Iowa Watershed Approach Phase II:
Clear Creek Watershed Project Evaluation

by

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

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

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1. Introduction

From 2011–2013, Iowa suffered eight Presidential Disaster Declarations encompassing 73 counties and more than 70% of the state. As devastating as these events were, this period is but a brief moment in Iowa's long history of enduring and recovering from major floods. Figure 1-1 shows just one example of the devastation caused by floods in Coralville during June 2008. Long-term data show that heavy precipitation and flood events are increasing in frequency across the Midwest, and Iowans need to be prepared for the economic, social, and environmental impacts of these changing trends.

Figure 1-1. Aerial view of flooding in Coralville, June 2008 (Dave Schwartz / Iowa City Press-Citizen)

In January 2016, the state of Iowa received a $97 million award for the Iowa Watershed Approach (IWA) (Weber et al., 2018). 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 Figure 1-2, including the Upper Iowa River, Upper Wapsipinicon River, Middle Cedar River, Clear Creek, English River, North Raccoon River, East Nishnabotna River, West Nishnabotna River, and Bee Branch Creek. In addition, urban projects in the cities of Dubuque, Coralville, and Storm Lake focused on infrastructure improvements to mitigate flood risk.

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

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

Figure 1-3. Flood mitigation pond and fringe wetland (CC-015 Sippy) constructed as part of the IWA in the Middle Clear Creek watershed, a sub-watershed of Clear Creek.

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 Clear Creek Watershed to detail the practices constructed and evaluate their individual and cumulative benefits.

Ultimately, 57 BMPs were completed in the Clear Creek Watershed as part of the IWA:

- 14 WASCOBs
- 13 Ponds
- 12 Grade Stabilizations
- 10 Grassed Waterways
- 4 Floodplain Restorations
- 2 Wetland Restorations
- 1 Wetland
- 1 Perennial Cover

Figure 1-3 and Figure 1-4 show examples of these projects. The total design and construction costs of these projects was approximately $1.8 million. Chapter 6 provides details of all 57 practices, and Chapter 7 summarizes the results of the project evaluation.

Figure 1-4: Flood mitigation pond (CC-010 Asumussen) constructed as part of the IWA in the Middle Clear Creek watershed, a sub-watershed of Clear Creek.

2. Iowa's Hydrology and Water Quality

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

a. Land Surface and Use

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

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

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

In contrast, northeastern Iowa experienced a period of extreme cold (21,000 to 16,500 years ago) during the last glacial maximum, resulting in extensive erosion of the landscape and the formation of the Iowan Surface landform region. Characteristic features include gently rolling topography, common glacial "erratics" (rocks and boulders not native to Iowa transported here by glaciers), and loess-mantled paha (northwest to southeast trending uneroded upland remnants of the former landscape). The depth to bedrock is often shallow on this landform region. Surficial materials

consist of poorly consolidated glacial deposits with the potential for extensive local sand bodies. In areas where the depth to bedrock is shallow, these materials provide limited protection from surface water infiltrating into bedrock.

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

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

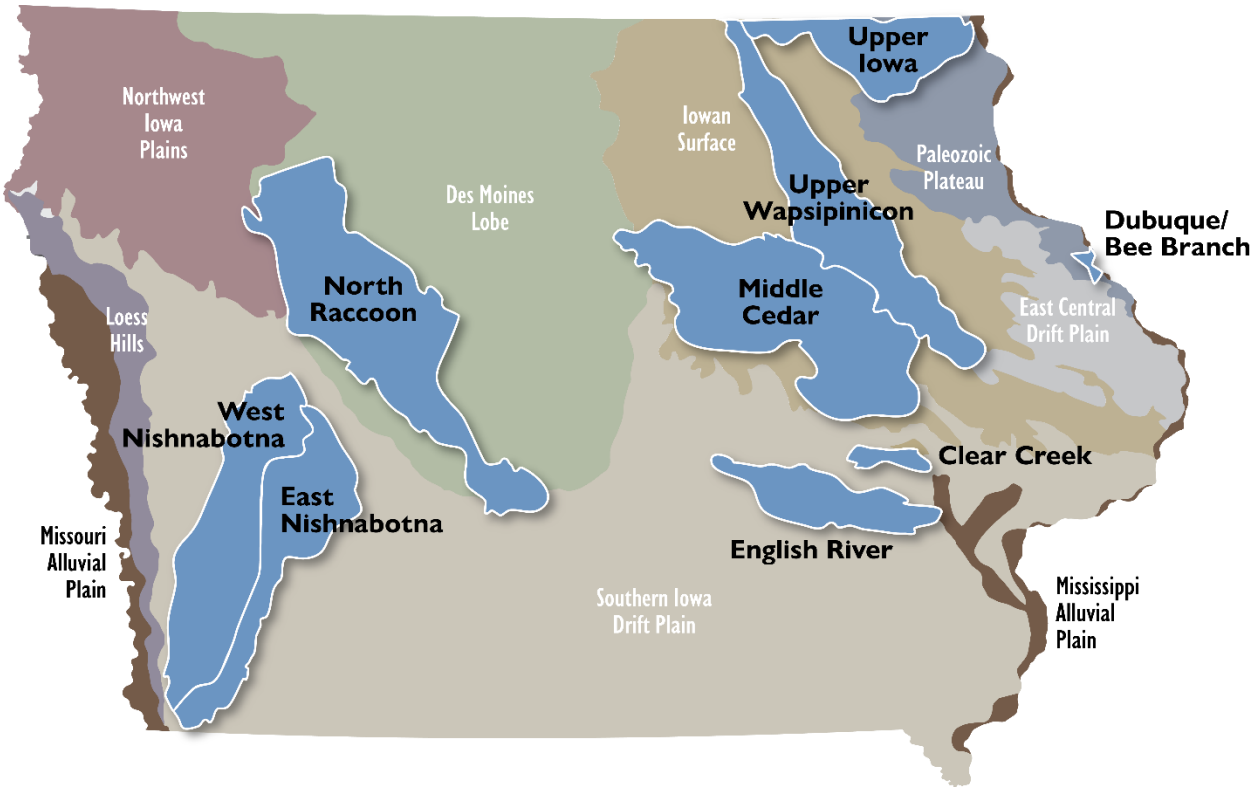

Figure 2-1. The IWA watersheds' positions within the landform regions of Iowa.

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

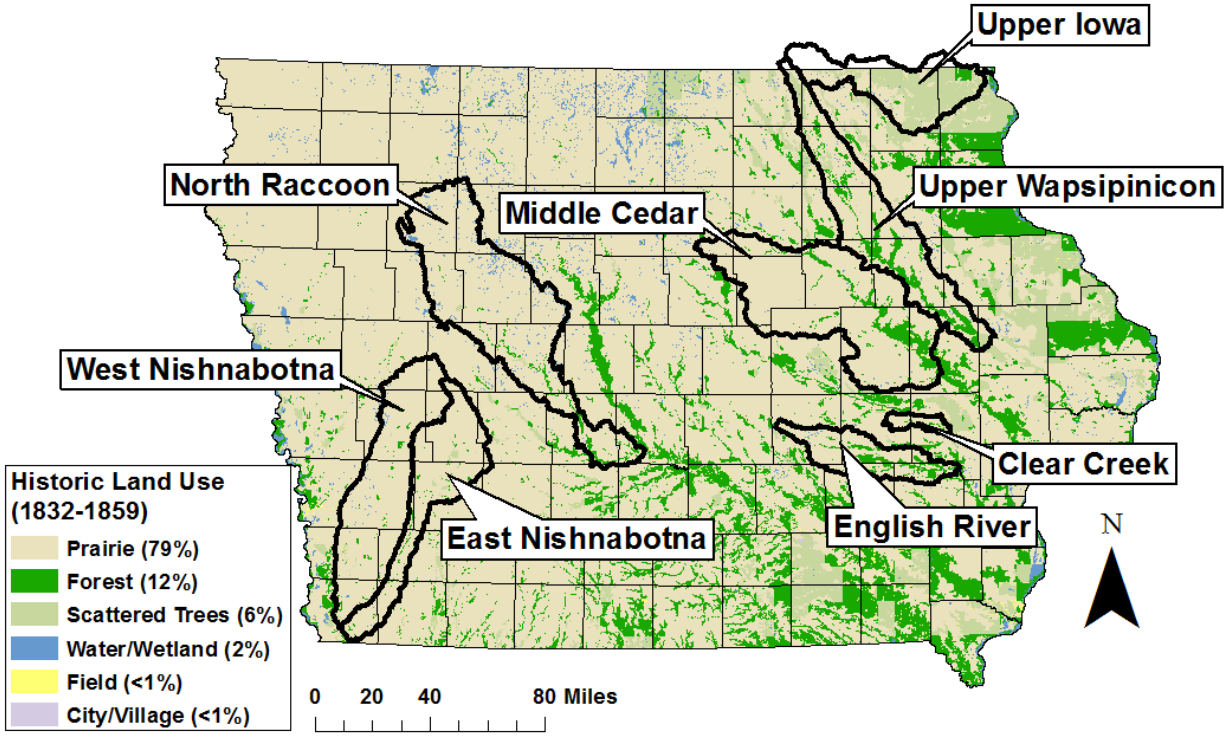

Figure 2-2. Historic vegetation of Iowa 1832–59. Raw data downloaded from the Iowa Geographic Map Server (https://ortho.gis.iastate.edu/).

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

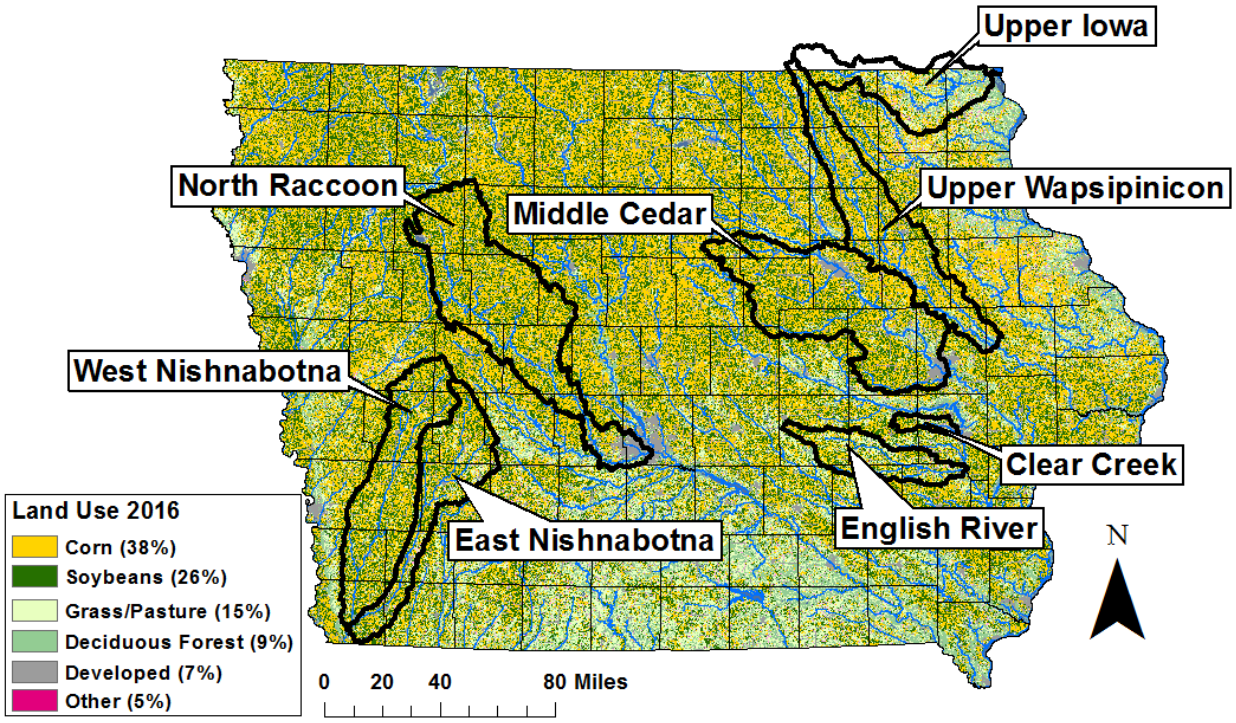

Figure 2-3. Land use composition in the state of Iowa 2016. Cropland Data Layer.

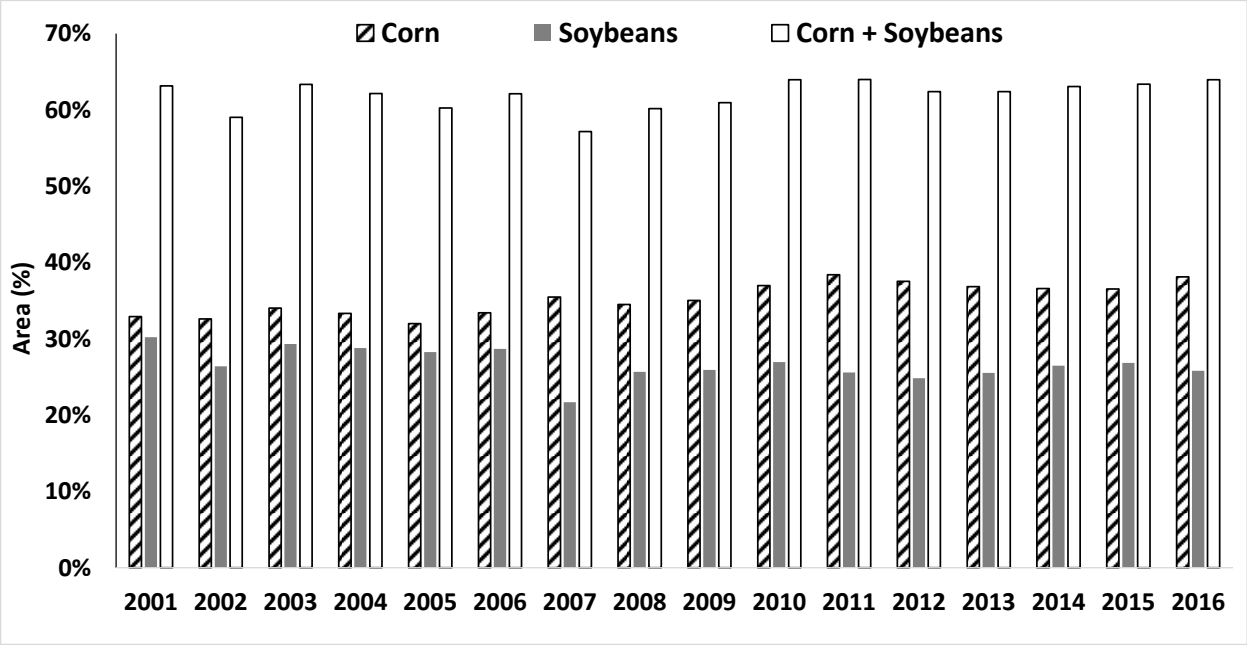

Figure 2-4. Percent of Iowa's total area planted with row crops between 2001 and 2016. Cropland Data Layer.

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

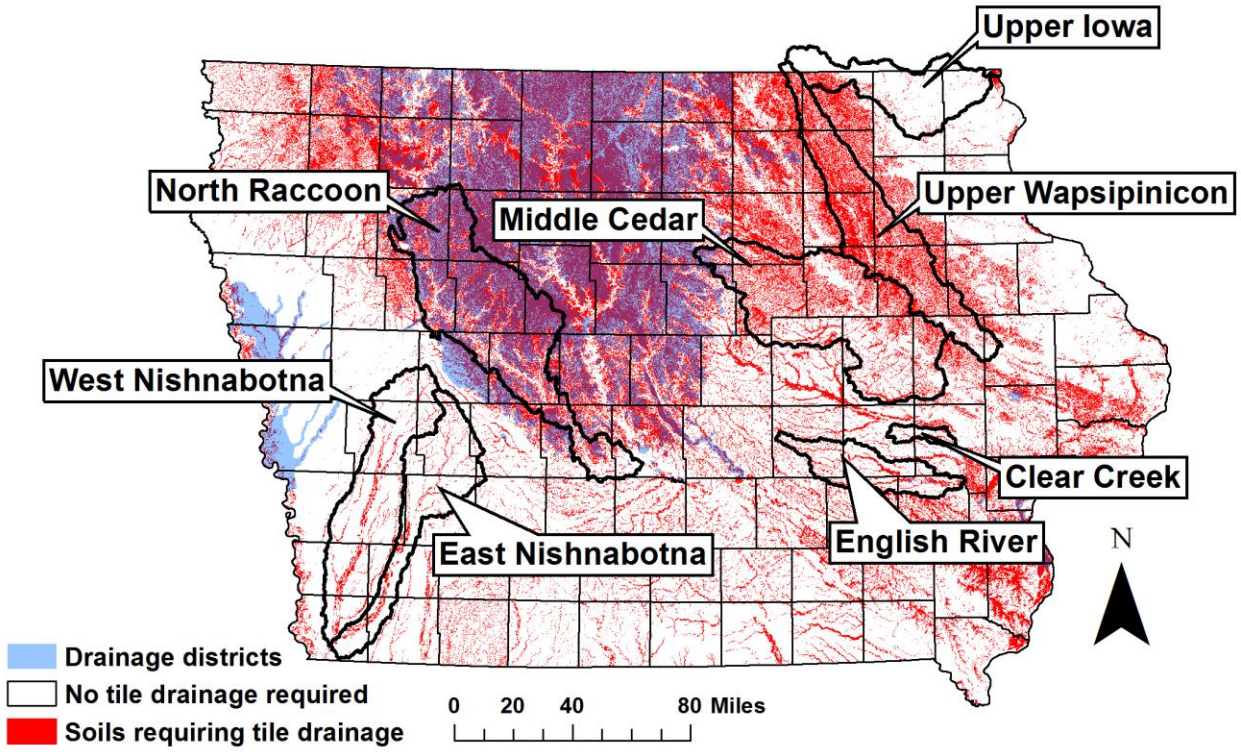

Figure 2-5. Soils requiring tile drainage for full productivity and drainage districts. Raw data source: DNR's NRGIS Library.

b. Climate and Water Cycle

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

i. Statewide Precipitation

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

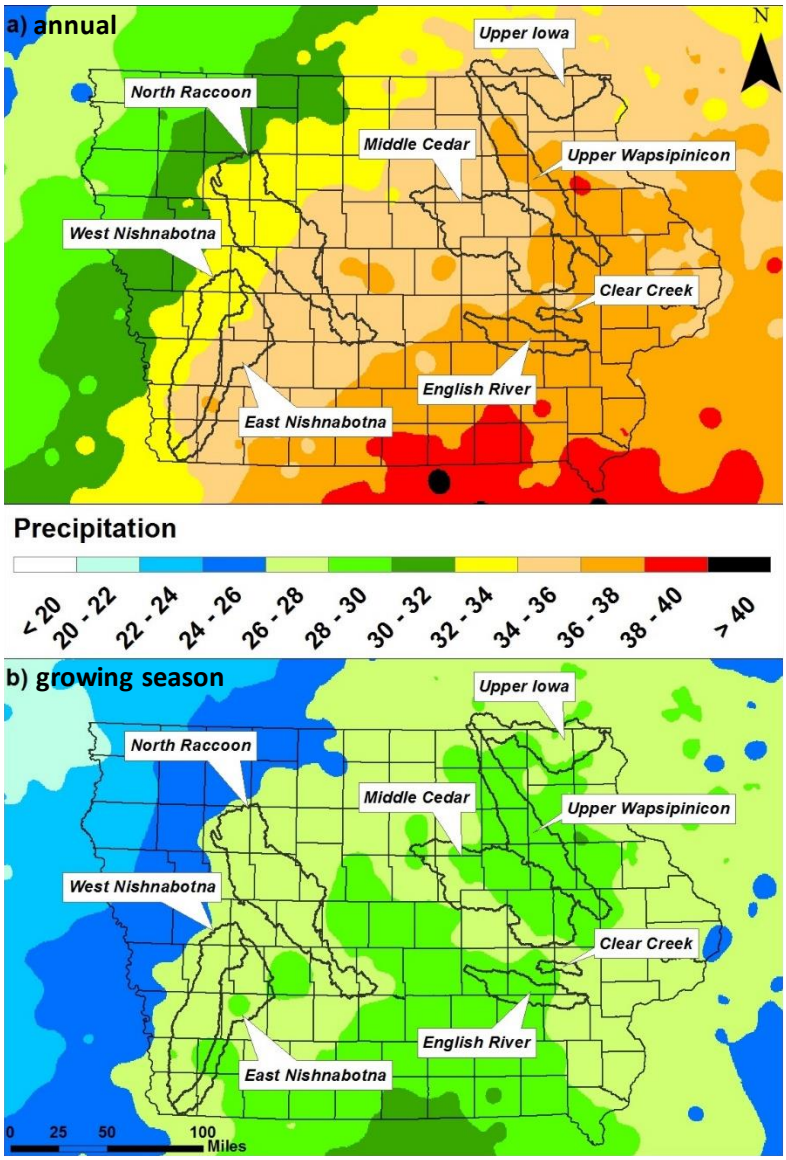

Figure 2-6. Average precipitation (inches): (a) annual; and (b) growing season (April–October). Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

Records show small variations in average annual precipitation among the eight IWA watersheds; the North Raccoon receives the least (33.8 inches), and the English River the most (36.6 inches). Historically, the quantity of annual precipitation presented in Figure 2-6b has been ideal for

agricultural needs, such that Iowa has not required irrigation systems like other parts of the country. The state's average precipitation between April and October is approximately 27 inches, and the months with highest precipitation accumulations (May, June, and July) occur during the peak of the growing season. These climatological characteristics make Iowa an ideal place for agriculture.

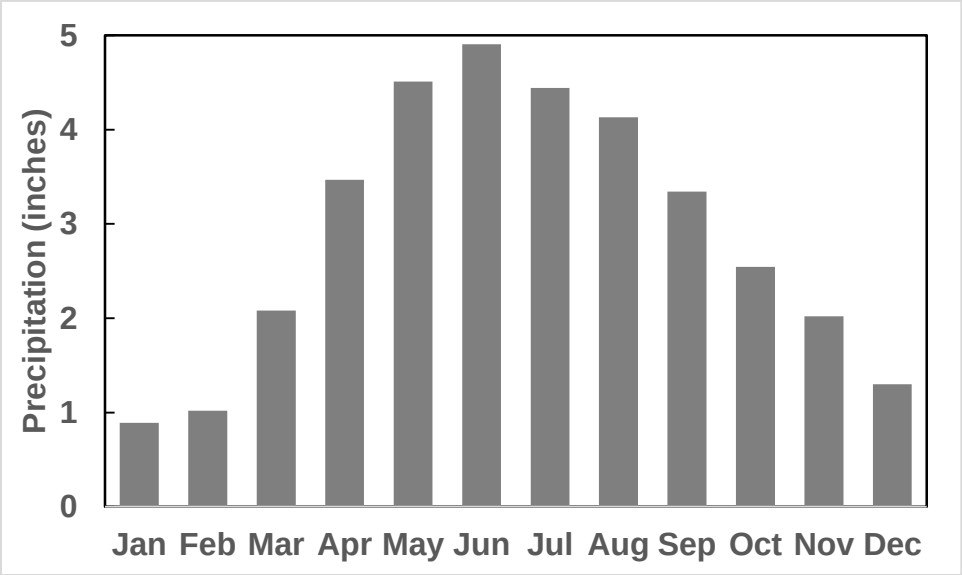

Figure 2-7. Statewide average monthly precipitation. Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

ii. The Water Cycle in Iowa

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

Evapotranspiration

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

Surface Flow

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

Baseflow

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

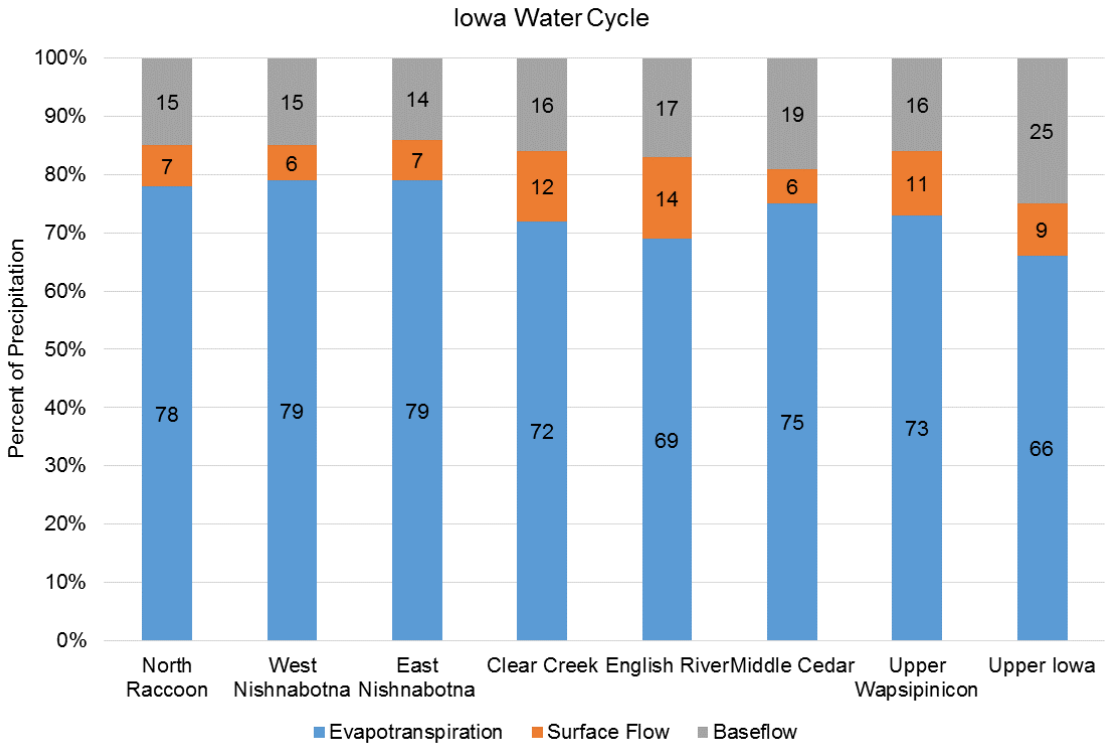

Figure 2-8. Iowa water cycle for the IWA watersheds. This shows the partitioning of average precipitation into evapotranspiration, surface flow, and baseflow components.

iii. Shallow Groundwater and Soil Moisture Trends

Shallow groundwater and soil moisture conditions can play an important role in the transformation of rainfall into runoff. For example, several studies have identified the occurrence of very wet winters and springs (and the subsequent high soil moisture and groundwater levels) as contributing factors to the major floods of 1993 and 2008 (Linhart and Eash, 2010; Mutel, 2010; Bradley, 2010; Smith et al., 2013). Across the state, almost 400 sensors continuously monitor the condition (e.g., streamflow and stage) of the Iowa rivers. In contrast, long-term continuous data on groundwater levels or soil moisture are sparse. Figure 2-9 displays shallow groundwater information from two

United States Geological Survey (USGS) wells located in two different Iowa counties. The location of the water table is influenced by several factors, such as location on the landscape, land cover, soil type, etc. In Iowa, it is very common to find the water table within the first 25 feet of the soil column, except in the deep loess hills in western Iowa and incised bedrock valleys of northeast Iowa.

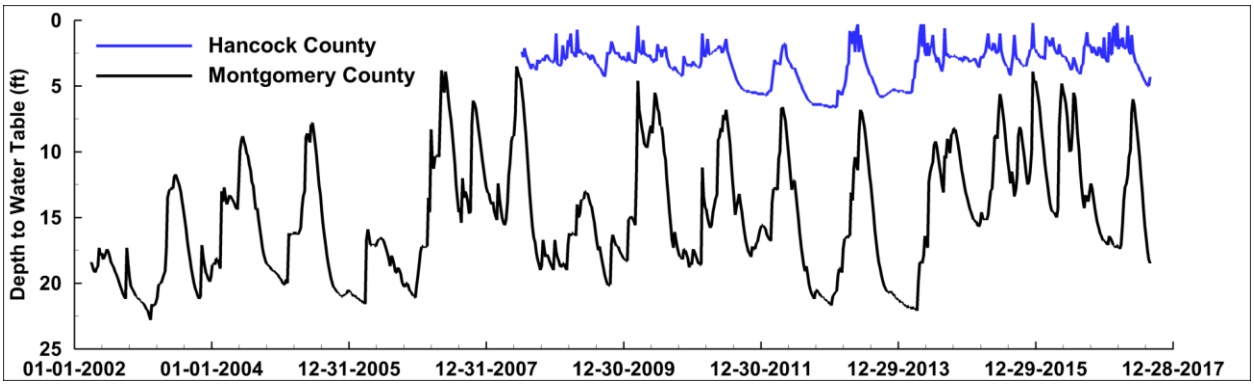

Figure 2-9. Shallow groundwater data (USGS wells).

iv. Floods

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

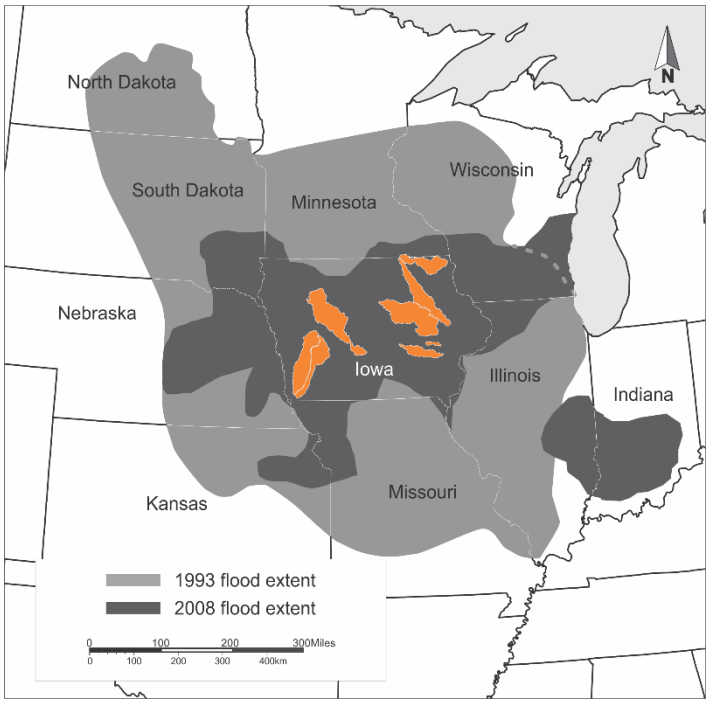

Figure 2-10. The extent of the flooding during the 1993 and 2008 floods (Bradley, 2010).

