Upper Wapsipinicon Watershed

Hydrologic Assessment Report

IIHR Report
No. 527
October, 2019

Prepared by:
Iowa Flood Center / IIHR — Hydroscience & Engineering

Sponsored by:
Upper Wapsipinicon Watershed Management Authority

Iowa Watershed Approach
Phase I Report

IIHR — Hydroscience & Engineering
The University of Iowa
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Iowa City, Iowa 52242

Hydrologic Assessment of the Upper Wapsipinicon Watershed

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Natural Resources Conservation Service
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Northeast Iowa Resource Conservation and Development
Howard County

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Introduction

From 2011–13, 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 small portion of Iowa's long history of enduring and recovering from major floods. Figure 1 shows just one example of devastation caused by floods in Independence in the fall of 2016. Long-term data shows 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.

In January 2016, the state of Iowa received a $97 million award for the Iowa Watershed Approach (IWA). The grant was part of the U.S. Department of Housing and Urban Development's (HUD) National Disaster Resilience Competition, which funds cutting-edge projects to address unmet needs from past natural disasters and reduce Americans' vulnerability to future disasters. The project will end in September 2021.

Figure 1. Aerial view of flooding in Independence, September 2016

The Iowa Watershed Approach (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 will accomplish 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; and
6) Develop a program that is scalable and replicable throughout the Midwest and United States.

The IWA brings Iowans together to address factors that contribute to floods. Nine distinct watersheds are involved in the project, 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 will focus on infrastructure improvements to mitigate flood risk.

Figure 2. Tour of a flood mitigation project in the Soap Creek Watershed, which was one of the basins that participated in the Iowa Watersheds Project (2010–16).

Each watershed has 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. IIHR—Hydroscience & Engineering (IIHR) and the Iowa Flood Center (IFC) are developing a hydrologic assessment of each watershed that will provide WMAs, local leaders, landowners, and residents with an understanding of the hydrology – the movement of water – within their watershed. This assessment will deliver valuable information to stakeholders to help guide strategic decision-making to efficiently address flooding and water-quality concerns.

IIHR and IFC have developed this report for the Upper Wapsipinicon Watershed. Information in this report will be integrated into a comprehensive watershed resiliency plan. The watershed resiliency plan will guide long-term watershed management initiatives and planning efforts, as well as identify goals and objectives to meet the current and future needs of local stakeholders and community members.

WMAs in the IWA watersheds have identified eligible sub-watersheds (e.g., HUC 12s) for practice implementation efforts. This report will help guide the implementation of small-scale flood mitigation projects. Through the IWA, volunteer landowners will be eligible to receive 90% cost-share assistance to implement best management practices (BMPs) such as ponds, wetlands, and water and sediment control basins (WASCOBS) to reduce the magnitude of downstream flooding and improve water quality during and after flood events. The implementation of BMPs is an essential step toward the long-term recovery to improve Iowa's future flood resiliency.

Figure 3. Flood mitigation structure in the Soap Creek Watershed.

The success of the 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. Partnerships 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 & 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
- Local Resource Conservation and Development Offices
- Benton, Buena Vista, Fremont, Iowa, Johnson, Mills, Winneshiek, and Howard counties

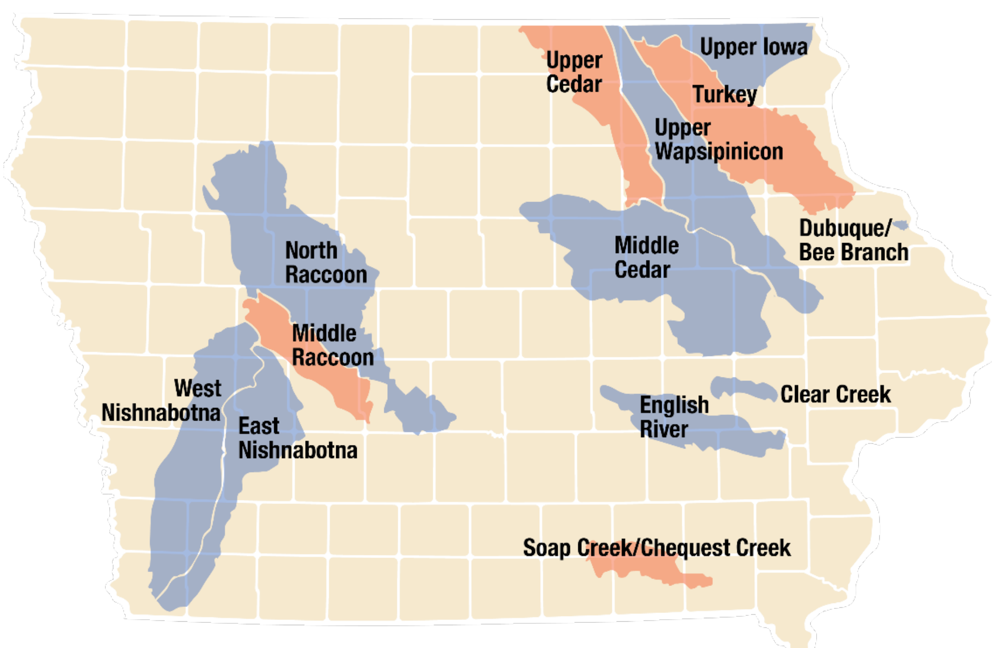


Figure 4. Current IWA watersheds in blue and completed IWP watershed in red.

The IWA is an expansion of the Iowa Watersheds Project (IWP) (Weber et al. 2018), a similar effort in the five Iowa watersheds (Upper Cedar River, Turkey River, Soap Creek, Middle Raccoon, and Chequest Creek) shown in Figure 4. HUD funded the IWP in the aftermath of the devastating 2008 floods; and the project was active from 2010–16. The success of the IWP (see Figures 2 and 3) served as a significant source of leverage for the state of Iowa to receive funding for the IWA, providing a framework to build upon, continuing Iowa's leadership and commitment to working together and improving flood resiliency. For more information on the Iowa Watersheds Project, visit http://iowafloodcenter.org/projects/watershed-projects/. For more information about the Iowa Watershed Approach, visit www.iowawatershedapproach.org.

1. 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 IWA watersheds shown in Figure 1.1.

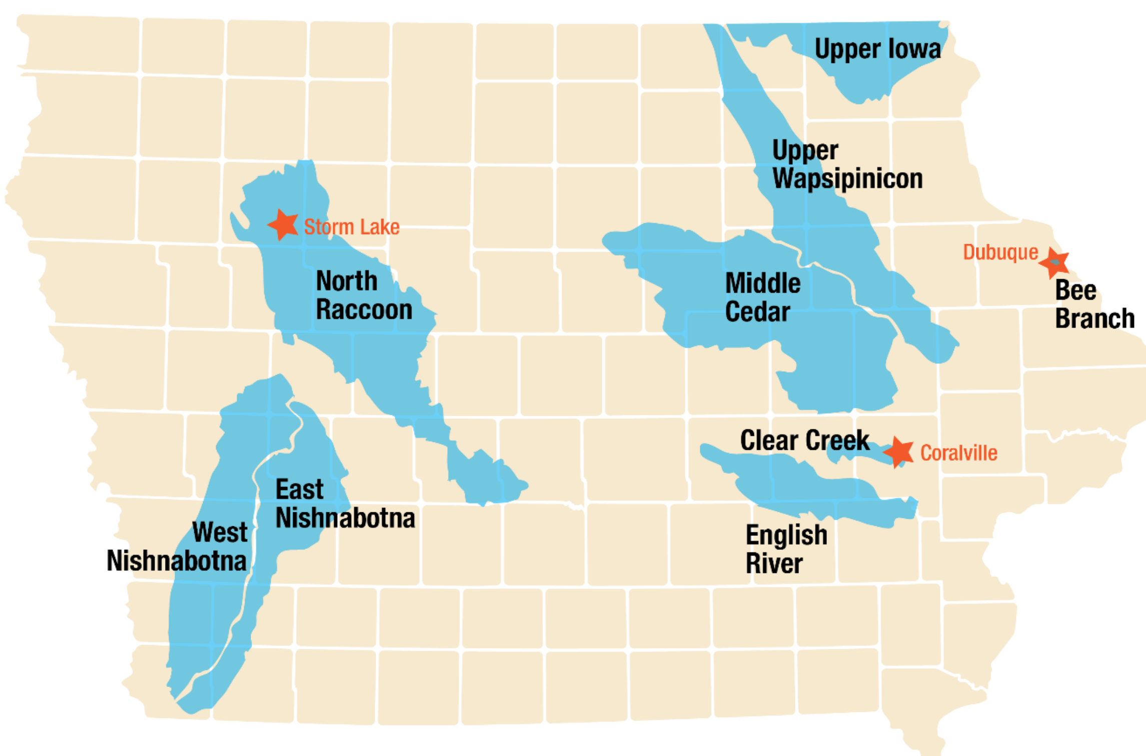


Figure 1.1. Iowa Watershed Approach study areas.

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 1.2 (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 is 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.

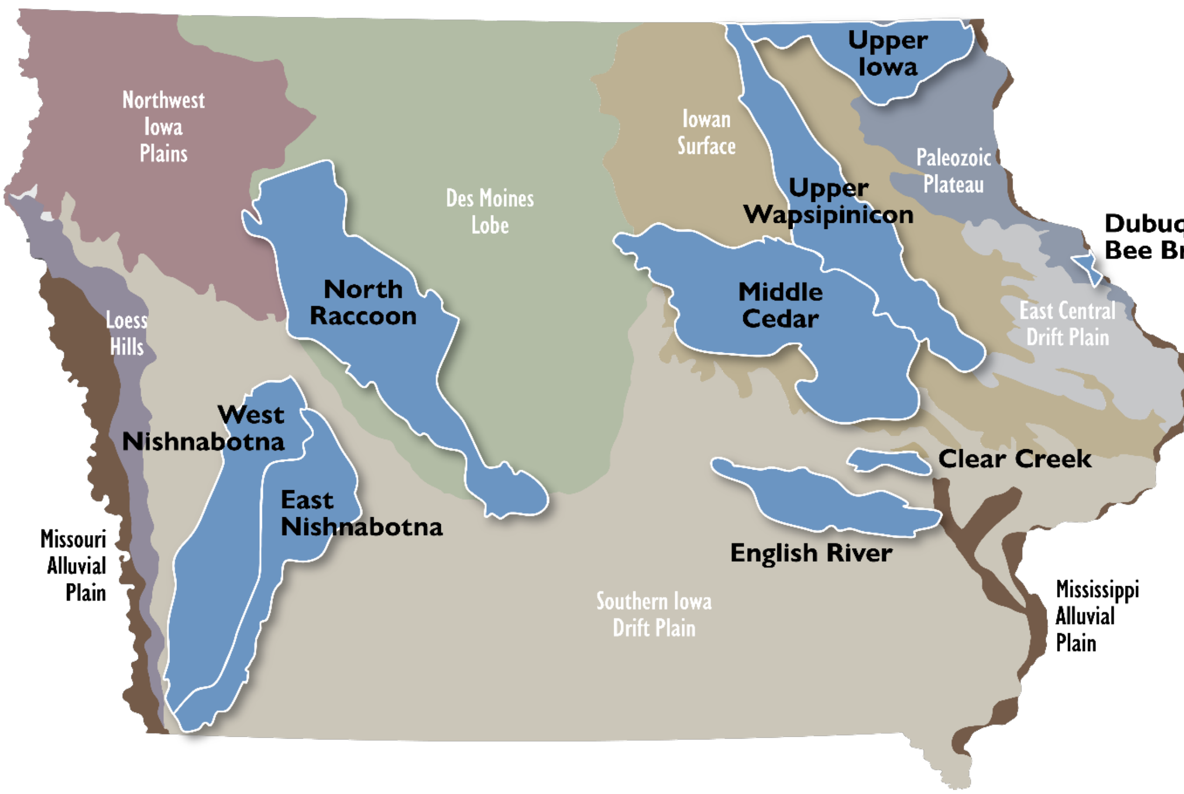


Figure 1.2. Landform regions of Iowa.

Prairies covered Iowa before the arrival of European settlers, as depicted in historical vegetation shown in Figure 1.3. 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).

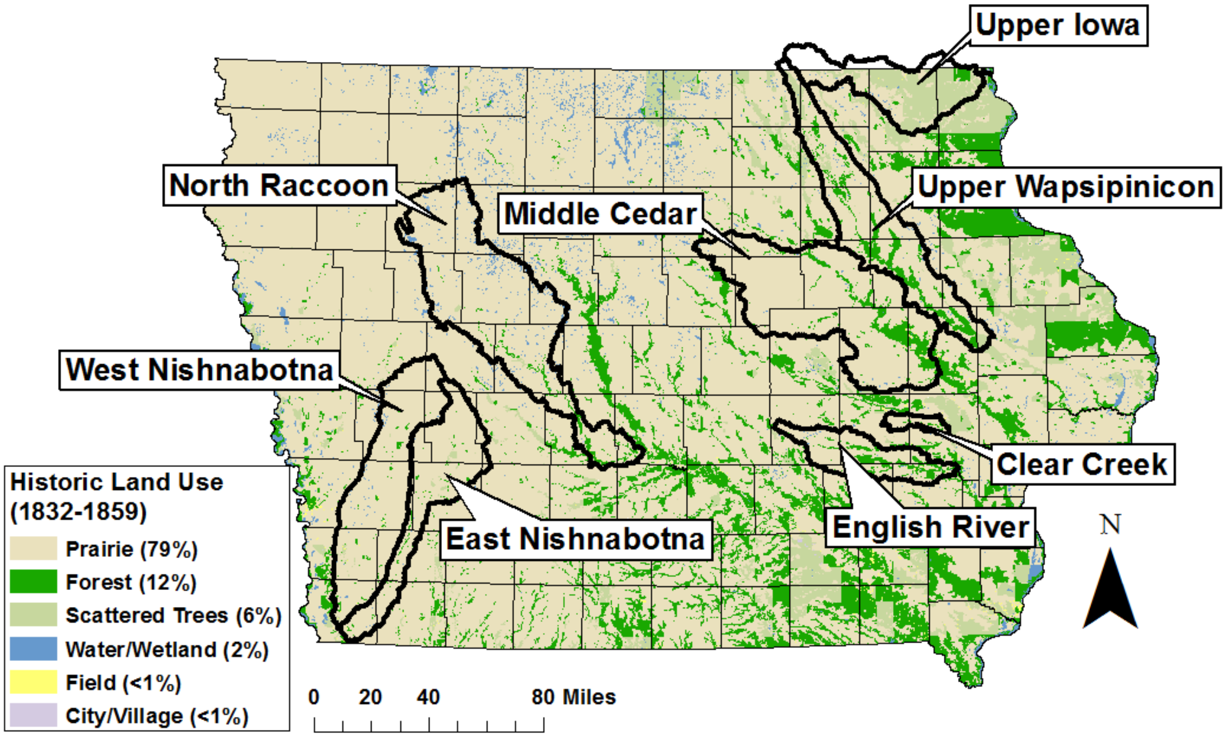


Figure 1.3. Historic vegetation of Iowa 1832–59. Raw data downloaded from the Iowa Geographic Map Server (https://ortho.gis.iastate.edu/).

Today, corn and soybeans cover 64% of Iowa (see Figure 1.4), 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 1.5.

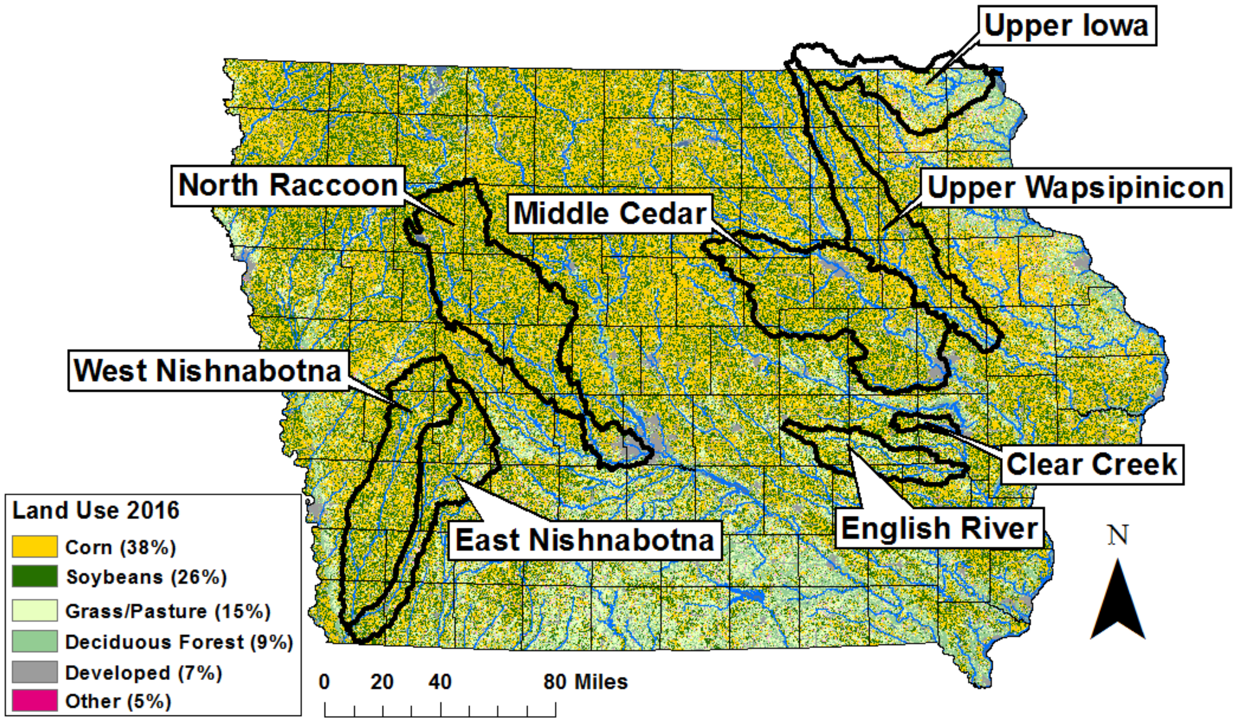


Figure 1.4. Land use composition in the state of Iowa 2016. Cropland Data Layer.

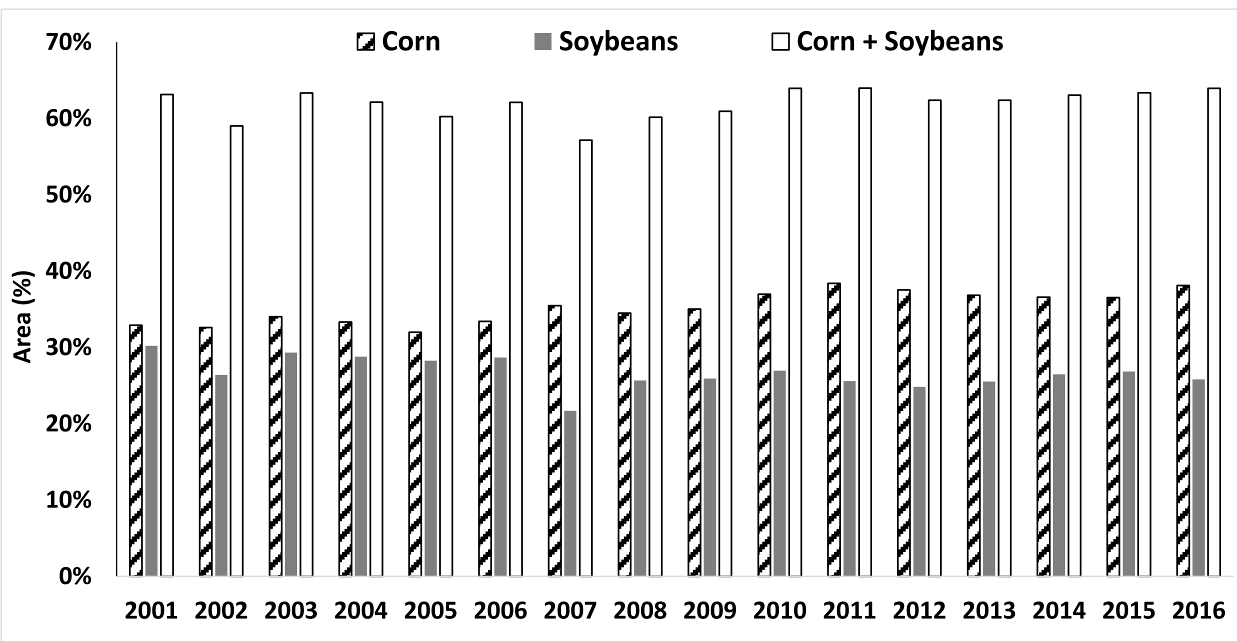


Figure 1.5. Percent of Iowa's total area planted with row crops between 2001 and 2016. Cropland Data Layer.

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 1.6. 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 1.6, have the power to tax and bond and are governed by trustees.

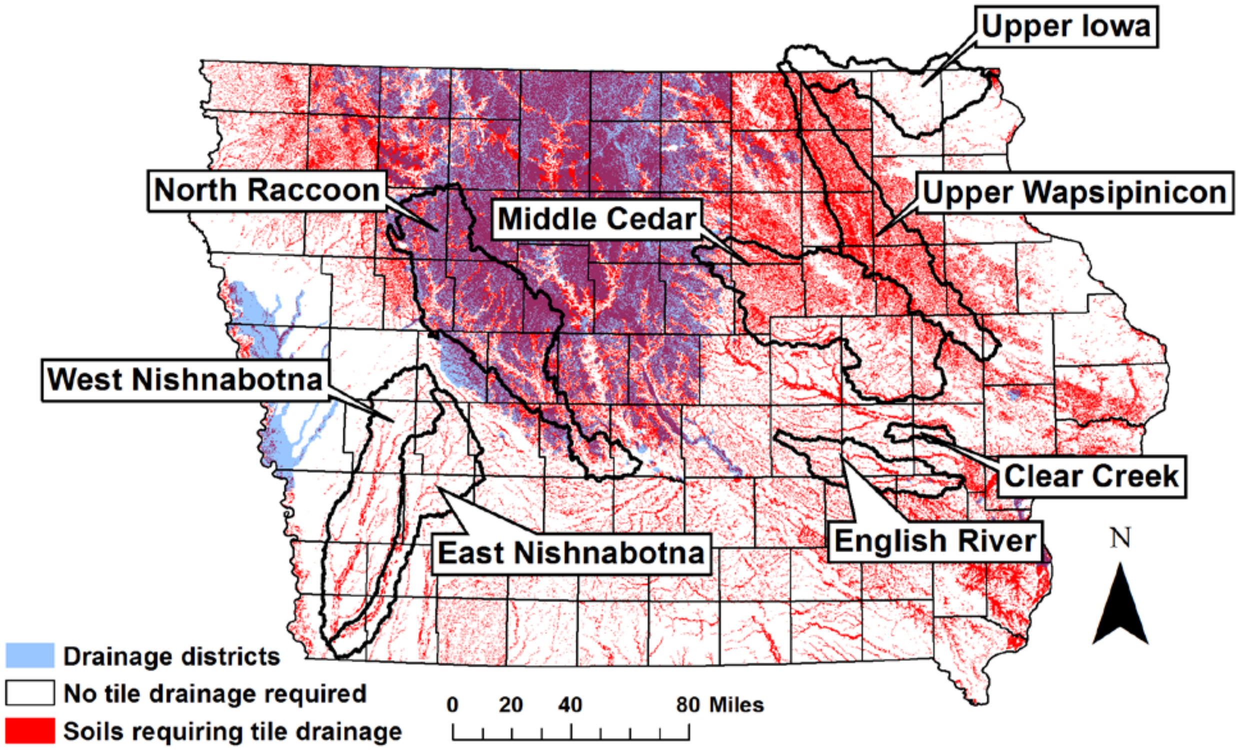


Figure 1.6. Soils requiring tile drainage for full productivity and drainage districts. Raw data source: DNR's NRGIS Library.

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

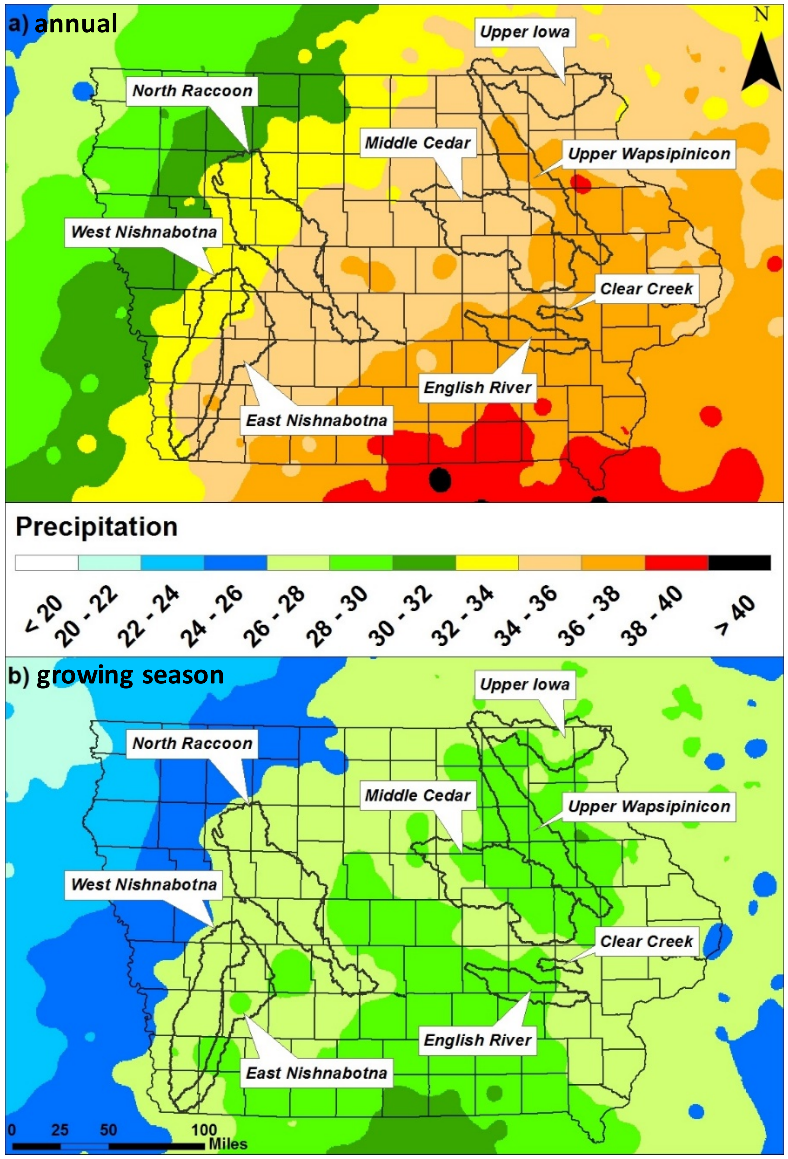


Figure 1.7. Average precipitation (inches): (a) annual; and (b) growing season (April–October). Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

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 1.7b has been ideal for agricultural needs, such that Iowa has not required irrigation systems like other parts of the country. The state 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.

