IIHR Report
No. 500

September, 2016

Iowa Watersheds Project
Phase II Report

Beaver Creek Watershed

Project Evaluation

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

Sponsored by:
Upper Cedar River Watershed Management Improvement Authority

Iowa Flood Center
IIHR Hydroscience & Engineering

IIHR — Hydroscience & Engineering
The University of Iowa
C. Maxwell Stanley Hydraulics Laboratory
Iowa City, Iowa 52242

Iowa Watersheds Project Phase II: Beaver Creek Watershed Evaluation of Project Performance

September 2016

IIHR Technical Report No. 500

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

Acknowledgements

The Iowa Flood Center and IIHR—Hydroscience & Engineering would like to thank the following agencies and organizations for providing data and engaging in discussions that contributed to this assessment:

Ducks Unlimited, Inc. of Bismarck, ND
Floyd County Soil & Water Conservation District
Chickasaw County Soil & Water Conservation District
Iowa Department of Natural Resources
Mitchell County Soil & Water Conservation District
Natural Resources Conservation Service
Upper Cedar River Watershed Management Improvement Authority

Cover photograph. Beaver Creek, Chickasaw County. Photograph by Chickasaw County Soil & Water Conservation District.

Table of Contents

List of Figures

List of Tables

1. Introduction

Heavy rains and subsequent flooding during the summer of 2008 brought economic, social, and environmental impacts to many individuals and communities in watersheds across the state of Iowa. In the response and recovery aftermath, a handful of Watershed Management Authorities — bodies consisting of representatives from municipalities, counties, and soil and water conservations districts — have formed to tackle local challenges with a unified watershed approach.

In 2010, Iowa received $8.8 million from the U.S. Department of Housing and Urban Development (HUD) to assist with ongoing disaster recovery programs following these devastating floods. The Iowa Flood Center (IFC), a unit of the University of Iowa's IIHR—Hydroscience & Engineering, led an effort called the Iowa Watersheds Project. Its goal was to evaluate and implement flood reduction methods in Iowa watersheds. The Upper Cedar Watershed, in collaboration with the Upper Cedar River Watershed Management Improvement Authority, was one of four watersheds (see Figure 1.1) selected to demonstrate a watershed approach for flood risk reduction.

In Phase I of the project, the Iowa Flood Center carried out a hydrologic assessment of the Upper Cedar River Watershed (Iowa Flood Center, 2014). The assessment characterized the water cycle of the Upper Cedar River using historical observations. It also investigated trends observed for the Upper Cedar River within the broader context of changes in land use and weather patterns. Researchers implemented a hydrologic model of the Upper Cedar River using the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) to identify areas in the watershed with high runoff potential and to run simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed. For scenario development, researchers focused on understanding the impacts of: (1) increasing infiltration in the watershed through land use change and application of cover crops and (2) implementing a system of distributed storage projects (ponds) across the landscape.

Modeling results and scenario simulations from the Phase I hydrologic assessments are being added to the Iowa Watershed Decision Support System (IoWaDSS), as part of an Iowa Flood Center project funded by the U.S. Army Corps of Engineers Institute for Water Resources. The system aims to assemble data, tools, and models in one place to: (i) inform watershed stakeholders of the current status and forecasts in Iowa watersheds, (ii) support the assessment of alternative strategies for sustainable watershed resources, (iii) provide real-time, integrated data, and simulation models from multiple disciplines, and (iv) facilitate collaboration and the sharing of resources and model results across agencies and communities. A video tutorial of the IoWa DSS can be found at https://www.youtube.com/watch?v=-yIikldRrXA. Modeling results for the Soap Creek Watershed and the Turkey River Watershed are now available online (http://iowawatersheds.org/dev/dss_alpha/). Results for the Upper Cedar River Watershed may be added to the IoWaDSS in the future.

In Phase II of the project, researchers identified a smaller catchment (known as a HUC12 sub-watershed) for development and construction of flood mitigation projects. In collaboration with the Upper Cedar Watershed Management Improvement Authority, they selected the Beaver Creek

Watershed (see Figure 1.1), where IFC researchers evaluated the flood mitigation performance of proposed projects through monitoring and detailed hydrologic modeling. The team developed small-scale hydrologic simulations for the Beaver Creek Watershed using a more detailed representation of the watershed and flood mitigation strategies than was used in Phase I. This report describes the assessment results for Phase II of the project for the Beaver Creek Watershed.

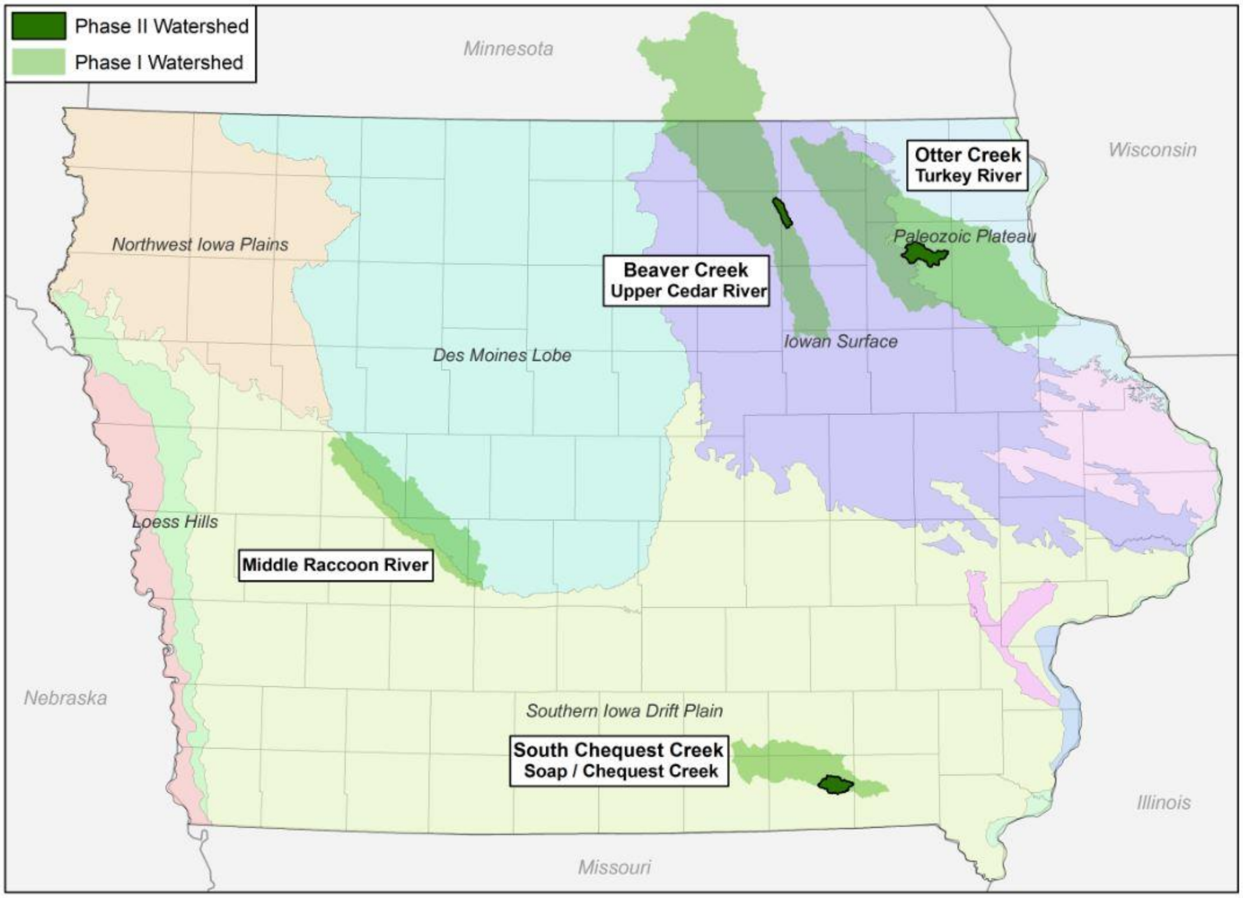


Figure 1.1. Iowa Watersheds Project, Phase I and Phase II selected watersheds.

2. Beaver Creek Watershed Study Area

The Beaver Creek Watershed is a 17.7-square-mile (45-square-kilometer) catchment located in the agriculturally dominated Upper Cedar River Watershed (see Figure 2.1). The watershed lies in a humid continental climactic region, characterized by large temperature and precipitation variations. Average annual precipitation ranges from 33.7 to 35.9 inches (Hutchinson and Christiansen, 2013), with approximately 75% lost to evaporation (Sanford and Selnick, 2013; Schilling et al., 2008). A total of 70% of the average annual precipitation occurs between March and July, and approximately half of that occurs in March and April. This provides evidence that spring rainfall and snowmelt processes are significant sources of increased runoff. Groundwater is extracted for residential use, but it is not required for irrigation because frequent rainfall provides enough water to satisfy agricultural needs. The rural watershed contains approximately 500 people, and the total groundwater extracted for residential use is assumed to be negligible.

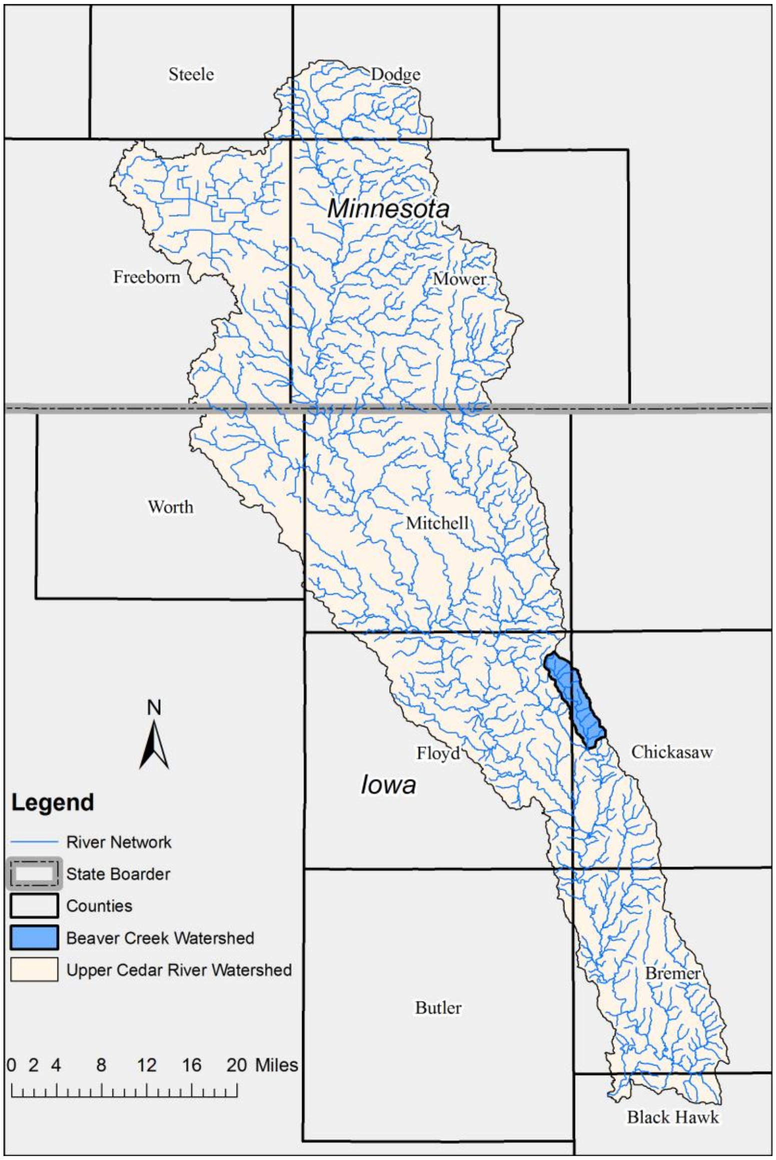


Figure 2.1. Beaver Creek Watershed location within the Upper Cedar River Watershed.

a. Hydrology

Beaver Creek is a sub-watershed within the Upper Cedar River Watershed as defined by the boundary of eight-digit Hydrologic Unit Code (HUC8) 07080201. The Upper Cedar River Watershed is located in north central Iowa and encompasses approximately 1,685 square miles (mi^2); the outlet discharges to the Cedar River approximately three miles south of Janesville, Iowa. The Beaver Creek Watershed has a drainage area of approximately 17.7 mi^2 and is located in Floyd and Chickasaw counties. Beaver Creek's outlet discharges into the Little Cedar River near Bassett, Iowa.

Average annual precipitation for this region of northeast Iowa is roughly 36 inches (PRISM Climate Group, 2016, 1981–2010 normal precipitation), with about 70% of the annual precipitation falling as rain during the months of April–September. During this period, thunderstorms capable of producing torrential rains are possible; the peak frequency of such storms occurs in June. Northeast Iowa has experienced increased variability in annual precipitation since 1975, along with a general increase in the amount of spring rainfall (Benning et al., 2013).

b. Geology and Soils

The Beaver Creek Watershed is located within the Iowan Surface landform region, which provides an important imprint on the rainfall-runoff characterization of the watershed (Figure 2.2). The Iowan Surface of north central Iowa is dominated by gently rolling terrain created during the last period of intense glacial cold, 21,000 to 16,000 years ago. Hilly landscapes succumbed to vigorous episodes of weathering and leveling as materials were loosened and moved (Iowa Geological and Water Survey, 2013).

Shallow limestone coupled with the dissolving action of groundwater yields numerous caves, springs, and sinkholes (Iowa Geological and Water Survey, 2013). The Iowa Department of Natural Resources (IDNR) has mapped the locations of over 2,000 sinkholes in the Upper Cedar River Watershed (Figure 2.3). No sinkholes have been mapped within the Beaver Creek Watershed, but with the close proximity of others to Beaver Creek Watershed, and the continual mapping program, there is a possibility for sinkholes to occur locally.

The Natural Resources Conservation Service (NRCS) classifies soils into four Hydrologic Soil Groups (HSG) based on the soil's runoff potential. The four HSGs are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, the NRCS assigns dual code soil classes to certain wet soils: A/D, B/D, and C/D. 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 most water from doing so. For example, a B/D soil will have the runoff potential of a B-type soil if the shallow water table were to be drained away, but the higher runoff potential of a D-type soil if it is not. Complete descriptions of the Hydrologic Soil Groups can be found in the USDA-NRCS National Engineering Handbook, Part 630 – Hydrology, Chapter 7 (Natural Resource Conservation Service, 2009).

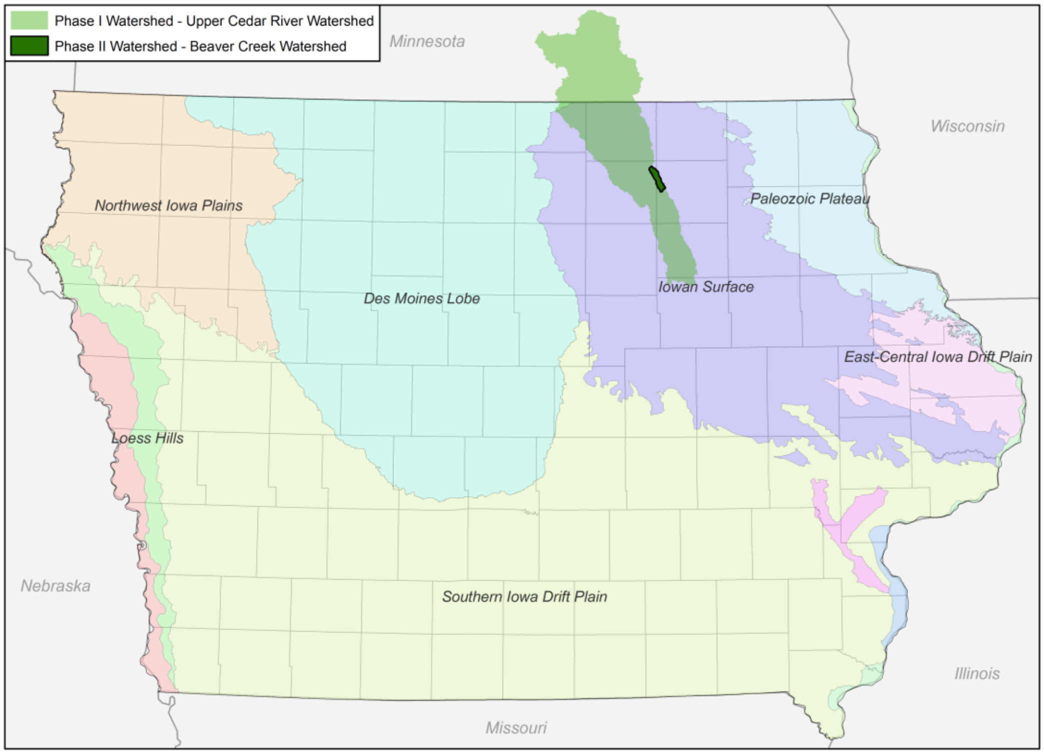


Figure 2.2. Landform regions of Iowa. The Beaver Creek Watershed is shown within the Upper Cedar River Watershed.

The Iowan Surface consists primarily of a mix of HSG B, C, B/D, and C/D type soils, resulting in areas that range from moderate to higher runoff potential. The soils overlying the bedrock (limestone) are largely C-type soils, with areas of exposed rock or very shallow soils over rock that are classified as D-type. These soils allow much less water to infiltrate the ground, resulting in much higher runoff potential. The soil distribution of the Beaver Creek Watershed as described in the digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WSS) is shown in Figure 2.4. Figure 2.5 shows the soil texture classification of the soils found within the watershed.

Viewing the soil distribution at this map scale is difficult, but the map does illustrate how much soils vary in space and the noticeable difference in soil types between the near stream and upland regions of the Beaver Creek Watershed. Table 2.1 shows the approximate percentages by area of each soil type.

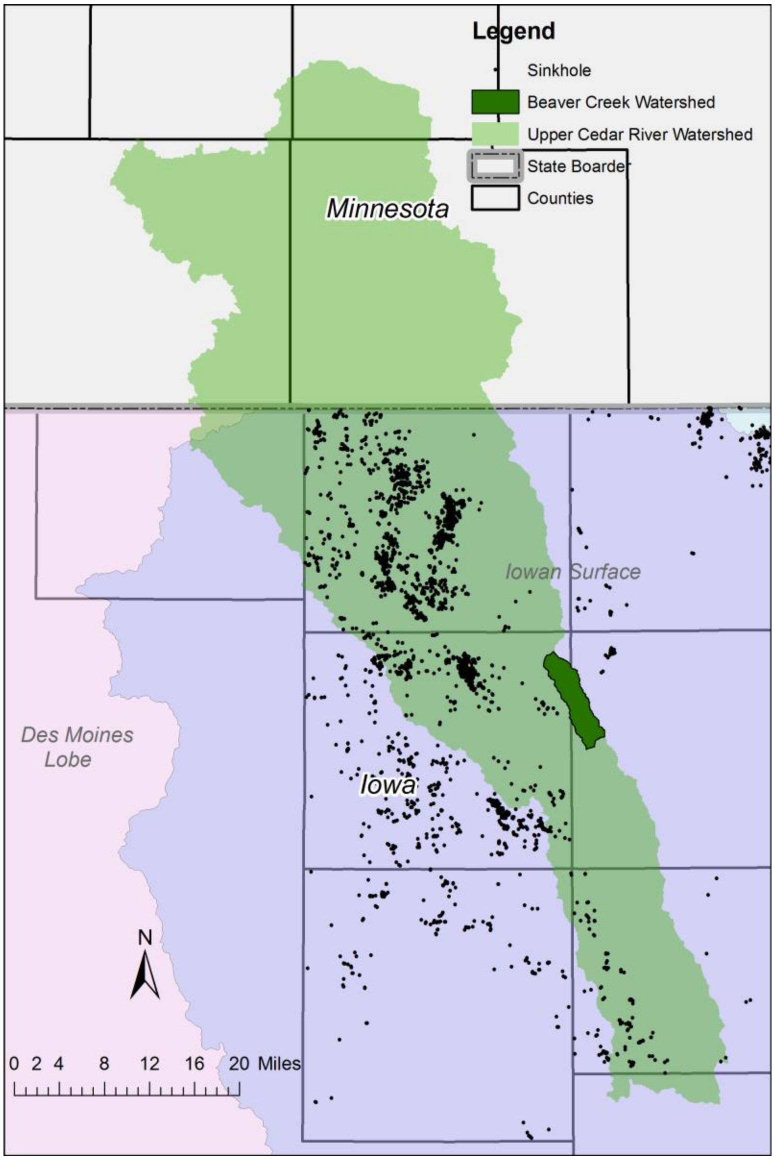


Figure 2.3. Location of sinkholes as mapped by Iowa Department of Natural Resources.

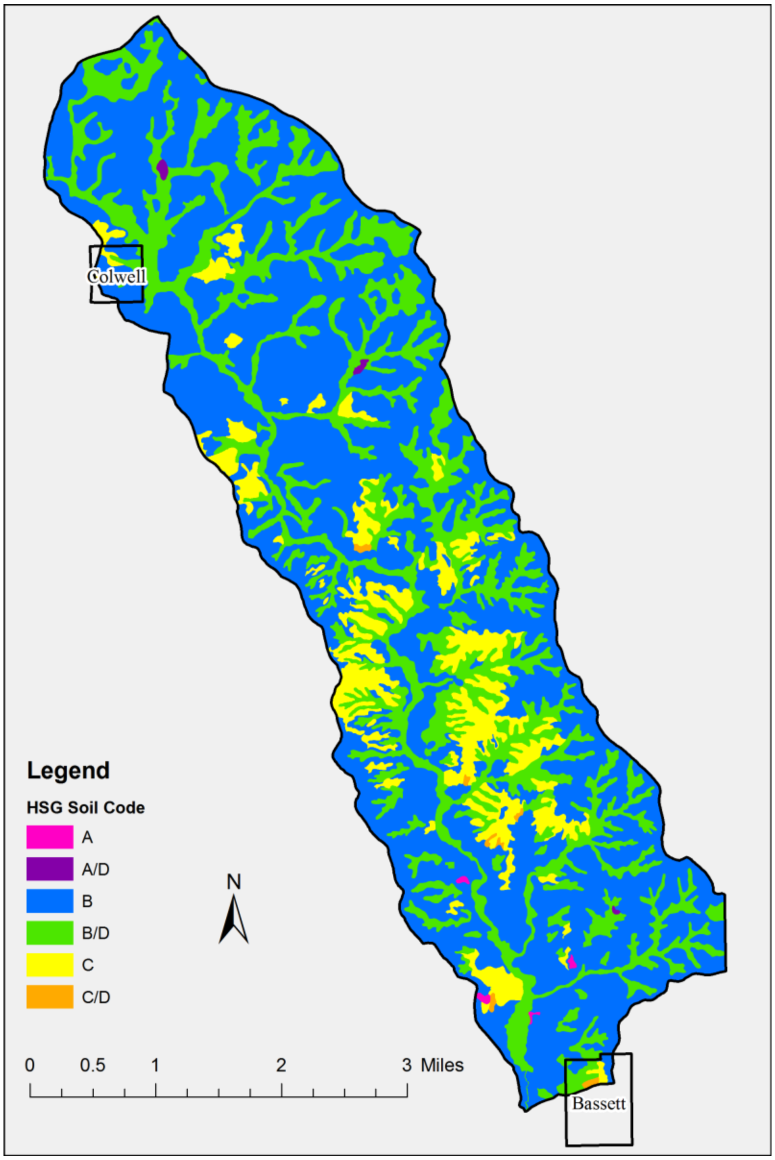


Figure 2.4: Distribution of Hydrologic Soil Groups in the Beaver Creek Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with Type A representing the lowest runoff potential and Type D representing the highest runoff potential.

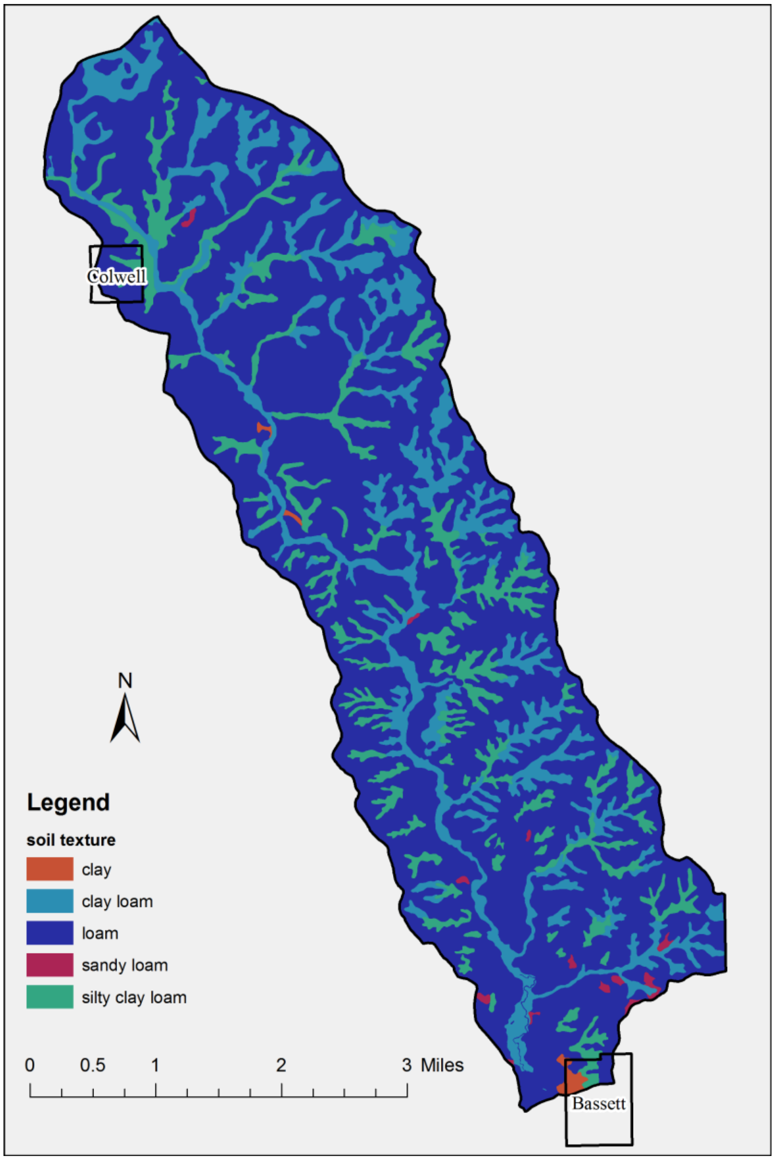


Figure 2.5: Soil texture within the Beaver Creek Watershed.

Table 2.1: Hydrologic soil groups within the Beaver Creek Watershed and approximate areas (in mi^2 and % of watershed)

Hydrologic Soil Group	Area (mi^2)	Area (%)
A	0.02	0.1
A/D	0.02	0.1
B	10.56	60.0
B/D	5.40	30.6
C	1.57	8.9
C/D	0.04	0.2
D	0.00	0.0

c. Topography

The topography (Figure 2.6) of the Beaver Creek Watershed varies from north to south. The northern half of the watershed displays low relief, and the majority of change in elevation is the product of raised roadways and incised stream channels (Figure 2.7). The southern half of the watershed is described by more steeply sloping terrain and well-defined streams. Elevations range from approximately 1,193 feet above sea level in the uppermost part of the watershed to 997 feet at the outlet. Figure 2.7 depicts the land surface slope in the Beaver Creek Watershed. Slopes generally range from 1 to 9 percent in the headwater regions and gradually steepen as you move south toward the outlet.

d. Land Use

Land use in the Beaver Creek Watershed (Figure 2.8) is predominantly agricultural, dominated by cultivated crops (corn/soybeans) on approximately 73% of the acreage, followed by grass/hay/pasture on approximately 16%. The remaining acreage in the watershed is about 8% forest (primarily deciduous forest), 2% developed land, and less than 1% open water and/or wetlands, according to the 2009 High Resolution Land Cover Data (NLCD) Set. In excess of 90% of the land within the watershed is privately owned.

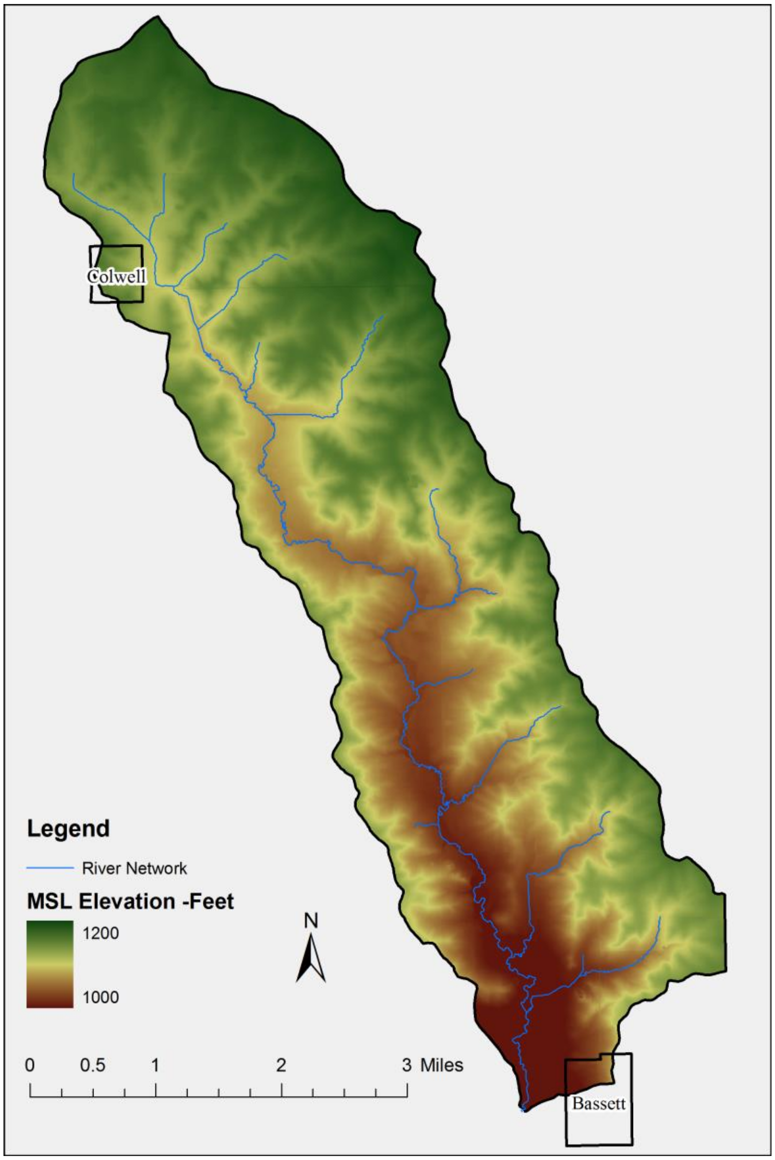


Figure 2.6: Topography of the Beaver Creek Watershed.

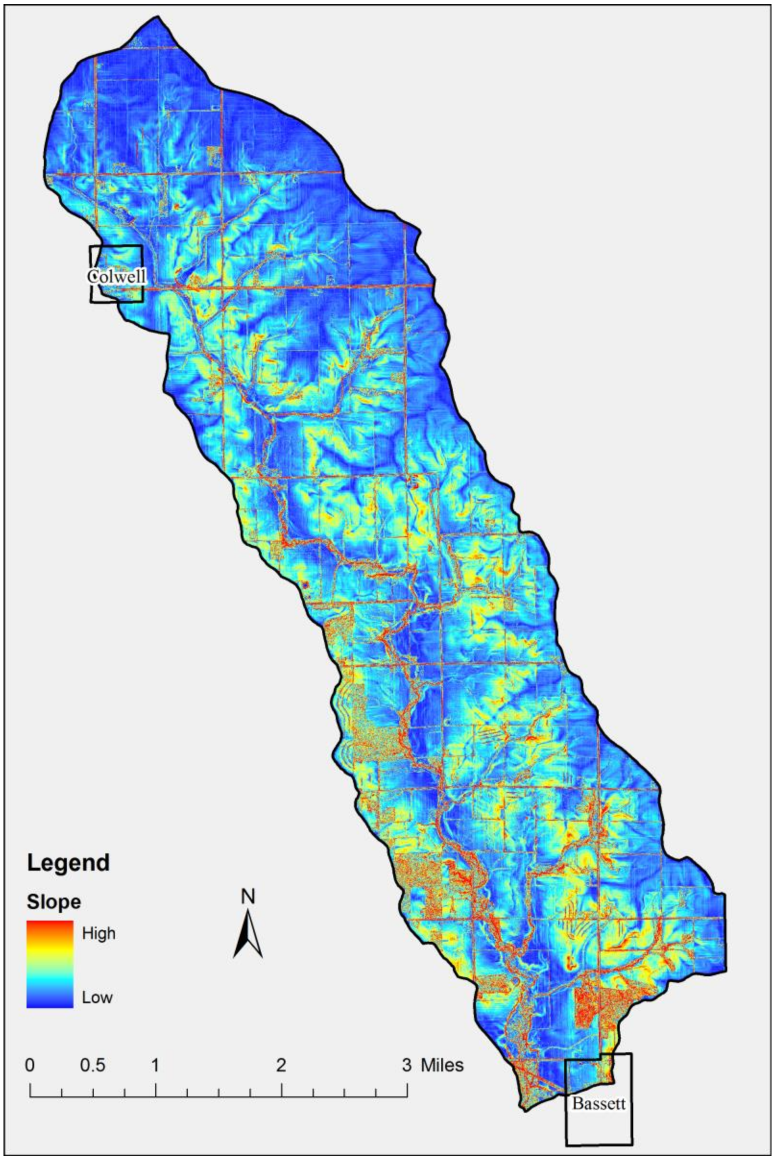


Figure 2.7: Land surface slopes within the Beaver Creek Watershed.

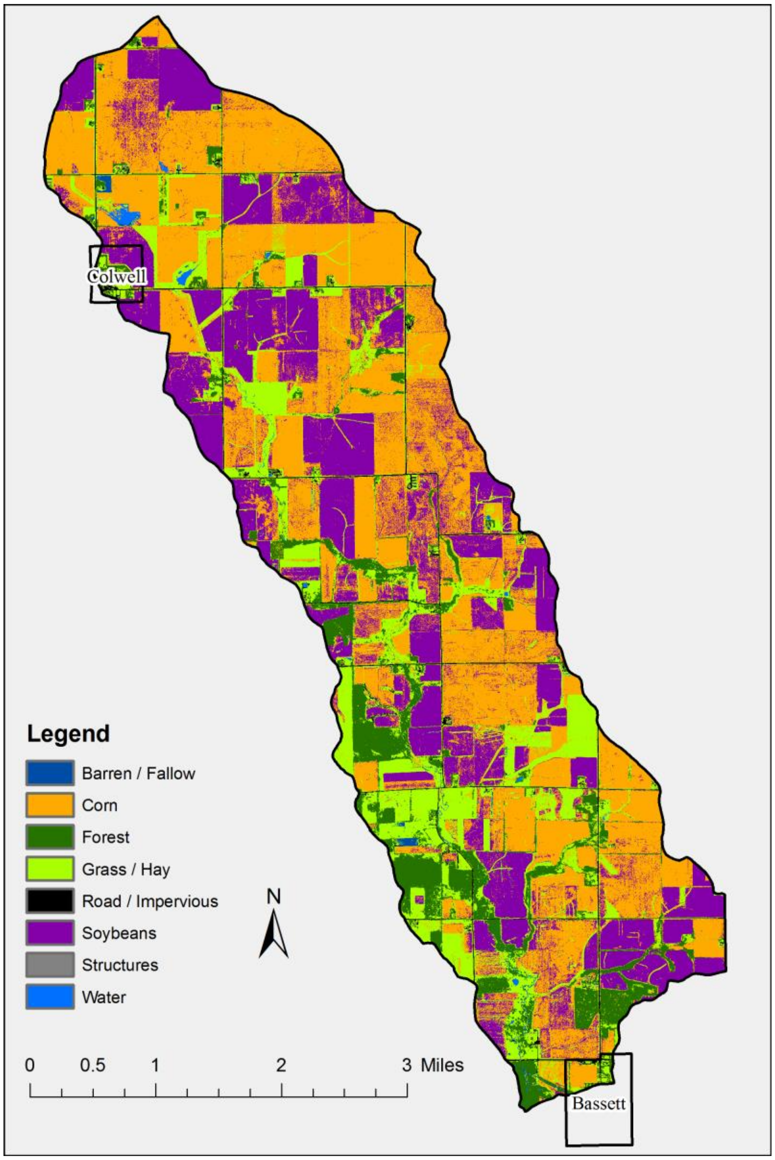


Figure 2.8: Land use composition in the Beaver Creek Watershed per the 2009 High Resolution Land Cover Database. Cultivated crops are shown in orange.

