varied considerably from 10 to 30 lbs/ac. Water yields correlate with nitrate yields, and higher water yields result in larger nitrate loads because of the increased water volume.

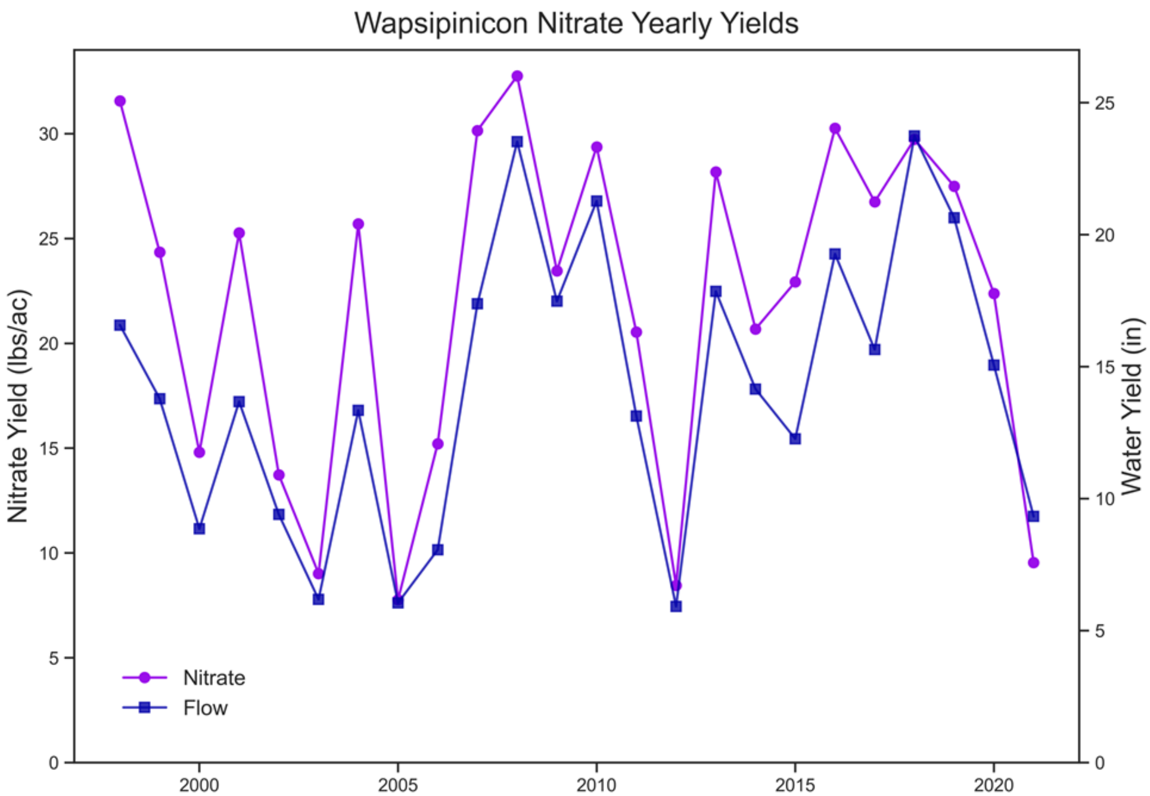

Figure 0-11: Yearly nitrate and water yields.

ii. Phosphorus Estimates

Figure 3-12 shows the daily TP concentrations, which are much more positively skewed than the nitrate concentrations. No clear trend exists in the daily TP concentrations, and values range between 0.01 to 1.4 mg/L. Seasonality may also be present, with higher concentrations occurring in the spring and early summer.

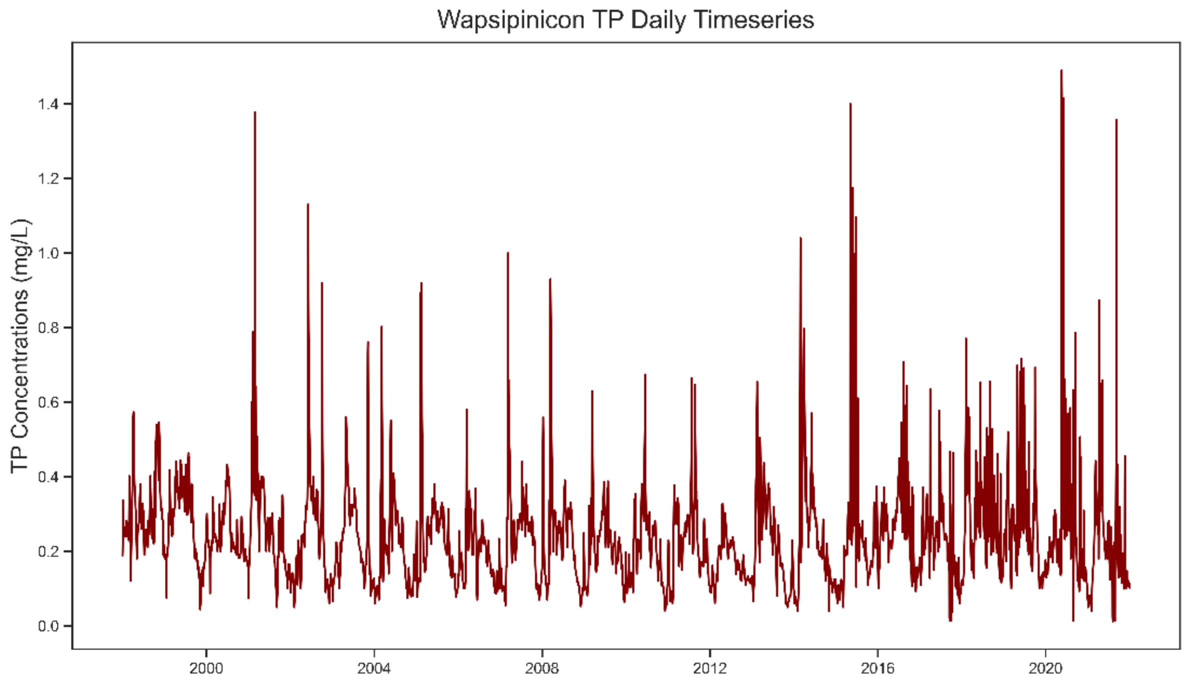

Figure 0-12: Daily TP concentrations.

Figure 3-13 shows the annual average TP concentrations and the annual water volume. The average concentrations seem to be pretty constant across the timeframe. The typical yearly concentrations were generally near 0.25 mg/L, and these concentrations generally were unrelated to the annual water volumes of the Wapsipinicon.

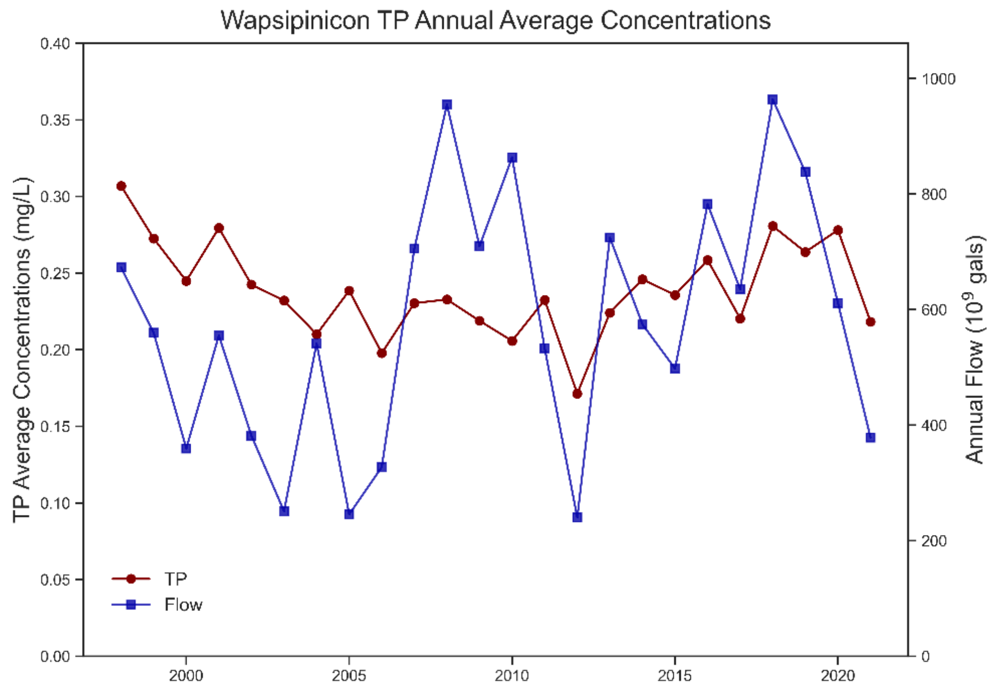

Figure 0-13: Annual average TP concentrations.

Similarly, the concentrations were separated by month for TP. Figure 3-14 shows boxplots of these monthly concentrations. These boxplots are quite positively skewed, and each month contains many outliers. The medians varied slightly by month, with the highest values occurring during the spring and early summer months. The medians were mainly near 0.2 mg/L.

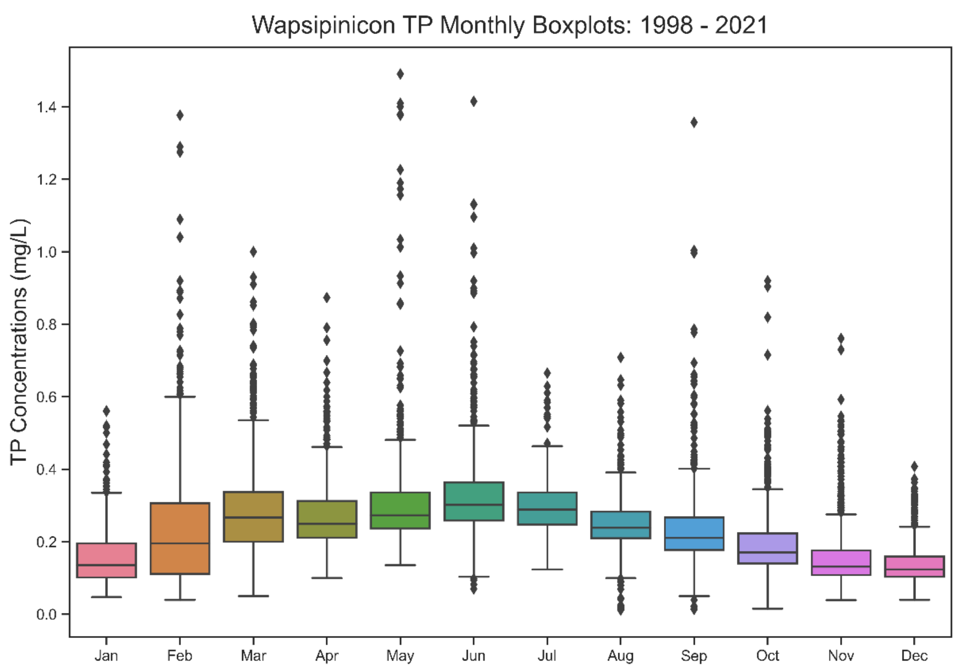

Figure 0-14: Boxplots of monthly TP concentrations.

Figure 3-15 displays the daily TP loads for the Wapsipinicon. These loads are very positively skewed. High TP concentrations tend to occur on days with high flows; i.e., streamflow is correlated with TP. Since these two factors tend to occur coincidently, the resulting loads can become extremely skewed. The maximum loads were near 50,000 lbs per day.

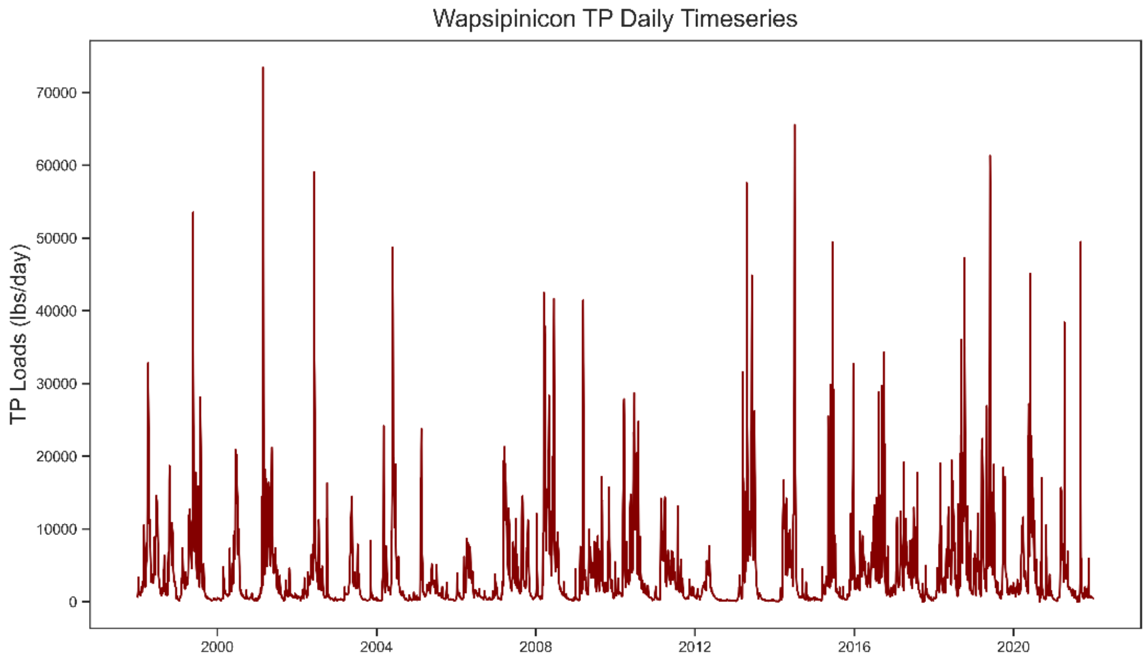

Figure 0-15: Daily TP loads.