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

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

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

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

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

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

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

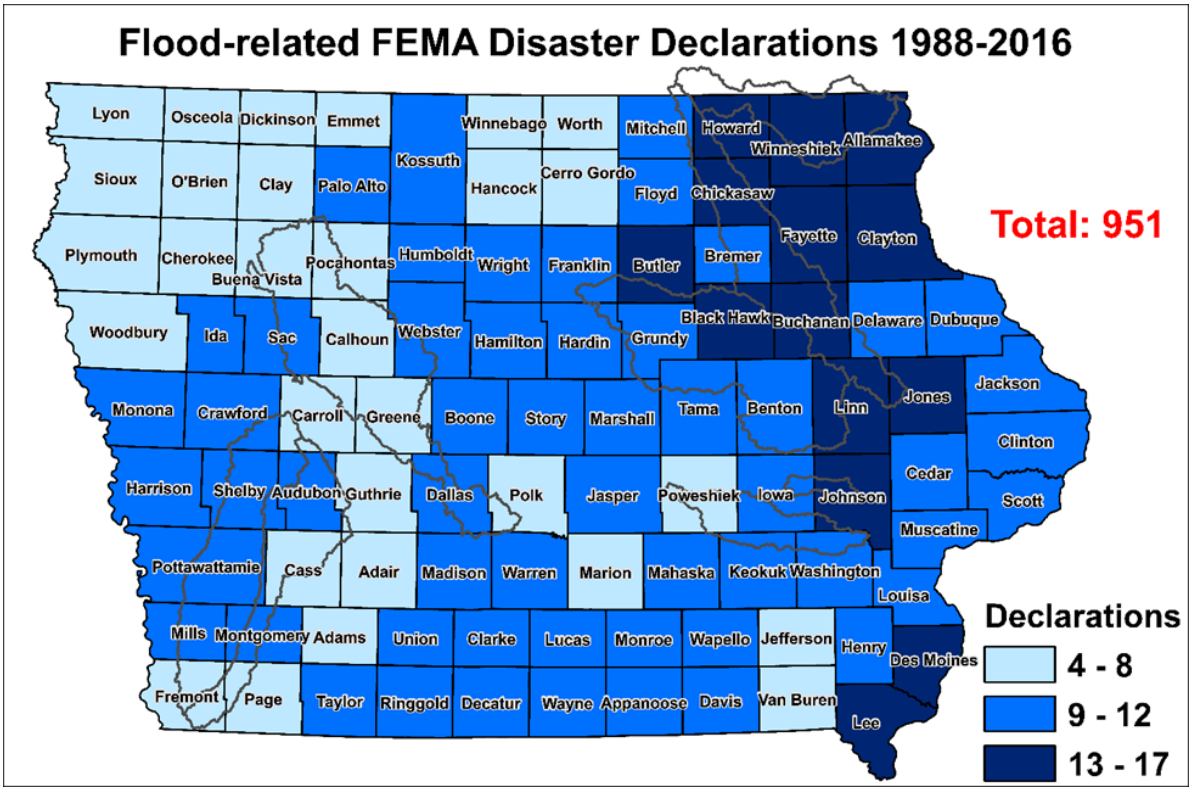

Figure 2-11. Number of flood-related federally declared disasters in Iowa counties (1988–2016). Data source: https://www.fema.gov/.

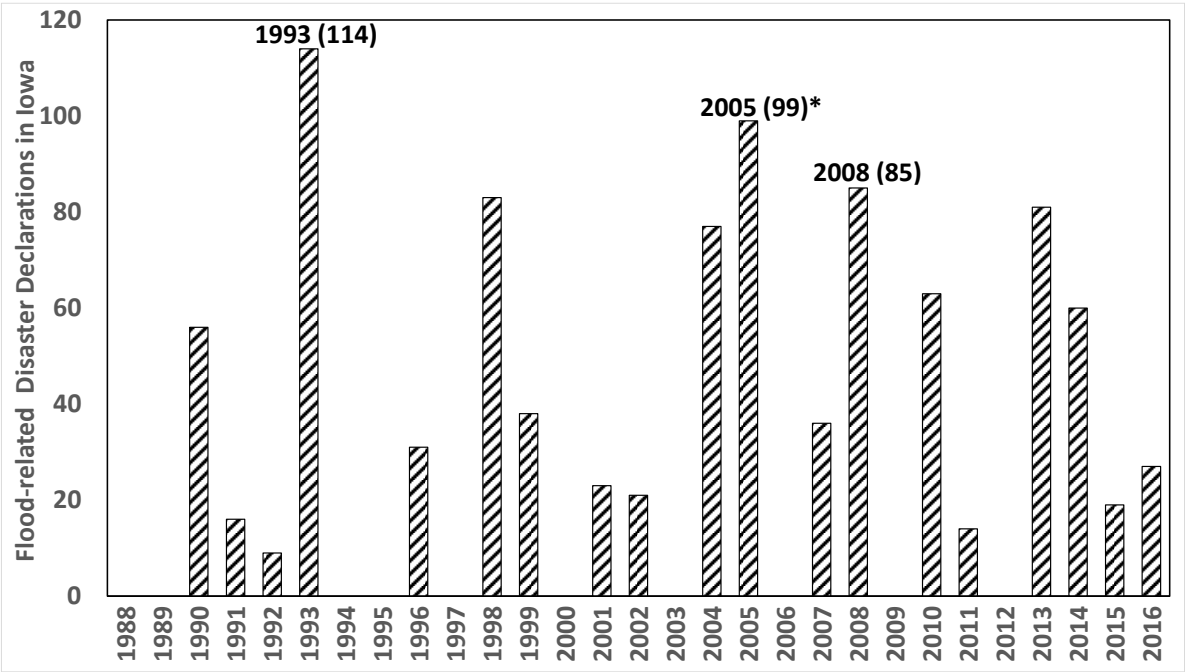

Figure 2-12. The number of flood-related federally declared disasters in Iowa (1988–2016). Data source: https://www.fema.gov/.

v. Droughts

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

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

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

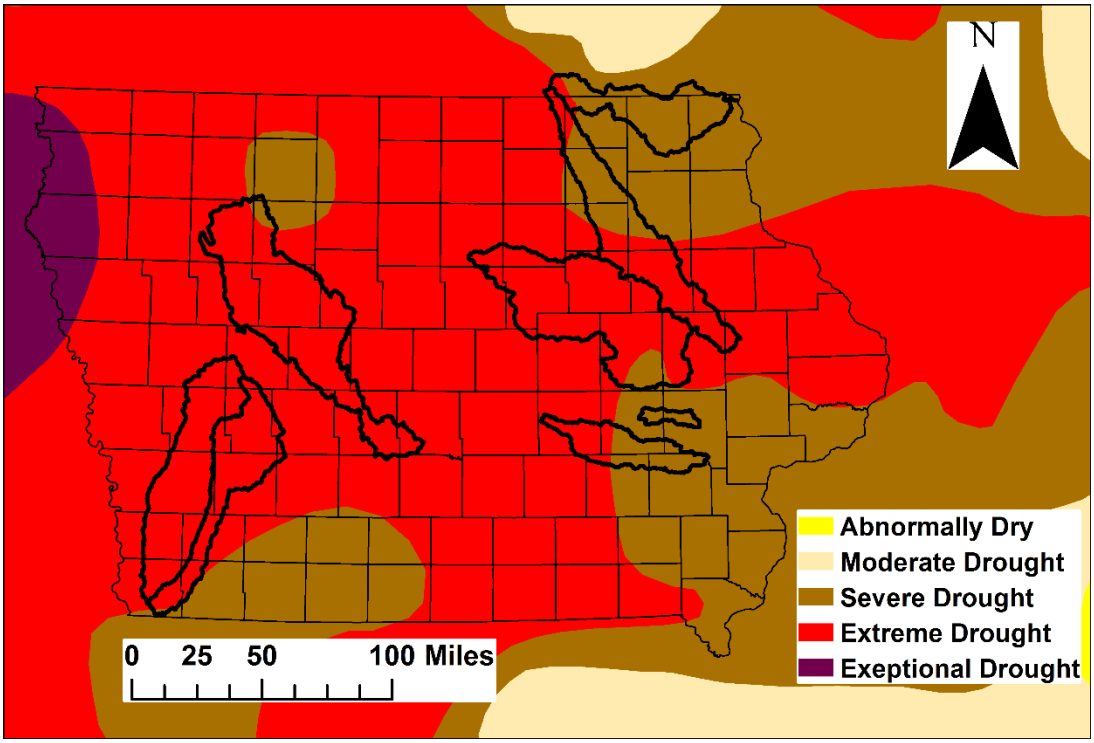

Figure 2-13. Drought conditions, October 09, 2012 (Source: http://droughtmonitor.unl.edu/).

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

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

i. Hydrological Alterations from Agricultural-Related Land Use Changes

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

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

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

Timeline	*Land use status, change, and interventions*	*Hydrologic effect(s)*	*Source*
Pre-1830s	Native vegetation (tallgrass prairies and broad-leaved flowering plants) dominates the landscape	Baseflow dominated flows; slow response to precipitation events	Petersen (2010)
1830–1980	Continuous increase in agricultural production by replacement of perennial native vegetation with row crops 1940: <40% row crop (Raccoon) 1980: 75% row crop (statewide)	Elimination of water storage on the land; acceleration of the upland flow; expanded number of streams; increased stream velocity	Jones & Schilling (2011); Knox (2001)
1820–1930	Wetland drainage, stream channelization (straightening, deepening, relocation) leading to acceleration of the rate of change in channel positioning	Reduction of upland and in-stream water storage, acceleration of stream velocity	Winsor (1975); Thompson (2003); Urban & Rhoads (2003)
1890–1960 2000–present	Reduction of natural ponds, potholes, wetlands; development of large-scale artificial drainage system (tile drains)	Decrease of water storage capacity, groundwater level fluctuations, river widening	Burkart (2010); Schottler et al. (2013)
1940–1980	Construction of impoundments and levees in Upper Mississippi Valley	Increased storage upland	Sayre (2010)
1950–present	Modernization/intensification of the cropping systems	Increased streamflow, wider streams	Zhang & Schilling (2006); Schottler et al. (2013)
1970– present	Conservation practices implementation: Conservation Reserve Program (CRP);	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 Figure 2-14) *and globally and is expected to continue to increase over the next few decades* (2021–2050, see Figure 2-15)*, annual average temperatures are expected to rise by about 2.5°F for the United States, relative to the recent past (average from 1976–2005), under all plausible future climate scenarios."*

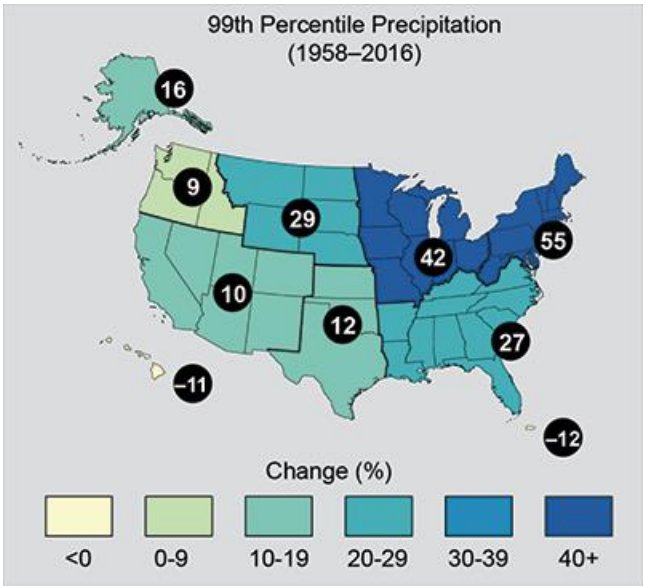

Figure 2-14. Observed change in heavy precipitation (the heaviest 1%) between 1958 and 2016. Figure taken from "The Climate Science Special Report" (Easterling et al. 2017) (https://science2017.globalchange.gov/).

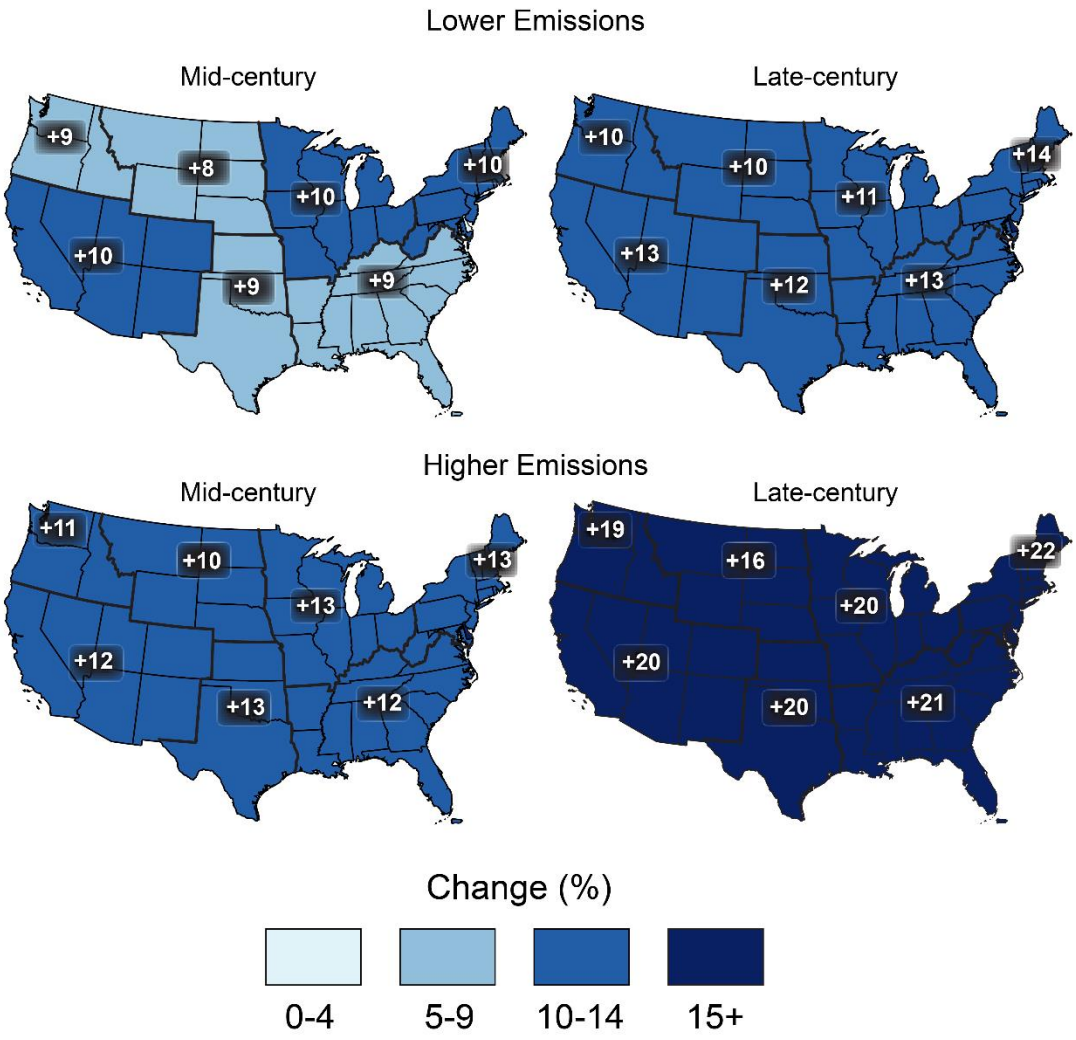

Figure 2-15. Projected change in heavy precipitation. Twenty-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps). Results are shown for a lower emissions scenario (top maps; RCP4.5) and for a higher emissions scenario (bottom maps, RCP8.5). Figure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

iii. Hydrological Alterations Induced by Urban Development

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

stream drainage system. Although traditional stormwater management practices aim to reduce increased flood peaks, urban areas have long periods of high flows that can erode stream channels and degrade aquatic habitat.

d. Assessment of Iowa's Water Quality

i. Iowa Water-Quality History

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

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

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

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

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

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

of sewage treatment plants under the construction grants program; and (6) recognized the need for planning to address the critical problems posed by non-point source pollution.

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

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

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

by fish kills. Figure 2-16 lists the main causes. Figure 2-17 shows historical numbers of impaired Iowa waters.

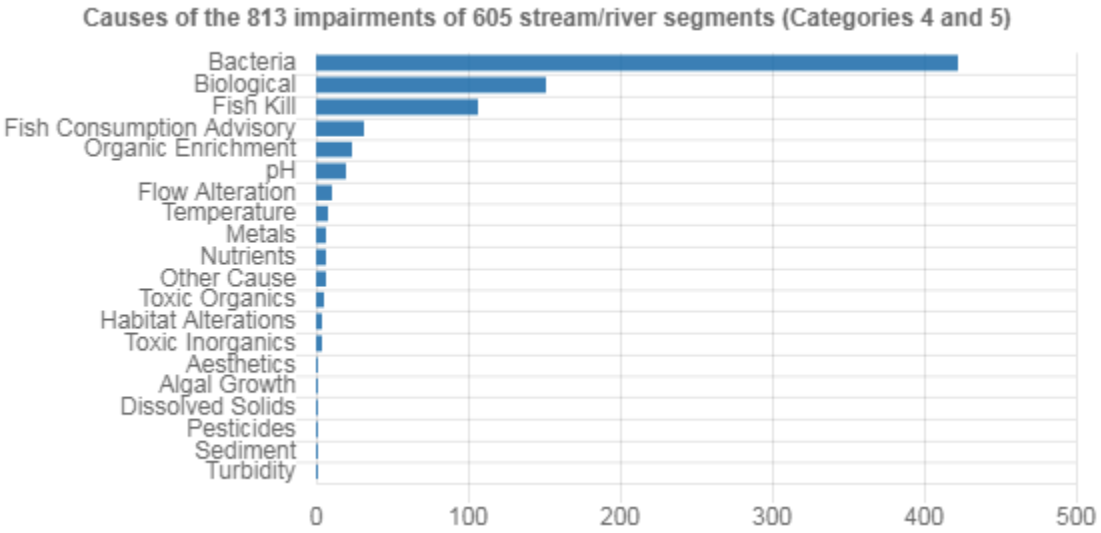

Figure 2-16. Causes of impairments in Iowa's impaired waters. (Iowa Department of Natural Resources, 2018).

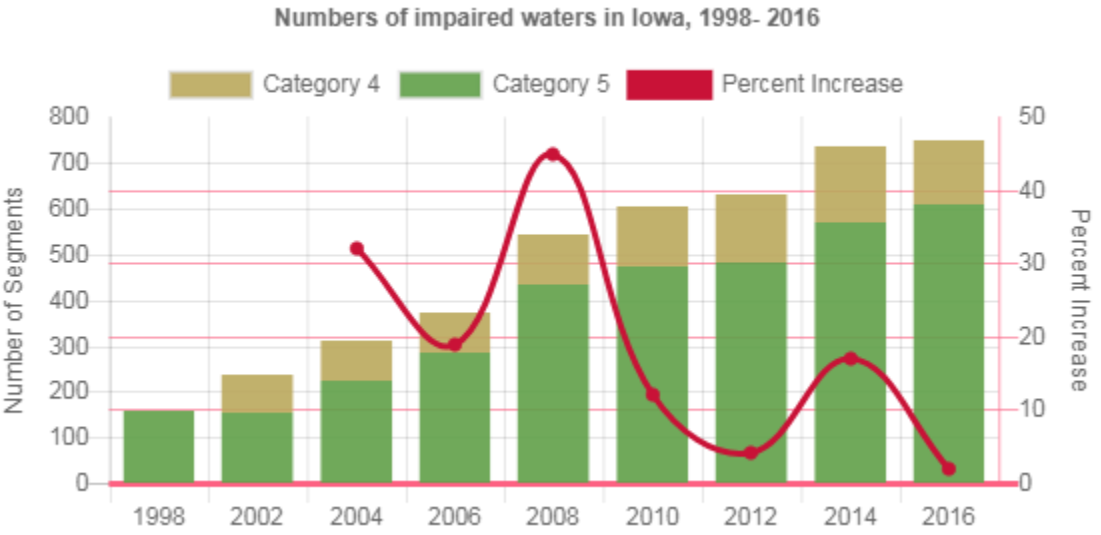

Figure 2-17. Numbers of impaired Iowa waters, 1998–2016. (Iowa Department of Natural Resources, 2018).

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

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

i. The Iowa Flood Information System (IFIS)

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

Floodplain inundation maps

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

Community-based inundation maps

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

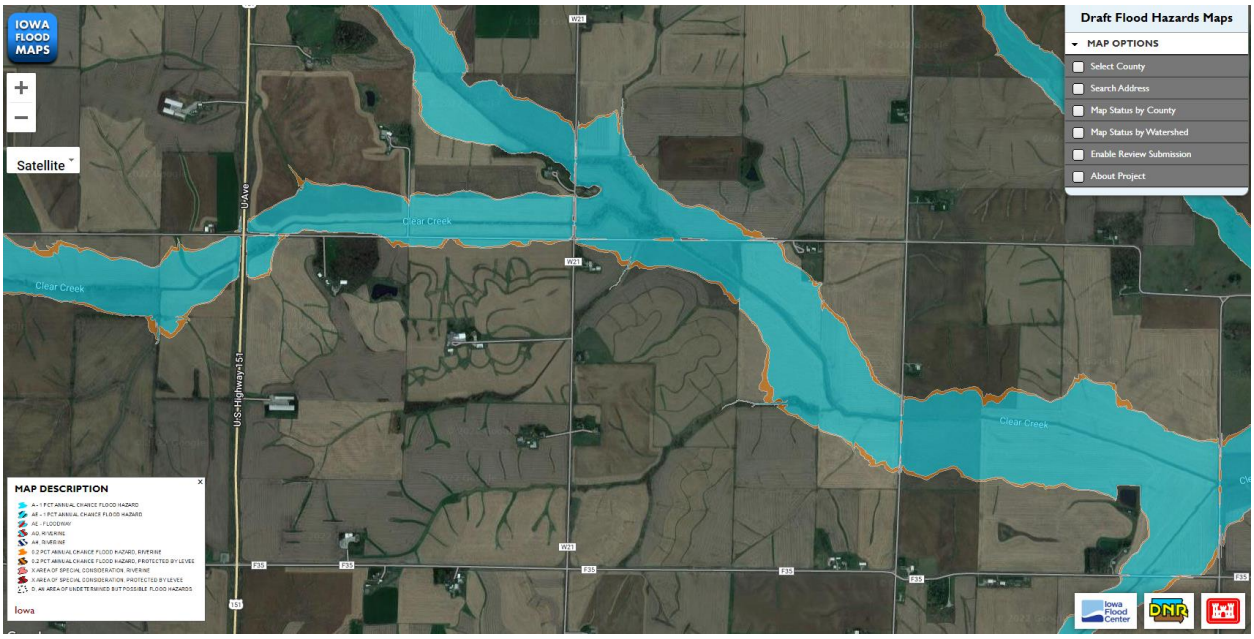

Figure 2-18. Statewide floodplain map data showing different levels of annual flood risk.

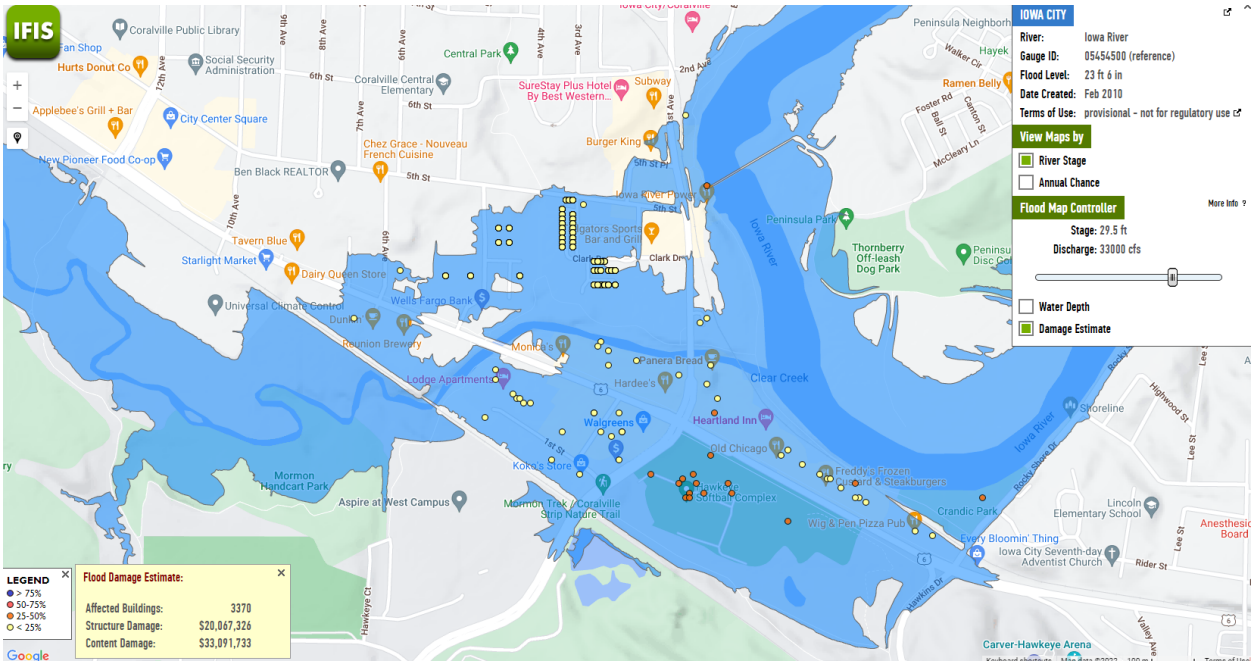

Figure 2-19. Flood inundation map library for the Iowa River in the city of Coralville.

Observed stream conditions

IFIS displays data from more than 400 sensors continuously monitoring Iowa stream conditions in real time, as shown in Figure 2-20. Currently, the USGS collects streamflow data at approximately 200 locations, and the IFC administers and maintains a growing network of more than 250 stream-stage sensors that record stage conditions.

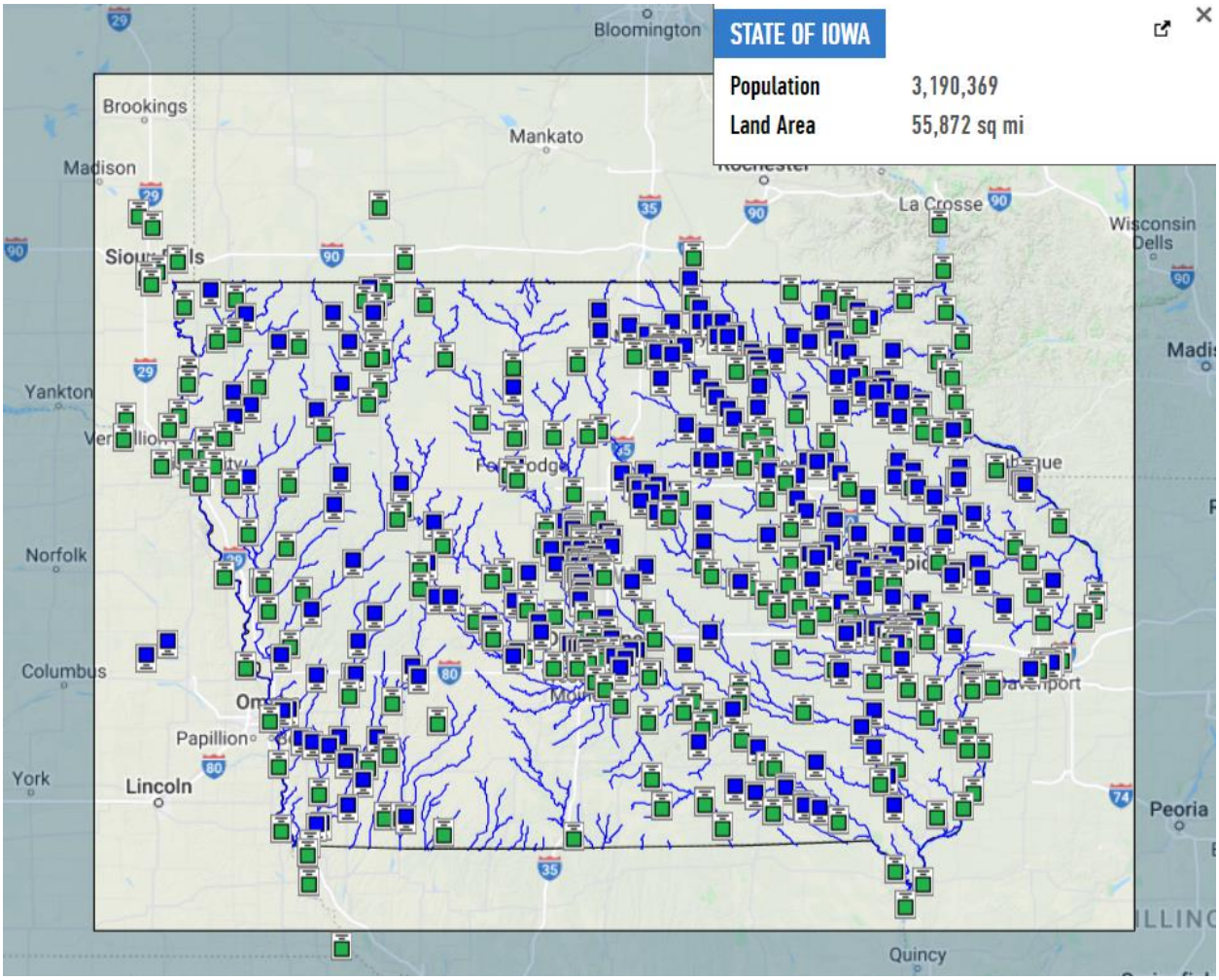

Figure 2-20. USGS (green) and Iowa Flood Center (blue) stream-stage monitoring locations displayed in the Iowa Flood Information System (IFIS).