3. Data Collection

As part of the Phase II work on the Iowa Watersheds Project, the Iowa Flood Center is monitoring the hydrology of the Beaver Creek Watershed. IIHR—Hydroscience & Engineering partnered with the IFC to monitor water quality and collect data through a statewide network. This chapter summarizes the Phase II data collection efforts in the Beaver Creek Watershed.

a. Water and Water Quality Measurement Locations

In the spring of 2014, researchers installed instrumentation throughout the Beaver Creek Watershed to monitor water quantity and water quality. The Iowa Flood Center deployed sensors to measure hydrologic variables, such as stream stage and rainfall/soil moisture, and IIHR—Hydroscience & Engineering led the water quality monitoring. The instrumentation includes three rain gauge and soil moisture (RGSM) platforms, three stage sensors, six shallow groundwater wells, and two water quality sensors. The locations of the sensor sites are shown in Figure 3.1. The sensor station names and period of record are shown in Table 3.1.

Table 3.1: Iowa Flood Center (IFC) hydrologic stations and IIHR water quality stations in the Beaver Creek Watershed.

Gage Type	Period of Record
IFC Stream (stage) BEAVER01	May 2014–present
IFC Stream (stage) BEAVER02	May 2014–present
IFC Stream (stage) BEAVER03	May 2014–present
IFC Rain Gauge/Moisture/ Soil Temperature BEAVER1	May 2014–present
IFC Rain Gauge/Moisture/ Soil Temperature BEAVER2	May 2014–present
IFC Rain Gauge/Moisture/ Soil Temperature BEAVER3	May 2014–present
IIHR Water Quality WQ0013	May 2014–present
IIHR Water Quality WQ0014	May 2014–present

Rain Gauge and Soil Moisture Platforms: At each of the three rain gauge and soil moisture platform locations, the instruments measure soil water content at 2-inch, 4-inch, 8-inch, and 20-inch intervals, with horizontally installed Campbell Scientific CS655 Water Content Reflectometers. Dual MetOne 380 precipitation gauges are collocated with the soil moisture sensors and measure 15-minute precipitation accumulations. When temperatures go below freezing in the late fall, the precipitation gauges are removed and soil moisture measurements are considered unreliable, as moisture near the surface freezes. Each of the sensors is located in short grass open areas adjacent to agricultural activity.

Shallow Groundwater Wells: Of the six shallow groundwater wells, three are collocated with rain gauge platforms, two are located in nearby floodplains, and one is located at a local elevation peak. Each well is constructed from 5.08 cm PVC pipe drilled to a depth ranging from 4.57 m to 6.10 m. Well screens are installed in three meter increments, beginning at depth of 1.52 m, and continuing to 4.57 m. Each site is backfilled with bentonite and equipped with a Decagon CTD-10 water level transducer.

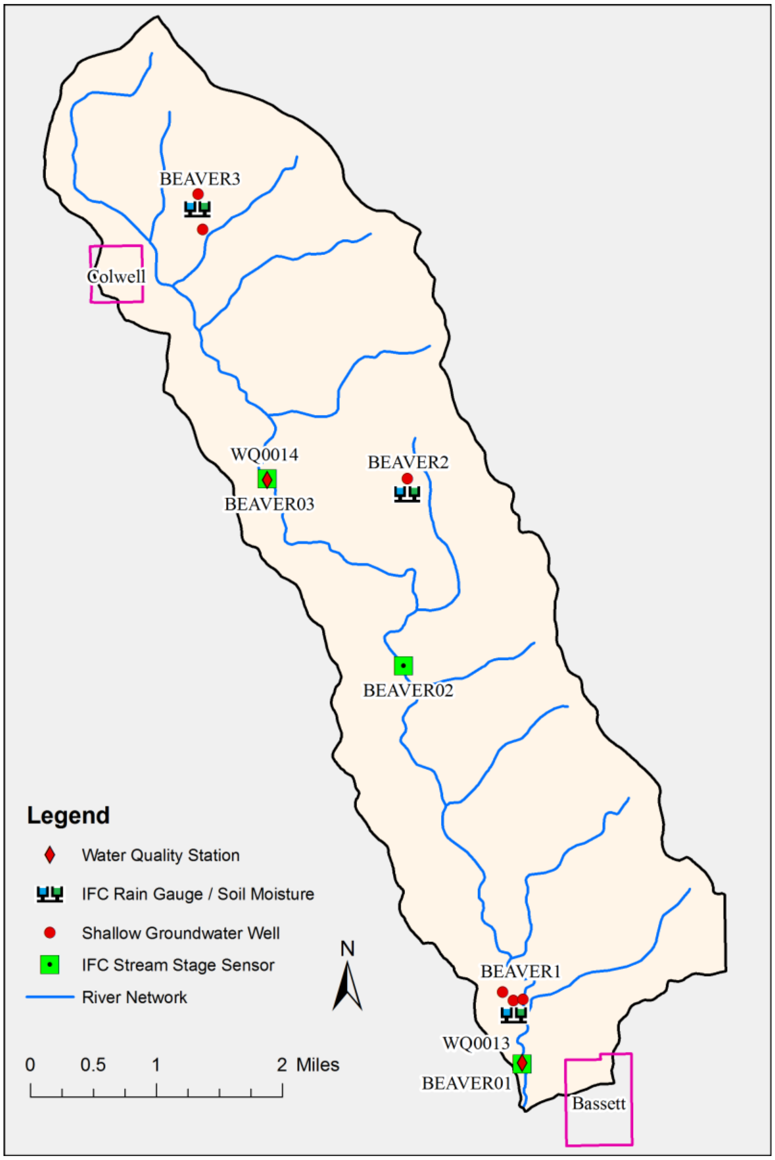


Figure 3.1: Monitoring locations in the Beaver Creek Watershed from spring 2014 installation. Displayed in this figure are RGSM platforms (3), stream stage sensors (3), water quality stations (2), and shallow groundwater wells (6).

Stream Stage Sensors: The three stream stage sensors are mounted at road crossings. The sensors use ultrasonic sound pulses to measure the distance to the water. The sensor unit is self-contained, and the battery is charged with a solar panel. The collected data are transmitted via a cell modem. An approximation of the bed elevation enables the estimation of water depth.

Water Quality Sensors: Two water quality stations are collocated with the BEAVER01 and BEAVER03 stream stage sensors (see Figure 3.1). The sensor platform consists of a Hach Nitratax SC Nitrate Sensor, an FTS DTS- 12 Turbidity Sensor, and an Ott-Hydromet Hydrolab DS5X Sonde. The Hydrolab multiprobe sensors were configured to measure water temperature, specific conductance, chlorophyll a, pH, and dissolved oxygen.

Each monitoring system consists of an IIHR—Hydroscience & Engineering developed datalogger, battery, solar panel, and cellular modem. Data were collected, transmitted, and ingested into servers at the University of Iowa on a 15-minute schedule.

The Iowa Flood Center's Iowa Flood Information System (IFIS) online suite of tools provides real-time information on watersheds, precipitation, and stream levels for more than 1,000 Iowa communities. Data collected from the rain gauge and soil moisture platforms, shallow groundwater wells, and stream sensors deployed in the Beaver Creek Watershed can be accessed at http://ifis.iowafloodcenter.org/ifis/app.

IIHR—Hydroscience & Engineering's Iowa Water-Quality Information System (Iowa WQIS) online tool is built on the same user-friendly Google Maps interface as IFIS, which was developed by the IFC. Iowa WQIS integrates data gathered by IIHR and the U.S. Geological Survey (USGS) and allows users to track water-quality conditions in real-time. Water-quality data for Beaver Creek can be accessed from the site at http://iwqis.iowawis.org/app.

The Iowa Flood Information System (IFIS) and the Iowa Water-Quality Information System (Iowa WQIS) provide extensive and critical information needed by scientists, policy-makers, and other Iowans to make science-based decisions that will help us accomplish Iowa's water-quality objectives.

b. Stream Stage Measurements

With the installation of the IFC sensors, we have collected continuous observations of hydrologic conditions at station locations. Figure 3.2 shows stream stage and precipitation observations for the 2014 measurement season. The figure shows the hourly average precipitation rate (in inches per hour) for the three rain gauge platforms, and the 15- minute stream stage observations (in feet above sea level) at two locations in the upper watershed (BEAVER01 and BEAVER02). The figure illustrates that the watershed responds quickly when it rains; the stream stages increase rapidly with heavy rainfall, then recede immediately after they reach their peak. In 2014, the heaviest rainfall occurred in late June and early July and produced several stream-stage peaks. After the storm runoff passes, the stage returns to lower levels at which streamflow is the result of groundwater inflow to the stream (known as baseflow). In general, the baseflow levels are slightly higher in the spring, when there are greater levels of soil moisture, and decrease throughout the summer and fall as soil moisture is depleted and groundwater levels drop. Baseflow measurements tend to oscillate daily, which is most likely related to acoustic sensors that are affected by daily temperature variations, and not a real oscillation in water levels.

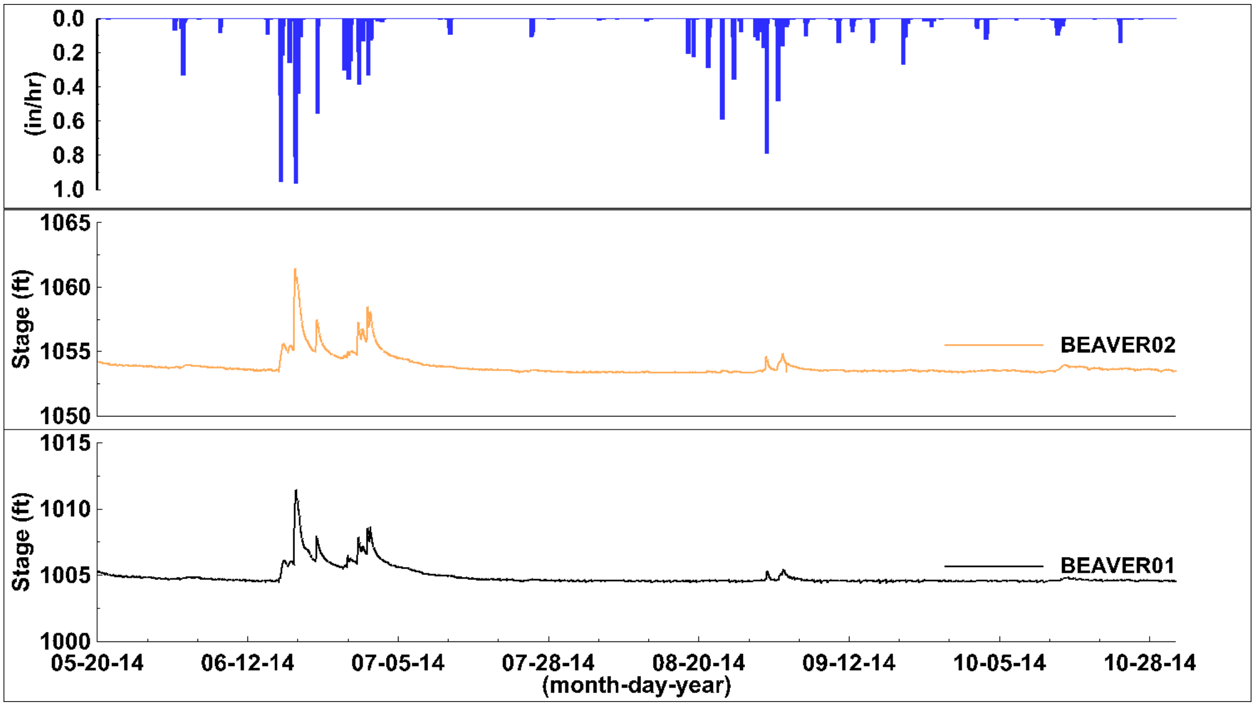


Figure 3.2: Stream-stage hydrographs and precipitation measurements for the 2014 season. The stream-stage elevation (in feet above sea level) is shown for two sites in Beaver Creek: the BEAVER02 site in the middle watershed, and the downstream BEAVER01 site in the lower watershed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

Figure 3.3 shows an eight-day period in June 2014 that includes the highest stream stages that occurred in 2014. Three distinct stage hydro- graph peaks are seen, associated with three heavy rainfall periods with an accumulation of more than 0.9 inch. The first was the 2.3-inch rainstorm on June 16 and 17. The storm caused stream stages to rise nearly 2 feet and slowly recede. After the storm, the baseflow stages are clearly higher than before. This suggests that a significant portion of the rainfall soaked into the ground and recharged the groundwater, increasing the baseflow to the stream. The next peak occurred on June 19 when several rainy periods occurred within 24 hours. The first rainy period saw 2.5 inches of rain, causing the stream stages to rise nearly 6 feet (with a short intermediate peak before the largest peak). Even though this rainy period produced nearly the same rainfall as the one three days earlier (2.5 inches compared to 2.3 inches), its peak was much higher than the one from the June 16–17 storm. During the first rainy period in June, a portion of the water soaked into the ground while another portion ran off quickly into the stream (causing stages to rise). Three days later when the next heavy rainfall occurred, less water was able to soak into the already wet soils. As a result, more water ran off and caused higher peak stages. Again, baseflow stages after the two rainy periods were higher than before, suggesting that a portion of rainfall had recharged baseflows. The third heavy rainfall period on June 22 produced much less rainfall (0.9 inches), but with the wet soils, it was sufficient to cause stream stages to rise to a higher level than had been seen from the June 16–17 storm (2.3 inches).

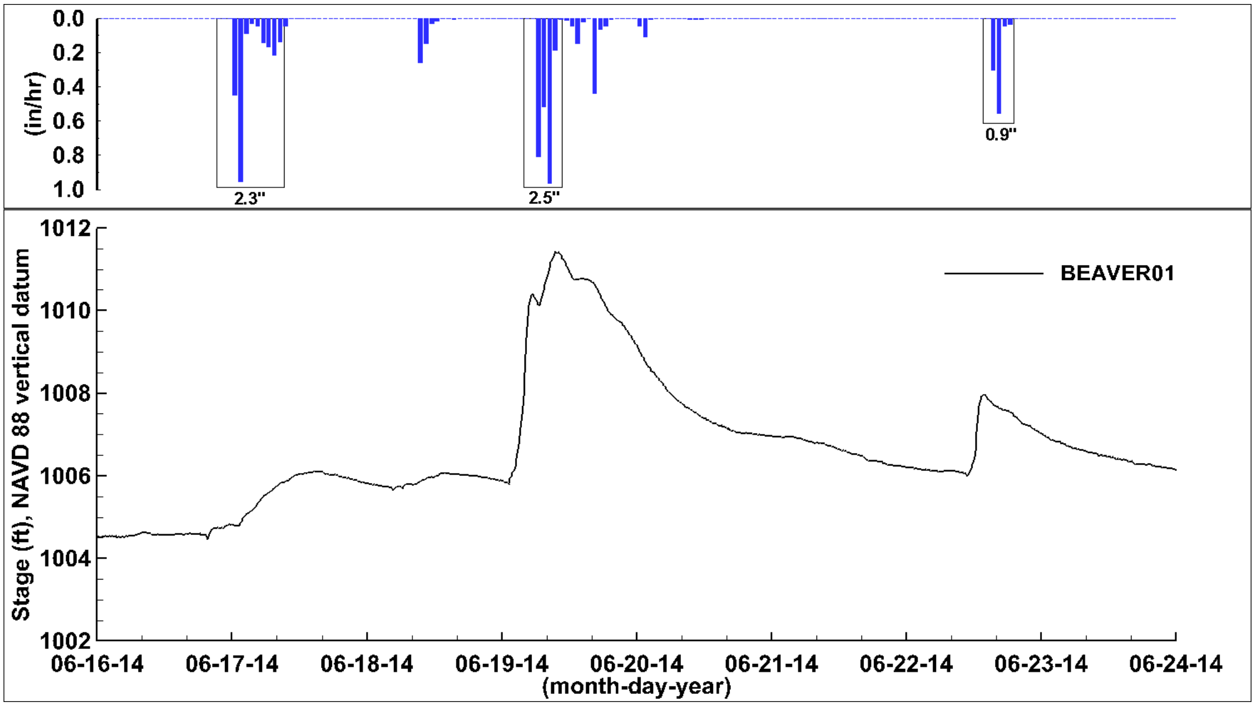


Figure 3.3: Stream-stage hydrographs and precipitation measurements for an eight-day period in June 2014. The stream-stage elevation (in feet above sea level) is shown for BEAVER01 site in the lower watershed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

c. Soil Moisture Measurements

Figure 3.4 shows soil moisture and precipitation observations for the 2015 measurement season. The figure shows the soil moisture (in %) at 2-, 4-, 8-, and 20-inch depths; the observations are the average soil moisture at these depths at the five soil moisture platforms (see Figure 3.1). The precipitation is the hourly average precipitation rate for the five rain gauge platforms. Clearly, the soil moisture reacts differently at different depths. The soil moisture content varies in response to rainfall the most at the 2-inch depth, going from near saturation (100%) to dry conditions (as low as 25%) numerous times throughout the season. The variation at the 4-inch depth is similar, but not as extreme as at 2 inches. The variation is even less at the 8-inch depth. All the way down at the 20-inch depth, the soil moisture changes much more slowly and over a much narrower range.

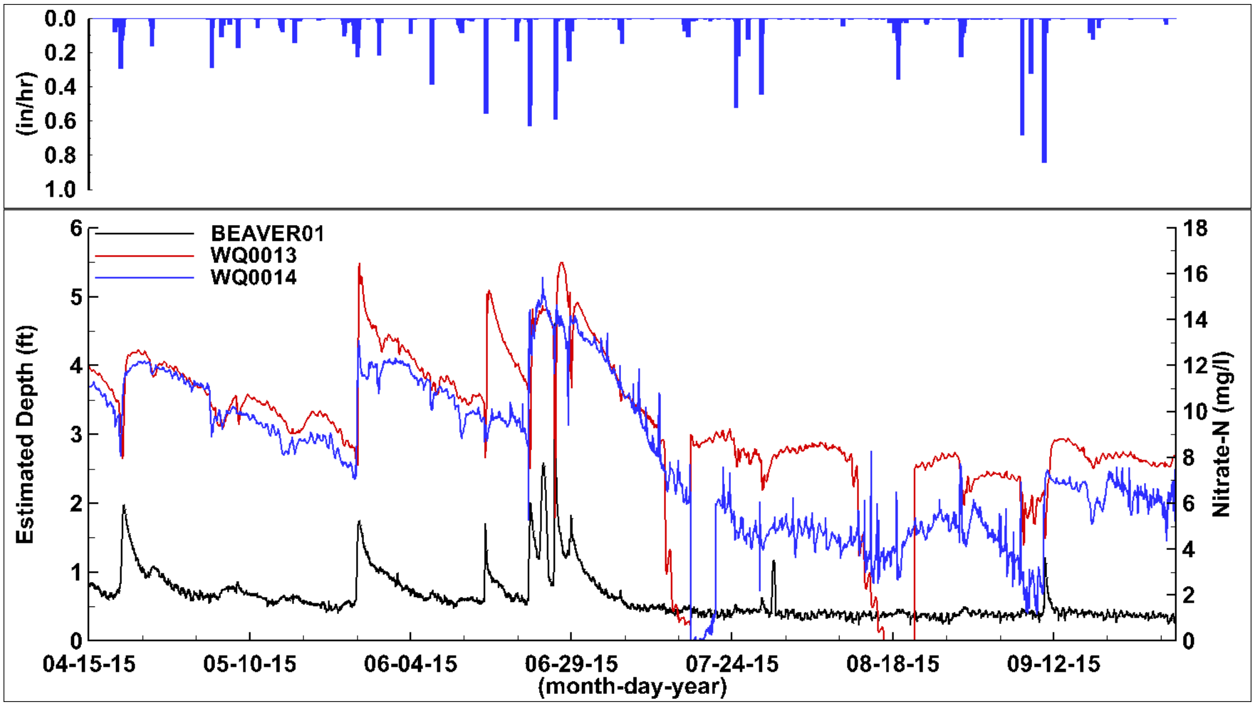


Figure 3.4: Soil moisture and precipitation measurements for the 2015 season. Soil moisture is reported at the following depths from the surface: 2-, 4-, 8-, and 20-inches. The soil moisture values are the average from the three rain gauge/soil measurement platforms in the Beaver Creek Watershed. Soil moisture is reported as a percentage; saturated conditions correspond to a soil moisture of 100%. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

At depths from 2- to 8-inches, soil moisture increases rapidly when sufficient rainfall infiltration occurs. Afterwards, the soil dries more quickly near the surface (2-inch depth). The drying is delayed at the 4-inch depth, and even more so at the 8-inch depth. This occurs through a combination of evapotranspiration and percolation. The water nearest the surface is most readily available for evaporation and transpiration (by plants and vegetation). The water that does not evaporate percolates down through the soils, keeping the soil moisture at greater depths higher longer. Down at the 20-inch depth, the soil moisture only increases rapidly during storms when the entire profile is wet, which occurs at times from April to September. After its peak in late June, the soil moisture at this depth slowly decreases into August, even though some rainstorms significantly increase soil moisture near the surface. The depletion of soil moisture at this level (and lower) in the summer growing season helps explain why baseflow (stream inflow from saturated groundwater) typically decreases through the summer months. Rainstorms in late August and the last big September storm reverse this trend, but the subsequent dry spell in fall results in some of the driest soil moisture conditions of the season.

Figure 3.5 shows a 30-day period in May and June 2015 that includes several rainy periods. Before the first heavy rain period on May 24, the soils are drying at all four levels; it dries more quickly nearest the surface, and progressively slower at lower depths. When the 1.8-inch rain occurs on May 24–25, soil moisture increases the quickest at the 2-inch depth, going from about 32 to 88%. The soil moisture at the 4-inch and 8-inch depths also increases, but starting from somewhat wetter conditions. At the 20- inch depth, there is no significant increase in soil moisture until late in the storm, after moisture approaches saturation at the three upper depths. After the storm ends, the soil moisture is similar at all four depths (around 90%). Then the typical drying progression commences; soil near the surface dries faster than deeper soils after the rainfall ceases. The remaining rainstorms during the 30-day period are smaller. Each rainstorm increases the moisture in the 2-inch to 8-inch depths, but not at the 20-inch depth. The response of the soils to rainfall and the partitioning of rainfall into infiltration and surface runoff depends on the soil moisture near the surface and throughout the entire profile.

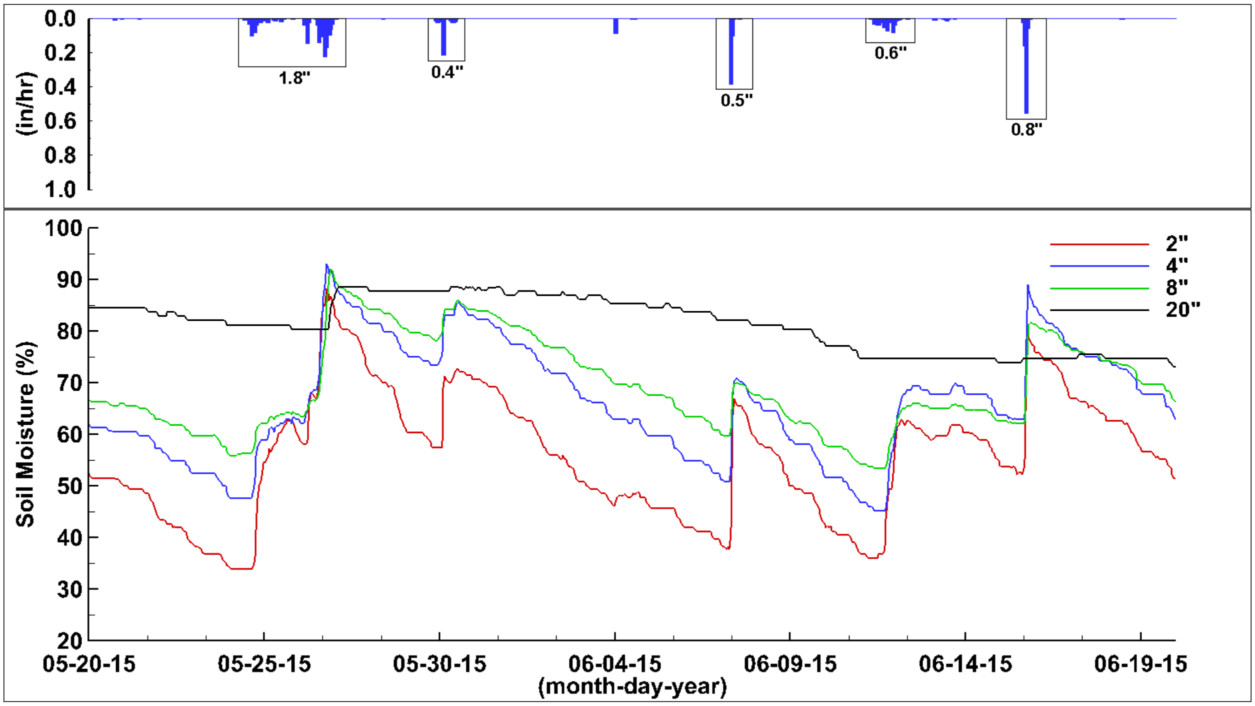


Figure 3.5: Soil moisture and precipitation measurements for a 30-day period in late spring of 2015. Soil moisture is reported at 2-, 4-, 8-, and 20-inch depths from the surface. The soil moisture values are averaged from three rain gauge/soil measurement platforms in the Beaver Creek Watershed. Soil moisture is reported as a percentage; saturated conditions correspond to a soil moisture of 100%. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

d. Soil Temperature Measurements

Figure 3.6 shows soil temperature and precipitation observations for the 2015 measurement season. The figure shows the soil temperature (in ◦F) at 2-, 4-, 8-, and 20-inch depths; the observations are the average temperatures for these depths at the three soil moisture platforms (see Figure 3.1). The precipitation is the hourly average precipitation rate for the three rain gauge platforms. The variations in temperature are as one would expect; the largest diurnal range in temperature occurs nearest the surface (the 2-inch depth), where the ground heats during the day and cools rapidly at night. A smaller diurnal range is seen at lower depths. At the lowest depth (20 inches), daily fluctuations are very minor. Overall, the soil warms from April to mid-September (with some cooling in late-August). From mid-September to November, the soil cools. Note the temperature at the lowest depth (20 inches) lags behind those at the other stations, both during the warm-up in spring and summer and during the cool-down in fall.

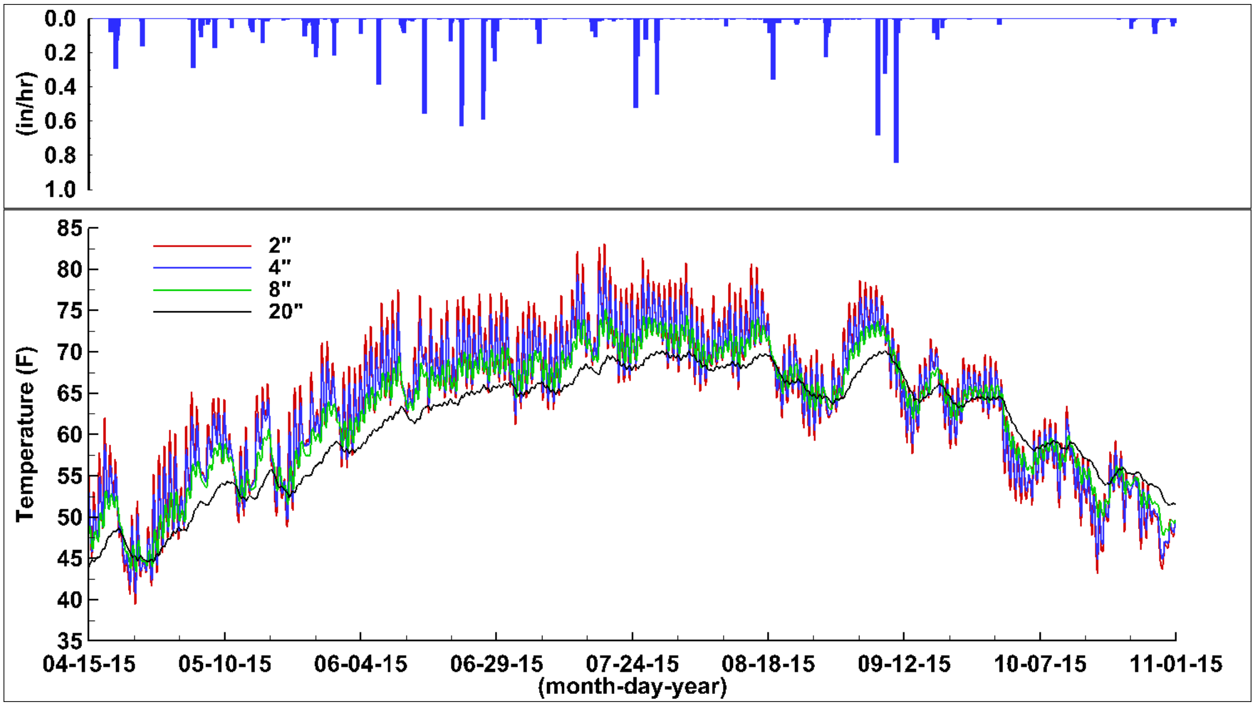


Figure 3.6: Soil temperature and precipitation measurements for the 2015 season. Soil temperature (in ◦F) is reported at 2-, 4-, 8-, and 20-inch depths from the surface. The soil temperature values are the average from the three rain gauge/soil measurement platforms in the Beaver Creek Water- shed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

Many of these features can be seen more clearly during a 30-day period in May and June 2015, shown in Figure 3.7. The soil temperature is higher and has a larger daily range at the 2-inch depth (nearest to the surface). The temperature drops progressively lower and has a more limited daily range at the 4-, 8-, and 20-inch depths. The effects of a rainy period on soil temperature are also clearly seen. On days with significant rain, the daily range of soil temperature tends to be lower than on dry days. Rainy days often have less sunshine to warm the soils. Furthermore, after it rains, the soil is heated less because more incoming solar radiation is used to evaporate soil moisture. These two factors explain why rainy days tend to have a lower daily temperature range.

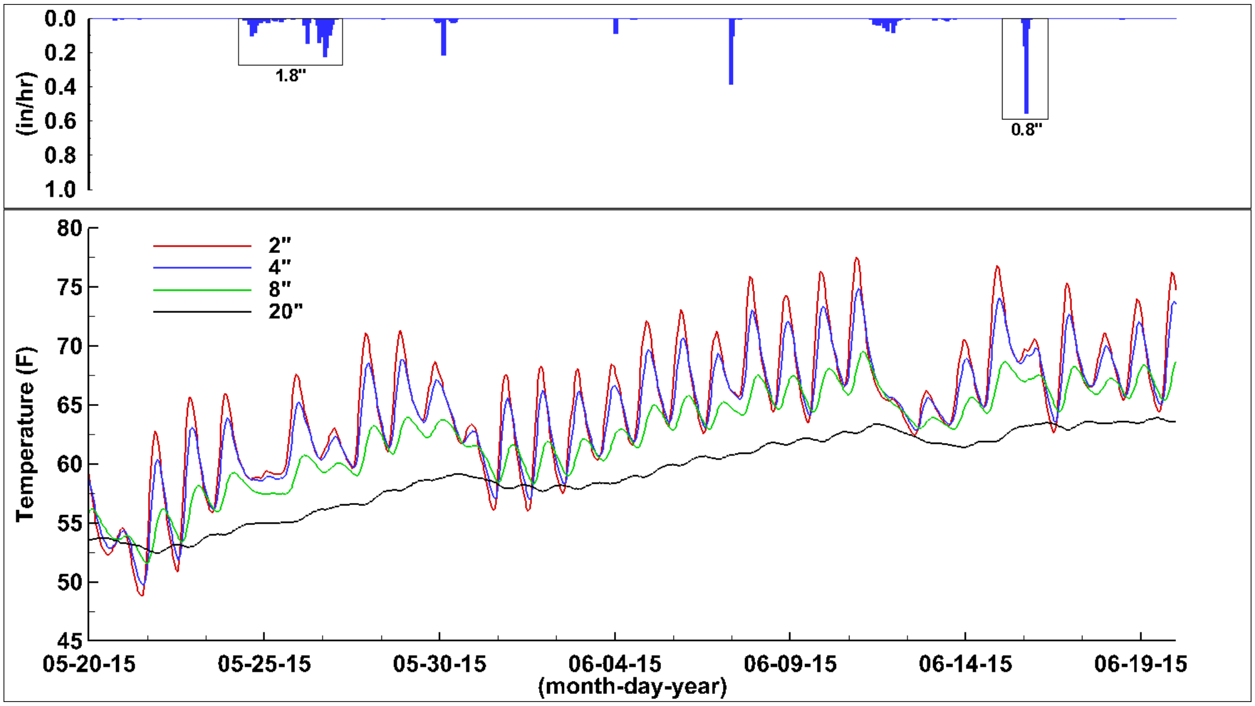


Figure 3.7: Soil moisture and precipitation measurements for a 30-day period in late spring of 2015. Soil temperature (in ◦F) is reported at 2-, 4-, 8-, and 20-inch depths from the surface. The soil temperature values are the average from the three rain gauge/soil measurement platforms in the Beaver Creek Watershed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

e. Groundwater Measurements

Figure 3.8 shows groundwater levels and precipitation observations for the 2015 measurement season. The figure shows the groundwater below the surface at two of the six groundwater sites (collocated with the rain gauge/soil platforms). One site is located in the middle watershed (BEAVER2), while the other is in the lower watershed (BEAVER1) (see Figure 3.1). The precipitation is the hourly average precipitation rate for the three rain gauge platforms. Only the BEAVER2 site was operational in March and April, and it saw significant groundwater recharge then, as indicated by the rising groundwater levels. Both sites saw isolated rapid increases (over a few days) at similar times, suggesting that recent rainfall and groundwater percolation were causing the groundwater rises. After these rises, groundwater levels slowly begin to fall until the groundwater is recharged again. Note that the water level at BEAVER1 is much closer to the surface, and it responds more quickly to percolating rainfall. Beginning in late June, the BEAVER1 groundwater levels begin a fairly steady drop that continues through August. The BEAVER2 groundwater levels begin a steady drop after a peak in late April. In the growing season, more water retention and evaporation at the surface during rainstorms cause a seasonal drop in groundwater levels in late summer.