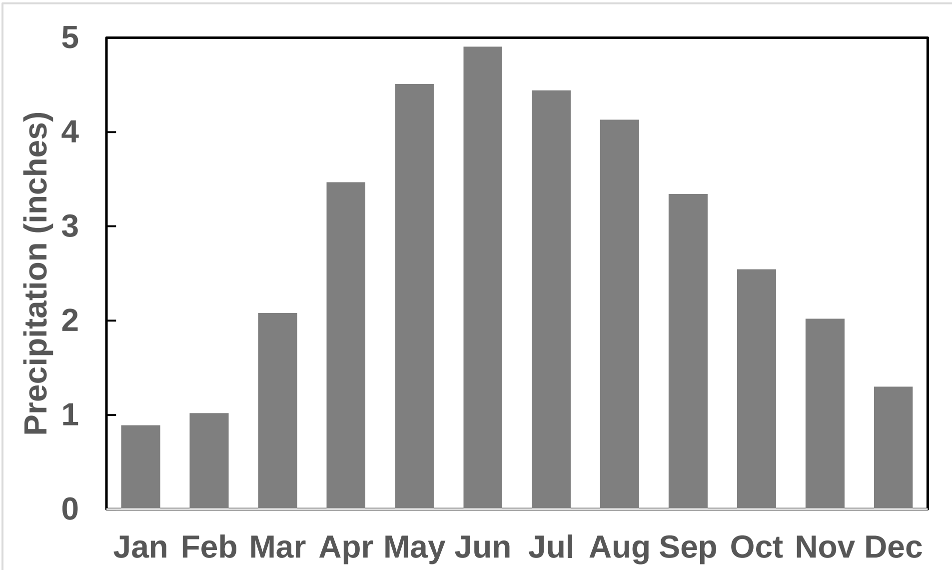


Figure 1.8. Statewide average monthly precipitation. Precipitation estimates are based on the 30-year annual average (1981–2010). (Raw data downloaded from: http://www.prism.oregonstate.edu/).

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 1.9.

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, percolates down to the groundwater, and then 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, sub-surface drainage flows are typically lumped with groundwater flows.

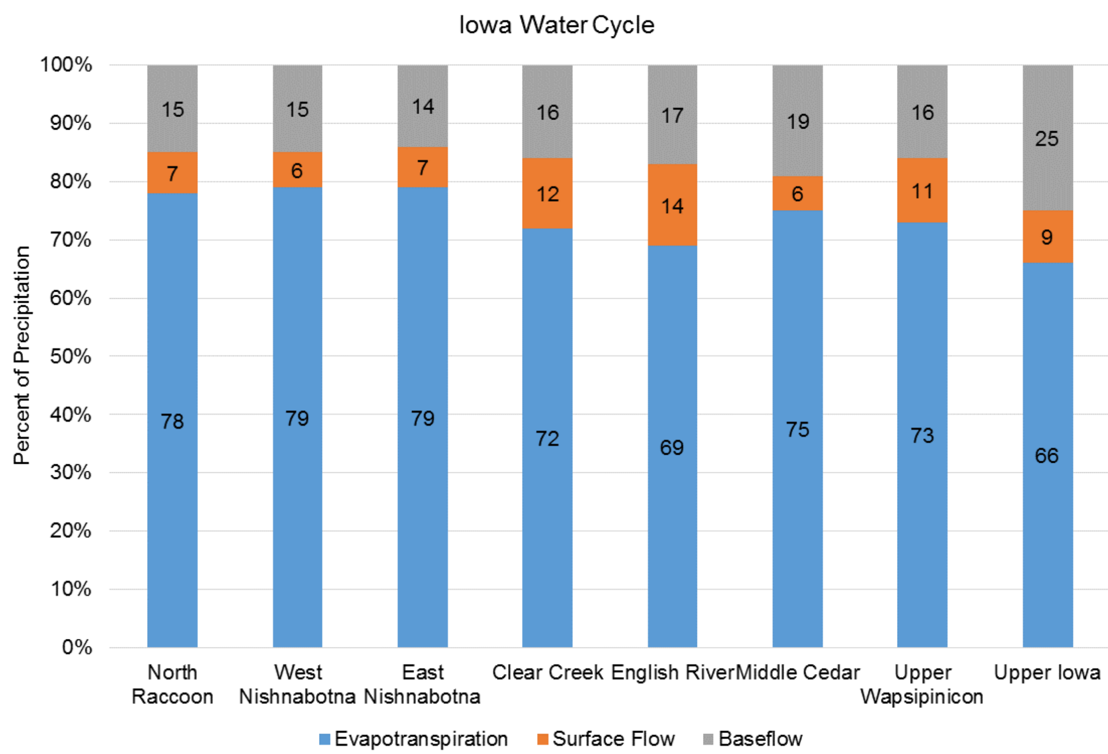


Figure 1.9. Iowa water cycle for the IWA watersheds. This shows the partitioning of average precipitation into evapotranspiration, surface flow, and baseflow components.

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 in 1993 and 2008 (Linhart and Eash, 2010; Mutel, 2010; Bradley, 2010; Smith et al., 2013). Across the state, almost 400 sensors continuously monitor the condition (e.g., streamflow and stage) of the Iowa rivers. In contrast, long-term continuous data on groundwater levels or soil moisture are sparse. Figure 1.10 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.

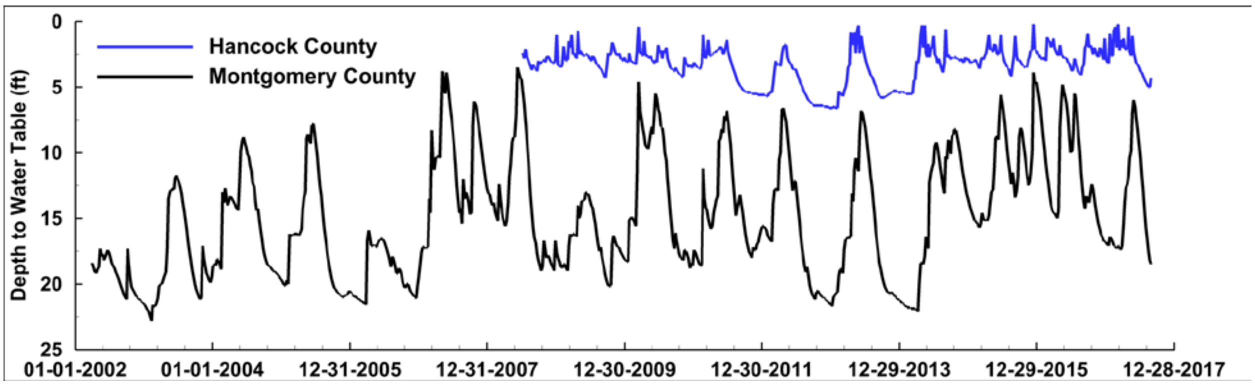


Figure 1.10. Shallow groundwater data (USGS wells).

iv. Floods

Rivers and streams have a finite capacity to convey water within their banks. When the amount of water surpasses that capacity, flooding occurs. Floods are typically related to large amounts of precipitation or snow melt and saturated or frozen soil. In Iowa, historic records show that the great majority (>90%) of floods occur in the spring and summer; the month of June shows the highest number of flood events. Precipitation records show that heavy rains occurred in the fall as well; however, Iowa soils have a larger capacity to infiltrate water late in the year, and therefore fall floods are less common. In Iowa's flood history, the events of 1993 and 2008 are on an entirely different scale than the others. These two events stand out from the rest when looking at the extent of the area impacted, recovery costs, precipitation amounts, and stream flows recorded (Bradley 2010; Smith et al., 2013). Figure 1.11 shows the extent of the flooding during the flood events of 1993 and 2008. In both years, flooding impacted the eight IWA watersheds.

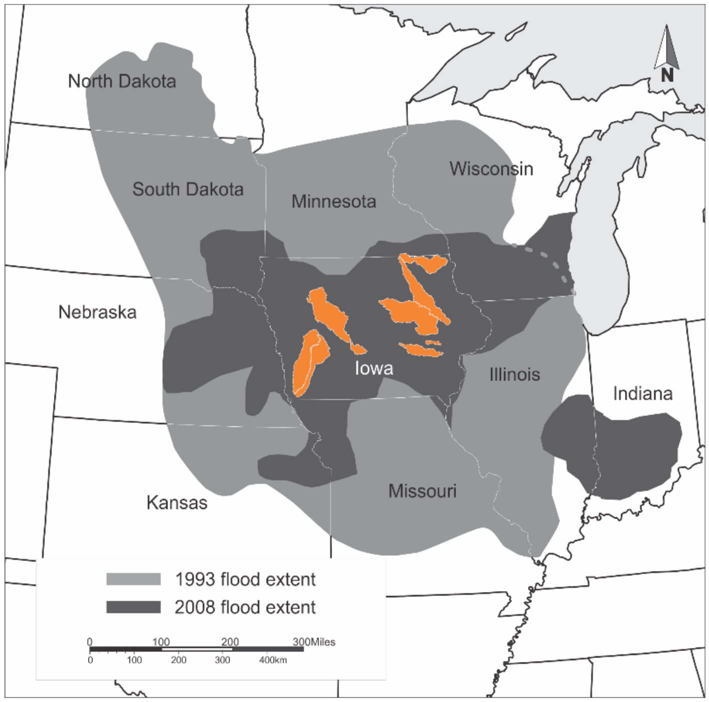


Figure 1.11. The extent of the flooding during the 1993 and 2008 floods (Bradley, 2010).

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 1.12) and one for the Sac and Fox Tribe of the Mississippi in Iowa. All the FRDD in Iowa have been major disaster declarations except the 99 related to Hurricane Katrina evacuation (see Table 1.1), which were classified as emergency disaster declarations.

Table 1.1. FEMA disaster declarations in Iowa Counties (1988–2016). Data source: https://www.fema.gov/.

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

- In the last 30 years, every county in Iowa has experienced sufficiently large and severe flood events to warrant a presidential disaster declaration. The number of FRDDs for each Iowa county from 1988–2016 is shown in Figure 1.12.

- 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 1.13. 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).

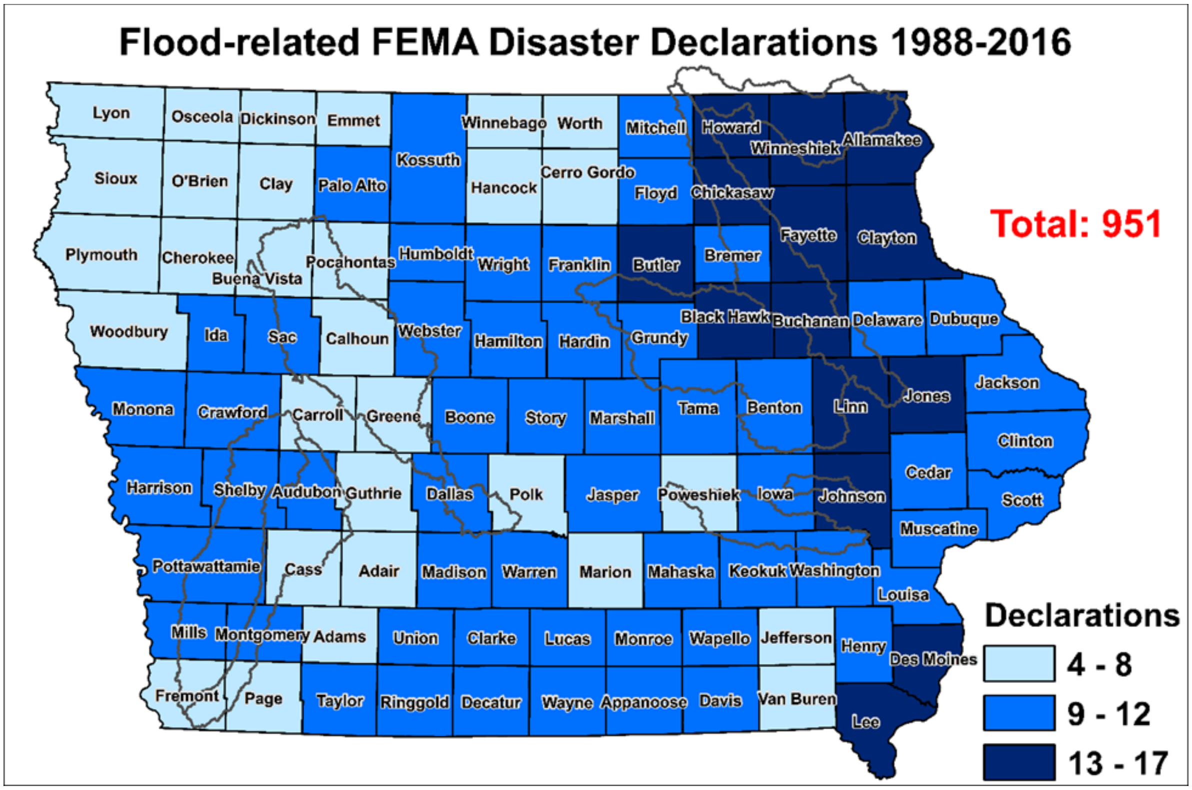


Figure 1.12. Number of flood-related federally declared disasters in Iowa counties (1988–2016). Data source: https://www.fema.gov/.

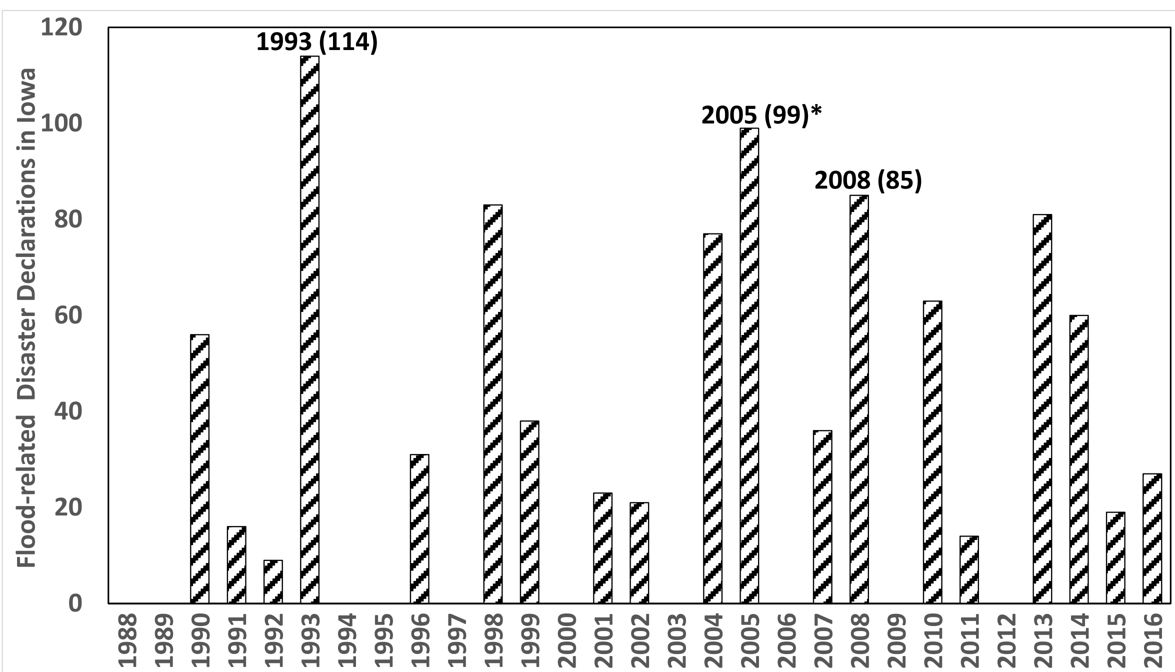


Figure 1.13. The number of flood-related federally declared disasters in Iowa (1988–2016). Data source: https://www.fema.gov/.

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 streamflows 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 1.14, shows the extent of 2012 drought in Iowa using data generated by the USDM.

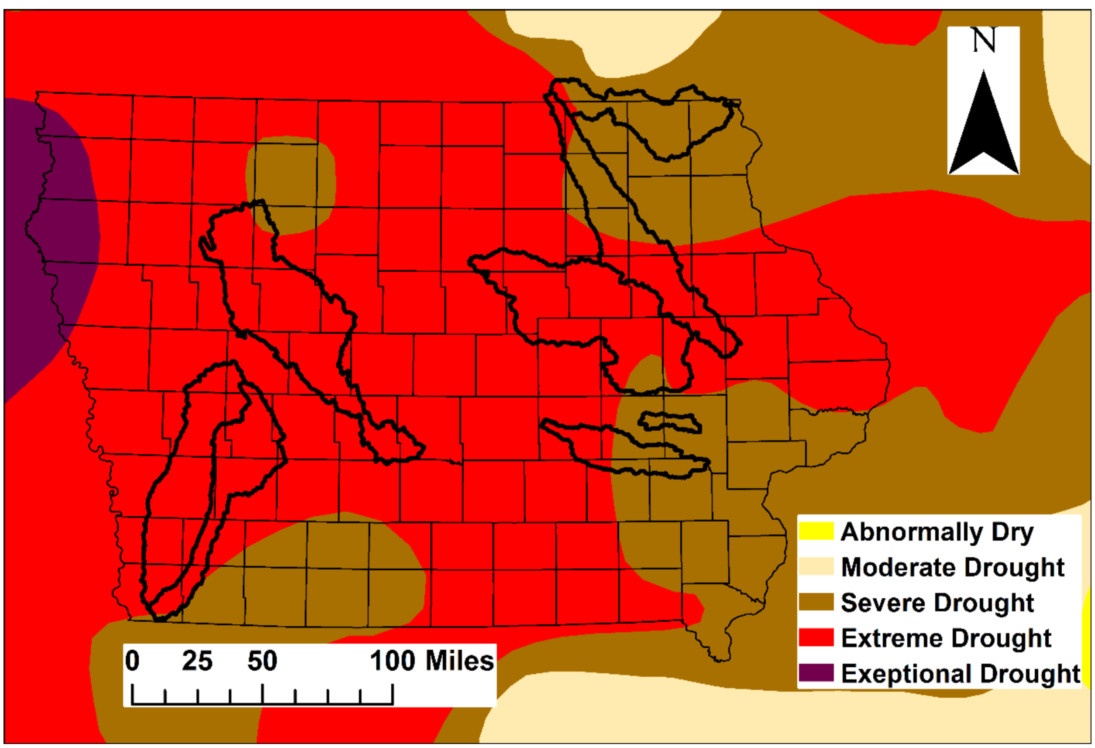


Figure 1.14. Drought conditions, October 09, 2012. (Source: http://droughtmonitor.unl.edu/).

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 1.3 and 1.4). Within Iowa, the land cover changes in the first decades of settlement occurred at an astonishing rate (Wehmeyer et al., 2011). Using land cover information obtained from well-documented studies in 1859, 1875, and 2001, Wehmeyer et al. (2011) estimated that the increase in runoff potential in the first 30 years of settlement represents the majority of predicted change in the 1832 to 2001 study period.

Still, other transformations associated with an agricultural landscape have also impacted runoff potential (see Table 1.2). For example, the introduction of conservation practices in the second half of the 20th century tend to reduce runoff, as suggested by a recent study of an Iowa watershed (Papanicolaou et al., 2015). The Conservation Reserve Program (CRP) originally began in 1950s. The federal government established many programs in the 1970s to remove lands from agricultural production and establish native or alternative permanent vegetative cover; in an effort to reduce erosion and gully formation, government agencies also encouraged practices such as terraces, conservation tillage, and contour cropping. The Farm Bill of 1985 was the first act that officially established the CRP as we know it today; the Farm Bills of 1990, 1996, 2002, and 2008 expanded these activities. The 2014 Farm Bill gradually reduced the CRP cap from 32 million acres to 24 million acres, although the 2018 Farm Bill is expected to increase the CRP cap to 29 million acres. Table 1.2 summarizes the timeline of agriculture-driven land use changes and their impacts on local hydrology.

Table 1.2. Agricultural-Related Alterations and Hydrologic Impacts.

Timeline	*Land use status, change, & interventions*	*Hydrologic effect(s)*	*Source*
1830s–Prior	Native vegetation (tall-grass prairies and broad-leaved flowering plants) dominate the landscape	Baseflow dominated flows; slow response to precipitation events	Petersen (2010)
1830–1980	Continuous increase in agricultural production by replacement of perennial native vegetation with row crops 1940: <40% row crop (Raccoon) 1980: 75% row crop (statewide)	Elimination of water storage on the land; acceleration of the upland flow; expanded number of streams; increased stream velocity	Jones & Schilling (2011); Knox (2001)
1820–1930	Wetland drainage, stream channelization (straightening, deepening, relocation) leading to acceleration of the rate of change in channel positioning	Reduction of upland and in-stream water storage, acceleration of stream velocity	Winsor (1975); Thompson (2003); Urban & Rhoads (2003)
1890–1960 2000–present	Reduction of natural ponds, potholes, wetlands; development of large-scale artificial drainage system (tile drains)	Decrease of water storage capacity, groundwater level fluctuations, river widening	Burkart (2010); Schottler et al. (2013)
1940–1980	Construction of impoundments and levees in Upper Mississippi Valley	Increased storage upland	Sayre (2010);
1950–present	Modernization/intensification of the cropping systems	Increased streamflow, wider streams	Zhang & Schilling (2006); Schottler et al. (2013)
1970– present	Conservation practices implementation: Conservation Reserve Program (CRP); Conservation Reserve Enhancement Program (CREP); Wetland Reserve Program (WRP)	Reduction of runoff and flooding; increase of upland water storage	Castle (2010); Schilling (2000); Schilling et al. (2008);
2001–present	62% of Iowa's land surface is intensively managed to grow crops (dominated by corn and soybeans up to 63% of total)	About 25% to 50% of precipitation converted to runoff (when tiling is present)	Burkart (2010)

ii. Hydrological Alterations Induced by Climate Change

The U.S. 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 1.15) and globally and is expected to continue to increase over the next few decades (2021–2050, see Figure 1.16), 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."

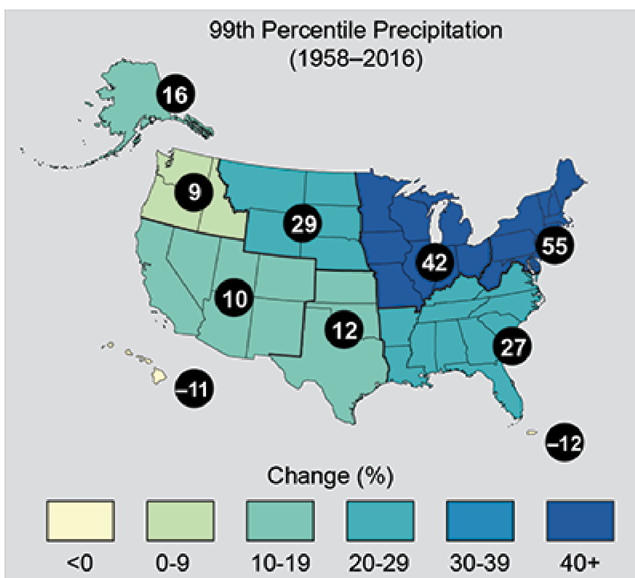


Figure 1.15. Observed change in heavy precipitation (the heaviest 1%) between 1958 and 2016. Figure taken from The Climate Science Special Report (Easterling et al. 2017) (https://science2017.globalchange.gov/).

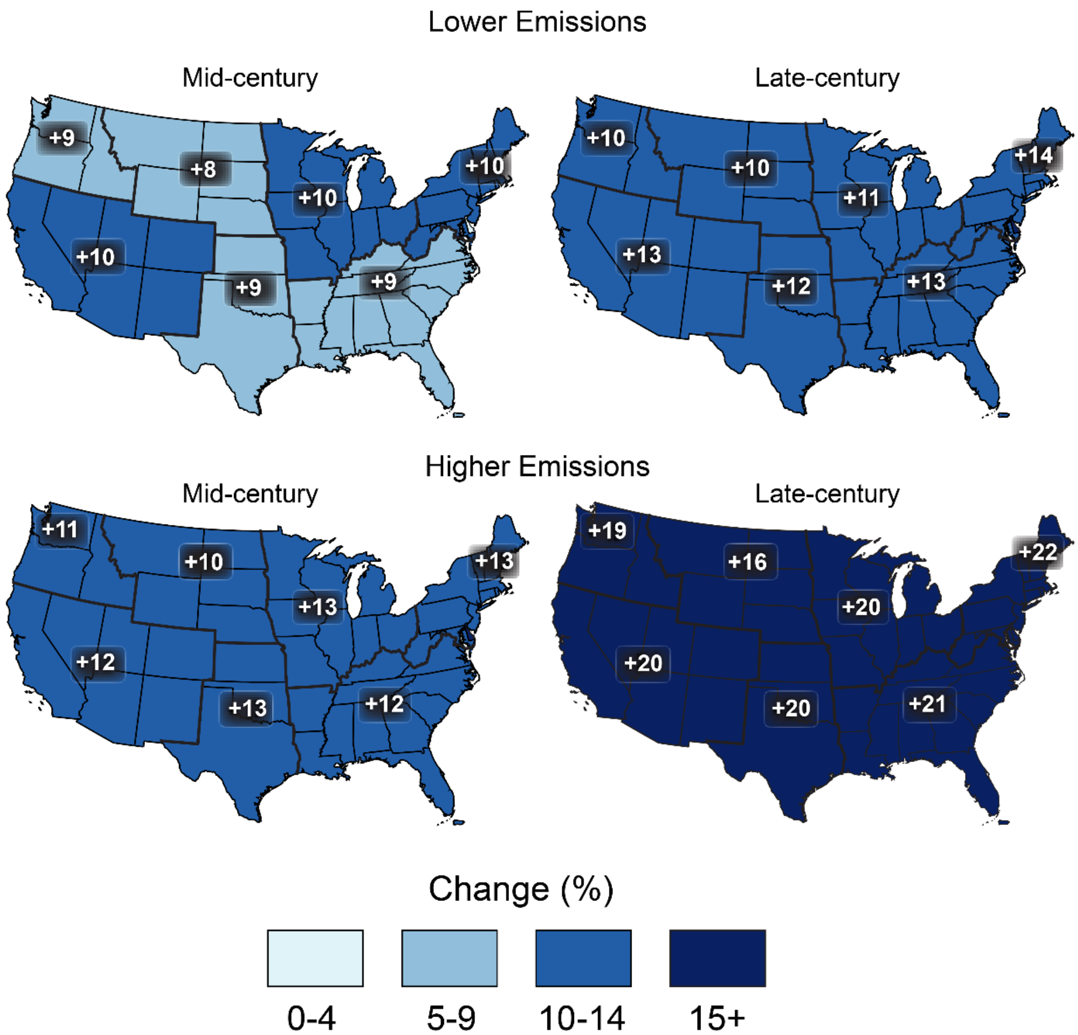


Figure 1.16. Projected change in heavy precipitation. Twenty-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps). Results are shown for a lower emissions scenario (top maps; RCP4.5) and for a higher emissions scenario (bottom maps, RCP8.5). Figure taken from The Climate Science Special Report (Easterling et al. 2017) (https://science2017.globalchange.gov/). RCP stands for Representative Concentration Pathway.

iii. Hydrological Alterations Induced by Urban Development

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

d. Assessment of Iowa's Water Quality

i. Iowa Water-Quality History

Prior to European settlement in the 19th century, Iowa was covered with prairies, oak savannahs, wetlands, and forests (see Figure 1.3). 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 flood plain after heavy rains, and river banks re-vegetated 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 1.2. 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 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 nonpoint source pollution.