Figure 3-16 shows the annual TP yields and water yields. Quite a variation exists between yearly yields, with the lowest value near 0.25 lbs/ac and the highest value near 1.5 lbs/ac. These yearly yields were closely linked to the annual water yields, and higher water yields are directly related to higher TP yields. The yields for TP are approximately 10 times smaller than those of nitrate.

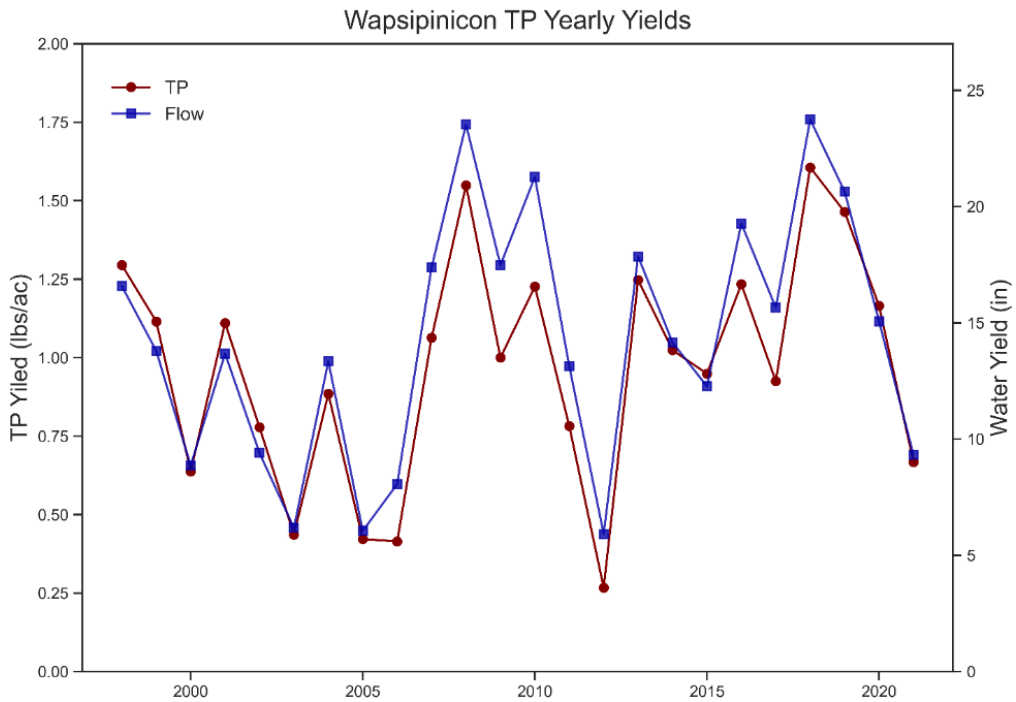

Figure 0-16: Yearly TP and water yields.

iii. Trend Detection

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

The tests revealed that daily concentrations were decreasing for the nitrate and TP. However, daily loads were increasing for both these constituents. Daily flows were also increasing, so this is likely the leading cause of increasing loads. No trends were present for the annual series. This absence of trends is somewhat unsurprising, as there are far fewer data points for these timeseries. With fewer points, it is harder to assess a trend's presence. Perfect agreement existed between the Mann-Kendall and Spearman tests. Both produced the same results, suggesting the test results are viable.

Table 3-3: Trend analysis results.

Variable	Property	Mann-Kendall			Spearman	
		trend	p-value	slope	trend	p-value
Nitrate	Daily Concentrations	**decreasing**	<0.001	-0.0002	**decreasing**	<0.001
	Daily Loads	**increasing**	<0.001	0.8164	**increasing**	<0.001
	Annual Concentrations	no trend	0.130	-0.049	no trend	0.133
	Annual Loads	no trend	0.747	1.43E+05	no trend	0.698
Total Phosphorus	Daily Concentrations	**decreasing**	<0.001	-3.61E-06	**decreasing**	<0.001
	Daily Loads	**increasing**	<0.001	0.0048	**increasing**	<0.001
	Annual Concentrations	no trend	0.568	-0.0008	no trend	0.633
	Annual Loads	no trend	0.442	1.49E+04	no trend	0.282
Flow	Daily Flows	**increasing**	<0.001	0.0699	**increasing**	<0.001
	Annual Flows	no trend	0.205	9.09E+09	no trend	0.124

d. Water-Quality Conclusions

The historic nutrient data at DeWitt, Iowa, made it possible to estimate nitrate and TP loads for the Wapsipinicon River. The IDNR has sampled the site every month since 1998, and the USGS completed additional sampling from 2004 to 2014 as part of the Big River Study. In more recent years, nitrate sensors and turbidimeters were installed that can continuously monitor data at this location. Researchers assembled data from these three sources for this analysis.

This analysis estimated daily nutrient loads from 1998 to 2021 and successfully implemented WRTDSK models for nitrate, OP, and Part P. The Part P models were further supplemented with a turbidity-based surrogacy model. Researchers added the final Part P concentrations to the OP concentrations that form TP concentrations. The estimated nitrate and TP concentrations were then coupled with daily mean flows monitored by the USGS to create daily nutrient loads.

The nitrate concentrations tended to be normally distributed, while the TP concentrations were more positively skewed. Nitrate concentrations ranged from 0.01 mg/L and 20 mg/L with an average of 5.46 mg/L. TP concentrations ranged from 0.01 mg/L and 1.4 mg/L with an average of 0.24 mg/L. Yearly nitrate yields ranged from 8 lbs/ac to 31 lbs/ac, with an average of 22 lbs/ac. Yearly TP yields ranged from 0.25 lbs/ac to 1.5 lbs/ac, with an average of 0.97 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 Wapsipinicon are greater than the rest of Iowa, while the TP yields are lower. Annual water yields strongly correlated to annual nutrient yields. Both the Mann-Kendall and Spearman trend detection tests suggested that daily concentrations for nitrate and TP were decreasing. However, these tests indicated that daily loads were increasing for nitrate and TP. Mean daily flows were also found to be increasing. No trends were present for the annual timeseries.

Model Development

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

a. Hydrologic Model Description

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

Watersheds in GHOST are discretized horizontally by a mesh of Voronoi (a.k.a., Thiessen) polygons, which improve the accuracy of gradient computations and calculated fluxes between these elements. Vertically, the elements are defined by three different zones: the surface zone, as well as two subsurface zones (unsaturated and saturated soil), separated by a dynamic water table (Fig. 4-1) (Politano, 2019).

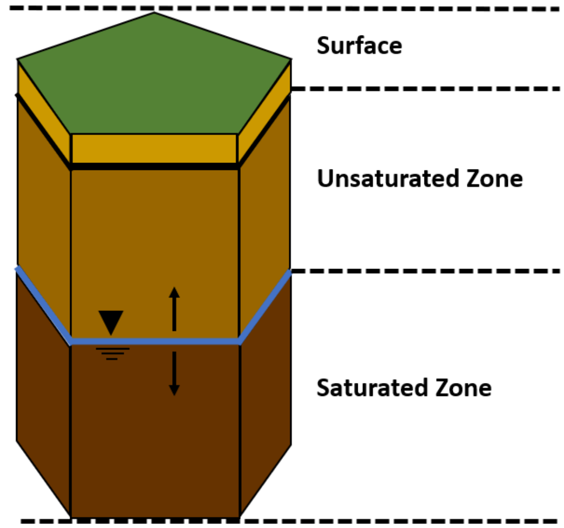

Figure 0-1: Vertical zones of a Voronoi element in GHOST: surface, unsaturated, and saturated zones.

GHOST computes all the major components of the water cycle, as shown by Fig. 4-2. Rain (or snow) is intercepted by the vegetation canopy before it reaches the surface. Water on the surface either evaporates, runs off, or infiltrates the soil. Infiltrated water transpires, evaporates, exfiltrates, or recharges the groundwater, which can then either be evaporated or discharged to streams through natural movement or tile drainage. GHOST calculates surface flow using the two-dimensional diffusive wave approximation of the Saint Venant equations, where water depth is computed using a one-dimensional approximation to capture the channel geometry. Flow in the unsaturated zone is assumed to be primarily vertical and is governed by the Darcy equation, while groundwater (the saturated zone) moves horizontally via the non-linear Bousinnesq equation. For a full documentation of GHOST's mathematical model, please refer to (Politano, 2019).

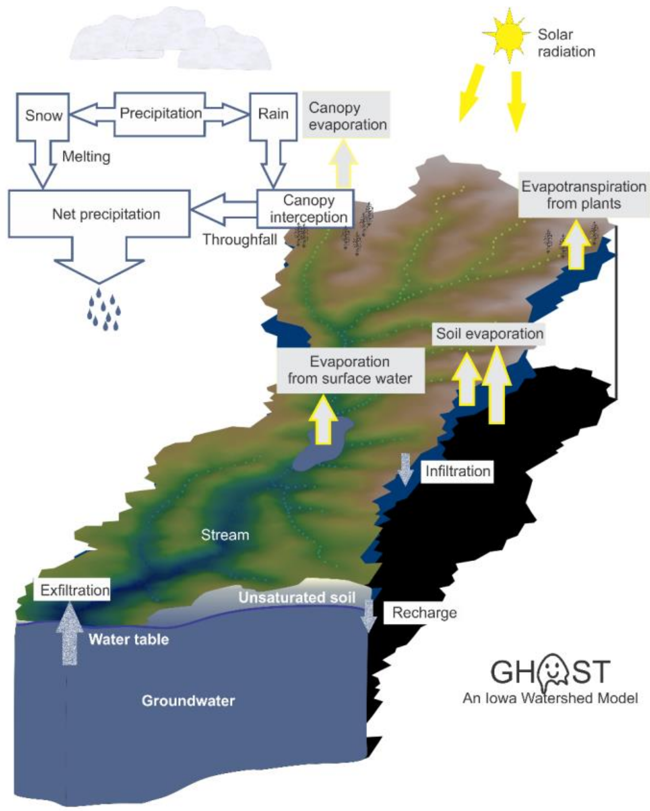

Figure 0-2: The hydrologic cycle calculated by GHOST (Politano, 2019).

b. Upper Wapsipinicon Model Construction

The GHOST model for the Upper Wapsipinicon Watershed consists of a computational mesh of Voronoi elements and a network of connected linear stream segments, shown in Fig. 4-3. 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.

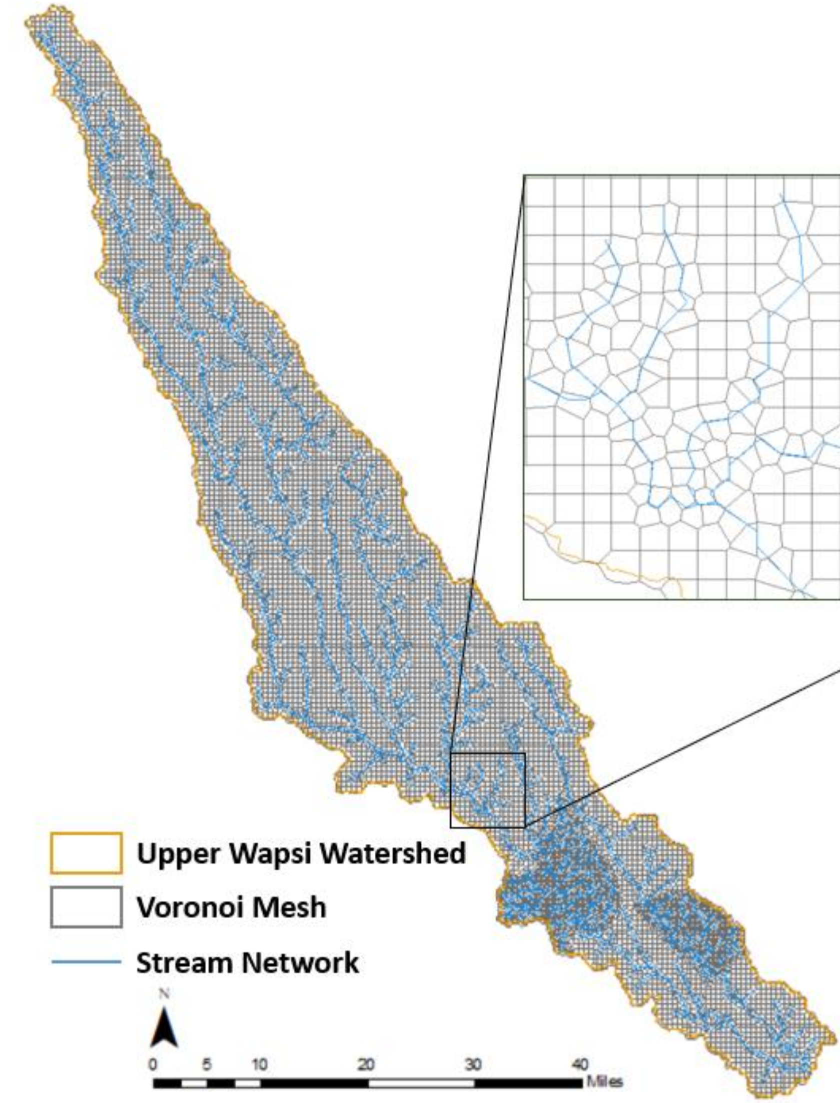

Figure 0-3: The Voronoi mesh and stream network used in the Upper Wapsipinicon GHOST model.