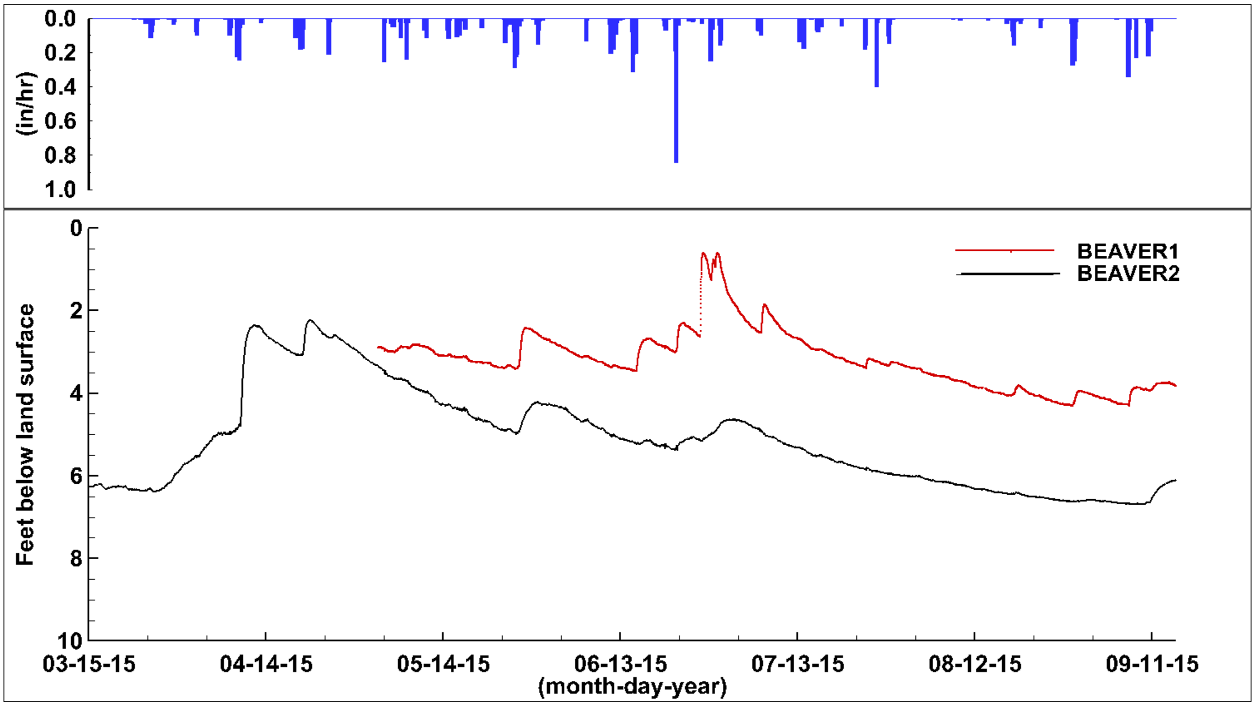


Figure 3.8: Groundwater levels and precipitation measurements for the 2015 season. The depth to the groundwater (in feet) is shown for two sites in Beaver Creek: the BEAVER2 site in the middle watershed, and the BEAVER1 site in the lower watershed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

Figure 3.9 shows a 30-day period in May and June 2015 that includes several rainy periods. At both groundwater sites, the groundwater levels are slowly dropping before a heavy rainfall period on May 24. Toward the end of the 1.8-inch event, both sites see groundwater levels raise several feet over a two- to three-day period. Note that the smaller rains in late May and early June do not dramatically change the groundwater levels, or significantly halt the drawdown in levels that begins after the ground- water is recharged from the earlier rains. However, the 0.8-inch event is sufficient to raise groundwater levels at the BEAVER1 site.

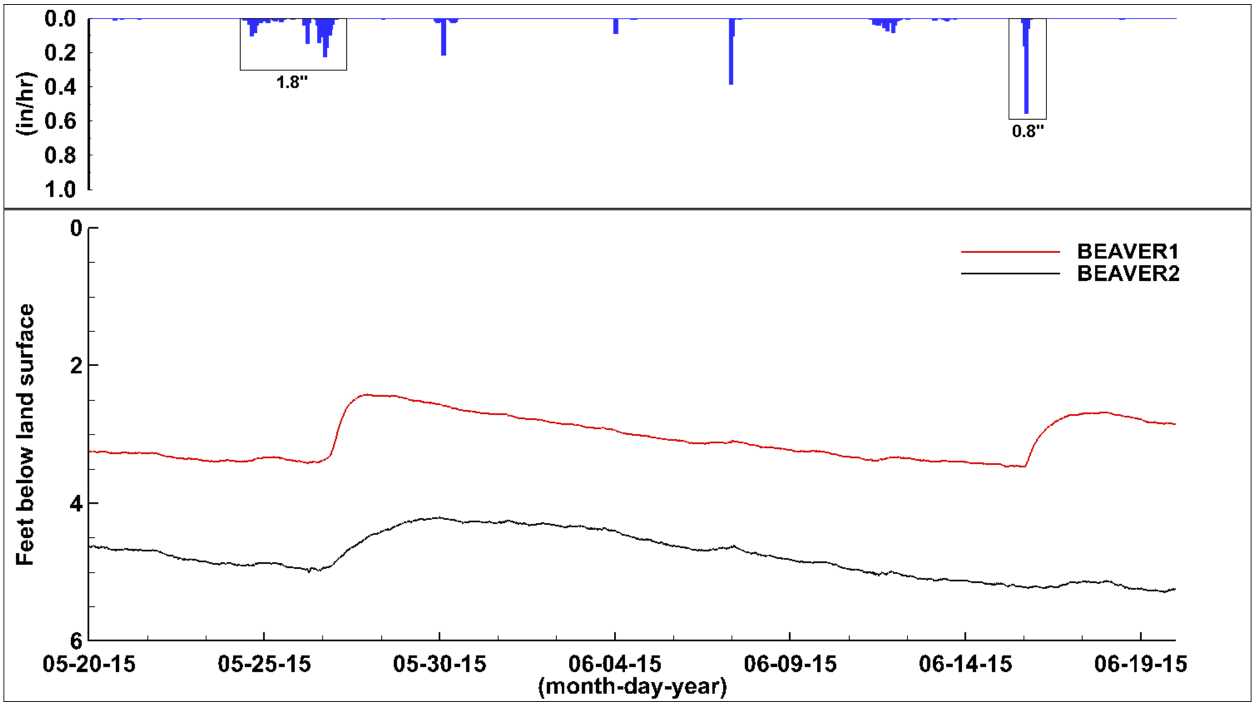


Figure 3.9: Groundwater levels and precipitation measurements for a 30- day period in late spring of 2015. The depth to the groundwater (in feet) is shown for two sites in Beaver Creek: the BEAVER2 site in the middle watershed, and the BEAVER1 site in the lower watershed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

f. Water Quality Measurements

Figure 3.10 shows nitrate concentrations, discharge, and precipitation observations for the 2015 measurement season. The figure shows the nitrate concentrations (Nitrate-N in mg/L) at both water quality stations in Beaver Creek (see Figure 3.1). The stream stage (in feet) at the downstream BEAVER01 sites is also shown. The precipitation is the hourly average precipitation rate for the three rain gauge platforms. At the downstream site (WGS0013), nitrate concentrations tend to be slightly higher than at the upstream site (WGS0014). The reason for the systematic difference is unclear, but one possible explanation is that nitrate removal in the pond projects, which are concentrated in the upper watershed, may account for the difference. The variations in nitrate concentration at both sites follow a similar pattern, which is related to the Beaver Creek streamflow. Concentrations increase after high runoff periods and slowly recede afterwards. However, at times, nitrate concentrations have abrupt temporary reductions during peak runoff periods. During heavy rainfalls, surface runoff volumes can briefly dilute nitrate concentrations.

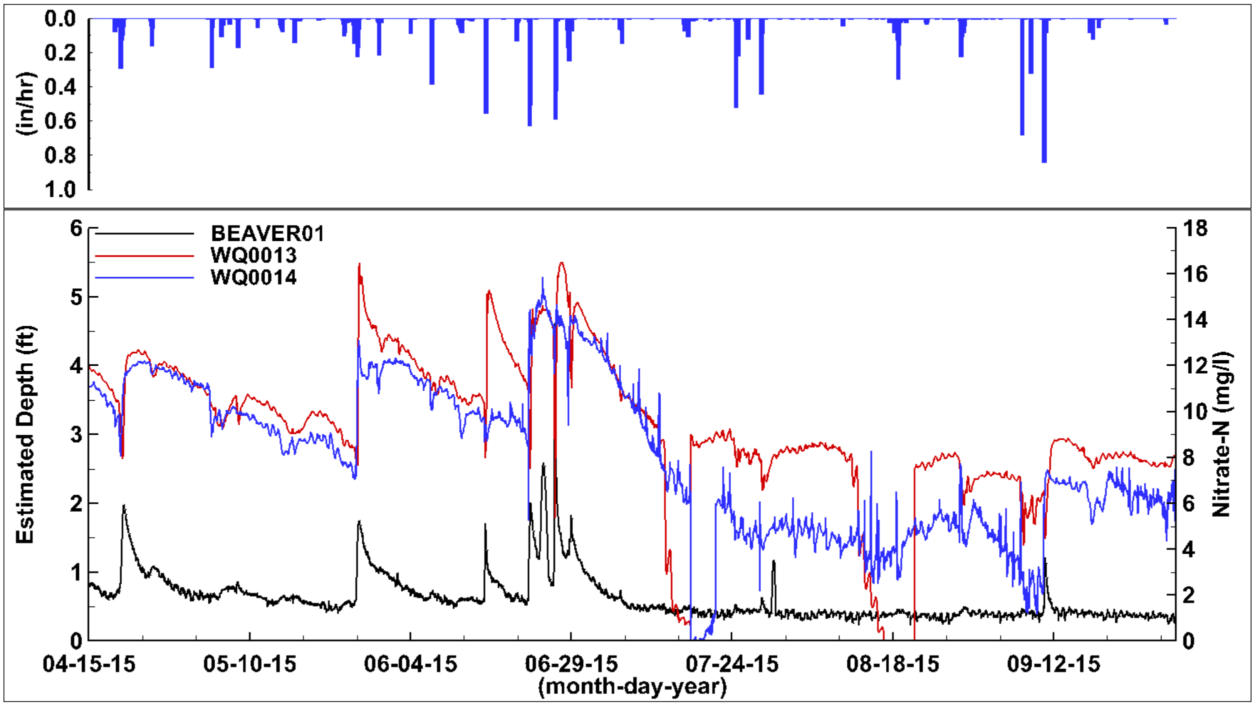


Figure 3.10: Nitrate concentrations, discharge, and precipitation measurements for the 2015 season. The nitrate concentrations (Nitrate-N in mg/L) are shown for two sites in Beaver Creek: WGS0014 in the middle watershed, and WGS0013 near the outlet. Estimated depth is the stream stage (in feet) at the BEAVER01 site. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

This effect is seen more clearly in Figure 3.11, which shows a 30-day period in May and June 2015 that includes several rainy periods. During the heavy rainfall periods between May 24 and 27, nitrate concentrations increase at both sites. However, the increase at WQ0013, which is co-located with BEAVER01, occurs slightly after the peak in stream stage. After the storm ends, runoff from groundwater sources (baseflow) continues, but at a higher rate than before the storm. The increased baseflow leaches and transports more of the nitrate stored in the soils, resulting in the higher nitrate concentration after the storm. In contrast, the small rains that follow do not increase nitrate concentration. In fact, they tend to produce slight temporary reductions in concentration, especially at the upstream site (WQ0014). The next significant rain occurs on June 16 and causes the stream stage to rise. It is associated with a temporary decrease in nitrate concentration at the downstream site (WQ0013), which rapidly rebounds to higher concentration levels afterwards. This change is not seen at the upstream site (WQ0014), where the pond projects may be capturing any runoff from the storm event.

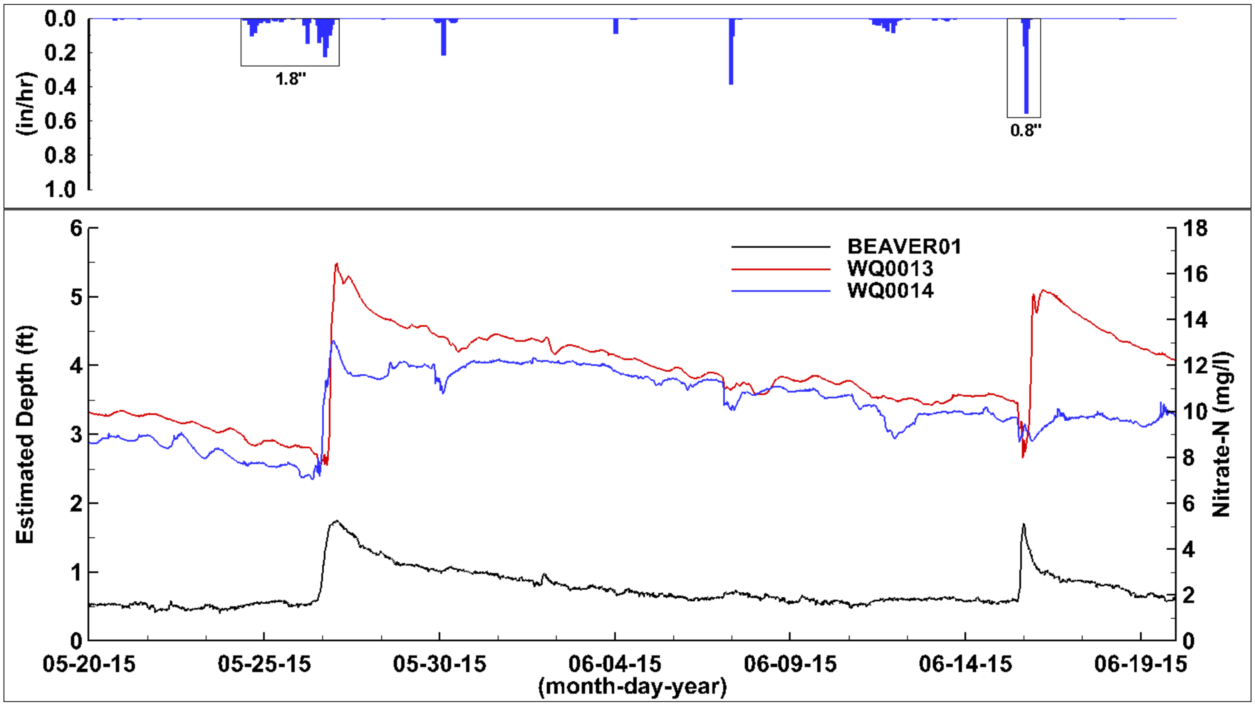


Figure 3.11: Nitrate concentrations, discharge, and precipitation measurements for a 30-day period in late-spring 2015. The nitrate concentrations (Nitrate-N in mg/L) are shown for two sites in Beaver Creek: WGS0014 in the middle watershed, and WGS0013 near the outlet. Estimated depth is the stream stage (in feet) at the BEAVER01 site. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

g. Monitoring Summary

Beginning in 2014, the Iowa Flood Center started intensive monitoring of water in the Beaver Creek Watershed. IIHR—Hydroscience & Engineering also began monitoring water quality. Instrumentation currently deployed in the watershed now measures precipitation, discharge, stream stage, soil moisture, soil temperature, groundwater levels, and water quality. The data collected during the 2014 and 2015 seasons record changes in water quantity and water quality within the watershed. This data collection effort guides our work to develop detailed hydrologic models that mimic observed watershed processes. The network of instruments will also be used to monitor changes in the watershed as researchers implement project activities.

4. Project Inventory

The development and construction of flood mitigation projects in the Beaver Creek Watershed were central activities of the Iowa Watersheds Project. The Upper Cedar Watershed Management Improvement Authority selected Beaver Creek as a pilot sub-watershed to construct and implement demonstration projects. Project locations were selected based on volunteer landowner interest and recommendations from the Iowa Flood Center. This chapter describes the Phase II projects built in the Beaver Creek Watershed.

a. Iowa Watersheds Project Wetlands

Many wetlands in Iowa have been constructed to provide flood storage. A schematic of a typical flood storage wetland is illustrated in Figure 4.1. The wetland is created by constructing an earthen embankment across the stream. The wetland holds some water all the time (called permanent wetland storage). However, if the water level rises high enough, an outlet passes water safely through the embankment. This outlet is called the principal spillway. As the water level rises during a flood, more water is stored temporarily in the wetland. Eventually, the water level reaches the auxiliary spillway (NRCS design documentation use the term auxiliary spillway, but the term emergency spillway is also commonly used). The auxiliary spillway is constructed as a means to release water rapidly so the flow does not damage or overtop the earthen embankment. The volume between the principal spillway elevation and auxiliary spillway elevation is called the flood storage.

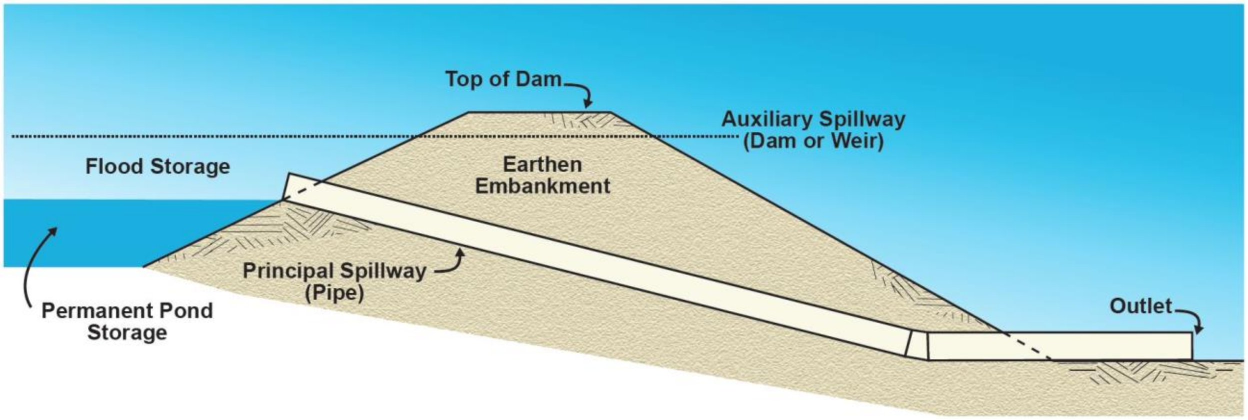


Figure 4.1: Prototype wetland for flood mitigation and nitrogen removal.

In 2015, six wetlands were built in the Beaver Creek Watershed through the Iowa Watersheds Project. The wetlands are designed to serve two purposes: flood mitigation and nitrogen removal. The permanent pool volume saturates the soils and enhances nitrogen removal (by a process called denitrification). The volume between the permanent pool and the auxiliary spillway provides storage for flood mitigation. Private consulting firms developed the project designs to meet the requirements of National Resource Conservation Service (NRCS) Conservation Practice Codes No. 410 (NRCS 1985), No. 378 (NRCS 2011), and Iowa Department of Natural Resources (IDNR) Technical Bulletin No. 16 (IDNR 1990). Table 4.1 describes the characteristics of the six wetlands projects. Figure 4.2 shows their location in the watershed.

Table 4.1: Iowa Watersheds Project wetland specifications. The pool storage is the water volume in the permanent pool defined by the principal spillway. The auxiliary spillway storage is the volume when the water reaches the auxiliary spillway elevation. The difference between the auxiliary spillway and pool storage is the flood storage. The number for each site corresponds to the project location shown in Figure 4.2.

Site	Name	Drainage Area (ac)	Flood Storage (ac-ft)	Auxiliary Spillway Storage (ac-ft)	Pool Storage (ac-ft)
1	Floyd County Site 1	460	20.04	32.41	12.04
2	Chickasaw County Site 2	158	16.85	12.38	4.36
3	Chickasaw County Site 3	196	15.42	21.21	3.52
4	Chickasaw County Site 4	139	16.25	4.36	4.40
5	Chickasaw County Site 5	109	6.79	18.93	3.84
6	Chickasaw County Site 6	292	15.53	3.52	9.45

The six wetlands provide a total flood storage of 90.9 acre-feet. The total drainage area regulated by these wetlands is 1,196 acres, or about 10.6% of the Beaver Creek Watershed (note that the Site 2 wetland drains into the Site 3 wetland, so its drainage area is also contained within Site 3). Overall, the flood storage volume of the wetlands is equal to 0.91 inches of runoff from their upstream drainage areas.

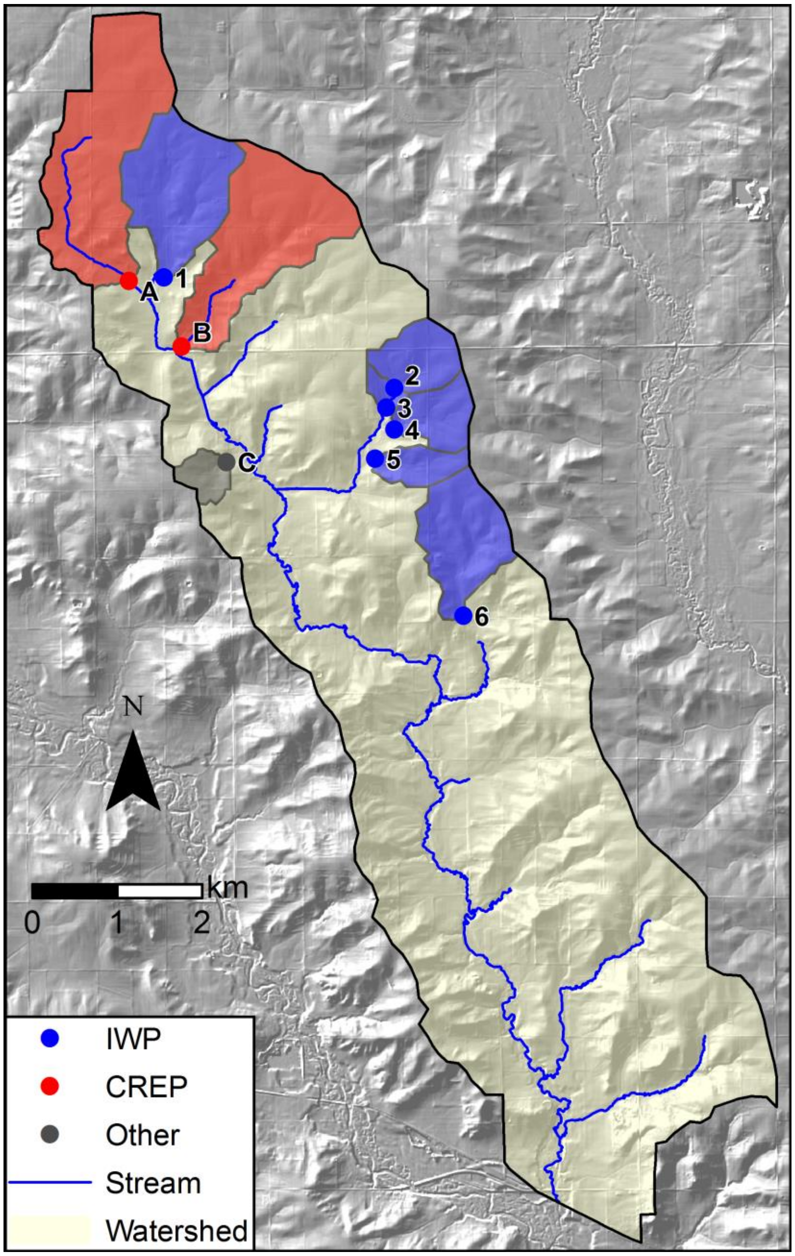


Figure 4.2: Beaver Creek Watershed structure locations and upstream drainage area. Colors indicate funding source. Numbers and letters correspond to Tables 4.1 and 4.2.

b. Existing Wetlands Projects

Prior to the Iowa Watersheds Project, three constructed multi-purpose wetlands-type projects were built in the Beaver Creek Watershed between 2006 and 2013. Table 4.2 describes the characteristics of the three existing wetlands projects, and Figure 4.2 shows their locations in the watershed.

Table 4.2: Existing wetland specifications. The pool storage is the water volume in the permanent pool defined by the principal spillway. The auxiliary spillway storage is the volume when the water reaches the

auxiliary spillway elevation. The difference between the auxiliary spillway and pool storage is the flood storage. The letter for each site corresponds to the project location shown in Figure 4.2.

Site	Name	Drainage Area (ac)	Flood Storage (ac-ft)	Auxiliary Spillway Storage (ac-ft)	Pool Storage (ac-ft)
A	CREP Site/Floyd County	648	31.47	42.64	11.17
B	CREP Site/Floyd County	548	26.16	–	–
C	Wohlers Pond	69	6.71	25.31	18.60

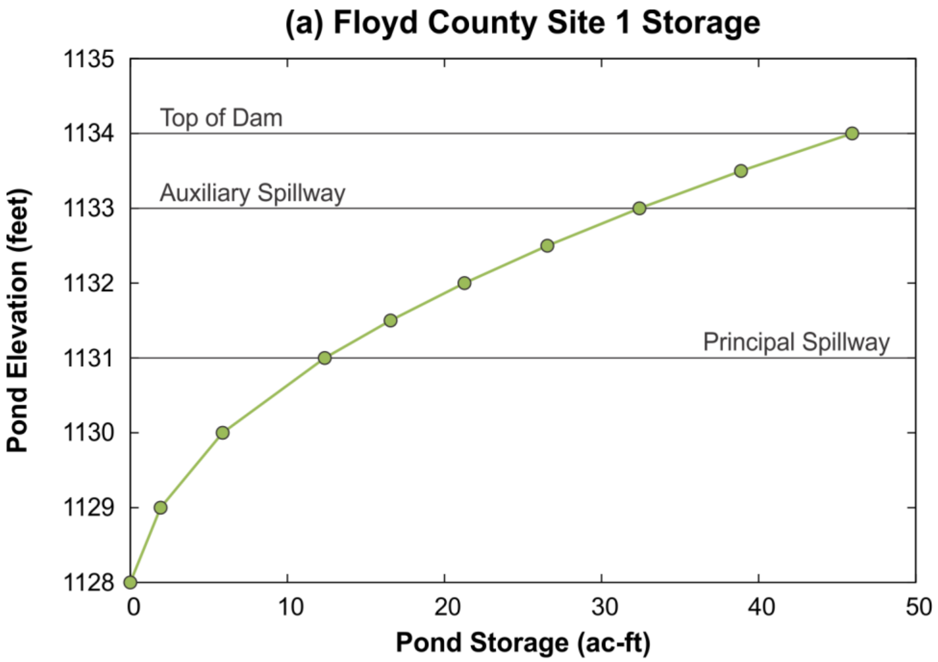
The Conservation Reserve Enhancement Program (CREP) funded two of the projects for nutrient reduction purposes. The wetlands have both a permanent pool for nitrogen removal and storage for flood mitigation. The CREP structures are located in the upper one third of the catchment area, draining the least sloped, most heavily cultivated areas. The third wetland is located to the south of the CREP wetlands and drains a smaller area than any of the CREP or Iowa Watersheds Project wetlands.

Together, the six Iowa Watersheds Project wetlands and three existing wetlands provide a total flood storage of 155.2 acre-feet. The total drainage area regulated by these wetlands is 2,461 acres, or about 21.7% of the Beaver Creek Watershed. Overall, the flood storage volume of the wetlands is equal to 0.76 inches of runoff from upstream drainage areas. Note that with the addition of the Iowa Watersheds Project wetlands, the drainage area regulated by wetlands nearly doubled, and the available flood storage was increased by 141%.

c. Hydraulics of Wetlands Projects

Wetlands projects can reduce flood damages by storing water during high runoff periods. Storage wetlands hold floodwaters temporarily and release water at a reduced rate, lowering the peak flood discharge downstream of a storage wetland. The effectiveness of any one storage wetland depends on its size (storage volume) and how quickly water is released. Wetlands are engineered to efficiently use their available storage for large floods (typically in the 10- to 50-year return period flood range).

To determine the wetland shape and outflow characteristics of the six Iowa Watersheds Project wetlands and the three existing wetlands, researchers gathered the design information. This included the project plans, which describe how the projects were built, as well as hydrologic design information used to select the principal and auxiliary spillway outflow structures. The wetland shape is defined by the relationship between the wetland water level and the wetland area; this relationship is used to estimate wetland storage. Figure 4.3(a) shows an example of a constructed elevation-storage relationship for one of the wetlands. The dimensions and characteristics of the principal and auxiliary spillways are used to determine how much water is released from the wetland at different water levels. Figure 4.3(b) shows an example of a constructed elevation-discharge relationship for one of the wetlands. Combining the wetland release with the wetland shape results in an elevation-storage-discharge relationship, which defines the hydraulic characteristics of the wetland.



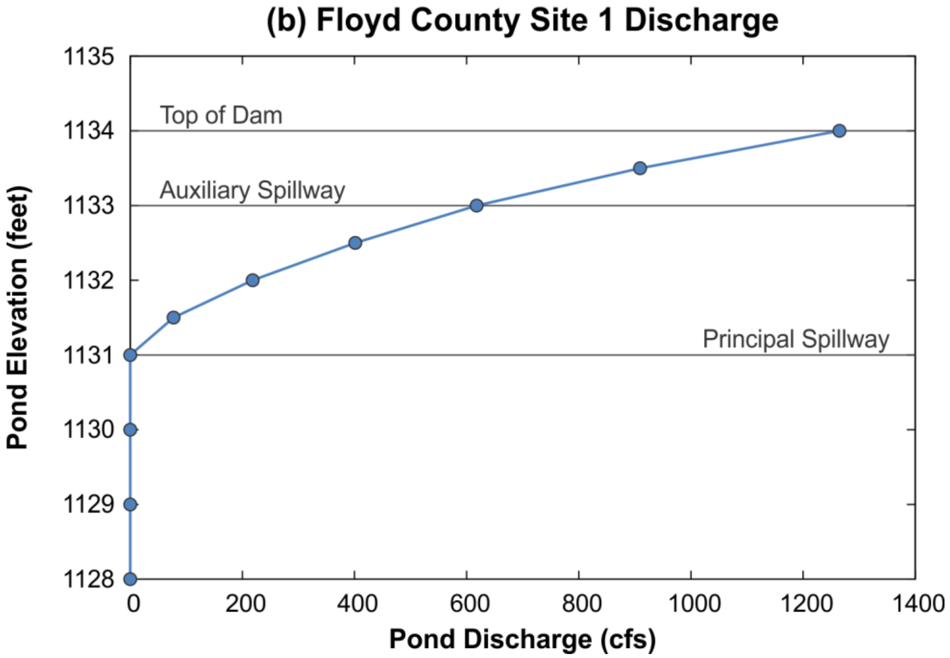


Figure 4.3: Wetland hydraulic relationships for the Floyd County Site 1 Wetland: (a) Elevation-storage relationship, and (b) elevation-discharge relationship. The elevations of the principal spillway, the auxiliary spill- way, and the top of dam are indicated.

For the six Iowa Watersheds Project wetlands and the two existing CREP wetlands, elevation-area-storage data are provided with the hydro- logic design information. However, we interpolated these data to determine storage at additional elevations in order to obtain a more refined representation of the wetland hydraulics. For the one wetland without elevation-area-storage data, we estimated the relationship using the permanent wetland area from the project plans and an assumed linear relationship between elevation and area (since the other eight wetlands have a nearly linear relationship). The hydrologic design information also contained details on the principal and auxiliary spillway outlets for all nine wetlands. We used this information to verify discharge calculations, and then interpolate to determine discharges at additional elevations. The derived representation of the elevation-storage-discharge relationship used to assess the hydrologic performance of the wetlands is provided in Appendix A.

d. Project Summary

The demonstration projects constructed through the Iowa Watersheds Project provide multiple benefits both on- and off-site. Landowners enjoy the farm wetlands on their property for the aesthetic beauty, recreation, and wildlife attracted to the habitat. In addition, landowners can use the wetlands to water livestock and control erosion on their land. Wetland structures were strategically placed in areas not suitable for farming and upon completion, gave landowners better, easier access to the rest of their farm.

Projects create storage on the landscape that reduces downstream flooding, protecting both people and infrastructure. The wetland structures provide significant savings in federal, state, and local road and bridge maintenance costs by managing runoff to reduce and mitigate structural and nonstructural flood damage. Constructed projects serve as demonstration sites to encourage other landowners to adopt similar conservation practices.

5. Detailed Predictions of Hydrologic Alterations

This section offers a comprehensive analysis of the fine scale impacts of the flood mitigation structures. To quantify the effects of human induced hydrologic alterations on the Phase II watersheds, researchers built a numerical model, calibrated and validated to monitoring data. They also used design storm analysis to investigate project performance for flood conditions. This chapter continues with a description and construction of the numerical model, calibration, validation, and a design storm assessment.

a. Numerical Model Description — HydroGeoSphere

Researchers selected the numerical model HydroGeoSphere (HGS) to investigate the detailed aspects of integrated watershed response to flood mitigation practices. HGS takes into account all of the key components of the hydrologic cycle, applying the most physically realistic representation of water movement (see Figure 5.1). Within the model domain, rainfall is partitioned between overland surface flow, evaporation, transpiration, and infiltration enabling discharge through the surface or subsurface into downstream water bodies or aquifer flows (Brunner and Simmons, 2012). The software can implement wells, tile drains, subsurface fractures, and channelized flow. Rainfall is applied to the surface of the domain. Interception, evaporation, and transpiration are modeled using the Kristensen and Jensen approach (Brunner and Simmons, 2012), where evapotranspiration is a function of soil water availability and vegetation growth characteristics. HGS quantifies and illustrates micro- and macro-scale effects of each project on the water balance and overall fluxes.

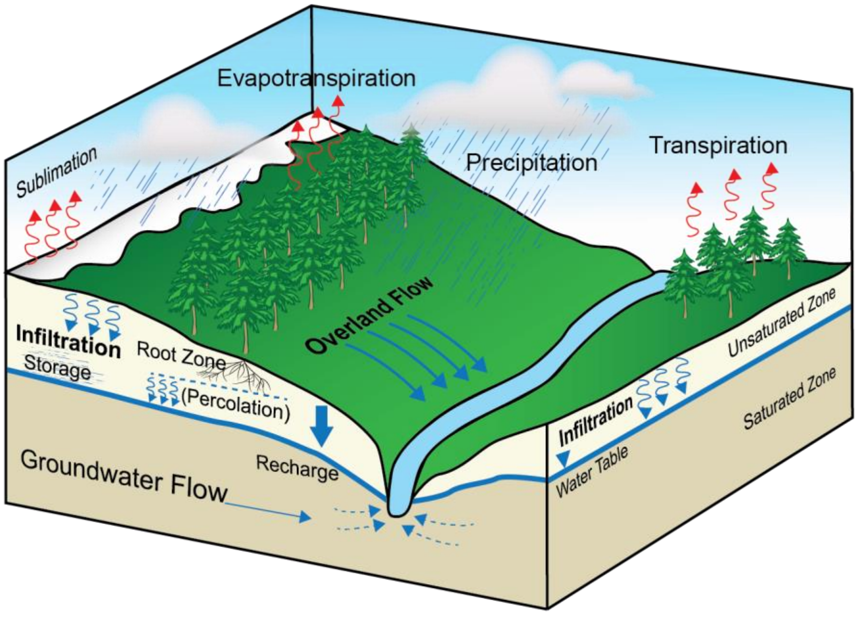


Figure 5.1: Hydrologic processes simulated by the numerical model HydroGeoSphere.

In direct comparison to the Hydrologic Assessment of the Upper Cedar River Watershed, HGS is a mathematical, physically based, distributed, coupled, surface subsurface hydrologic model.