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

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

Iowa policy-makers and watershed stakeholders look to the Impaired Waters list, Section 303(d), as a common reference point to gauge statewide water quality. According to Section 303(d) of the CWA, from "time to time" states must submit a list of waters for which effluent limits will not be sufficient to meet all state water-quality standards. The EPA has defined "time to time" to mean April 1 of even numbered years. The failure to meet water-quality standards might be due to an individual pollutant, multiple pollutants, "pollution," or an unknown cause of impairment. The 303(d) listing process includes waters impaired by point sources and non-point sources of pollution. States must also establish a priority ranking for the listed waters, considering the severity of pollution and uses. In 2016, there were 608 category 5 Iowa waterbodies with 818 impairments. In 2014, there were 571 impaired waterbodies with 754 impairments. Category 5 waterbodies are those where a Total Maximum Daily Load assessment is required. About 58% of Iowa streams are considered “impaired”; 23% are considered “potentially impaired”; and 19% are considered to have “good” water quality. Indicator bacteria (i.e., *E. coli*) are the most common cause of impairment, causing about half of all such designations. Biological impairments are next, followed by fish kills. Figure 1.17 lists the main causes. Figure 1.18 shows historical numbers of impaired Iowa waters.

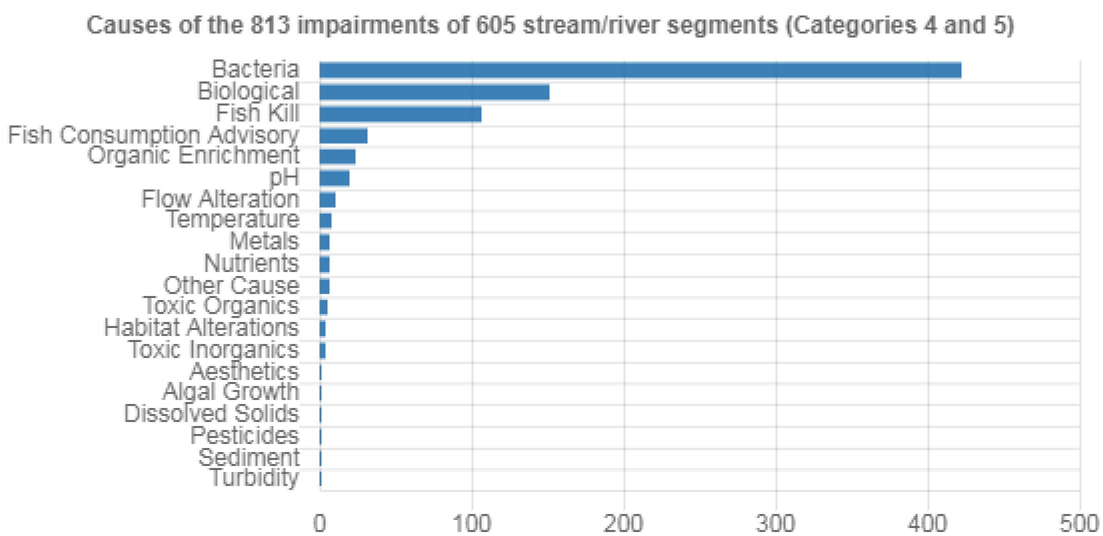


Figure 1.17. Causes of impairments in Iowa’s impaired waters. (Iowa Department of Natural Resources, 2018).

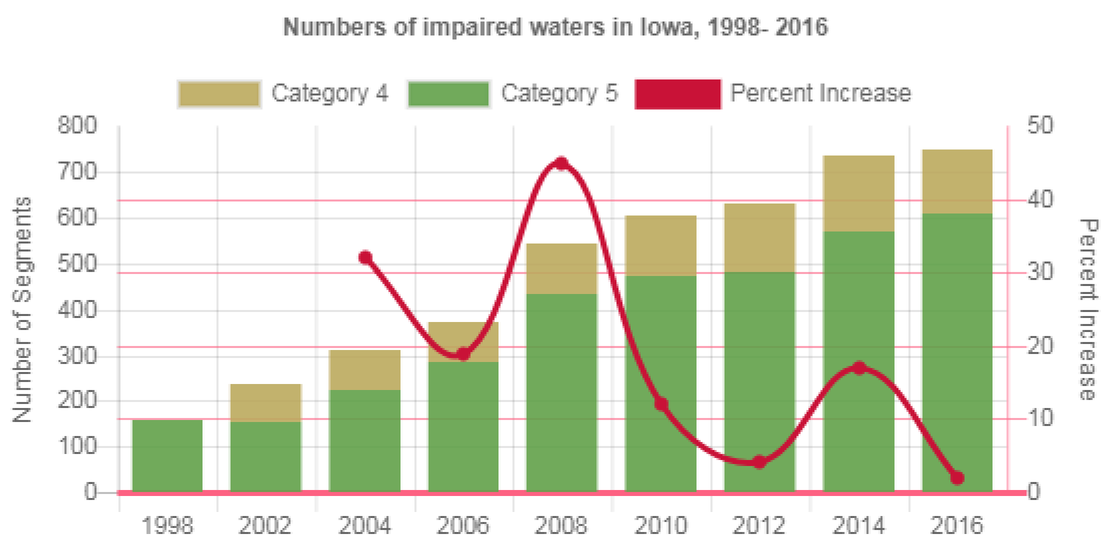


Figure 1.18. Numbers of impaired Iowa waters, 1998–2016. (Iowa Department of Natural Resources, 2018).

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

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

i. The Iowa Flood Information System (IFIS)

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

Floodplain inundation maps

In partnership with the IDNR, the IFC has created statewide floodplain maps that estimate flood hazard extents and depths for every stream in the state of Iowa draining greater than one square mile. The maps depict flood boundaries and depths for eight different annual probabilities of occurrence: 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-%, allowing Iowans to better understand their flood risks and make informed land management decisions. The statewide floodplain maps can be accessed through IFIS or at http://www.iowafloodmaps.org/. Figure 1.19 shows an example of statewide floodplain map data.

Community-based inundation maps

The IFC has also developed online inundation map libraries for more than 20 Iowa communities that relate forecasted or observed flow conditions to flood extents and depths. These inundation map libraries use detailed computer models that consider small-scale floodplain and channel features, bridges, and dams to better simulate the physics of flowing water. The maps allow a user to “translate” a forecasted river stage at a USGS gauge to flood extents and depths in the community, to better anticipate and respond to immediate flood hazards, and to consider “what-if” scenarios for long-term planning. Community inundation map libraries can be accessed on IFIS. Figure 1.20 shows the inundation map library interface for the city of Des Moines.

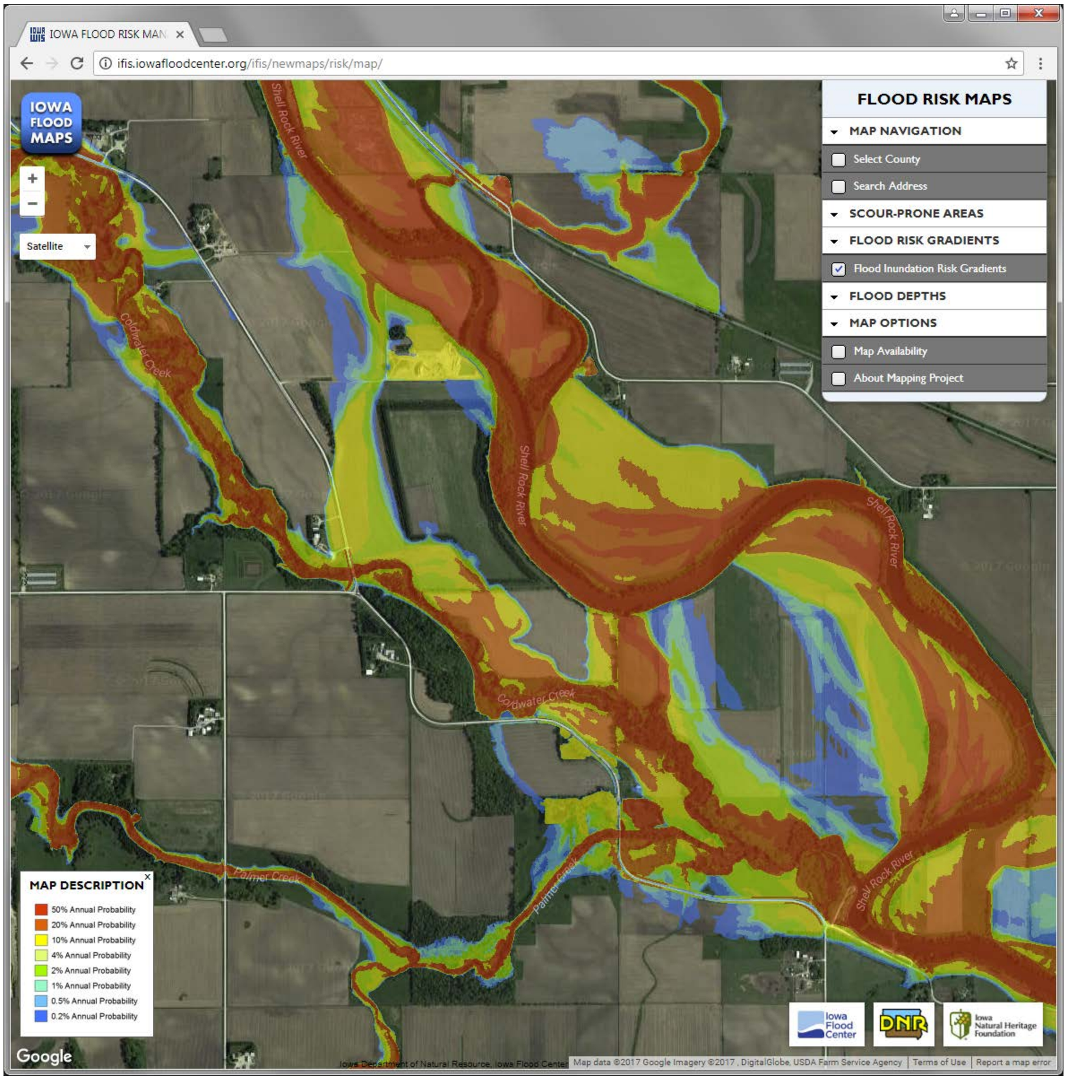


Figure 1.19. Statewide floodplain map data showing different levels of annual flood risk.

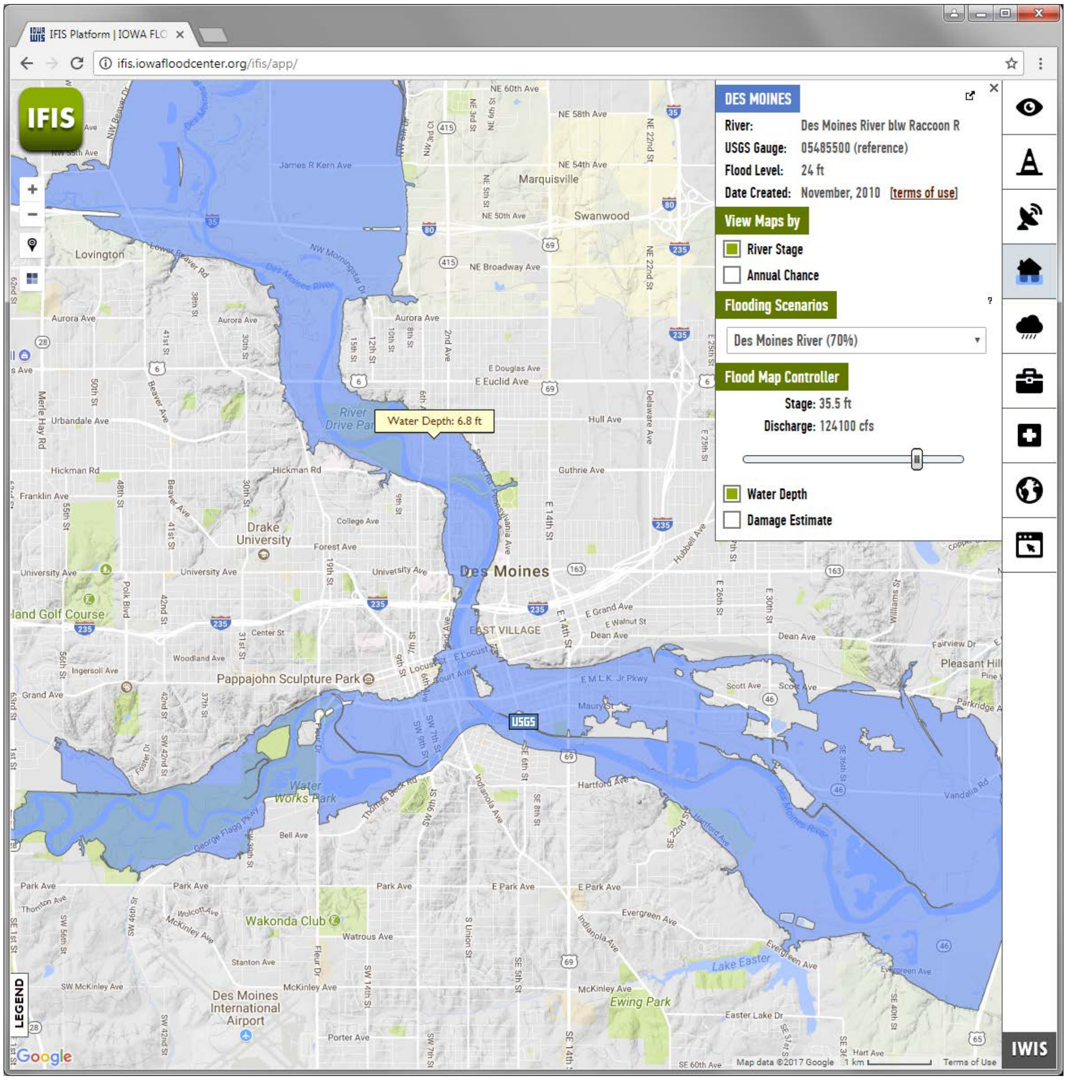


Figure 1.20. Flood inundation map library for the Des Moines and Raccoon rivers in the city of Des Moines.

Observed stream conditions

IFIS displays data from more than 400 sensors continuously monitoring Iowa stream conditions in real-time, which is shown in Figure 1.21. Currently, the USGS collects streamflow data at approximately 200 locations, and the IFC administers and maintains a growing network of more than 250 stream-stage sensors that record stage conditions.

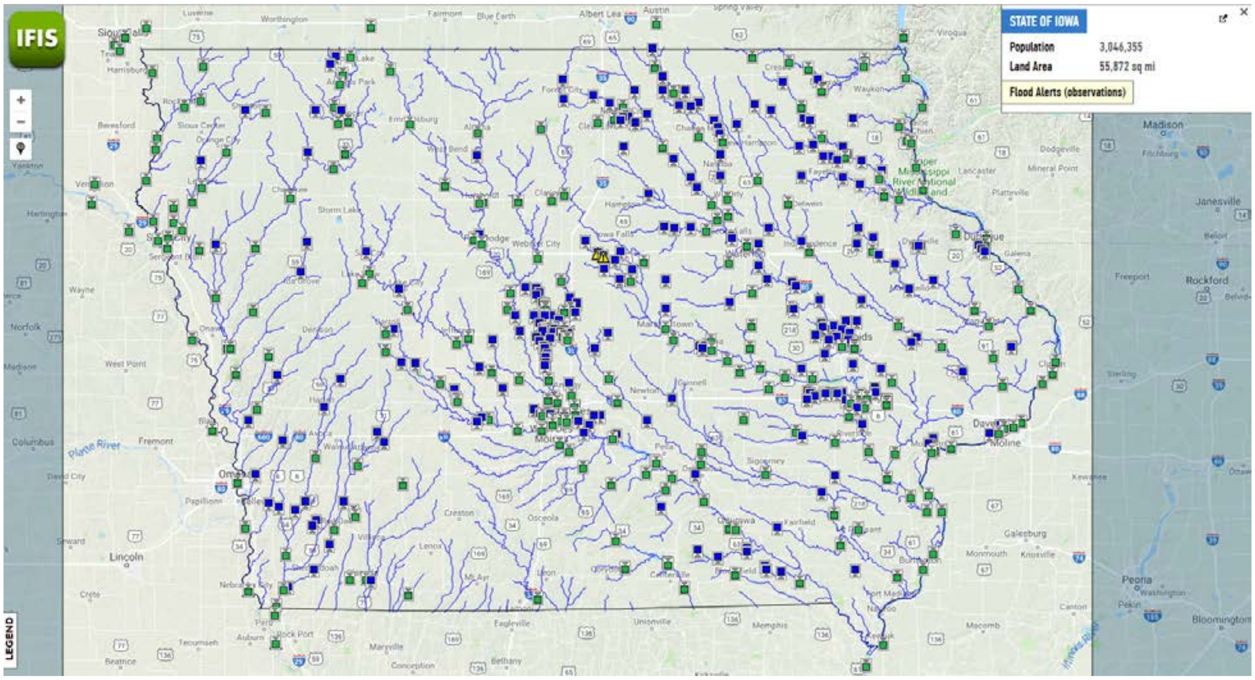


Figure 1.21. USGS (green) and Iowa Flood Center (blue) stream-stage monitoring locations displayed in the Iowa Flood Information System (IFIS).

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 the four flood stage levels (action, flood, moderate flood, and major flood). The flood forecast products included in IFIS are the NWS six-hourly 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 min 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. Iowa WQIS 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 Iowa to quantify the nutrient loads leaving the state. Figure 1.22 is a screenshot of IWQIS displaying the WQ network (2018).

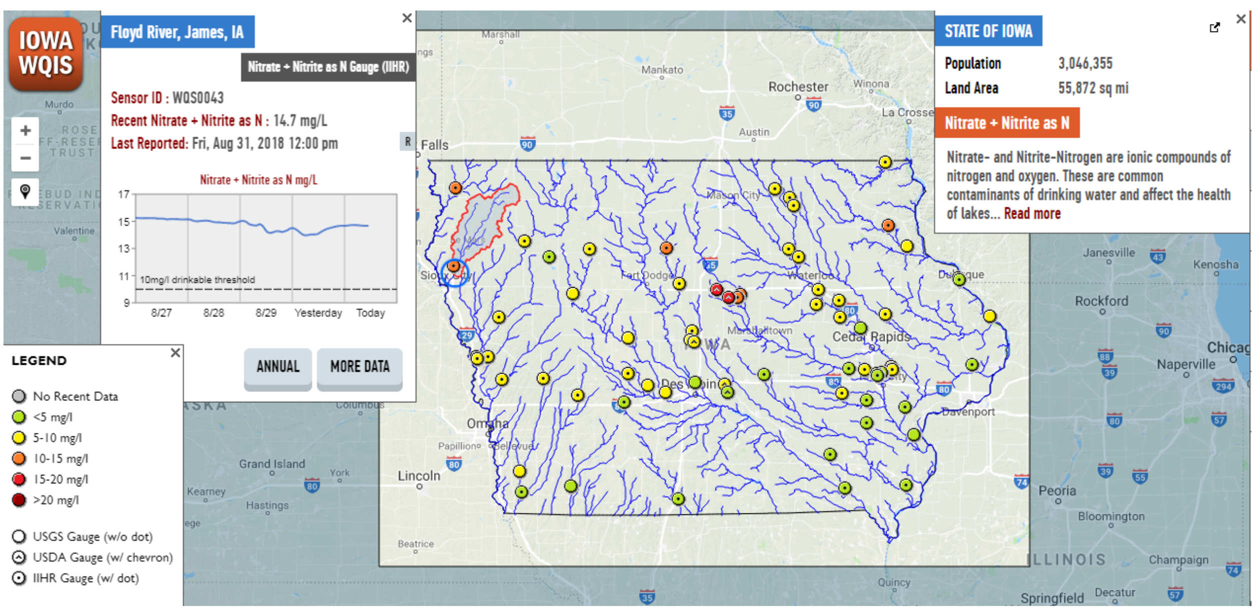


Figure 1.22. IIHR—Hydroscience & Engineering and USGS surface water-quality monitoring locations as displayed in the Iowa Water Quality Information System (IWQIS).

iii. The Iowa Watershed Approach Information System (IWAIS)

IIHR and IFC are developing a web-based information system to provide public access to general information and updates on the IWA project, existing and potential BMPs in IWA watersheds, hydrologic and water-quality data collected in the IWA watersheds, and resources to improve flood resiliency. The website can be accessed at: http://iowawatershedapproach.org. Figure 1.23 shows an example view of the IWAIS interface showing the number of existing ponds within each HUC 12 in the Middle Cedar River Watershed.

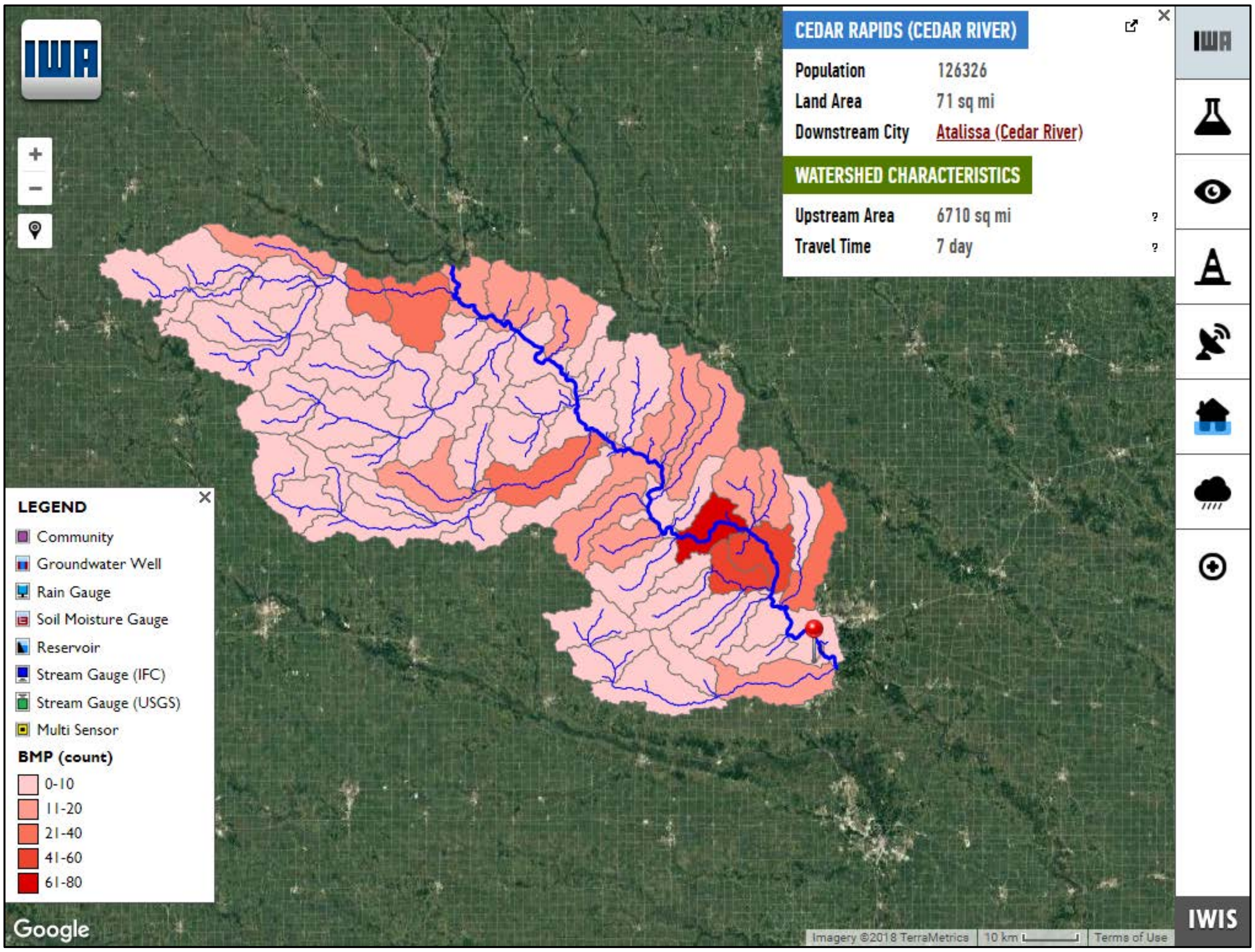


Figure 1.23. Example IWAIS interface view showing the number of existing ponds within each HUC 12 in the Middle Cedar River Watershed.

2. Conditions in the Upper Wapsipinicon Watershed

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

a. Hydrology

The Upper Wapsipinicon River Watershed as defined by the boundary of eight-digit Hydrologic Unit Code (HUC8) 07080102 is located in East - Central Iowa and encompasses approximately 1568 square miles (mi^2). The Wapsipinicon River flows into the Mississippi River at the border of Iowa and Illinois. The total drainage area of the Wapsipinicon River at the border of Illinois and Iowa is approximately 2549 mi^2. The Upper Wapsipinicon River Watershed boundary falls within eleven counties in total, however, the majority of the watershed area lies within Howard, Chickasaw, Bremer, Buchanan and Linn Counties.

Figure 2.1. The Upper Wapsipinicon River Watershed (HUC8 07080102).

Over the last 110 years annual precipitation in the watershed has fallen between 20 and 46 inches (Figure 2.3). Average annual precipitation ranges from roughly 33 inches in the upper part to 38 inches near Anamosa (Figure 2.2). About 30% of the annual precipitation is transformed into streamflow (Figure 2.4) and approximately 65% of the annual flow comes in the form of baseflow (Figure 2.5).