Flood alerts, warnings, and forecasts

IFIS provides flood alerts for stream sensors with stage values higher than the threshold values for the four flood levels defined by National Weather Service (NWS) and the IFC. Different colors represent these four flood stage levels (action, flood, moderate flood, and major flood). The flood forecast products included in IFIS are the NWS six-hour forecast for 48 hours and the NWS seasonal forecast for 90 days. IFIS integrates short-term NWS forecasts into real-time data series and more-info views. The NWS shares a seasonal forecast probability for minor, moderate, and

major flooding for a three-month period. The Iowa Flood Center has developed a real-time, high-performance, computing-based flood forecasting model that provides quantitative stage and discharge forecasts and a five-day flood risk outlook in IFIS for more than 1,500 locations (e.g., communities and stream gauges) in Iowa.

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

ii. The Iowa Water-Quality Information System

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

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

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

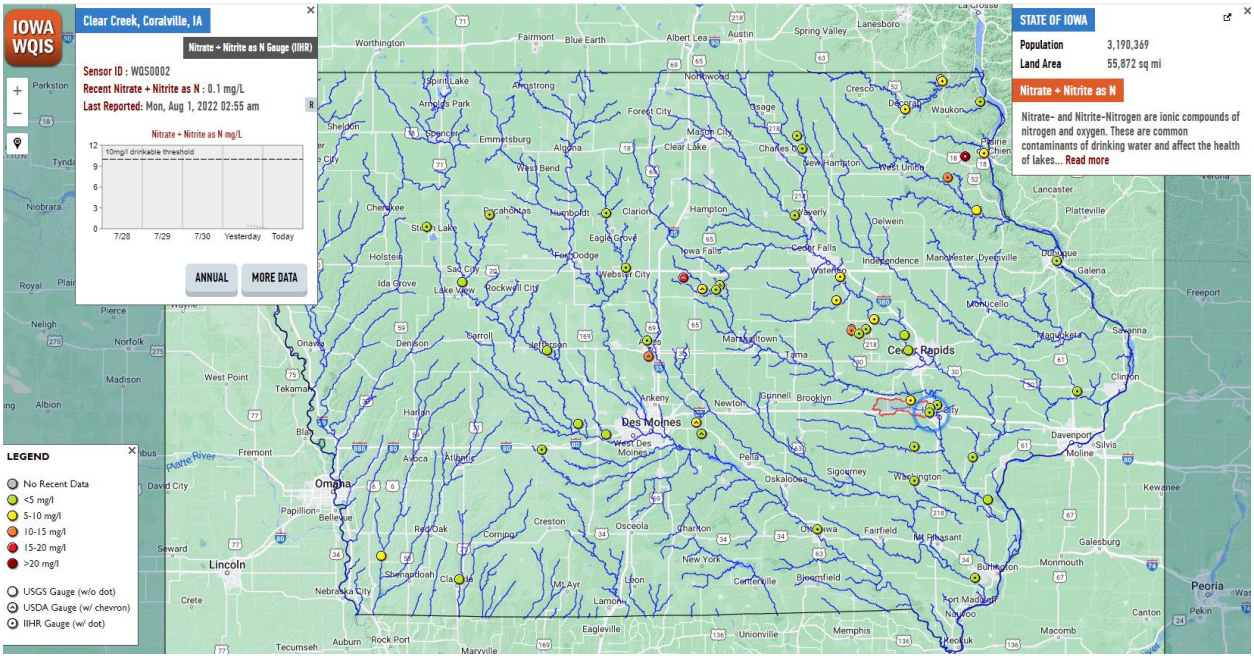

Figure 2-21. IIHR—Hydroscience and Engineering and USGS surface water-quality monitoring locations as displayed on the Iowa Water-Quality Information System (IWQIS).

iii. The Iowa Watershed Approach Information System (IWAIS)

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

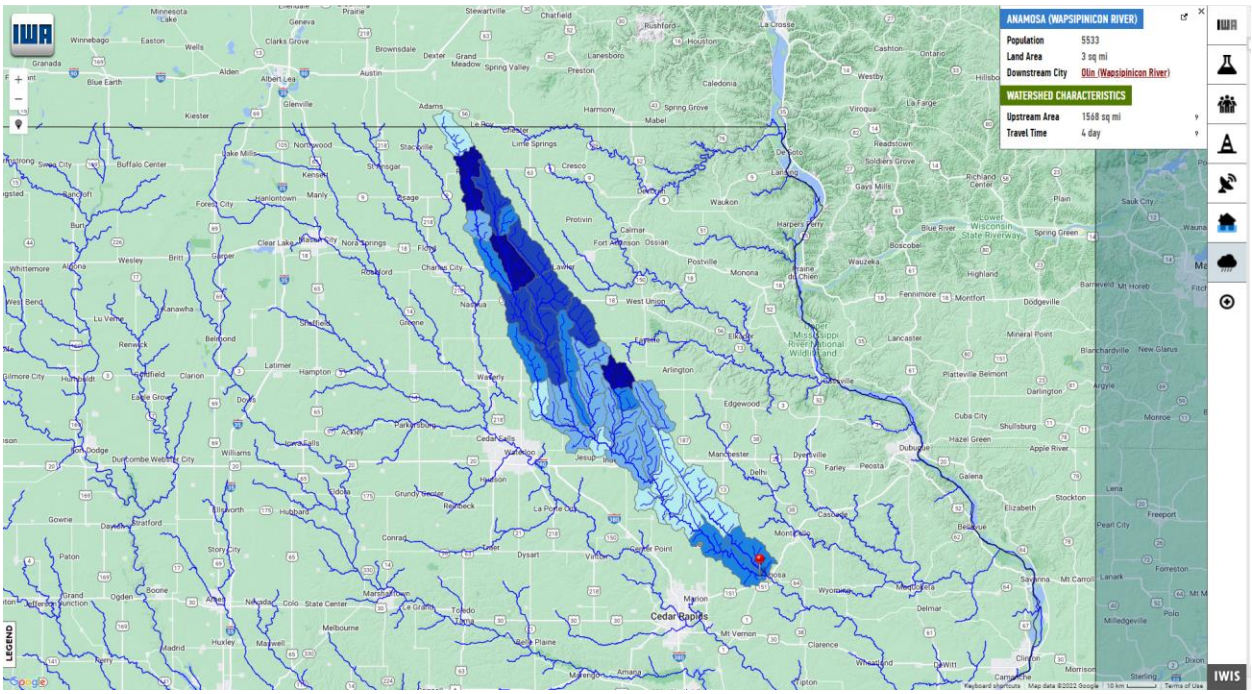

Figure 2-22. Example IWAIS interface view showing the number of existing water and sediment control basins within each HUC12 in the Upper Wapsipinicon Watershed.

3. Clear Creek Watershed Description

This chapter provides an overview of the current Clear Creek Watershed conditions including hydrology, geology, topography, land use, hydrologic/meteorologic instrumentation, as well as a summary of previous floods of record.

a. Hydrology

The Clear Creek Watershed (Figure 3-1) as defined by the boundary of ten-digit Hydrologic Unit Code (HUC10) 0708020904 is located in East-Central Iowa and encompasses approximately 104 square miles (mi^2). Clear Creek flows west to east into the Iowa River at Coralville, Iowa. The Clear Creek Watershed boundary falls within Iowa and Johnson counties.

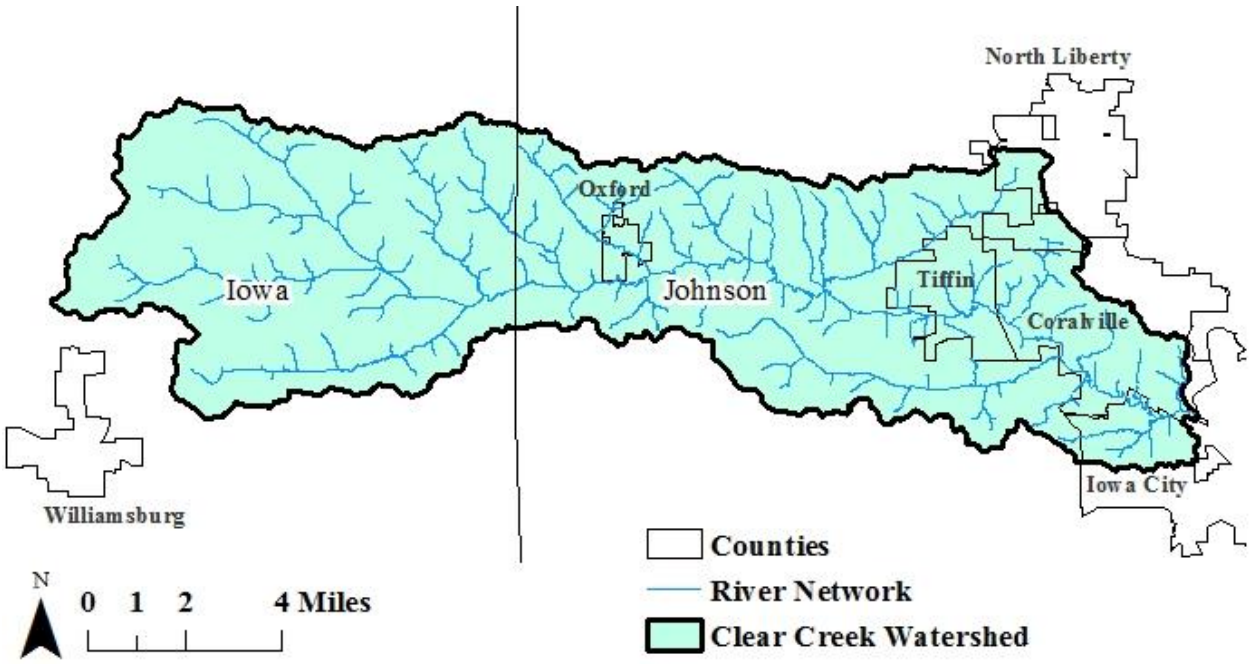

Figure 3-1. The Clear Creek Watershed (HUC10 0708020904), drains 104 mi^2. The Clear Creek River joins the Iowa River in Coralville, IA.

For the region of East-Central Iowa, the annual precipitation ranges from roughly 21 to 55 inches (Figure 3-2and Figure 3-3). About 70% of the annual precipitation falls as rain during the months of April - September. During this period, thunderstorms capable of producing torrential rains are possible with the peak frequency of such storms occurring in June. The region has experienced increased variability in annual precipitation since 1975, along with a general increase in the amount of spring rainfall. Analyses of streamflow records at the USGS stations near Oxford and Coralville show that on an annual basis approximately 30% of the precipitation is transformed into streamflow (Figure 3-4) and 60% of the streamflow is derived from groundwater (Figure 3-5).

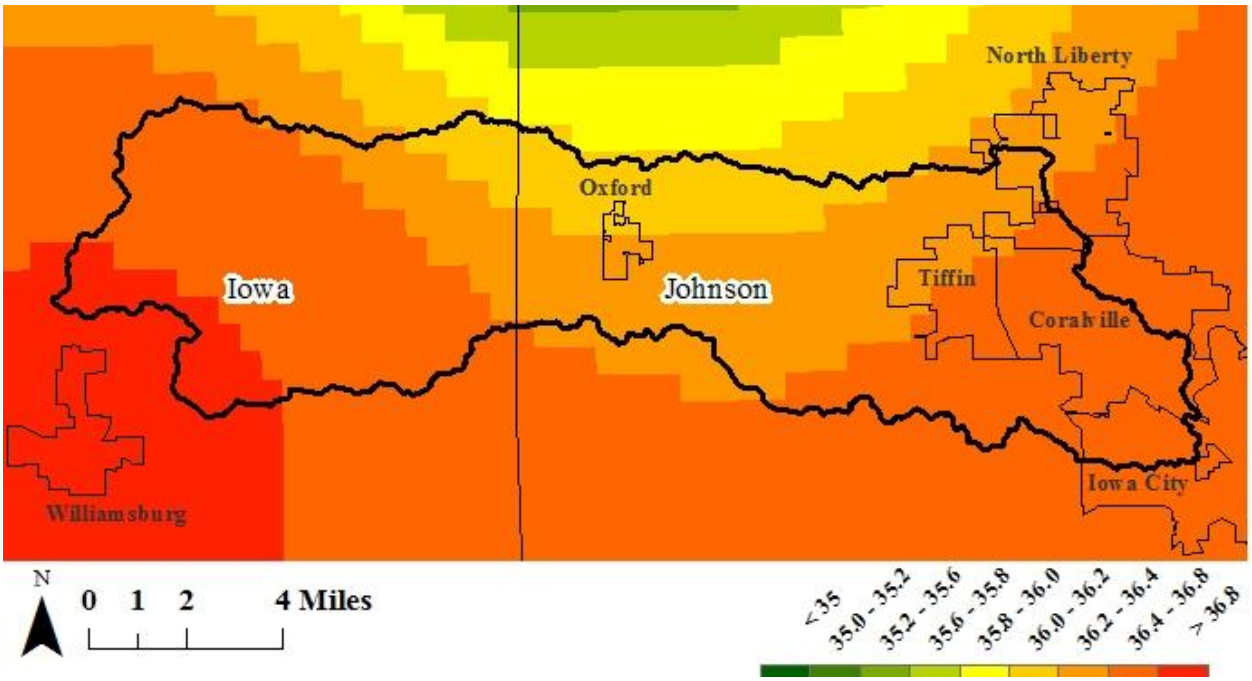

Figure 3-2. Average annual precipitation (inches). Estimates are based on the 30-year annual average (1981-2010).

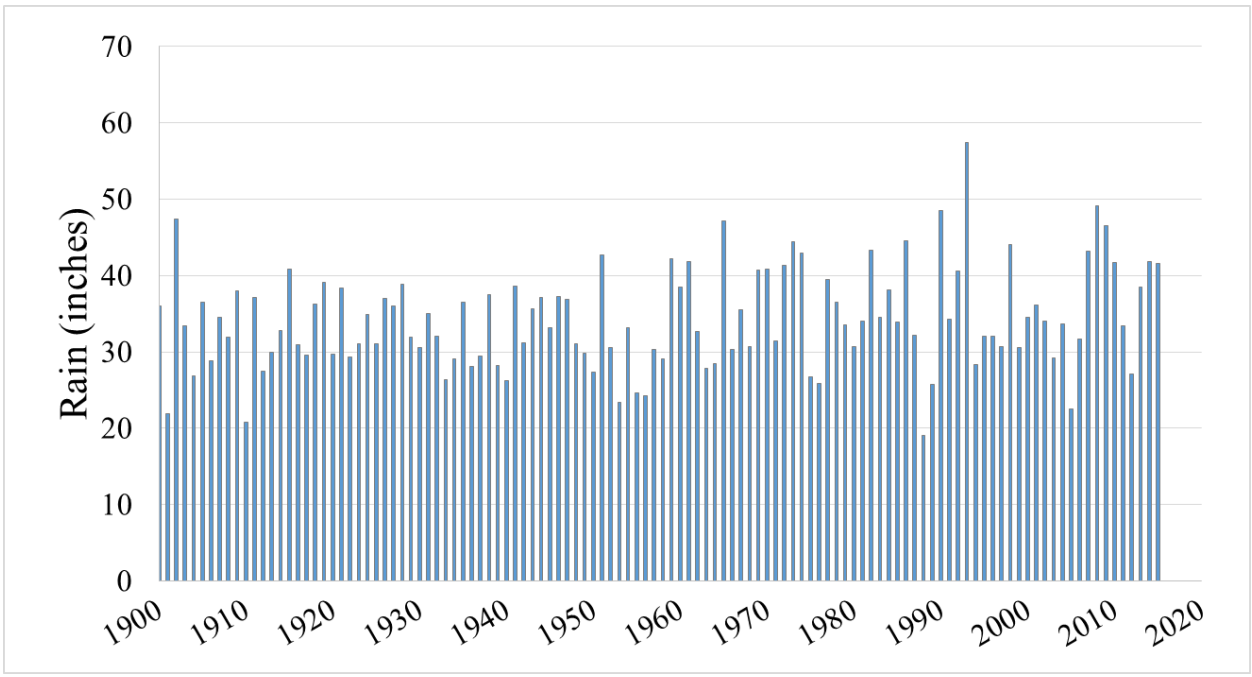

Figure 3-3. Bar graph of annual precipitation.

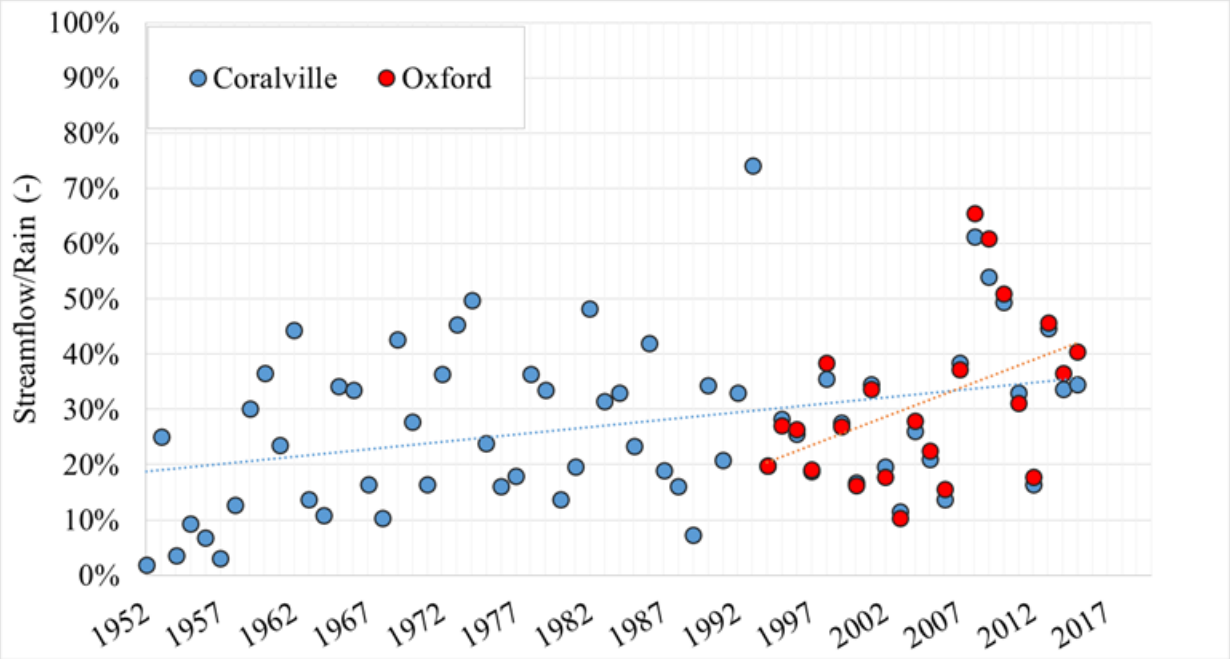

Figure 3-4. Annual ratio of streamflow to precipitation.

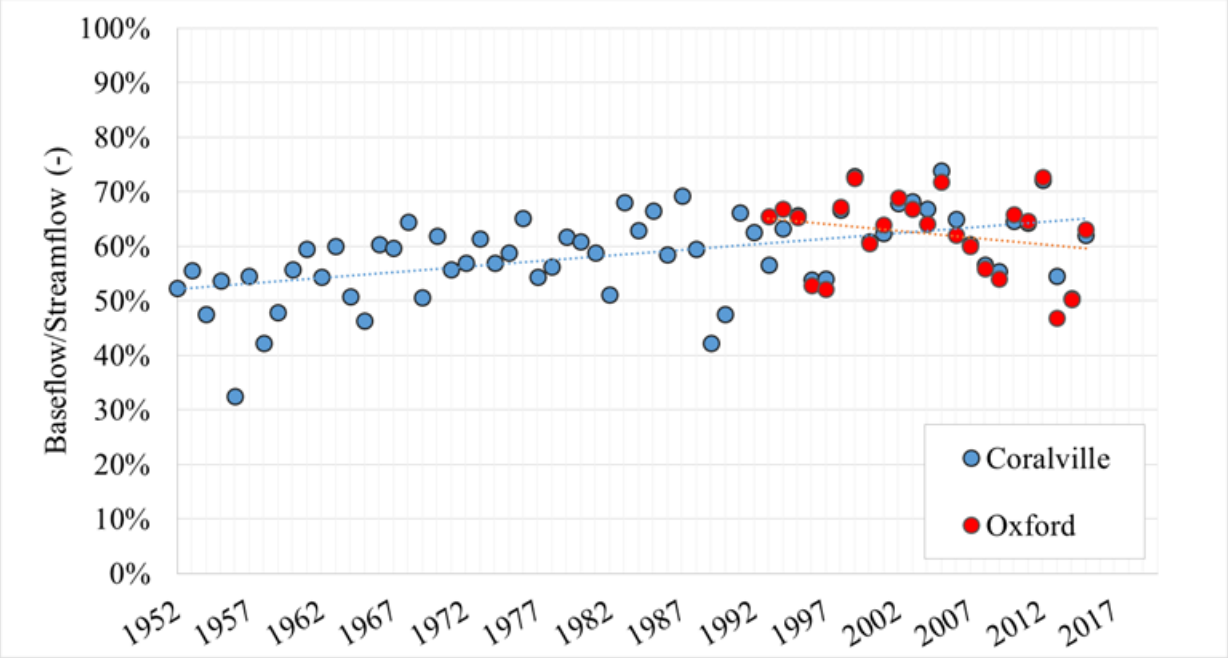

Figure 3-5. Annual ratio of baseflow to streamflow.

b. Geology and Soils

The Clear Creek Watershed is located almost entirely within the Southern Iowa Drift Plain landform region (Figure 2-1). There is a very small area in the northeastern portion of the

watershed that is part of the Iowan Surface landform region. The characteristics of each landform region have an influence on the rainfall-runoff potential and hydrologic properties of the watershed.

The Southern Iowa Drift Plain includes most of southern Iowa. This region was subjected to numerous episodes of glaciation between 500,000 and 2.6 million years ago. Since that time, periods of relative landscape stability and soil formation have alternated with episodes of erosion, shaping the land surface we see today (Prior, 1991). The landscape is characterized by steeply rolling topography and well-developed drainage divides (Figure 3-7). Glacial till deposits provide a thick confining unit on top of the bedrock surface and are generally mantled with a relatively thick package of loess (wind-blown silt). Glacial till and associated deposits may be greater than 400 feet thick in portions of the Clear Creek Watershed. Limited areas of shallow bedrock may be present.

Soils are classified into four Hydrologic Soil Groups (HSG) by the Natural Resources Conservation Service (NRCS) based on the soil's runoff potential. The four HSG's are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, there are dual code soil classes A/D, B/D, and C/D that are assigned to certain wet soils. In the case of these soil groups, even though the soil properties may be favorable to allow infiltration (water passing from the surface into the ground), a shallow groundwater table (within 24 inches of the surface) typically prevents much infiltration from occurring. For example, a B/D soil will have the runoff potential of a B-type soil if the shallow water table were to be drained away, but the higher runoff potential of a D-type soil if it is not. Complete descriptions of the Hydrologic Soil Groups can be found in the USDA-NRCS National Engineering Handbook, Part 630- Hydrology, Chapter 7.

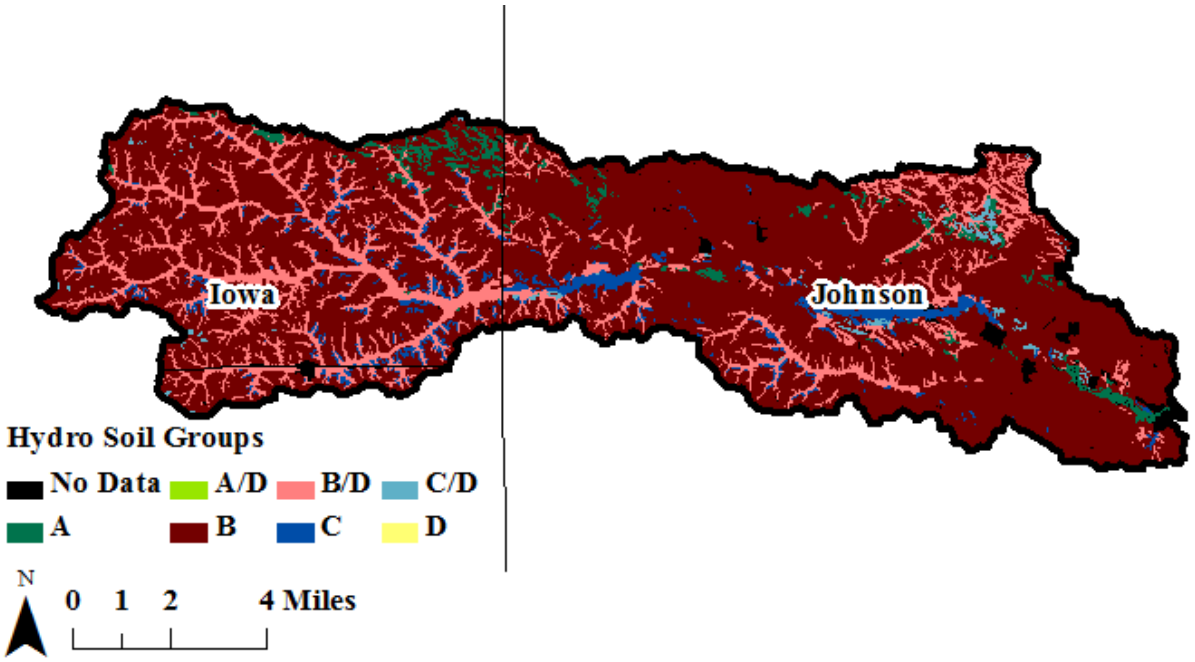

Figure 3-6. Distribution of Hydrologic Soil Groups in the Clear Creek Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with Type B representing the lowest runoff potential and Type D representing the highest runoff potential.

The soil distribution of the Clear Creek Watershed per digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WWS) is shown in Figure 3-6. Viewing the soil distribution at this map scale is difficult, but the map does illustrate the relative consistency of the HSG on this portion of the Southern Iowa Drift Plain landform region. Table 3-1 shows the approximate percentages by area of each HSG for the Southern Iowa Drift Plain in the Clear Creek Watershed. The Clear Creek Watershed consists primarily of HSG B type soils (75.3%), which have a moderate runoff potential when saturated. Relatively small components of type B/D (14.2%) soils are present, occurring in the adjacent valleys. The remaining classes each comprise less than 4% of the total.

Table 3-1. Approximate Hydrologic Soil Group Percentages by Area for the Clear Creek Watershed.

Hydrologic Soil Group	Southern Iowa Drift Plain Approximate %
A	2.5
A/D	0.0
B	75.3
B/D	14.2
C	3.4
C/D	1.0

D	0.0

c. Topography

Figure 3-7 shows the topography of the Clear Creek Watershed. Elevations range from approximately 900 feet above sea level in the upstream and western part of the watershed to 500 feet above sea level in the downstream portion of the watershed in Coralville.

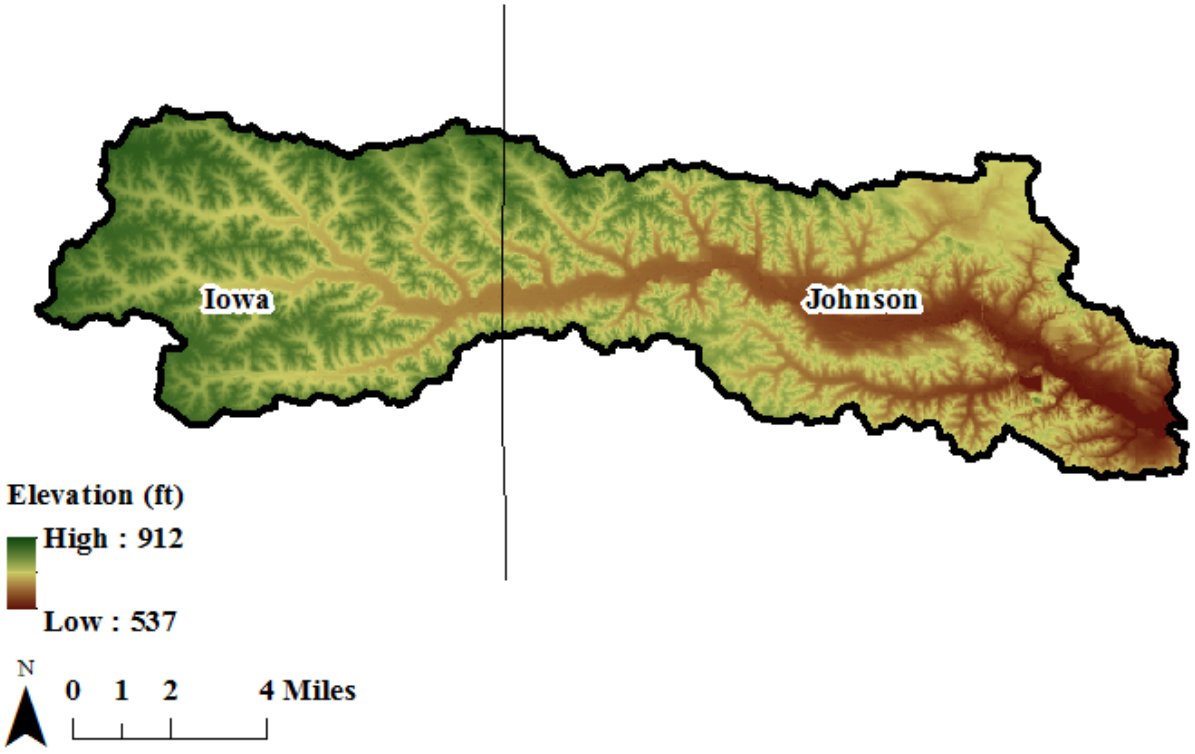

Figure 3-7. Topography of the Clear Creek Watershed.

d. Land Use

Land use in the Clear Creek Watershed is predominantly agricultural, dominated by cultivated crops (corn/soybeans) at approximately 55% of the acreage, followed by grass/pasture at approximately 20%. The remaining acreage in the watershed is about 14% developed land, concentrated in the downstream part of the watershed, 7% forest, 3% crops other than corn/soy and 1% open water and/or wetlands, per the 2017 USDA/NASS Cropland Data Layer.