Each of these items will be briefly discussed. The fact that HGS is a mathematical model implies the different hydrologic processes are represented by mathematical expressions based on the fundamentals of fluid mechanics or based in physics. HGS is a distributed parameter model, meaning physical characteristics of the watershed, such as land use and soil type, can vary from one location to the next. HGS is a coupled model, meaning the different hydrologic processes are solved jointly rather than independently. In reality, surface and subsurface processes are dependent on one another and their governing equations should be solved simultaneously. Finally, HGS is a surface-subsurface hydrologic model, meaning it is applicable to almost every hydrologic simulation.

b. Mesh Generation

The objectives of this study required investigating surface and near surface water flow processes. The automatic generation of variably sized triangular elements created a two-dimensional representation of the land surface. For this study, HGS produced a mesh from the watershed boundary, stream centerlines, roadways, and hydraulic structure locations. The watershed boundary was identified as the local topographic high, draining all internal areas to a single outlet location. This boundary acts as the lateral edge of both the surface and subsurface domains. A majority of Iowa is typified by mildly sloped agricultural expanses, divided by elevated roadways and incised stream channels. During heavy rainfall events, elevated roadways act as topographic divides, forcing rainfall into nearby drainage ditches and then into stream channels. HGS extracts elevation information from element edges. By allocating element edges along topographic features, the elevation at that location is enforced. Roadways and stream centerlines were deemed topographically significant features and included as mesh generation boundaries. Stream centerlines were delineated and incorporated to ensure continuous flow to the catchment outlet, maintaining travel times and realistically capturing surface-subsurface interactions (Li et al., 2008). To increase efficiency of numerical simulations, mesh elements were coarsened to 600 feet across mildly sloped areas and refined near streams and constructed projects to 80 feet. The final two-dimensional surface grid contained 24,764 triangular elements (see Figure 5.2).

The completed two-dimensional surface mesh was projected downward to the estimated bedrock depth (Witzke et al., 2010) to form three-dimensional subsurface elements (see Figure 5.3). The subsurface was divided into two zones: three feet below the surface, and from the three-foot depth to the bedrock. Ten elements were spaced vertically through the top three feet of soil, such that the depths of the soil moisture sensors were explicitly included (2 in., 4 in., 8 in., 20 in.). The remaining element depths varied in increasing thickness from 2 feet to 6 feet near the impermeable layer. The increased number of numerical elements near the surface allowed for a more accurate representation of the interactions between the surface and subsurface domains (see Figure 5.4). The product of mesh generation was a 371,460-element three-dimensional modeling domain.

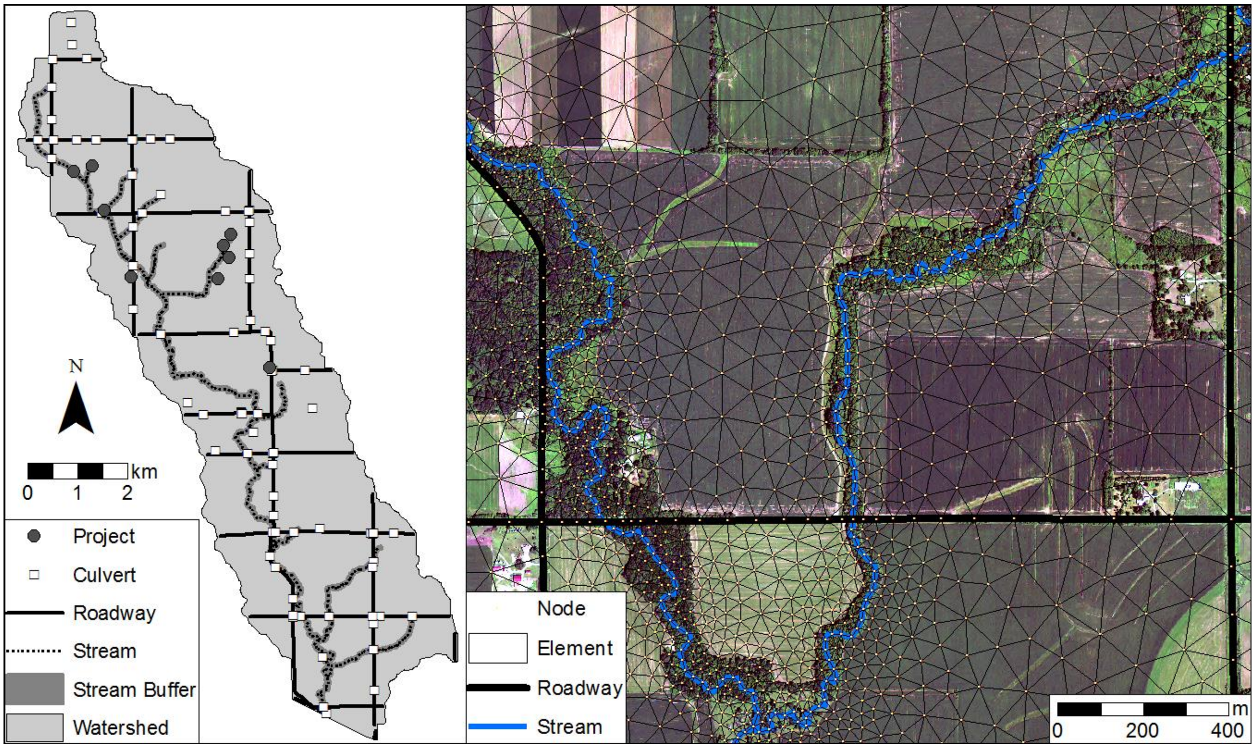


Figure 5.2: Beaver Creek Watershed surface domain grid generation: a) Boundaries for mesh generation; b) Example location of the completed 2-D finite element grid.

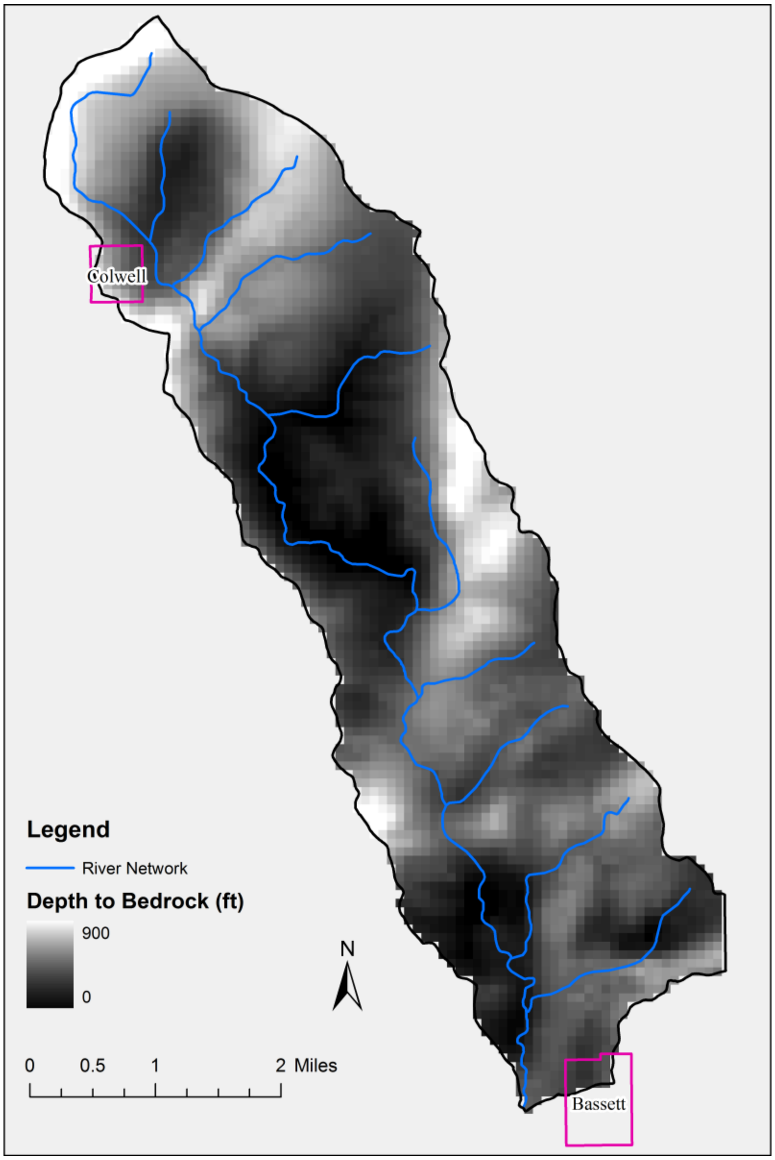


Figure 5.3: Estimated depth to bedrock as defined by the Iowa Geological Survey (Witzke et al., 2010).

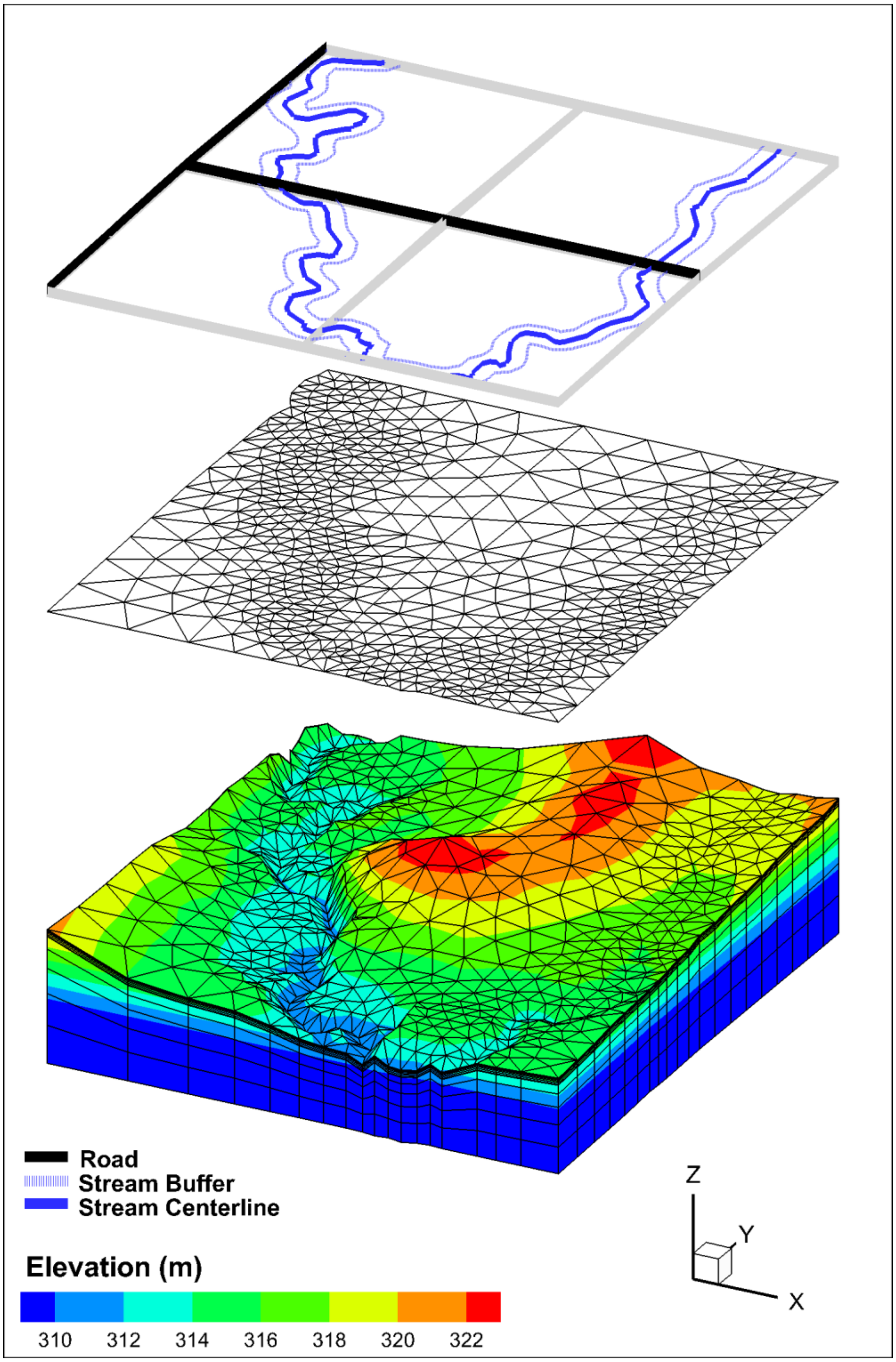


Figure 5.4: Generation of 2-D and 3-D mesh. Conceptual mesh generation though incorporation of important boundaries (top) to produce a 2-D mesh (middle), which was projected downwards to create a 3-D tetrahedral mesh (bottom). Vertical axis at 10:1 ratio.

c. Attributing the Model

Publicly available land use, soil type, and well log data 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 2006 (Fry et al., 2011) provided spatially variable land use classifications. Land classifications were simplified into five classifications: agriculture, grassland, forest, developed, and water; these were assigned to the appropriate elemental area (see Figure 2.8). The five surface land use classifications relate surface elements to overland flow resistance parameters and vegetation properties. The parameters used to calculate the actual evapotranspiration (Kristensen and Jensen, 1975) were described thoroughly by (Li et al., 2008).

The landscape topography was described by Light Detection and Ranging (LiDAR) datasets, which were aggregated for the entire state of Iowa between 2007 and 2010 (Iowa Geological and Water Survey, 2010). One-meter Digital Elevation Models of bare ground surface data were derived from the LiDAR products. A high spatial resolution topography enabled accurate identification of stream, roadway centerlines, watershed boundaries, and culvert locations for mesh generation. Element elevation data representing the land surface were extracted directly from the one-meter resolution elevation model. Mesh generation boundaries ensured that the extracted elevation data coincided with roadways and stream centerlines.

Subsurface

Subsurface stratigraphy was divided into surficial soils and deeper geologic soils. The surficial three feet of subsurface depth was described as spatially variable, vertically uniform to soil data. The deeper subsurface was represented though an aggregation of well log data creating a homogeneous deeper soil layer.

Researchers used the Soil Survey Geographic (SSURGO) database (Soil Survey Staff, 2014) (Figure 2.5) to describe the top three feet of the subsurface. They allocated the flow properties based on soil texture classification and assigned the mean textural properties.

The remaining deeper geology below the top three feet of soil was de- scribed by historical well logs at 86 sites across the watershed and surrounding area (Iowa Geological and Water Survey, 2015) (Figure 5.5). General trends in the geologic interpolation indicated variable layering of till, loess, and clay over confining layers of sedimentary carbonates and siliciclastics. The geologic formation contained intermittent sand and gravel lenses. The soil properties in this deeper region were volume weighted to produce an aggregated representation of geologic properties. The deeper subsurface was represented by the above described homogeneous representation of hydraulic properties from one meter deep to the estimated depth to bedrock.

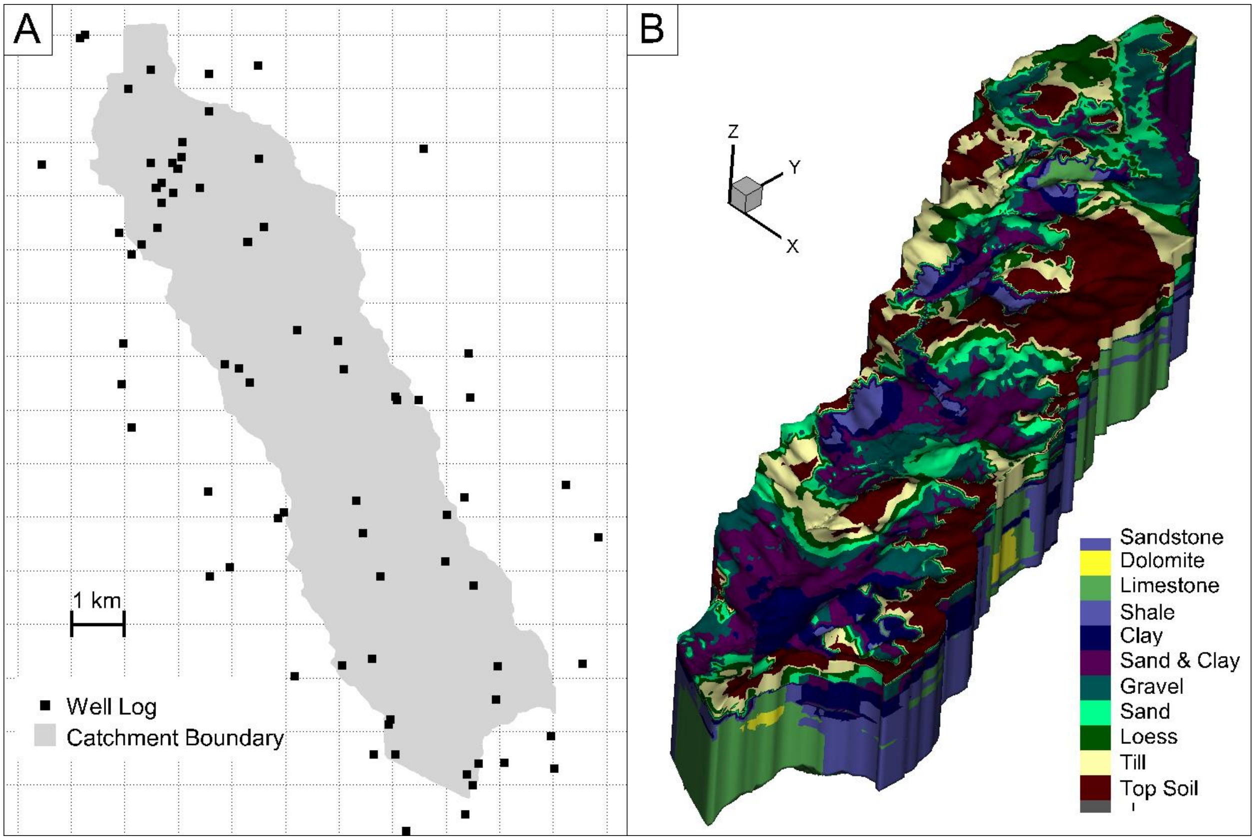


Figure 5.5: a) Geologic well log locations (86) within the Beaver Creek Watershed and the surrounding area. b) Inverse distance interpolation of well log points onto the mesh up to 100 m deep.

Meteorological Input for Hydrologic Simulation

Measured meteorological data for 2014 and 2015 from the Beaver Creek Watershed were applied for all annual simulations. This section describes the exact alterations to the raw data for input into numerical simulations.

Precipitation was measured at three locations within the Beaver Creek Watershed beginning May 15, 2014 at 15 minute increments (see Figure 3.1). The raw data were aggregated to the hourly time step and Thiessen polygon weighted over the Beaver Creek Watershed. This produced a uniformly distributed rainfall at hourly time steps from May 15, 2014 to December 31, 2015. From January 1, 2014 to May 15, 2014, we downloaded hourly liquid equivalent precipitation data from the Iowa State University AgClimate weather station at Nashua (Iowa State University, 2015) (Figure 5.6). The precipitation data from Nashua and from within Beaver Creek Watershed were combined and applied as a surface flux input for annual model simulations of 2014 and 2015. Precipitation was aggregated spatially as to remove rainfall variability from the catchment response. Similarly, the raw 15 minute data were aggregated to an hourly time step in an effort to reduce the impact of variable rainfall inputs on the basin response.

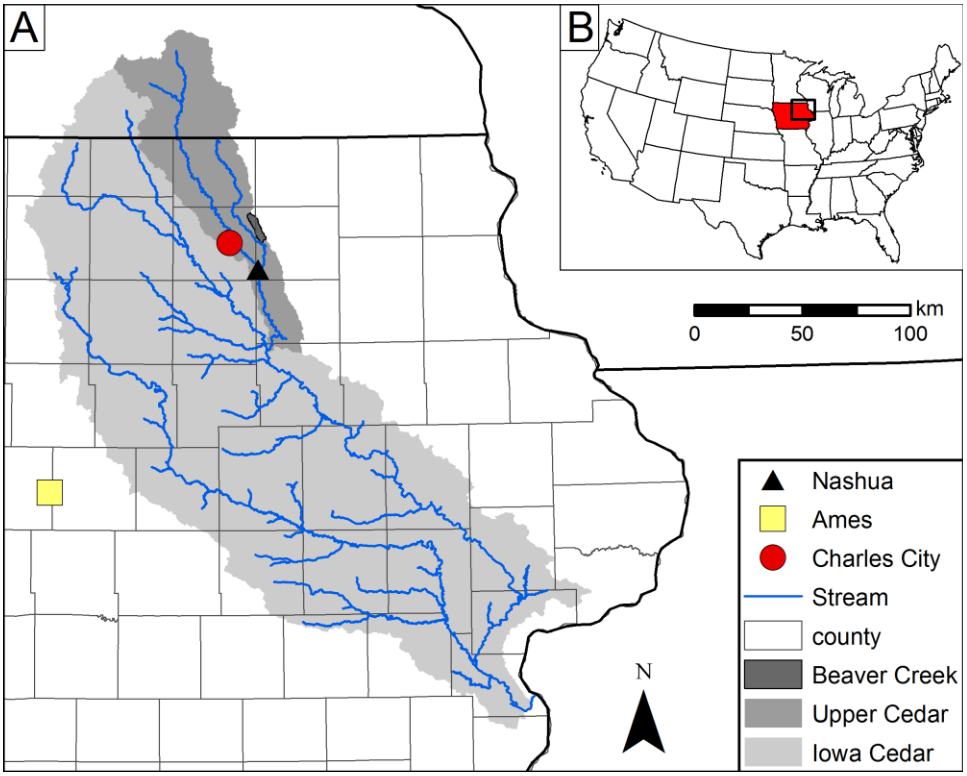


Figure 5.6: Data collection sites in Iowa. Ames SCAN–long term water content (yellow), Charles City–supplemental meteorological data for PET calculation (red), Nashua–PET data and supplemental hourly rainfall (black).

Input precipitation times series were further altered by incorporating solid form snow storage when temperatures dropped below freezing (32°F). PRISM daily average temperature data (PRISM Climate Group, 2016) were aggregated for the 2014 and 2015 time periods at the centroid of the Beaver Creek Watershed. When temperatures were below freezing, snow was assumed to accumulate on the land and stored until temperatures rose above freezing. A degree day method (Natural Resource Conservation Service, 2004a) allowed temperature to be used as an index for a wide range of energy fluxes affecting the melting process. A difference of temperature to a base temperature (freezing) allows daily melt depths to be calculated until the storage of snow has been depleted. For modeling purposes, this analysis was completed prior to simulation, where by the daily melt flux was input as a rainfall rate into the domain. This process shifts the introduction of frozen precipitation into the early spring months, saturating near surface soils and causing higher runoff potential. Daily potential evapotranspiration (PET) based on the Penman-Monteith approach and downloaded from the Iowa State AgClimate station at Nashua, Iowa (Iowa State University, 2015). A gap in PET data from April 1, 2014 to August 18, 2014 required supplemental PET data. Using time series on air temperature, dew point temperature, and cloud cover from Charles City, daily PET were estimated using a Penman approach (Shuttleworth, 1993). The Charles City and Nashua PET data were combined for further preprocessing.

PET data were modified to take into account the dominant land use, agriculture. A crop coefficient (K_c) was applied to each daily PET estimated based on the cumulative growing degree day base 50 (GGD50) method (High Plains Regional Climate Center, 2015; Iowa State University, 2015).

K_c takes into account the ground cover, canopy properties, and aerodynamic resistance of the specific crop (Allen et al. 1998). K_c increased PET during growing seasons, otherwise K_c reduced the PET. Due to model simplifications only a single PET value can be applied to the simulations. As a result the PET× K_c from corn was applied uniformly over the watershed.

Long-term Soil Water Content Record

Long term measured soil water content data were available at only a few locations in the state of Iowa. The Soil Climate Analysis Network (SCAN) was developed to gain insight into the soil-climate dynamics through the NRCS (Natural Resource Conservation Service, 2004b, 2015; Schaefer et al., 2007). A nearby SCAN site in Ames, IA, measured continuous soil water content data from 2002 to 2012. Soil water content was measured at 2 in., 4 in., 8 in., 20 in., and 40 in. depths using a dielectric measuring device (Natural Resource Conservation Service, 2004b). The data were used to identify long term soil moisture trends and as initial conditions to investigate antecedent moisture controls.

SCAN soil water content data were shown to vary with depth and time. Shallower soils were noted to have increased soil moisture variability, with lower median soil moisture values. As measurement depth increased, median soil moisture increased, and variability decreased. The highest median soil water values and lowest variability occurred in the months of March, April, and May, due to spring snowmelt and rainfall. June, July, and August were attributed with the highest variability and lowest median moisture values due to high evapotranspiration. Temporal trends held true at each depth.

d. Calibration

We adjusted model parameters so that simulated results match known annual ratios between components of the hydrologic cycle as closely as possible. The target ratios used were discharge to precipitation (Q/P), evapotranspiration to precipitation (ET/P), evaporation to evapotranspiration (E/ET), transpiration to evapotranspiration (T/ET), and baseflow to discharge (Q_b/Q). The targets for the ratios are presented in Table 5.1. When evaluating the existing literature for these ratios, studies performed in Iowa or other agriculturally dominated Midwestern landscapes were given preference, but in some cases we used ratios from other locations.

Precipitation and potential evapotranspiration are the major meteorological drivers in physically-based coupled simulations. We used meteorological data measured in 2014 to run recursive simulations and ultimately determine model parameters (Ajami et al., 2015). A comparison of surface, near surface, and groundwater storages from one year to the next indicated a convergence to a 1.0% change threshold after 4 years of model simulation. Results from the last year (4) of this recursive simulation are displayed in Figures 5.7 and 5.8.

Table 5.1: Annual ratios of hydrologic components used in the calibration and evaluation of the model. *Q* is total flow, *P* is precipitation, *ET* is evapotranspiration, *E* is evaporation, *T* is transpiration, and Q_b is base flow.

Ratio	Value	Sources
Q/P	0.24	Schilling et al. (2008)
	0.27	McDonald (1961)
	0.24	Hoyt (1936)
	0.29	Estimated with measured data
ET/P	0.76	Schilling et al. (2008)
	0.73	McDonald (1961)
	0.76	Hoyt (1936)
E/ET	0.26, 0.33	Kang et al. (2003)
	0.23, 0.35	Wang et al. (2013)
T/ET	0.67, 0.74	Kang et al. (2003)
	0.65, 0.77	Wang et al. (2013)
	0.61±0.15	Schlesinger and Jasechko (2014)
Q_b/Q	0.56	Schilling et al. (2008); Schilling and Libra (2003)
	0.45-0.66	Schilling (2005)

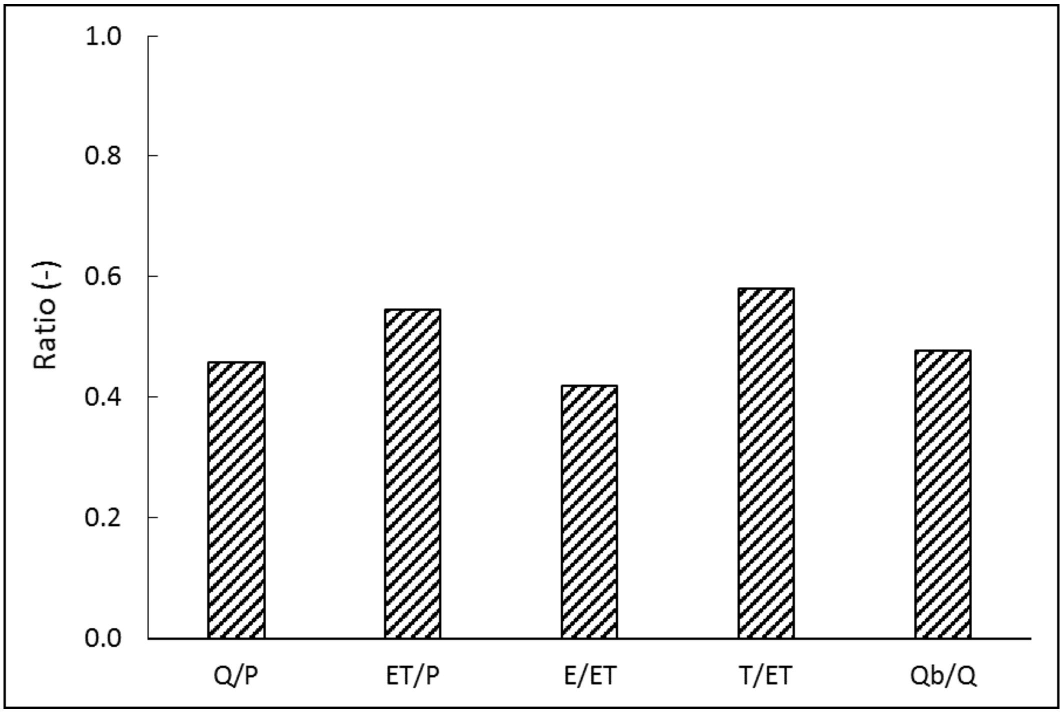


Figure 5.7: Calibration. Estimated annual ratios of hydrologic components obtained with the final set of parameters (4th year).

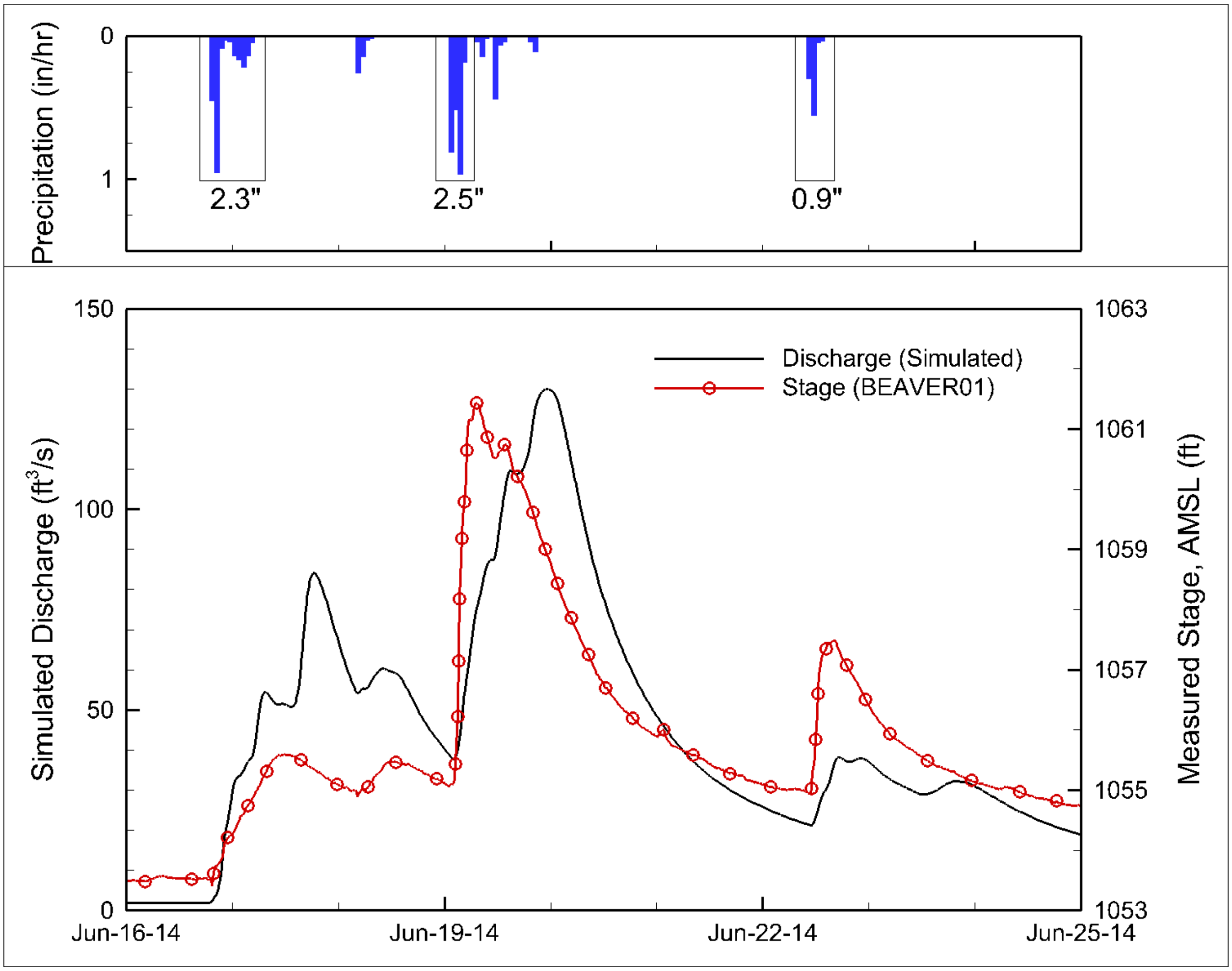


Figure 5.8: Calibration comparison for timing of simulated discharge (HGS) to stream stage measured at BEAVER01 (see Figure 3.1). Precipitation is the average of the measurements of the three rain gauge platforms.

Calibrated water balance components generally matched the calibration targets adequately. *Q/P* was 45%, with *ET/P* representing the remaining 55%, approximately 15% higher and lower than the respective ratios. This indicates that the watershed over this period tended toward a “wet” condition. This was a reasonable result because 2014 was wetter than normal (higher precipitation). An iterative cycle of a wet year pushes the model into a wet equilibrium. *E/ET* (41%) and *T/ET* (59%) allocated more water toward the evaporation component than the calibration targets, which is representative of a wet watershed condition. Evaporation is not limited near saturation, but transpiration is. Furthermore, evaporation acts on the top 8 inches of soil, while transpiration affects the top 3 feet.

Under wet conditions, more water is closer to the surface and available for evaporation. Baseflow accounted for approximately 48% of the total outflow, close to the calibration target range. The partitioning of water balance components over the iteratively run wet year respond in a logical pattern, tending toward a wetter condition.

We further used IFC stream-stage sensors to evaluate the timing of stream flow as compared to variations in stream stage. Although the magnitude of each component is not directly comparable, the peaks and valleys were representative of basin response time. We selected a series of events occurring in June 2014 as an example time period, whereby three heavy rainfall events produced peaks in simulated and measured time series. In each of the three events, the initiation of streamflow at the outlet or the start of the hydrograph increase was consistent with measured data. The lower first and third simulated peaks occurred approximately in time with measured data. The second and largest simulated peak occurred a few hours later. Overall, the timing of simulated hydrographs was adequate when compared to measured stream-stage peaks.

e. Validation

The purpose of model validation is to assess the model's capacity to match field observations for periods different from the calibration time window. Rainfall and potential evapotranspiration data collected in 2015 were used to drive the model, while all the models parameters determined in the calibration phase were kept constant. Figures 5.9 and 5.10 display results of the validation period.

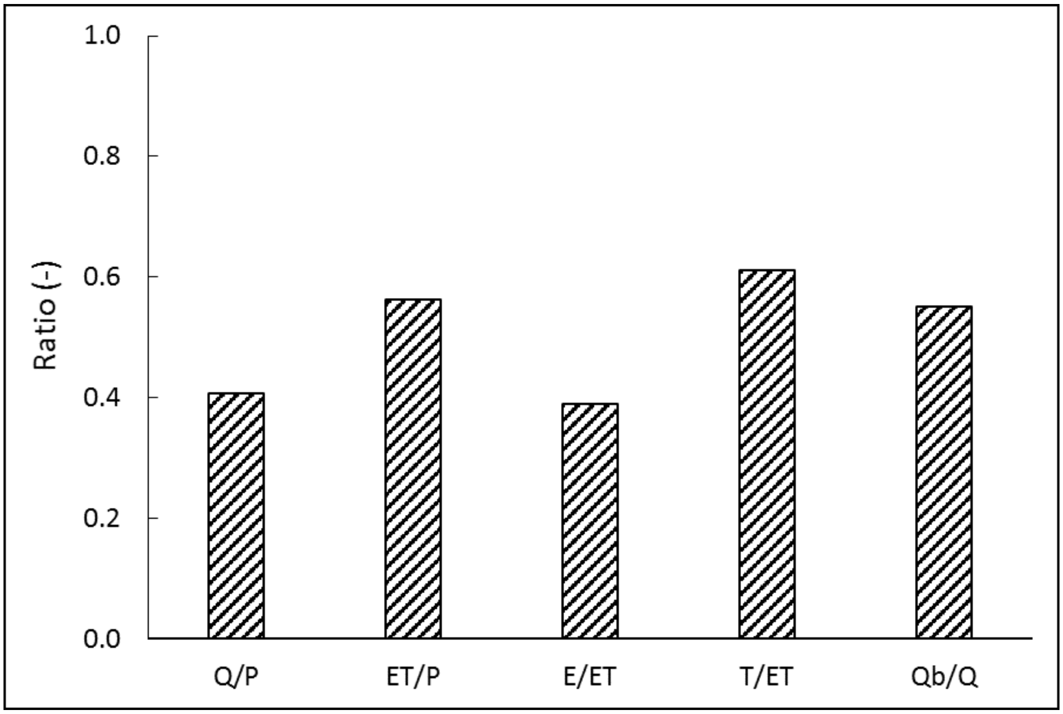


Figure 5.9: Validation. Estimated annual ratios of hydrologic components.