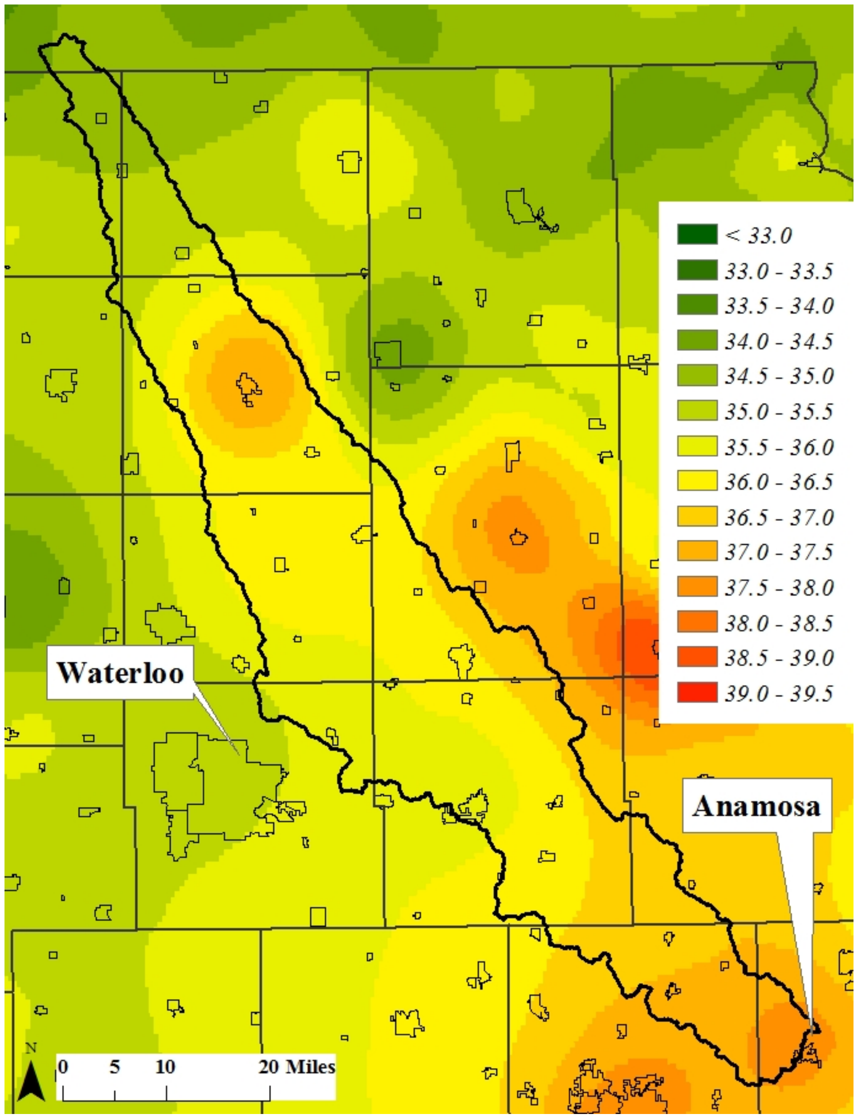


Figure 2.2. Average annual precipitation (inches). Estimates are based on the 30-year annual average (1981-2010).

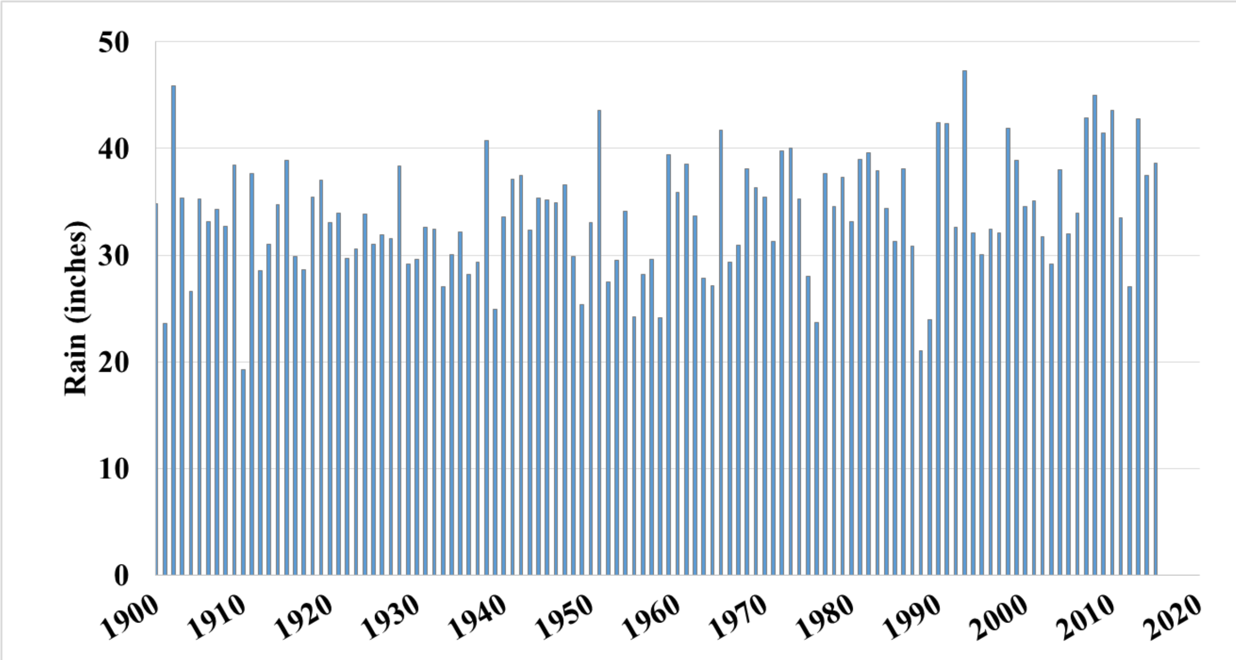


Figure 2.3. Bar graph of annual precipitation.

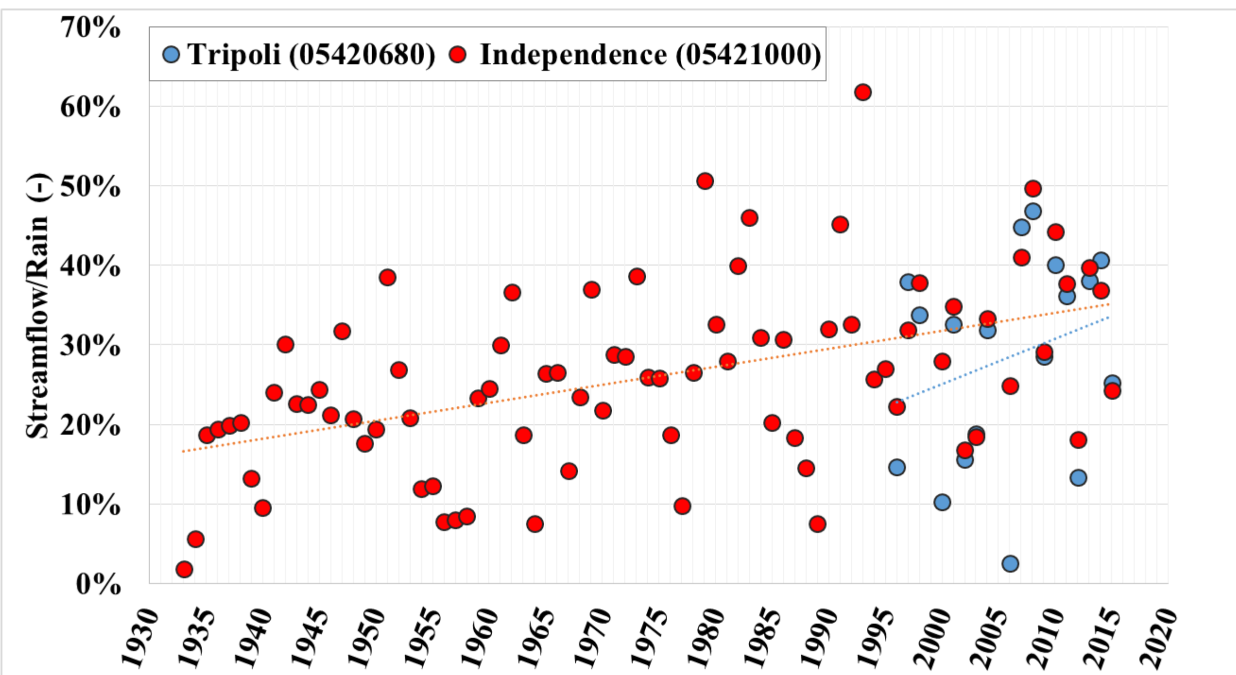


Figure 2.4. Annual ratio of streamflow to precipitation.

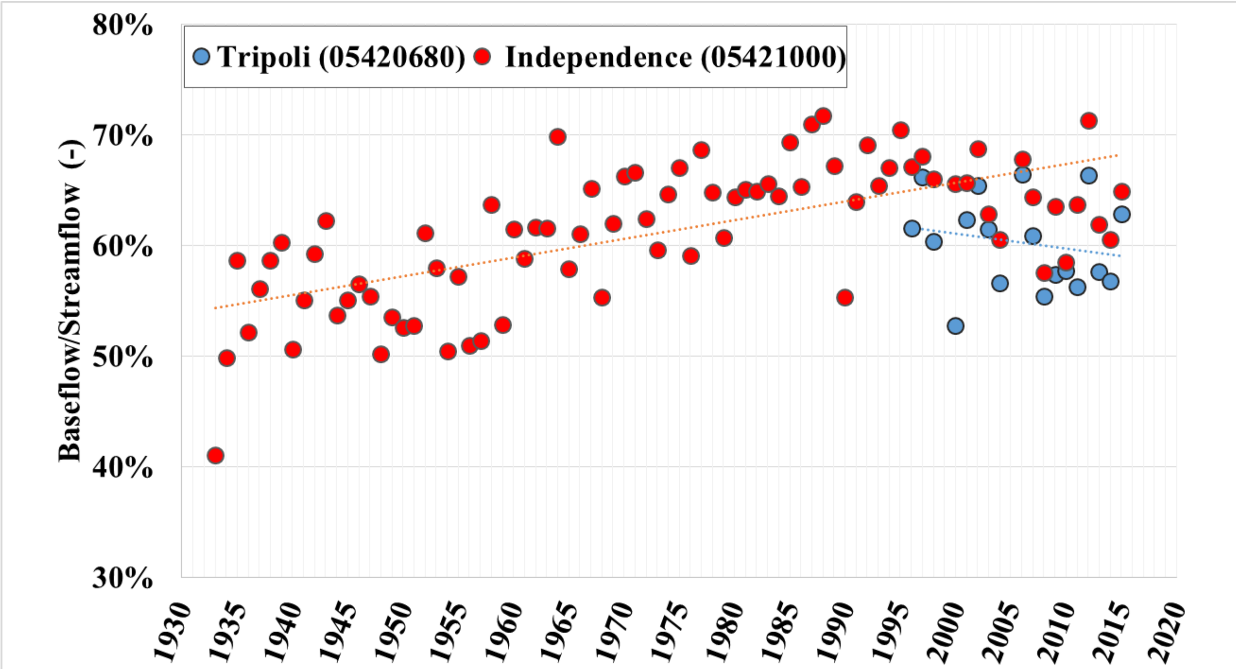


Figure 2.5. Annual ratio of baseflow to streamflow.

b. Geology and Soils

The Upper Wapsipinicon River Watershed is located almost entirely within the Iowan Surface landform region (Figure 1.2), with a very small area of East-Central Iowa Drift Plain on the downstream edge of the watershed. The characteristics of each landform region have an influence on the rainfall-runoff potential and hydrologic properties of the watershed.

The Iowan Surface encompasses much of northeast Iowa and is an area that was subjected to intense cold between 21,000 to 16,500 years ago during the last glacial advance into Iowa. The close proximity to the Des Moines Lobe ice margin resulted in tundra and permafrost conditions, and as a result wind and water action significantly eroded the landscape. Characteristic features include gently rolling topography, common glacial 'erratics' (rocks and boulders not native to Iowa that have been transported by glaciers), and loess-mantled paha (northwest to southeast trending uneroded upland remnants of the former landscape)(Figure 2.7). Glacial materials at the surface consist of poorly consolidated glacial deposits with the potential for extensive local sand bodies. In areas where the depth to bedrock is shallow, these materials provide limited protection from surface water infiltrating into bedrock. A limited number of sinkholes have been identified in the watershed.

Soils are classified into four Hydrologic Soil Groups (HSG) by the Natural Resources Conservation Service (NRCS) based on the soil's runoff potential. The four HSG's are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, there are dual code soil classes A/D, B/D, and C/D that are assigned to certain wet soils.

In the case of these soil groups, even though the soil properties may be favorable to allow infiltration (water passing from the surface into the ground), a shallow groundwater table (within 24 inches of the surface) typically prevents much infiltration from occurring. For example, a B/D soil will have the runoff potential of a B-type soil if the shallow water table were to be drained away, but the higher runoff potential of a D-type soil if it is not. Complete descriptions of the Hydrologic Soil Groups can be found in the USDA-NRCS National Engineering Handbook, Part 630- Hydrology, Chapter 7.

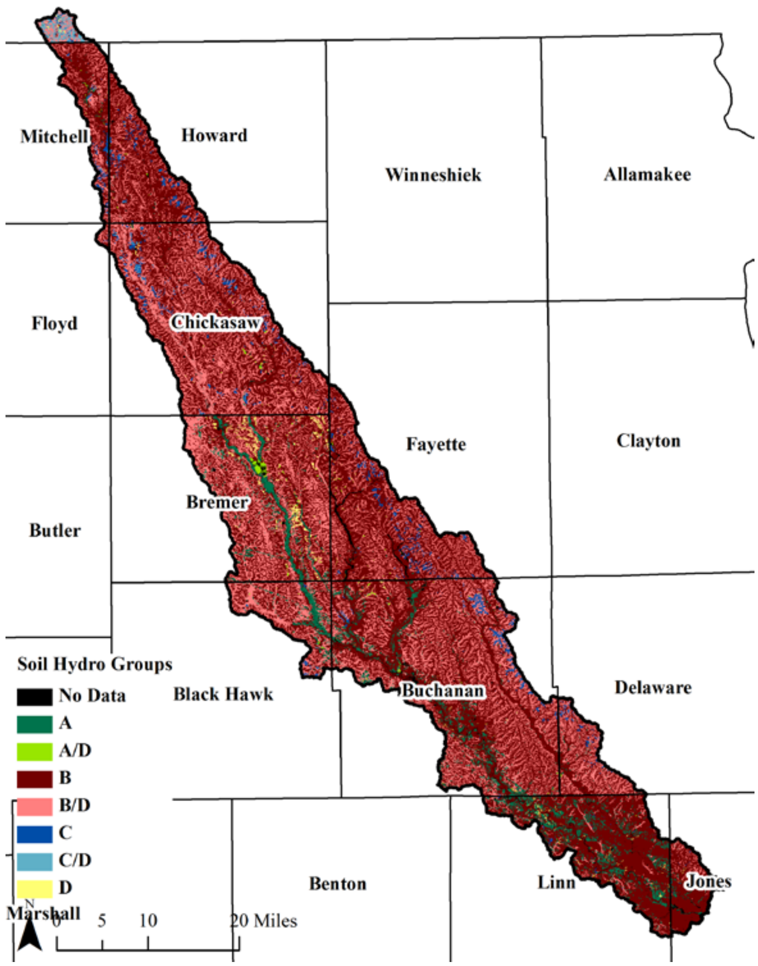


Figure 2.6. Distribution of Hydrologic Soil Groups in the Upper Wapsipinicon Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with Type A representing the lowest runoff potential and Type D representing the highest runoff potential.

The soil distribution of the Upper Wapsipinicon River Watershed per digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WWS) is shown in Figure 2.6. Viewing the soil distribution at this map scale is difficult, but the map does illustrate the relative consistency of the HSG on the Iowan Surface landform region. Table 2.1 shows the approximate percentages by area of each HSG for the Iowan Surface in the Upper Wapsipinicon River Watershed. The Upper

Wapsipinicon River Watershed consists primarily of HSG B (60.6%) and B/D (30.1%) type soils, which have a moderate runoff potential when saturated. The remaining soil types each comprise 5% or less of the watershed.

Table 2.1. Approximate Hydrologic Soil Group Percentages by Area for the Upper Wapsipinicon Watershed.

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

c. Topography

Figure 2.7 shows the topography of the Upper Wapsipinicon Watershed. Elevations range from approximately 1,400 feet above sea level in the upstream and western part of the watershed to 770 feet above sea level in the downstream portion of the watershed.

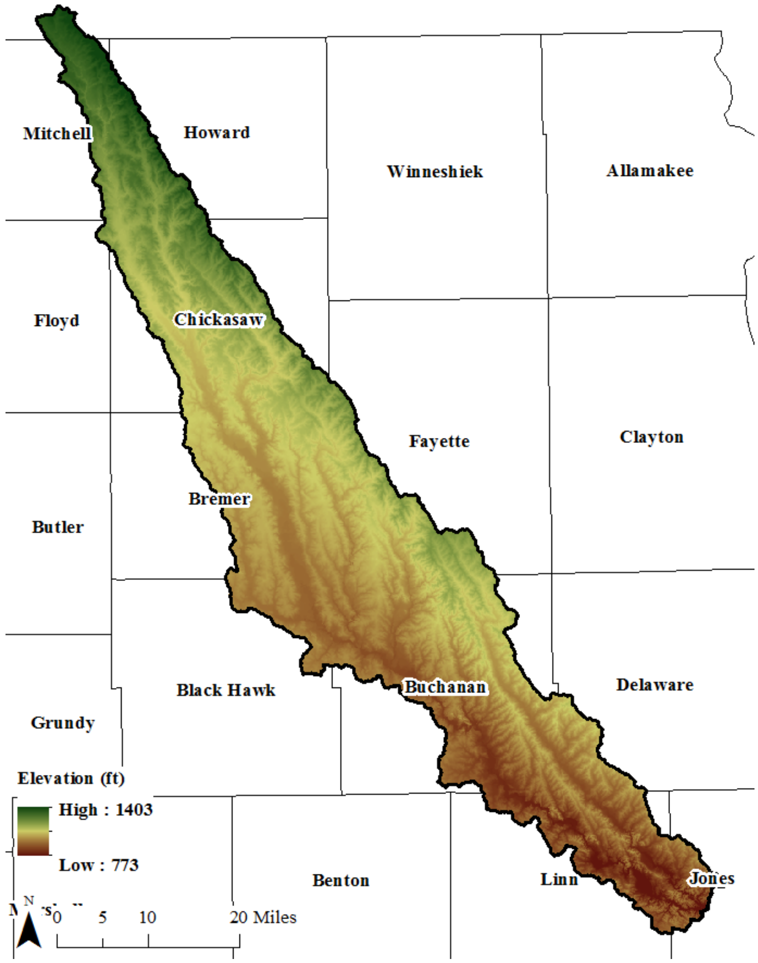


Figure 2.7. Topography of the Upper Wapsipinicon Watershed.

d. Land Use

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

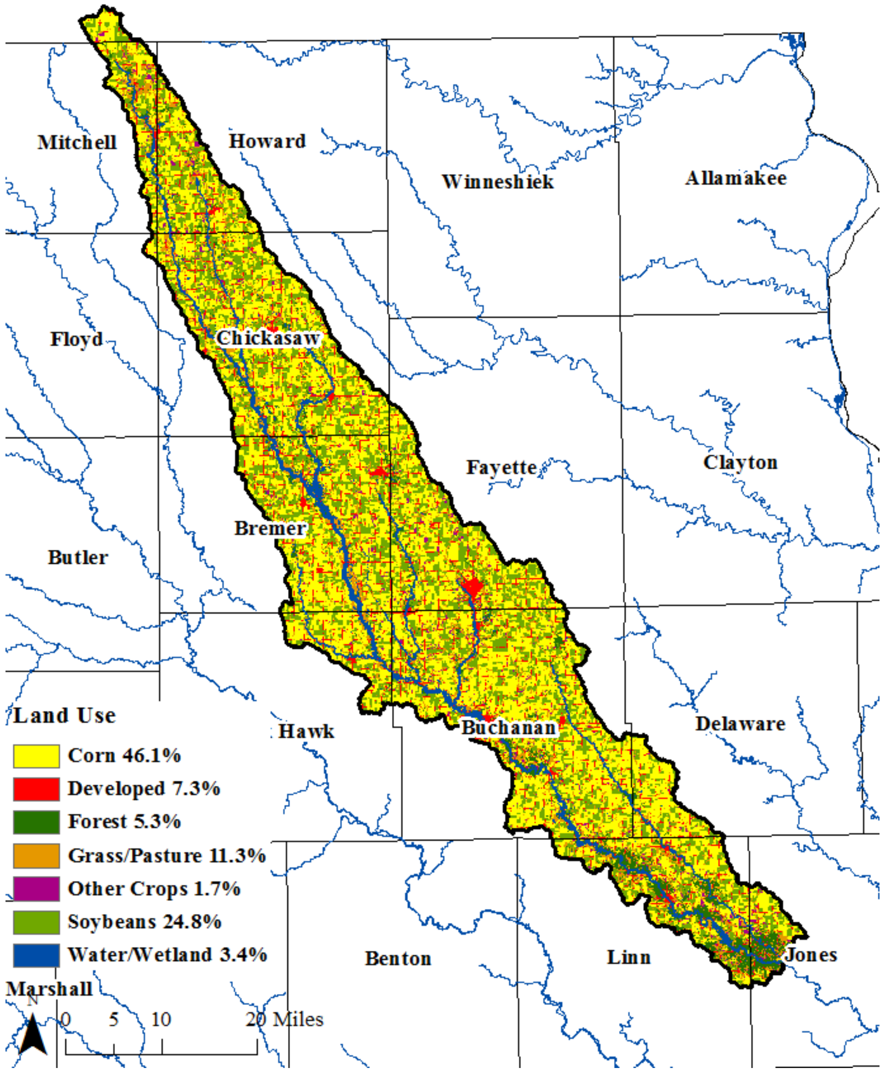


Figure 2.8. Land use composition in the Upper Wapsipinicon Watershed, per the 2017 USDA Cropland Data Layer.

e. BMP Mapping

Identifying existing conservation practices within a watershed serves as a benchmark for future implementation and 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 Upper Wapsipinicon watershed the total number of existing practices are 6712 acres of agricultural fields with contour buffer strips, 1309 acres of agricultural fields with strip cropping, 10477 acres of grassed waterways, 1350 terraces, 486 pond dams, and 2116 water and sediment control basins (WASCOBs). The spatial distribution of the conservation practices within the watershed is shown in Figure 2.9. Grassed waterways, terraces, pond dams, and WASCOBs, are most prevalent near the headwaters and outlet, with less prevalence within the central portion of the watershed. For strip cropping and contour buffer strips are not common in portions of the watershed.

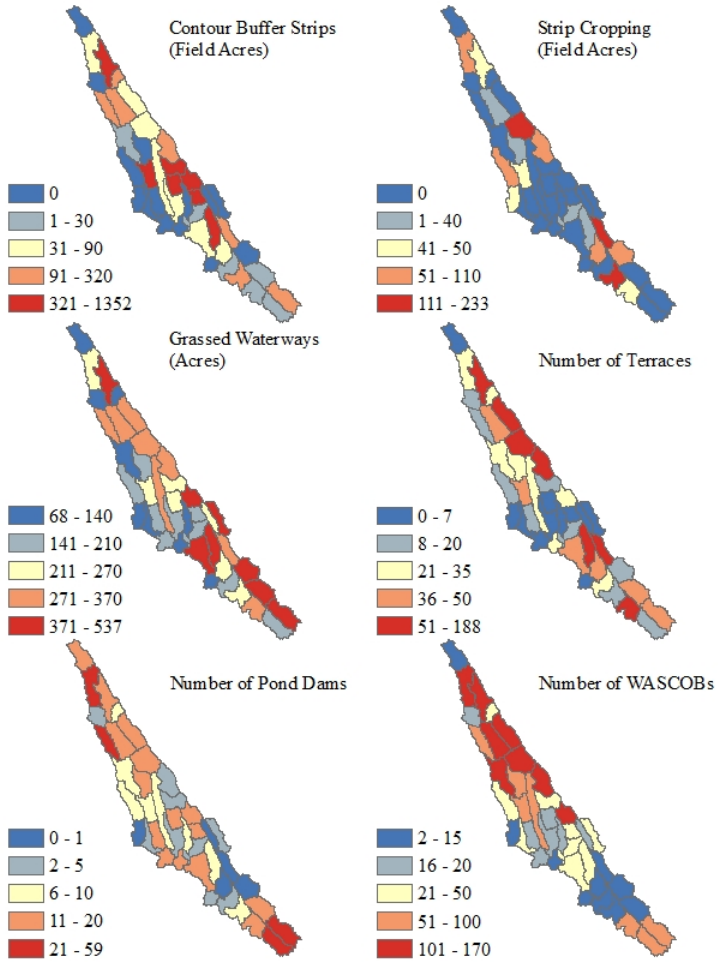


Figure 2.9. Iowa Best Management Practices Mapping Project.

f. Potential BMPs - Agricultural Conservation Planning Framework

Development of an effective watershed planning document will require identification of potential conservation practices and viable locations to implement them. One cutting-edge tool available for practical conservation planning is the Agricultural Conservation Planning Framework (ACPF) watershed planning toolbox, developed by Mark Tomer and his research team at the USDA-ARS in Ames, Iowa (Tomer et al., 2013). ACPF is a watershed approach to conservation planning facilitated with a set of semi-automated tools within ArcGIS software. Freely available and prepackaged GIS data can be used for terrain analyses to determine which fields within the watershed are most prone to runoff into streams. Users can apply the ACPF toolbox to identify locations where field-scale and edge-of-field practices could be installed based on general design criteria. These practices include controlled drainage, surface intake filters or restored wetlands, grassed waterways, contour buffer strips, WASCOBs, nutrient removal wetlands (NRWs), or edge-of-field bioreactors (North Central Region Water Network 2018). Using the ACPF toolbox, IFC has generated potential BMPs for each of the HUC 12s in the Upper Wapsipinicon Watershed. Potential BMPs aggregations based on HUC 12 area are presented in Figure 2.10.