The model for the Upper Wapsipinicon contains 10,728 elements, with an average size of 0.39 km^2 (96 acres), the largest at 1.10 km^2 (271 acres), and the smallest only 0.09 km^2 (22 acres). There are 2,711 river segments with a total length of 1,547 km (962 miles) and average, maximum, and minimum lengths of 571 m, 1,703 m, and 100 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 Fig. 4-4. Elements within these HUC12s were smaller than the rest of the watershed, with an average area of just 0.16 km^2 (40 acres); the largest was only 0.52 km^2 (128 acres).

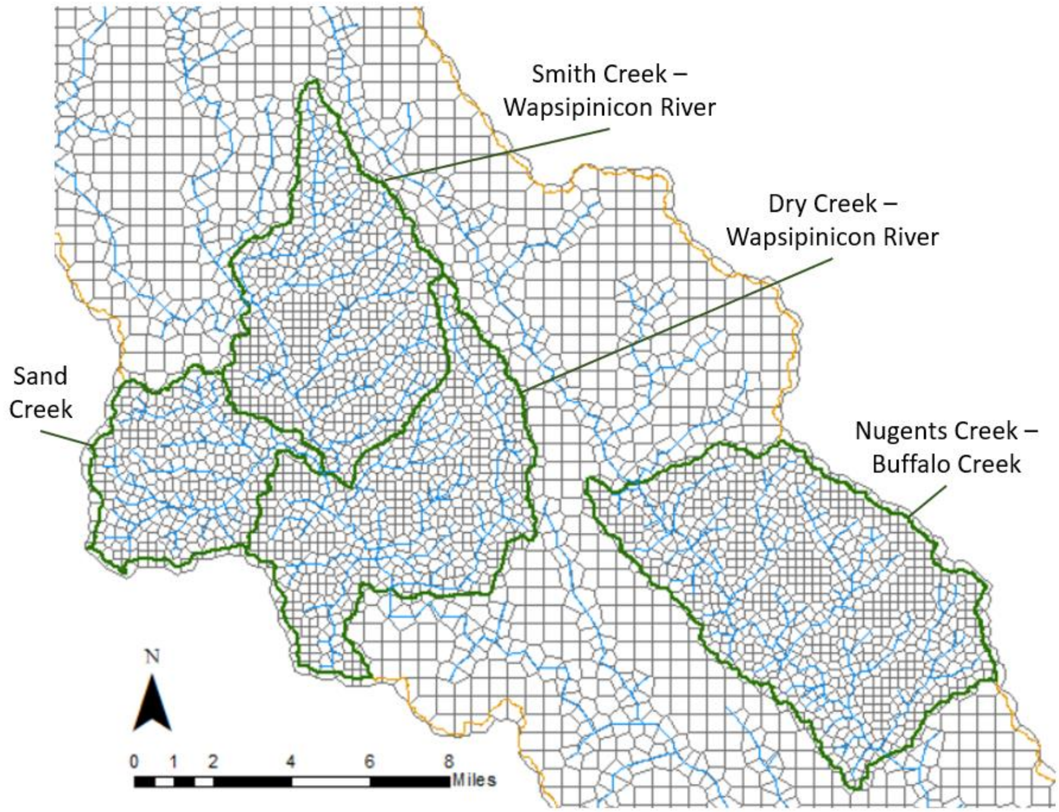

Figure 0-4: The mesh within IWA focus areas was constructed with a finer resolution than the rest of the watershed.

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, 89% are assigned to row crop, 7% to forest, 3% to grass/pasture, and just 1% to urban, as shown in Fig. 4-5.

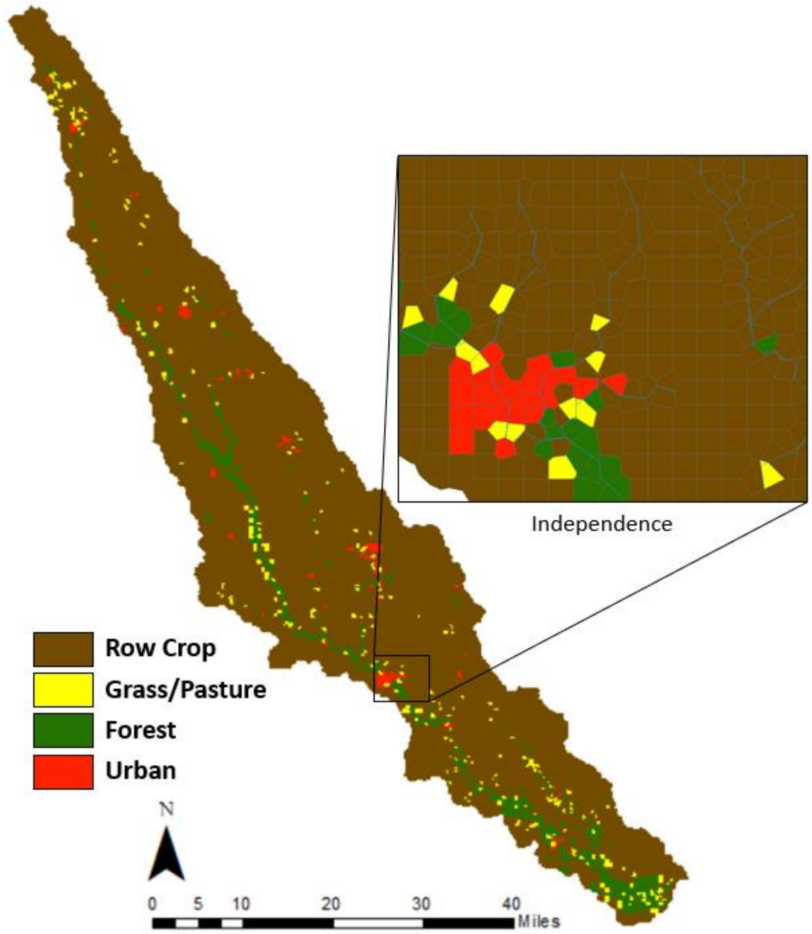

Figure 0-5: GHOST mesh with elements' land use classifications.

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 65 NLDAS pixels shown in Fig. 4-6.

Two USGS streamflow gauges provided references to calibrate the GHOST model; both are shown in Fig. 4-6. The gauge near Anamosa (USGS 05421740) is located just downstream from the outlet of the model and was therefore used as the primary calibration index because that flow represents the entire Upper Wapsipinicon Watershed. The second calibration index point is located near Independence (USGS 05421000) and serves as an intermediate point to ensure that our model was accurately capturing the hydrology higher in the watershed. The next section describes the process and results of model calibration.

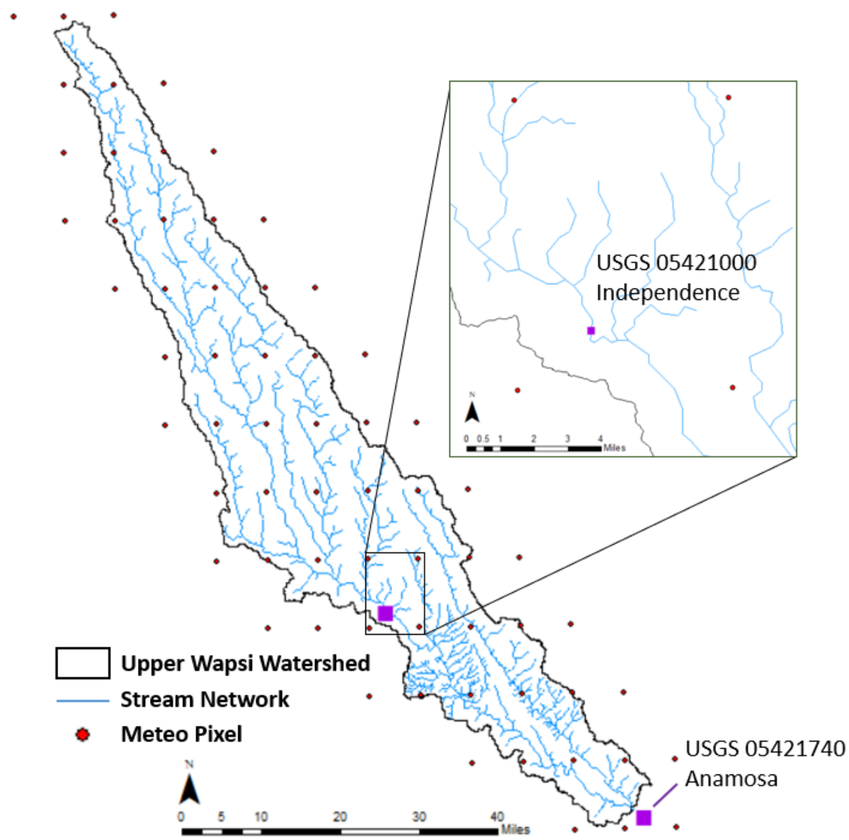

Figure 0-6: The location of the meteorological forcing data pixels and USGS gauges used in the Upper Wapsipinicon Watershed model.

c. Model Calibration

Calibration is the process of adjusting model parameters until simulated results match observed time series as closely as possible, typically stream discharge at a gauging station. Analyses based upon the model can therefore be assumed to reflect reality to a reasonable degree. Researchers performed model calibration for an 18-year period from 2003–2020. Simulated flows were compared to observed flows at the USGS stream-gauge stations near Anamosa (05421740) and Independence (05421000), as shown in Fig. 4-6. The comparison of observed and simulated average daily discharges for both gauges is shown in Fig. 4-7. 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 4-1. The NSE and R^2 at both Anamosa and Independence exceed this threshold, while the PBIAS for both are slightly more negative than the ideal range. This indicates that the model has a small tendency to over-predict streamflow. It's also important to note that these values were calculated on daily values over an 18-year period, which is more stringent than common practice.

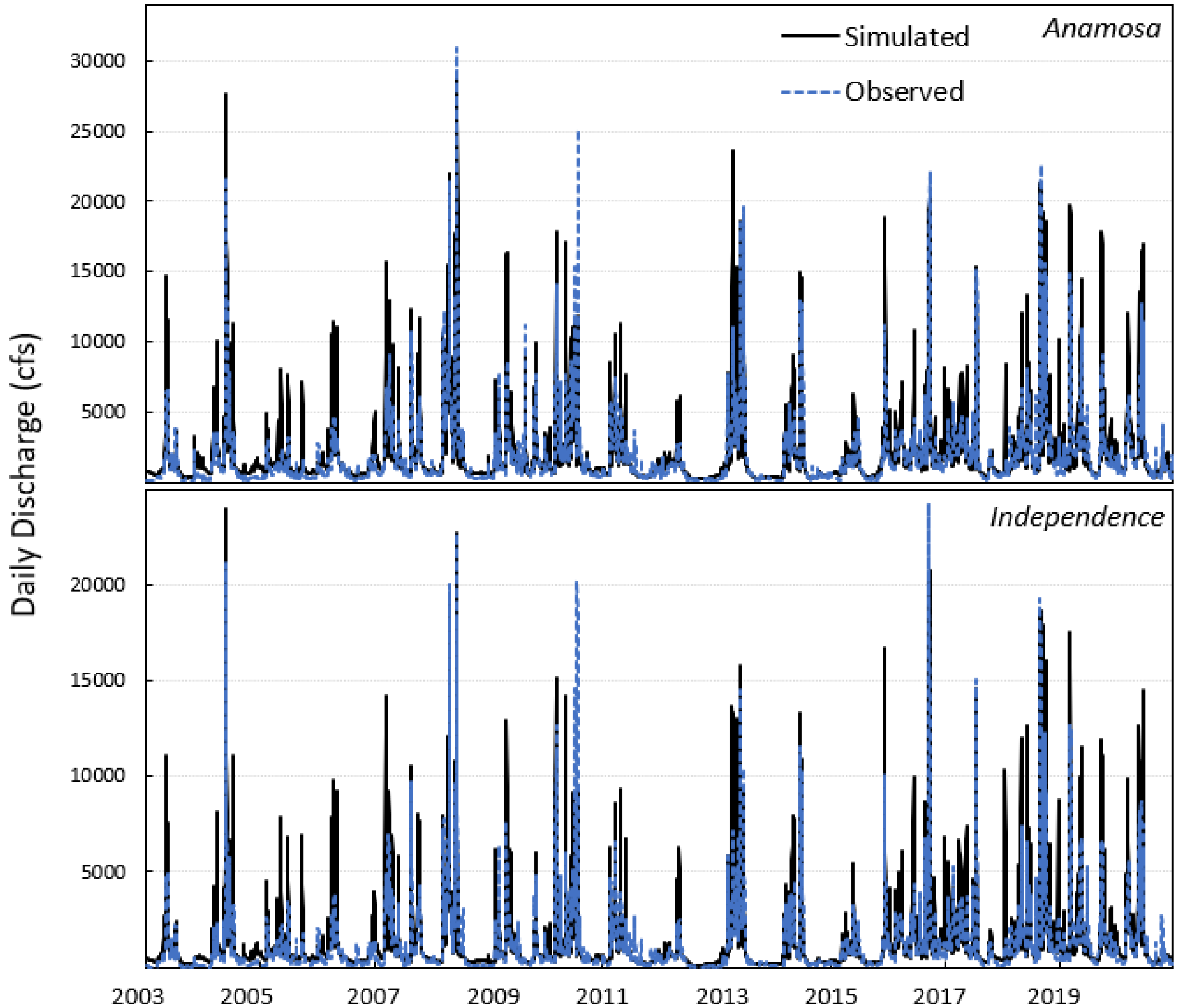

Figure 0-7: Comparison of simulated (black) and observed (blue) daily average discharge at both Anamosa (top) and Independence (bottom).