Over the validation period, precipitation was divided into 40% stream flow and 60% *ET*. These water balance components trend well from a wet state (2014) initial condition toward the calibration target of 30% *Q*, 70% *ET*. *ET* was divided into 39% *E*, 61% *T*, consistent with calibration results, and moving toward the 30/70% E/T calibration target. Baseflow increased to 55%, fitting the water balance metrics well.

Major differences in calibration and validation results can be attributed to model complexities and calibration time period. Beaver Creek Watershed has a relatively fast time of concentration; the basin responds to rainfall within hours. Although we collected rainfall data locally, refining the space and time distributions of rainfall can greatly impact a watershed response. Additionally, the hydrologic model does not take into account frozen ground or snow accumulation and melt processes, each of which alters the winter and spring watershed response. The most significant differences were due to the 2014 calibration period. This period was selected for iterative calibration because there were only two years of local data. The year 2014 represented a wet year; starting the watershed off in a wet condition shifted water balance components and stream flow response in a manner that produced more flow per unit precipitation annually. This caused the surface soils to be wetter. Overall, the calibration and validation periods succeeded in depicting the expected variation from the calibration targets and represented overall watershed processes well.

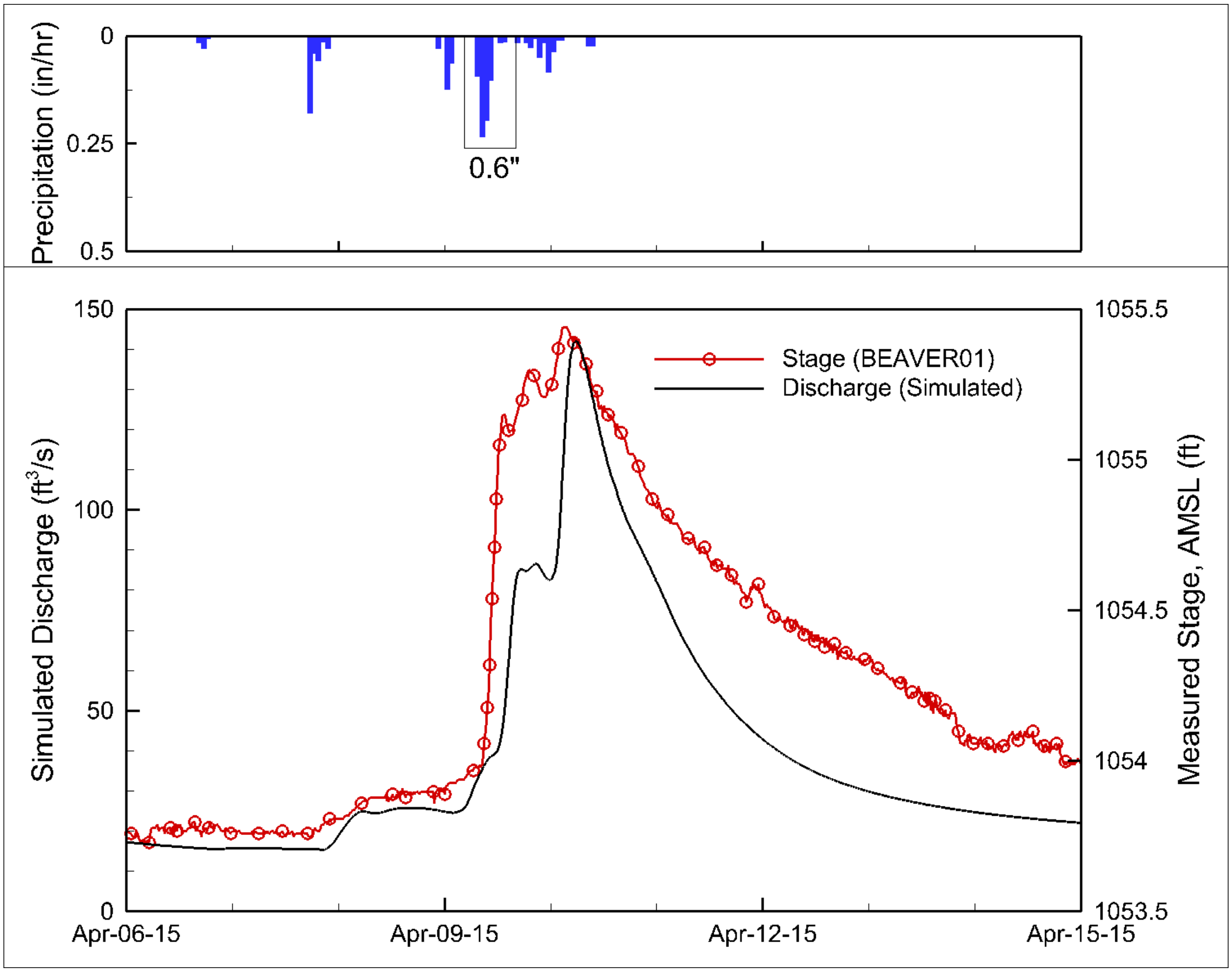


Figure 5.10: Validation comparison for timing of simulated discharge (HGS) to stream stage measured at BEAVER01 (see Figure 3.1). Precipitation is the average of the measurements of the three rain gauge platforms.

f. Localized Impact of Projects

The HydroGeoSphere numerical model of the Beaver Creek Watershed was used to analyze localized project impacts, providing a comprehensive numerical depiction of water dynamics. This section continues as follows: description of project incorporation into the HGS model, addition of flood mitigation projects were tested under high and low synthetic potential peak flow reduction scenarios, projects were analyzed for the local influence on a historical flood event.

Project Inclusion (Mesh and Elevation)

We incorporated nine structures, described in Chapter 4, into the mesh through two components; the structural embankment centerline and the estimated inundation limits of the emergency spillway (Figure 5.11). We extracted elevation contours at the emergency spillway elevation from the 36-foot resolution DEM and incorporated them into the mesh. We refined the mesh in proximity to the detention structures, ensuring the appropriate representation of inundation, flow, and storage. Elevation of the top of dam, the normal pool outlet, and the emergency spillway were assigned per design specifications (Figure 5.11). The remaining nodal elevations remained consistent with the original LiDAR-derived elevation data.

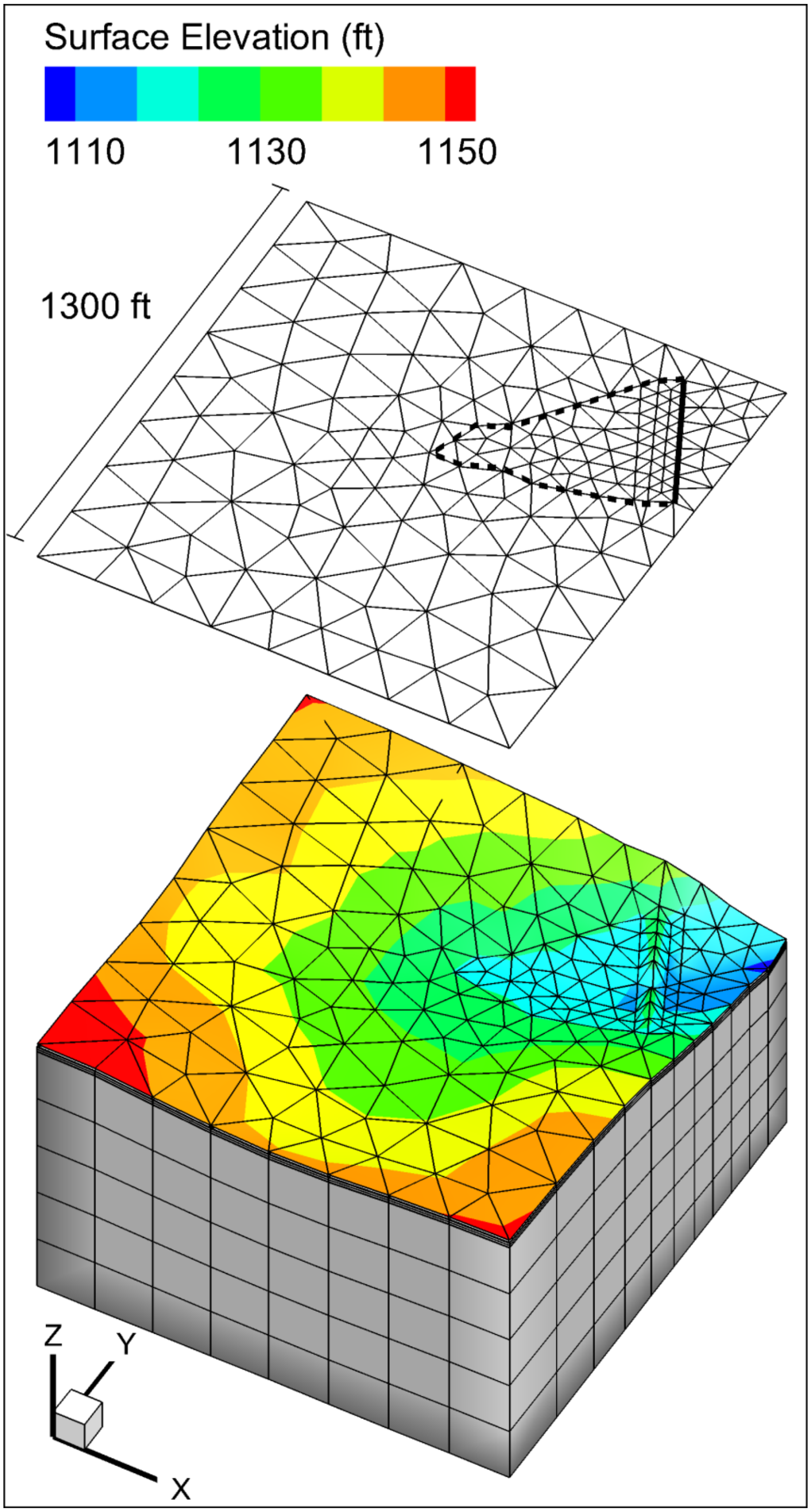


Figure 5.11: Example of project incorporation into the numerical mesh through embankment centerline (solid line), and estimated maximum inundation extent (dashed line). Note the additional refinement of the numerical mesh near the project embankment and estimated inundation area.

Synthetic Analysis of Watershed Response with Incorporated Flood Mitigation Measures

We analyzed the new project installations for a range of antecedent wetness conditions and pre-event project storage conditions, as well as for a given design storm precipitation event. Antecedent soil wetness refers to how wet the soil was prior to precipitation; the wetter the soil, the greater the basin's peak flow response. Pre-event storage refers to the amount of surface water contained behind a flood mitigation detention structure prior to a precipitation event. An empty project condition provides a reduced peak flow when compared to a normal pool storage condition. Similarly, as the depth of rainfall increases, the watershed response increases in a nonlinear manner. This section describes the range of watershed responses to precipitation depth, antecedent soil moisture, and pre-event project storage.

Synthetic Precipitation

We developed hypothetical storms for comparative analysis of distributed projects. These hypothetical storms apply a uniform depth of rainfall across the entire watershed, with the same timing everywhere. We used NRCS Type-II distribution, 24-hour storms for all hypothetical storms. Using the online version of NOAA Atlas 14 – Point Precipitation Frequency Estimates (Perica et al., 2013), we determined 24-hour point precipitation values (rainfall depths) for the 100-year average recurrence interval (7.4 inches) at the basin centroid.

Antecedent Soil Moisture

Numerous methods are available for incorporating antecedent moisture into hydrologic models, but they are not directly applicable to a coupled surface-subsurface model, which dynamically varies soil moisture spatially and with depth. For this study, we aggregated soil moisture data for a 10-year period beginning January 1, 2002, from the Soil Climate Analysis Network (SCAN, Ames location) (Natural Resource Conservation Service, 2015). Without prior knowledge of a vertical distribution to represent soil moisture variability, we applied a non-parametric approach. This study treated initial soil moisture as an independent variable over a range of exceedance probabilities based on an estimated cumulative distribution function (CDF) of measured soil moisture.

We normalized, ranked, and plotted the hourly soil moisture data with measured soil porosity at each depth (Figure 5.12) (Natural Resource Conservation Service, 2004b, 2015). We extracted the 98% and 50% exceedance probability soil moisture contents at each measurement depth, representing very wet (98%) and normal soil wetness (50%) conditions. Initial soil moisture conditions were uniformly distributed across the basin. However, near stream channels, the soil was assumed to be saturated (100%) for the profile depth, because streams in the Beaver Creek Watershed are perennial in nature, indicating the subsurface immediately below is likely saturated.

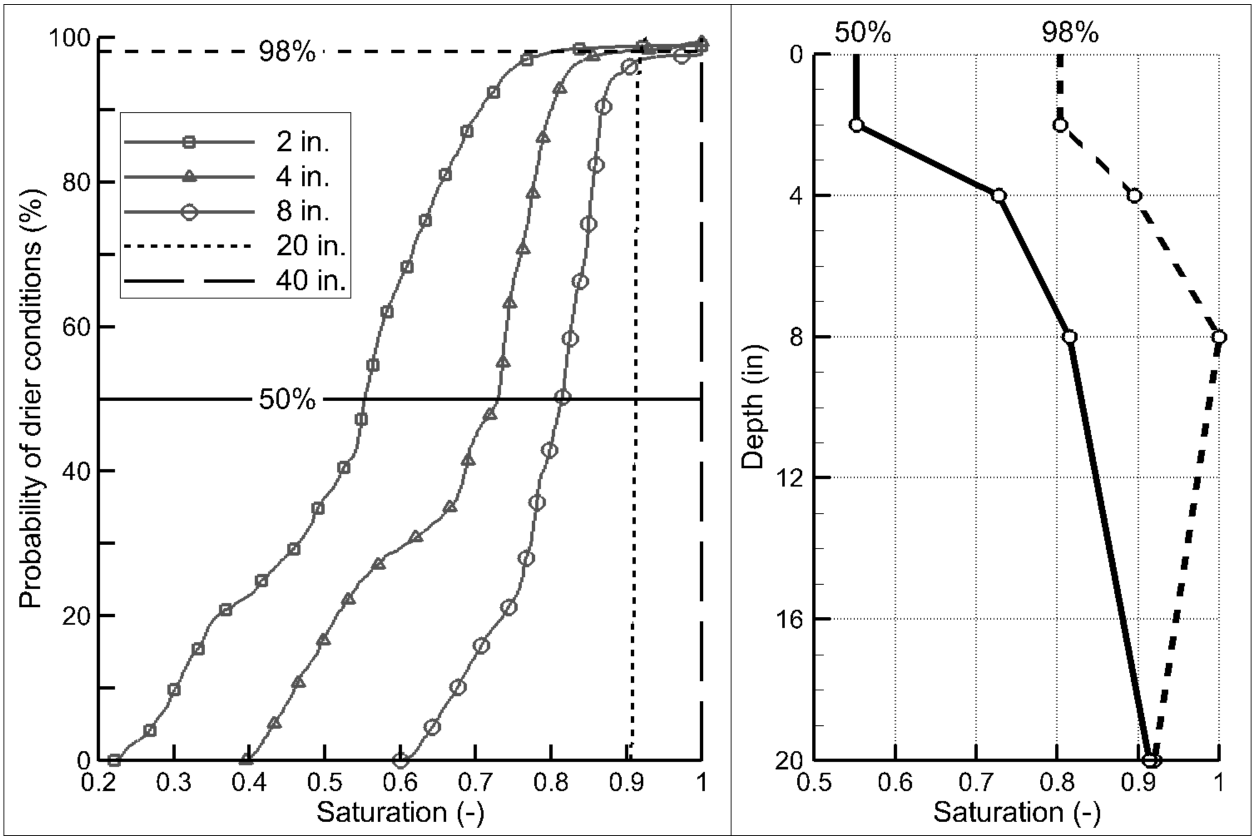


Figure 5.12: (Left) Ranked saturation values at five measured depths. Horizontal lines represent the initial conditions for event simulation. (Right) Soil water initialization saturation for the first 20 in. The 40-inch initialization state was equal to 1.0 for all chosen exceedance probabilities. Circles indicate soil measurement location, and lines represent linearly interpolated HGS input values.

Detention Basin Storage Initial Condition

We have previously noted peak flow alterations from flood control structures as dependent upon the initial storage. We chose three project conditions to adequately encompass the detention basin initial conditions: no projects, full projects, and empty projects. These conditions represent a control (no projects), a maximum peak flow reduction potential (empty projects), and a minimum peak flow reduction potential (full projects). Full project simulations were initialized with water up to the normal pool. Empty project scenarios were initialized without surface water stored behind the structures. This amount of storage capacity is unlikely, as a combination of low precipitation, high evapotranspiration, and/or high infiltration over a prolonged duration would be required to empty the surface storage. The empty project scenario captures the maximum magnitude of peak flow reduction this suite of practices is capable of.

Synthetic Storm Analysis

We performed an analysis to quantify the impact of all projects (six HUD funded wetlands, two CREP wetlands, and one other detention structure) within the Beaver Creek Watershed. Calibration and validation to events and water balance components ensured appropriate model parameterization. We selected the 100-year average recurrence interval rainfall event for comparison of pre- and post-project construction basin response under heavy rainfall. The local area containing projects 2–5 (Figure 5.13), representing the location of maximum project influence, was isolated for further analysis. We extracted hydrographs from the outlet of each project location and a downstream tributary location to quantify the project induced hydrologic impacts.

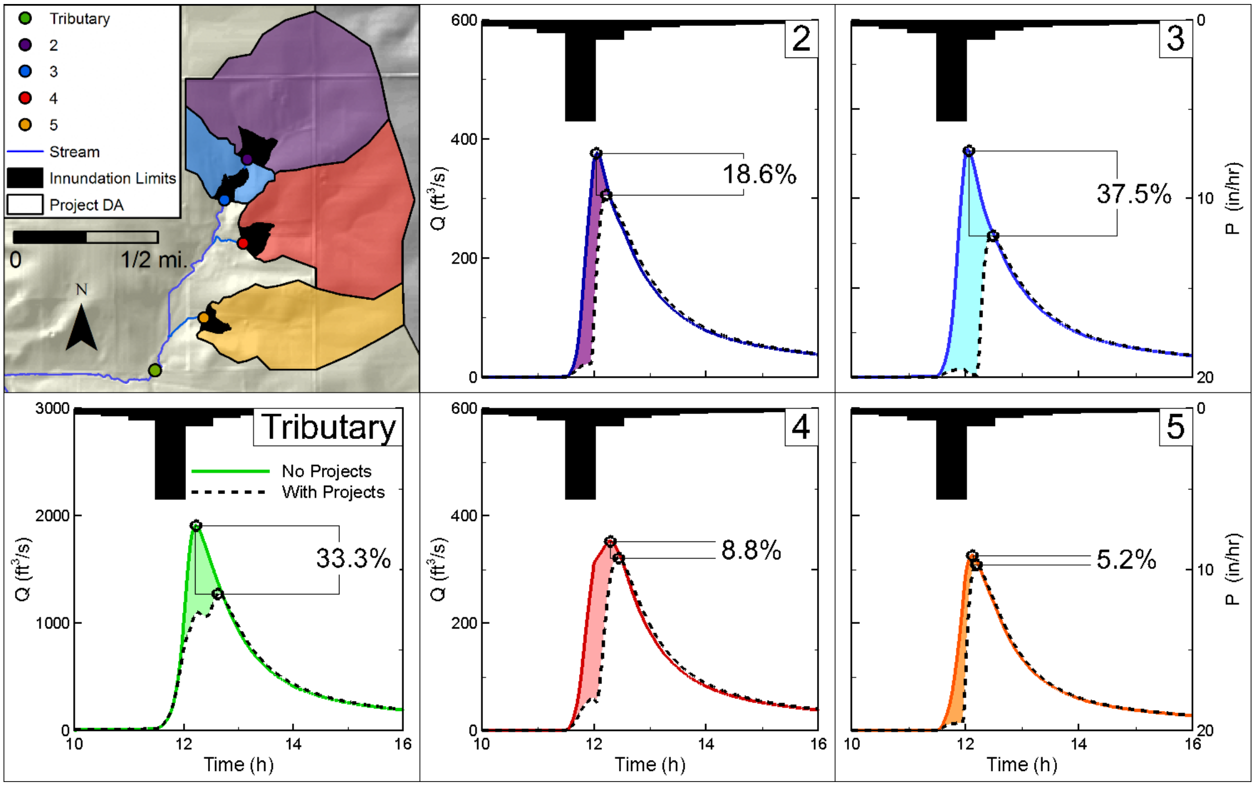


Figure 5.13: HydroGeoSphere simulation of the 100-year design storm under normal soil moisture, with empty project initial conditions, and a comparison between with and without flood mitigation projects at location of maximum influence.

We selected soil moisture antecedent conditions from the 10-year aggregation described in the *Antecedent Soil Moisture* to represent a normal wetness condition (50%) and a high wetness condition (98%). This range encompasses a reasonable range of flood-producing soil moisture conditions. We simulated events using three different initial conditions. First, we assigned the normal wetness condition to have no pre-event water held behind the structures. This situation provided the maximum storage capacity available, representing an upper boundary on flood mitigation potential. Second, we assigned the normal wetness condition with a normal pool initial storage condition. This was representative of the most likely circumstances. Third, we assigned the high wetness condition a normal pool initial storage condition. This condition represents a lower bound for peak flow reduction, as neither the soil moisture nor the projects have a large remaining holding capacity for this incoming heavy rainfall.

Figure 5.13 describes the varied peak flow response from normal wetness conditions, with and without flood detention structures. The input design storm temporal distribution was such that over 45% of the precipitation depth occurred over 0.5 hours, beginning at simulation hour 11.5. Peak flows in each scenario always occurred after simulation hour 12. Without flood detention structures, peak flows varied from 330 cfs to 510 cfs at each of the project outlets. The tributary monitoring location representative of the combination of all four projects peaked at 1,910 cfs. Each hydrograph occurred as a single peaked response after the end of the largest pulse in rainfall.

The addition of empty projects reduced peak flows by 5.2% to 37.5% at the project outlet, and a combined 33.3% at the tributary location. The maximum peak flow reduction of 37.5% occurred at location 3, the second of two projects in series (2 and 3). Each project reduced and delayed peak flows in a similar fashion. Project 3 had the added benefit of the additional upstream peak flow detention of project 2, acting additively to significantly decrease downstream peak flows. The variability of delay in peak flow response at the project outlets resulted in a multi-peaked tributary hydrograph. The first peak represented the response from the local drainage area to the tributary, not upstream of a project. The second peak represented the response of the project outlet peaks.

Figure 5.14 describes the varied peak flow response from normal wetness conditions, with and without flood detention structures and with a normal pool initial condition. Without flood detention structures, peak flows varied from 330 cfs to 510 cfs at each of the project outlets. The tributary monitoring location representative of the combination of all four projects peaked at 1,910 cfs. These represent the same pre-storage conditions as observed in Figure 5.13, because we initialized the soil wetness condition in the same manner. The addition of empty projects reduced peak flows by 2.7% to 16.9% at the project outlet, and a combined 11.1% at the tributary location. The maximum peak flow reduction of 16.9% occurred at project location 3. Each project reduced and delayed peak flows in a similar single peaked manner. With reduced flood storage available, the peak flow rates were slightly reduced and delayed from the pre-project conditions.

Figure 5.15 describes the varied peak flow response from a high wetness condition, with and without flood detention structures. Without flood detention structures, peak flows varied from 440 cfs to 690 cfs at the outlet of each project. These represent approximately a 25% increase in peak flows compared to normal wetness conditions. As the soil wetness increased, the remaining soil storage capacity filled faster, partitioning more rainfall into runoff earlier in the rainfall time series, resulting in an increased peak flow response that occurred sooner. The tributary location experienced a peak flow rate of 2,590 cfs.

For a high soil wetness initial condition, we added projects under a normal pool initial storage condition. Peak flows were reduced by 2.6% and up to 14.8% at the project outlets, resulting in a 14.7% reduction in peak flow at the tributary location. At each project location, any available storage in the projects filled up prior to the hyetograph peak at 11.5 hr.

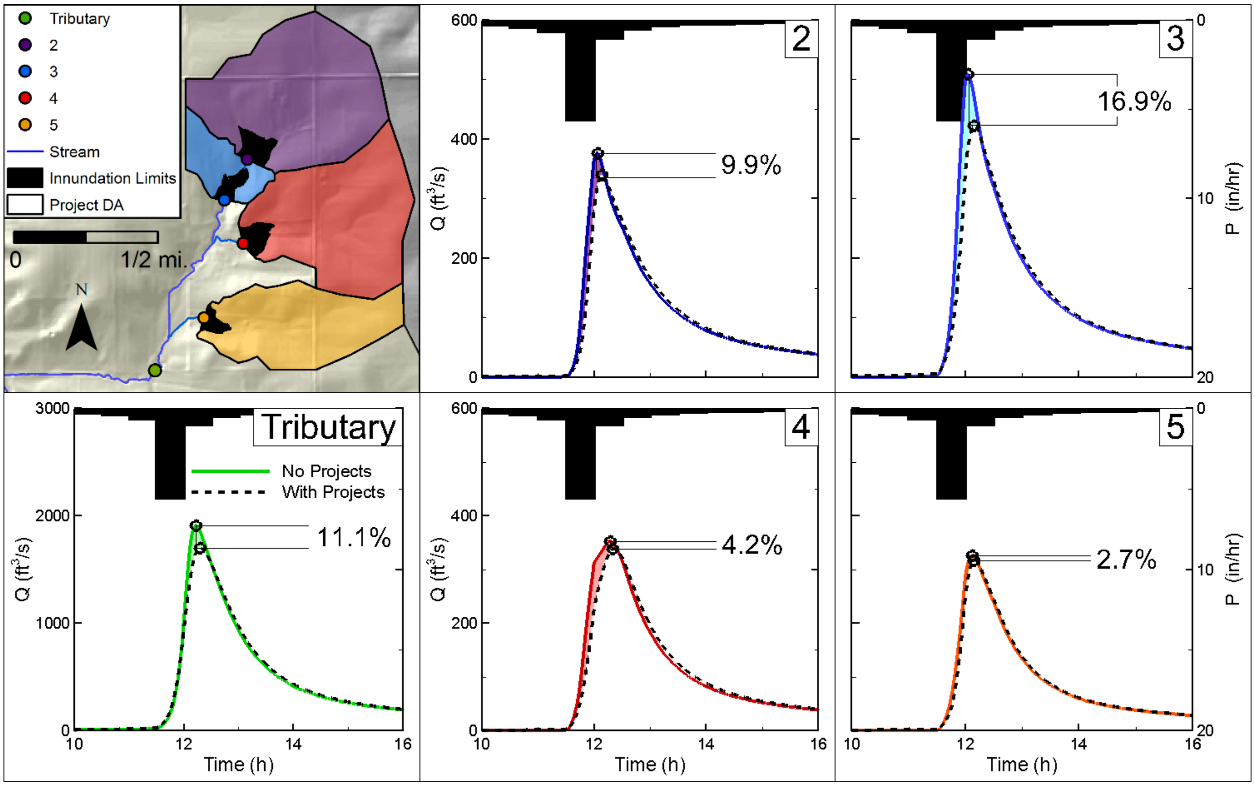


Figure 5.14: HydroGeoSphere simulation of the 100-year design storm under normal soil moisture, with full project initial conditions, and a comparison between with and without flood mitigation projects at location of maximum influence.

This becomes clear when investigating the shaded regions in Figure 5.13, Figure 5.14, and Figure 5.15. In this situation, the main function of the flood mitigation projects was to attenuate peak flows though dilution of rapid channelized surface flows over an enlarged ponded area. The response of uncontrolled area and controlled area was very similar. This is noted by the single peak hydrograph at the tributary location, a product of low project storage availability. This resulted in a minor extension of the hydrograph rising limb in time.

The combined results of the normal to high wetness, and empty to nor- mal pool pre event storage conditions, adequately bounded the effective- ness of projects 2-5 locally under heavy rainfall. As wetness increased, peak flow reduction decreased. Similarly, as the pre event storage was filled, peak reductions were reduced at the outlet of each project location. These effects were translated downstream to the tributary location receiving the maximum project influence. The bounds of peak reduction for the 100 year storm range from 2.6% to 37.5%, dependent upon project location, initial soil wetness, and available project storage. Project influence was expected to decrease as the ratio of area drained to a project reduced. This implies that peak flow reductions at the outlet were expect to be less than 37.5%, with the greatest being measured at the outlet of a project.

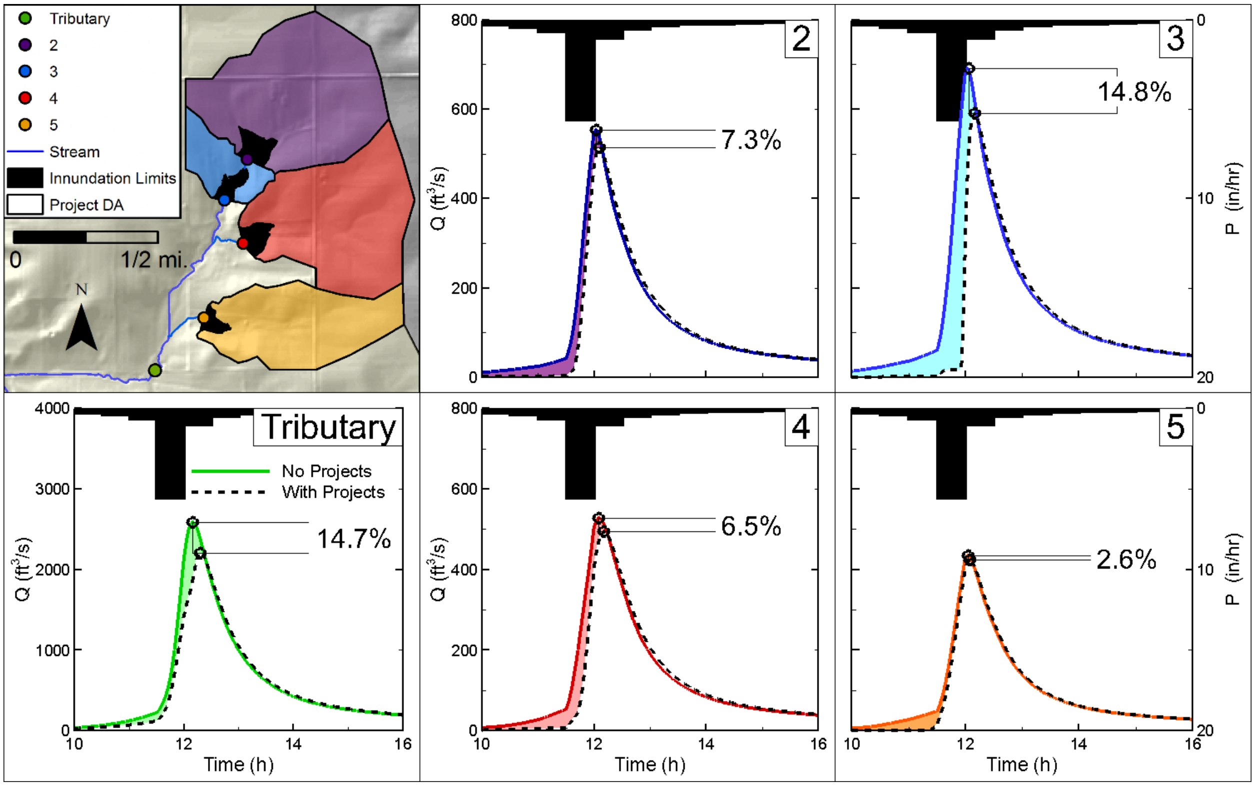


Figure 5.15: HydroGeoSphere simulation of the 100-year design storm under wet soil moisture, with full project initial conditions, and a comparison between with and without flood mitigation projects at location of maximum influence.

June 2008 Flood Event

As documented in the Hydrologic Assessment of the Upper Cedar River Watershed (Iowa Flood Center, 2014), the June 2008 flood produced some of the greatest discharges and stages on record throughout the Upper Cedar River Watershed. Basin average precipitation over the period June 3–12 totaled 8.3 inches, with nearly 50% of that falling on June 7–8. As a result, record discharges were recorded on the Cedar River at Austin (20,000 cfs, 23.26 feet), Charles City (34,600 cfs, 25.33 feet), and Janesville (53,400 cfs, 19.45 feet, NWS flood stage defined as 13 feet), as well as on the Little Cedar River near Ionia (24,700 cfs, 21.32 feet, NWS flood stage defined as 10 feet). Damages were severe, and recovery is still taking place.

Within the Beaver Creek Watershed, the precipitation was higher than the average across the larger HUC8 Upper Cedar River, averaging 10.0 in. and ranging from 9.2 to 10.8 inches (Figure 5.16). This event serves as an example of the projects' impact during extreme historical events. We will describe the watershed-wide response from June 2 to June 12, 2008. We will then narrow the focus to projects 2 and 3 and the upstream response to the 2008 flood.

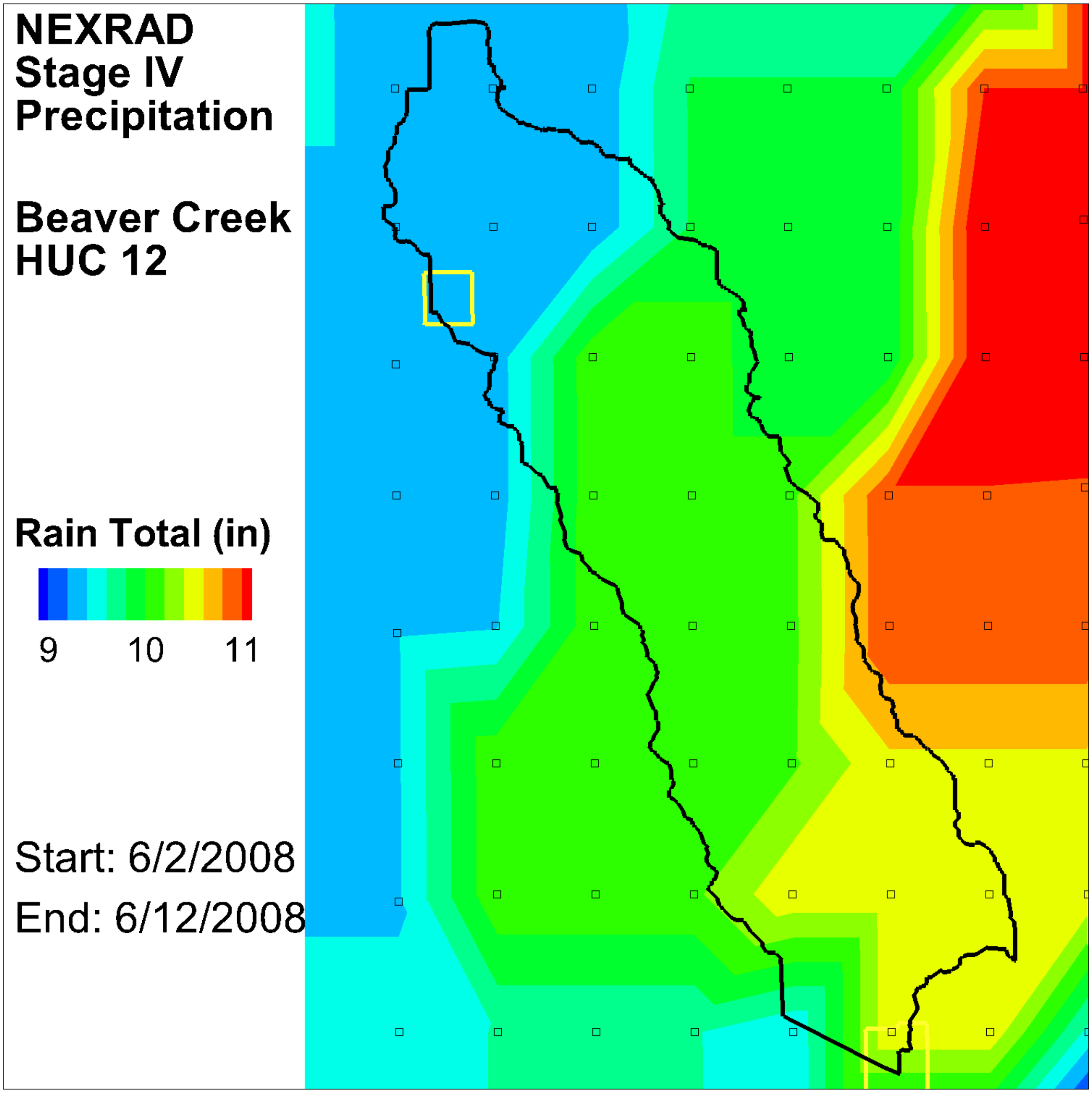


Figure 5.16: NEXRAD Stage IV radar rainfall sum from June 2 to June 12, 2008.