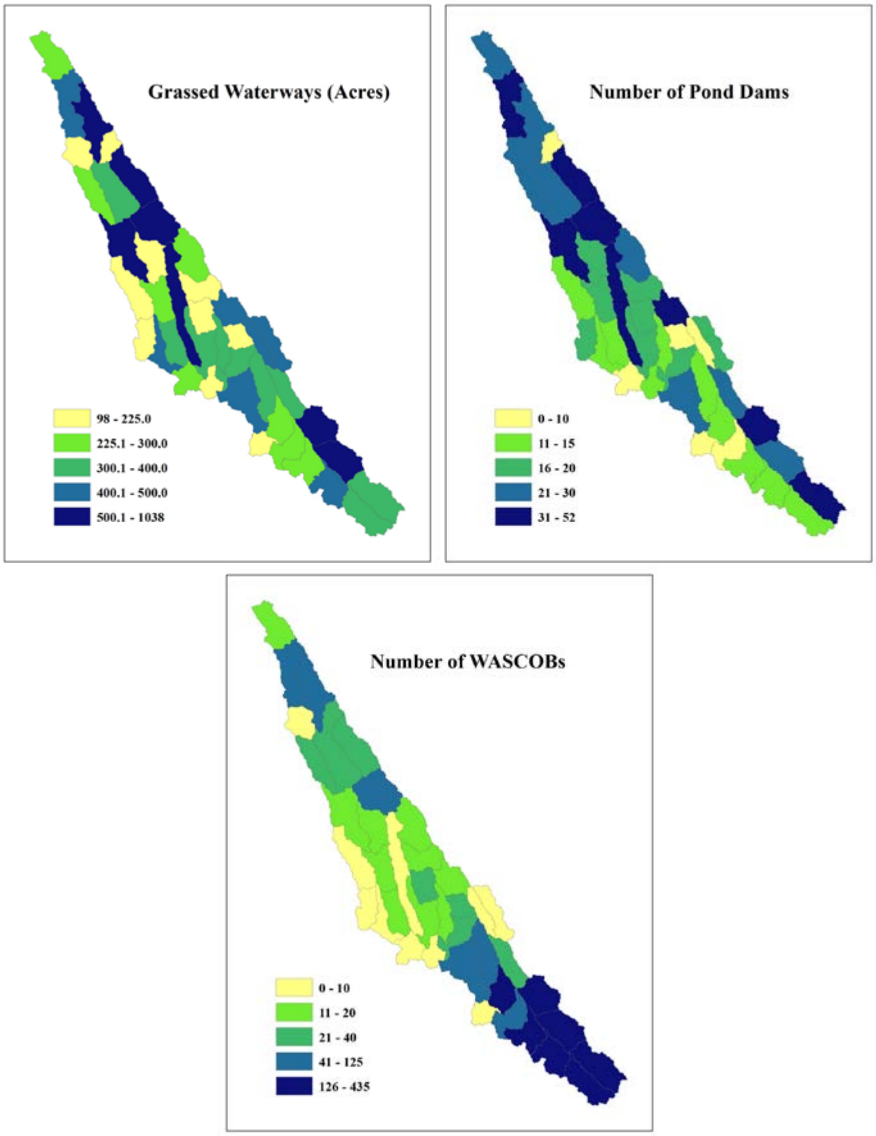


Figure 2.10. Potential BMPs. Ponds Dams represent nutrient removal wetlands.

g. Instrumentation/Data Records

The Upper Wapsipinicon Watershed has instrumentation installed to collect and record stream stage, discharge, and precipitation measurements. There are two United States Geological Survey (USGS) operated stage & discharge gages and two Iowa Flood Information System (IFIS) stream stage sensors located within the watershed.

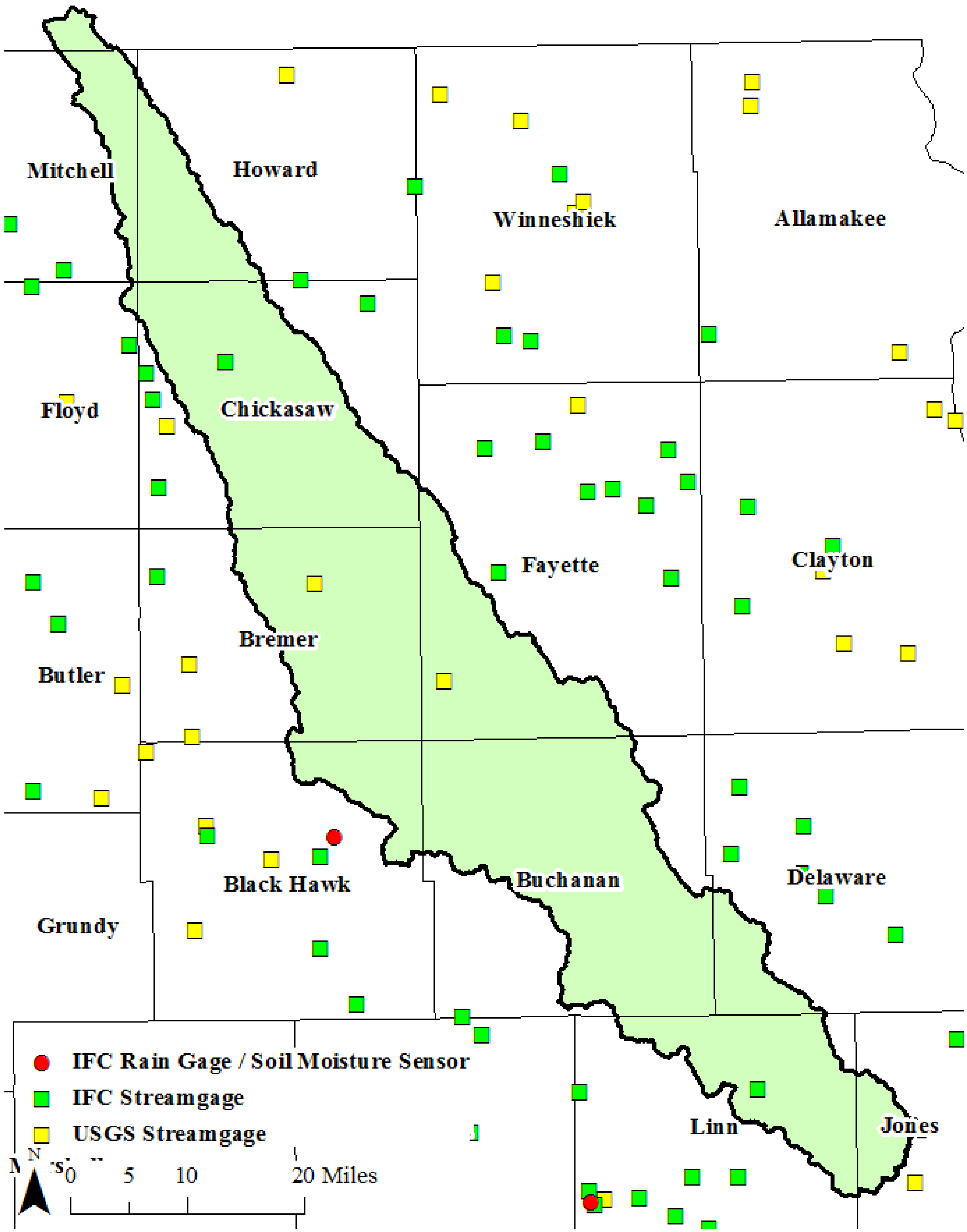

Mitchell
Howard
Winneshiek
Allamakee
Floyd
Chickasaw
Fayette
Clayton
Butler
Bremer
Black Hawk
Buchanan
Delaware
Grundy
Linn
Jones
IFC Rain Gage / Soil Moisture Sensor
IFC Streamgage
USGS Streamgage
N
0 5 10 20 Miles

Figure 2.11. Hydrologic and meteorologic instrumentation in the Upper Wapsipinicon Watershed. Stage/discharge gages are shown in yellow or green while precipitation and soil moisture gages are shown in red.

h. Floods of Record

Nine large flood events (greater than 20,000 cfs) are recorded at the Wapsipinicon River USGS gaging station at Independence. The six largest events are shown in Table 2.2. Of the six events, five of them have occurred since 1990 including: May 18, 1999 with 31,100 cfs, September 25, 2016 with 25,200 cfs, August 26, 1990 with 24,400 cfs, June 11, 2008 with 23,700 cfs, and July 24, 2010 with 22,800 cfs. The floods of 2008 and 2016 were also major flood events upstream near Tripoli and downstream near Anamosa. Before 1990 there were two large flood events. In July 18, 1968, the Wapsipinicon River discharge at Independence was 26,800 cfs and downstream near Anamosa three days later a discharge of 20,000 cfs was recorded. Then in July 1, 1969 near Tripoli, the discharge was recorded at 18,900 cfs. Ultimately, the discharge recorded near Anamosa goes downstream to the Lower Wapsipinicon River and eventually to the Mississippi River.

Table 2.2. Discharge from the Six Largest Flooding Events at USGS Gaging Stations in the Wapsipinicon River Watershed including; the Wapsipinicon River near Tripoli, Wapsipinicon River at Independence, and the Wapsipinicon River near Anamosa

Wapsipinicon River near Tripoli USGS 05420680 (1969, 1997-Present)	7/21/1999 19,400 cfs	7/1/1969 18,900 cfs	6/9/2008 18,300 cfs	9/23/2016 14,000 cfs	5/23/2004 9,680 cfs	3/14/2010 7,380 cfs
Wapsipinicon River at Independence USGS 05421000 (1934-Present)	5/18/1999 31,100 cfs	7/18/1968 26,800 cfs	9/25/2016 25,200 cfs	8/26/1990 24,400 cfs	6/11/2008 23,700 cfs	7/24/2010 22,800 cfs
Wapsipinicon River near Anamosa USGS 05421740 (1968, 1999, 2003-Present)	6/13/2008 31,800 cfs	7/26/2010 25,700 cfs	9/27/2016 23,100 cfs	5/26/2004 22,000 cfs	5/31/2013 20,500 cfs	7/21/1968 20,000 cfs

3. Upper Wapsipinicon Hydrologic Model Development

The modeling activities described in this report were performed using the physically-based integrated model GHOST developed at IIHR to simulate the hydrologic response at watersheds ranging in area from 100 to 2,500 square miles over time periods on the order of decades. GHOST stands for Generic Hydrologic Overland-Subsurface Toolkit. The model takes into account Iowa's varied topography, soils, and land use. GHOST is based on the open source hydrologic code MM-pihm (Qu and Duffy 2007, Yu et al. 2013), which fully couples surface and subsurface water systems to predict streamflow and groundwater movement for normal and extreme rainfall and snowmelt events. Specific models were developed at IIHR and incorporated into the code to properly predict water budgets for the long-term simulations required for the large-scale IWA watersheds. The main advantage of a physically-based model is that the model can be used for a wide range of applications and beyond the window of calibration. Best management practices (BMP) are resolved or modeled in GHOST depending on the structure scale.

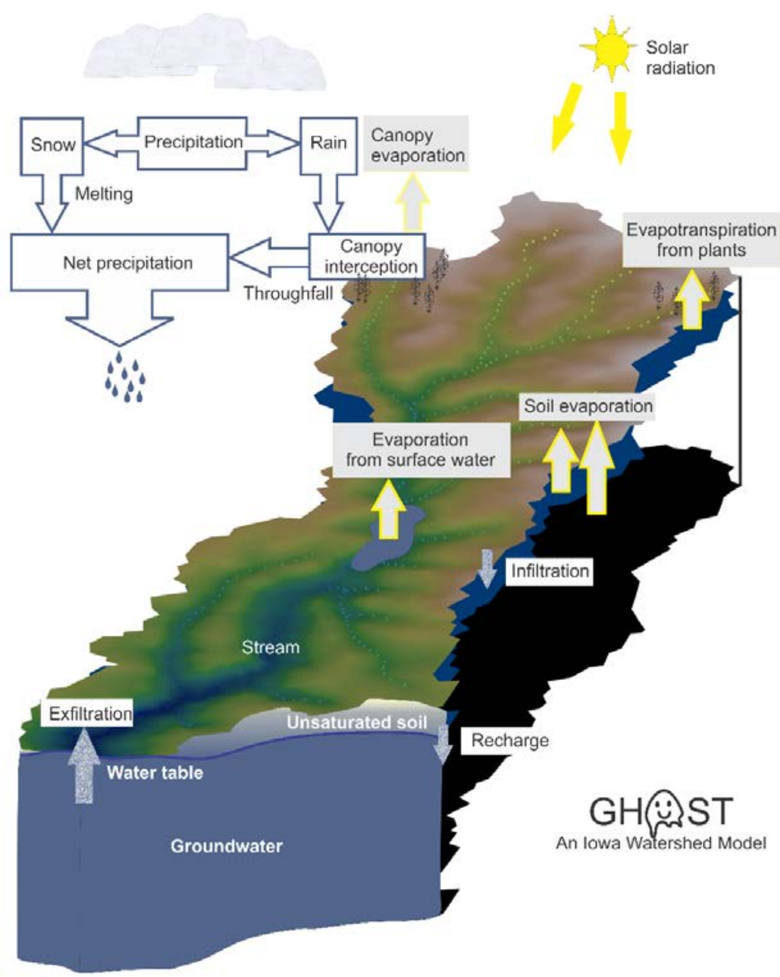


Figure 3.1. Hydrologic processes modeled in GHOST.

Figure 3.1 presents the water cycle and the major hydrologic processes modeled in GHOST. The model uses precipitation, air temperature and solar radiation to compute evaporation and plant transpiration. The form of precipitation, rain or snow, is determined by air temperature values. At temperature values above the freezing point, accumulated snow melts contributing to net precipitation. The canopy can intercept rain, which then evaporates from the canopy or can reach the ground surface by canopy drip. At the ground surface water can infiltrate to the unsaturated region, contribute to surface runoff or be evaporated. Infiltrated water can evaporate from the soil, be transpired by plants, or drain to the saturated zone. Water stored in the saturated zone can evaporate or discharge to a stream.

a. Model Development

The watershed is conceptualized in three distinct zones: a surface region and two regions beneath the surface representing the unsaturated soil and groundwater (Kumar et al. 2009). The code uses a finite volume formulation to solve the governing equations. Surface flow is represented with a two-dimensional diffusive wave approximation of the Saint-Venant equations. Unsaturated flow is simulated considering that the dominant flow direction is vertical. Water depth at channels and streams is computed using a one-dimensional approximation to properly capture the channel geometry and the effect of flood mitigation structures without local grid refinement along the network. The water table is represented with a moving interface separating the unsaturated and saturated soil regions.

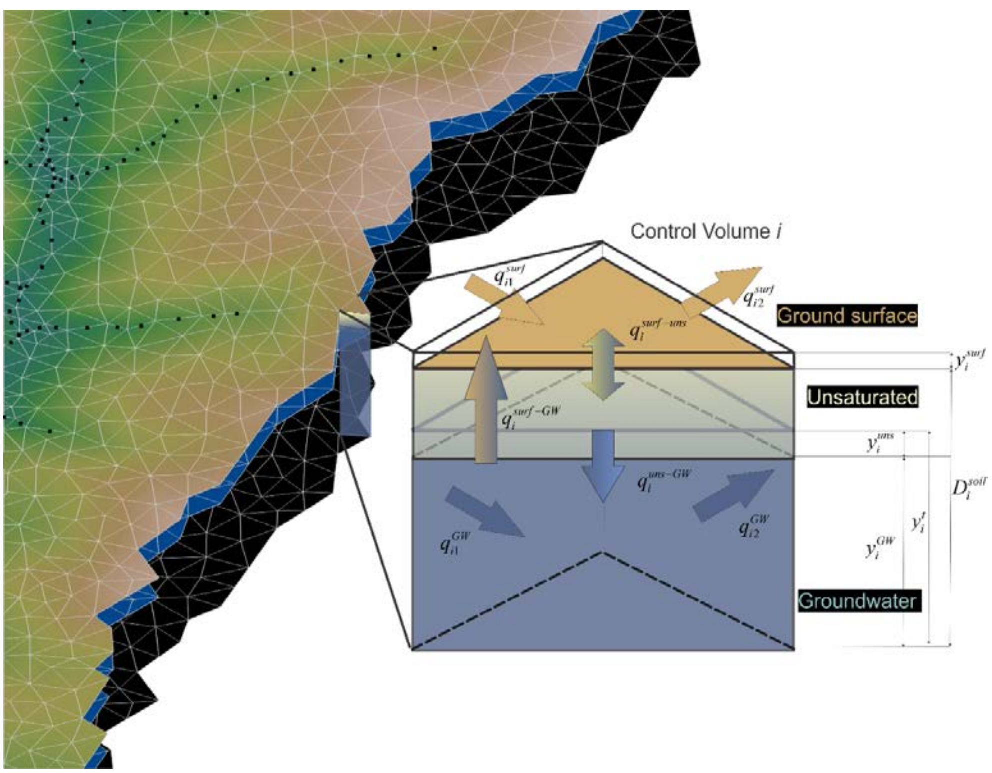


Figure 3.2. The three coupled flow domains representing a watershed in GHOST.

b. Attributing the Model

Publicly available land use, soil type, surface elevations were used to spatially describe surface and subsurface classifications.

Surface

Each triangular surface element was assigned spatially variable land use and topographic information, relating the location to overland roughness, evapotranspiration properties, and land surface slopes, respectively.

The National Land Cover Database 2016 (NLCD 2016) provided spatially variable land use. Land classifications were simplified into four groups: rowcrop, grassland, forest, and developed; these were assigned to the appropriate elemental area. The four surface land use classifications relate surface elements to overland flow resistance parameters and vegetation properties.

The landscape topography was described based on ten-meter Digital Elevation Models of bare ground surface data obtained from the National Elevation Dataset (NED). A high spatial resolution topography enabled accurate identification of streams and watershed boundaries for mesh generation. Mesh element elevation data representing the land surface were extracted from ninety-meter elevation models obtained from aggregating the ten-meter data.

Subsurface

Researchers used the Soil Survey Geographic (SSURGO) database (Soil Survey Staff, 2014) (Figure 2.6) to describe the properties of both the saturated and unsaturated regions.

Forcing Data

Stage IV radar rainfall estimates (NCEP/EMC 4KM Gridded Data (GRIB) Stage IV Data) were used as the precipitation input for simulation. The Stage IV data set is produced by the National Center for Environmental Prediction (NCEP) by taking radar rainfall estimates produced by the 12 National Weather Service (NWS) River Forecast Centers across the Continental United States and combining them into a nationwide 4 km x 4 km (2.5 mile x 2.5 mile, see Figure 3.3) gridded hourly precipitation estimate data set. These data are available from January 1, 2002 – Current. Use of radar rainfall estimates provides increased accuracy of the spatial and time distribution of precipitation over the watershed and Stage IV estimates provide a level of manual quality control (QC) performed by the NWS that incorporates available rain gage measurements into the rainfall estimates. Other meteorological data such as air temperature, relative humidity, wind speed, shortwave/longwave radiation and surface pressure were obtained from North American Land Data Assimilation System Phase 2(NLDAS-2) products (Xia et al., 2012). The temporal resolution of all the forcing data used was hourly.

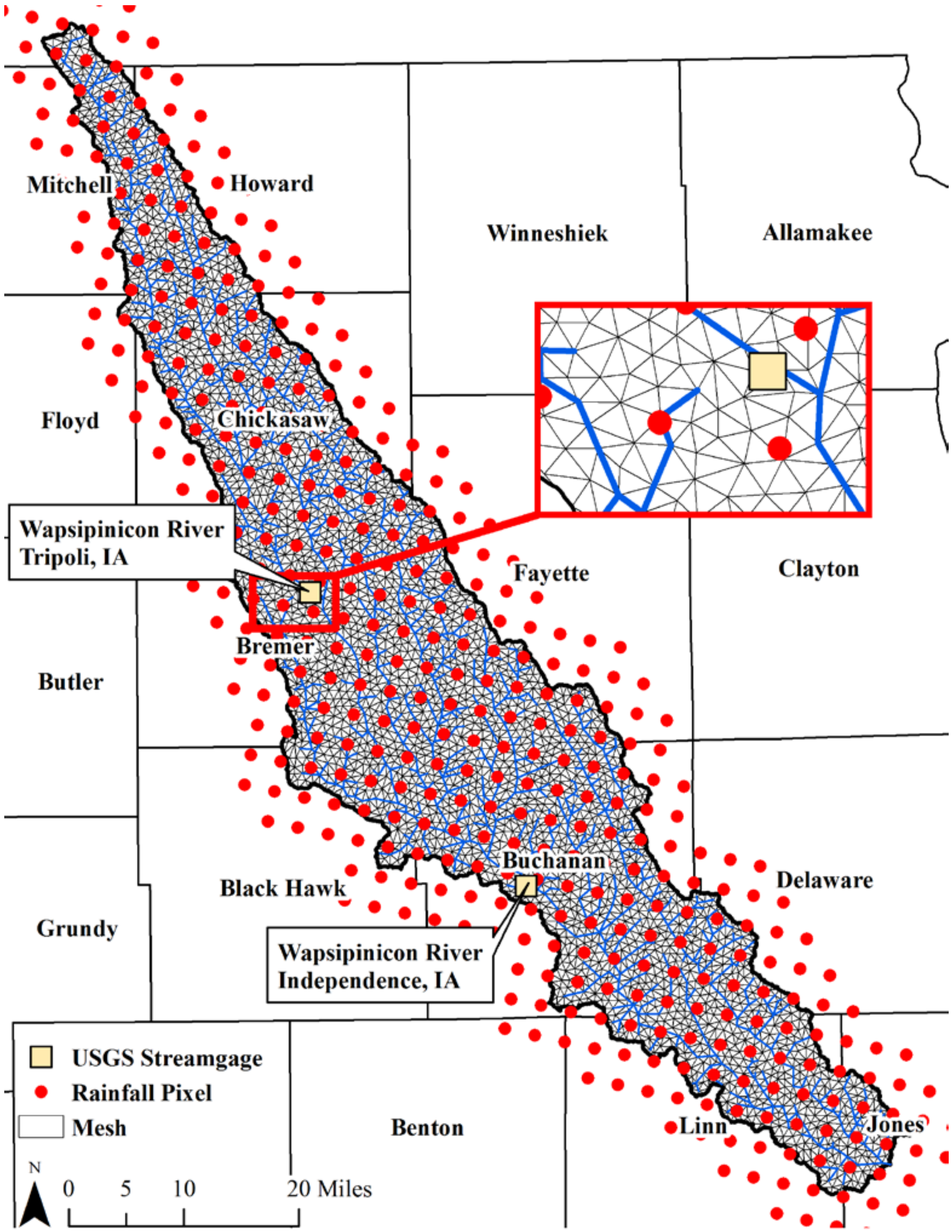


Figure 3.3. Computational mesh and rainfall pixels.

c. Calibration and Validation

Model calibration is a process of taking an initial set of parameters developed for the hydrologic model and making adjustments to them so that simulated results match as close as possible observed time series, typically stream discharge at a gaging station. For model validation, the intent is to use the model parameters developed during calibration process to simulate other events and evaluate how well the model is able to replicate observed watershed's response to precipitation. Model calibration was carried out for a nine-year period (2002-2010) and during the validation process the model performance was evaluated using measurements taken between 2011 and 2016. Simulated flows were compared against observed flows at two USGS stream-gage stations: Wapsipinicon River at Independence: USGS 05421000 and Wapsipinicon River near Tripoli USGS 05420680. For the years 2004, 2005, and 2006 measured data near Tripoli is either missing or have significant gaps. These three years were omitted from the analysis presented below.

Figure 3.4 and 3.5 show the daily flow time series for both the calibration and validation periods. Overall, model predictions match well the measurements. These figures display both periods where the simulated values follow closely measured values, and others when it does not. Given that a hydrologic model is a simplified representation of the actual watershed some level of mismatch is to be expected. Table 3.1 presents common metrics used in hydrologic model performance evaluation. Based on Moriasi et al., (2007) model simulations can be judged as satisfactory if Nash-Sutcliffe efficiency (NSE) > 0.50, Percent bias (PBIAS) ± 25% for streamflow, and the coefficient of determination (R^2) values are close to 1. The Upper Wapsipinicon model results for both the calibration and validation periods display metrics that meet those criteria.

Table 3.1. Hydrologic model evaluation metrics for both the calibration and validation periods. Nash-Sutcliffe efficiency (NSE), Percent bias (PBIAS), and coefficient of determination (R^2).

	NSE		PBIAS		R^2	
	Cal	Val	Cal	Val	Cal	Val
Independence	**0.75**	**0.66**	**-5.31**	**11.21**	**0.88**	**0.84**
Tripoli	**0.71**	**0.60**	**2.99**	**7.74**	**0.88**	**0.89**

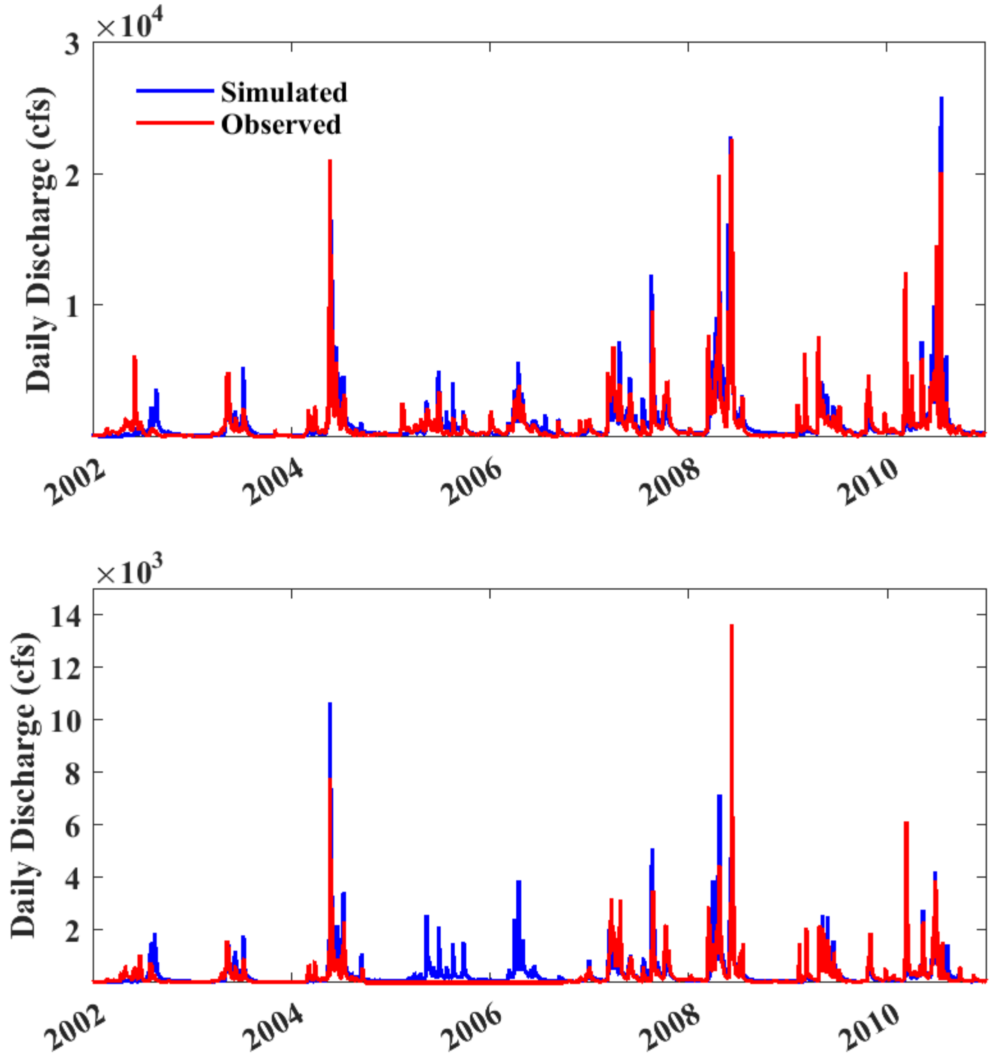


Figure 3.4. Observed and simulated daily flow time series. Calibration period. Top: Independence (USGS 05421000), Bottom: Tripoli (USGS 05420680).