Table 4-1: Performance parameters for the calibrated GHOST model.

Metric	Anamosa	Independence
NSE	0.65	0.62
R^2	0.77	0.75
PBIAS	-16.0	-19.2

The Upper Wapsipinicon Watershed displays a monthly pattern typical in Iowa, with the highest runoff depths from March through July and relatively drier conditions during the rest of the year. The model captures this pattern well, with slight tendencies to over-predict most months other than July and August. This is the case for both Anamosa and Independence, as seen in Fig. 4-8. Overall, the GHOST model's performance matched observed average monthly runoff depths closely, with R^2 values of 0.87 in Anamosa and 0.89 in Independence.

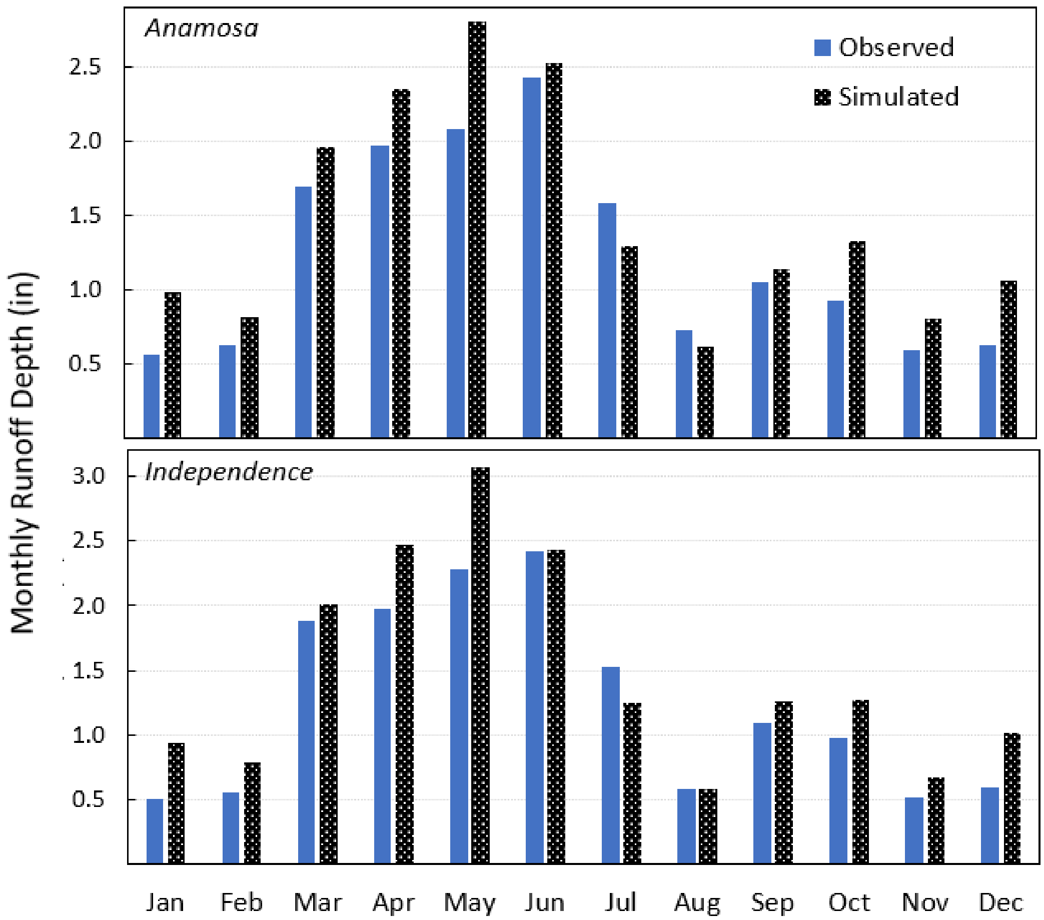

Figure 0-8: Observed and simulated average monthly runoff depths from 2003–2020 at Anamosa (top) and Independence (bottom).

Researchers compared the peak annual discharge for each year to assess the model's ability to capture the largest flood events. Figure 4-9 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.

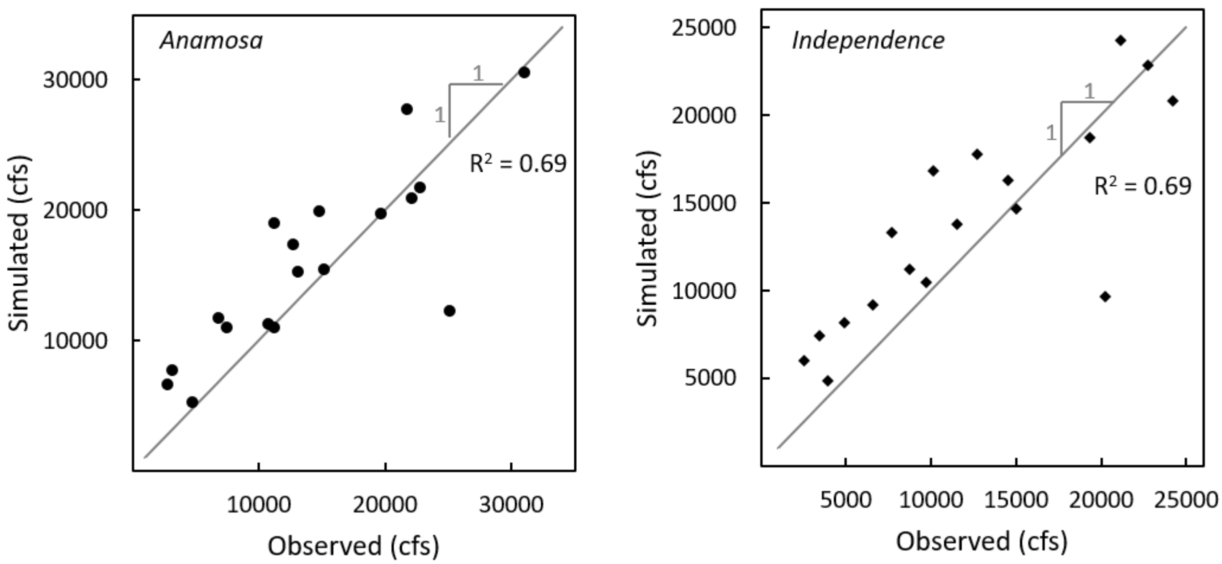

Figure 0-9: Annual peak discharge plotted against a 1:1 line, showing how well modeled peaks matched observed values for both Anamosa (left) and Independence (right).

The largest peaks were simulated very well in both locations. In Anamosa, the 2008 flood was by far the largest, and the model's peak discharge was only 1.4% lower than the observed peak. The individual NSE for that year was 0.89, the best year of the study period, with an annual runoff depth only 6.6% larger than observed. In Independence, the 2016 flood was slightly larger than 2008, followed by 2004, and the model captured all three well. The outlier in both locations is the 2010 flood, which was the only drastically under-predicted peak. Otherwise, there appears to be a slight bias to over-predict flood peaks; however, performance overall was good, with both locations achieving R^2 values of 0.69. Figure 4.10 shows hydrographs for 2008 in Anamosa and 2010 in Independence to illustrate both ends of the model's performance spectrum.

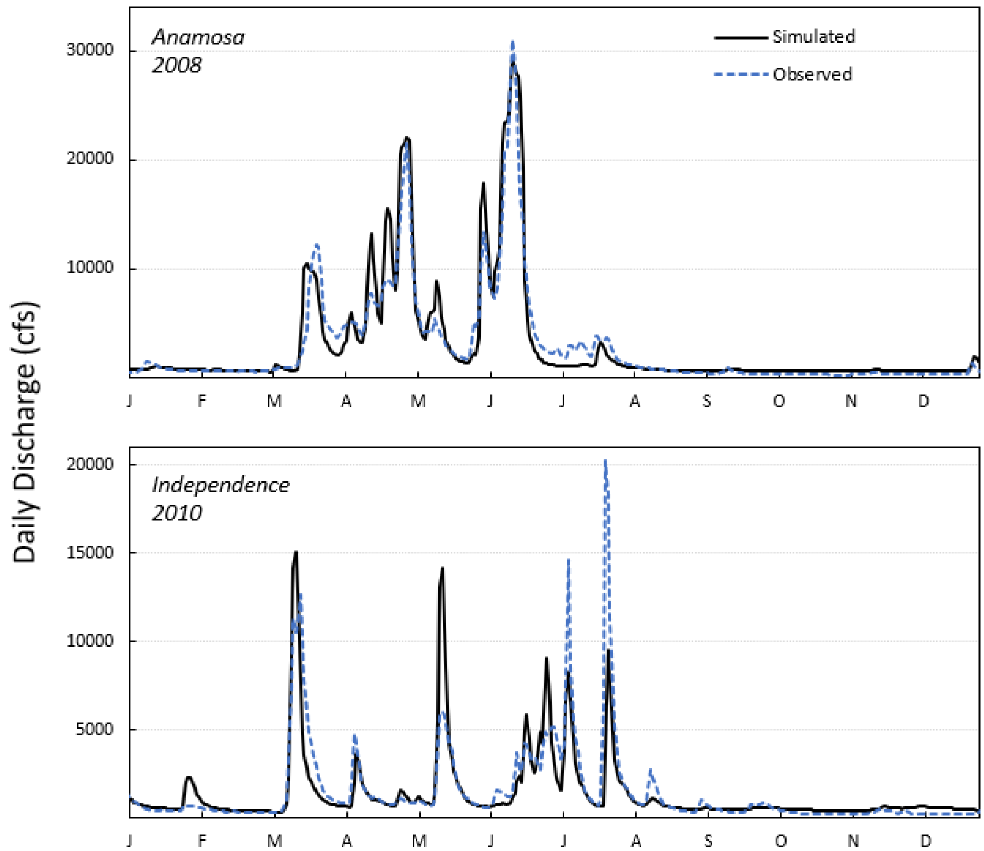

Figure 0-10: Comparison of simulated (black) and observed (blue) daily average discharge for 2008 in Anamosa (top) and 2010 in Independence (bottom).

The accuracy of the model at different scales of discharge can be assessed using the flow duration curve in Fig. 4-11. For the entire record (2003–2020), we ranked daily flows from largest to smallest and then plotted against the probability that the given flow will be equaled or exceeded. The observed and simulated curves show good agreement at exceedance probabilities less than 60% (i.e., the model does a good job of predicting higher flows, but tends to over-predict lower flows). This is consistent with the previous observations of slight over-prediction in the monthly runoff (Fig. 4-8) and annual peaks (Fig. 4-9). However, the model captures the statistical behavior of the study period well overall. The flow duration curve for Independence exhibits a pattern very similar to that of Anamosa.

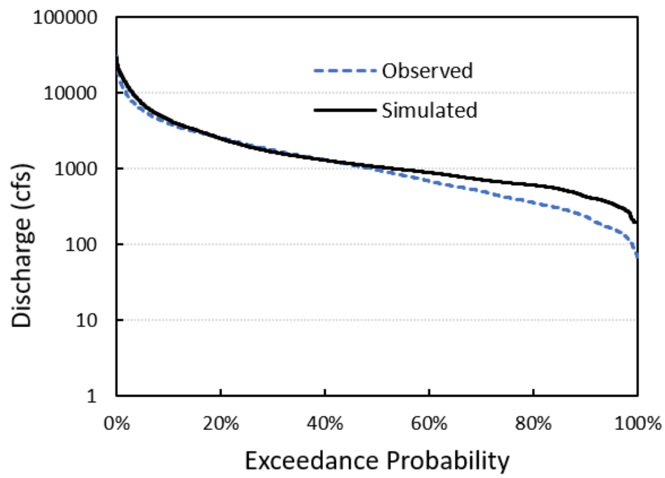

Figure 0-11: Daily flow duration curve for Anamosa.

Based on the performance metrics, hydrographs, and auxiliary figures presented in this section, the GHOST model was deemed to be well-calibrated for the Upper Wapsipinicon 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 5 provides a full catalogue of the 28 projects constructed in the Upper Wapsipinicon, 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 4-12 shows this set-up for several of the IWA projects in the Upper Wapsipinicon.

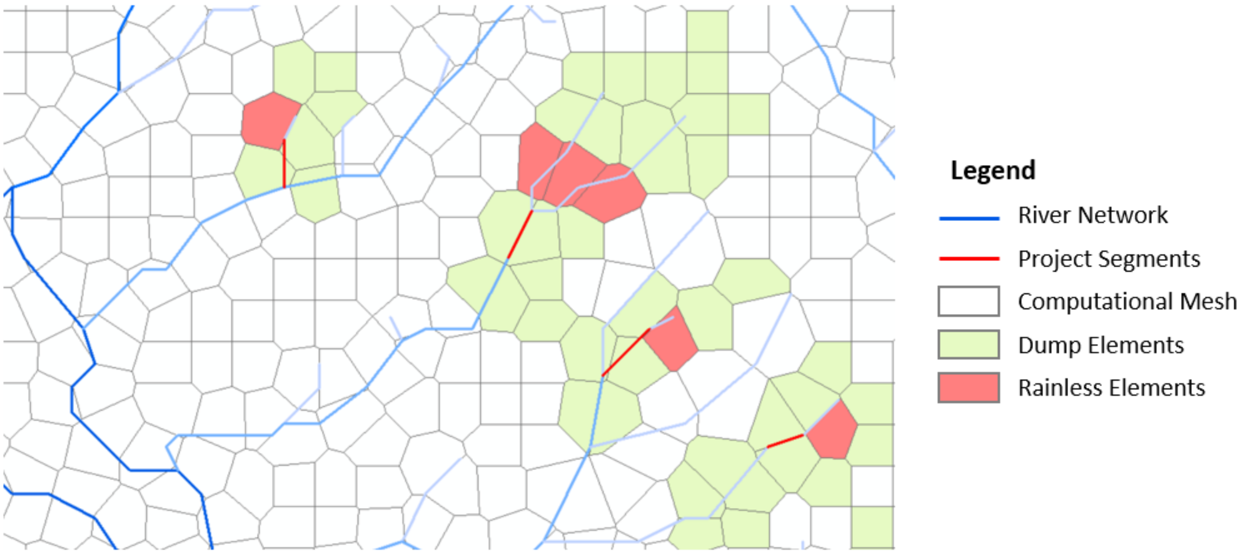

Figure 0-12: A portion of the GHOST model that shows how project effects are simulated by dumping the attenuated outflow hydrograph calculated for each project while eliminating rainfall upstream, which would produce the original, unaltered streamflow.