Model Initialization

We initialized the Beaver Creek HGS model in the same manner as the 2014 Calibration period (Section 5.d). The mode was initialized with the groundwater table equal to the surface, followed by a recursive spin-up period. The year 2007 daily precipitation from the centroid of the Beaver Creek Watershed (PRISM Climate Group, 2016) and PET from Nashua (Iowa State University, 2015) were recursively input to force the hydrologic model for five repeated years, until a dynamic steady state was reached.

2008 Rainfall

We initialized the simulation for year 2008 with output from the recursive 2007 simulation, providing a pseudo-steady state condition. Our staff input daily rainfall (PRISM Climate Group, 2016) data from January 1 to May 28, 2008. Beginning with the period May 28 through June 30, 2008, we used Stage IV radar rainfall as the precipitation input. The National Center for Environmental Prediction (NCEP) produced the Stage IV data set by taking Stage III radar rainfall estimates generated 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) gridded hourly precipitation estimate dataset. Stage IV radar rainfall estimates are available from January 2002–present. Use of radar rainfall estimates provides increased accuracy of the spatial and temporal distribution of precipitation over the watershed. Stage IV estimates provide a level of manual quality control performed by the NWS that incorporates available rain gauge measurements into the rainfall estimates.

Watershed Wide Response

We applied spatially variable Stage IV precipitation data to the HGS Beaver Creek numerical watershed model. Heavy precipitation on the evening of June 7 and through June 8, 2008, induced a peak flow rate of 3,420 cfs. Over this 10-day period, a series of heavy rainfall events and wet soil conditions created a runoff ratio of over 80%. Figure 5.17 shows the varying surface depth response to rainfall, immediately prior to and post peak flow rate. Heavy rainfall varied in intensity across the watershed, forcing streams with the most intense rainfall rates to expand and exit their banks causing overland flooding. The Beaver Creek Watershed responds rapidly to rainfall, routing water across the landscape into stream channels and out of the system in a matter of hours. The resulting outflow from Beaver Creek and many other watersheds like it provided the volume of water required to devastate downstream communities.

Figure 5.18 isolates two of the most effective flood mitigation projects to quantify the local impact of built structures during the June 8, 2008, flood event. The left and right panels in Figure 5.18 compare the water depth across the project drainage area. The blue regions denote the pre- project conditions, with most of the water contained in the stream channel or near channel areas throughout the domain. Streams swell under increased rainfall (right panel) and recede into the channels with more moderate rainfall intensities (left panel). At the local spatial scale of an individual project, hydrographs rise, fall, and generally travel through the system more rapidly than larger scales. Within the time period of a single large event at the outlet, the time variable rainfall produced multiple peaks at the project scale catchment. A maximum flow rate of 120 cfs at the outlet of project 3 occurred in response to repeated rainfall on the morning of June 8. Two smaller peaks occurred throughout the remainder of June 8 at 42 cfs and 95 cfs.

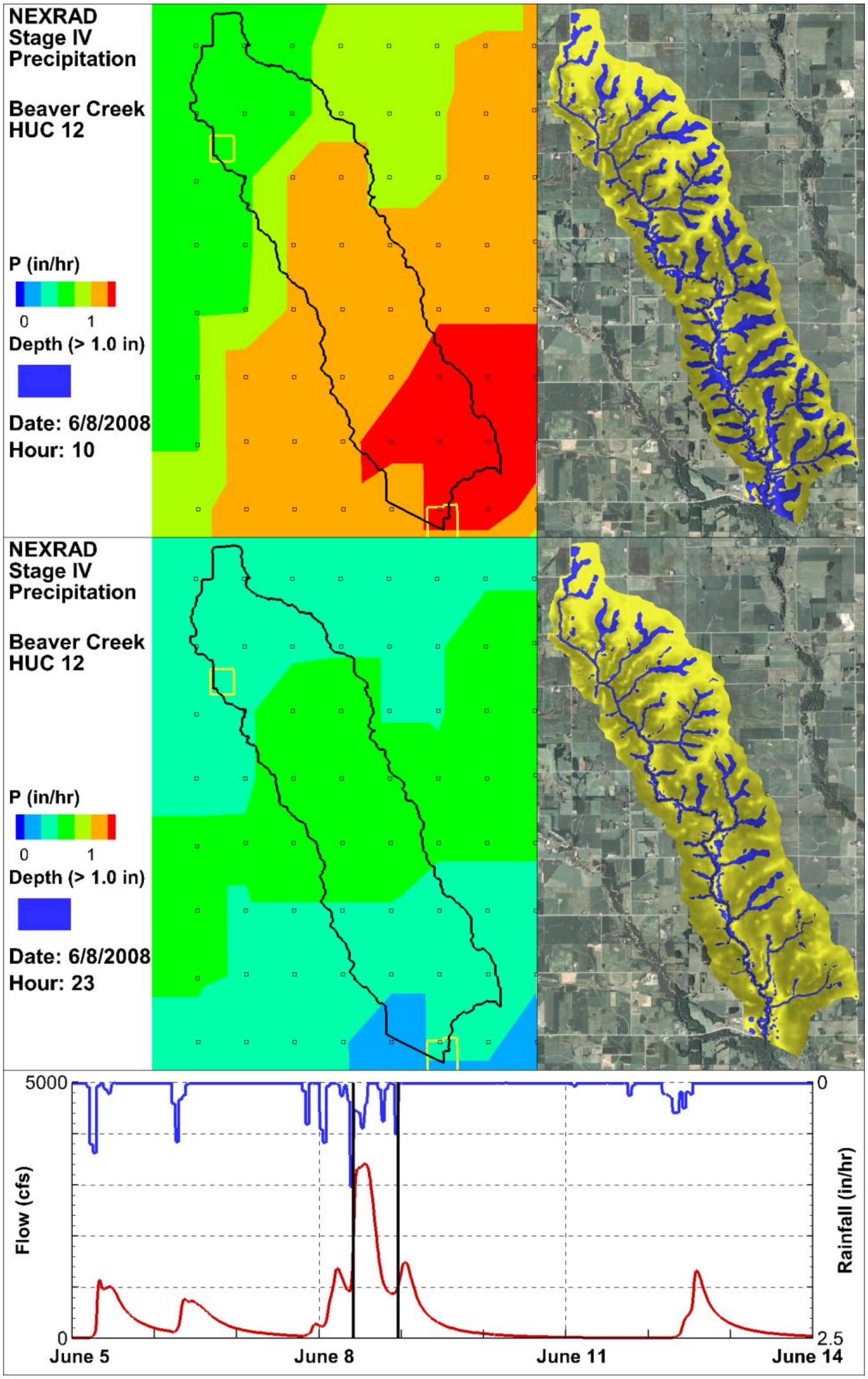


Figure 5.17: Beaver Creek Watershed response to NEXRAD Stage IV radar rainfall for the June 8 flood event: (top) Rainfall and stream inundation extent on June 8 at 11:00; (middle) rainfall and stream inundation extent on June 8 at 20:00; and (bottom) resulting outflow hydrograph.

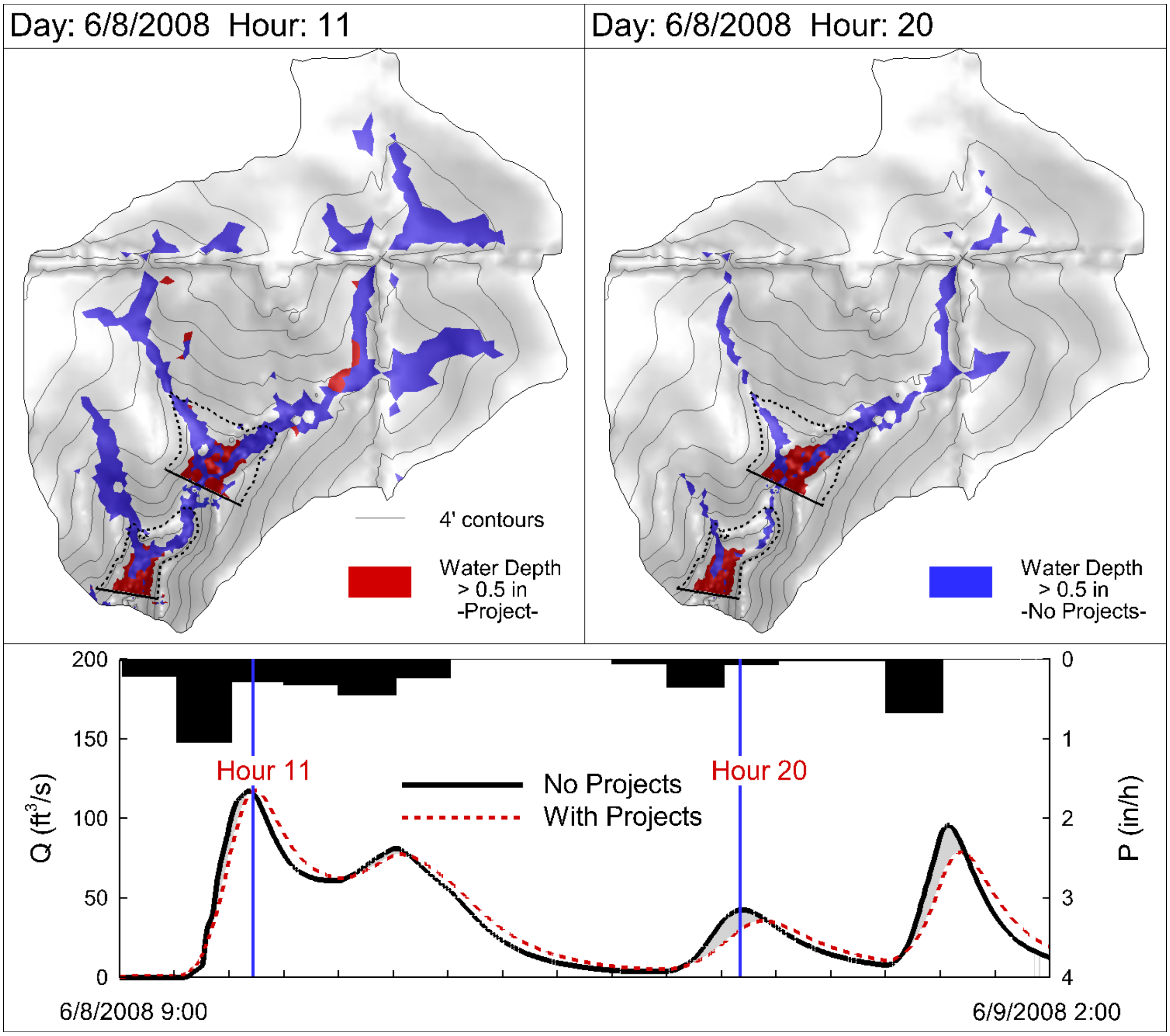


Figure 5.18: The response of projects 2 and 3 (see Figure 4.2) to early June 2008 rainfall events. Inundation extent with projects (red) and without projects (blue) on June 8 at 6:00 (left) and 12:00 (right), and resulting outflow hydrograph (bottom).

We added projects 2 and 3 in series as denoted by the solid black lines in Figure 5.18. The red shaded areas highlight the inundated area with projects installed. The inundated areas just upstream of projects 2 and 3 represent the largest differences in water depth across the sub-basin. The addition of a berm across the stream centerline forced water to build up behind the structures, filling the normal pool and delaying the down- stream movement of water. The resulting peak flow is 120 cfs, with two remaining peaks of 35 cfs and 79 cfs.

In hour 11, the inclusion of two flood mitigation projects did not alter the pre-project peak flow rate, but rather only delayed the peak. A wet antecedent condition formed by regular rainfall in the previous few days, a lack of remaining project storage, and heavy rainfall all combined to impede the flood reduction capabilities of this system. These structures are commonly built to withstand the 25-year design storm event, under greater rainfall depths, the flood reduction capabilities as displayed in the first event can become negligible.

In the two preceding events on June 9, peak flows were reduced by 16.7% and 16.8% respectively at hour 20 and at 0:00. Each of the later storm events was smaller in magnitude than the hour 11 event, which resulted in a large portion of the hydrograph peak being stored and released by the series of projects. The built projects did not reduce the magnitude of the maximum flow of 120 cfs during this time period; the volume of water superseded the available capacity, but it was delayed. A delaying effect of the hydrograph can alter the downstream arrival time of numerous tributaries, producing an overall reduced and elongated response. What is important to notice is the influence of projects under medium intensity storms, reducing and delaying peak flows by a consistent 17%.

g. Summary and Conclusion

This section describes the local project influence on a synthetic heavy rain- fall event, under a range of soil and project storage initial conditions. The results indicated that under the best case scenario, the projects could provide a 38% maximum peak flow reduction locally, decreasing to 2% under the least ideal conditions. The additive effects in the downstream tributary location reduced peaks from 11% to 33%. We observed that these peak flow reductions attenuated as additional uncontrolled watershed areas added to the streamflow. The larger basin-wide response is highlighted in Chapter 6.

Finally, we explored the projects for their influence on the 2008 flood event. A combination of wet soil conditions, normal pool project conditions, and heavy rainfall events produced little to no reduction in the largest magnitude flood events at the outlet of project 3. A further investigation revealed that subsequent small peak flows were reduced by approximately 17%. These projects were designed to withstand the 25- (or 50-) year return period event, and larger events often overwhelm the projects' capacity to alter downstream flood reductions.

Physically based coupled surface subsurface modeling offers many capabilities important for the investigation of flood mitigation strategies. Physics-based modeling offers a fundamental approach to fluid movement though the surface and subsurface domains. Surface and subsurface domains are parameterized by measurable known quantities. We were able to realistically incorporate projects into the model with altered elevations that directly mimicked the natural case. Inundation extents and stream channels are dynamically formed without explicit numerical representation. Baseflow is physically represented through subsurface surface exchange. Furthermore, these incorporations allow the investigation of antecedent moisture and pre-event storage in a realistic manner.

The drawbacks of this style of modeling are the extensive time required to set up, calibrate, and validate the model. Simulation run times often exceed 72 hours for a year of simulation time, reducing the model's capability to handle long-term datasets with accuracy. Another style of modeling can better complete a realistic evaluation of the structures over long-term historical meteorological forcing. The next section describes a simplified approach to the incorporation of realistic fluid dynamics without comprehensively solving the fundamental equations of fluid mechanics. This approach allows for reduced computational time, increased historical simulation, and a comprehensive view of peak flow reduction over a long period of historical events.

6. Simulation of Flood Control Project Performance

This section summarizes the development of a long-term continuous simulation computer model for the Beaver Creek Watershed. We performed the modeling using the Environmental Protection Agency (EPA) Hydrological Simulation Program–FORTRAN (HSPF) Version 12.2 (Bicknell et al., 2005). HSPF is designed to make long-term continuous simulations of hydrologic (rainfall-runoff) and water-quality (e.g., nutrient) processes of a watershed. The model has been used for water quantity and quality simulation for large and small watersheds across Iowa (Donigian et al., 1983a, 1984; Bradley et al., 2015) and the United States. For instance, a community effort has used the Chesapeake Bay Watershed HSPF model for many years to study water management and restoration options for inflows to the threatened Chesapeake Bay. The remaining sections describe the model representation of the Beaver Creek Watershed.

a. Beaver Creek HSPF Model Development

The Beaver Creek HSPF model is based on the Cedar River HSPF model developed for the Iowa Department of Natural Resources (RESPEC, 2007). The EPA used the model as part of its Total Maximum Daily Load (TMDL) program to establish water-quality criteria for pathogens, using the indicator bacteria *E. coli* (Love and Whitney, 2008; Environmental Protection Agency, 2010). The model simulates the entire 7,830 mi^2 Cedar River Watershed and makes predictions at 126 river locations. It simulates runoff from the land surface for seven different land use types, and routes the runoff downstream through the river network. The developers calibrated the model at selected stream gauges and verified its predictive ability at others not used in calibration. They performed the simulations for an 11-year period (1995 to 2005) (Environmental Protection Agency, 2010).

For this study, we extracted portions of the calibrated Cedar River HSPF model for simulation of Beaver Creek. As a first step, we extracted the Upper Cedar River Watershed elements from the original model; the model is identical to the original in all aspects, except that it only simulates the hydrology of the Upper Cedar River Watershed. Then we obtained additional weather input data to extend the simulation to 64 years (1949–2012). With the Upper Cedar River HSPF model, we simulated streamflow at stream gauge locations throughout the watershed and verified that the model adequately represents the watershed hydrology over the longer simulation period.

The Beaver Creek Watershed (at 17.7 mi^2) is too small to be represented explicitly in this model; the watershed is lumped together with other sub-watersheds within the model. Therefore, we created a more detailed representation of the Beaver Creek Watershed to represent its stream network and the movement of water through the basin. However, we used the land surface model parameters estimated for the Cedar River HSPF model, which represent conditions for individual land uses types, to represent runoff processes in the Beaver Creek HSPF model. The following sections describe the data and model setup needed for the Beaver Creek HSPF model.

Historical Weather Inputs

Historical weather information is the main time series input driving an HSPF watershed simulation. Figure 6.1 shows the weather stations with long-term records used to construct hourly weather inputs for the Beaver Creek HSPF model.

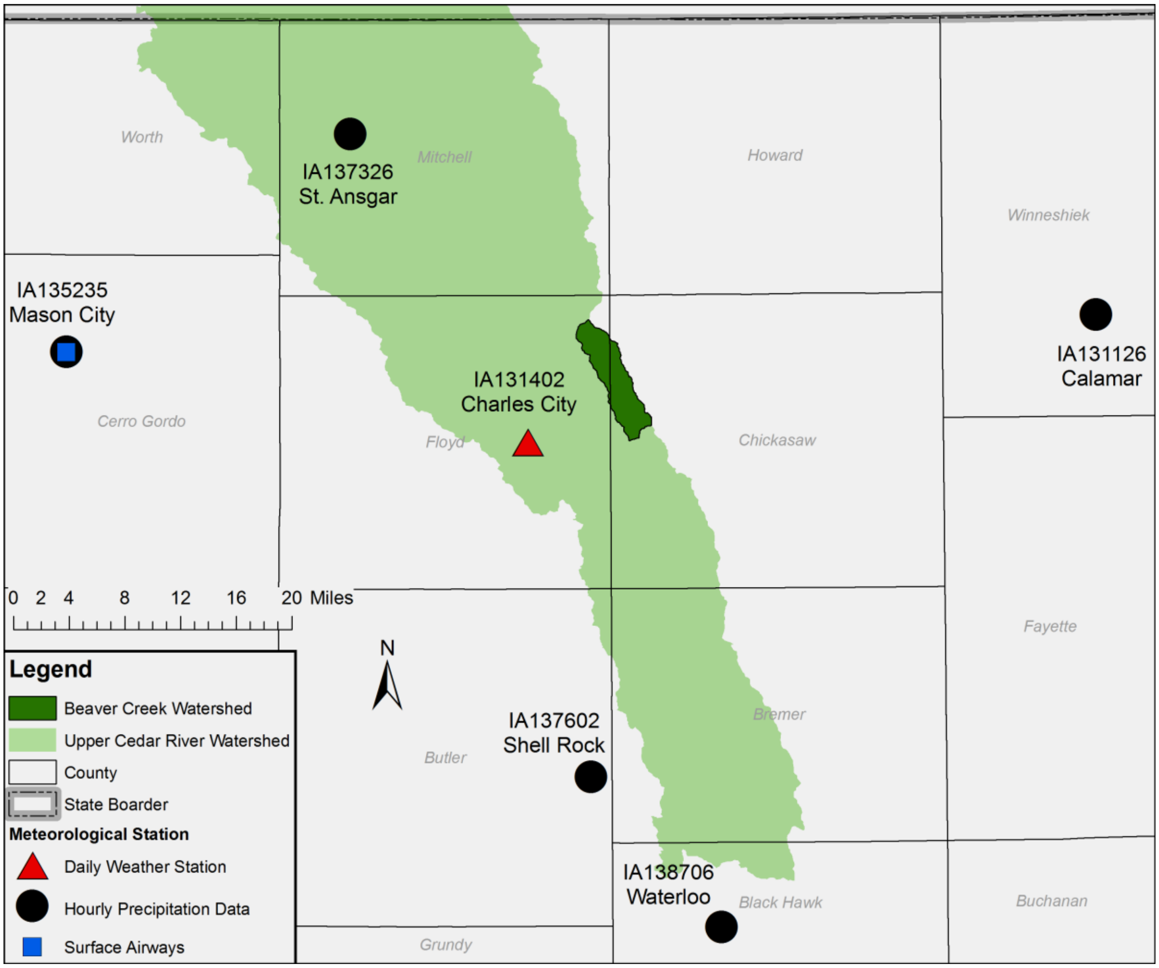


Figure 6.1: Weather stations used in the HSPF model of Beaver Creek. The Charles City station provides long-term daily precipitation and temperature data. We used hourly precipitation data at nearby stations to disaggregate the daily precipitation to an hourly time step. Other weather inputs, such as cloud cover, wind speed, and dew point temperature, came from the Mason City Municipal Airport surface airways station.

The closest long-term weather station to Beaver Creek is at Charles City (Cooperative Observer ID IA131402). The station collects daily precipitation and air temperature data. Observations at the site were gathered from October 1948 to the present, although gaps in the record do exist (observations are missing or incomplete). We filled these gaps by interpolating data from nearby daily weather stations. We use this information to create a continuous hourly precipitation and temperature time series from the Charles City daily data to represent the conditions at Beaver Creek. We disaggregated the daily precipitation into hourly time steps using the precipitation pattern at nearby hourly stations: St. Ansgar (IA137326), Shell Rock (IA137602), Mason City Municipal Airport (IA135235), Waterloo Municipal Airport (IA138706), and Calmar (IA131126). We generated hourly temperature time series from daily records of maximum and minimum temperature using a fixed daily cycle.

HSPF also requires time series inputs on cloud cover, wind speed, and dew point temperature. These data are used primarily in the cold season to predict snowfall, snow accumulation, and snow melt. Cloud cover, wind speed, and dew point temperature are measured at surface airways stations, located at certain airports in Iowa. The closest station is at Charles City, but the record is only available since 1995. The closest long-term station is at Mason City Municipal Airport, and we used its record for the 1948-2012 simulation period. Even though the site is located some distance from the watershed, cloud cover, wind speed, and dew point temperature will be similar at both locations.

Finally, HSPF requires time series inputs on potential evapotranspiration and solar radiation. These variables are rarely measured directly. However, methods based on weather inputs can provide reliable estimates for hydrologic modeling. Using time series on air temperature, dew point temperature, and cloud cover, we estimated daily time series of potential evapotranspiration and solar radiation using a Penman approach (Shuttleworth, 1993). Potential evapotranspiration is the more critical variable. Along with precipitation, it predicts the overall water balance and storage of water in the subsurface (soils) for the simulation. Solar radiation is used only to predict snow melt during the cold season. Still, this approach provides consistent estimates of the two (related) variables for both uses of the data. Hourly time series are then generated from the daily values using a fixed daily cycle.

River Reach Delineation

Figure 6.2 shows the subdivision of the Beaver Creek Watershed into 59 sub-basin areas. These sub-basins define the drainage areas to a portion of the river network of streams (shown as the blue lines in Figure 6.2). Within HSPF, these areas are known as river reaches; runoff from the surrounding drainage area, as well as flow from upstream river reaches, combines to predict the resulting flow at the river reach outlet using an HSPF RCHRES operation. Hence, we made model predictions at the outlets of the river reaches. For the Beaver Creek HSPF model, the average river reach drainage area is 0.30 square miles (192 acres).

For each river reach segment, HSPF RCHRES requires river channel hydraulic information to determine how quickly water moves through the reach. The storage-discharge relationship summarizes this information. It defines the discharge at the outlet for a given amount of water stored within the channel of the river reach. For locations with a stream gauge, this information is straightforward to estimate. A stream gauge provides direct measurements of the discharge and the channel cross-section flow area. By multiplying the area by the HSPF river reach length, we can also obtain the reach storage. Unfortunately, there are no sites within the Beaver Creek Watershed with suitable stream gauge measurements. A standard approach for estimating channel reach information uses a scaling relationship between channel reach dimensions and drainage area. Using a relationship fitted to measurements from seven nearby U.S. Geological Survey stream-gauge sites, we estimated the channel reach dimensions for all 59 HSPF RCHRES segments. Combining the dimensions with the reach lengths and using estimates of the hydraulic roughness for the channel and floodplain area, we estimated a storage-discharge relationship for all the segments for the Beaver Creek HSPF model.

6.1.4 Land Segment Definition

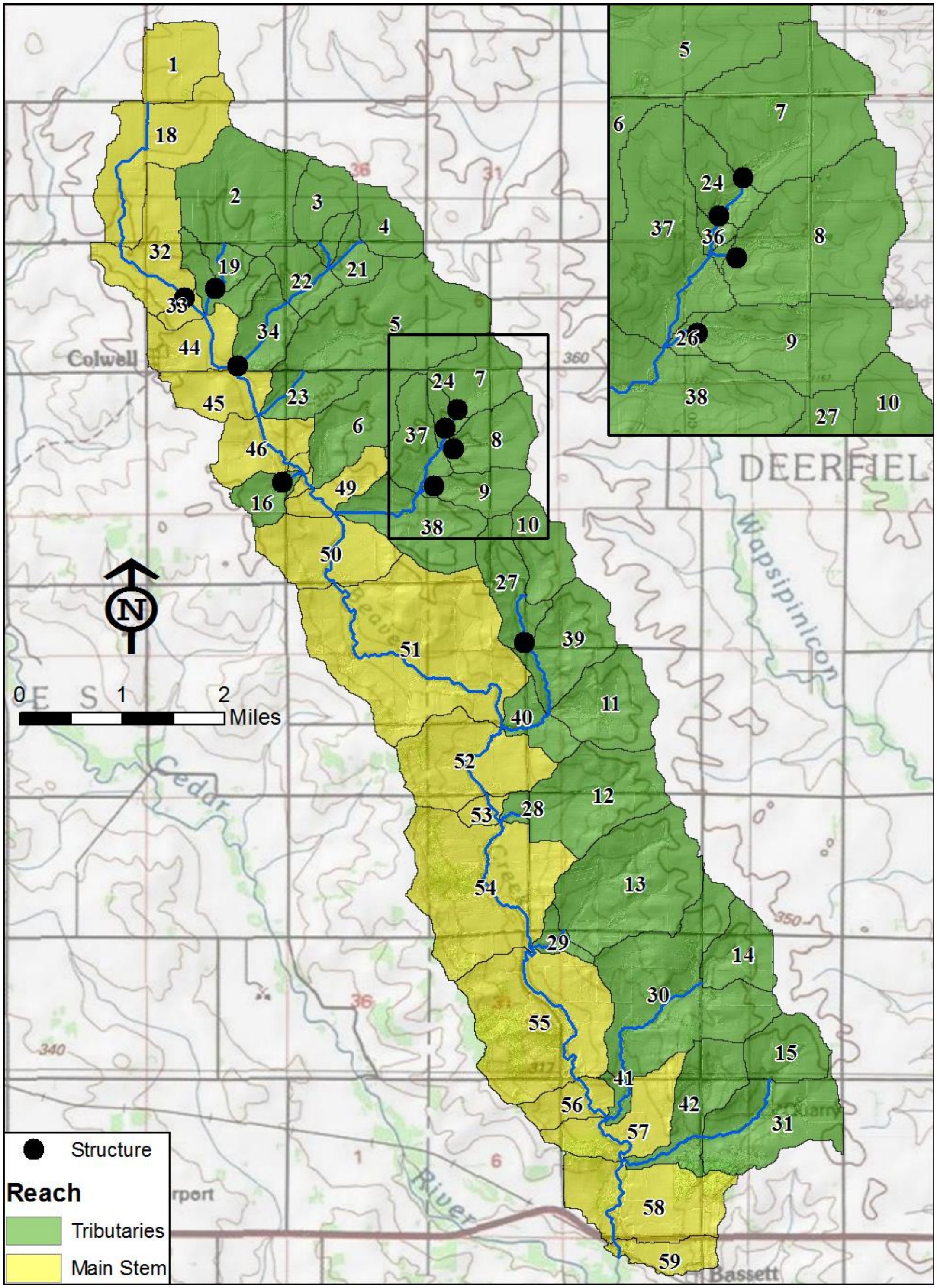


Figure 6.2: Subdivision of the Beaver Creek Watershed into HSPF RCHRES river reaches. The blue lines indicate the Beaver Creek network of streams; the black lines outline the drainage area of the river reaches. The locations of wetland flood storage projects are indicated by the red circles. Note that HSPF RCHRES river reaches are sub-basin areas, and the runoff from these areas is combined with flows from upstream river reaches to make predictions at the outlet of the reach.

HSPF uses land segments to represent the hydrologic response at different locations. Pervious land segments (PLSs) represent the response from most areas. Impervious land segments (ILSs) represent the response from roads and urban areas where water cannot infiltrate the ground.

Land segments are not meant to represent the hydrology of any one specific point in the watershed. Instead, they represent the average response from locations with similar characteristics (soils and land use) given the input weather time series. Therefore, land segments are defined by identifying areas with similar characteristics. In the Cedar River HSPF model (Environmental Protection Agency, 2010), land segments were defined for the following land uses: croplands, ungrazed grassland, forest, grazed grassland, and built-up areas. The land use map for Beaver Creek (see Figure 2.8) was used to reclassify areas to these five distinct land uses. For example, corn and soybeans were assigned to the cropland land use. Ungrazed and planted grassland areas were assigned to the ungrazed grassland land use, and the remaining grassland was assigned to the grazed grassland land use. Table 6.1 shows the percentage of the Beaver Creek Watershed assigned to each land use classification.

Table 6.1: Watershed area (in %) by land use classification for the Beaver Creek HSPF model.

Land Use	Watershed Area (%)
Cropland	71.1
Ungrazed Grassland	14.8
Forest	6.2
Grazed Grassland	5.0
Built-Up Areas	2.5

Each land use classification is represented by a unique pervious land segment. However, a portion of the built-up area is also represented by an impervious land segment. The impervious land segment is used to represent roads and paved areas, where water cannot infiltrate the ground. Since water and wetlands are only a small fraction of the entire watershed (less than 0.09%), they are included in the built-up impervious land segment area. Based on this representation, there are six different land segment types simulated for the Beaver Creek Watershed.

HSPF Continuous Simulation

With the river reach and land segment definitions established for Beaver Creek, we used the HSPF model to do a long-term continuous simulation for water years 1949–2013. A water year begins in October (when flows tend to be low) and continues through September of the following year, so the simulation period runs from October 1948 through September 2013. HSPF first computes runoff from the six land segments at an hourly time step. It then routes the runoff through the river reach network at a five-minute time step.

Figure 6.3 shows the daily time series at the Beaver Creek Watershed outlet for a 10-year period. The results show how runoff responds to the hourly weather inputs. Because the model continuously tracks the amount of water on the land surface after precipitation, runoff, and evaporation occur, its moisture conditions will reflect the effects of drought spells (e.g., dry soil conditions) or extended rainy periods (e.g., wet soil conditions).

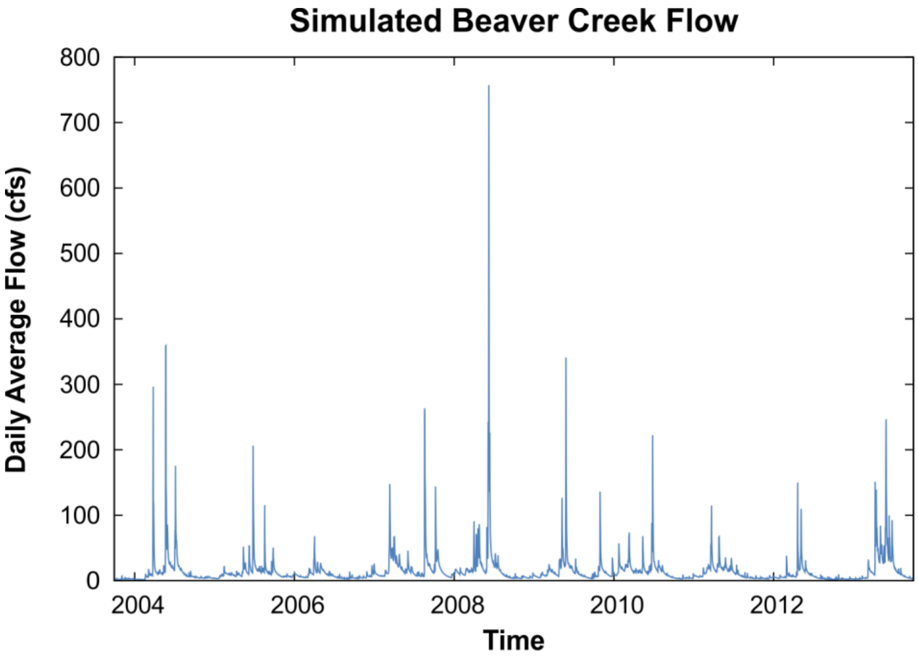


Figure 6.3: Simulated daily flow time series for the Beaver Creek outlet (BEAVER1) for water years from 2004–2013.

Given the inherent limitations of hydrologic modeling, one should not expect simulated flows to exactly match what actually occurred over the past 64 years. The model uses nearby weather inputs (not those that actually occurred), and it employs a simplified representation of the rainfall- runoff process. Furthermore, the land use conditions are based on recent observations and may not represent the changing conditions over the simulation period. However, despite some expected mismatches with actual flows, over the long-term, the model is expected to give a reasonable representation of the components of the water cycle.

One example of this is illustrated in Figure 6.4, which shows the simulated monthly water cycle at the Beaver Creek outlet (BEAVER1). For comparison, the figure also displays the observed monthly water cycle for the Little Cedar River near Ionia (USGS 05458000). The Little Cedar River is a much larger watershed (at 306 mi2), and the Beaver Creek Watershed (at 17.7 mi2) is one of its tributaries. The average monthly water depths are based on water years 1955–2013, the overlap period when data are available at both sites. Overall, there is a pronounced seasonal cycle in runoff, and the simulated and observed monthly water cycles are similar. However, the simulated depths for Beaver Creek are consistently higher than observed depths for the Little Cedar, except in March and April. These are the months with the highest runoff for the Little Cedar, and may reflect that its watershed extends further northward into Minnesota, and that snow accumulation and melt are more significant. The Little Cedar has a secondary peak in June, when the simulated runoff depth peaks at Beaver Creek. Still, the long-term average flows simulated by the Beaver Creek HSPF model are a reasonable approximation based on this comparison.