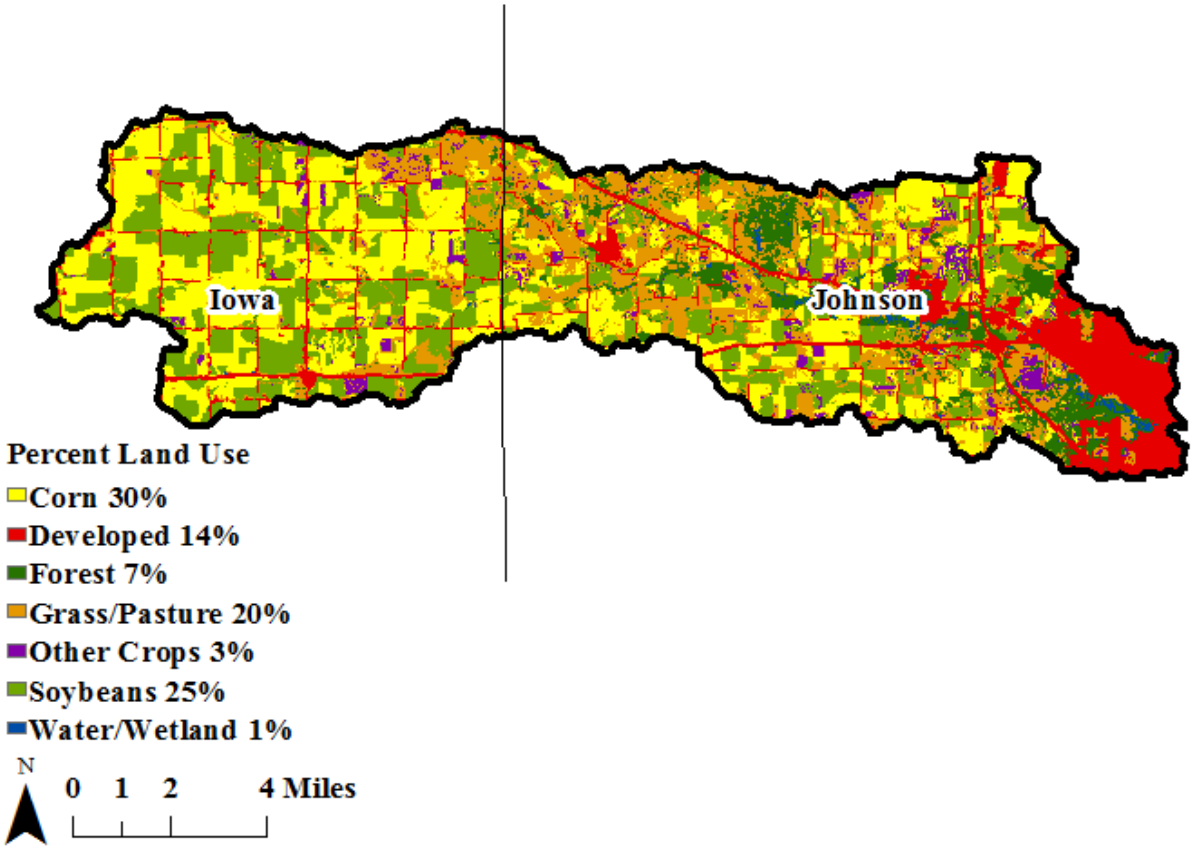

Figure 3-8. Land use composition in the Clear Creek Watershed, per the 2017 USDA Cropland Data Layer.

e. BMP Mapping

Identifying existing conservation practices within a watershed serves as a benchmark for future implementation and provide information where more practices are needed. The Iowa Best Management Practices Mapping project (IBMP) identified existing conservation practices throughout the state of Iowa using data from the 2007 to 2010 timeframe. For the Clear Creek watershed the total number of existing practices are 1308 acres of agricultural fields with contour buffer strips, 373 acres of agricultural fields with strip cropping, 1004 acres of grassed waterways, 156 terraces, 135 pond dams, and 207 water and sediment control basins (WASCOBs). The spatial distribution of the conservation practices within the watershed is shown in Figure 3-9. Besides pond dams, the most prevalent location for conservation practices is located in the headwaters of Clear Creek. Pond dams are most common in Middle Clear Creek (Figure 3-9).

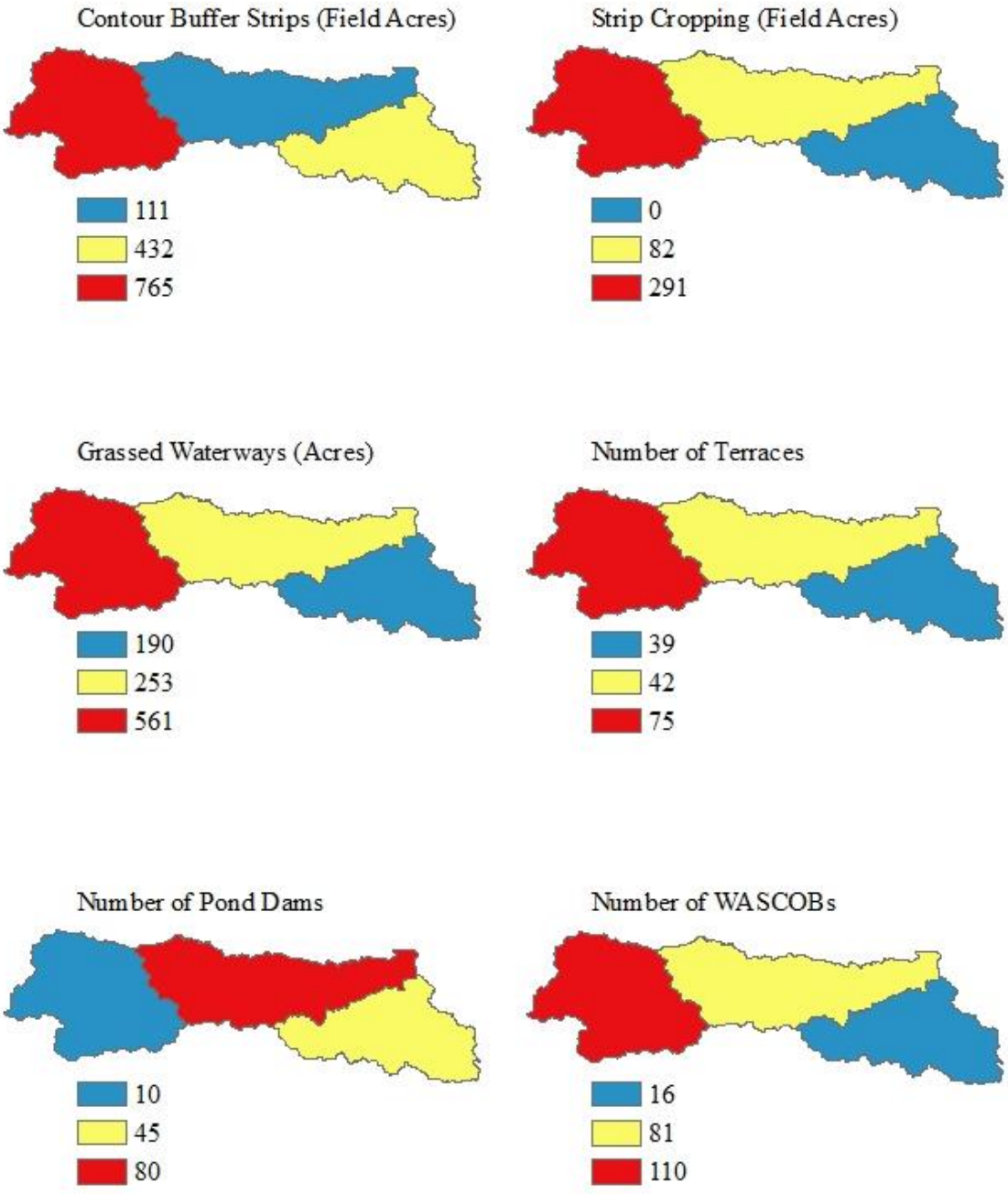

Figure 3-9. Iowa Best Management Practices Mapping Project.

f. Potential BMPs - Agricultural Conservation Planning Framework

Development of an effective watershed planning document will require identification of potential conservation practices and viable locations to implement them. One cutting-edge tool available for practical conversation planning is the Agricultural Conservation Planning Framework (ACPF) watershed planning toolbox, developed by Mark Tomer and his research team at the USDA-ARS (Agricultural Research Service) 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 Clear Creek Watershed. Potential BMPs aggregations based on HUC12 area are presented in Figure 3-10.

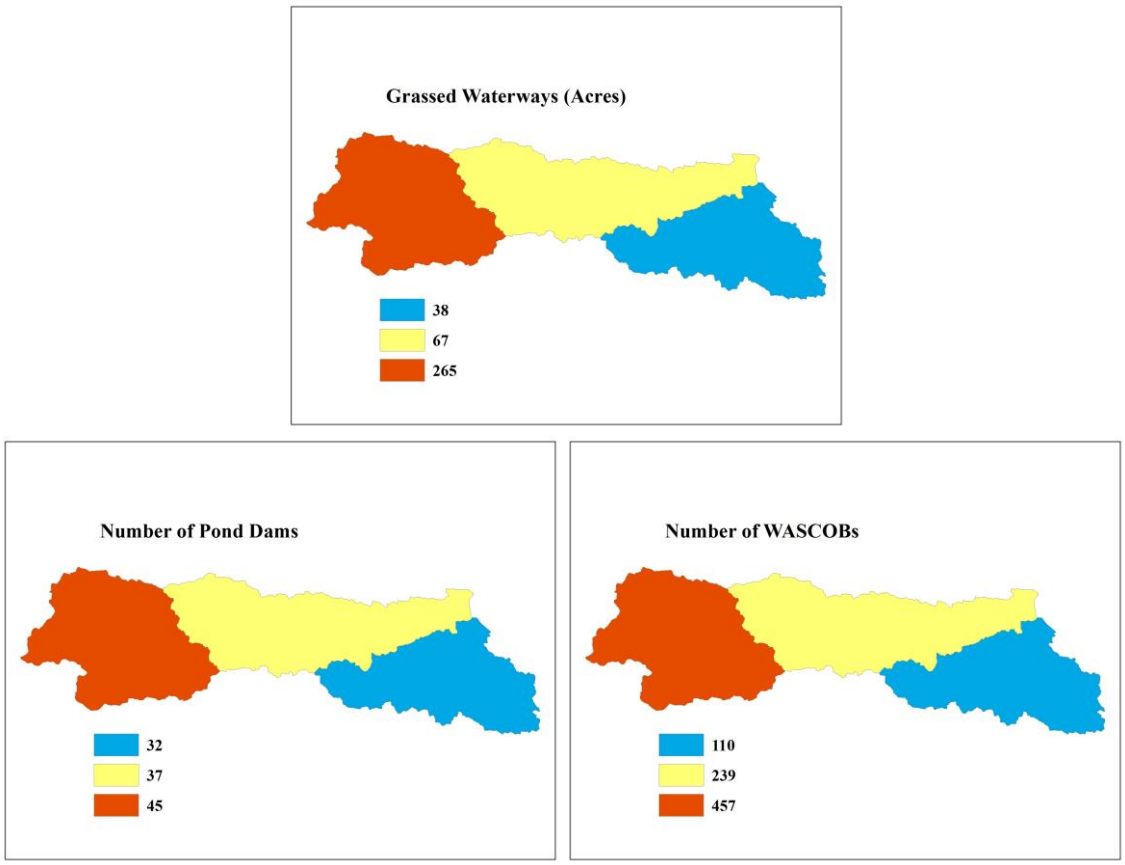

Figure 3-10. Potential BMPs. Ponds Dams represent nutrient removal wetlands.

g. Instrumentation/Data Records

The Clear Creek Watershed has instrumentation installed to collect and record stream stage, discharge, and precipitation. There are two United States Geological Survey (USGS) streamflow gages and nine IFC stream stage sensors located within the watershed. There are also seven Rain Gage/ Soil Moisture Sensors owned by IFC.

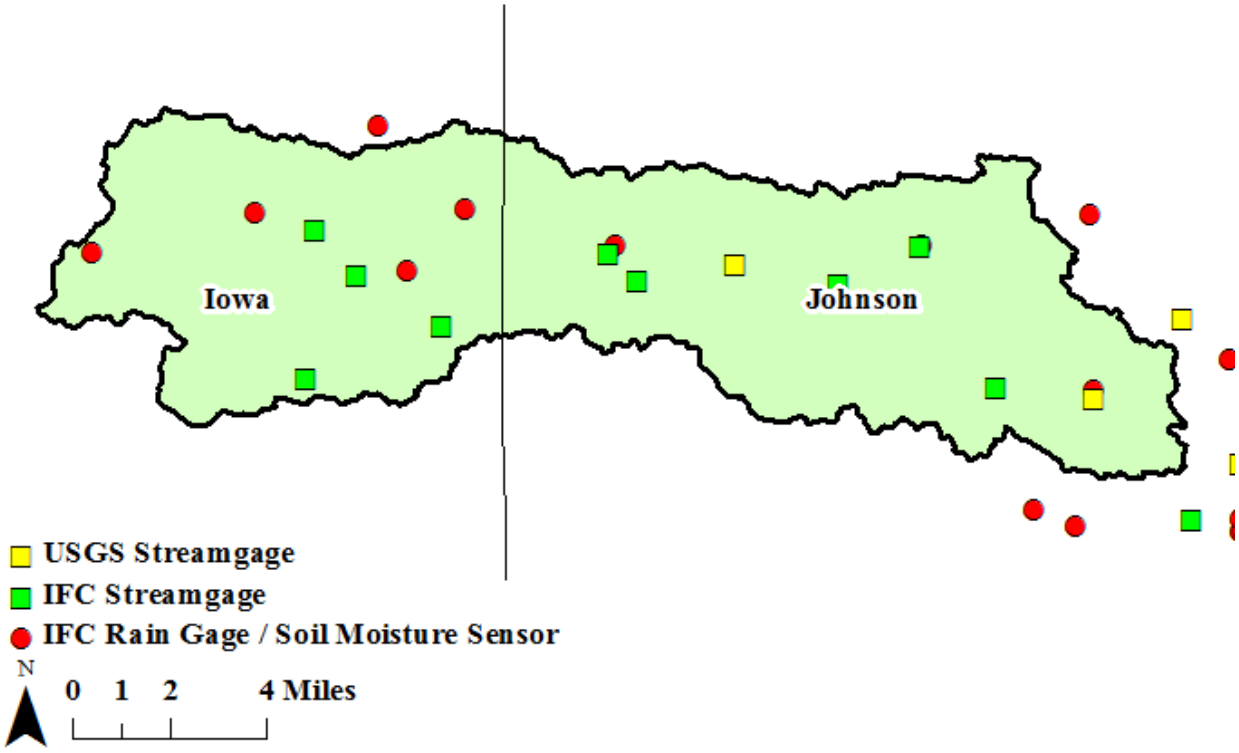

Figure 3-11. Hydrologic and meteorologic instrumentation in the Clear Creek Watershed. Stage/discharge gages are shown in yellow or green while precipitation and soil moisture gages are shown in red.

h. Floods of Record

Seven flood events (greater than 5,000 cfs) were recorded at the Clear Creek USGS gaging station near Coralville since 1953. Four of these events have occurred since 1990 including: June 17, 1990 with 10,200 cfs, July 6, 1993 with 6,760 cfs, April 18, 2013 with 6,480 cfs and the seventh largest event July 1 2014 with 5,010 cfs. The six largest flood events recorded by the USGS for Clear Creek near Oxford and near Coralville are shown in Table 3-2**Error! Reference source not found.**. Before 1990, there were three large flood events recorded near Coralville including: June 15, 1982 with 6,520 cfs, May 29, 1962 with 5,390 cfs and May 17, 1974 with 5,380 cfs.

Table 3-2. Discharge from the Six Largest Flooding Events at USGS Gaging Stations in the Clear Creek Watershed near Oxford and near Coralville.

Clear Creek near Oxford USGS 05454220 (1994-Present)	*4/18/2013*	*7/1/2014*	*5/10/1996*	*6/20/2009*	*2/21/1997*	*6/23/2007*
	6,000 cfs	4,630 cfs	4,230 cfs	3,390 cfs	3,240 cfs	3,140 cfs
Clear Creek near Coralville USGS 05454300 (1953-Present)	*6/17/1990*	*7/6/1993*	*6/15/1982*	*4/18/2013*	*5/29/1962*	*5/17/1974*
	10,200 cfs	6,760 cfs	6,520 cfs	6,480 cfs	5,390 cfs	5,380 cfs

4. Water Quality Analysis

a. Data Availability

This analysis aimed to estimate riverine nutrient loads for the Clear Creek watershed. The primary nutrients of concern traveling through Iowa's rivers are nitrate and phosphorus. Reducing these nutrients in Iowa waters is a central goal of the Iowa Watershed Approach and water quality improvement efforts more generally.

i. Data Requirements

Historical nutrient data are needed to estimate riverine loads for any site of interest. Several programs monitor nutrient data every month by collecting grab samples that are brought to a laboratory for analysis. However, most of this sampling occurs along larger rivers and streams in Iowa. Since the Clear Creek watershed is relatively small, no monthly grab sampling has occurred along Clear Creek. It has become possible in the past decade to deploy in-situ sensors along a river that continuously measure nitrate. These sensors have greatly enhanced nitrate data collection by creating a more complete record for recent years in locations that have historically lacked grab samples. In the early 2010s, the Iowa Water Quality Information System (IWQIS) deployed several nitrate sensors along Clear Creek, resulting in the first publicly available nutrient data within the watershed. Measuring phosphorus on-site is currently infeasible, and grab samples remain the only way to measure its concentrations directly. The lack of historical grab sampling at Clear Creek has resulted in no phosphorus data being present within the watershed. Consequently, an analysis concerning that nutrient is not currently possible.

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

ii. Sources of Data

The Clear Creek watershed extends approximately 20 miles west from the stream's outlet into the Iowa River near Iowa City, IA. The most downstream location along Clear Creek that contains significant nutrient data is found at Camp Cardinal Blvd in the city of Coralville, IA. This site's nitrate has been continuously measured by IWQIS since 2012.

The Coralville site contains nearly 96% of Clear Creek's total watershed, and all tributary streams enter Clear Creek upstream of its location. The USGS has also maintained a stream gauge here—

with streamflow measurements dating back to 1952. This site is an obvious choice for any nutrient analyses conducted along Clear Creek, as it has the largest amount of historical data and encompasses the vast majority of the watershed. The exact location of the Coralville site within the Clear Creek watershed is shown below; the pink pin in Figure 4-1 corresponds to the IWQIS nitrate sensor and USGS streamflow gauge 05454300.

Figure 4-1. Coralville, IA data collection site.

IWQIS began measuring nitrate at this location in 2012, and monitoring continues to the present day. The nitrate sensor in Coralville often collects a new measurement every 15 minutes, and daily means are calculated by averaging the high-resolution values. There are several days each year in which nitrate was not measured, and these are largely due to deployment issues with the sensor. Nitrate sensors often cannot be deployment in the winter, as freezing waters can damage the equipment. Consequently, wintertime nitrate data is rare in Clear Creek, while much more data is present in the other seasons. Additional issues of sensor fouling or equipment malfunctions can also lead to occasional gaps within the dataset. Table 4-1 summarizes the number of days in each year containing nitrate measurements, as well as the number of days with nitrate each month. Overall, the on-site efforts of IWQIS have resulted in a robust nitrate dataset, enabling the estimation of nitrate loads from 2012 to the present.

Table 4-1. Top: Days with nitrate data per year. Bottom: Days with nitrate data per month.

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Days w/ Nitrate	187	223	138	285	247	247	307	257	265	280

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Days w/ Nitrate	4	13	124	237	250	262	293	300	292	307	280	74

b. Methods

Because there are numerous days in which nutrient data is unavailable, it is necessary to estimate nitrate concentrations on these days without direct measurements. If nitrate concentrations can be accurately estimated over the period of available data, it is possible to calculate nutrient loads comprehensively. In the case of Clear Creek, the goal was to estimate daily concentrations from 2012 to 2021—a timeframe commensurate with data availability and the Iowa Watershed Approach schedule.

The simplest way to estimate the missing data is to interpolate between actual measurements. Studies have indicated that this may be sufficient for nitrate in some larger Iowa streams. However, uncertainty associated with nitrate in smaller watersheds is often too great for interpolation to be viable. Surrogacy-based models are more commonly used when interpolation is not practical. Several models have been developed that use flow and seasonal factors to predict water-borne constituents. These models are almost always possible to implement, as the USGS constantly measures streamflow, and seasonal metrics are always present.

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

Nitrate was modeled from 2012 to 2021 using these WRTDSK methods. The daily flow values utilized by this model are shown in Figure 4-2.

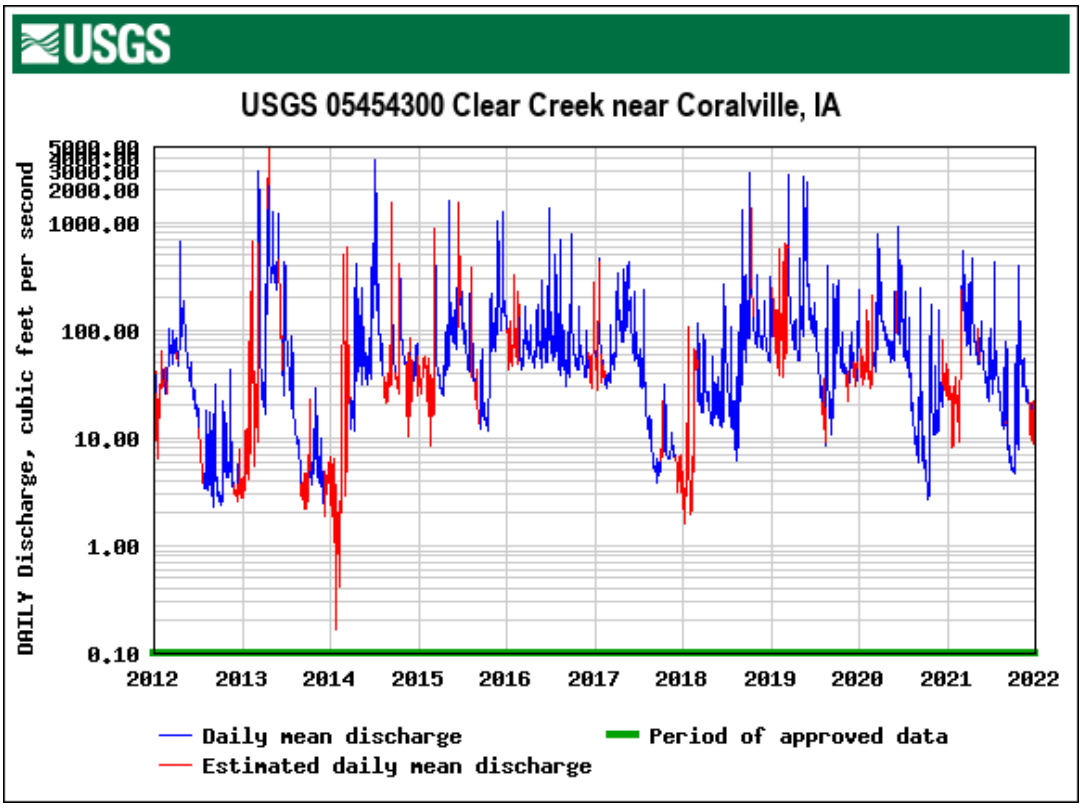

Figure 4-2. Daily flow values for Clear Creek at Coralville, IA.

i. Nitrate

The WRTDSK nitrate model was successfully implemented and showed significant improvement upon linear interpolation.

Table 4-2. WRTDSK model performance metrics.

River	Type	R2	RMSE	R2.ln	RMSE.ln	FluxBias
Clear Creek	Nitrate	0.74	1.50	0.72	0.50	-0.02

The observed (black dots) and estimated (solid line) concentrations are shown in Figure 4-3. Due to continuous deployment of the nitrate sensor at Coralville, actual nitrate observations were present on most days. The nitrate concentrations generally ranged from 0.01 to 15.0 mg/L. The predicted concentrations largely remained within the range of observed values and were consistently below 12.0 mg/L. Many more observed values have been available in recent years due to sensor deployment. All model performance metrics are shown in Table 4-2.

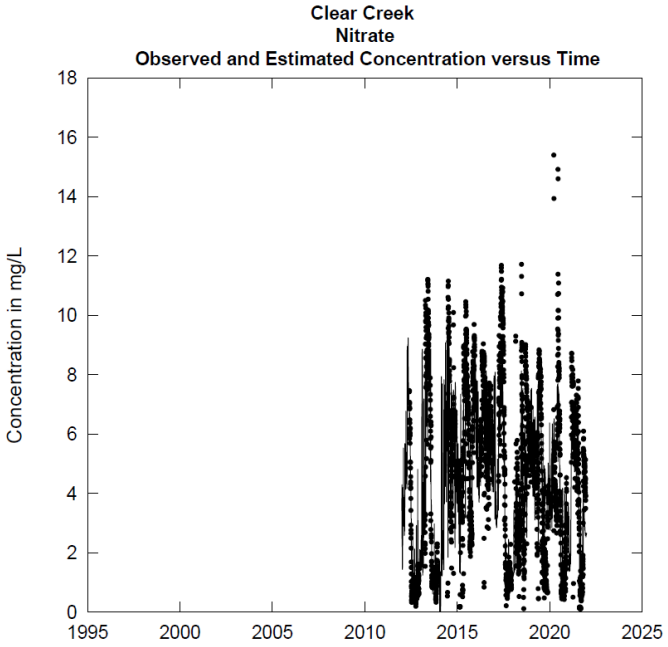

Figure 4-3. WRTDSK nitrate model results.

Figure 4-4 contains an example of the Kalman filter being applied to the nitrate estimates. The black lines show the original WRTDS concentrations, and the red points are the observed samples—the exact nitrate measurements at the Coralville site. These are also present in Figure 4-3. The green lines show the new concentrations made by implementing the Kalman filter. The closer the concentrations are to the actual measurements, the more they get adjusted to match these measurements.

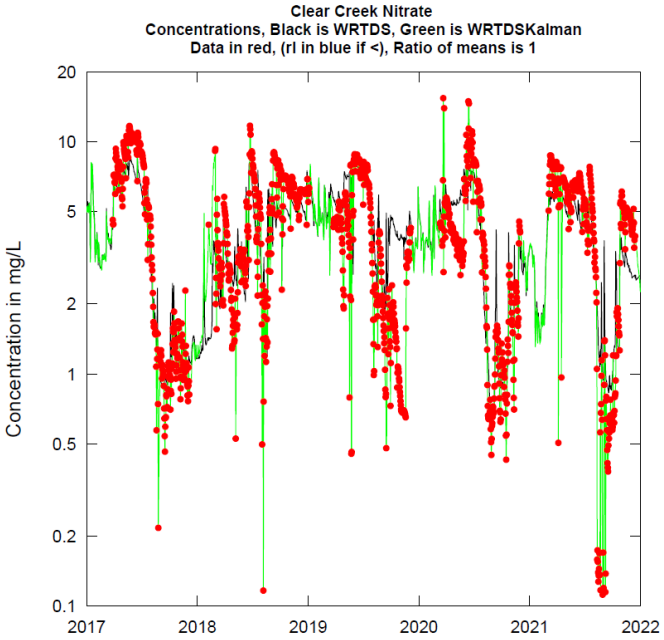

Figure 4-4. WRTDSK nitrate Kalman filter application.

ii. Trend Detection

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

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

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

c. Results

A summary of the descriptive statistics for each pertinent variable is shown in Table 4-3. The flows are the daily mean streamflow values measured by the USGS. Nitrate concentrations were estimated using WRTDSK models, and nitrate loads (N Load) were similarly calculated using these concentrations and the daily flow values.

Table 4-3. Descriptive statistics for Clear Creek flow and nitrate.

Stat	Flow (cfs)	Nitrate (mg/L)	N Load (lbs)
count	3653	3653	3653
mean	51.6	4.38	1651
std	141.6	2.74	3559
min	0.1	0.001	0.0003
10%	2.0	0.91	10.1
25%	8.2	1.79	90.8
50%	25.5	4.23	598
75%	50.1	6.36	1642
90%	101.0	8.25	3949
99%	499.8	10.66	16856
max	4440.0	15.40	78734

i. Nitrate Estimates

Figure 4-5 contains the final daily nitrate concentrations. These concentrations generally appear to be normally distributed. The values also appear relatively constant over the entire record, though there may be a decrease within the past five years Seasonality and autocorrelation are present throughout the timeseries, with higher concentrations occurring nearby one another in the early summer months. The highest single nitrate concentration was 15.4 mg/L; the lowest concentrations of 0.001 mg/L occurred in numerous instances throughout the years.