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 6 presents the results from testing the individual and cumulative impacts of the IWA projects during flooding.

Project Inventory

a. IWA Projects in the Upper Wapsipinicon Watershed

The Iowa Watershed Approach helped fund the design and construction of 28 new BMPs throughout the Upper Wapsipinicon Watershed, providing 90% cost-share assistance to volunteer landowners. A summary of the 28 projects is given in Table 5-1.

Table 5-1: Project Summary Table.

PROJECT	PRACTICE	WATERSHED	COST	DRAINAGE AREA (ac)	Berm Storage (ac-ft)
UW-001-DAUBENBERGER	Pond	Smith Creek-Wapsipinicon River	$ 26,265.20	6.3	5
UW-003-FRANK	Pond	Smith Creek-Wapsipinicon River	$ 51,176.00	77.1	9.55
UW-022-CITY OF QUASQUETON	Wetland	Smith Creek-Wapsipinicon River	$ 22,239.10	10.32	1.63
UW-002-FALCONER	Pond	Dry Creek-Wapsipinicon River	$ 25,487.92	11.8	9.8
UW-006-KREMER	Pond	Smith Creek-Wapsipinicon River	$ 19,129.74	29.1	9.4
UW-020-KREMER	Grade Stabilization	Smith Creek-Wapsipinicon River	$ 11,091.92	13.7	2
UW-011-WEBER	Pond	Dry Creek-Wapsipinicon River	$ 52,817.02	24	19.63
UW-023-HOOVER	Pond	Dry Creek-Wapsipinicon River	$ 24,236.92	19.5	4.89
UW-010-SHANNON	Pond	Smith Creek-Wapsipinicon River	$ 24,639.50	266	3.36
UW-012-WOLFE	Oxbow	Dry Creek-Wapsipinicon River	$ 25,675.00	Oxbow	1.5
UW-016-IDNR CEDAR ROCK	Oxbow	Smith Creek-Wapsipinicon River	$ 198,984.00	44	9.6

UW-027-OSBORN	Pond	Smith Creek-Wapsipinicon River	$ 60,084.75	63.2	12.11
UW-015-IDNR MANGOLD TRACT	Wetland	Nugents Creek-Buffalo Creek	$ 215,121.50	209	33.2
UW-024-IDNR BUFFALO CREEK	Wetland	Nugents Creek-Buffalo Creek	$ 78,385.60	718	64.6
UW-028-IDNR	Oxbow/Wetland	Nugents Creek-Buffalo Creek	$ 22,992.00	9.9	0
UW-019-SHANNON	Wetland	Dry Creek-Wapsipinicon River	$ 49,714.70	1273	10.4
UW-029-LUTZ	Pond	Dry Creek-Wapsipinicon River	$ 80,596.50	148	25.9
UW-032-BRISLAWN	Oxbow	Dry Creek-Wapsipinicon River	$ 12,804.00	Oxbow	0.7
UW-033-LANE	Oxbow	Dry Creek-Wapsipinicon River	$ 12,378.00	Oxbow	1.7
UW-030-WEBER	Pond	Smith Creek-Wapsipinicon River	$ 95,442.40	52.5	32.5
UW-031-WEBER	On-Road Detention	Smith Creek-Wapsipinicon River	$ 227,282.30	592	86.2
UW-007-MONAT	Oxbow, Pond	Dry Creek-Wapsipinicon River	$ 48,811.00	280	21.5
UW-045-BURRELL	Pond	Smith Creek-Wapsipinicon River	$ 46,677.00	45	6.7
UW-040-BOHNENKAMP	On-Road Detention	Dry Creek-Wapsipinicon River	$ 118,963.20	66	6.9
UW-042-BRETZ	Pond	Dry Creek-Wapsipinicon River	$ 111,107.30	100.1	34.3
UW-044-PAYN	WASCOBs	Smith Creek-Wapsipinicon River	$ 65,482.20	85.7	0

UW-034-LOPATA	Grass Waterway	Dry Creek-Wapsipinicon River	$ 37,047.00	25.4 and 67.2 (two drainages)	0
UW-037-LOPATA	Grass Waterway	Smith Creek-Wapsipinicon River	$ 70,877.00	27.9 and 13.3 (two drainages)	0
Total	**--**	**--**	**$1,835,508.77**	**4,239.3**	**413.1**

BMPs were constructed in three of the four HUC12s selected to be part of the IWA; no projects were built in the Sand Creek Sub-watershed. Figure 5-1 shows the locations of the 28 projects in the Upper Wapsipinicon. All three sub-watersheds that received projects are "pass-through" HUC12s, through which a high-order stream enters and exits (the Wapsipinicon River for Smith and Dry Creeks, and Buffalo Creek for Nugents Creek). The nature of these sub-watersheds limits the impact of the projects, which is further discussed in Chapter 6.

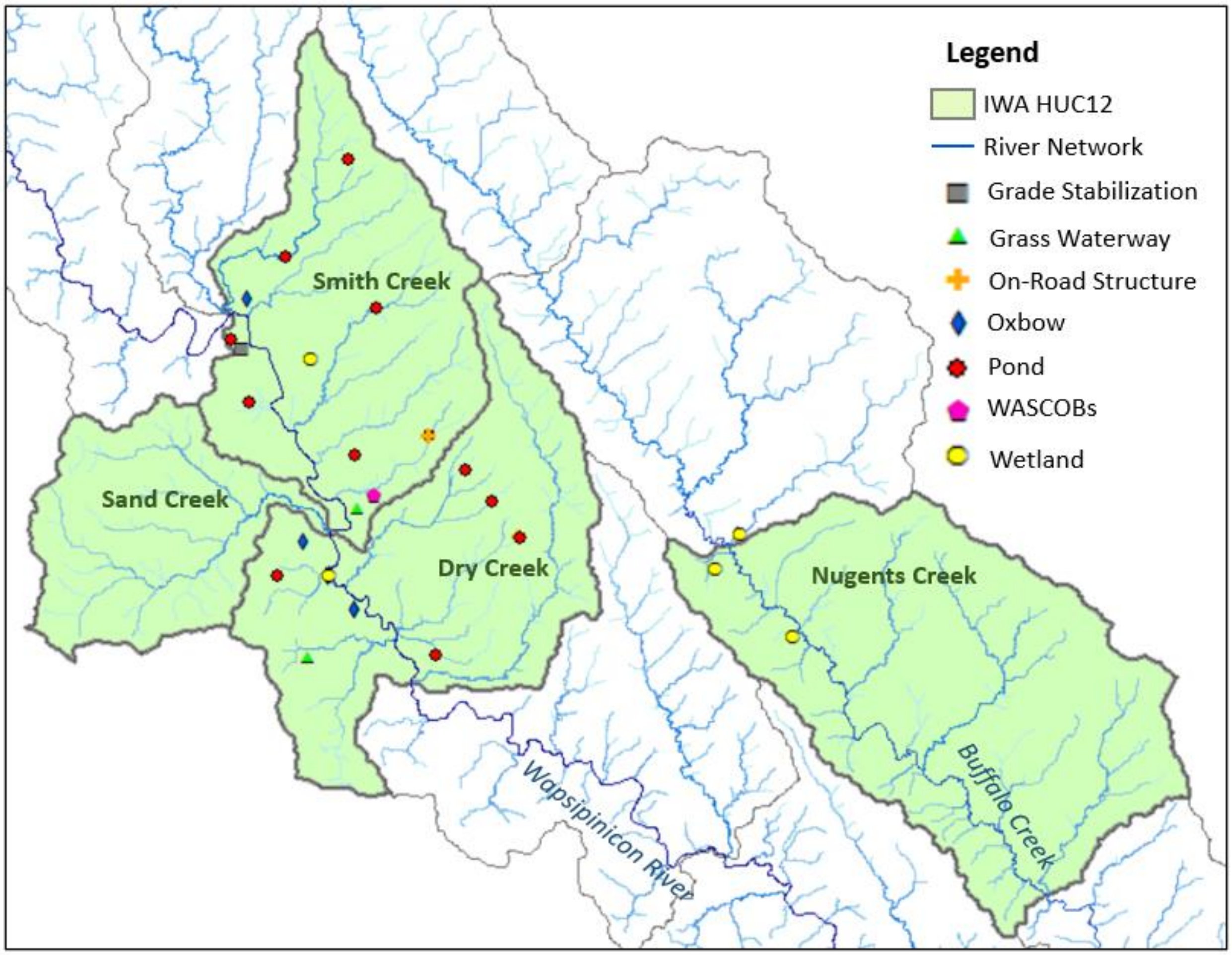

Figure 0-1: Location and type of the 28 IWA projects in the Upper Wapsipinicon. Note that in several instances, two projects are too close together to appear separate.

b. Hydraulics of Flood Mitigation Projects

Seven different types of BMPs were constructed in the Upper Wapsipinicon Watershed: 12 ponds, 6 oxbows, 4 wetlands, 2 on-road detention structures, 2 grass waterways, 1 WASCOB complex, and 1 grade stabilization. Several projects are not easy to implement in the GHOST model: UW-028 IDNR is an oxbow with wetland features; UW-007 Monat is primarily an oxbow reconstruction but with a pond; and UW-020 Kremer is classified as a grade stabilization or a "dry pond." Aside from grass waterways, most projects provide at least some attenuation. However, while oxbows store water on the landscape, it is generally water intercepted from a flooding stream; it can be very difficult to estimate the "inflow" and "outflow." For the most part, the ponds, wetlands, and on-road structures all 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 5-2 illustrates a classic difference in streamflow with and without a storage project.

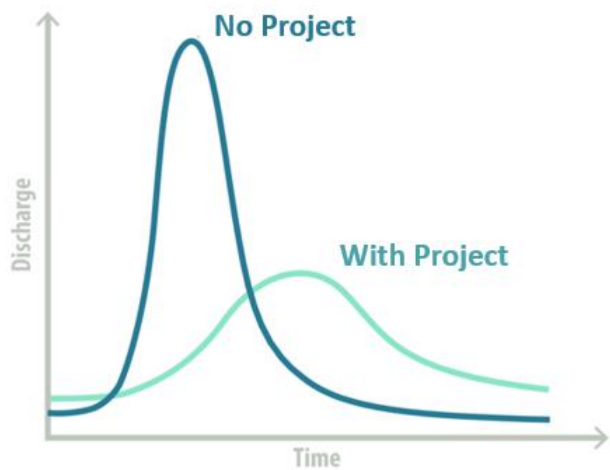

Figure 0-2: A classic comparison of a streamflow hydrograph with and without a flood mitigation project. The addition of the project does not change the volume of water moved but rather lowers the peak flow passed and gradually releases the water at slower rates.

A basic storage structure design (Fig. 5-3) 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.

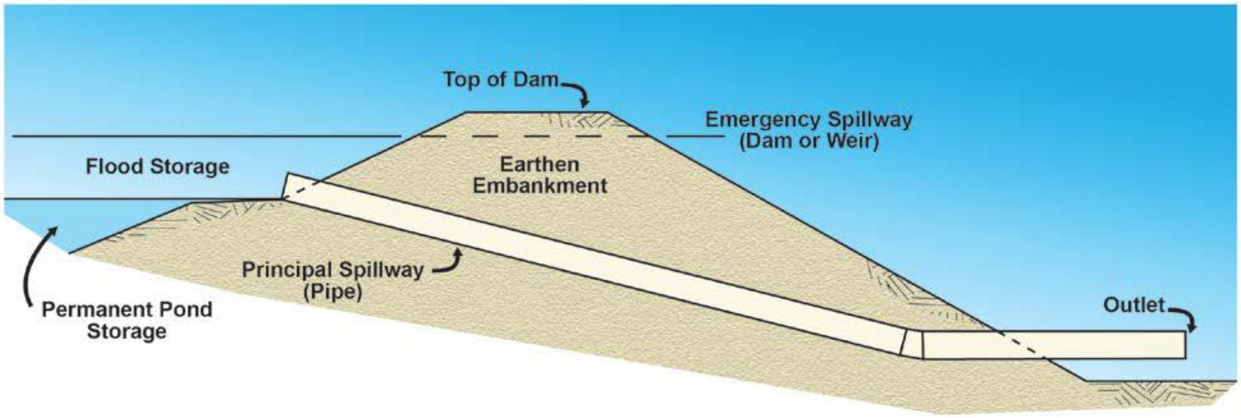

Figure 0-3: Schematic of a pond constructed to provide flood storage.