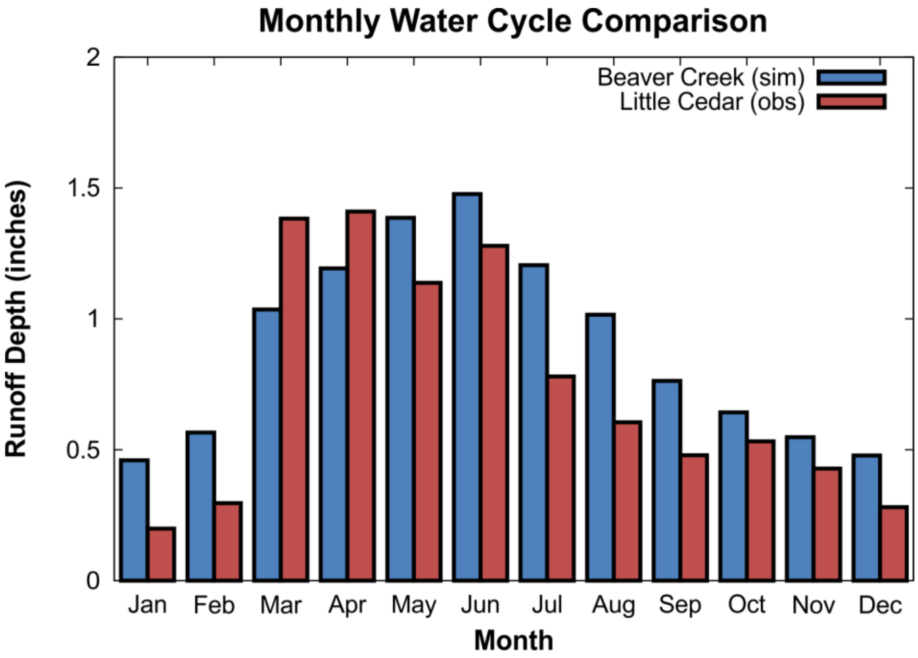


Figure 6.4: Simulated and observed average monthly runoff depth (in inches) within the Upper Cedar Watershed. The simulated depths are for the Beaver Creek outlet (BEAVER1). The observed depths are for the Little Cedar River near Ionia (USGS 05458000). Both results are based on the same period (water years 1955–2013).

b. Flood Characteristics of the Beaver Creek Watershed

Before evaluating the performance of the Iowa Watersheds Project flood control wetlands, we must first examine the flood characteristics of the Beaver Creek Watershed. We based our baseline evaluation on the 65-year continuous simulation of the watershed without wetland projects using the Beaver Creek HSPF model. We will later use this baseline to examine the changes in flood characteristics with the constructed wetlands.

Using the simulated peak discharges at the sub-basin outlets, we can examine what individual extreme floods are like in the watershed. Peak discharge is an insufficient measure to identify extreme floods. Peak discharges for large drainage areas are usually much larger than for small drainage areas, even in cases when a flood is “more severe” at small drainage locations. Hence, we will use a flood severity index to characterize flood peak discharge at all locations. Our flood severity index is simply the ratio of the peak discharge to the mean annual flood at a location. Since the mean annual flood is a rough measure of the bankfull discharge, a flood severity of 1 or greater is an indicator of a flood. By determining the flood severity index for the annual maximum peak discharge at all sites for each year, we can rank the outcomes to identify times with extreme flooding. Table 6.2 shows the ranking of the top five years.

Table 6.2: Ranking of the top simulated floods in the Beaver Creek Watershed based on a flood severity index. The index is the ratio of peak discharge for the event and the mean annual flood. The flood events are ranked below based on the average index at all 59 sub-basin outlets. The maximum and minimum index values at locations within the watershed are also shown.

Rank	Event	Average	Maximum	Minimum
1	July 1999	6.30	8.72	5.05
2	August 1979	5.48	5.98	4.38
3	June 1998	5.47	5.90	4.02
4	August 1980	5.09	5.68	4.52
5	August 1993	3.38	3.52	2.99

All the top five simulated floods are summertime events. This is when highest rainfall intensities occur (with thunderstorms). The rainfall accumulations over a few hours or less are sufficient to cause streams to quickly rise out of their banks. The rainfall accumulations for these overtop events at different durations is shown in Table 6.3. Notice that the most severe simulated flood event (July 1999) does not have the largest rainfall accumulations. For this event, soils were already wet from heavy rain that occurred several hours before. Since the model continuously tracks soil moisture conditions, it represents the soil conditions that would exist at the time of the storm (e.g., wet conditions from a series of rainy periods, or dry conditions after a long period without rain).

Table 6.3: Maximum rainfall accumulations for 1-hour, 2-hour, and 3-hour durations for the top simulated floods in the Beaver Creek Watershed.

			Duration	
Rank	Event	1-hour (in)	2-hour (in)	3-hour (in)
1	Jul 1999	1.71	3.04	3.04
2	Aug 1979	2.20	2.39	2.39
3	Jun 1998	1.97	2.59	3.22
4	Aug 1980	2.33	3.97	4.20
5	Aug 1993	1.08	1.73	2.27

Based on the average flood severity index across all locations, the July 1999 event is the top simulated flood. The average index value is 6.30. On average, the peak discharge was 6.3 times the mean annual flood across the watershed. Figure 6.5 maps out the flood severity index for sub-basins in 1999. The flood severity index shows that the simulated flooding was more intense along the middle and lower main stem of Beaver Creek; the flooding was less severe in the upstream and tributary areas.

The next two simulated top flood events — the August 1979 and the June 1998 floods — are very similar. Both have nearly the same average flood severity index values, and their maximum/minimum ranges are similar. Figure 6.6 maps out the flood severity index for sub-basins for an August 1979 event. Unlike the top July 1999 flood, the August 1979 event has more intense simulated flooding in the upper watershed and tributary areas. The flooding was less severe as water moved out into middle and lower main stem of Beaver Creek. The flood severity index map for the June 1998 is almost identical to the August 1979 map (see Figure B.1 in Appendix B).

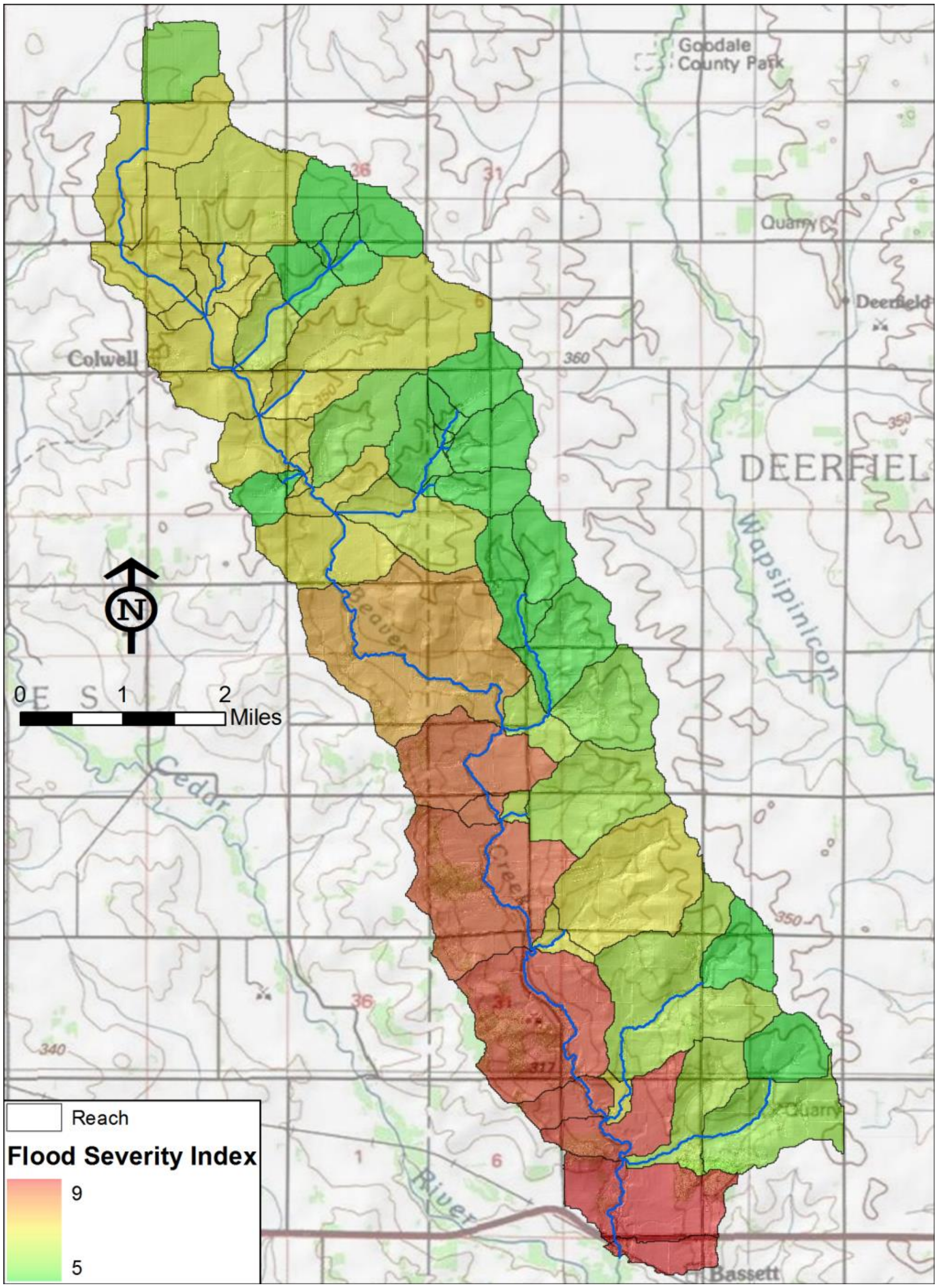


Figure 6.5: Flooding intensity and extent for the July 1999 flood. The map shows the estimated flood severity index at each sub-basin outlet.

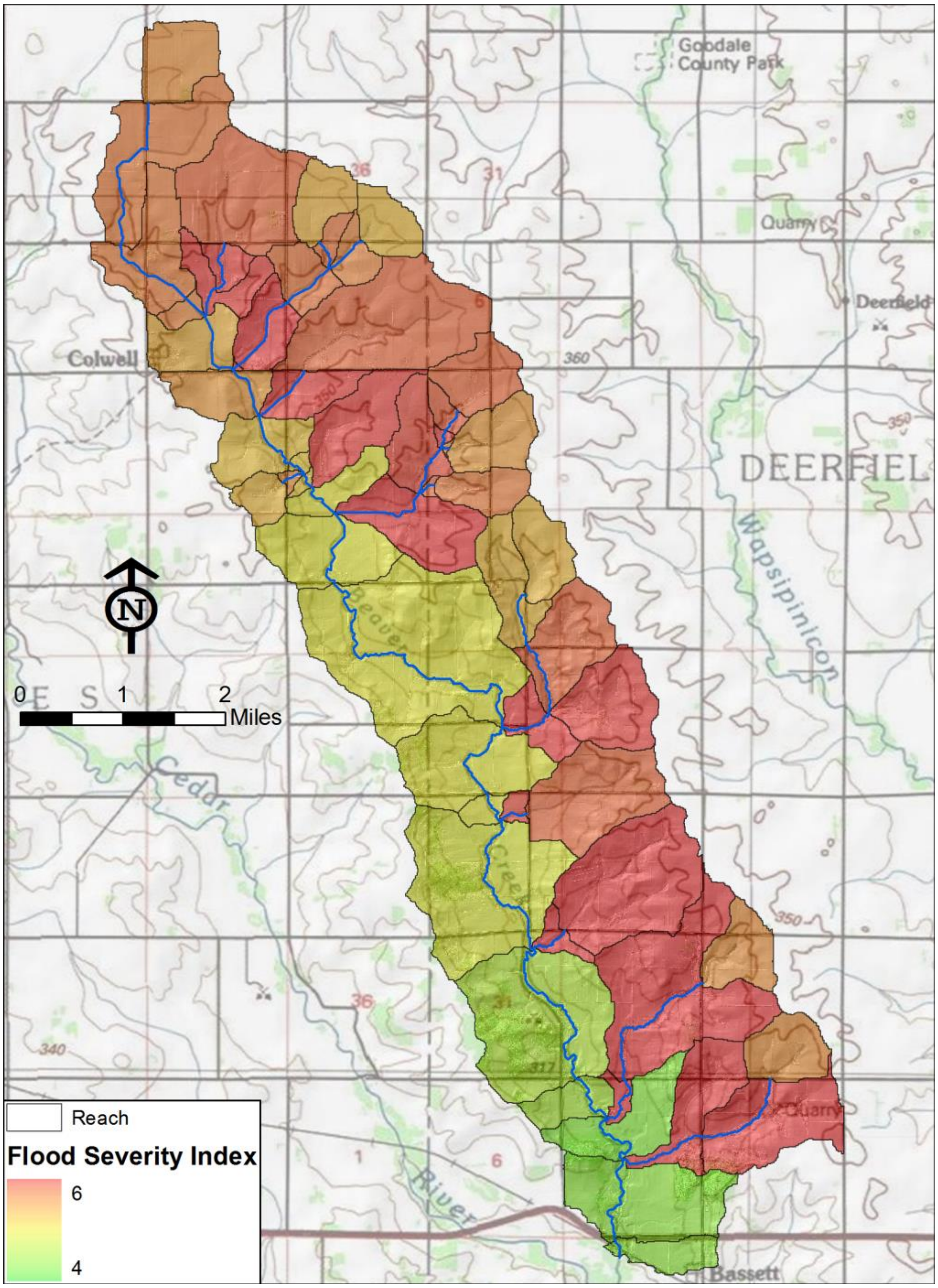


Figure 6.6: Flooding intensity and extent for the August 1979 flood. The map shows the estimated flood severity index at each sub-basin outlet.

The remaining two events have lower average flood severity index values. The August 1980 event is slightly lower at 5.09, and the August 1993 event is much lower at 3.38. The August 1980 event is more like the July 1999 event; it has more severe flooding along the Beaver Creek main stem in the upper and middle watershed (see Figure B.2 in Appendix B). However, the flooding severity dissipates somewhat in the lower reaches of the main stream. The August 1993 event is more like the August 1979 and June 1998 events, with more severe flooding upstream and in the tributary areas (see Figure B.3 in Appendix B).

The examination of extreme flooding from the 65-year Beaver Creek HSPF model simulations provides a better understanding of the nature of these events in the watershed. The largest floods in Beaver Creek tend to be summertime events. During one of these events, significant flooding occurs throughout the watershed. (Note that widespread flooding is due in part to the use of uniform rainfall from a single gauge at the input to the entire watershed; however, given the small size of the watershed, the spatial variability of extreme rainfall accumulation across the watershed should be relatively small.) All parts of the basin react rather quickly to storm rainfall, so intense rainfall over durations up to 2 or 3 hours is sufficient to cause a flood. Although flooding is widespread during these events, its severity is not uniform. Events tend to either be more severe in the tributary areas (in reaction to short duration high-intensity rainfall), or along the main stem (in reaction to the steady accumulation of runoff from the tributary over longer durations).

From a flood mitigation planning perspective, it is important to recognize how different individual flood extremes can be. One advantage of using a continuous simulation model (like HSPF) for evaluation is that the performance of flood mitigation wetlands over a range of potential flood conditions can be simulated and evaluated. In the remaining sections of this chapter, we will use this approach to evaluate the effect of wetland projects on reducing peak discharges for flood events.

c. Evaluation of Flood Mitigation from Wetland Projects

In this section, we will use the Beaver Creek HSPF model to simulate the effect of wetland storage on flood peaks. First, we inserted the six Iowa Watersheds Project and three existing wetlands into the HSPF model, routing flow from upstream reaches through the wetland storage. We determined the outflow from each wetland based on its elevation-storage-discharge relationship, as shown in Appendix A. We simulated the wetland performance continuously for the 65-year simulation period. The following sections will compare the simulated flows with the nine wetlands to the baseline simulated flows without wetlands for the 65-year period.

Hydrographs for Top Flood Events

Figure 6.7 shows eight locations in the watershed that we selected as points of reference (index points) for comparing simulated floods with wetland to the baseline case. The four locations are in Beaver Creek tributary areas; another four locations are on the Beaver Creek main stem.

Figure 6.8 shows flood hydrographs for the July 1999 flood at the four tributary locations. Results are shown for baseline simulation with no wetlands, and with the nine wetlands. The wetlands all significantly reduce flood peaks for this event (the largest simulated flood in the 65-year period). The two tributary sites downstream of a single wetland — Floyd County site 1 or Chickasaw County site 6 — both have similar drainage areas (0.86 mi2 and 0.88 mi2) and similar peak reductions (10.6% and 9.0%). The tributary downstream of Chickasaw County sites 2 and 3 has a smaller drainage (0.32 mi2), but has two wetlands in a series upstream. As a result, it has the largest peak reduction (77.4%). At its tributary outlet (at 1.42 mi2), the two wetlands in series, along with two other wetlands regulate the upstream flows. The peak reduction at this location is also significant (33.8%).

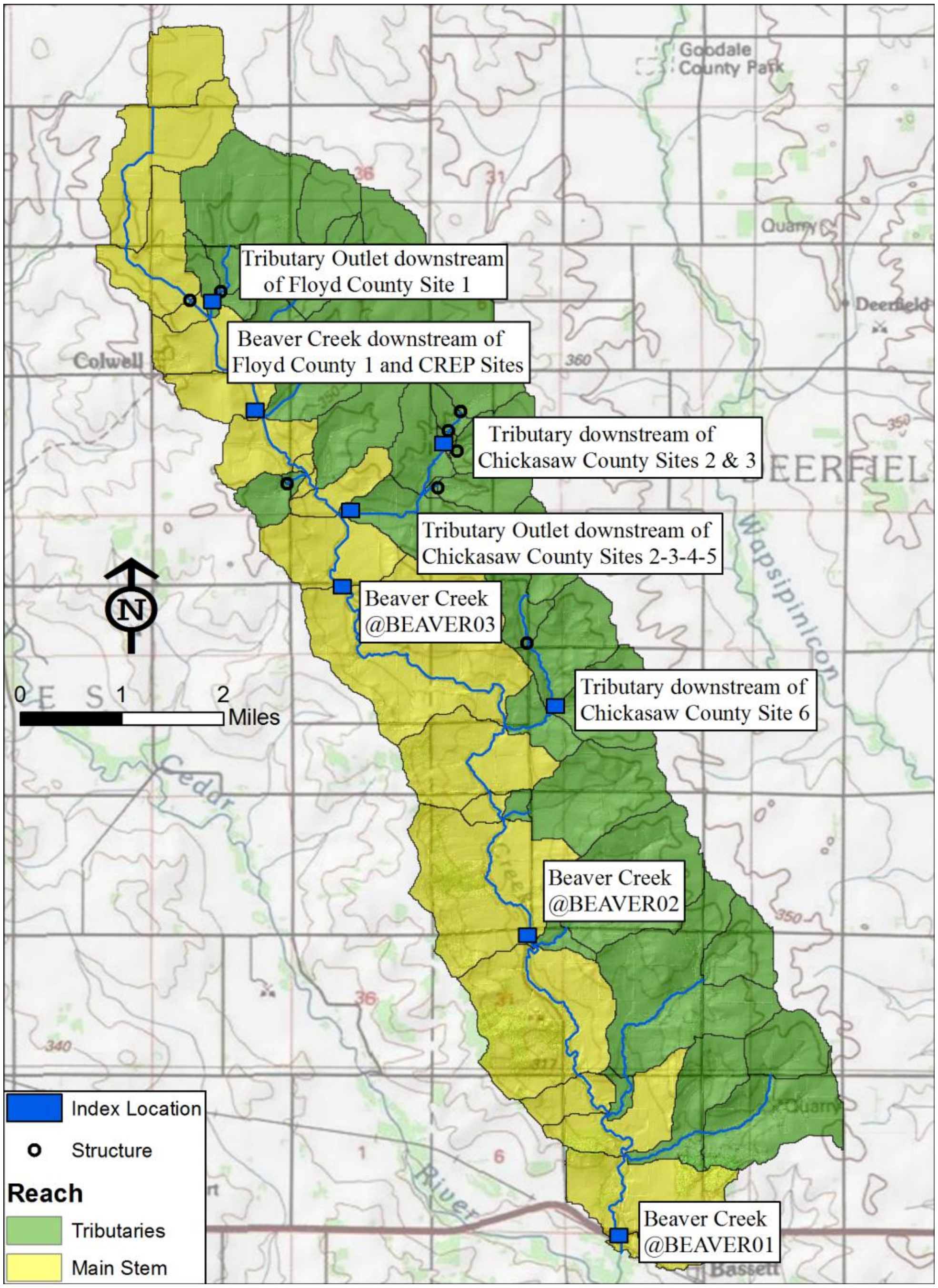


Figure 6.7: Index point locations.

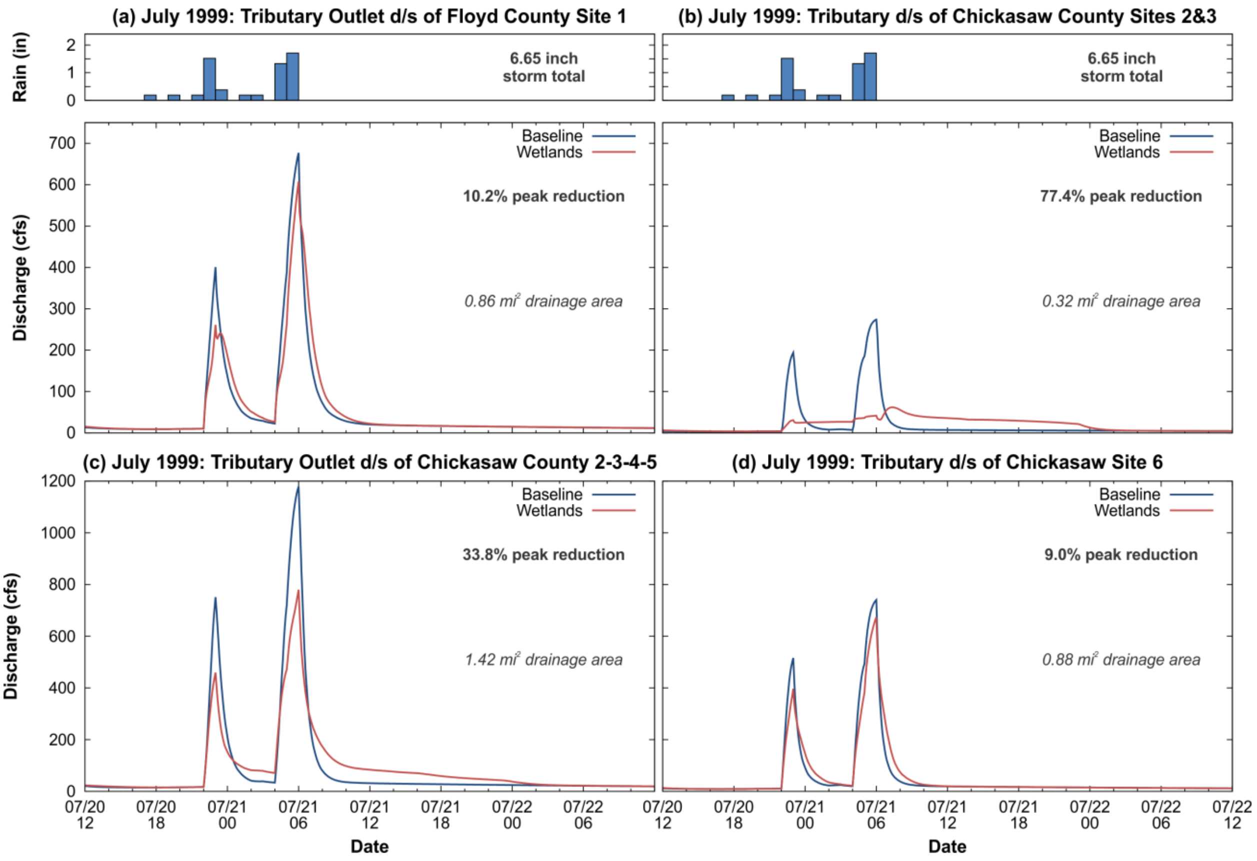


Figure 6.8: Flood hydrographs for the July 1999 event at four tributary locations: (a) the tributary outlet downstream of Floyd County Site 1; (b) the tributary downstream of Chickasaw County sites 2 and 3; (c) the tributary outlet downstream of Chickasaw County sites 2-3-4-5; and (d) the tributary downstream of Chickasaw County site 6.

Figure 6.9 shows flood hydrographs for the July 1999 flood at the four Beaver Creek main stem locations. Even though all the wetland projects are in upstream areas, they still significantly reduce flood peaks at most main stem locations. However, the peak reduction effect is highest at the location downstream of the Floyd County 1 and CREP sites (20.3%), and diminishes as one moves downstream through the watershed. Near the outlet at BEAVER01, there is no peak reduction for the July 1999 flood. This is result of the unfortunate timing of the rainfall. At all locations, we see two peaks; one is associated with the first peak in rainfall (1.52 inches in one hour), and the second is associated with the second peak in rainfall (3.04 inches in two hours). The wetlands temporarily store runoff from the first rainfall peak and delay its release downstream. Unfortunately, that means that when the runoff from the second rainfall peak arrives at the lower main stem, it combines with the delayed release to negate the peak reduction.

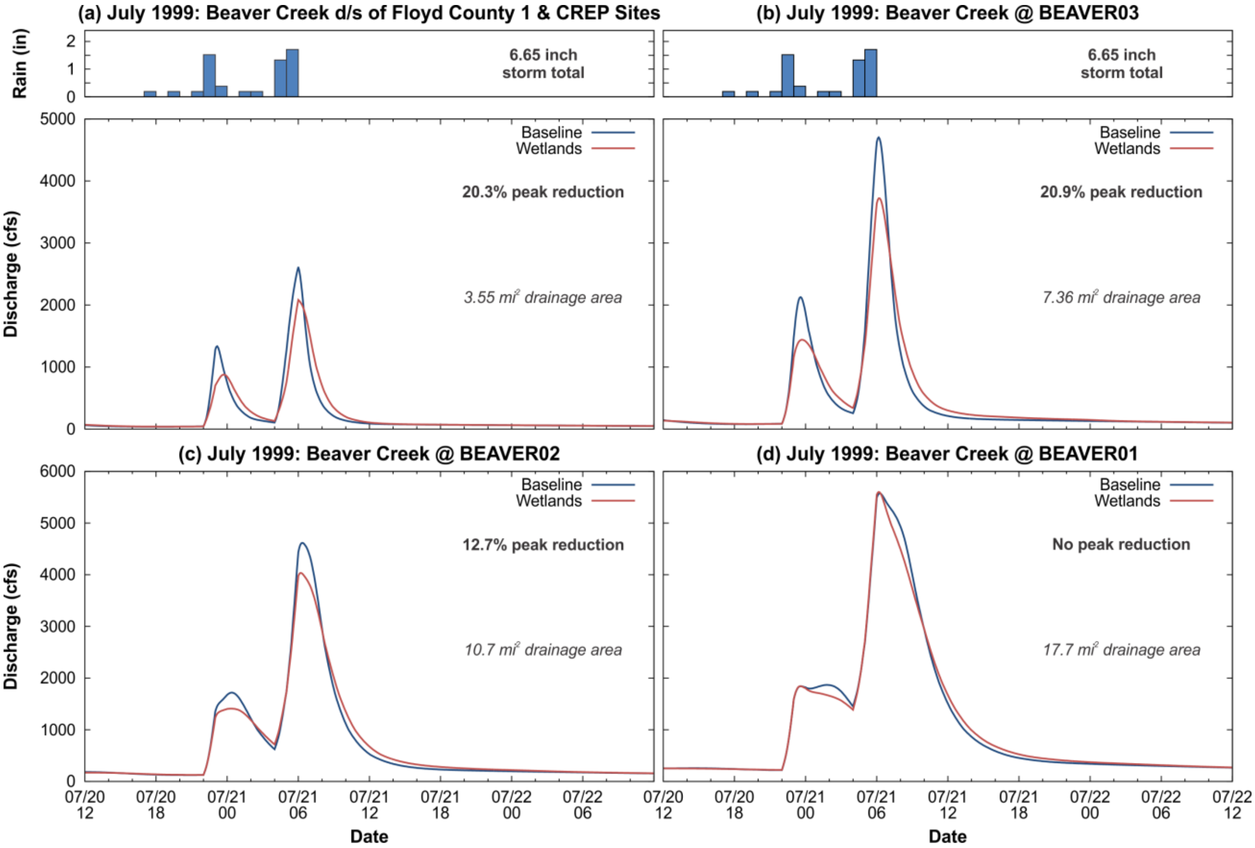


Figure 6.9: Flood hydrographs for the July 1999 event at four main stem locations: (a) Beaver Creek downstream of Floyd County 1 and CREP sites; (b) Beaver Creek at the BEAVER03 stage sensor; (c) Beaver Creek at the BEAVER02 stage sensor; and (d) Beaver Creek at the BEAVER01 stage sensor.

We mapped the peak reduction effect at all locations for the July 1999 flood in Figure 6.10. The peak reduction is shown at all the wetland project outlets (circles) and at the outlet of each sub-basin (colored sub-basin areas). Obviously, upstream of all the project locations, the wetlands do not regulate flow (so no peak reduction mapping is shown). Not surprisingly, high peak reductions occur at the project outlets. The peak reduction effect diminishes as one moves downstream from the projects and as additional runoff enters from contributing drainage areas. The highest peak reductions occur in the tributary with the four Iowa Watersheds Project wetlands.

The July 1999 event is notable in that two heavy rainfall periods occurred within about six hours. Runoff from the first period used wetland flood control storage, so less was available when the second (larger) rain occurred. This reduced the peak reduction effect of the wetlands. In the other top flood events, this situation did not occur, and the peak reduction effect from the wetlands was greater. Figure 6.11 shows flood hydrographs for the August 1979 flood at the four tributary locations. Although significant rainfall caused a flood peak earlier, that rain started 24 hours before the main event. That was enough time for the wetlands to release a majority of the water, and most of their storage was available when heavier rainfall occurred the next day. As a result, the peak reduction for the August 1979 flood is greater than for the July 1979 flood.

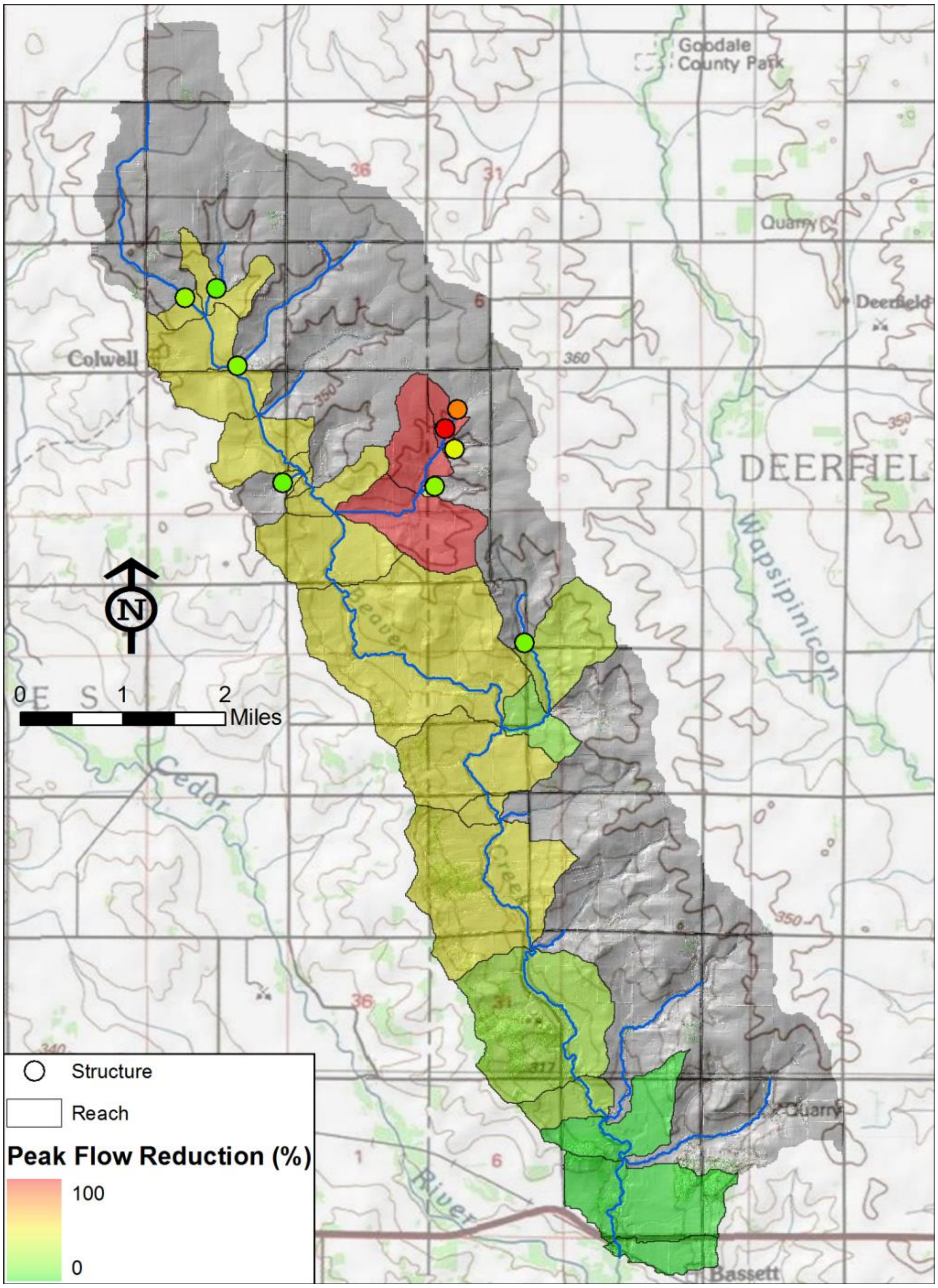


Figure 6.10: Peak reduction (%) for the July 1999 flood with nine wetland projects. The map shows the estimated peak reduction at each sub-basin outlet compared to the baseline simulation without wetlands.