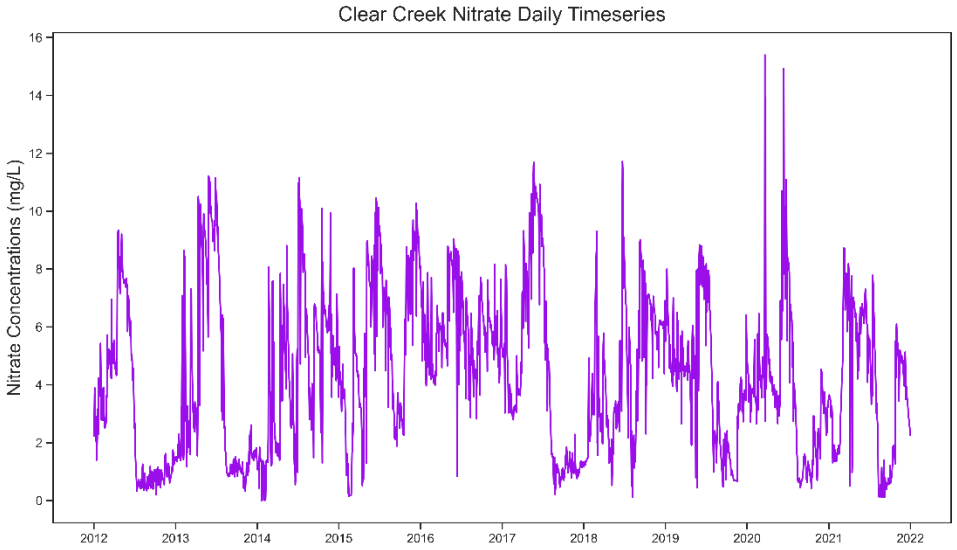

Figure 4-5. Daily nitrate concentrations.

Average yearly concentrations are shown in Figure 4-6. These averages are simply the arithmetic mean of all daily concentrations within a given year. The annual averages range from about 3.0 to 6.0 mg/L, with a typical year near 4.4 mg/L. The decline in recent 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 Clear Creek are on the order of ten billion gallons per year. The wettest years occurred in 2013 and 2019.

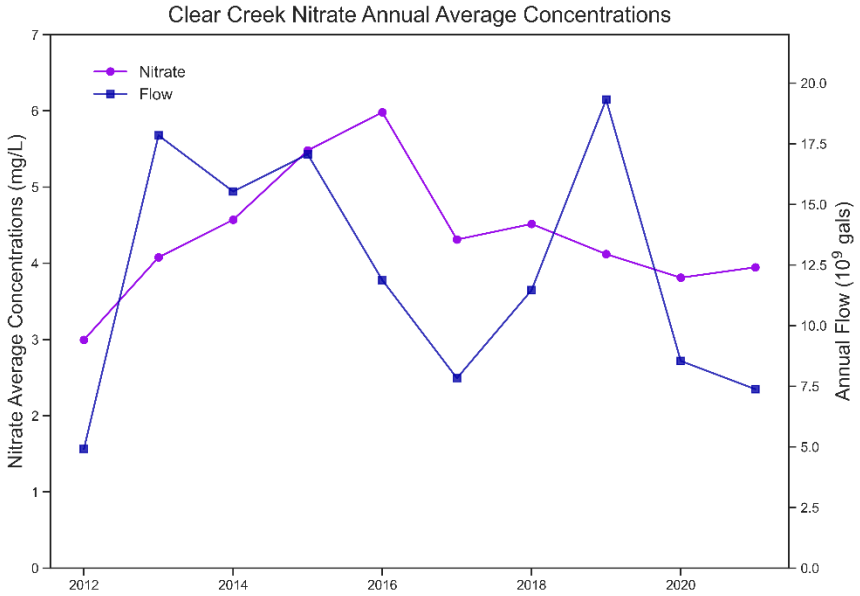

Figure 4-6. Average annual nitrate concentrations.

Figure 4-7 contains the boxplots for nitrate concentrations separated by month. The boxplots show the variation of concentrations within each month, along with the median, interquartile range, and potential outliers. The monthly distributions seem mostly symmetric. The highest medians occur during the May and June months, while the lowest concentrations occur in August, September, and October.

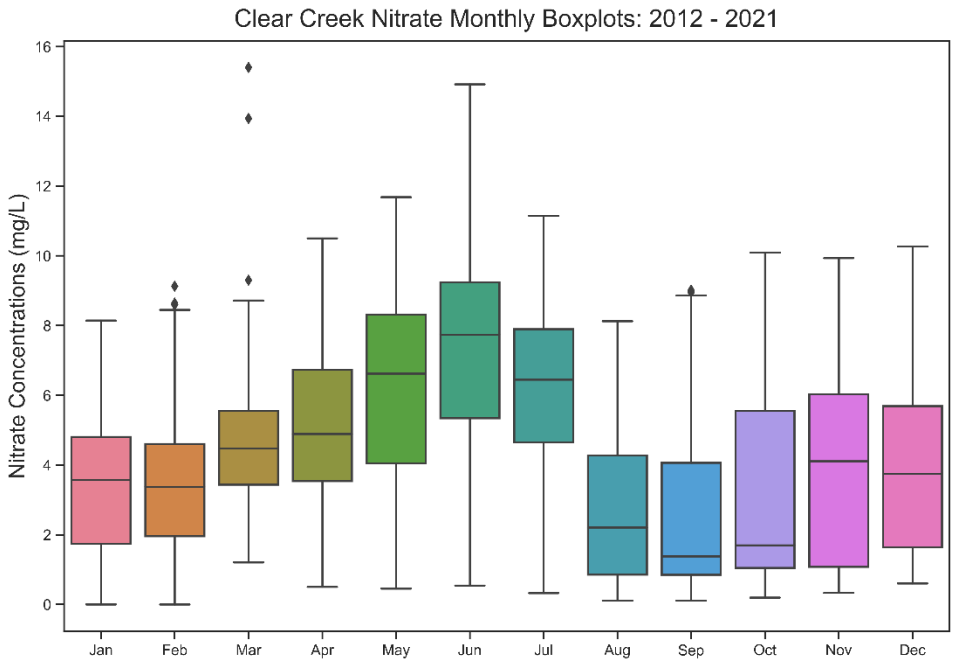

Figure 4-7. Boxplots of monthly nitrate concentrations.

Figure 4-8 shows the daily nitrate loads. These were calculated by multiplying the daily concentrations by their corresponding mean flow values. Flows values are generally positively skewed, often following a lognormal distribution. Due to the skewness of the flows, the nitrate loads also tend to be positively skewed. The highest loads tend to be near 10,000 lbs of nitrate per day, with the highest daily load greater than 75,000 lbs. There were also periods of low flow that resulted in minimal nitrate loads.

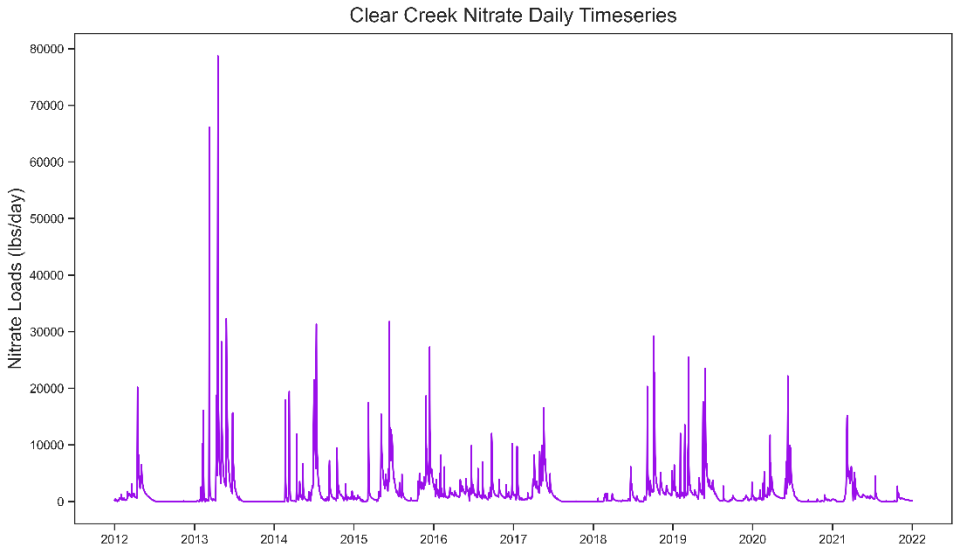

Figure 4-8. Daily nitrate loads.

Figure 4-9 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 Dorchester site, which is 98.1 square miles. The yearly yields varied considerably from 4.0 to 16.7 lbs/ac, with a mean near 9.6 lbs/ac. Water yields correlate with nitrate yields, and higher water yields result in larger nitrate loads due to the increased water volume.

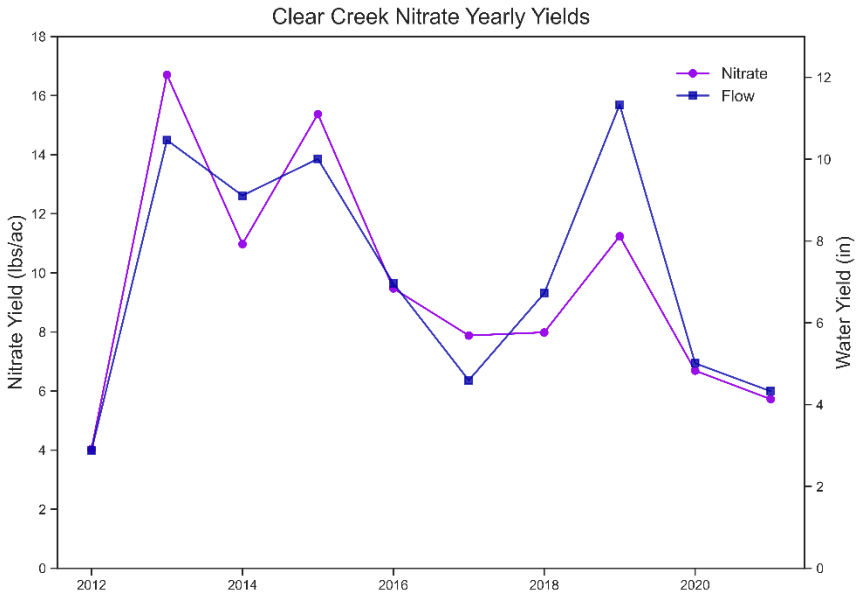

Figure 4-9. Yearly nitrate and water yields.

ii. Trend Detection

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

No overall trend was found for daily nitrate concentrations, but daily nitrate loads were found to be increasing. Daily flow values were also found to be increasing, suggesting that the increased amount of water traveling through Clear Creek is likely responsible for larger recent nitrate loads. No trends were present for the annual timeseries. This is unsurprising, as only 10 years are present within these records. With this small number of data points, it becomes difficult to determine any trends with great statistical certainty.

Table 4-4. Trend analysis results.

Variable	Property	Mann-Kendall			Spearman	
		trend	p-value	slope	trend	p-value
Nitrate	Daily Concentrations	no trend	0.955	-2.36E-06	no trend	0.827
	Daily Loads	**increasing**	0.015	0.0073	**increasing**	0.006
	Annual Concentrations	no trend	0.720	-0.038	no trend	0.726
	Annual Loads	no trend	0.210	-4.69E+04	no trend	0.405
Flow	Daily Flows	**increasing**	<0.001	0.0010	**increasing**	<0.001
	Annual Flows	no trend	0.474	9.00E+08	no trend	0.700

d. Conclusions

The historical IWQIS nutrient data at Coralville, IA, made it possible to estimate nitrate loads for Clear Creek. The data at the Coralville site was excellent, containing a mostly continuous record of nutrient data beginning in 2012. IWQIS has maintained an on-site nitrate sensor routine measures nitrate most of the year, and the USGS operates a co-located gauge that has monitored streamflow since 1954. Data from these two sources were assembled for this analysis. Daily nutrient concentrations were estimated from 1998 to 2021, with a WRTDSK model successfully implemented for nitrate. The estimated nitrate concentrations were then coupled with daily mean flows monitored by the USGS to create daily nutrient loads. A lack of historical phosphorus data made it infeasible to conduct any sort of analysis on waterborne phosphorus within the Clear Creek watershed.

The nitrate concentrations tended to be normally distributed, while the loads were more positively skewed. Nitrate concentrations ranged from 0.01 mg/L and 15.4 mg/L with an average of 4.4 mg/L. Yearly nitrate yields ranged from 4.0 lbs/ac to 16.8 lbs/ac, with an average of 9.6 lbs/ac. Previous studies have estimated Iowa's statewide yield for nitrate across similar timeframes as 16 lbs/ac. The nitrate yields from Clear Creek are smaller than the rest of Iowa. Annual water yields strongly correlated with annual nutrient yields. Both the Mann-Kendall and Spearman trend detection tests indicated that daily concentrations were stagnant for nitrate concentrations but increasing for nitrate loads. Since mean daily streamflow was also increasing, the increased flow in Clear Creek is likely behind the larger nitrate loads being observed in recent years.

5. Model Development

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

a. Hydrologic Model Description

GHOST is based on MM-PIHM (Multi-Modular Penn State Integrated Hydrologic Model), an open-source code developed by Qu and Duffy (2007) that specializes in coupling surface and subsurface flows. Modifications of the original model in GHOST include: "1) capturing main hydrological processes to predict observed multi-year hydrographs and annual water budgets; 2) increasing accuracy using a Voronoi-based discretization; and 3) improving computational

efficiency through multithread parallel computing" (Politano, 2019). In addition, Razmand (2020) added tile drainage to GHOST to capture this important component of Iowa's hydrology.

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

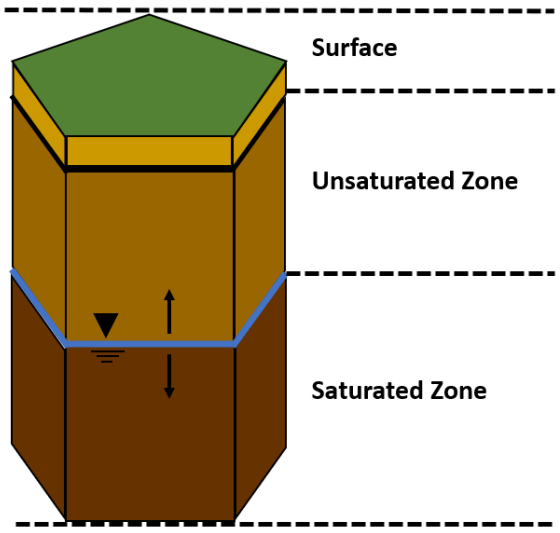

Figure 5-1. Vertical zones of a Voronoi element in GHOST: surface, unsaturated, and saturated zones.

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

groundwater (the saturated zone) moves horizontally via the non-linear Bousinnesq equation. For a full documentation of GHOST's mathematical model, please refer to Politano (2019).

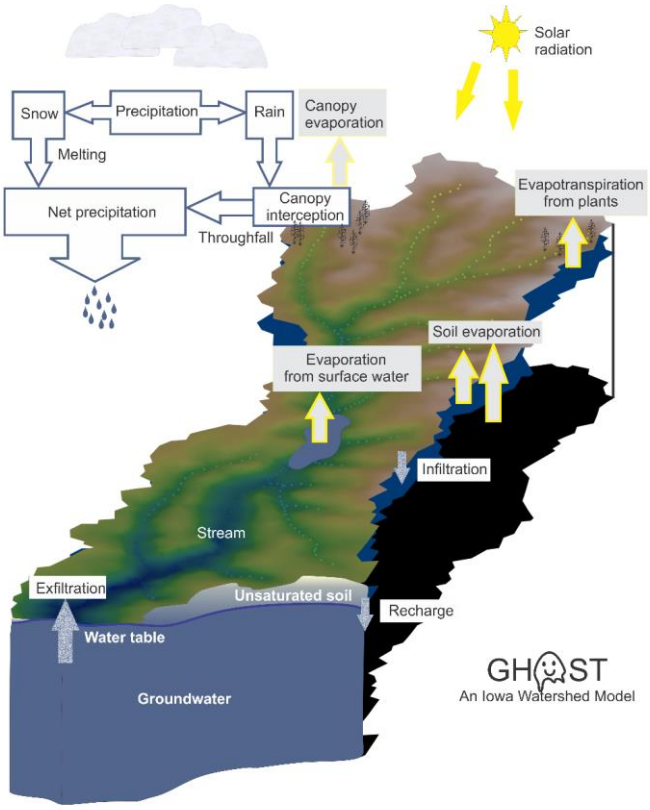

Figure 5-2. The hydrologic cycle calculated by GHOST (Politano, 2019).

b. Clear Creek Model Construction

The GHOST model for the Clear Creek Watershed consists of a computational mesh of Voronoi elements and a network of connected linear stream segments, shown in Figure 5-3. Modelers delineated the stream network using a 10-meter resolution digital elevation model (DEM) procured from the National Elevation Dataset (NED). Within each element, water fluxes are calculated and communicated to neighboring elements and stream segments. Each element contains information about its location, minimum and maximum elevation, area, soil, and land use type. The stream network is detailed by each segment's location, length, minimum and maximum elevation, and

stream order, with corresponding parameters including depth, width, roughness, and connection to the surface and subsurface of its neighboring elements.

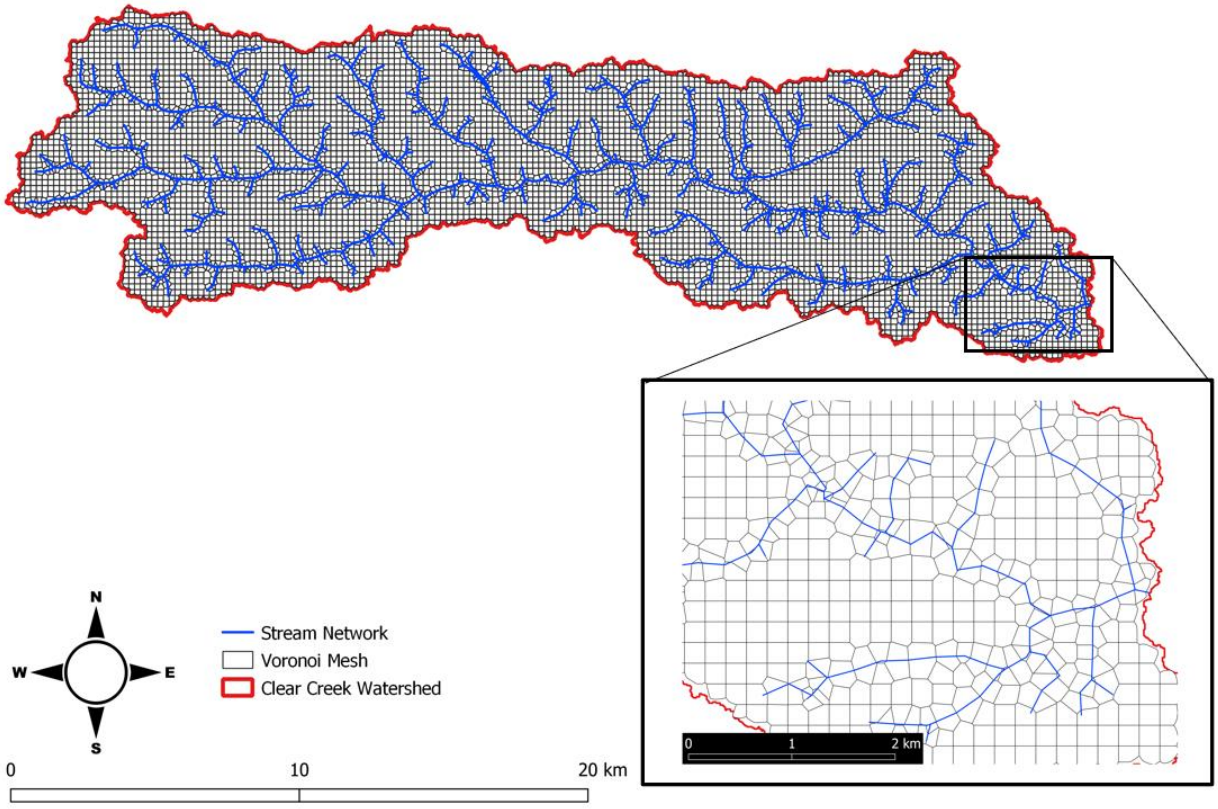

Figure 5-3. The Voronoi mesh and stream network used in the Clear Creek GHOST model.

The model for Clear Creek contains 8,059 elements, with an average size of 0.03 km^2 (7.4 acres), the largest at 0.06 km^2 (14.8 acres), and the smallest only 992 m^2 (0.25 acres). There are 1,362 river segments with a total length of 29.7 km (18.45 miles) and average, maximum, and minimum lengths of 218 m, 301 m, and 20 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.

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, 68% are assigned to row crop, 8% to forest, 15% to grass/pasture, and just 9% to urban, as shown in Figure 5-4.

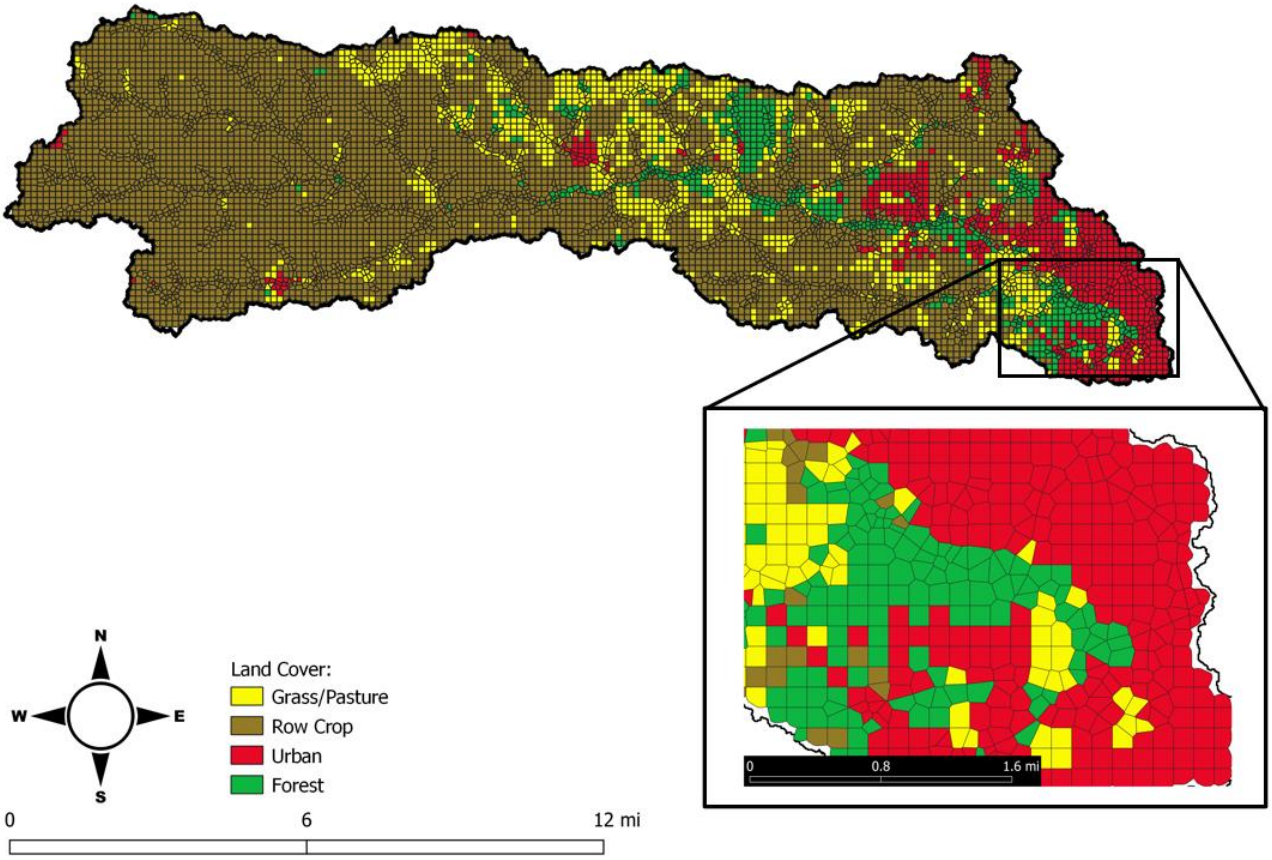

Figure 5-4. GHOST mesh with elements' land use classifications.

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 5 NLDAS pixels shown in Figure 5-5.

Two USGS streamflow gauges provided references to calibrate the GHOST model; both are shown in Figure 5-5. The gauge near Coralville (USGS 05454300) is located just upstream from the outlet of the model and was therefore used as the primary calibration index because that flow represents the entire Clear Creek Watershed. The second calibration index point is located near Oxford (USGS 05454220) 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.

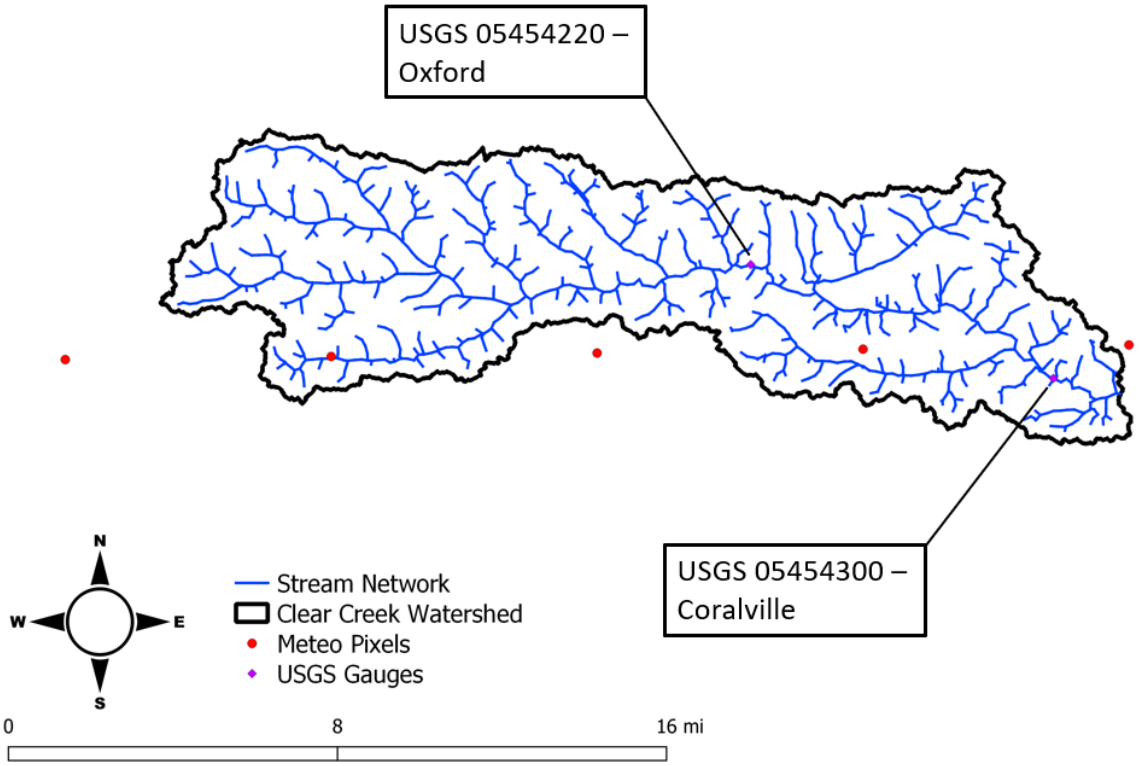

Figure 5-5. The location of the meteorological forcing data pixels and USGS gauges used in the Clear Creek Watershed model.

c. Model Calibration

Calibration is the process of adjusting model parameters within a range of typical values 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 Coralville (05454300) and Oxford (05454220), as shown in Figure 5-6. The comparison of observed and simulated average daily discharges for both gauges is shown in Figure 5-7. In general, GHOST did a good job of capturing low-flow periods as well as flood events. We can use several performance metrics to evaluate how well a model matches observed discharges. Based on Moriasi et al., 2007, model simulations can be judged as satisfactory if Nash-Sutcliffe efficiency (NSE) > 0.60, Percent bias (PBIAS) < ±15%, and the coefficient of determination (R^2) > 0.50. The metrics for this model are shown in Table 5-1. The NSE and R^2 at both Coralville and Oxford exceed this threshold. While the PBIAS value for Coralville is well within the accepted threshold, the value for Oxford is slightly more negative than the ideal range. This indicates that the model has a small tendency to over-predict streamflow at Oxford. 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.