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, 28 new BMPs were constructed in the Upper Wapsipinicon Watershed:

- 12 Ponds
- 6 Oxbows
- 4 Wetlands
- 2 On-Road Structures
- 2 Grass Waterways
- 1 WASCOB Complex
- 1 Grade Stabilization/Dry Pond

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 Upper Wapsipinicon.

Upper Wapsipinicon Hydrologic Assessment

a. Individual Impacts of IWA Projects

In order to assess the flood reduction impacts of IWA projects in the Upper Wapsipinicon Watershed, a design storm was imposed on GHOST. The storm generated 6.5 inches of rain within a 24-hour period, as shown in Fig. 6-1. 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 4.d, to more accurately match the inflow hydrographs that the projects were designed for.

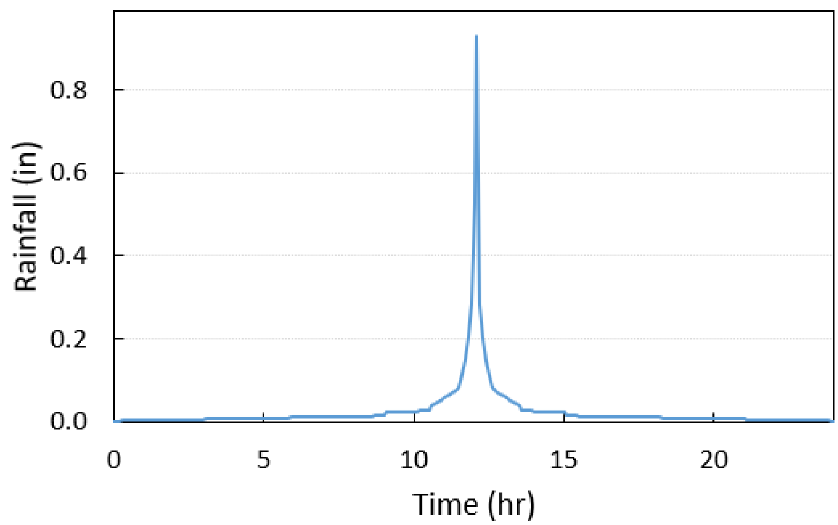

Figure 0-1: Rainfall hyetograph from the design storm used in GHOST to test the effects of projects on flood peak reductions.

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 4.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 analyses include examples of the primary types of flood mitigation projects (ponds, on-road structures, and wetlands) and represent the various streamflow responses to project implementation on a local scale.

In the Dry Creek-Wapsipinicon River HUC12, the pond UW-042 Bretz receives its inflow from the outflow of on-road detention structure UW-040 Bohenkamp. Together, these two projects exhibit classic flood peak reduction behavior in a tributary that feeds directly into the Wapsipinicon. Figure 6-2 shows the location of these projects in relation to the GHOST stream network and the hydrographs (with and without projects) at the different marked downstream locations.

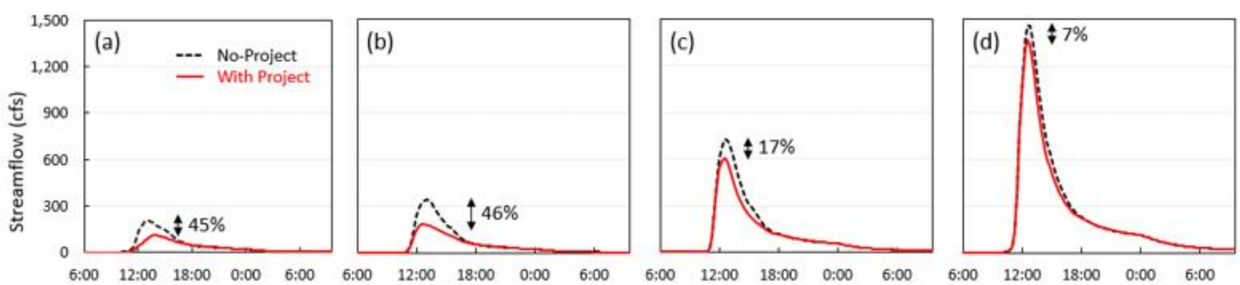

Figure 0-2: The location of projects UW-040 and UW-042, along with hydrographs comparing the streamflow with (solid red) and without (dashed black) projects at various points downstream.

At point a immediately downstream of the project, streamflow is rather low but adding the projects achieved a 45% reduction in peak flow. Point b lies just below a confluence with a small stream, and the peak reduction is maintained despite approximately double the streamflow. The projects' gradual release of water is augmented by flow from the other branch. Moving downstream, the tributary picks up more and more water, as seen by the increasing magnitude of the streamflow at points c and d. However, with this incoming water, the peak reduction is lessened because all the new water comes after the projects and is not affected by them. By the time the flood event reaches the Wapsipinicon, peak flow reduction is less than 7%. Stream stage, or height of water, at this downstream-most index point is reduced by 0.12 feet (1.4 inches) with projects in place.

A similar response is observed in Honey Creek, a slightly larger Wapsipinicon tributary just north of the Bohenkamp and Bretz projects' unnamed creek. Here, two ponds (UW-011 Weber and UW-023 Hoover) attenuate flows in parallel branches that ultimately converge, along with other, unregulated branches. Figure 6-3 shows the location of these projects and hydrographs illustrating their downstream effects.

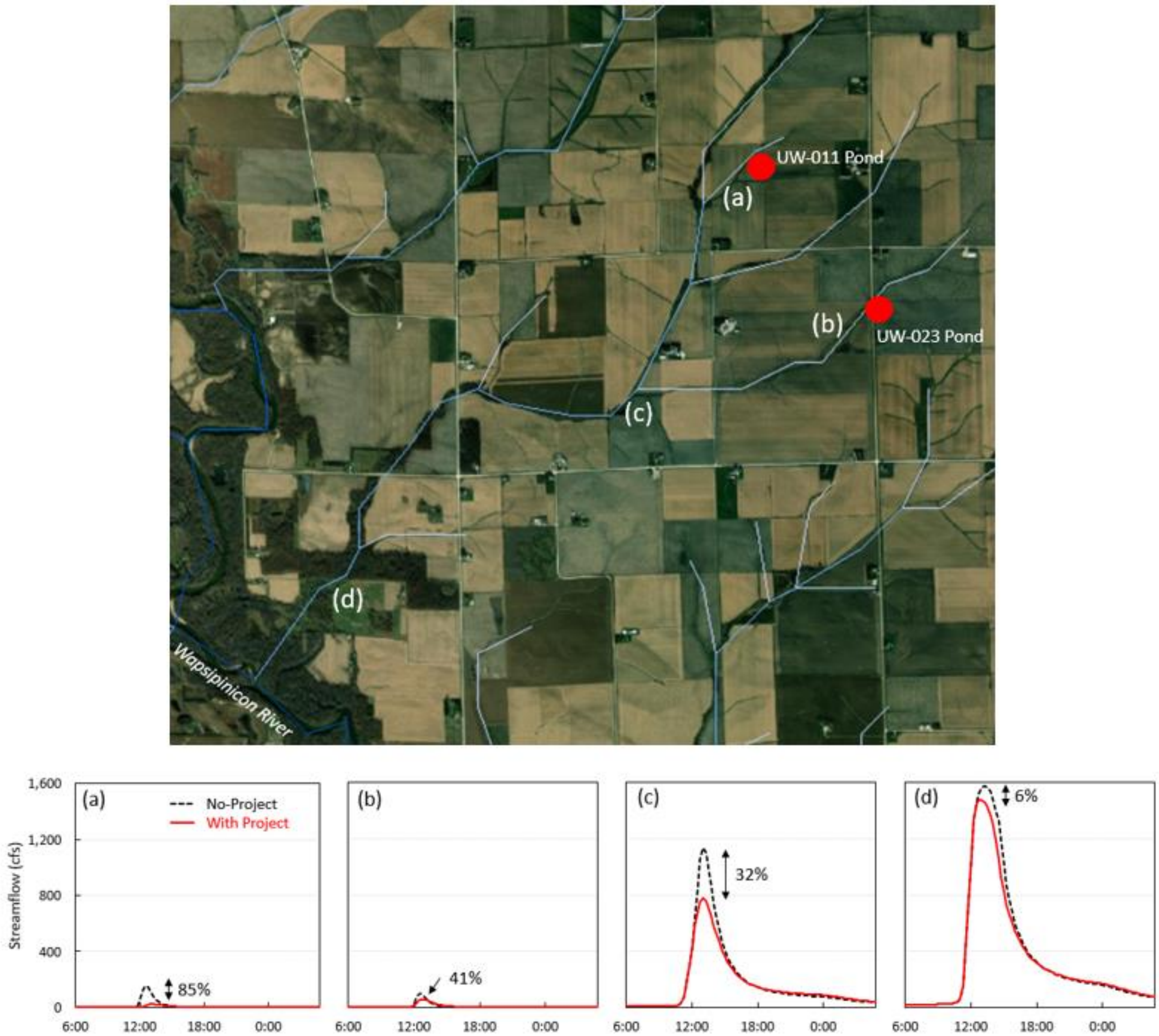

Figure 0-3: The location of ponds UW-011 and UW-023, along with hydrographs comparing the streamflow with (solid red) and without (dashed black) projects at various points downstream.

Both ponds produce significant flood peak reductions immediately downstream — 85% for UW-011 and 41% for UW-023. Even after their branches and several others converge, the peak magnitude increases to over 800 cfs, yet the peak reduction is still 32%. However, after travelling farther downstream and picking up even more water, eventually the peak reduction is just 6% before it enters the Wapsipinicon. The stage difference at point d is 0.28 feet. Again, this behavior reflects the common streamflow response to upstream projects: significant local impacts that quickly deteriorate at larger scales.

An example of a project that produced a different, less-typical response is found in on-road structure UW-031 Weber and its companion pond, UW-30 Weber, located in the Smith Creek HUC12. The on-road structure regulates the combined flow of the two forks northeast of it, which comprise a large fraction of the total drainage area. The pond regulates a much smaller side-drainage that feeds into the outflow of the on-road structure. Figure 6-4 shows the location and effects of these projects.

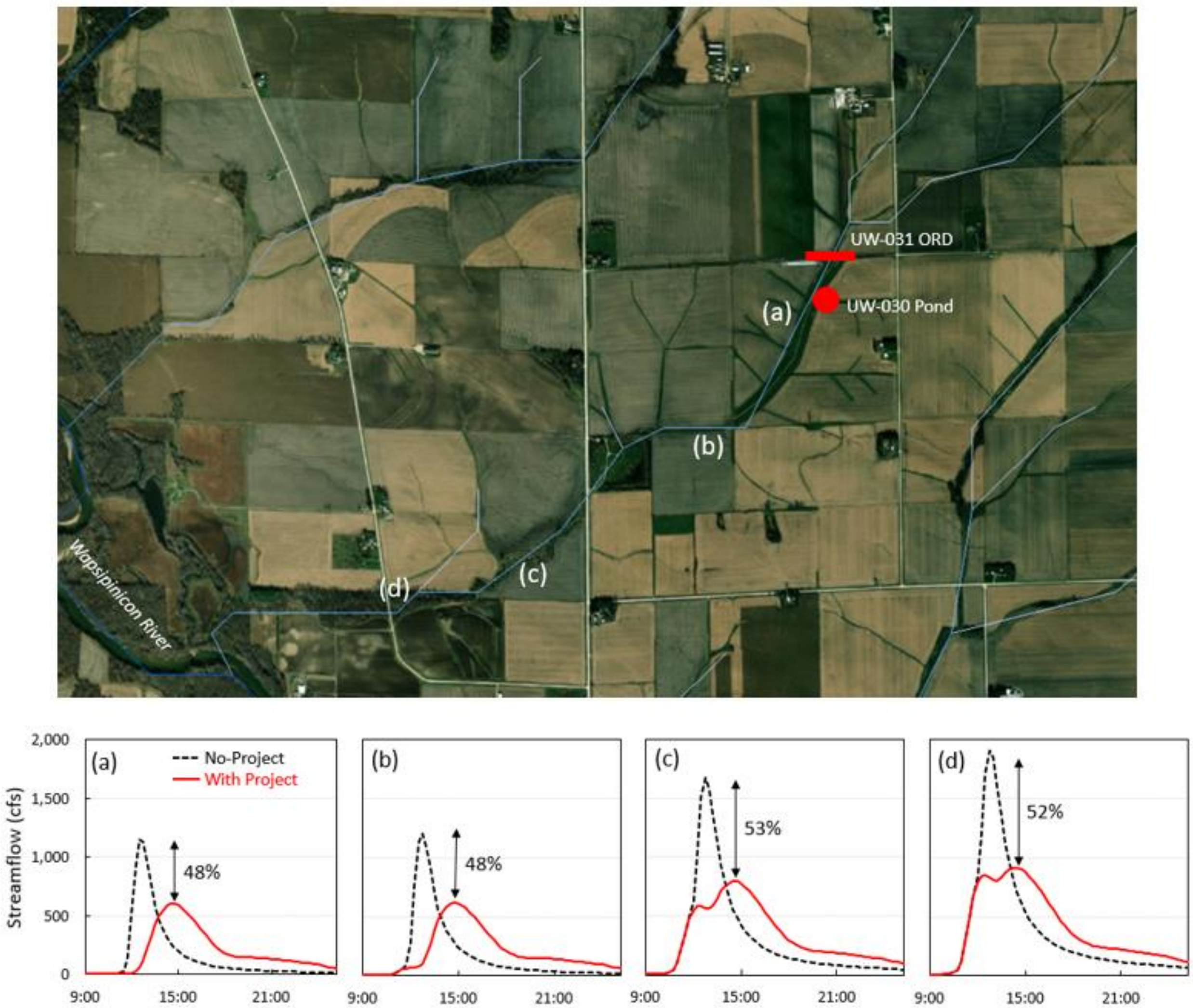

Figure 0-4: The location of projects UW-030 and UW-031, along with hydrographs comparing the streamflow with (solid red) and without (dashed black) projects at various points downstream.