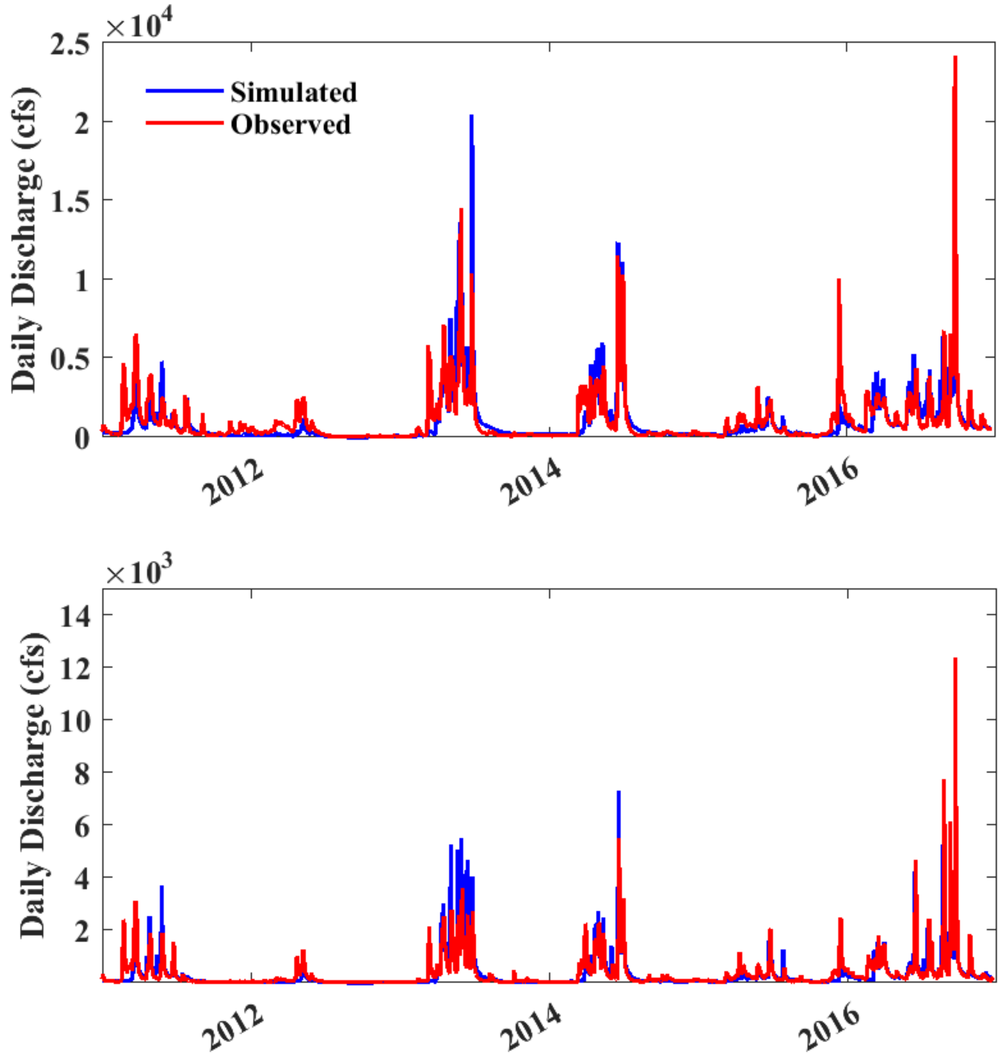


Figure 3.5. Observed and simulated daily flow time series. Validation period. Top: Independence (USGS 05421000), Bottom: Tripoli (USGS 05420680).

Monthly Water Cycle

In the Upper Wapsipinicon Watershed monthly runoff depths display a marked seasonal cycle with the window between April and August showing the highest runoff depths (Figure 3.6). Model results show a tendency to overestimate runoff at Independence for the wettest months (May-July). This trend is less apparent when making comparison between simulated and observed flow near Tripoli. Conversely, Figure 3.6 shows that simulated runoff during the winter and fall is slightly underestimated by the model. Overall, simulated monthly runoff values match observations closely with values of R^2>0.88.

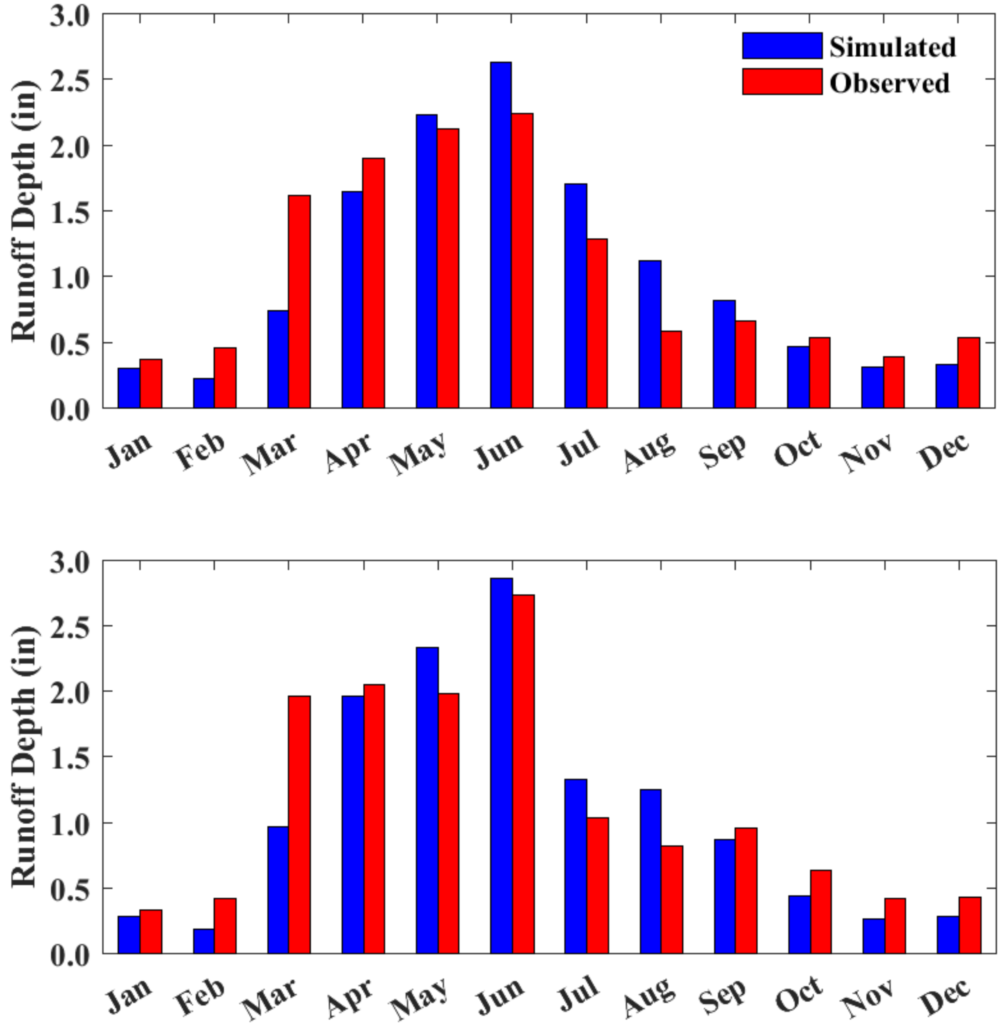


Figure 3.6. Observed and simulated average monthly runoff depth (in inches) for the Upper Wapsipinicon Watershed. Results are shown for both the calibration and validation periods (2002-2016). Top: Independence (USGS 05421000), Bottom: Tripoli (USGS 05420680).

Annual Maximum Peak Discharge and Flow Duration Curves

To assess the model ability to predict flood characteristics in the Upper Wapsipinicon simulated and observed annual peak flows were compared at Independence and near Tripoli (see Figure 3.7). Model results show no bias and annual peaks are both slightly under-predicted and over-predicted (data on both sides of the one-to-one line).

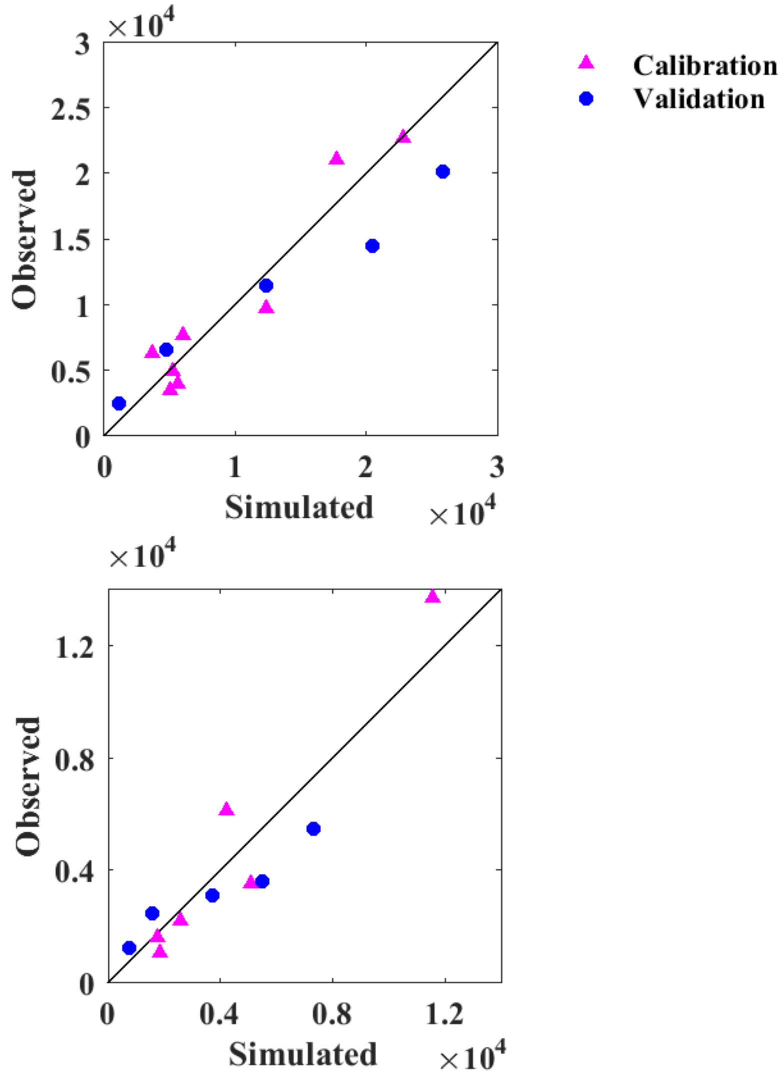


Figure 3.7. Simulated versus observed annual maximum peak daily discharges (cfs). Top: Independence (USGS 05421000), Bottom: Tripoli (USGS 05420680).

Flow duration curves provide the means to condense long term records of hydrologic data in a simple plot and can be used to compare measured data and model predictions, study the effect of differences in geology and climate on watersheds hydrologic response, illustrate the benefits associated with different conservation scenarios and inform water resources planning. The flow duration curve shows the percent of the time that a given flow exceeded. In this report flow duration curves were used to both compare measurements and model predictions and analyze the effect of the different conservation scenarios presented in Chapter 4.

For the entire record (2002-2016) daily flows were ranked from smallest to largest and then plotted against the probability that a given flow will be equaled or exceeded (see Figure 3.8, flow duration curves). The observed and simulated flow duration curves show good agreement for flow values with exceedance probabilities lower than 10% (e.g. flood events). Model predictions for one individual flood event may be either low or high. However, the model captures the statistic behavior of the historic record and therefore is an appropriate tool to make flood impact reductions assessments.

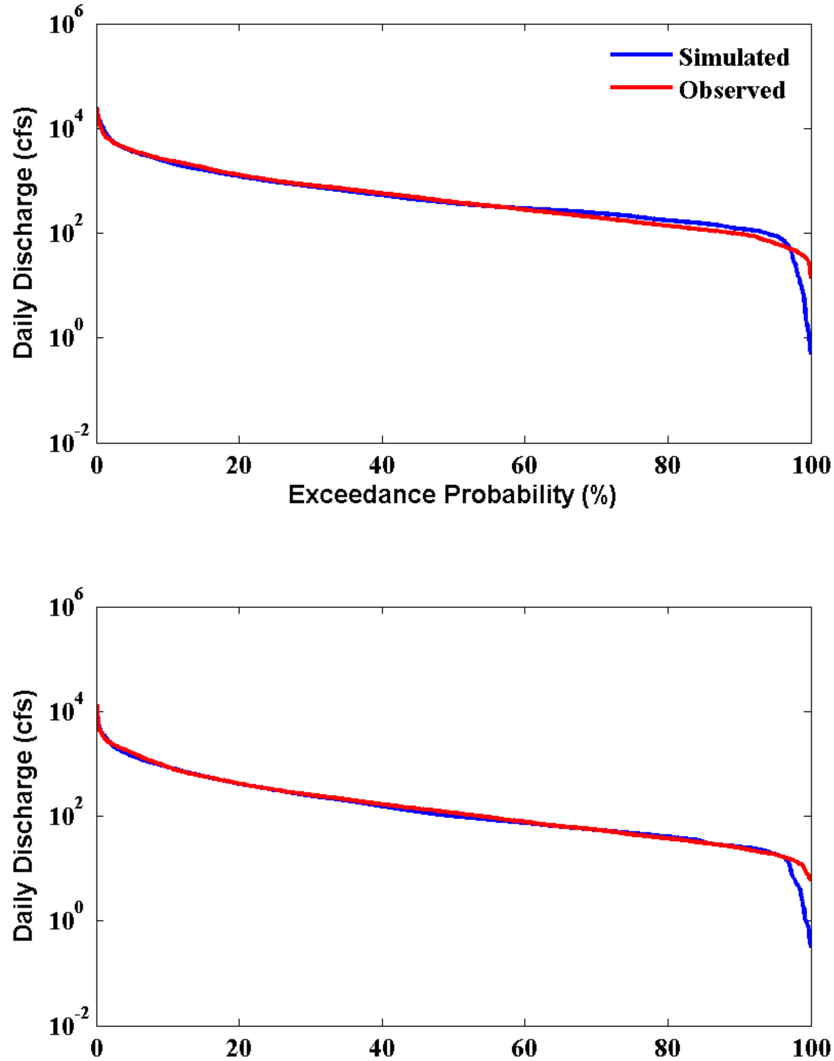


Figure 3.8. Daily flow duration curves. Top: Independence (USGS 05421000), Bottom: Tripoli (USGS 05420680).

4. Analysis of Watershed Scenarios

The GHOST model of the Upper Wapsipinicon Watershed was used to identify areas in the watershed with high runoff potential and run simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed as well as the consequences of projected increases in heavy downpours in Iowa and the Midwest for the mid and late 21st century described in the latest Climate Science Special report (see Figure 1.16). Focus for the scenarios was placed on understanding the impacts of (1) increasing infiltration in the watershed and (2) implementing a system of distributed storage projects (ponds) across the landscape.

a. Increased Precipitation and Index Points

To generate forcing data for the increased precipitation (IP) simulations a simple approach was followed. For each one of the rainfall pixels with observed hourly data (2002-2016), daily accumulations were calculated (see Figure 3.3). All the days were ranked and for the wettest 5% of the non-zero-rain days hourly precipitation values were increased by 10%. No other meteorological data were modified for the IP simulations. For the 15 years of available data, precipitation for approximately 95 days was altered.

This simple approach maintained the same spatial and temporal patterns of the heavy storms observed between 2002 and 2016 while increasing precipitation volumes. Furthermore, it is not an attempt to be a comprehensive weather generation exercise but rather an easy way to quantify the impact of projected changes in heavy precipitation on flooding in the Upper Wapsipinicon watershed. The IP simulations have slightly higher (< 3%) average values of annual precipitation. However, unsurprisingly, model predictions show more severe flooding events when using the altered precipitation time series.

The hydrologic model makes predictions at approximately 1,500 locations along the stream network. Twelve index points were selected to present the results for the different watershed scenarios. These points were chosen based on several criteria including location of a USGS gauging station, areas of high risk potential and/or proximity to a community, and to demonstrate the model results at different spatial scales. Points are presented in Table 4.1.

Table 4.1. Index points.

Index Point	Description
1	East Fork Wapsipinicon River
2	Wapsipinicon River near Tripoli (USGS Gauge)
3	Little Wapsipinicon River
4	Wapsipinicon River at Independence (USGS Gauge)
5	Buffalo Creek
6	Wapsipinicon River upstream from Anamosa

b. High Runoff Potential Areas

Identifying areas of the watershed with higher runoff potential is the first step in selecting mitigation project sites. High runoff areas offer the greatest opportunity for retaining more water from large rainstorms on the landscape and reducing downstream flood peaks. Figure 4.1 shows the runoff coefficient as a percentage (from 0% for no runoff to 100% when all rainfall is converted to runoff). Runoff coefficients in the Upper Wapsipinicon Watershed vary between 28% and 38% with the highest runoff potential areas primarily located upstream from the index point 5 as well as in the upper part of the watershed. Agricultural land use dominates these areas, however this is not the sole reason they might produce higher runoff. From a hydrologic perspective, flood mitigation projects that can reduce runoff from these high runoff areas would be a priority.

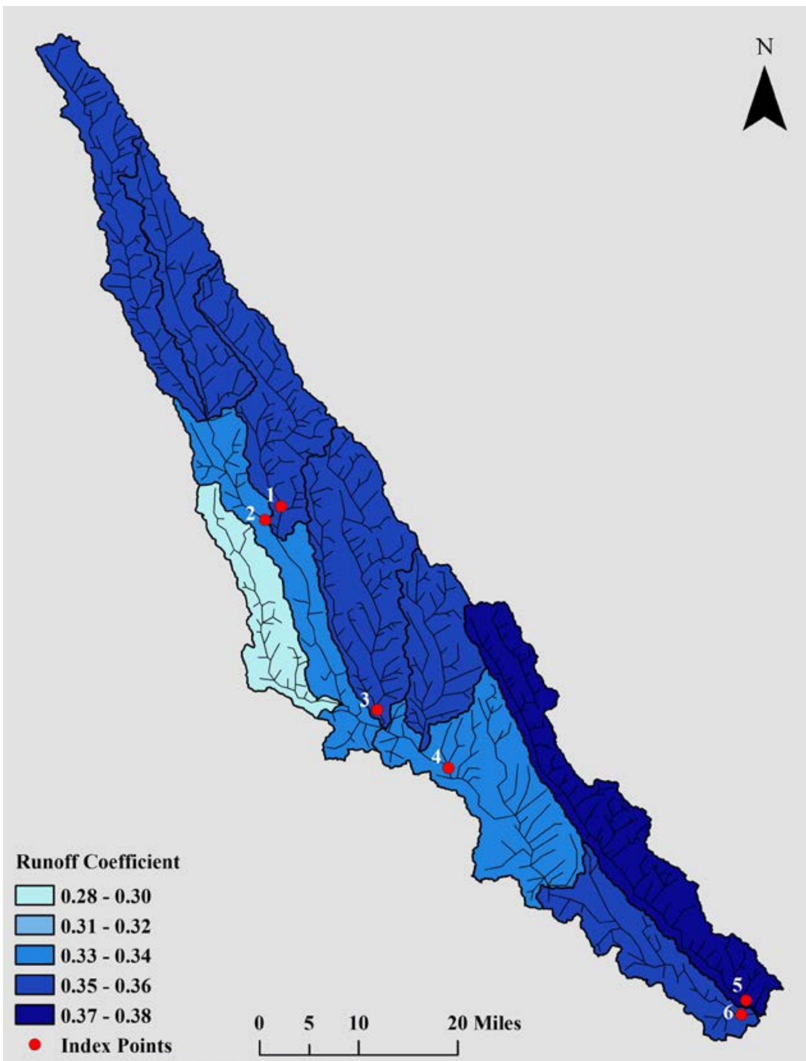


Figure 4.1. Index Points and runoff coefficient analysis for the Upper Wapsipinicon Watershed. This figure shows the runoff coefficients for the simulation period (2002-2016).

High runoff potential is but one factor in selecting locations for potential flood mitigation strategies. There are many factors to consider in site selection. Landowner willingness to participate is essential. Locations may have existing conservation practices in place or areas such as timber that should not be disturbed. Stakeholder knowledge of places with repetitive loss of crops or roads/road structures is also valuable in selecting locations. Lastly, the geology of the area may limit the effectiveness or even prohibit application of certain mitigation projects.

c. Mitigating the Effects of High Runoff with Increased Infiltration

Changes in a watershed that result in a particular area having greater infiltration will reduce the volume of water that leaves that drainage area during the storm event and for a few days thereafter. The increased water that passes from the surface into the ground may later evaporate or it will travel through the soil, either seeping deeper into the groundwater stores or travel beneath the surface towards a stream. The rate of travel of the water in this path beneath the surface is much slower than if it were running across the surface. While much of this water may eventually make it to a stream, it will be at a much later time than if it were surface runoff.

In this section, we examine two different alternatives to reduce runoff through land use changes and soil quality improvements. One hypothetical land use change would be the conversion of row crop agriculture back to native tall-grass prairie. Another possible land use change would be improvements to agricultural conditions that would result from planting cover crops during the dormant season as well as adoption of no-till in 100% of the rowcrop acres. These are hypothetical examples and are only meant to illustrate the potential effects on flood reduction. The examples are also not project proposals; they are either economically undesirable or not practically feasible. Still, the hypothetical examples do provide valuable benchmarks on the limits of flood reduction that are physically possible with broad-scale land cover changes.

Modifications to baseline model parameters to represent land use changes (e.g. native vegetation and cover crops/no-till) were based on information reported by several studies: Baschle, (2017); Mohamoud, (1991); VanLoocke et al., (2012); Kang et al. (2003); Baron et al. (1993), Bharati et al. (2002); Yimam et al. (2015), and Cronshey, (1986).

i. Mitigating the Effects of High Runoff with Native Vegetation

Much has been documented about the historical hydrology of the native tall-grass prairie of the Midwestern states, with evidence suggesting the tall-grass prairie could handle up to six inches of rain without having significant runoff. This is a result of the deep, loosely-packed soils and the deep root systems of the prairie plants that allowed a high volume of the rainfall to infiltrate into the ground. The water was retained across the landscape in the soil pores or it slowly flowed beneath the ground surface through the soil instead of finding a rapid course to a nearby stream as surface flow. Much of the water once in the subsurface was actually taken up by the root systems of the prairie grasses and returned to the atmosphere via transpiration.

An analysis could be performed proposing a scenario where all current rowcrop acres are converted back to native tall-grass prairie with its much higher infiltration characteristics within the Upper Wapsipinicon Watershed. The goal of the IWA project is to sustain Iowa's valuable agricultural economy while protecting vulnerable residents and communities. Therefore the simulation results from a scenario that assumes massive implementation of native vegetation is not intended to be a recommended flood mitigation strategy; rather these results are meant to provide a theoretical maximum of the flood reduction benefits that can be expected from land use changes.

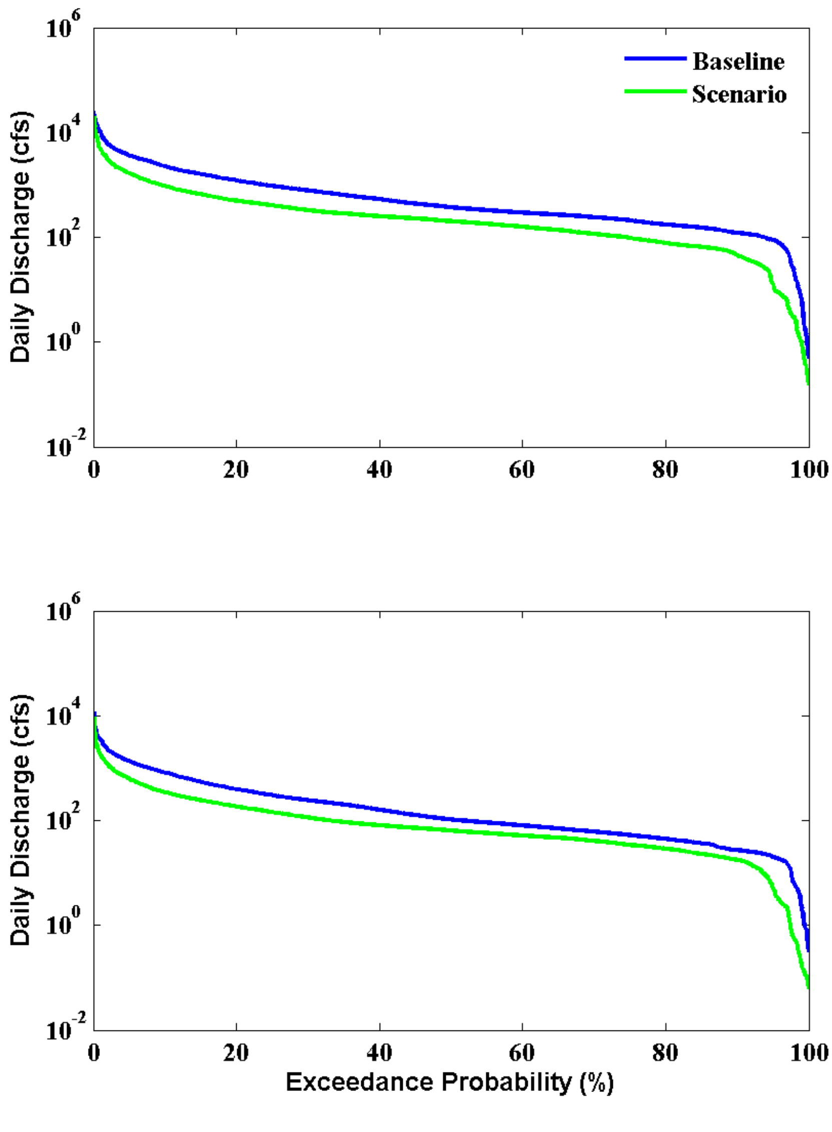


Figure 4.2. Native vegetation scenario. Daily flow duration curves. Top: Independence. Bottom: Tripoli.