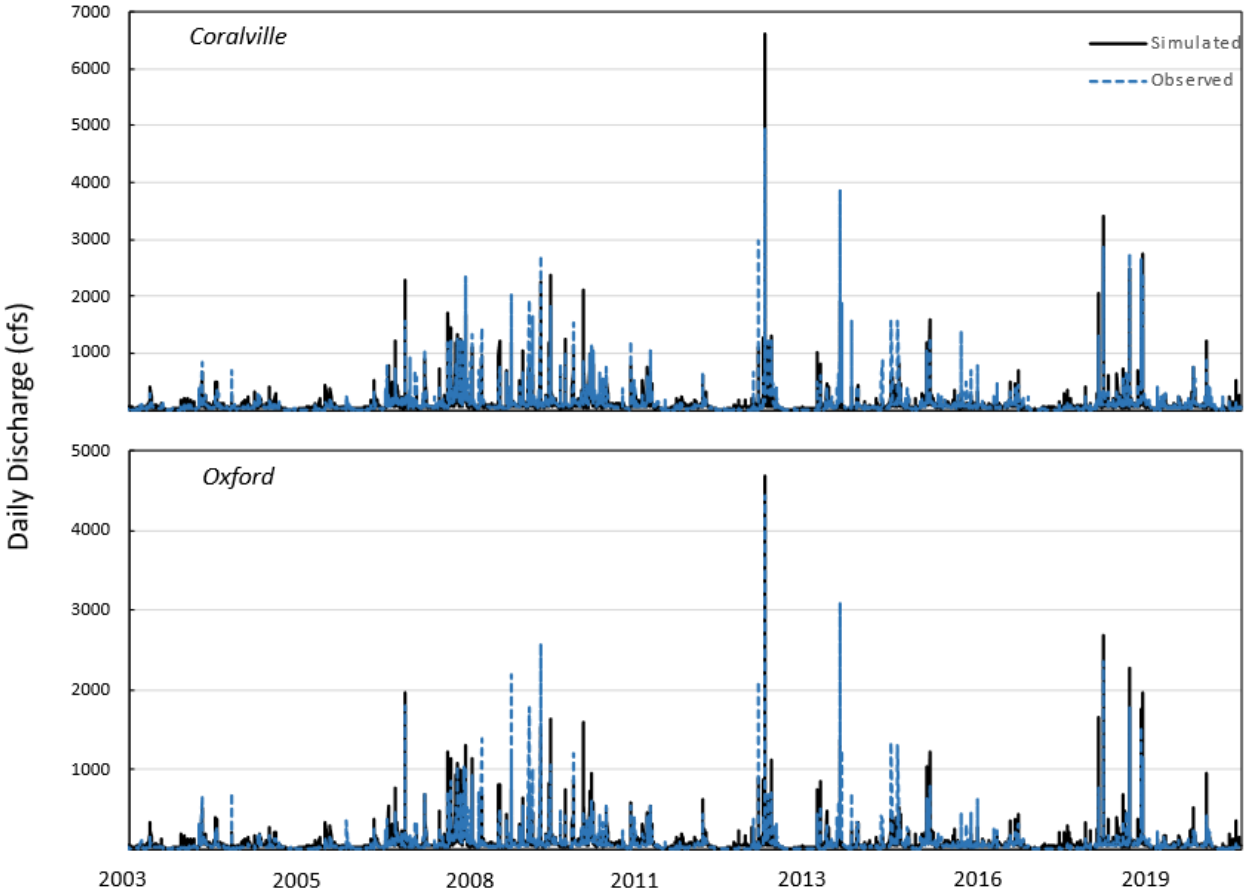

Figure 5-6. Comparison of simulated (black) and observed (blue) daily average discharge at both Coralville (top) and Oxford (bottom).

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

Metric	Coralville	Oxford
NSE	0.70	0.66
R^2	0.77	0.76
PBIAS	2.20%	-19.56%

The Clear Creek Watershed displays a monthly runoff 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 under-predict in the mid-late Summer and over-predict during Fall and Winter. This is the case for both Coralville and Oxford, as seen in Figure 5-7. Overall, the GHOST model's performance matched observed average monthly runoff depths closely, with R^2 values of 0.72 in Coralville and 0.71 in Oxford.

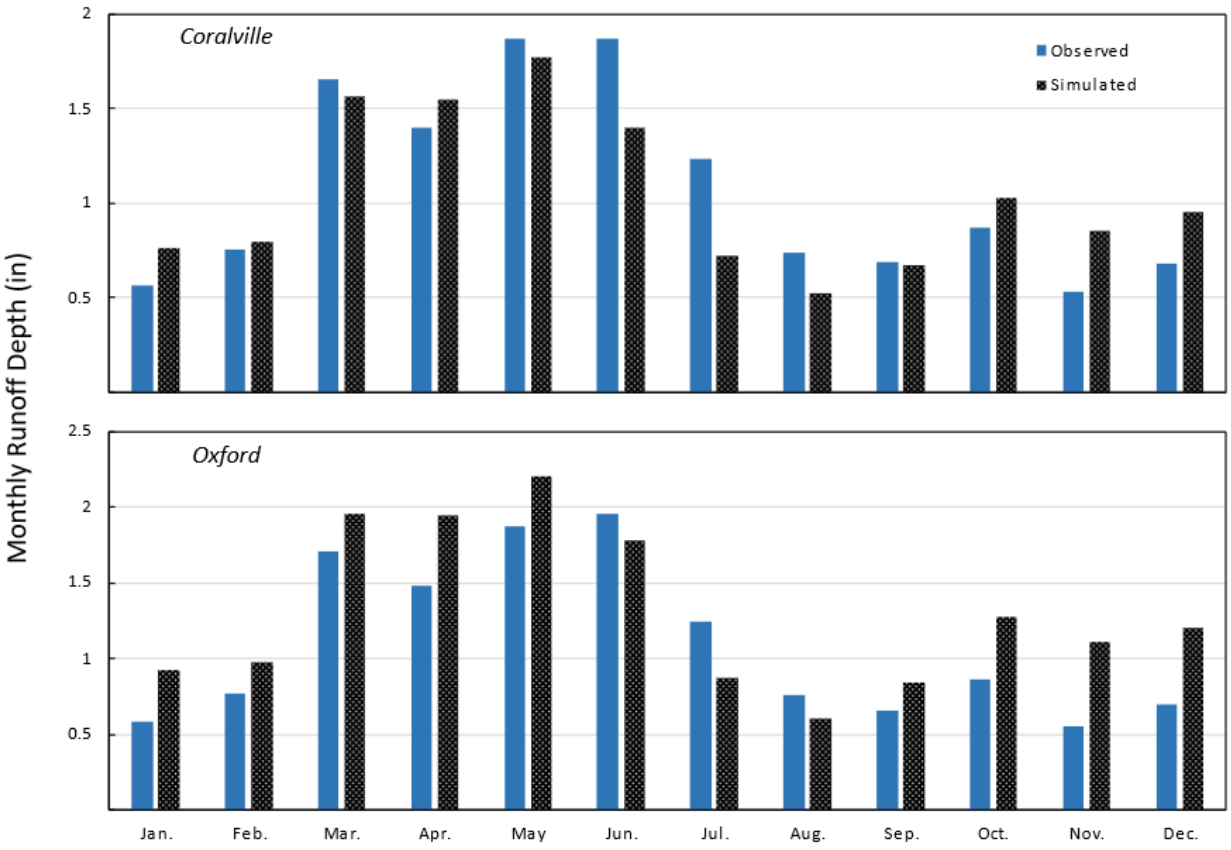

Figure 5-7. Observed and simulated average monthly runoff depths from 2003–2020 at Coralville (top) and Oxford (bottom).

Researchers compared the peak annual discharge for each year to assess the model's ability to capture the largest flood events. Figure 5-8 plots each annual peak with observed discharge on the x-axis and simulated on the y-axis to assess how closely the two values match — that is, how close each point is to the one-to-one line.

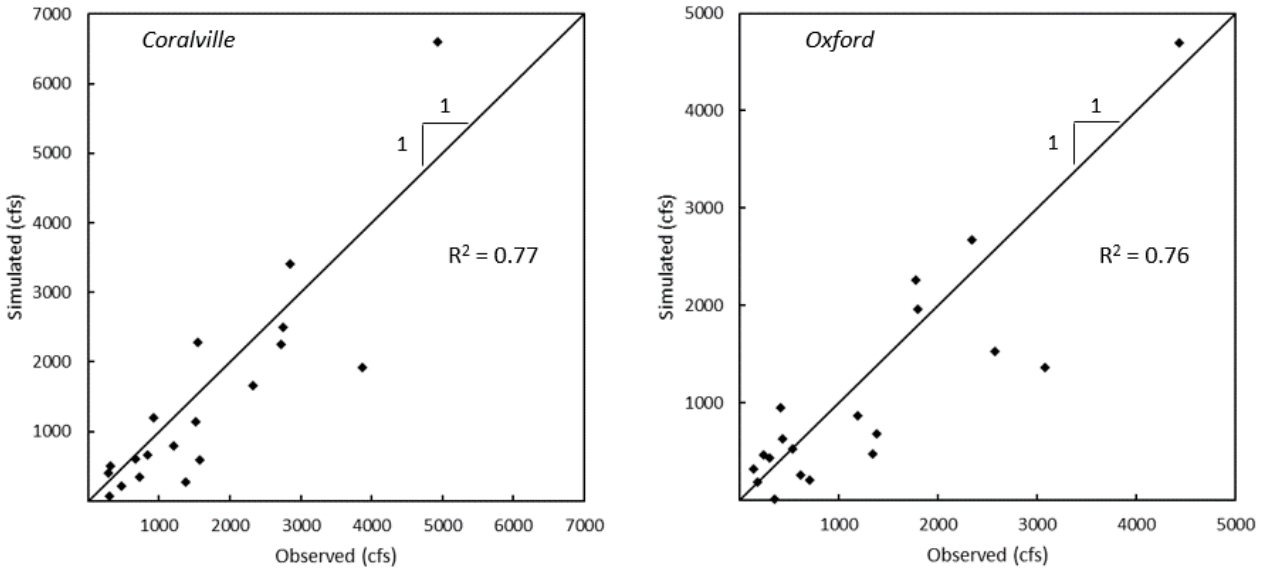

Figure 5-8. Annual peak discharge plotted against a 1:1 line, showing how well modeled peaks matched observed values for both Coralville (left) and Oxford (right).

Annual peak flow events were simulated very well at both locations. At both locations, the model exhibited a slight preference for predicting small to moderate peak flood events. The 2013 flood was by far the largest during the simulated period at both locations. The model over-predicted this event by 34% at Coralville and only 6% at Oxford. The annual NSE at Oxford that year was 0.89 -- the best performance at either location during the study period. The worst performing year both locations had in common was 2016 – a relatively dry year with poor annual NSE performance and a small annual peak flood event. The model had a slight bias to under-predict flood peaks at Coralville while the bias exhibited at Oxford was negligible. Overall, performance at both locations was adequate with Coralville and Oxford achieving R^2 values of 0.77 and 0.76, respectively – exceeding the threshold ($R^2 > 0.50$) outlined in Moriasi et al., 2007, by a significant margin. Figure 5-9 shows daily hydrographs for 2016 in Coralville and 2013 in Oxford to illustrate both ends of the model's performance spectrum.

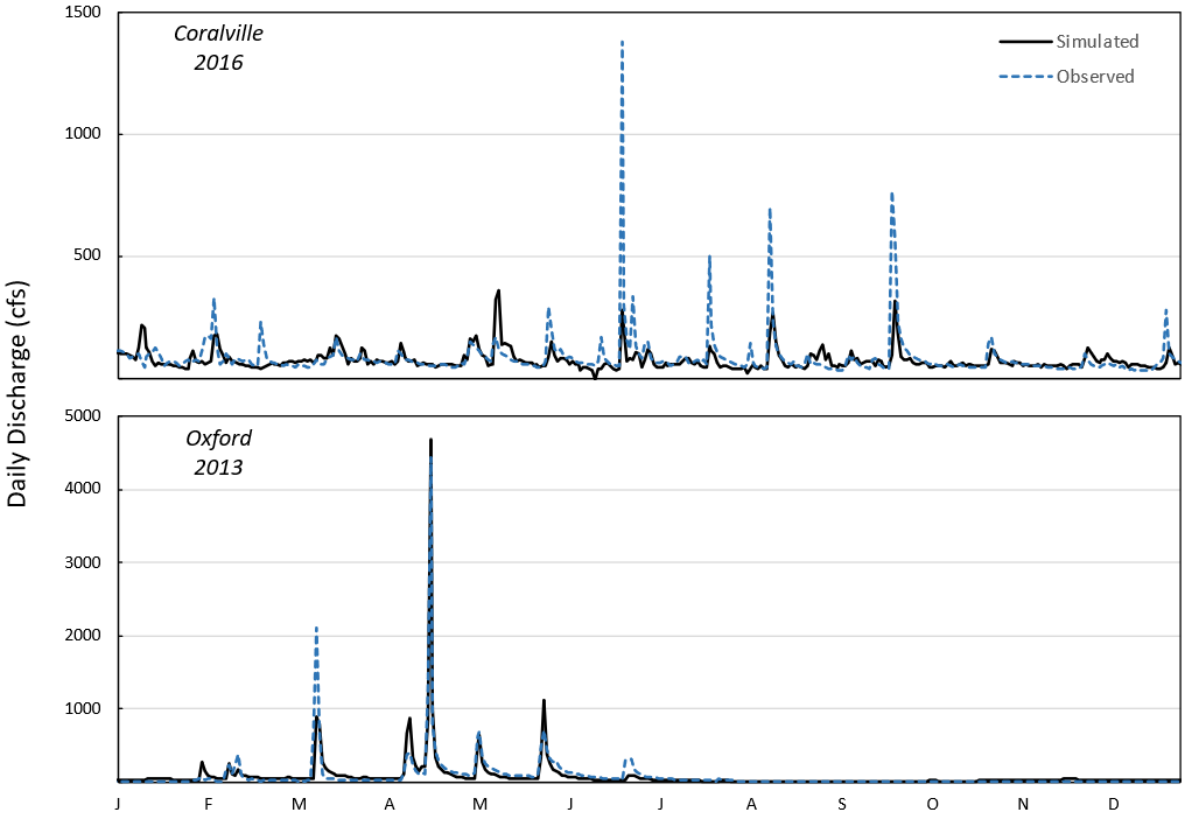

Figure 5-9. Comparison of simulated (black) and observed (blue) daily average discharge for 2016 in Coralville (top) and 2013 in Oxford (bottom).

The accuracy of the model at different scales of discharge can be assessed using the flow duration curve in Figure 5-10. For the entire record (2003–2020), we ranked daily discharge from largest to smallest and then plotted against the probability that the given flow will be equaled or exceeded. At Coralville, the observed and simulated curves show good agreement at exceedance probabilities less than ~50% (i.e., the model does a good job of predicting higher flows but tends to over-predict lower flows). A similar trend is exhibited at Oxford, where the model excels at predicting flows at exceedance probabilities less than ~40%. At both locations, the model displays a tendency to over-predict lower flows – consistent with the previous observations regarding average monthly runoff (Figure 5-7) and annual peaks (Figure 5-8). However, the model captures the statistical behavior of the study period well overall.

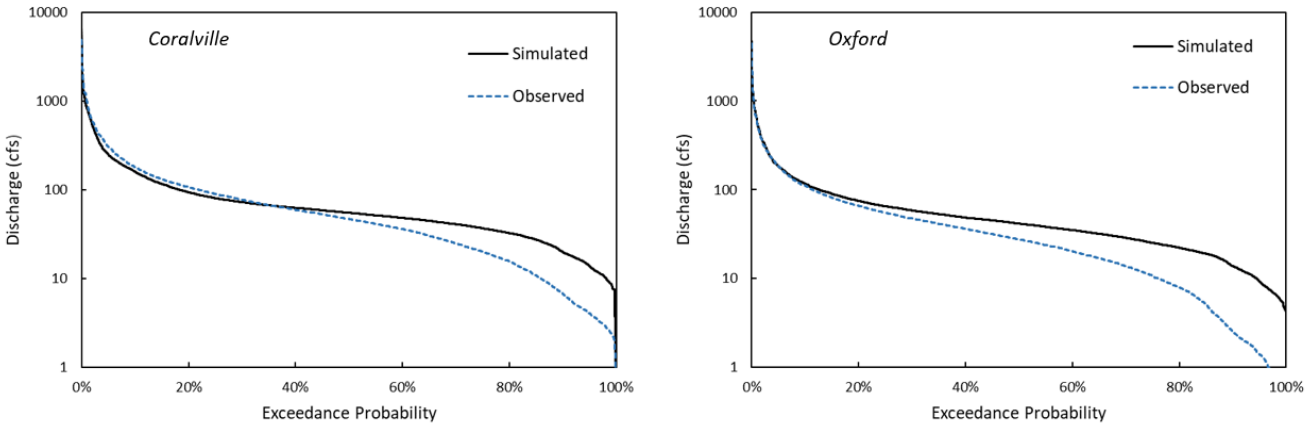

Figure 5-10. Daily flow duration curve for Coralville (right) and Oxford (left).

Based on the performance metrics, hydrographs, and auxiliary figures presented in this section, the GHOST model was deemed to be well-calibrated for the Clear Creek 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 Clear Creek Watershed described in the preceding sections was used to evaluate the individual and cumulative hydrologic effects of the BMPs constructed as part of the IWA, with a particular focus on flood events. Chapter 6 provides a full catalogue of the 57 projects constructed in Clear Creek, as well as in-depth details on several samples. This section describes how the effects of the projects were incorporated in the hydrologic model.

Most projects provide significant flood mitigation benefits, with the exception of several grass waterways, grade stabilization projects, and oxbows. Design engineers provided stage-discharge curves for those projects that could store water. These curves detail how much water is discharged by the project based on the depth (stage) of water within the project's retention basin. Therefore, discharge during an event can be calculated by using the inflow hydrograph to determine how much water is entering the project; using the total volume of water to calculate the depth; and using that depth with the stage-discharge curve to determine the outflow and volume of water leaving. This process is repeated iteratively at each timestep to generate the outflow hydrograph.

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

is being replaced by the flow imposed by the outflow hydrograph. Figure 5-11 shows an example of the configuration used for several of the IWA projects in Clear Creek Watershed.

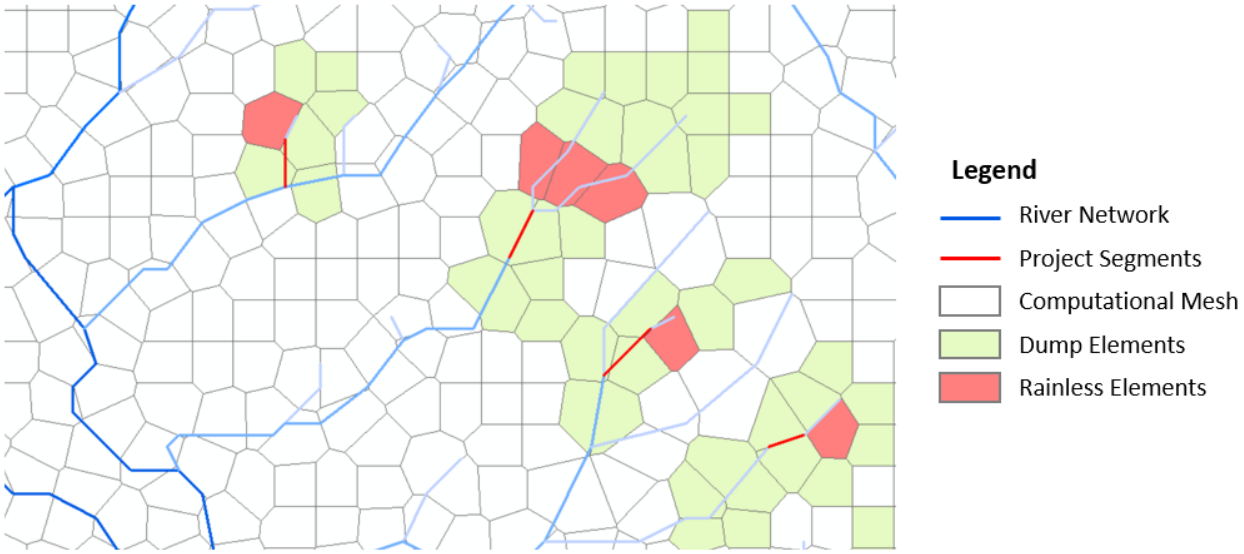

Figure 5-11. A portion of the GHOST model that shows how project effects are simulated by dumping the attenuated outflow hydrograph calculated for each project while eliminating rainfall upstream, which would produce the original, unaltered streamflow.

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

6. Project Inventory

a. IWA Projects in the Clear Creek Watershed

The Iowa Watershed Approach helped fund the design and construction of 57 new BMPs across the Clear Creek Watershed, providing 90% cost-share assistance to volunteer landowners. A summary of the 57 projects is given in Table 6-1.

Table 6-1. Project Summary Table.

Project	Practice	Watershed	Cost	Drainage Area	Flood Storage (ac-ft)	Total Storage (ac-ft)
CC-001-OGDEN	ROCK CHUTE	MIDDLE CLEAR CREEK	$10,400.00	8.4	minimal	minimal
CC-002-OGDEN	ROCK CHUTE	MIDDLE CLEAR CREEK	$13,880.00	7.8	minimal	minimal
CC-014-SIPPY	POND	MIDDLE CLEAR CREEK	$31,022.50	13.5	3.54	7.7
CC-015-SIPPY	POND & FRINGE WETLAND	MIDDLE CLEAR CREEK	$78,865.00	87.35	19.55	35.0
CC-016-SIPPY	POND	MIDDLE CLEAR CREEK	$59,340.00	18.2	7.79	14.7
CC-063-DOWNES	POND	MIDDLE CLEAR CREEK	$65,252.50	80.6	19.8	37.0
CC-078-TANDY	POND	MIDDLE CLEAR CREEK	$37,282.00	18.1	6.69	15.7
CC-080-MAHER	GRADE STAB	MIDDLE CLEAR CREEK	$18,354.00	14.3	minimal	1.8
CC-085-SIPPY	POND	MIDDLE CLEAR CREEK	$48,435.00	36.5	8.17	19.3
CC-047-GRABIN	POND	MIDDLE CLEAR CREEK	$49,660.00	8.8	4.1	8.6
CC-048-GRABIN	POND	MIDDLE CLEAR CREEK	$55,710.00	16.2	7.05	15.7
CC-049-GRABIN	WASCOB	MIDDLE CLEAR CREEK	$35,571.50	8	minimal	4.0
CC-058-GRABIN	POND	MIDDLE CLEAR CREEK	$88,000.00	49.5	12.54	29.5
CC-059-GRABIN	POND	MIDDLE CLEAR CREEK	$36,700.00	7.1	3.75	6.8
CC-079-GRABIN	POND	MIDDLE CLEAR CREEK	$38,000.00	15.3	4.48	11.3
CC-020-CONKLING	WASCOB	UPPER CLEAR CREEK	$16,100.00	4.7	minimal	0.6
CC-021-CONKLING	WASCOB	UPPER CLEAR CREEK	$21,400.00	13.8	minimal	2.1
CC-022-CONKLING	WASCOB	UPPER CLEAR CREEK	$9,100.00	1.6	minimal	0.2
CC-023-CONKLING	WASCOB	UPPER CLEAR CREEK	$14,000.00	5	minimal	0.3
CC-030-CONKLING	GRASSED WATERWAY	UPPER CLEAR CREEK	$10,900.00	109.7	minimal	minimal

CC-031-CONKLING	GRASSED WATERWAY	UPPER CLEAR CREEK	$8,700.00	22.6	minimal	minimal
CC-032-CONKLING	GRASSED WATERWAY	UPPER CLEAR CREEK	$16,400.00	52.8	minimal	minimal
CC-033-CONKLING	GRASSED WATERWAY	UPPER CLEAR CREEK	$8,600.00	29.5	minimal	minimal
CC-034-CONKLING	GRASSED WATERWAY	UPPER CLEAR CREEK	$27,400.00	213.44	minimal	minimal
CC-072-SCHMIDT	WASCOB	UPPER CLEAR CREEK	$9,810.00	3.6	minimal	0.4
CC-073-SCHMIDT	WASCOB	UPPER CLEAR CREEK	$14,810.00	9.4	minimal	0.4
CC-074-SCHMIDT	GRASSED WATERWAY	UPPER CLEAR CREEK	$9,410.00	17.2	minimal	minimal
CC-075-SCHMIDT	GRASSED WATERWAY	UPPER CLEAR CREEK	$4,410.00	3.8	minimal	minimal
CC-093-CONKLING	GRASSED WATERWAY	UPPER CLEAR CREEK	$20,835.00	80.2	minimal	0.2
CC-094-CONKLING	WASCOB	UPPER CLEAR CREEK	$9,075.00	2.7	minimal	0.3
CC-095-CONKLING	WASCOB	UPPER CLEAR CREEK	$8,450.00	2.1	minimal	0.4
CC-096-CONKLING	GRASSED WATERWAY	UPPER CLEAR CREEK	$5,000.00	5.1	minimal	minimal
CC-118-CONKLING	WASCOB	UPPER CLEAR CREEK	$32,465.00	11.8	minimal	2.4
CC-010-ASMUSSEN	POND	MIDDLE CLEAR CREEK	$48,915.00	26	4.88	8.2
CC-011-ASMUSSEN	ROCK CHUTE	MIDDLE CLEAR CREEK	$11,397.00	6.9	minimal	minimal
CC-159-ASMUSSEN	ROCK CHUTE	MIDDLE CLEAR CREEK	$15,370.00	9.5	minimal	minimal
CC-160-ASMUSSEN	ROCK CHUTE	MIDDLE CLEAR CREEK	$20,743.00	6.9	minimal	minimal
CC-161-ASMUSSEN	ROCK CHUTE	MIDDLE CLEAR CREEK	$21,970.00	9.5	minimal	minimal
CC-089-YERIES	GRADE STABILIZATION	MIDDLE CLEAR CREEK	$36,220.00	27.3	minimal	0.5
CC-090-YERIES	WASCOB	MIDDLE CLEAR CREEK	$13,220.00	5.2	minimal	0.9

CC-111-EISTER	POND	MIDDLE CLEAR CREEK	$44,665.00	28.3	5.94	13.5
CC-113-RATH	GRADE STABILIZATION	MIDDLE CLEAR CREEK	$26,815.00	13.3	minimal	0.7
CC-114-RATH	ROCK CHUTE	MIDDLE CLEAR CREEK	$16,125.00	1.1	minimal	minimal
CC-115-STRAMAGLIA	WETLAND RESTORATION	MIDDLE CLEAR CREEK	$21,375.00	27.8	minimal	2.4
CC-116-BOYLE	ROCK CHUTE	MIDDLE CLEAR CREEK	$20,705.00	16.6	minimal	minimal
CC-117-BOYLE	WETLAND RESTORATION	MIDDLE CLEAR CREEK	$73,550.00	27.2	minimal	1.6
CC-152-ODONNELL	GRASSED WATERWAY	MIDDLE CLEAR CREEK	$14,950.00	15.3	minimal	minimal
CC-162-CORALVILLE	FLOODPLAIN RESTORATION	LOWER CLEAR CREEK	$83,458.00	n/a	minimal	minimal
CC-163-CORALVILLE	FLOODPLAIN RESTORATION	LOWER CLEAR CREEK	$111,243.50	n/a	minimal	minimal
CC-164-CORALVILLE	FLOODPLAIN RESTORATION	LOWER CLEAR CREEK	$110,270.50	n/a	minimal	minimal
CC-064-JIRAS	WASCOB	MIDDLE CLEAR CREEK	$14,410.00	1.7	minimal	0.2
CC-065-JIRAS	WASCOB	MIDDLE CLEAR CREEK	$17,245.00	1.6	minimal	0.2
CC-119-JIRAS	WASCOB	MIDDLE CLEAR CREEK	$20,120.00	6	minimal	1.2
CC-130-FASELT	FLOODPLAIN RESTORATION	MIDDLE CLEAR CREEK	$104,500.00	3004	minimal	minimal
CC-131-FASELT	PRAIRIE (CONS. COVER)	MIDDLE CLEAR CREEK	$15,000.00	n/a	minimal	minimal
CC-132-FASELT	ROCK CHUTE	MIDDLE CLEAR CREEK	$12,000.00	n/a	minimal	minimal
		TOTAL	***$1,787,604.50***	***4212.9***	***108***	***243.5***

BMPs were constructed in all three of the HUC12s selected to be part of the IWA; The upper, middle and lower clear creek watersheds. Figure 6-1 shows the location of the 57 projects in the Clear Creek Watershed.

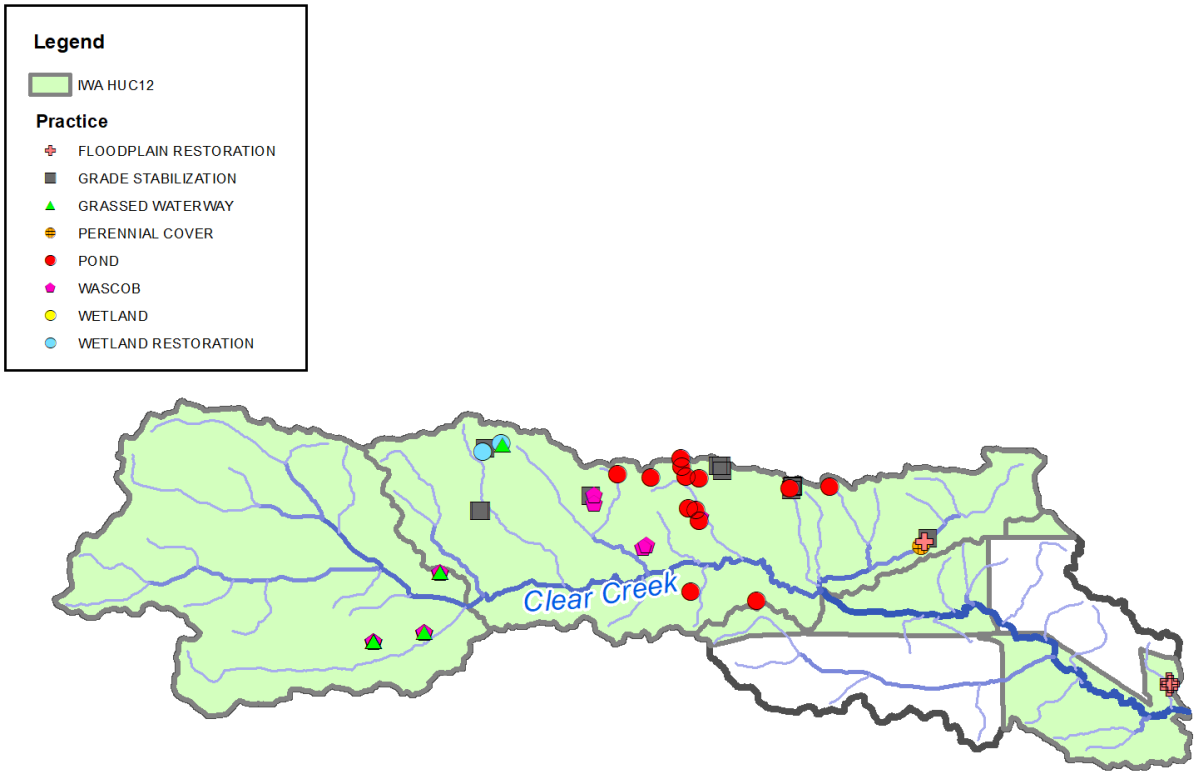

Figure 6-1. Location and type of the 57 IWA projects in the Clear Creek Watershed. Note that in several instances, two projects are too close together to appear separate.

b. Hydraulics of Flood Mitigation Projects

Eight different types of BMPs were constructed in the Clear Creek Watershed: 14 WASCOBs, 13 ponds, 12 grade stabilizations, 10 grassed waterways, 4 floodplain restorations, 2 wetland restorations, 1 wetland, and 1 perennial cover project. Aside from grass waterways, most projects provide at least some runoff attenuation. However, some smaller types of projects are difficult to implement in the GHOST model due to the difference in project size versus mesh resolution. Therefore, only relatively larger projects with relatively large upstream drainage area and flood storage such as ponds, and wetlands were incorporated into GHOST modeling. All these practices were assumed to follow the same hydraulic principle for flood attenuation.