The 48% reduction at index point a is maintained downstream at point b, but increases slightly at points c and d. This is likely because the bulk of the streamflow (two-thirds) enters the stream immediately downstream of the on-road structure, coming from the small tributaries downstream from it. The with-project hydrographs at points c and d exhibit a bimodal shape, where the rising limb is coincident with that of the no-project version; this is the water from the downstream portion of the drainage area. However, the second peak's arrival is delayed, thanks to the on-road structure, therefore reducing the peak flow. The stage difference at point d is 0.55 feet. This behavior may be easier to see in Fig. 6-5, which superimposes the hydrographs (with and without projects) from all four index points on one graph. Streamflow increases but the peak reduction remains approximately constant.

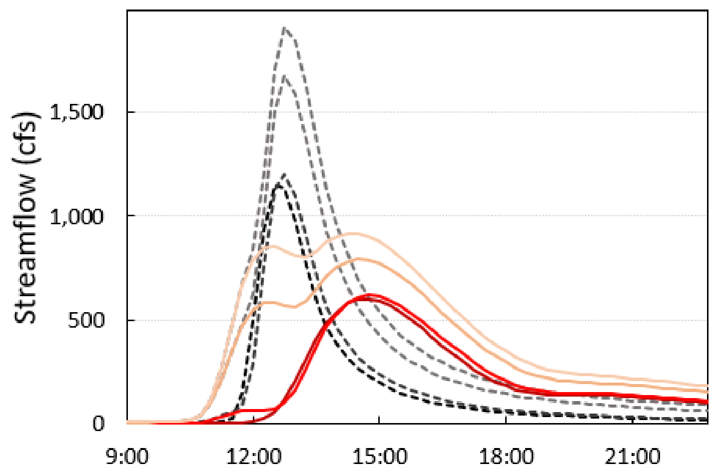

Figure 0-5: Streamflow with (solid red) and without (dashed black) UW-030 and UW-031 at four points downstream, moving from bolder to lighter curves.

The unusual but more-beneficial behavior of this project is largely caused by its placement lower in the watershed, where it receives over half of the stream's contributing drainage. Other projects located higher up in their basins don't provide as much flood reduction benefit.

The final individual example of this report will focus on a wetland, UW-015 Mangold, that attenuates flows from a small tributary of Buffalo Creek in the Nugents Creek HUC12 (see Fig. 6-6). The wetland produces a small, 24% peak reduction immediately downstream, which is harder to determine slightly farther downstream where backwater effects from Buffalo Creek complicate the streamflow (though the initial peak is 15% lower). Once the wetland's tributary joins Buffalo Creek, the peak in that higher-order stream is only 1.3% lower with the wetland in place. Since a vast amount of streamflow is already coming from upstream in Buffalo Creek, a small reduction in a small tributary becomes rather inconsequential. This is a theme that will become even more evident in the next section when examining the cumulative effects of all the IWA projects at larger scales.

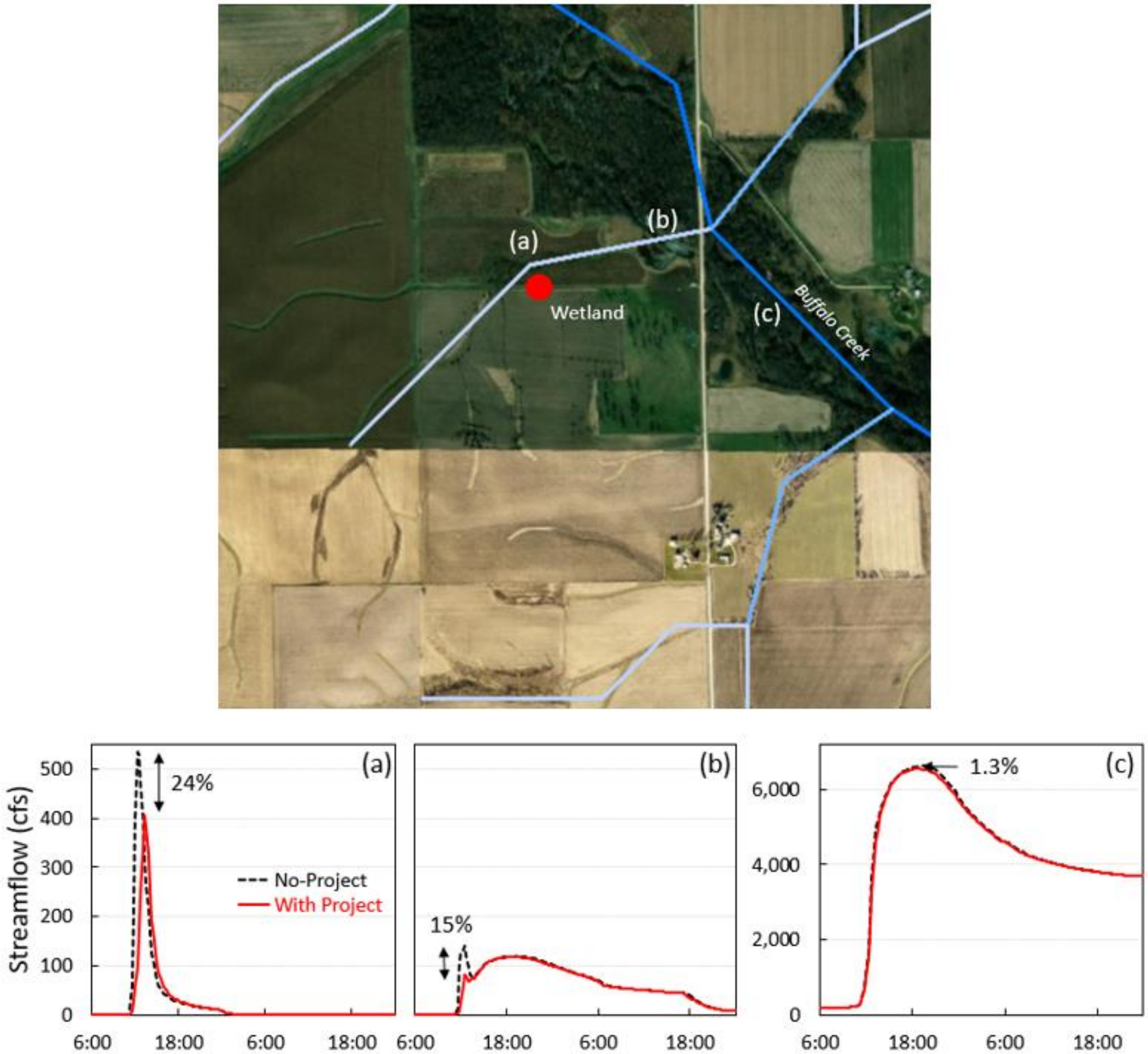

Figure 0-6: The location of wetland UW-015, along with hydrographs comparing the streamflow with (solid red) and without (dashed black) projects at various points downstream.

b. Watershed-Scale Effects

Although most of the projects produced considerable local flood reduction benefits, these impacts are drastically reduced at larger spatial scales. Figure 6-7 shows peak reductions at several large-scale index points for the design storm used to generate the examples in the previous section.

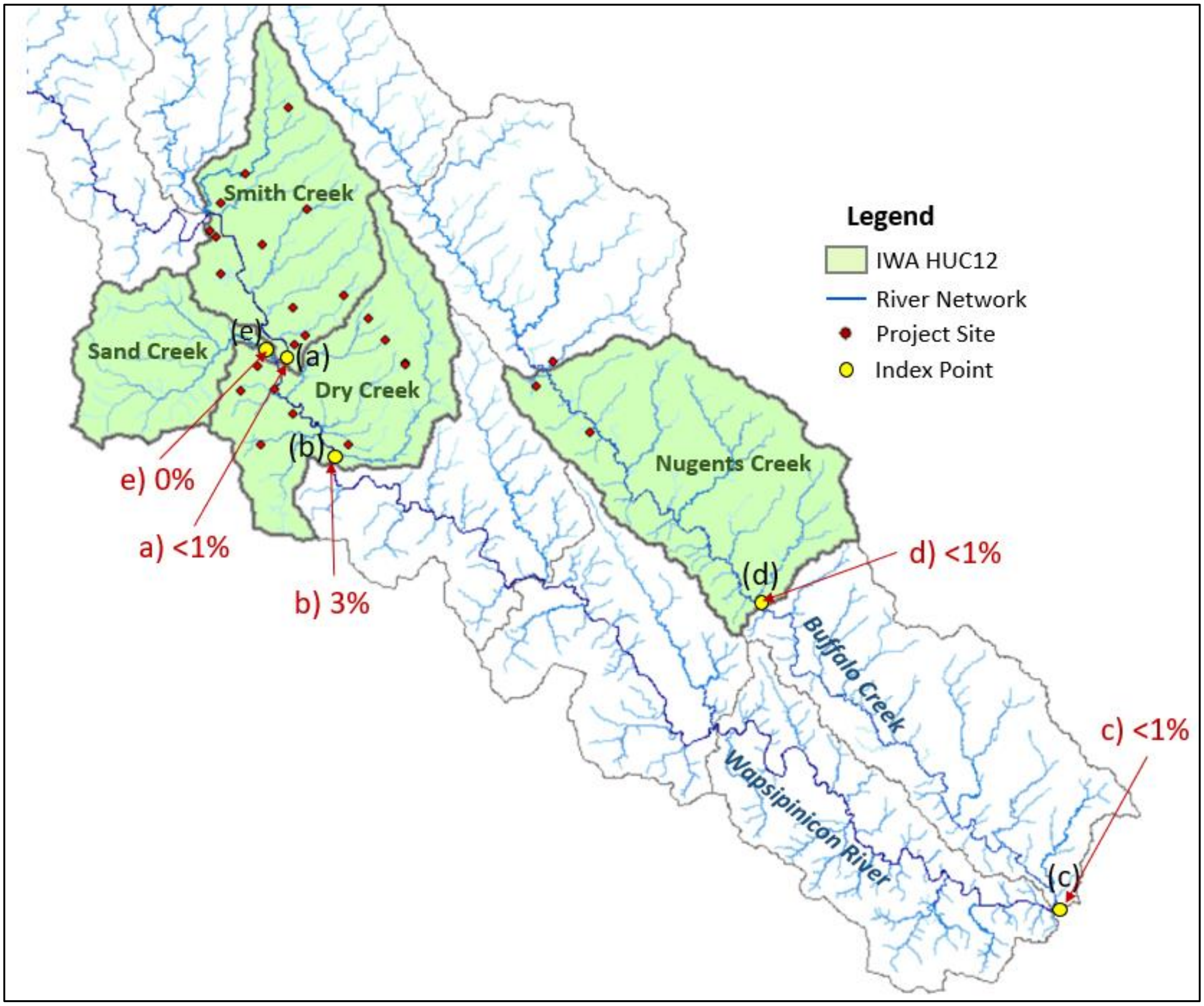

Figure 0-7: Flood peak reduction (red text) at five watershed-scale index points: the Wapsipinicon River at: a) Smith Creek HUC12 outlet; b) Dry Creek HUC12 outlet; c) Anamosa; d) Buffalo Creek at Nugents Creek HUC12 outlet; and e) Sand Creek HUC12 outlet

The three IWA sub-watersheds that ended up constructing projects are all "pass-through" HUC12s, where the Wapsipinicon River or Buffalo Creek enter and exit, as opposed to headwater HUC12s such as Sand Creek, where all of the flow at the HUC12 outlet originated within that HUC12. Unfortunately, no projects were built in the Sand Creek HUC12, which would have offered the best chance for notable sub-watershed-scale impacts at index point e. Flows along the Wapsipinicon River were largely unchanged, with negligible peak reductions at index points a) Smith Creek HUC12 outlet and c) Anamosa. The 3% peak reduction at index point b) Dry Creek

HUC12 outlet is somewhat inspiring because adding a few more projects downstream of Smith Creek would have produced a non-zero, though small, peak reduction. A negligible peak reduction was also observed at index point d) Buffalo Creek at the Nugents Creek HUC12 outlet. This is not surprising because only three projects were built upstream of this rather large tributary.

c. Limitations of the IWA Projects

While impactful on a local scale, the limited flood reduction benefits of the 28 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 regulated by the IWA projects is 4,239 acres, only 0.42% of the entire Upper Wapsipinicon Watershed. It is not surprising, therefore, that peaks are reduced <1% at Anamosa, when <1% of the basin's drainage area is captured by projects. Figure 6-8 compares the drainage area of each of the four IWA HUC12s with the area regulated by the projects within their boundaries.