The hydrologic processes affected by the parameter modifications for the native vegetation simulations were 1) high transpiration by modifying leaf area index (LAI), crop-coefficient, and root depth 2) parameters controlling infiltration were increased by approximately 60% 3) the amount of water stored in the unsaturated zone (e.g. available to plants) was increased on average 9% 4) surface roughness for the overland flow was multiplied by a factor of 4. It is important to mention that the differences between baseline conditions and scenario results are the reflection of the parameter modifications reported above and are not a confirmation that the flood reduction benefits will come to pass if the scenario is implemented. In other words, the validity of the results presented here are highly dependent on the accuracy of the information reported in the studies we are basing our analyses on.

Figure 4.2 displays the effects of having deep-rooted vegetation in the landscape all year round. High, medium, and low flows are attenuated by replacing rowcrop acres with Switchgrass. Results presented in Figure 4.2 are consistent with high infiltration, high transpiration, and high surface roughness conditions.

Figure 4.3 displays the flood frequency analysis at six index points (see Table 4.1 and Figure 4.1) for three different simulations: baseline, native vegetation, and native vegetation plus increased precipitation. The plots were built using the 15 annual maximum peak discharges and a sample estimate of the exceedance probability. Results show that the adoption of native vegetation significantly reduces peak discharges at all six locations, for all the 15 years, and under both historic and increased precipitation conditions.

In each one of the panels in Figure 4.3 the average peak flow reduction is reported for both Baseline vs. Native Vegetation and Baseline vs. Native Vegetation + IP. Peak flow reduction decreases as one moves downstream. The highest average peak flow reductions were found at the index point 1 and the lowest at point 6. Under historic precipitation conditions, the average peak flow reduction in the Upper Wapsipinicon River upstream from Anamosa (index point 6) is 47% whereas that value for the IP simulations is reduced to 34%. We mapped average peak reductions at the six index points in Figure 4.4. Results in this figure were obtained with information from the baseline and Native Vegetation simulations.

The transformation of rainfall into runoff is known to be a highly non-linear process and therefore increases in precipitation volumes by a given percentage are not expected to result in similar increases in peak flow magnitude. In other words, a 10% increase in heavy precipitation does not necessarily create flood peaks that are 10% larger. Model predictions show that for the most severe floods (see Figure 4.3, exceedance probabilities < 20%, scenario vs. scenario + IP), increases in peak discharges due to increases in heavy precipitation are up to approximately 40%.

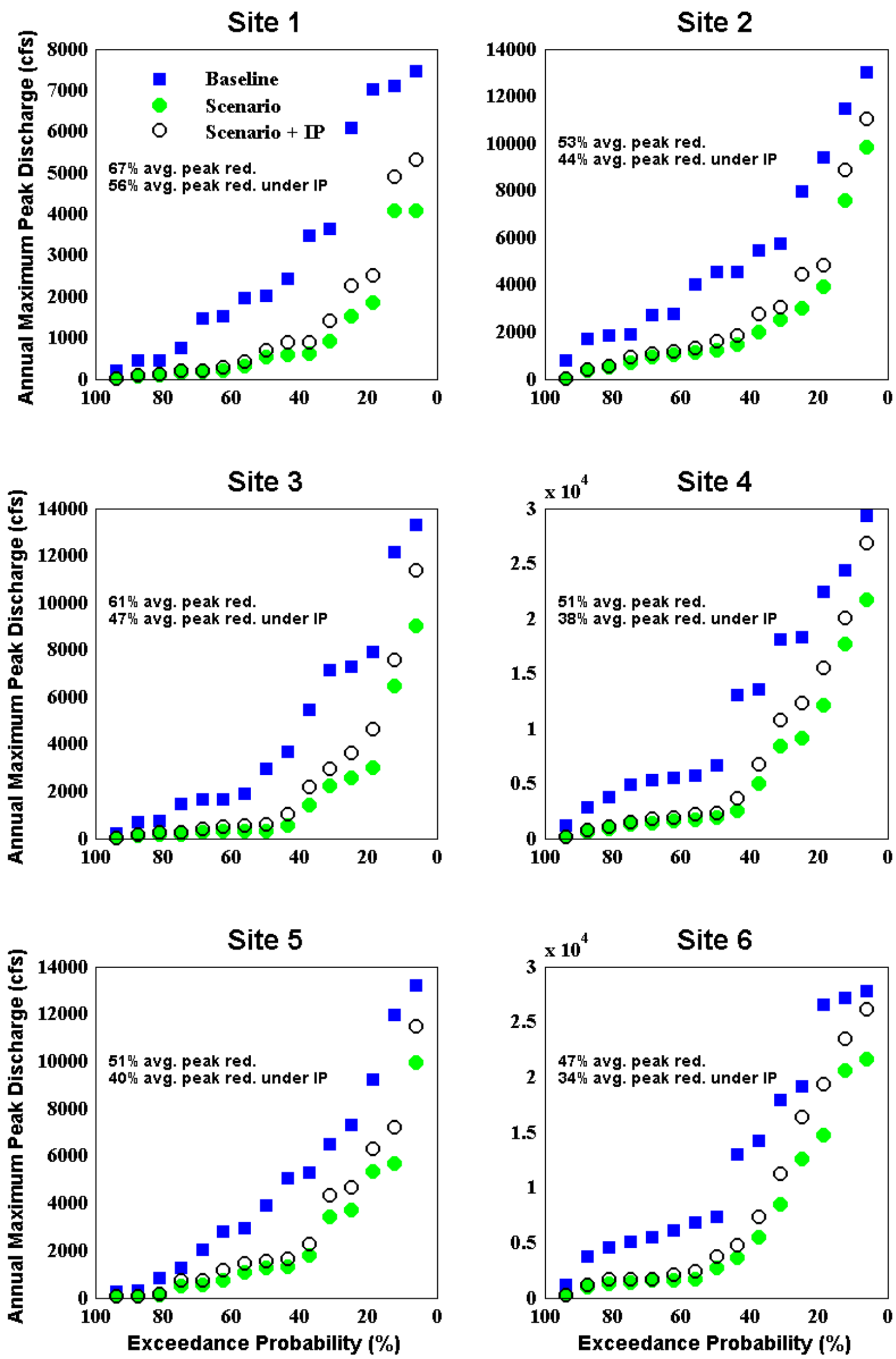


Figure 4.3. Sample probability distribution of annual maximum peak discharges for the baseline, native vegetation, and native vegetation plus increased precipitation simulations. Results are shown at the six index points displayed in Figure 4.1 and Table 4.1. Baseline corresponds with the calibrated model.

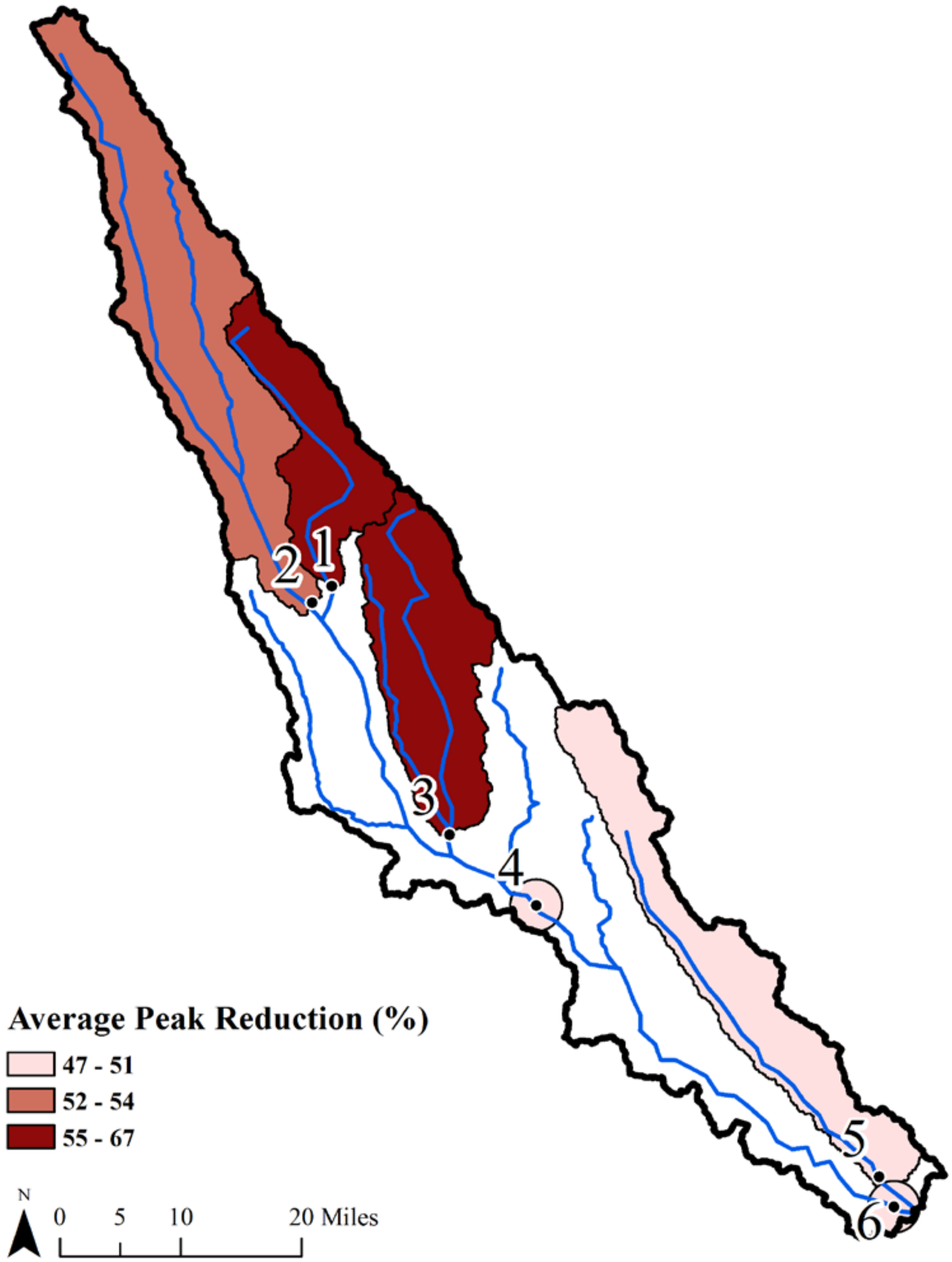


Figure 4.4. Average peak discharge reduction (%) for index points in the Upper Wapsipinicon Watershed. Baseline vs. Native Vegetation (historic precipitation).

ii. Mitigating the Effects of High Runoff with Cover Crops/Soil Health/No-Till

Cover crops can be an effective farming conservation practice. Cover crops are typically planted following the harvest of either corn or soybeans and "cover" the ground through winter until the next growing season begins. The cover crop can be killed off in the spring by rolling it or grazing it with livestock or most often with Roundup (Glyphosate); afterwards, row crops can be planted directly into the remaining cover crop residue. Cover crops provide a variety of benefits including improved soil quality and fertility, increased organic matter content, increased infiltration and percolation, reduced soil compaction, and reduced erosion and soil loss. They also retain soil moisture and enhance biodiversity (Mutch, 2010). One source suggests that for every one percent increase in soil organic matter (e.g. from 2% to 3%), the soil can retain an additional 17,000-25,000 gallons of water per acre (Archuleta, 2014). Examples of cover crops include clovers, annual and cereal ryegrasses, winter wheat, and oilseed radish (Mutch, 2010).

The purpose of this hypothetical example is to investigate the impact of improved agricultural management practices could have on reducing flood peak discharges throughout the watershed. Planting cover crops across all agricultural areas in the watershed during the dormant (winter) season is hypothesized to lower the runoff potential of these same areas during the growing season (spring and summer) due to increased soil health and fertility. To be clear, this scenario does not represent the conversion of the existing agricultural landscape to cover crops. Rather, the existing agricultural landscape is kept intact, but its runoff potential during the growing season has been reduced by planting cover crops, in all rowcrop acres, during the dormant season.

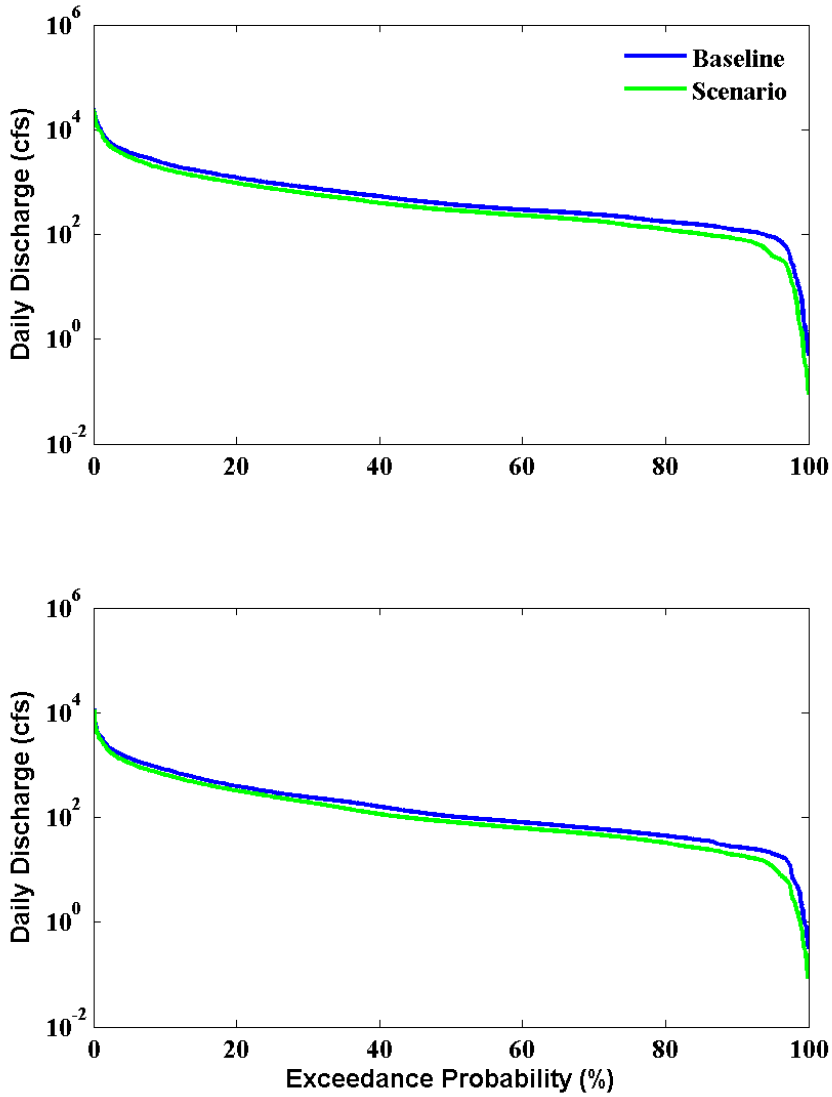


Figure 4.5. Cover Crops/Soil Health/No-Till scenario. Daily flow duration curves. Top: Independence. Bottom: Tripoli.

The hydrologic processes affected by the parameter modifications for the cover crop/soil health/no-till simulations were 1) high transpiration by modifying leaf area index (LAI), crop-coefficient, and root depth for the dormant season 2) parameters controlling infiltration were increased by approximately 40% 3) the amount of water stored in the unsaturated zone (e.g. available to plants) was increased on average 4% 4) surface roughness for the overland flow was multiplied by a factor of 3. It is important to mention that the differences between baseline conditions and scenario results are the reflection of the parameter modifications reported above and are not a confirmation that the flood reduction benefits will come to pass if the scenario is implemented. In other words, the validity of the results presented here are highly dependent on the accuracy of the information reported in the studies we are basing our analyses on.

The model parameter modifications described above to simulate the massive implementation of cover crops and no-till practices in the Upper Wapsipinicon Watershed are a "light version" of the changes implemented in the model for the native vegetation scenario. Both scenarios assume that the soil is covered all year round, that infiltration is increased, transpiration increases, and overland flow is less likely to occur with all those changes being more severe in the native vegetation scenario than in the cover crops/no-till simulations.

Figure 4.5 shows that daily streamflows are reduced by the implementation of cover crops/no-till practices. Based on the model results, cover crops/no-till practices reduce peak discharges for all the years at all index points when using measured precipitation data (Figure 4.6). This is largely true for the model results of the simulations with cover crops/no-till plus increased precipitation but there are some instances with peak discharge values for the simulations with increased precipitation being larger than those of the baseline condition (see Figure 4.6, Index Points 2, 4, and 6, black circles above the blue squares). This behavior was found at the index points along the Upper Wapsipinicon River and for the annual peaks with low exceedance probability. The largest and the smallest average peak flow reductions were found at points 1 and 6, respectively. Average peak discharge reductions are presented in Figure 4.7 for all the index points.

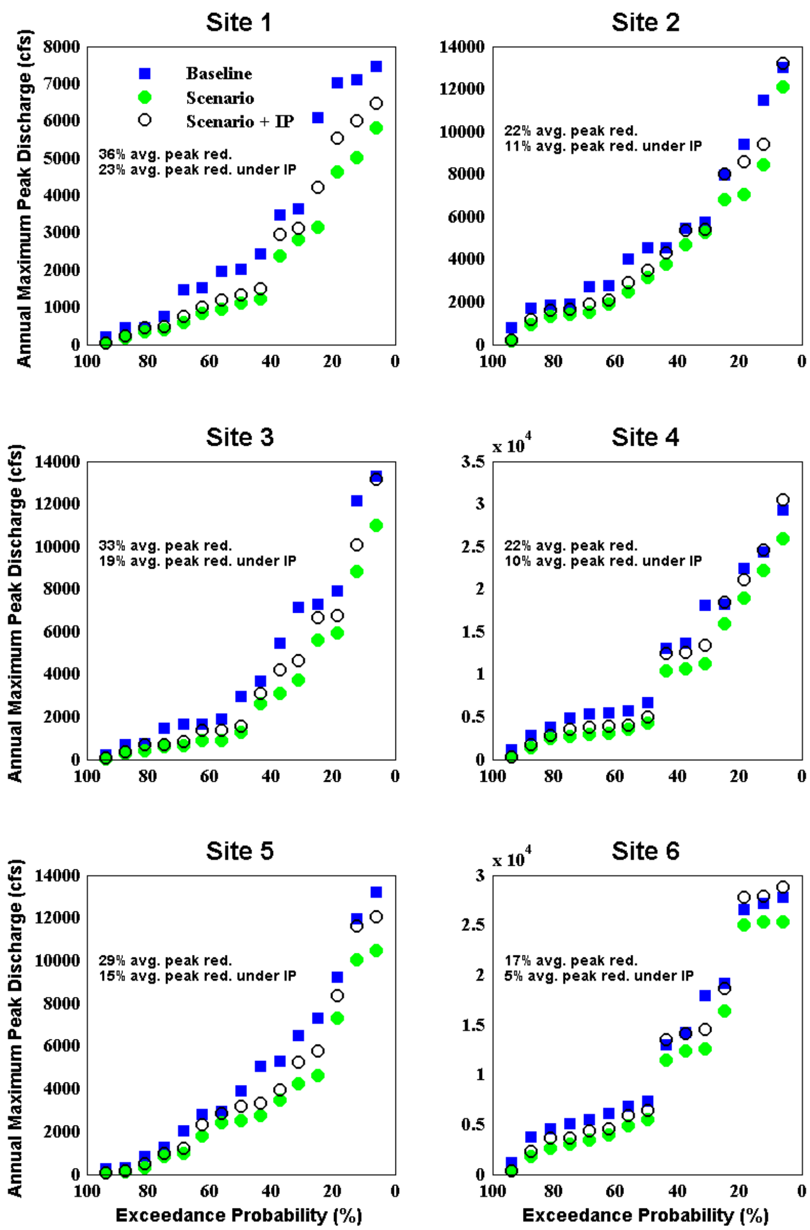


Figure 4.6. Sample probability distribution of annual maximum peak discharges for the baseline, cover crops/no-till, and cover crops/no-till plus increased precipitation simulations. Results are shown at the six index points displayed in Figure 4.1 and Table 4.1. Baseline corresponds with the calibrated model.

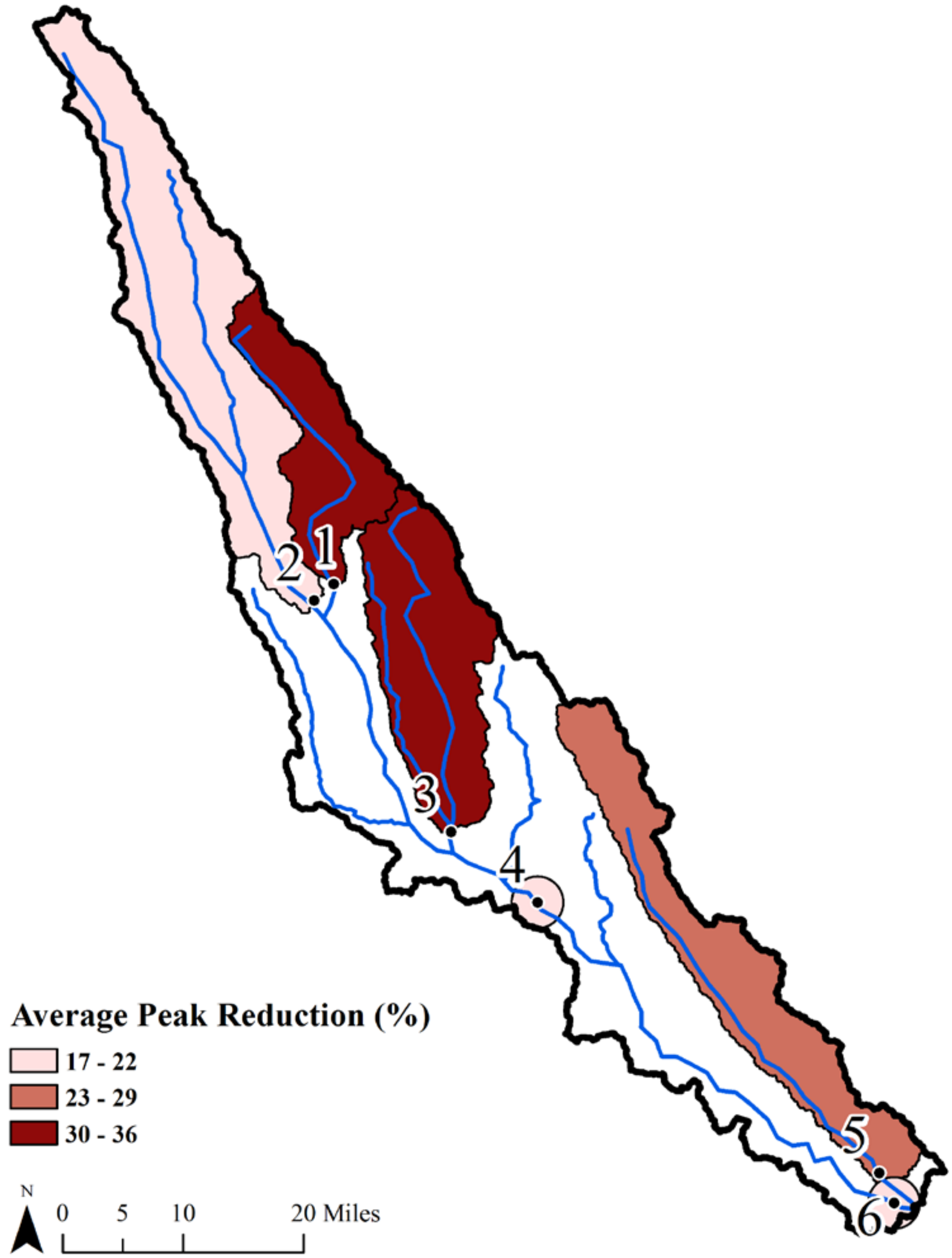


Figure 4.7. Average peak discharge reduction (%) for index points in the Upper Wapsipinicon Watershed. Baseline vs. Cover Crop/No-Till (historic precipitation).

d. Mitigating the Effects of High Runoff with Distributed Storage

Storage ponds (Figure 4.8) hold floodwater temporarily, and then release it at a lower rate later. Therefore, the peak flood discharge downstream of the storage pond is lowered. The effectiveness of any one storage pond depends on its size (storage volume) and how quickly water is released.

By adjusting the size and the pond outlets, storage ponds can be engineered to efficiently utilize their available storage for large floods. Generally, these ponds have a permanent pond storage area, meaning the pond holds water all the time. This is done by constructing an earthen embankment across a stream and setting an outlet (usually a pipe) called the principal spillway at some elevation above the floor of the pond. When there is a storm event, runoff enters the pond. Once the elevation of the water surface is greater than the pipe inlet, water will pass through the pipe, and leave the pond, but at a controlled rate. Additionally, the earthen dam is built higher than the pipe, allowing for more storage capacity within the pond. An emergency spillway that can discharge water at a much faster rate than the pipe is set some elevation higher than the pipe. This emergency spillway is constructed as a means to release rapidly rising waters in the pond so they do not damage the earthen embankment. The volume of water stored between the principal spillway and the emergency spillway is called the flood storage.

The hypothetical distributed storage analysis performed using the Upper Wapsipinicon GHOST model was based on potential project locations developed from the outputs of the ACPF tool (see Figure 2.10) within the Upper Wapsipinicon Watershed and the distributed storage concept developed by the Soap Creek Watershed.

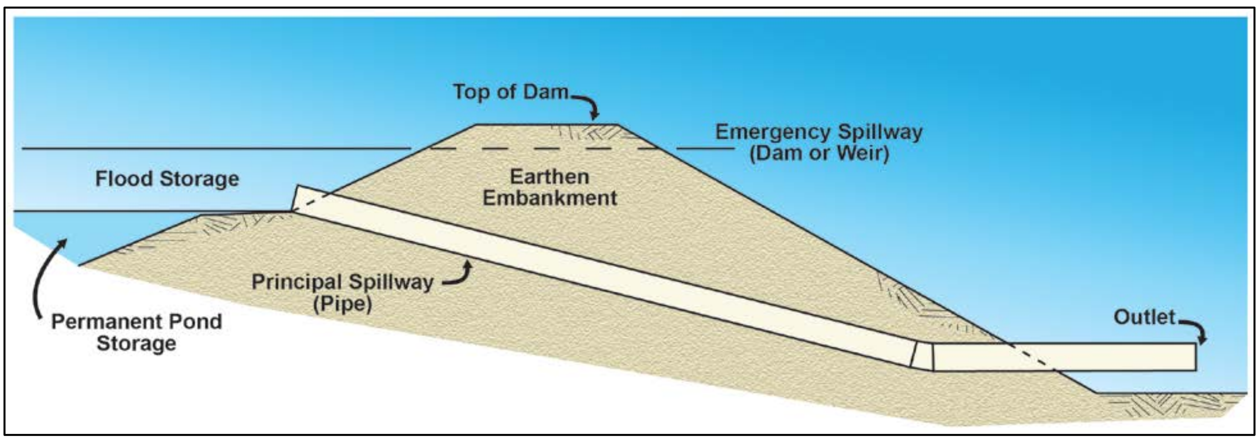


Figure 4.8. Schematic of a pond constructed to provide flood storage.