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

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

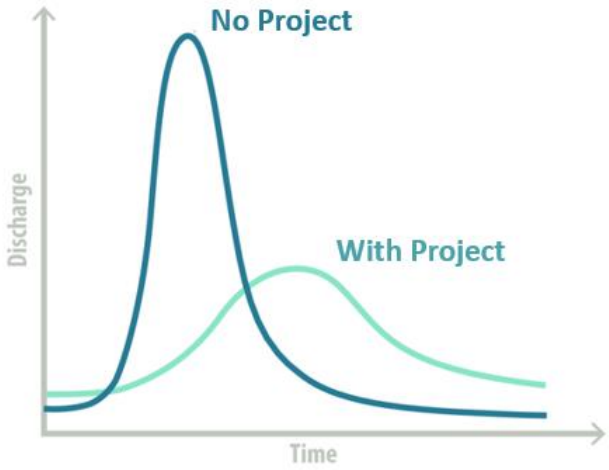

Figure 6-2. A classic comparison of a streamflow hydrograph with and without a flood mitigation project. The addition of the project does not change the volume of water moved but lowers the peak flow passed and gradually releases the water at lower rates.

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

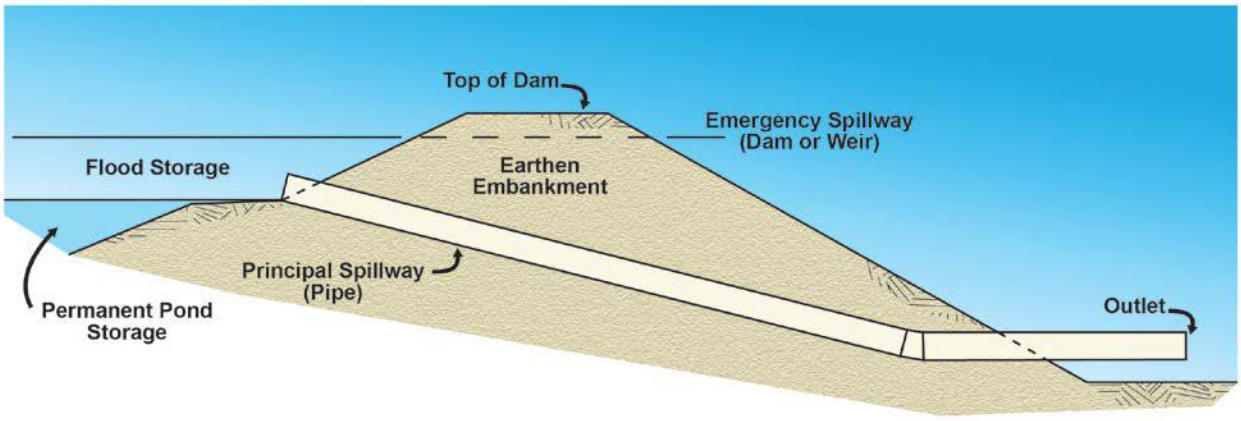

Figure 6-3. Schematic of a pond constructed to provide flood storage.

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

c. Project Summary

As a result of the Iowa Watershed Approach, 57 new BMPs were constructed in the Clear Creek Watershed:

- 14 WASCOBs
- 13 Ponds
- 12 Grade Stabilizations
- 10 Grassed Waterways
- 4 Floodplain Restorations
- 2 Wetland Restorations
- 1 Wetland
- 1 Perennial Cover

Most of these projects will provide meaningful storage and flood reduction benefits for the watershed, and all will help improve water quality. Ponds, wetlands, 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. 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 Clear Creek Watershed.

7. Clear Creek Hydrologic Assessment

a. Individual Impacts of IWA Projects

In total, 13 IWA projects located in five different tributaries within the Middle Clear Creek HUC12 were included in the model. The modeling efforts were limited to 13 ponds and wetlands as they represent ~91% of the total storage distributed amongst 33 IWA projects. The total drainage area of tributaries impacted by projects amounts to ~19 $mi.^2$ – nearly 50% of the HUC12. Total drainage area upstream of modeled projects totals to only ~0.6 $mi.^2$ – 1.6% of the HUC12. Project locations as well as an area analysis of impacted tributaries are shown in Figure 7-1.

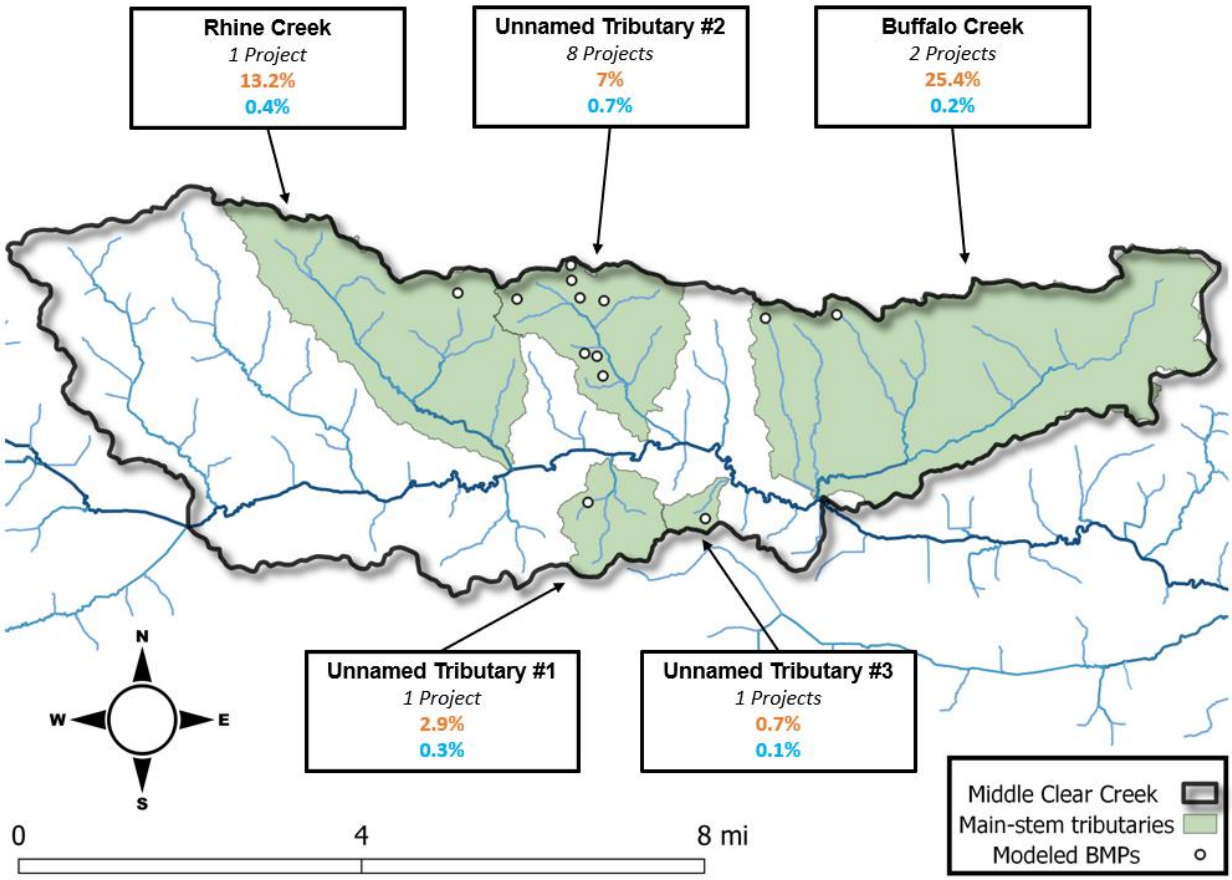

Figure 7-1. Area analysis of the Middle Clear Creek HUC12 and tributaries impacted by modeled BMPs. Total number of modeled BMPs, tributary area contribution to the HUC12 (orange text), and project drainage area contribution to the HUC10 (blue text) are visualized for each HUC12.

To assess the flood reduction impacts of IWA projects in the Clear Creek Watershed, a design storm was imposed on GHOST. The storm generated 6.1 inches of rain within a 24-hour period, as shown in Figure 7-2. The watershed response to this storm was measured first in a "control" version without projects to ensure that streamflow at the future project sites was consistent with expectations provided by the design engineers. For some projects, a different streamflow had to be introduced at the future project site, using the method described in Section 5.d, to more accurately match the inflow hydrographs that the projects were designed for.

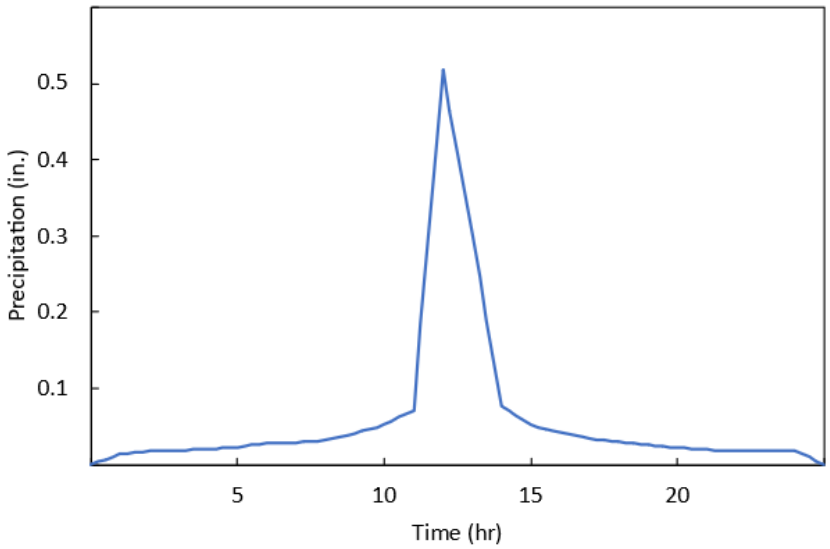

Figure 7-2. Rainfall hyetograph from the design storm used in GHOST to test the effects of projects on flood peak reductions.

This first run provides a baseline comparison of how the watershed would react to a storm like this while no projects are present. Next, modelers added projects by imposing the outflow hydrographs at their respective locations (see Section 5.d for the full methodology). In these cases, streamflow immediately downstream of each project reflects the conditions with projects in place and can be compared to the control. The following analyses include examples of the primary types of flood mitigation projects (ponds and wetlands) and represent the various streamflow responses to project implementation on a local scale.

In the Rhine Creek tributary of the Middle Clear Creek HUC12, the pond and fringe wetland CC-015 attenuates flows generated within an 87-acre drainage area. The project exhibits classic flood peak reduction behavior in the tributary that feeds directly into the main channel of Rhine Creek before joining the main stem of Clear Creek. Figure 7-3 shows the location of this project in relation to the GHOST stream network and the hydrographs (with and without project) at the different marked downstream locations.

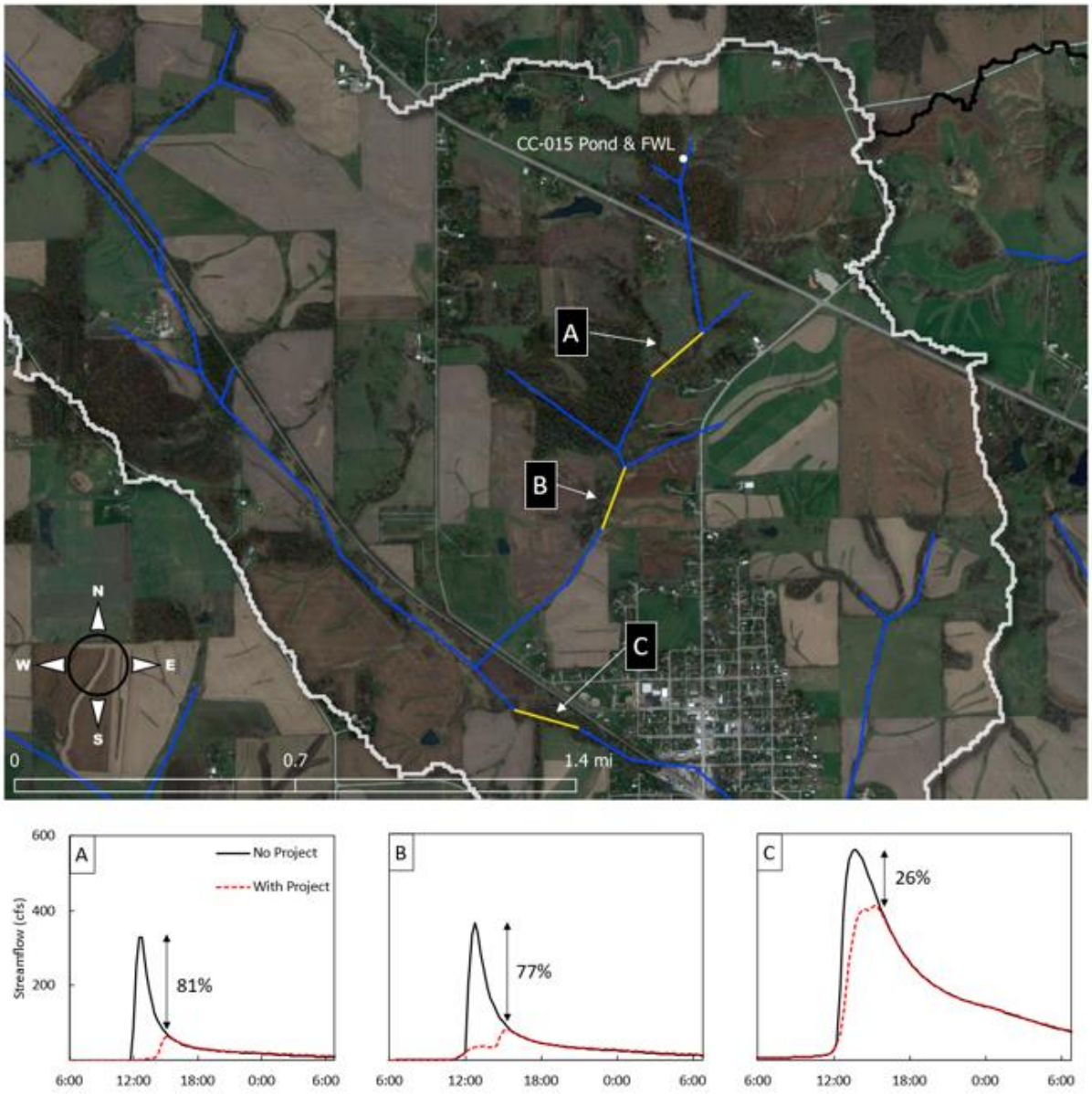

Figure 7-3. Analysis of the project in the Rhine Creek main-stem tributary, along with hydrographs comparing the streamflow with (dotted red) and without (solid black) projects at various downstream index points.

At index point A downstream of the project, the hydrograph exhibits a sharp peak that the project attenuates by 81%. Index point B lies a short distance downstream – preceded by inflows from two small streams. Despite the flow added by the two streams, peak flow reduction is only diminished by ~4% to 77%. Moving downstream, the tributary maintains significant reduction until joining the main channel of Rhine Creek, just upstream of index point C. Adjacent to the town of Oxford, peak flow reduction at index point C is diminished to 26%. This diminished reduction is the result of added flow from upstream drainage area not regulated by the project. Just

outside of Oxford, Rhine Creek flows into the main stem of Clear Creek – where a 2% peak flow occurs.

Downstream of Rhine Creek, a similar response is observed in unnamed tributary #1. The tributary houses the pond CC-063 which attenuates flows generated within an 81-acre drainage area. Shortly downstream of the project, the tributary flows directly into the main stem of Clear Creek. Figure 7-4 shows the location of this project and hydrographs illustrating the downstream impacts.

At index point A the project exhibits a significant local impact immediately downstream with an 87% reduction in peak flow. Index point B lies immediately downstream of the confluence between the project branch and a small stream, diminishing peak flow reduction by 4%. Significant reduction is maintained until flow reaches the tributary's confluence with the main stem of Clear Creek. At index point C, located on the main stem of Clear Creek shortly downstream of the tributary's outlet, peak flow reduction is diminished to 5%. This behavior reflects the common streamflow response to upstream projects: significant local impacts that quickly deteriorate at larger scales.

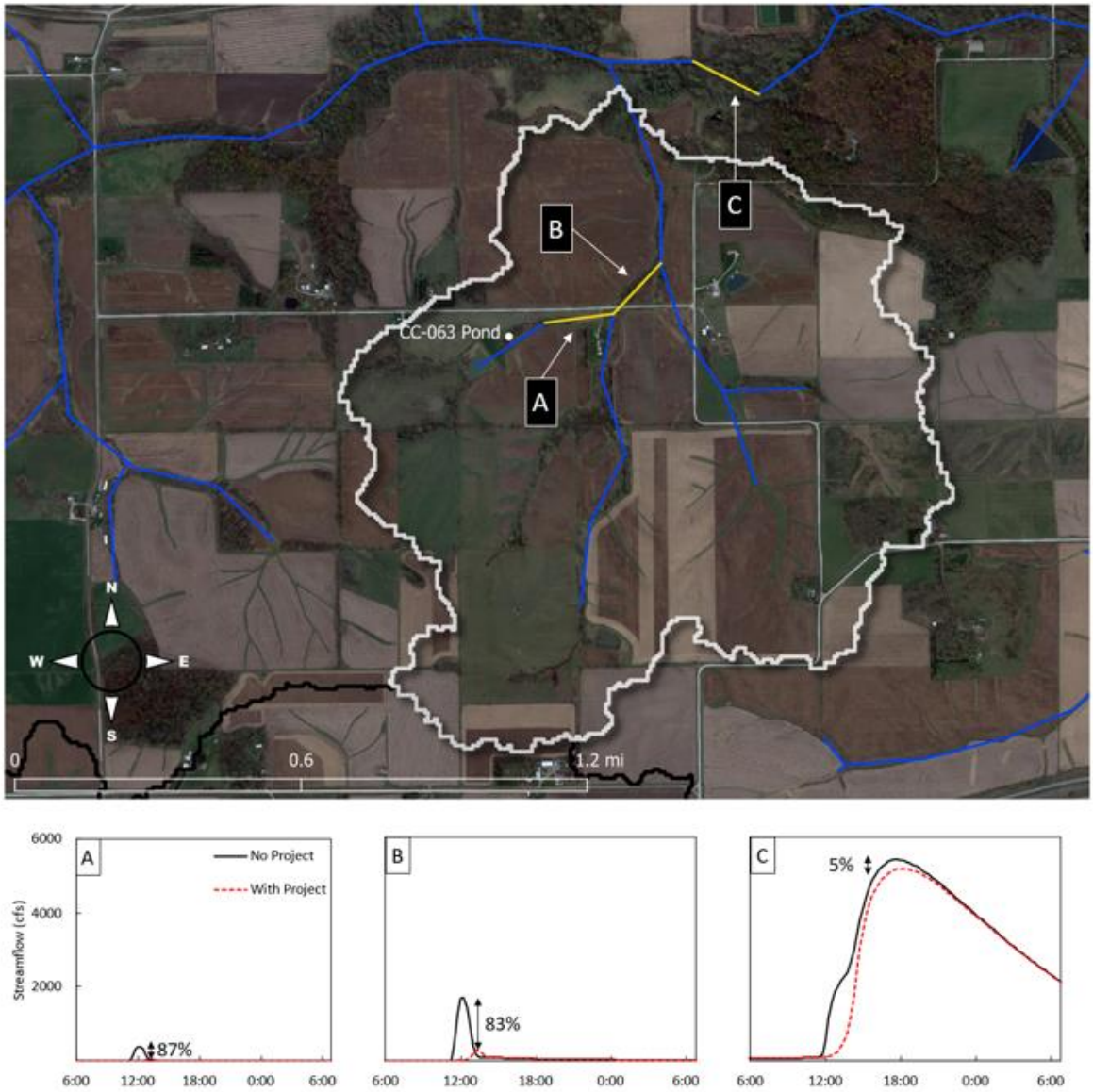

Figure 7-4. Analysis of the project in the first unnamed main-stem tributary, along with hydrographs comparing the streamflow with (dotted red) and without (solid black) projects at various downstream index points.

Located a short distance downstream of unnamed tributary #1, unnamed tributary #2 is densely populated with modeled practices. The tributary houses eight ponds; CC-016, CC-079, CC-058, CC-014, CC-085, CC-048, CC-059, and CC-047. In total, these ponds regulate flow generated within 165 acres of drainage area. The main channel of this tributary drains directly into the main stem of Clear Creek. Figure 7-5 shows the project locations and hydrographs illustrating the downstream impacts.

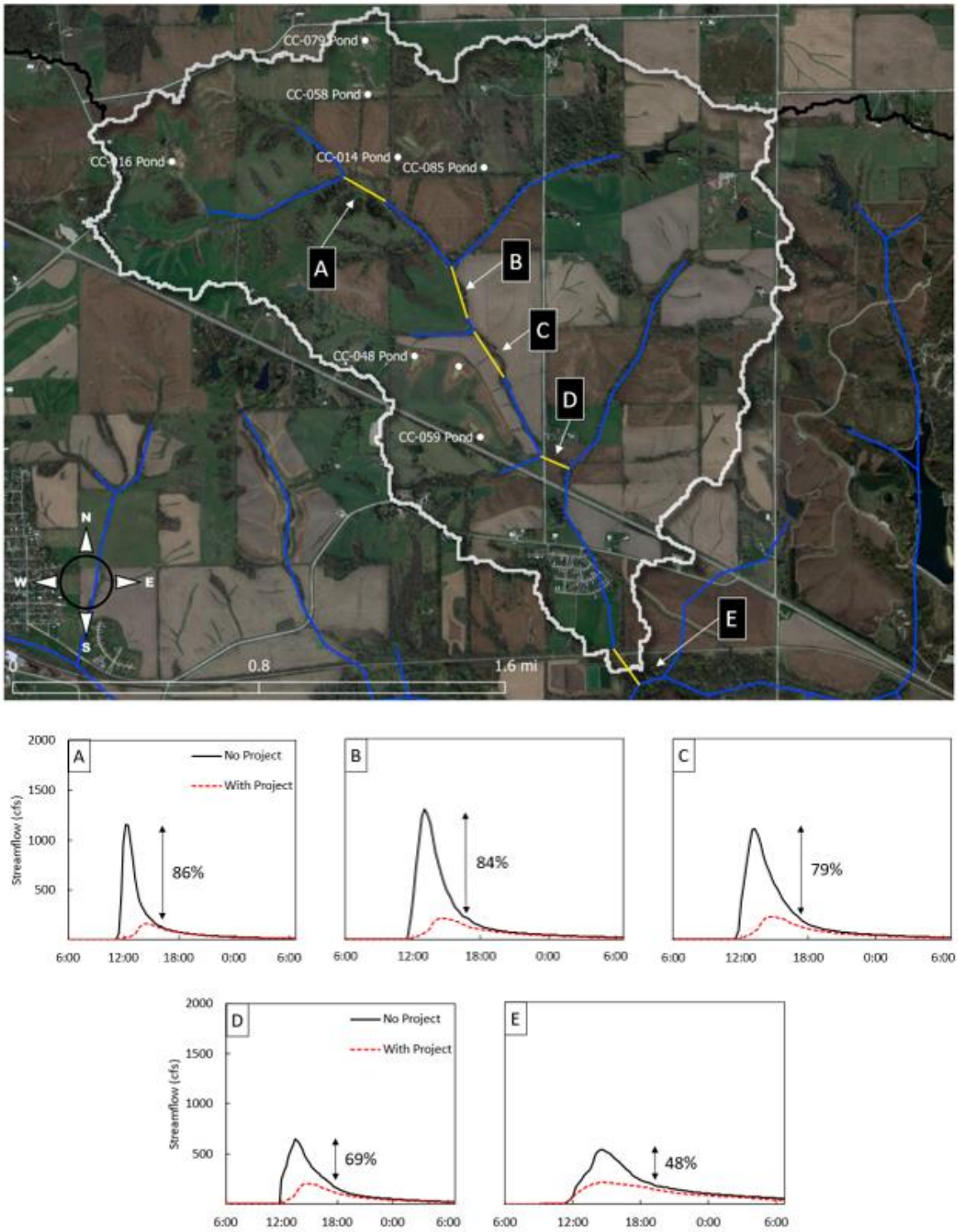

Figure 7-5. Analysis of the projects in the second unnamed main-stem tributary, along with hydrographs comparing the streamflow with (dotted red) and without (solid black) projects at various downstream index points.

Index point A lies downstream of the confluence of two branches impacted by four upstream projects; CC-016, CC-058, CC-079, and CC-014. Given this index point's proximity to half of the

projects housed in the tributary and its upstream location, it displays the most significant reduction in peak flow at 86%. Index point B lies downstream of the confluence between the branch housing index point A (impacted by four projects) and the branch impacted by CC-085. Despite the clear increase in peak flow and volume, peak flow reduction is only diminished by 4%. Downstream, index point C lies just below the confluence of the branch housing index point B (impacted by five projects) and the branch impacted by CC-047 and CC-048. The addition of more drainage area regulated by projects conserves a significant reduction of 79%. At index point D, the addition of the branch housing CC-059 helps to conserve a 69% reduction in peak flow. This reduction is diminished to 48% at index point E just before the tributary joins the Clear Creek main stem. The diminished reduction is expected, as the only stream unregulated by projects joins the tributary's main channel just downstream of index point D.

The smallest of the tributaries impacted by projects within the Middle Clear Creek HUC12 – Unnamed tributary #3 joins the main stem of Clear Creek downstream of unnamed tributary #2. The tributary houses one pond that regulates an 18-acre drainage area: CC-078. Shortly downstream of the project, the tributary flows directly into the main stem of Clear Creek. Figure 7-6 shows the location of this project and hydrographs illustrating the downstream impacts.

Index point A lies immediately downstream of the project. Similar to the performance of CC-015 and CC-063, the hydrograph exhibits a sharp peak and a significant reduction in peak flow (77%) at the index point located furthest upstream. Moving downstream, the addition of unregulated drainage area diminishes peak flow reduction at index point B by 16%. This is evident when inspecting the corresponding hydrograph which exhibits a shallower, wider shape and reduced peak flow.

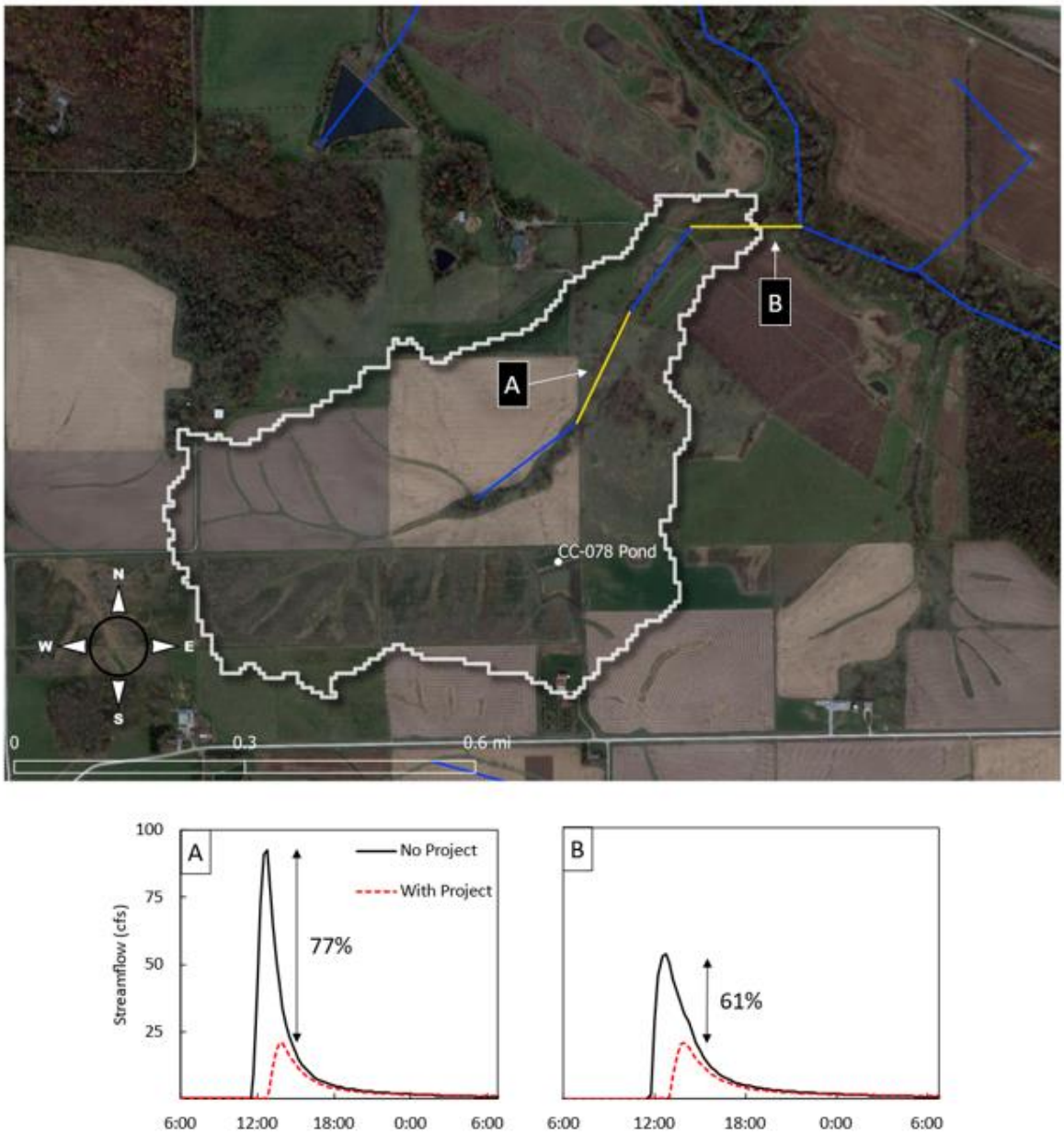

Figure 7-6. Analysis of the project in the third unnamed main-stem tributary, along with hydrographs comparing the streamflow with (dotted red) and without (solid black) projects at various downstream index points.