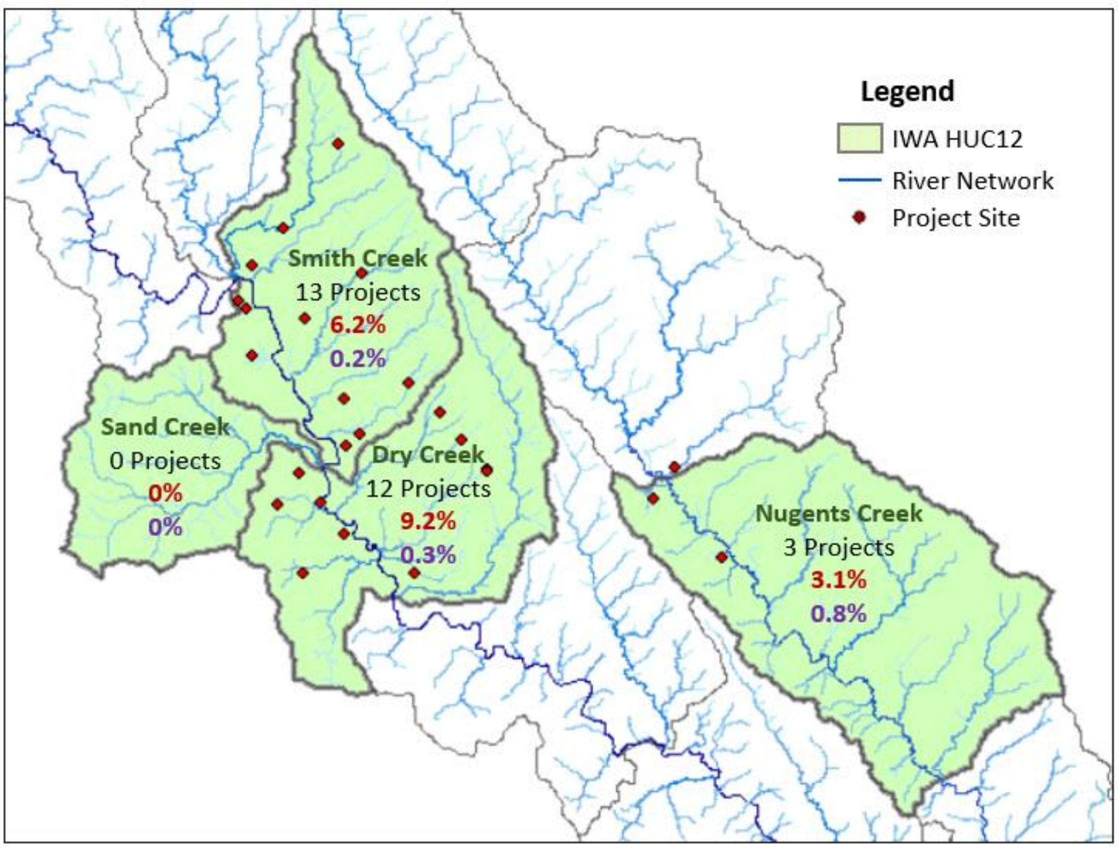

Figure 0-8: The number of projects in each IWA HUC12, the percent of each HUC12's own drainage area regulated by its projects (red), and the percent of each HUC12's upstream drainage area regulated by its projects (purple).

While projects achieve moderate flow reductions at smaller scales (approx. 3—9% in portions of the IWA sub-watersheds), the entire upstream area draining into and through the watersheds must be considered when evaluating cumulative project impacts. When considering entire IWA sub-watersheds and their upstream drainage, the areas affected by constructed projects represent less than 1% of the totals. Close to 10% of Dry Creek HUC12's own drainage area is controlled by projects, producing a peak flow reduction of 3% at its outlet during the design storm. Overall, however, far too little drainage area is regulated by projects. If 3–9% of Sand Creek's drainage area were regulated, similar to the other three sub-watersheds, it would not be unreasonable to expect similar values for percent peak reduction, which might be a worthy return on investment. Table 6-1 provides the details on the drainage area and storage provided by the IWA projects.

Table 6-1: Drainage area and storage capacity of IWA Projects relative to their HUC12 and the Upper Wapsipinicon Watershed (UW).

Watershed	**Area (ac)**	**% of UW**	**Project Drainage Area (ac)**	**Project % of HUC12**	**Project % of UW**	**Storage (ac-ft)**
Nugents Creek - Buffalo Creek HUC12	30,492	3.0%	937	3.1%	0.09%	98
Dry Creek - Wapsipinicon HUC12	21,530	2.1%	1,990	9.2%	0.20%	178
Smith Creek - Wapsipinicon HUC12	21,108	2.1%	1,313	6.2%	0.13%	137
Sand Creek HUC12	11,934	1.2%	0	0%	0%	0
Total	*85,064*	*8.5%*	*4,239*	*5.0%*	*0.42%*	*413*

In addition to drainage area, the storage capacity provided by these projects is crucial in understanding their flood reduction capabilities. Storage is essentially the volume of water a project can hold back during a flood event. The total storage of the IWA projects is 413 ac-ft, which may be a difficult number to comprehend without some context.

During the flood of June 2008, the record flood in Anamosa, over 600,000 ac-ft of water flowed through the town between June 5 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 0.1% of the floodwaters. The flood of September 2016 — a smaller, though still significant, event — moved over 300,000 ac-ft of water and would have been reduced only ~0.14% had the IWA projects been in place.

d. Future Implications

The impact of the 28 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. Based on the storage capacity achieved with the $1.8M spent on the 28 IWA projects, reducing the 2008 flood by just 10% would likely require at least 4,000 projects and over $250M. The Phase I IWA report for the Upper Wapsipinicon Watershed estimated that 919 ponds built across the entire HUC8 would achieve an average peak reduction of only 5% at Anamosa. Based on the Phase II construction, this would cost close to $60M.

To get an idea of the investment needed to produce watershed-scale flood-reduction benefits, Fig. 6-9 shows the approximate cost to achieve a 20% peak reduction in the top-10 floods from 2002-2020, extrapolating from the cost of 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 of dollars.

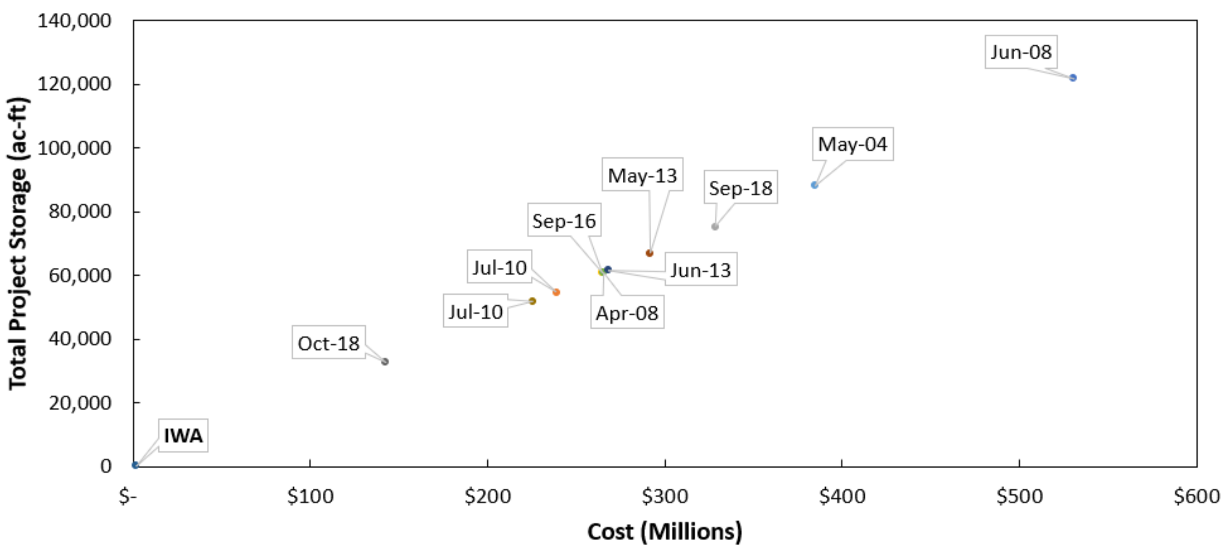

Figure 0-9: Approximate flood storage and cost required to achieve a 20% peak reduction in the top-10 flood events ("Month-Year") between 2002–2020, compared to the IWA.

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 $300–500M in the Upper Wapsipinicon seem more appropriate. Iowa has a tremendous need to reduce flooding and improve water quality. IIHR estimates that it would cost about $3M for each HUC12 to begin to address flooding and another $3M to address water quality. With 41 HUC12s in the Upper Wapsipinicon, we estimate that more than $120M would be required to make a dent in flooding; this agrees well with Fig. 6-9.

Summary and Conclusions

The Upper Wapsipinicon 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 Upper Wapsipinicon, a catalogue of projects constructed, the model used to assess them, and the results of that evaluation.

a. Watershed Characteristics

The Upper Wapsipinicon Watershed is a HUC8 located in eastern Iowa, lying mostly on the Iowan Surface. The entire Wapsipinicon Watershed is 2,549 mi2, with the upper portion ending just upstream of Anamosa and measuring approximately 1,575 mi2. Over 70% of the watershed's land area is used for agriculture. Average annual precipitation ranges from roughly 33 inches in the upper part to 38 inches near Anamosa, approximately 30% of which becomes streamflow. Stream gauges operated by the USGS in Tripoli, Independence, and Anamosa were used in this analysis. Flooding is not an uncommon occurrence in the Upper Wapsipinicon, much like the rest of Iowa. Record floods occurred in 1999 for Tripoli and Independence, and in 2008 for Anamosa. The top-six floods in Anamosa have all occurred since 2004.

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 the majority of the Wapsipinicon Watershed because of the abundance of data available in DeWitt, Iowa, close to the river's confluence with the Mississippi. Nitrate concentrations ranged from 0.01 mg/L to 20 mg/L, with an average of 5.46 mg/L. Total phosphorus (TP) concentrations ranged from 0.01 mg/L to 1.4 mg/L, with an average of 0.24 mg/L. Yearly nitrate yields ranged from 8 lbs/ac to 31 lbs/ac, and TP yields were between 0.25 lbs/ac and 1.5 lbs/ac. Annual water yields strongly correlated to annual nutrient yields. Trend detection tests suggested that daily concentrations for nitrate and TP were decreasing. However, these tests indicated that daily loads were increasing for nitrate, and TP as mean daily flows were also found to be increasing. The Upper Wapsipinicon River in Independence achieved the highest Water Quality Index score out of all locations in Iowa, based on an analysis performed by Dr. Christopher Jones at IIHR. Although the watershed does not have superb water quality, it is good relative to the rest of the state.

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 Independence and Anamosa, and could therefore be used with confidence to assess watershed response to IWA projects (see Chapter 4). 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 28 BMPs across the Upper Wapsipinicon Watershed: 12 ponds, 6 oxbows, 4 wetlands, 2 on-road structures, 2 grass waterways, 1 WASCOB complex, and 1 grade stabilization. Note that a couple of the projects were defined as one type of practice despite consisting of a combination or hybrid of two. Table 5-1 lists the 28 projects and their details, and Fig. 5-1 shows a map of the projects. Projects were constructed in only three of the four IWA sub-watersheds in the Upper Wapsipinicon (Sand Creek HUC12 did not). 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. Peak flow reductions between 20% and 90% were common immediately downstream of project sites. In general, this reduction gradually diminished as streamflow increased downstream from the site (e.g., Figs. 6-2, 6-3, and 6-6) until the peak flow reduction was <10% in the tributary immediately before its confluence with the Wapsipinicon River. However, not all the projects produced similar effects. The on-road structure UW-031 Weber captured a large enough portion of its tributary's drainage area that its ~50% reduction of peak flow was maintained all the way to the confluence with the river (see Fig. 6-4).

Because of the limited number and size of projects, cumulative impacts on the watershed-scale were generally negligible. Peak flows were reduced by less than 1% below the Smith Creek HUC12, the Nugents Creek HUC12, and in Anamosa. The outlet of the Dry Creek HUC12 saw just a 3% peak flow reduction due to the IWA projects. The location of the projects was one of the main reasons for these small impacts. The single IWA sub-watershed where no projects were built (Sand Creek) was the only headwater HUC12; the three sub-watersheds that received projects all receive considerable inflow from upstream drainage areas as the Wapsipinicon or Buffalo Creek pass through them. It is difficult for a minor peak reduction in a small tributary to have a discernable impact on the larger river downstream.

The 28 IWA projects regulate drainage from over 4,000 acres and can store more than 400 ac-ft of water. However, these capacities are dwarfed by the size of the entire Upper Wapsipinicon Watershed. Less than 0.5% 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 0.07% of the floodwaters. An incredible investment in upstream flood mitigation infrastructure would be required to begin to address flooding on a watershed scale. In the IWA Phase I report, it was estimated that 919 ponds constructed across the watershed would reduce peak flows in Anamosa by an average of 5%. At least 4,000 ponds would have been required to reduce the 2008 flood by 10%, requiring an investment of over $250 million. Based on the storage achieved by the $1.8 million spent in the Upper Wapsipinicon during Phase II of IWA, hundreds of millions of dollars would be required to reduce the top-10 floods by 20% between 2002 and 2020 (see Fig. 6-9). 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 Upper Wapsipinicon 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, 28 best management practices were constructed within the four Upper Wapsipinicon 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 28 constructed projects do not have significant flood mitigation benefits at sub-watershed and Upper Wapsipinicon Watershed scales. Realization of watershed-scale benefits will require substantial additional investments in best management practices throughout the Upper Wapsipinicon Watershed. The Iowa Watershed Approach, through establishment of Watershed Management Authorities, watershed hydrologic assessments, and construction and evaluation of best management practices, has created a framework from which management efforts can continue and watershed-scale benefits can ultimately be achieved.

Appendix A – References

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/J0H993CC.

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 soilscapes to landscapes: A landscape oriented approach to simulate soil organic carbon dynamics in intensively manage landscapes,” Journal of Geophysical Research: Biogeosciences, 120, 2375-2401, doi:10.1002/2015JG003078. 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 Walley,” 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/J0DJ5CTG

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.