The Soap Creek Watershed Board was formed in the 1980’s as a result of the watershed’s landowners coming together wanting to do something to reduce flood damage and erosion within their watershed. They adopted a plan that included identifying the locations of 154 distributed storage structures (mainly ponds) that could be built within the watershed. As of 2018, 135 of these structures have been built (Stolze, 2018).

Soap Creek Watershed drains approximately 250 square miles, equaling an average density of 1 built pond for every 1.9 square miles of drainage area. Further analysis of the Soap Creek structures shows that most of these structures are constructed in the headwater areas of the watershed, which allows for smaller structures, rather than having large, high-hazard class structures on the main rivers.

For the analysis, 919 ponds were simulated in the Upper Wapsipinicon Watershed (Figure 4.9). A “typical” pond was developed for use for the Upper Wapsipinicon Watershed using the existing

Soap Creek ponds and NRCS Technical References as guidance. The geometry of this typical pond consists of a 12-inch pipe outlet as the principal spillway with a 10-foot wide emergency spillway set at an elevation above the pipe to provide a flood storage of 20 acres-feet. Site topography will actually dictate the placement of the emergency spillway and the potential dam height. The stage-storage relationship of a pond also depends on local topography and is highly variable from site to site. There certainly are opportunities to design and construct ponds at locations in subbasins that have not been used in this analysis. Furthermore, some of the locations selected for ponds may be far from ideal. Therefore flood reductions presented below do not represent the theoretical maximum of the flood reduction benefits that can be expected from massive construction of ponds throughout the watershed.

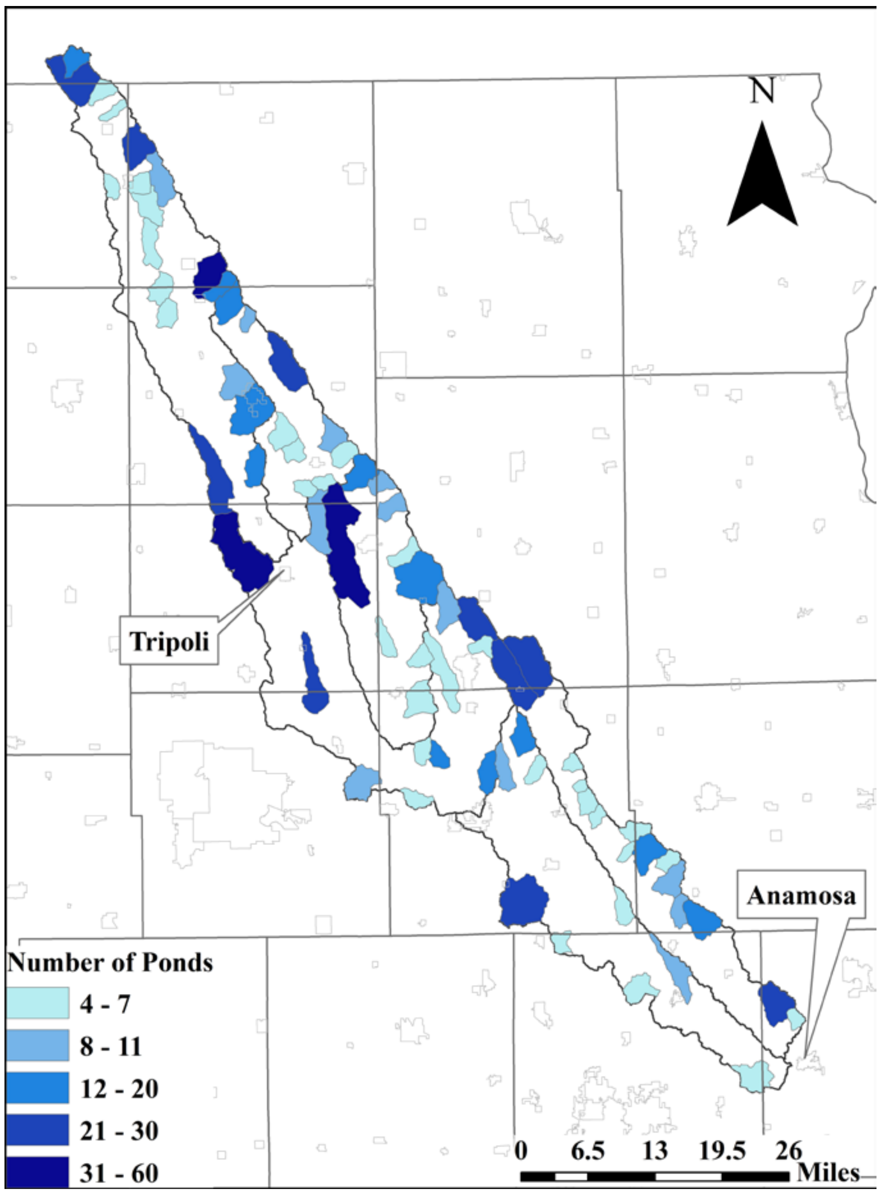


Figure 4.9. Ponds (919) placement in the Upper Wapsipinicon Watershed.

Model results show that the system of ponds generates minor changes in the daily flow duration curve at both Tripoli and Independence (see Figure 4.10). It is important to mention that in both the native vegetation and cover crops/no-till simulations more water was being removed from the watershed via transpiration than in the baseline case. In contrast, the pond scenario does not have different transpiration parameters than the baseline case.

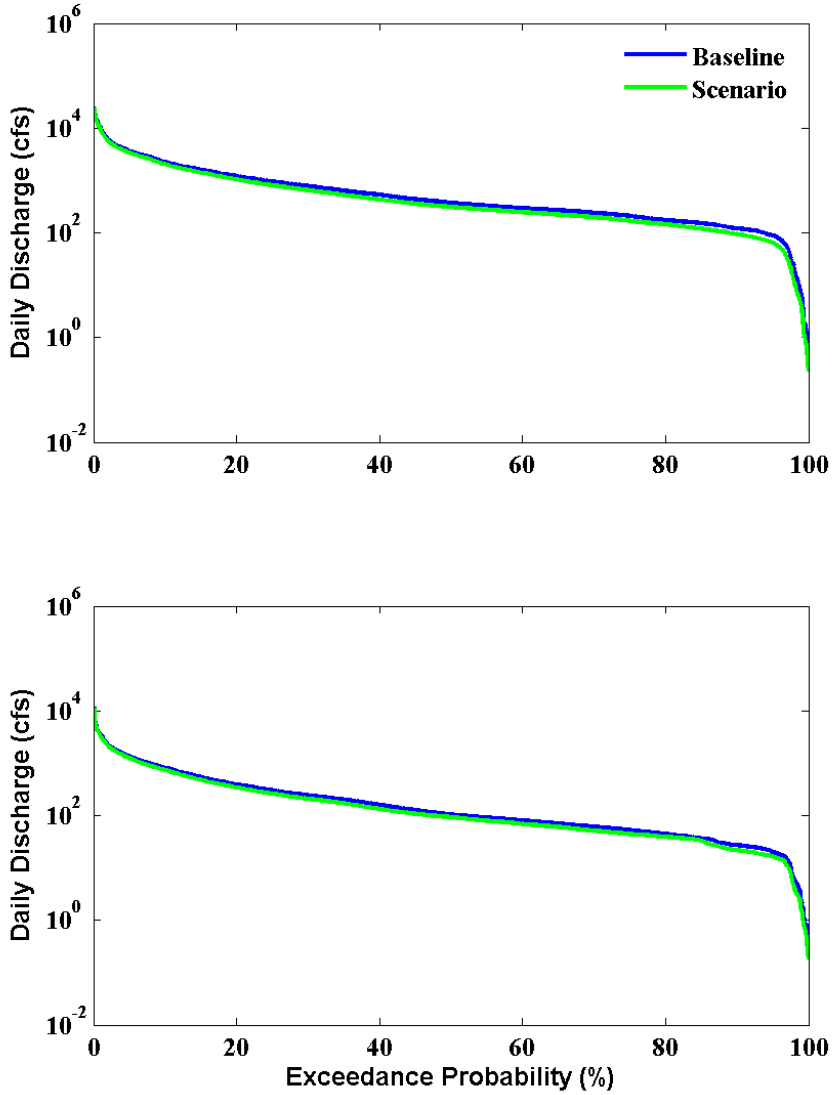


Figure 4.10. Distributed Storage scenario. Daily flow duration curves. Top: Independence. Bottom: Tripoli.

Information on annual peak discharge reduction is presented in Table 4.2 and Figures 4.11 and 4.12. The 919 ponds result in average peak flow reductions at all index points, under historic precipitation conditions, that range between 5% and 16%. However, this reductions are smaller than those of the cover crops/no-till and native vegetation scenarios. As expected smaller reductions are found at the index points along the Upper Wapsipinicon River mainstem (Index Points 2, 4, and 6).

Simulation results with increased precipitation conditions show that only at index points 1 and 5 the largest peaks are slightly attenuated by the system of ponds (see Figure 4.11). At the other index points the ponds are insufficient to keep the highest predicted flows below the baseline conditions (points 2, 3, 4, and 6).

Table 4.2. Average peak flow reduction at the index points.

Index Point	Drainage Area (DA) (mi^2)	Number of Ponds	Drainage Area Regulated (DAR)(mi^2)	DAR/DA	Avg. Peak Reduction (%)	Avg. Peak Reduction under IP (%)
1	132.9	86	47.0	0.35	16	2
2	346.5	254	125.6	0.36	5	-9
3	206.9	129	82.6	0.40	8	-11
4	1051.8	654	355.4	0.34	5	-10
5	223.8	178	85.5	0.38	11	-2
6	1334.2	741	417.6	0.31	5	-9

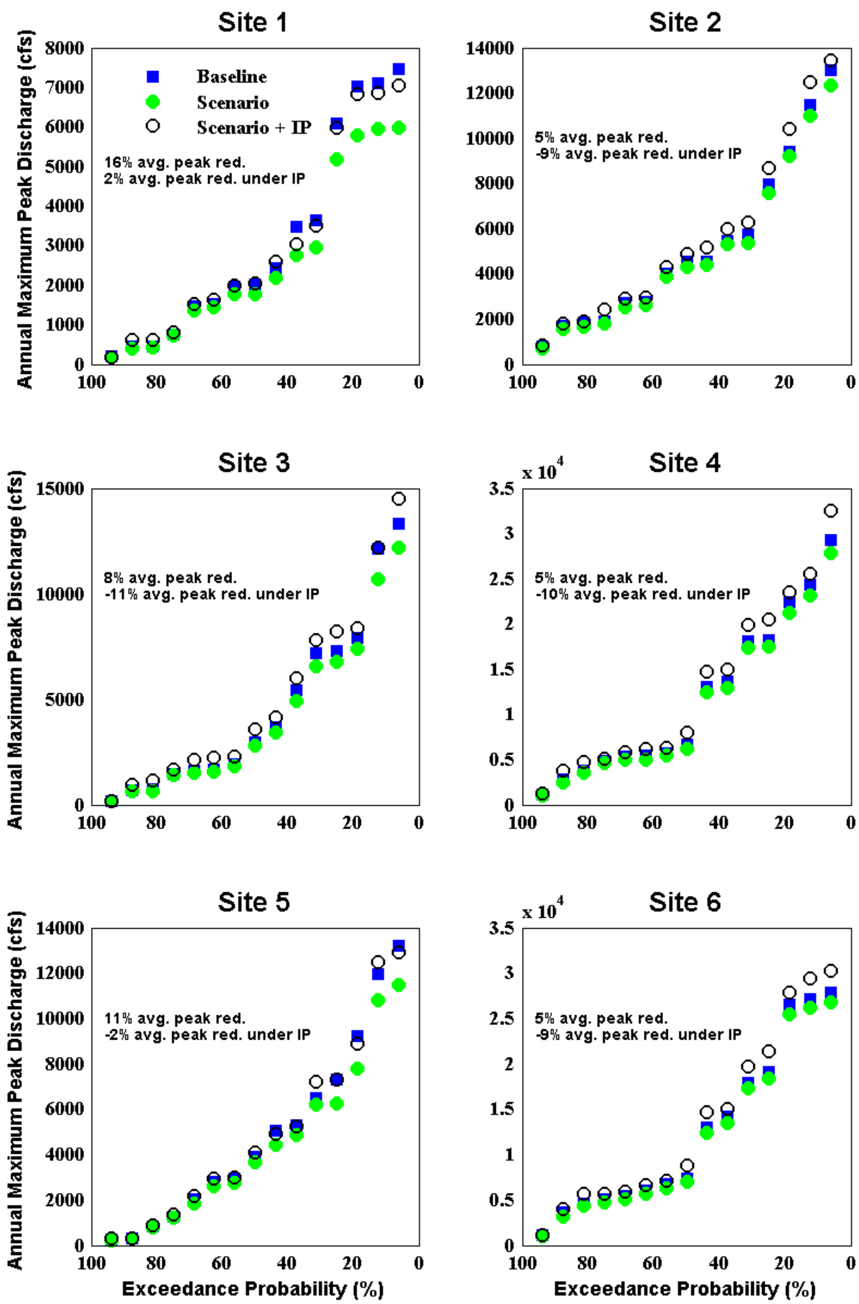


Figure 4.11. Sample probability distribution of annual maximum peak discharges for the baseline, distributed storage, and distributed storage plus increased precipitation simulations. Results are shown at the six index points displayed in Figure 4.1 and Table 4.1. Baseline corresponds with the calibrated model.

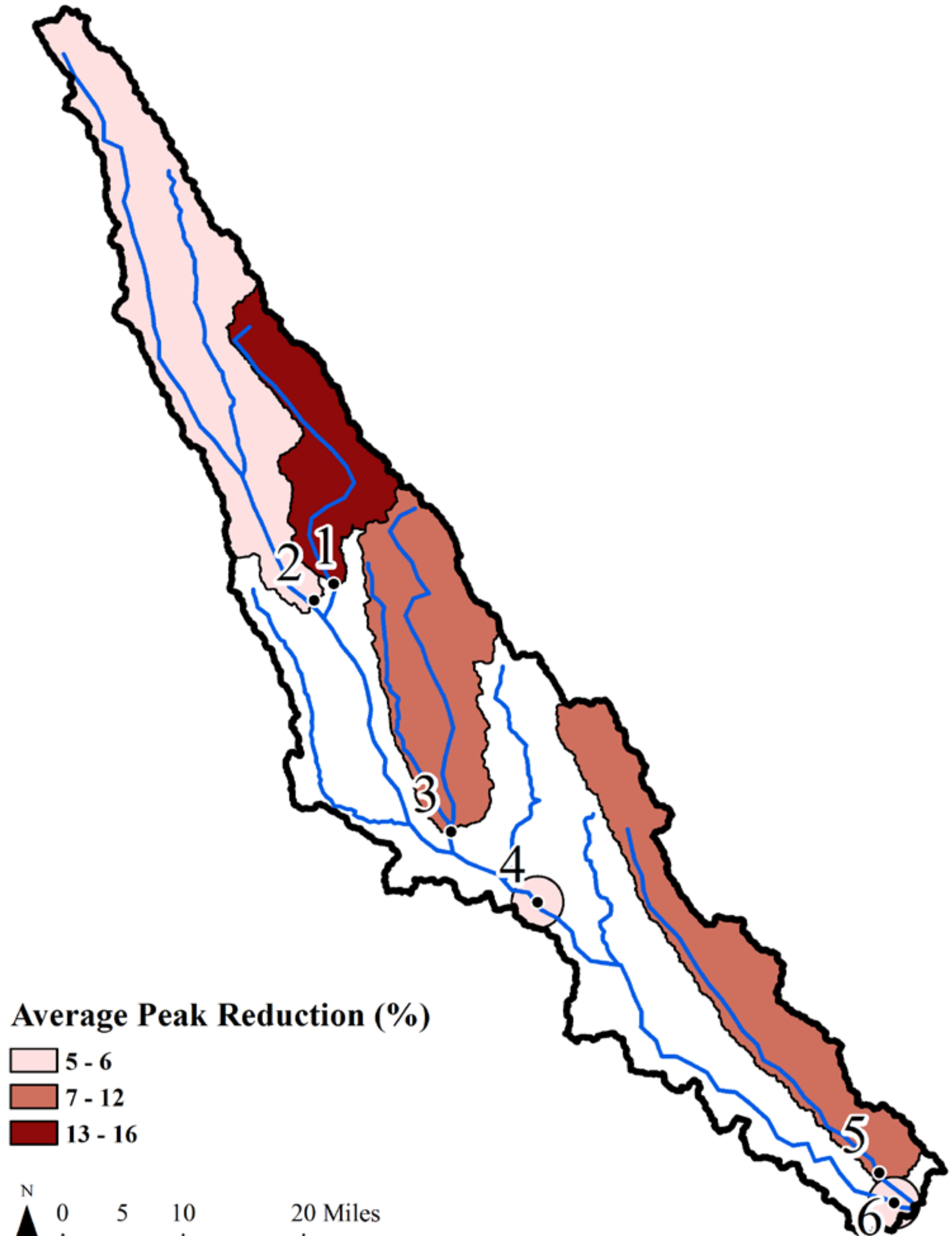


Figure 4.12. Average peak discharge reduction (%) for index points in the Upper Wapsipinicon Watershed. Baseline vs. Distributed Storage (historic precipitation).

5. Summary and Conclusions

The Upper Wapsipinicon Watershed is one of nine distinct Iowa watersheds participating in the IWA program. The program will accomplish six specific goals in each watershed: (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 purpose of this hydrologic assessment report is to provide an understanding of the watershed hydrology in the Upper Wapsipinicon Watershed and the potential of various hypothetical flood mitigation strategies that may be leveraged to accomplish goals of the IWA.

a. Upper Wapsipinicon Water Cycle and Watershed Conditions

We examined the water cycle of the Upper Wapsipinicon Watershed using historical precipitation and streamflow records. The average annual precipitation for the Upper Wapsipinicon Watershed is approximately 36.0 inches (33 inches in the upper part and 38 inches in the lower part). Of this precipitation amount, roughly 70% (25.0 inches) evaporates back into the atmosphere and the remaining 30% (11.0 inches) runs off the landscape into the streams and rivers. The majority of the runoff amount is baseflow (65% or 7.2 inches), and the rest is surface flow (35% or 3.8 inches). Average monthly streamflow peaks in June, and decreases slowly through the summer growing season. In most years, the largest discharge observed during the year occurs in May or June, associated with heavy spring/summer rainfall events.

The water cycle has changed due to land use and climate changes. Since the 1970s, Iowa has seen increases in precipitation, changes in timing of precipitation, and changes in the frequency of intense rain events. Streamflow records in Iowa (including those for the Upper Wapsipinicon watershed) suggest that average flows, low flows, and perhaps high flows have all increased and become more variable since the late 1960s or 1970s; however, the relative contributions of land use and climate changes are difficult to sort out.

The Upper Wapsipinicon River Watershed is located almost entirely within the Iowan Surface landform region, with a very small area of East-Central Iowa Drift Plain on the downstream edge of the watershed. The soil distribution of the Upper Wapsipinicon Watershed shows that the watershed consists primarily of HSG B type soils (60.6%), which have a moderate runoff potential when saturated. Relatively small components of type B/D (30.1%) soils are present. The remaining classes each comprise less than 5% of the total.

b. Upper Wapsipinicon Watershed Hydrologic Model

The modeling activities described in this report were performed using the physically-based integrated model GHOST developed at IIHR to simulate the hydrologic responses over time periods on the order of decades. GHOST stands for Generic Hydrologic Overland-Subsurface Toolkit. GHOST is based on the open source hydrologic code MM-pihm (Qu and Duffy 2007, Yu et al. 2013), which fully couples surface and subsurface domains to predict streamflow as well groundwater movement for normal and extreme rainfall and snowmelt events. All the model simulations, baseline and scenarios, were forced using 15 years (2002-2016) of hourly climatological data with 4-km spatial resolution and provided information not only for flood events but also on the watershed's hydrology during medium and low flows. Simulations were run using both measured precipitation as well as increased precipitation values obtained by applying the projected changes in heavy precipitation reported in the Climate Assessment Report for the mid and late 21st century.

c. Watershed Scenarios for the Upper Wapsipinicon Watershed

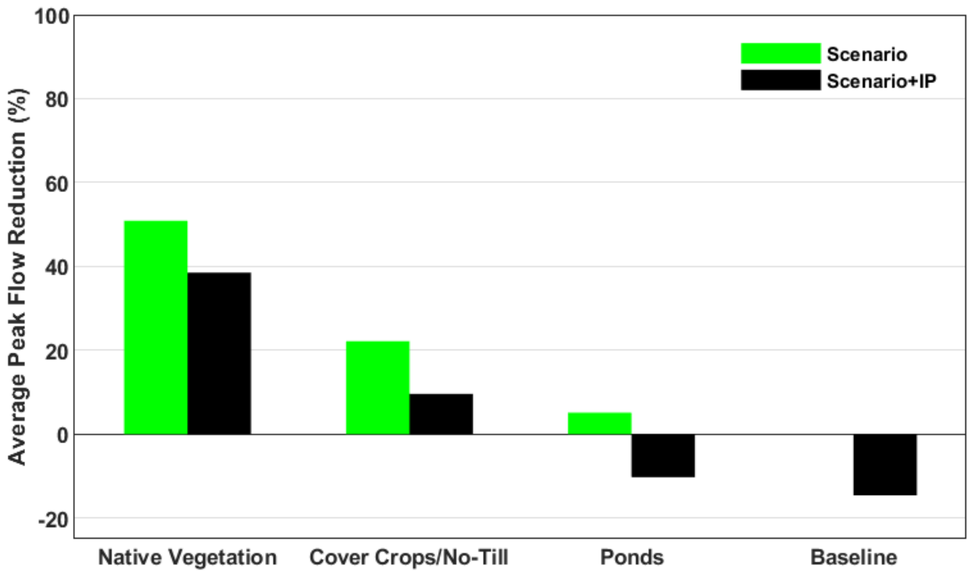
We used the GHOST model to better understand the flood hydrology of the Upper Wapsipinicon Watershed, and to evaluate potential flood mitigation strategies. We first assessed the runoff potential throughout the basin identifying locations with the highest runoff potential; mitigating the effects of high runoff from these areas should be a priority for flood mitigation planning.

The GHOST model was used to quantify the potential effects of three different flood mitigation strategies applied throughout the Upper Wapsipinicon Watershed: 1) conversion of 100% of the rowcrop acres to native vegetation, 2) adoption of both no-till and cover crops in 100% of the rowcrop acres, and 3) a distributed storage system built with ponds located in the headwater catchments.

The results for these strategies were compared to simulations of flows for the existing watershed condition using both historical and increased precipitation values. Although each scenario simulated is hypothetical and simplified, the results provide valuable insights on the relative performance of each strategy for flood mitigation planning.

Figure 5.1 presents model results at index point 4 (Wapsipinicon River at Independence). Average peak flow and peak flow stage reductions were estimated in reference to the baseline simulation with historic precipitation. The native vegetation scenario results reveal the enormous flood reduction potential of this practice and highlights why this land use change should be considered when evaluating flood reduction alternatives. When a landowner decides to take some land out of production (e.g. CRP program or excessive wetness making the land unprofitable) planting native vegetation in those acres has the potential to generate flood reduction benefits. Cover Crops/No-Till is a management practice that when implemented throughout agricultural watersheds has the potential to lead to important flood reduction benefits. Based on the Upper Wapsipinicon model results, this practice shows average peak flood reduction of 22% and 9% at Independence for the simulations with historic rain and increased precipitation, respectively. The 919 ponds provide peak flow reductions of 5% with historic rain but when increased precipitation conditions were simulated model results show higher peak flows than those of the baseline condition.

Under historic precipitation conditions (in 2008, see Figure 5.1 bottom panel) flood stage reductions predicted by the model are 41 and 7 inches for the native vegetation and pond scenarios, respectively. Using increased precipitation (e.g. 2008 rain plus projected increases in heavy rain) conditions the model predicts that neither cover crops nor the 919 ponds are able to keep the flood stages below the baseline conditions.



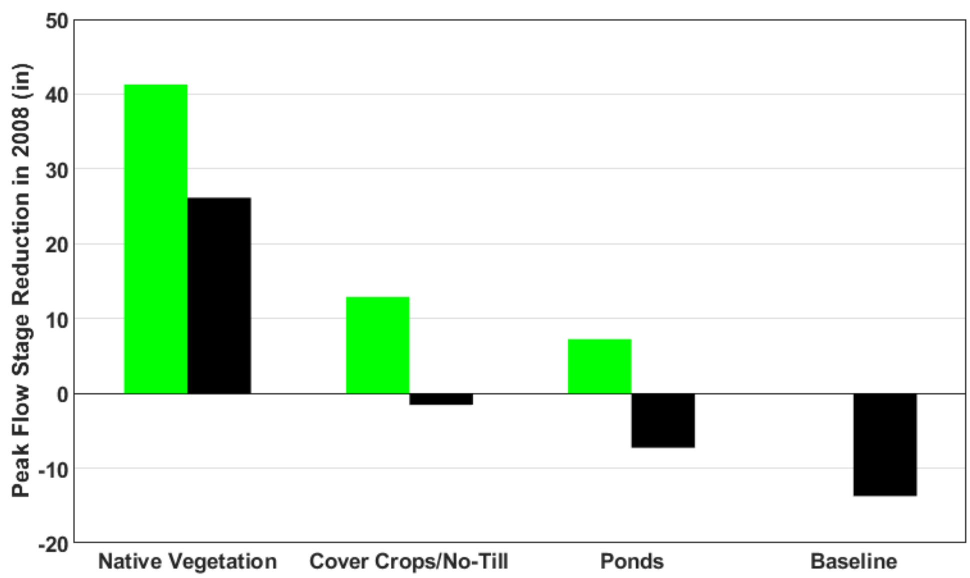


Figure 5.1. Model results at Independence. Top: average peak flow reductions for all the simulations. Bottom: Peak flow stage reduction in 2008.

d. Watershed Scenarios for the Upper Wapsipinicon Watershed

As a final note, it is important to recognize that the modeling scenarios evaluate the *hydrologic effectiveness* of the flood mitigation strategies, and not their effectiveness in other ways. For instance, while certain strategies are more effective from a hydrologic point of view, they may not be more effective economically. As part of the flood mitigation planning process, factors such as the cost and benefits of alternatives, landowner willingness to participate, and more need to be considered in addition to the hydrology.

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