The largest of the tributaries impacted by projects within the Middle Clear Creek HUC12 – Buffalo Creek joins the main stem of Clear Creek downstream of unnamed tributary #3 near the HUC12's outlet. The tributary houses two ponds of similar size that regulate a 54-acre drainage area within the tributary: CC-010 and CC-111. Figure 7-7 shows the location of this project and hydrographs illustrating the downstream impacts.

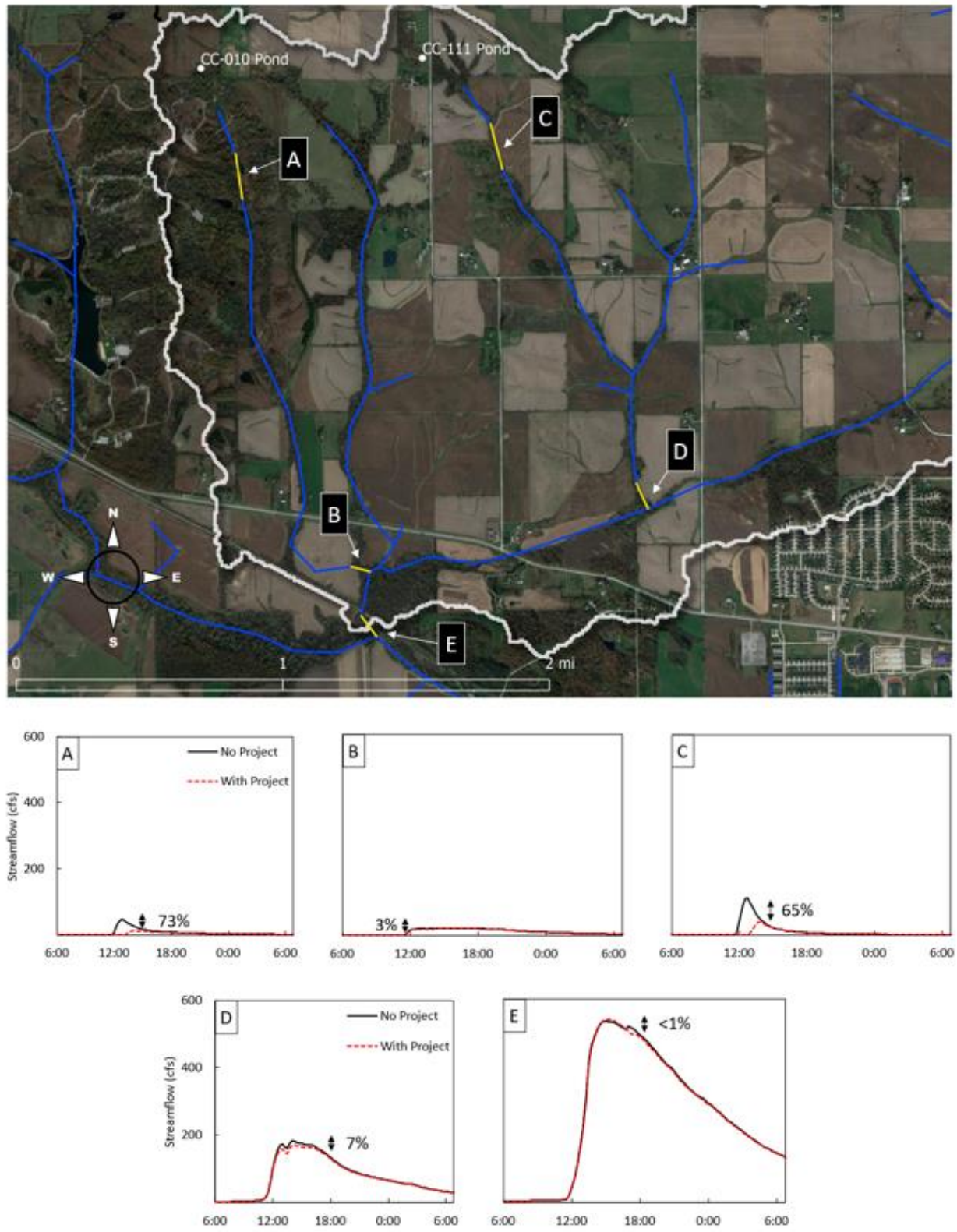

Figure 7-7. Analysis of the projects in the Buffalo Creek main-stem tributary, along with hydrographs comparing the streamflow with (dotted red) and without (solid black) projects at various downstream index points.

Index point A lies immediately downstream of CC-010. The corresponding hydrograph illustrates a significant reduction in peak flow (73%). The addition of unregulated drainage area between index point A and B diminishes peak flow reduction to only 3%. Index point C lies immediately downstream of CC-111. The corresponding hydrograph illustrates a slightly smaller reduction in peak flow (65%) when compared to the reduction observed at index point A. This difference is due to CC-111 having slightly larger storage and drainage area. Downstream at index point D, reduction is diminished to 7% as more unregulated drainage area and additional stream branches convey additional flow. Index point E, situated at the outlet of Buffalo Creek, exhibits <1% reduction. Recalling that Buffalo Creek has the largest drainage area of all impacted tributaries in the Middle Clear Creek HUC12, this behavior is expected as significant local impacts diminish at large scales.

b. Watershed-Scale Effects

The tributaries containing modeled projects produced considerable local flood reduction benefits. Figure 7-8 displays peak reductions at the outlet of each tributary in the Middle Clear Creek HUC12 for the design storm used to generate the examples in the previous section.

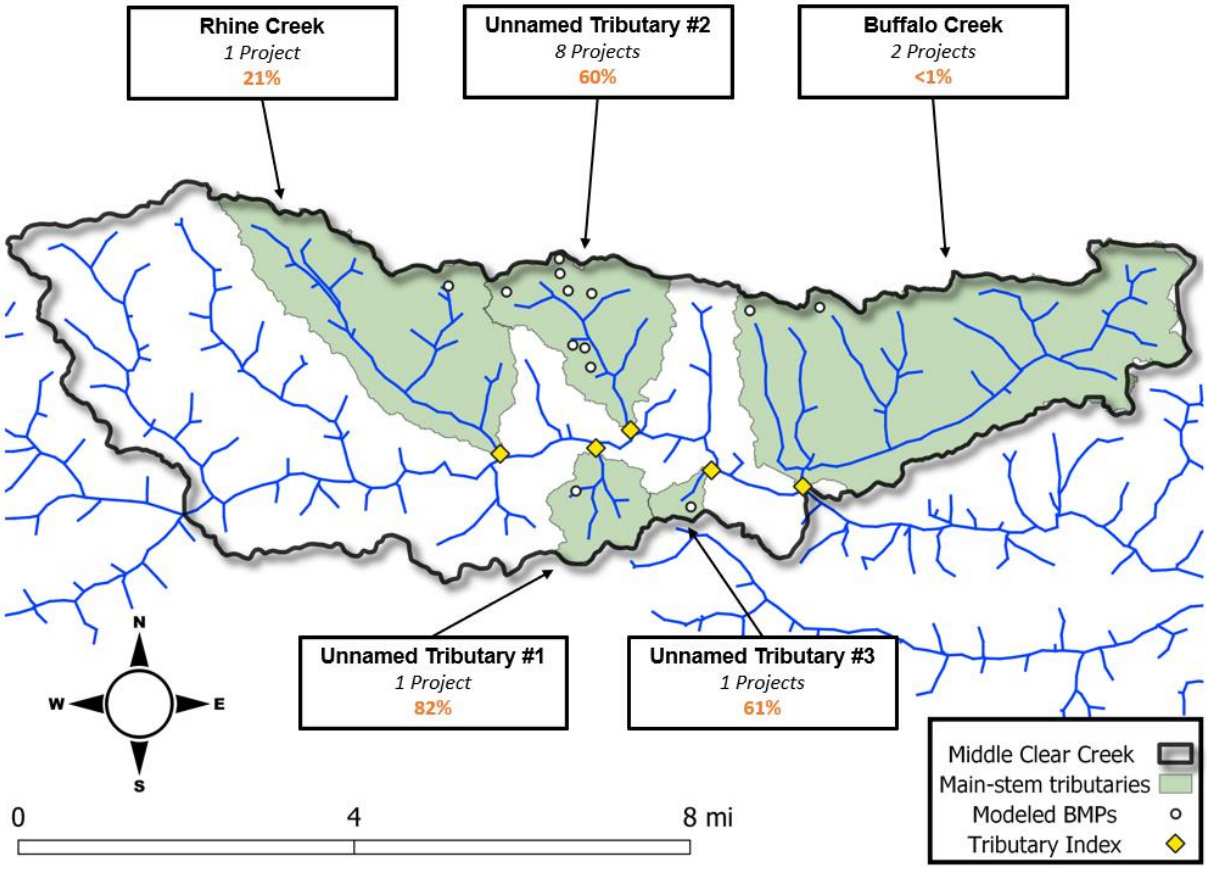

Figure 7-8. Flood peak reduction (orange text) at five index points in the Middle Clear Creek HUC12: Rhine Creek outlet; Unnamed Tributary #1 outlet; Unnamed Tributary #2 outlet; Unnamed Tributary #3 outlet; and Buffalo Creek outlet.

All 13 projects included in the model impact five tributaries contained within the Middle Clear Creek HUC12. Peak flow reduction at the outlets of affected tributaries ranges from nearly non-existent (<1% at Buffalo Creek) to relatively significant (82% at unnamed tributary #1).

Although most of the projects produced considerable local flood reduction benefits, these impacts are drastically reduced at larger spatial scales. Figure 7-9 shows peak reductions at several large-scale index points for the design storm used to generate the examples in the previous section.

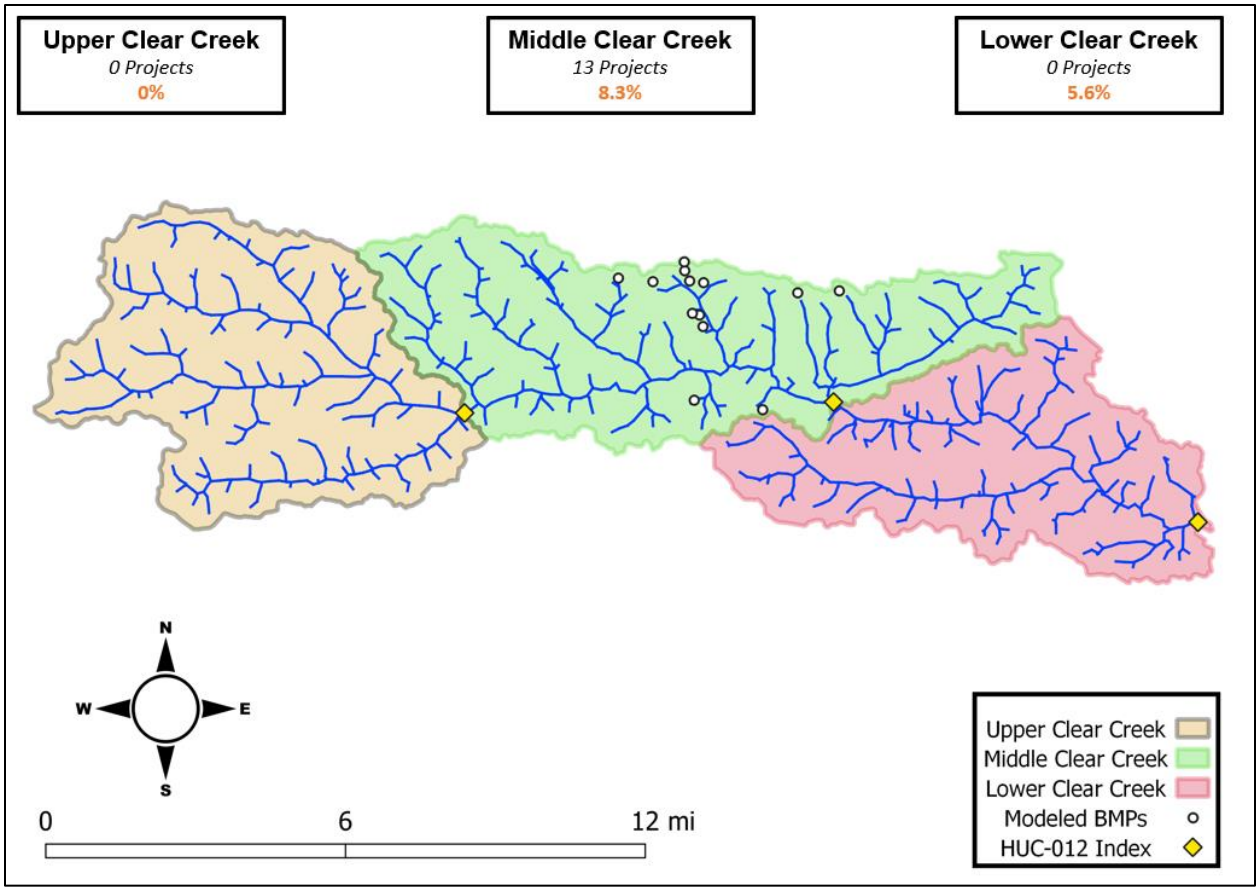

Figure 7-9. Flood peak reduction (orange text) at three watershed-scale index points: Clear Creek at: Upper Clear Creek HUC12 (yellow area) outlet; Middle Clear Creek HUC12 (green area) outlet; and Lower Clear Creek HUC12 (red area) outlet.

The IWA sub-watershed that housed all model projects is a "pass-through" watershed, where the main stem of Clear Creek enters and exits, as opposed to a "headwater" watershed like the Upper Clear Creek HUC12, where all the flow at the outlet originated from within the watershed boundary. Unfortunately, no projects were built in the Upper Clear Creek HUC12, which could have offered some reduction at the outlet of Clear Creek's only headwater sub-basin. Despite unchanged flow conditions in Upper Clear Creek, the 13 modeled projects produce an 8.3% reduction in peak flow downstream at the outlet of the Middle Clear Creek HUC12. Peak flow reduction along the Clear Creek mainstem within Middle Clear Creek ranges from <1% - 10%. Fluctuations in reduction at a given segment along the main stem are dependent on proximity to the tributaries housing modeled projects, project density within impacted tributaries, and upstream drainage area. In general, reductions are first observed at Rhine Creek and increase as the mainstem connects with the three unnamed tributaries. Reductions begin decreasing as Buffalo Creek intersects the main stem, becoming less significant as flows exit Middle Clear Creek into the Lower Clear Creek HUC12. At the outlet of the Clear Creek HUC10, reductions diminish ~3% when compared to the reduction at the outlet of Middle Clear Creek. As expected for a smaller watershed like the Clear Creek HUC10, reductions at the outlet of the HUC10 are not as negligible when

compared with other IWA watersheds. These results are somewhat inspiring given projects were only implemented in one of three HUC12s contained within the study area.

c. Limitations of the IWA Projects

While impactful at local scales, the limited flood reduction benefits of the 13 modeled IWA projects at the outlet of the three HUC12's that comprise the study area is not surprising when considering the area analysis presented in Figure 7-10.

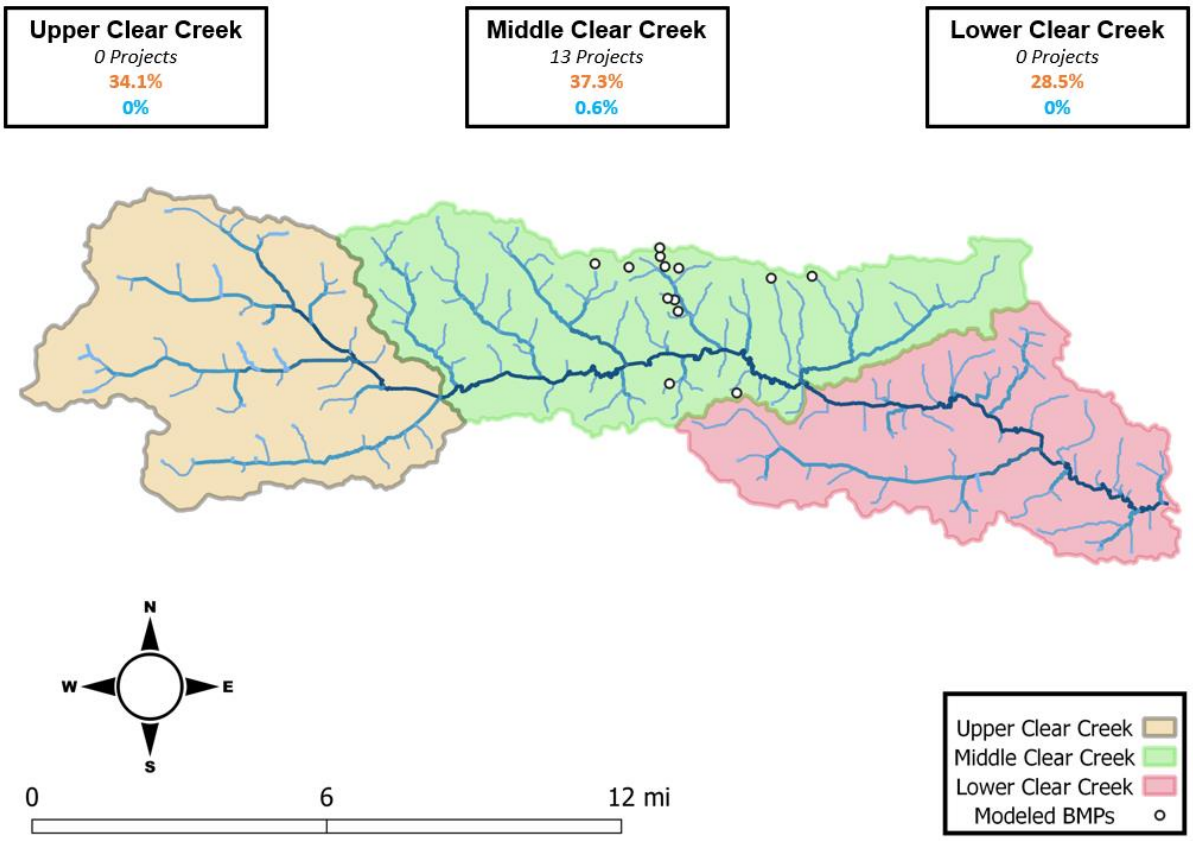

Figure 7-10. Area analysis of the Clear Creek Watershed (HUC10) and the three HUC12 watersheds it contains. Total number of modeled BMPs, area contribution to the HUC10 (orange text), and project drainage area contribution to the HUC10 (blue text) are visualized for each HUC12.

Streamflow is ultimately related to a river's upstream drainage area. The larger the proportion of total upstream drainage affected by flood mitigation projects, the more significant reduction in flow at the outlet. The total drainage area regulated by IWA projects is only 405 acres which amounts to only 0.6% of the entire Clear Creek watershed. Given uniform distribution of projects within the Middle Clear Creek HUC12 and their small contribution to the HUC10's total drainage area, their reduced impact at larger scales is expected. Overall, far too little drainage is regulated by projects. Table 7-1 provides more details on the drainage area and storage provided by the modeled IWA projects.

Table 7-1. Drainage area and storage capacity of IWA Projects relative to their HUC12 and the Clear Creek Watershed (HUC10).

Watershed	Watershed Area (ac)	Watershed Area % of HUC 10	Project Drainage Area (ac)	Project Drainage Area % of HUC12	Project Drainage Area % of HUC10	Total Storage (ac-ft)
Upper Clear Creek HUC12	22,570	34.13%	0	0%	0%	0
Middle Clear Creek HUC12	24,968	37.34%	405	1.64%	0.61%	223
Lower Clear Creek HUC12	18,868	28.53%	0	0%	0%	0
Total	*66,136*	*100%*	*405*	*1.64%*	*0.61%*	*223*

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 retain during a flood event, reducing both volume and magnitude of flood peaks experienced downstream. The total storage of modeled IWA projects is approximately 223 ac-ft, of which 108 ac-ft is flood storage, which are abstract figures to comprehend without context.

During the flood of April 2013, the record flood for both Oxford and Coralville during the study period spanning 2002-2020, nearly 25,000 ac-ft of water flowed through Coralville between April 14th and April 26th. During the smaller but still significant flood of July 2014, over 18,000 ac-ft of water was experienced at Coralville. If the IWA projects had been implemented for these floods in 2013 and 2014, their volume would only have been reduced by ~0.6% and 0.9%, respectively.

d. Future Implications

The impact of the 33 IWA projects is still significant, providing local flood reduction, water-quality, and wildlife habitat benefits. However, additional improvements on a watershed-scale would require significant additional investment and effort. Based on the storage capacity achieved with the $1.1M spent on the 33 IWA projects, reducing the 2013 flood by just 10% at Coralville would likely require at least 456 projects and nearly $15.4M.

To get an idea of the investment needed to produce watershed-scale flood-reduction benefits, Figure 7-11 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, as well as lives affected. The price tag to achieve this, however, ranges from approximately 4 to 28 times the initial IWA investment.

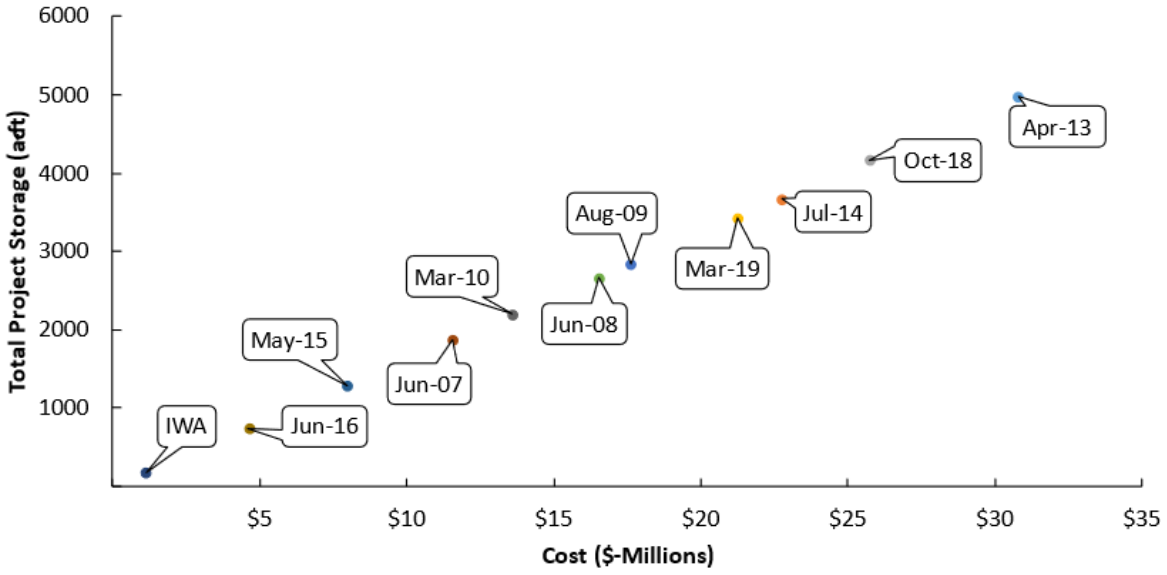

Figure 7-11. Approximate flood storage and cost required to achieve a 20% peak reduction in the top-10 flood events ("Month-Year") between 2002–2020, compared to the IWA.

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 $20–30M in Clear Creek 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 3 HUC12s in Clear Creek, we estimate that more than $9M would be required to make a dent in flooding; this agrees well with Figure 7-11.

8. Summary and Conclusions

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

a. Watershed Characteristics

The Clear Creek Watershed is a HUC10 located in eastern Iowa, lying on both the Iowan Surface and Southern Iowa Drift Plain. The entire HUC10 is 103 mi.^{2} and is comprised of three HUC12s: Upper Clear Creek (35 mi.^{2}), Middle Clear Creek (39 mi.^{2}), and Lower Clear Creek (29 mi.^{2}). Nearly 70% of the watershed's land area is used for agricultural purposes. Average annual precipitation totals ~36 inches, 30% of which is contributes to streamflow. USGS stream gauges operated near Oxford and Coralville were used for this analysis. Flooding is not an uncommon occurrence in Clear Creek, similar to the rest of Iowa. Record flooding occurred in 2013 in Coralville and 1990 in Oxford. For the top six floods on record in Coralville – 4 have occurred since 2007.

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 using data from the Camp Cardinal Boulevard water quality monitoring site in Coralville, which has been active since 2012 and receives flow from nearly 96-percent of the Clear Creek Watershed. At Camp Cardinal Boulevard, nitrate concentrations ranged from 0.01 mg/L to 15.4 mg/L, with an average of 4.4 mg/L. Yearly nitrate yields ranged from 4.0 lbs/ac to 16.8 lbs/ac, with an average of 9.6 lbs/ac. Annual water yields strongly correlated with annual nutrient yields. Trend detection tests indicated no trend in daily concentration but an increasing in nitrate loads.

c. Hydrologic Model

The modeling activities described in this report were performed using the process-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 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 Coralville and Oxford, 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

Eight different types of BMPs were constructed in the Clear Creek Watershed: 14 WASCOBs, 13 ponds, 12 grade stabilizations, 10 grassed waterways, 4 floodplain restorations, 2 wetland restorations, 1 wetland, and 1 perennial cover project. Aside from grass waterways, most projects provide at least some runoff attenuation. 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 57 projects and their details, and Figure 5-1 shows a map of the projects. Projects were constructed in all three IWA sub-watersheds in the Clear Creek Watershed. Of the ~$1.8M spent to create 57 BMPs, approximately ~$1.1M was used to erect 33 practices with some degree of storage. Just over 1/5th 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. 12 ponds and one pond & fringe wetland were included in the model, representing ~91% of storage implemented across all 57 BMPs. The 13 projects spanned five separate tributaries that discharge into the main stem of Clear Creek. Peak flow reductions between 60% and 90% were common immediately downstream of project sites. In general, this reduction gradually diminished at various index points downstream in tributaries housing IWA projects. Reduction at the outlets of the five tributaries ranged from <1% to 80%. This variation is the result of varied upstream drainage area, project density, and project geometry. Not all tributaries housing IWA projects produced similar effects. The pond CC-063 captured a large enough portion of flow in unnamed tributary #1 to maintain ~80% reduction in peak flow until reaching its confluence with the main channel of Clear Creek. Contrary to the previous example, the reductions from ponds CC-010 and CC-111 were nearly non-existent at the outlet of Buffalo Creek. Though some measure of significant peak flow reduction was generally maintained within project-impacted tributaries, these reductions were diminished substantially once their respective flows outfall to the main channel of Clear Creek. The change in reduction experienced in the main channel between segments upstream and downstream of the tributary outlets ranged from <1% to 3%.

Despite notable local reductions within the tributaries, cumulative impacts on the watershed-scale were less significant. In the Upper Clear Creek HUC12, no projects had significant enough storage to warrant inclusion in the model – resulting in a 0% reduction for the sub-watershed. All 13 modeled projects were contained within the Middle Clear Creek HUC12. Reduction along the main stem increased as the channel meanders through the HUC12, increasing incrementally at each confluence with tributaries containing regulated drainage area. Though peak main channel reduction in this HUC12 was ~10%; they diminish to 8.3% at the outlet. The Lower Clear Creek HUC12 experienced a 5.6% reduction in peak flow at the outlet near Coralville.

The 57 IWA projects regulate drainage from over 400 acres and can store more than 200 ac-ft of water. Unfortunately, these capacities are dwarfed by the size of the entire Clear Creek Watershed. Only 0.6% of the entire drainage area is regulated by these projects. If the projects had been in place during the flood of 2013, they would have been able to store just 0.6% of the floodwaters experienced at Coralville. An incredible investment in upstream flood mitigation infrastructure would be required to begin to address flooding on a watershed scale. To reduce this flood by 10% at Coralville, it would likely require at least 456 projects and nearly $15.4M. Based on the total storage achieved by the $1.8 million spent in Clear Creek during Phase II of IWA, tens of millions of dollars would be required to reduce the top-10 floods by 20% between 2002 and 2020 (see Figure 22). 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 Clear Creek 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, 57 best management practices were constructed within the three Clear Creek 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 57 constructed projects do not have significant flood mitigation benefits at sub-watershed and Clear Creek Watershed scales. Realization of significant watershed-scale benefits will require substantial additional investments in best management practices throughout Clear Creek. The Iowa Watershed Approach, through establishment of Watershed Management Authorities, watershed hydrologic assessments, and construction and evaluation of best management practices, has created a framework from which management efforts can continue and watershed-scale benefits can ultimately be achieved.

Appendix A – References

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