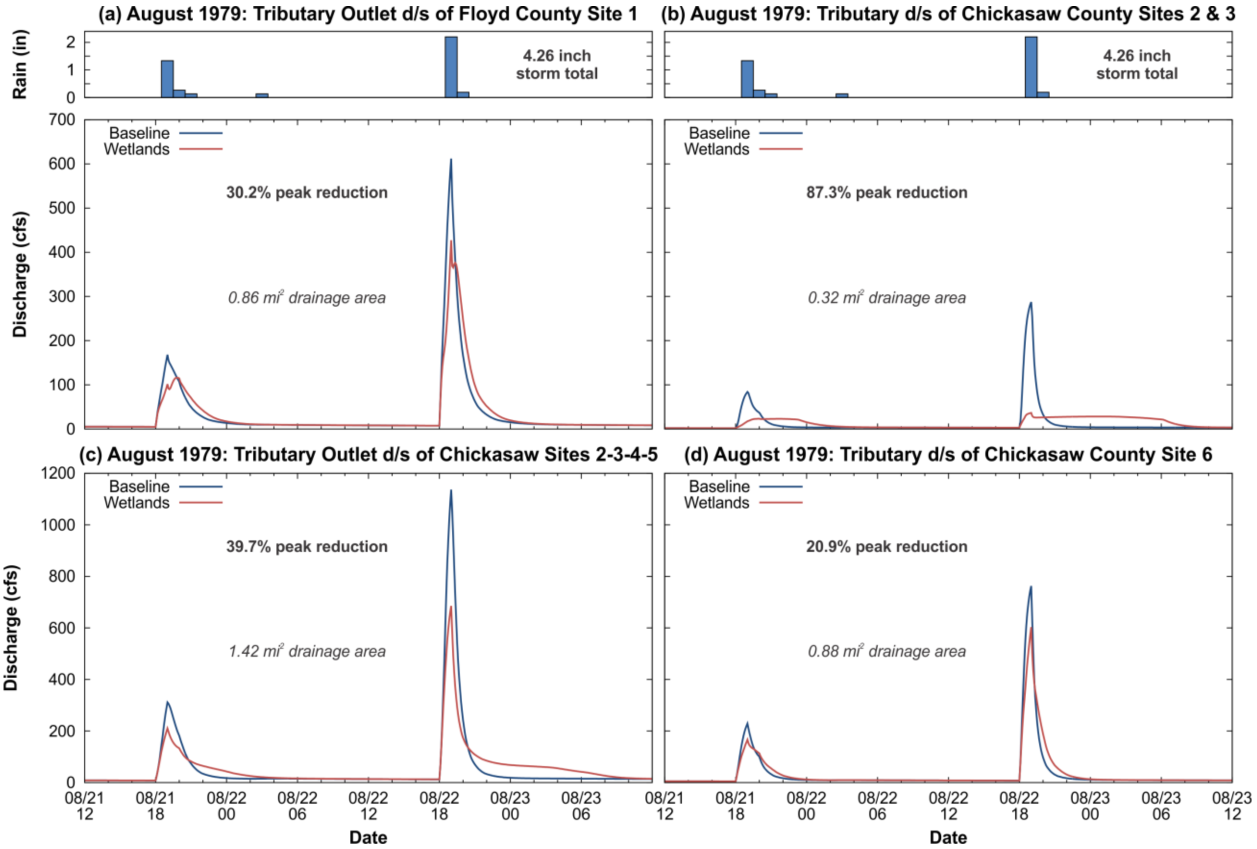


Figure 6.11: Flood hydrographs for the August 1979 event at four tributary locations: (a) the tributary outlet downstream of Floyd County Site 1; (b) the tributary downstream of Chickasaw County sites 2 and 3; (c) the tributary outlet downstream of Chickasaw County sites 2-3-4-5; and (d) the tributary downstream of Chickasaw County site 6.

Figure 6.12 shows flood hydrographs for the August 1979 flood at the four Beaver Creek main stem locations. As with the July 1999 flood, the wetlands significantly reduced flood peaks along the Beaver Creek main stem, except near the outlet at BEAVER01. At this location, we saw a secondary peak (for each of the two rain periods) in the baseline simulation. Runoff from areas in the lower watershed caused the first peak, followed by a second peak when runoff from upstream areas arrived about three hours later. The nine wetland projects in the upstream areas significantly reduced the secondary peak, as shown by the wetland simulation. However, when the first peak is larger, the wetlands have almost no effect. Therefore, the only way to achieve a more significant flood peak reduction in the lower main stem would be to construct additional wetland projects in the tributaries to the lower main stem (see section 6.3.3).

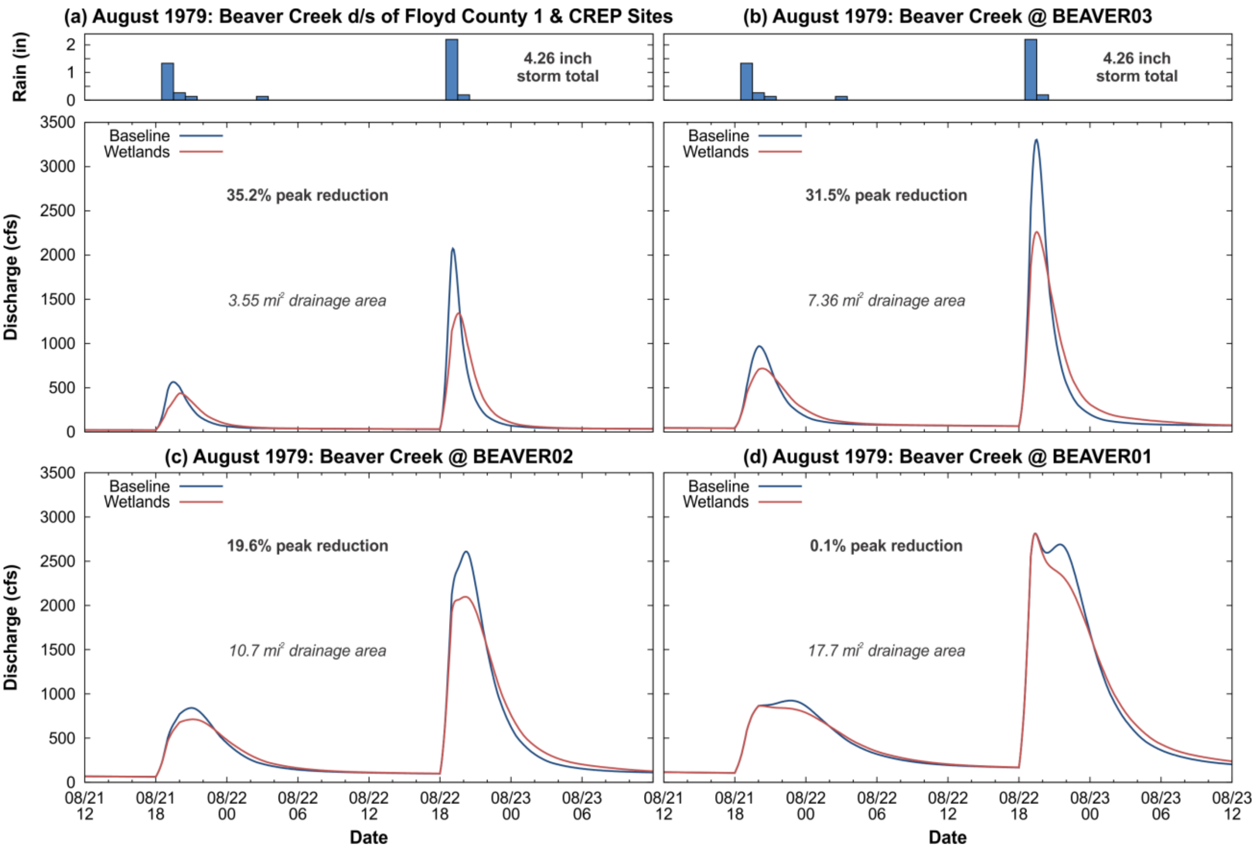


Figure 6.12: Flood hydrographs for the August 1979 event at four main stem locations: (a) Beaver Creek downstream of Floyd County 1 and CREP sites; (b) Beaver Creek at the BEAVER03 stage sensor; (c) Beaver Creek at the BEAVER02 stage sensor; and (d) Beaver Creek at the BEAVER01 stage sensor.

We mapped the peak reduction effect at all locations for the August 1979 flood in Figure 6.13. The peak reduction effect is larger for the July 1999 event, but the overall pattern remains the same. High peak reductions occurred at the project outlet. The peak reduction effect diminished downstream from the project. The highest peak reductions occurred in the tributary with the four Iowa Watersheds Project wetlands.

Flood Frequency Analysis

To study how the wetland projects perform over a range of possible flood events, we analyzed flood frequencies. Figure 6.14 shows the flood frequency analysis of simulated baseline condition (without wetlands) and the wetland simulation at the four tributary locations. For each year in the 65-year simulation, the annual maximum peak discharges (i.e., the largest discharge in a given year) are found at each location. Then, we ranked them from smallest to largest and plotted versus a sample estimate of their exceedance probability. Each plot also shows exceedance probabilities corresponding to the 2-year, 10-year, 25-year, and 50-year return periods (dashed vertical lines). We computed the average peak reduction based on all 65 pairs of annual maximums.

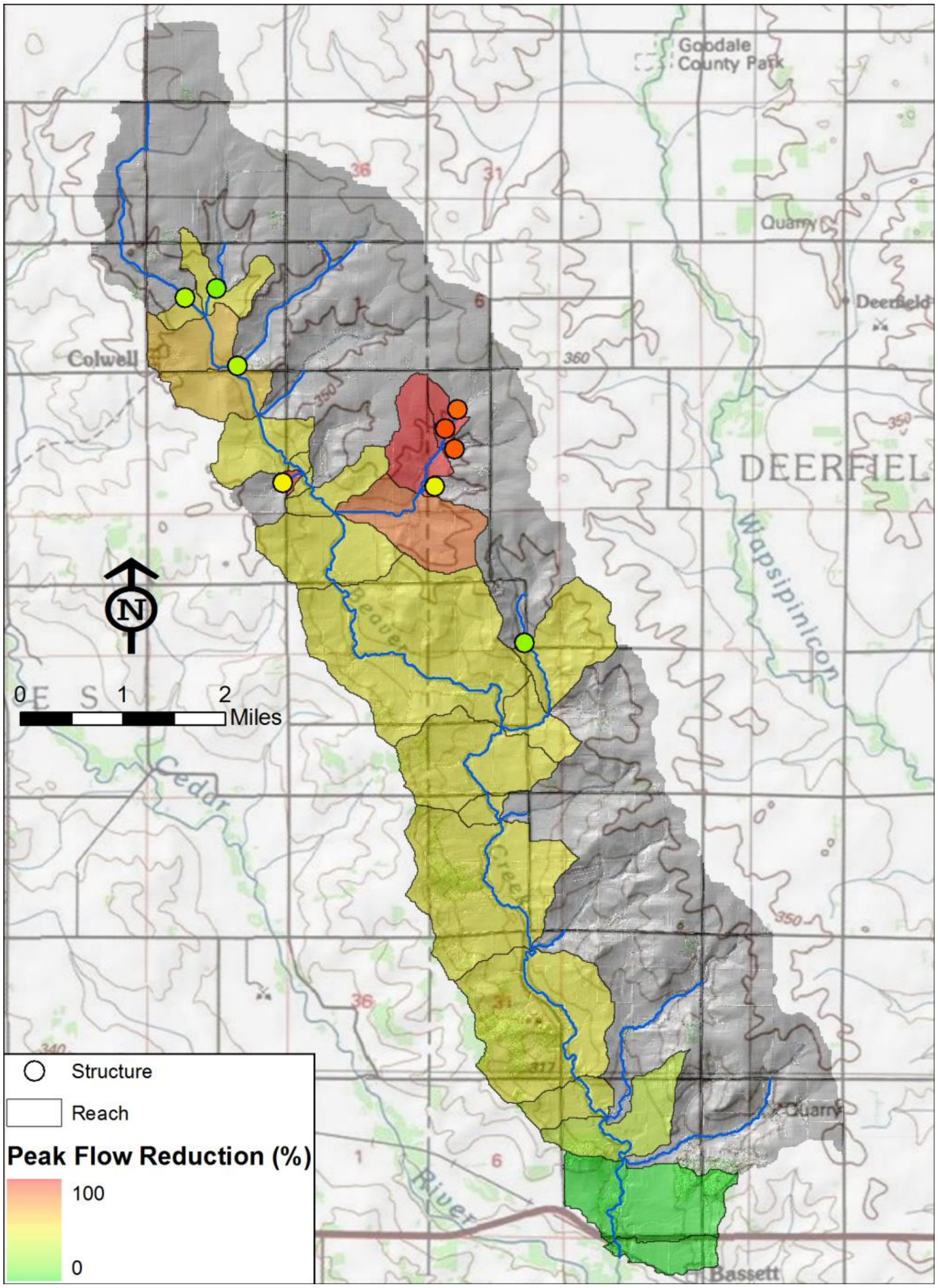


Figure 6.13: Peak reduction (%) for the August 1979 flood with nine wetland projects. The map shows the estimated peak reduction at each sub-basin outlet compared to the baseline simulation without wetlands.

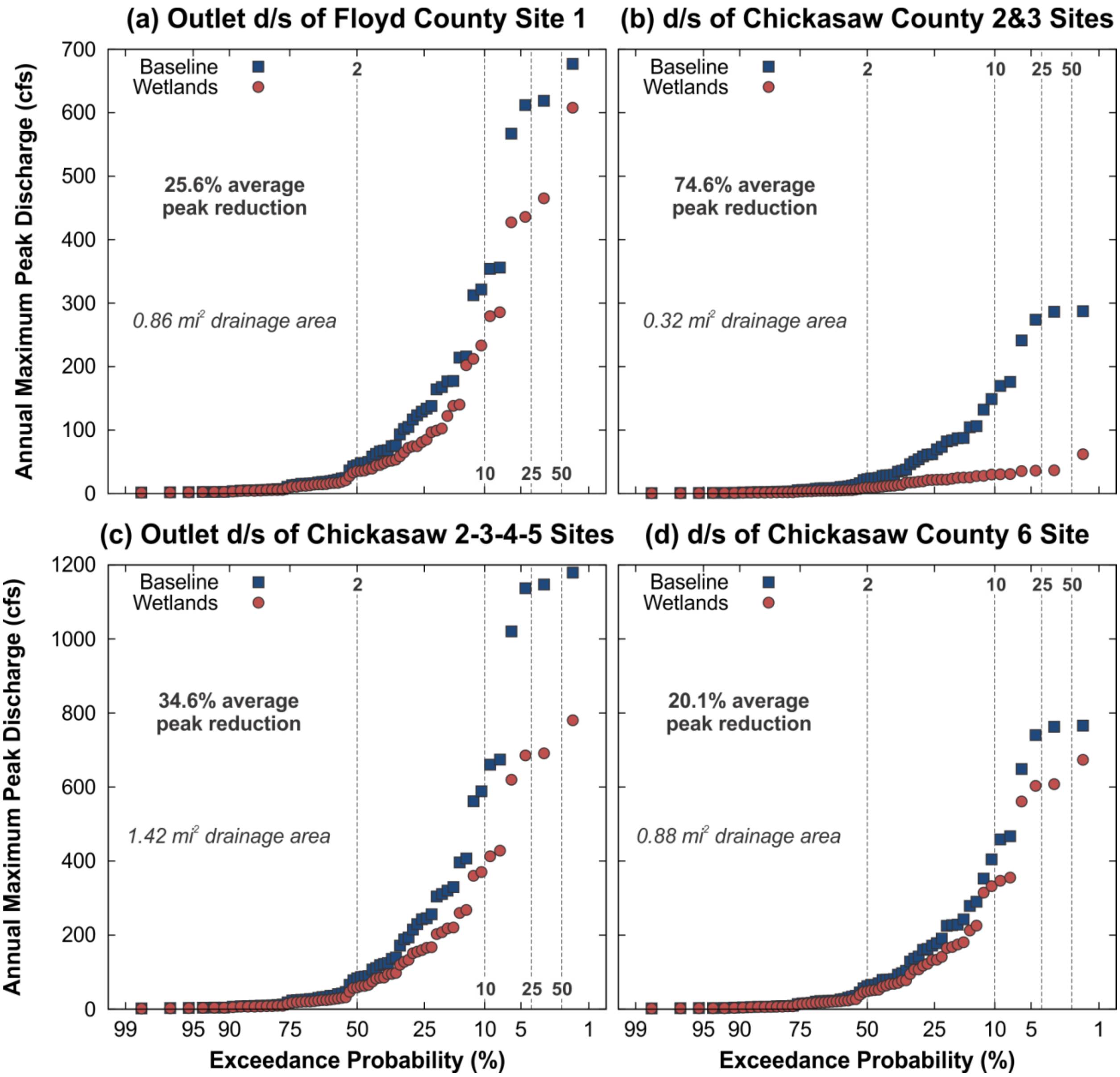


Figure 6.14: Sample probability distribution of annual maximum peak discharges for the baseline and wetland simulations at four tributary locations: (a) the tributary outlet downstream of Floyd County Site 1; (b) the tributary downstream of Chickasaw County sites 2 and 3; (c) the tributary outlet downstream of Chickasaw County sites 2-3-4-5; and (d) the tributary downstream of Chickasaw County site 6. Vertical dashed lines show the 2-, 10-, 25-, and 50-year return periods. We computed the average peak reduction based on all 65 pairs of annual maximums.

Similar to the two individual flood events in the previous section, the simulated peak discharge flood frequencies are lower for the wetlands simulation. The largest average peak reduction occurs downstream of Chickasaw County sites 2 and 3 (74.6%). At the outlet of this tributary, which has four wetlands upstream, the average peak reduction is still high (34.6%). The tributaries with a single wetland have slightly lower average peak reductions (at 25.6% and 20.1%). All significantly reduce peak discharges at the 10-, 25-, and 50-year return period flood levels.

Figure 6.15 shows the flood frequency analysis of simulated baseline condition (without wetlands) and the wetland simulation at the four main stem locations. The average peak reduction remained high below the Floyd County and CREP sites (27.5%) and below eight (of the nine) wetlands at BEAVER03 (25.3%). Average peak reduction diminishes further downstream at BEAVER02 (14.7%). As we observed with the individual flood events near the Beaver Creek outlet at BEAVER01, the average reduction is much smaller (3.3%).

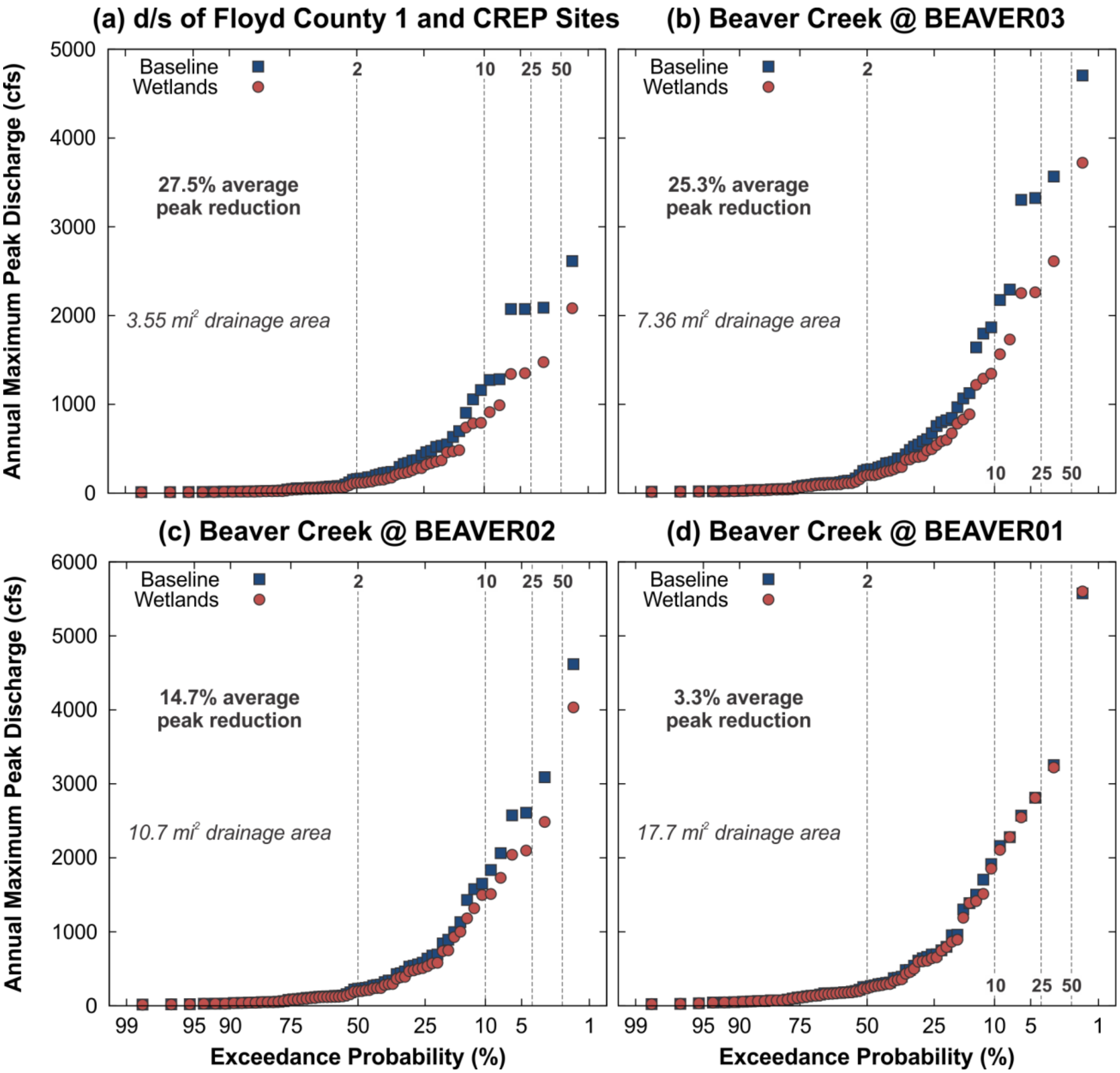


Figure 6.15: Sample probability distribution of annual maximum peak discharges for the baseline and wetland simulations at four main stem locations: (a) Beaver Creek downstream of Floyd County 1 and CREP sites; (b) Beaver Creek at the BEAVER03 stage sensor; (c) Beaver Creek at the BEAVER02 stage sensor; and (d) Beaver Creek at the BEAVER01 stage sensor. Vertical dashed lines show the 2-, 10-, 25-, and 50-year return periods. We computed the average peak reduction based on all 65 pairs of annual maximums.

By design, wetlands store a greater volume of water as flows increase. After the water level rises above the auxiliary spillway elevation, the flood storage volume is exhausted and the peak reduction diminishes. Therefore, the flood storage is most effective in reducing peak discharges for a targeted range of flows. The effects are illustrated in Table 6.4, which shows the peak reduction for different return periods at the outlet of the wetland projects. For most of the Iowa Watersheds Project wetlands, the peak reduction is largest for the 25-year return period. Peak reduction increases from the 2-year to 10-year flood, and from the 10-year to 25-year flood; then it decreases from the 25-year to the 50-year flood. The -designed wetlands show the same progression. The largest peak reduction is also greater than the average peak reduction for all 65 events. This occurs because the wetlands are using their storage for rarer large events, and not for smaller, more common high flow periods. The two exceptions are the Chickasaw County Site 6 and the Wohlers Pond site, which have their largest peak reduction at the 2-year return period.

Table 6.4: Peak reduction effect for the wetland project outlets (relative to the baseline simulation). Reductions (%) for the 2-, 10-, 25-, and 50-year return periods. The average (%) is the average reduction based on all 65 ranked annual maximum events.

		Return Period			
Location	Average	2-year	10-year	25-year	50-year
	Iowa Watersheds Project Wetlands				
Floyd County Site 1	19.2	16.1	17.9	21.5	13.1
Chickasaw County Site 2	63.9	46.1	73.0	83.4	66.0
Chickasaw County Site 3	75.5	59.6	82.7	89.4	81.6
Chickasaw County Site 4	66.6	51.7	79.0	83.7	48.7
Chickasaw County Site 5	40.5	38.7	44.8	45.2	30.1
Chickasaw County Site 6	25.8	27.8	24.9	25.0	20.1
	Existing Wetlands				
CREP Site 961502B	26.7	22.2	27.5	32.0	21.6
CREP Site 961502D	28.9	27.6	27.9	34.8	21.6
Wohlers Pond	66.7	84.5	62.2	50.3	28.9

Table 6.5 shows the peak reduction for different return periods at the tributary and main stem locations. Just like at the wetland outlets themselves, the largest peak reduction occurs at the 25-year return period level for most locations. Still, the wetlands remain highly effective in reducing peak discharge for 2- to 50-year return period floods. One exception is at the Beaver Creek outlet at BEAVER01. The highest peak reduction is for the 2-year return period flood (7.3%). The peak reduction for 25-year floods or higher is virtually negligible. As we observed for individual flood events here, any significant peak reduction at this location will require additional wetland areas in the lower watershed tributaries.

Table 6.5: Peak reduction effect for the wetland simulation (relative to the baseline simulation). Reductions (%) for the 2-, 10-, 25-, and 50-year return periods. The average (%) is the average reduction based on all 65 ranked annual maximum events.

		Return Period			
Location	Average	2-year	10-year	25-year	50-year
		Tributary Locations			
Outlet d/s of Floyd County Site 1	25.6	20.3	24.8	27.4	14.6
d/s of Chickasaw County Sites 2 & 3	74.6	58.3	80.8	87.0	81.2
Outlet d/s of Chickasaw Sites 2-3-4-5	34.6	29.7	37.2	39.7	35.7
d/s of Chickasaw County Site 6	20.1	22.5	20.7	19.2	14.7
		Main Stem Locations			
Beaver Creek d/s of Floyd and CREP Sites	27.5	27.5	30.3	32.8	22.8
Beaver Creek @ BEAVER03	25.3	23.5	28.0	30.0	22.4
Beaver Creek @ BEAVER02	14.7	14.8	12.8	19.6	14.3
Beaver Creek @ BEAVER01	3.3	7.3	2.9	0.4	-0.2

To illustrate how the wetland projects change simulated flood peaks, Figure 6.16 maps the peak reduction at sub-basin outlets throughout the watershed for the 25-year return period. Note that some wetland outlets (circles) have very high peak reductions, while others are much lower. The peak reduction at wetland outlet ranges from about 20% to almost 90%. Flood storage is most effective immediately downstream of a wetland. As one moves downstream from a structure, the peak reduction effect diminishes rapidly. The effect continues to diminish along the main stem below all nine wetland locations, to a minimum of just 0.4% at the Beaver Creek outlet.

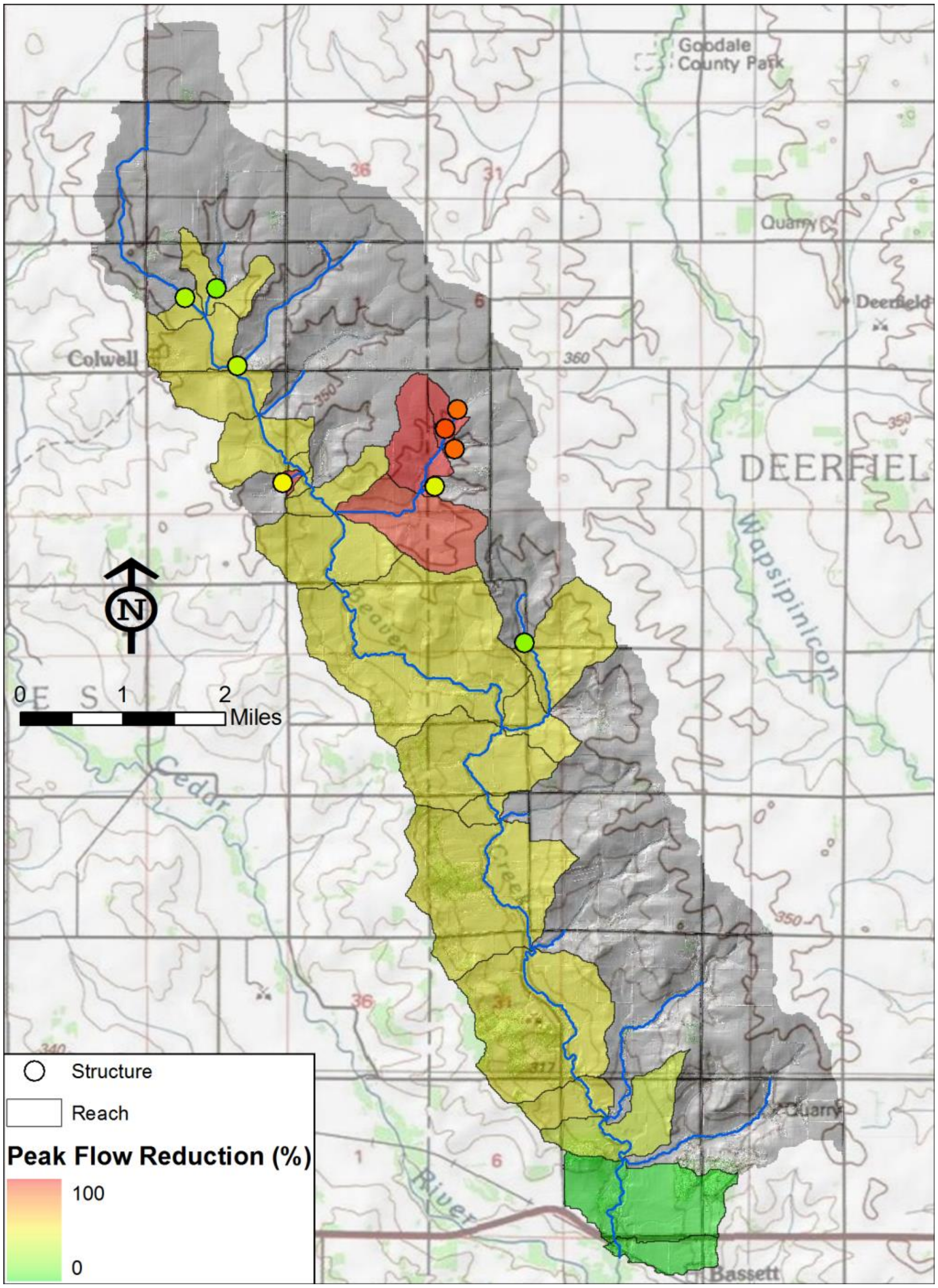


Figure 6.16: Average peak discharge reduction (%) for locations in the Beaver Creek Watershed for the 25-year return period flood. We computed the peak reduction effect from the 65 ranked annual events.

Effects of Additional Hypothetical Wetlands

Although the Iowa Watersheds Project wetland projects are effective in reducing peak discharges in Beaver Creek, the peak reduction is modest in the lower main stem reaches. Additional investments in wetland projects could improve peak reduction in these areas. We can use the Beaver Creek HSPF model to explore potential options for future project investments. In this section, we investigate several hypothetical wetland scenarios.

For these hypothetical scenarios, additional wetlands are distributed in tributary areas of the lower Beaver Creek Watershed. Because an actual wetland design requires detailed site-specific information, we used a prototype wetland design mimicking the hydrologic impacts of flood storage. Therefore, this example is not a proposed plan for siting additional wetlands. We have not determined whether suitable sites are available in the simulated locations. Still, this hypothetical example does provide a quantitative benchmark on the effectiveness of additional flood storage and the flood reduction benefits that are physically possible.

For this analysis, we developed a prototype wetland based on the stage-storage relationship of the constructed Iowa Watersheds Project wetlands. Since the wetlands vary in size and shape, we chose to base our prototype on four with similar flood storage (in the range of 15.42 to 16.85 acre-feet). After plotting their stage-discharge relationships, we found that averaging the stage-storage for two wetlands (Chickasaw County Sites 2 and 4) results in a realistic average relationship. These two sites have the same principal spillway (24-inch riser) and auxiliary spillway (40-foot wide crest), so we also used the stage-discharge relationships developed for these wetlands for the prototype wetland. Finally, since these two constructed wetlands have drainage areas between 139 and 158 acres, we assumed the hypothetical wetlands would have similar drainage areas.

Figure 6.17 shows the locations selected for six hypothetical wetlands. As noted, this analysis only examines additional wetlands located in the lower watershed. We simulated three scenarios, as shown in Table 6.6. The first scenario adds two wetlands in tributaries closest to the main stem outlet. The second adds two more wetlands in the next two upstream tributary areas. The third adds two more in the two closest tributaries.

Table 6.6: Scenarios with hypothetical prototype wetland projects added to the watershed.

Scenarios	Wetland Added	Prototype Wetlands
S1	2 Wetlands	H1, H2
S2	4 Wetlands	H1, H2, H3, H4
S3	6 Wetlands	H1, H2, H3, H4, H5, H6

Figure 6.18 shows simulated hydrographs for the July 1999 flood for hypothetical wetland scenarios at the Beaver Creek outlet. Recall that with the constructed Iowa Watersheds Project wetlands, there is no peak reduction at this downstream location. However, with two wetlands added in the tributaries closest to the outlet (scenario S1), the peak reduction is now 4.7%. Adding two more wetlands farther upstream (scenario S2) increases it to 7.6%. Finally, adding two additional wetlands in the closest tributaries increases the peak reduction to 11.9%. Figure 6.19 shows that the hypothetical wetland scenarios are even more effective in reducing peak discharges at this location for the August 1979 flood.

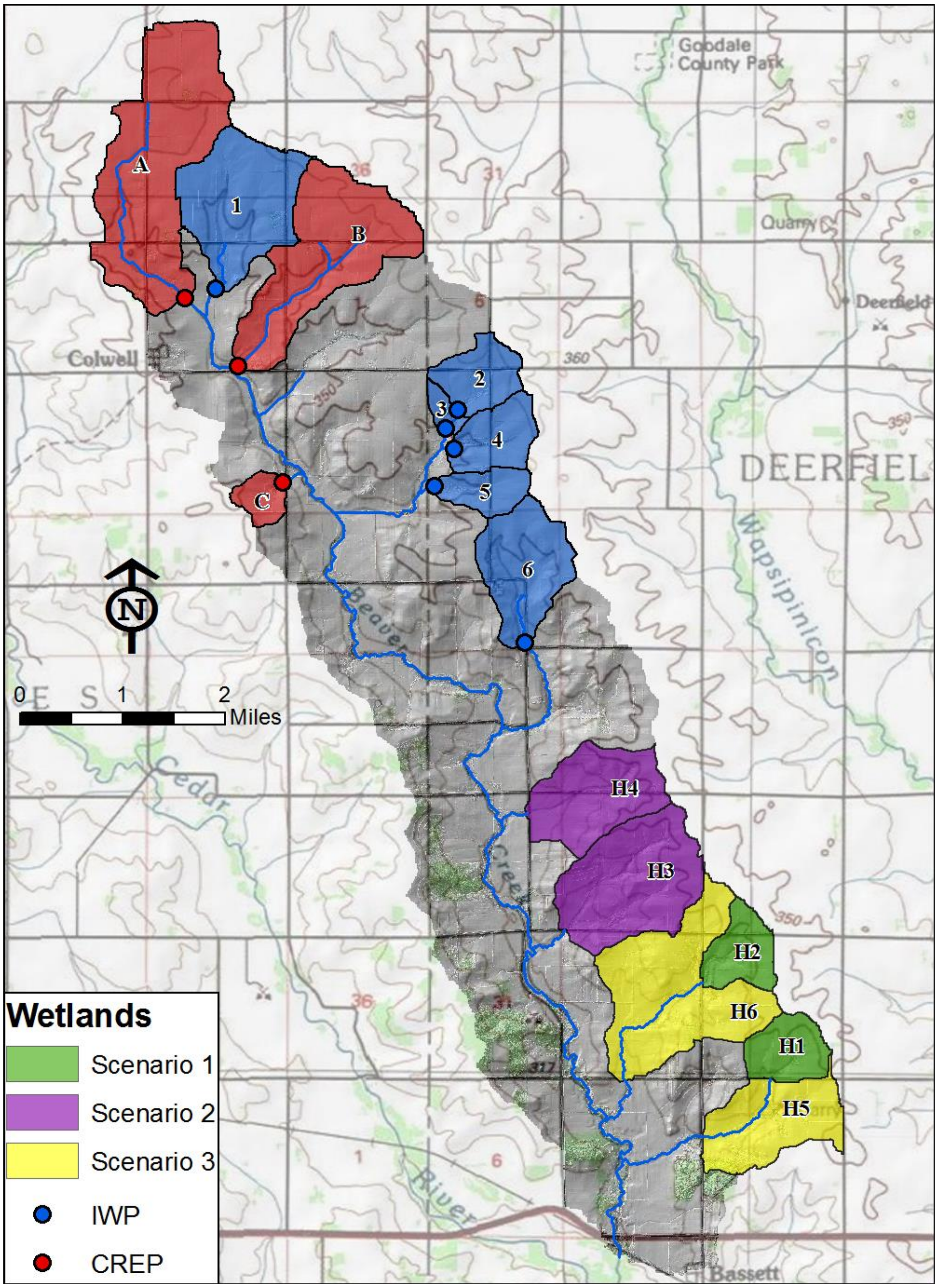


Figure 6.17: Sub-basins selected for the addition of hypothetical wetlands to assess potential future flood reduction beyond what was achieved with the Iowa Watersheds Project Phase II flood mitigation structures.

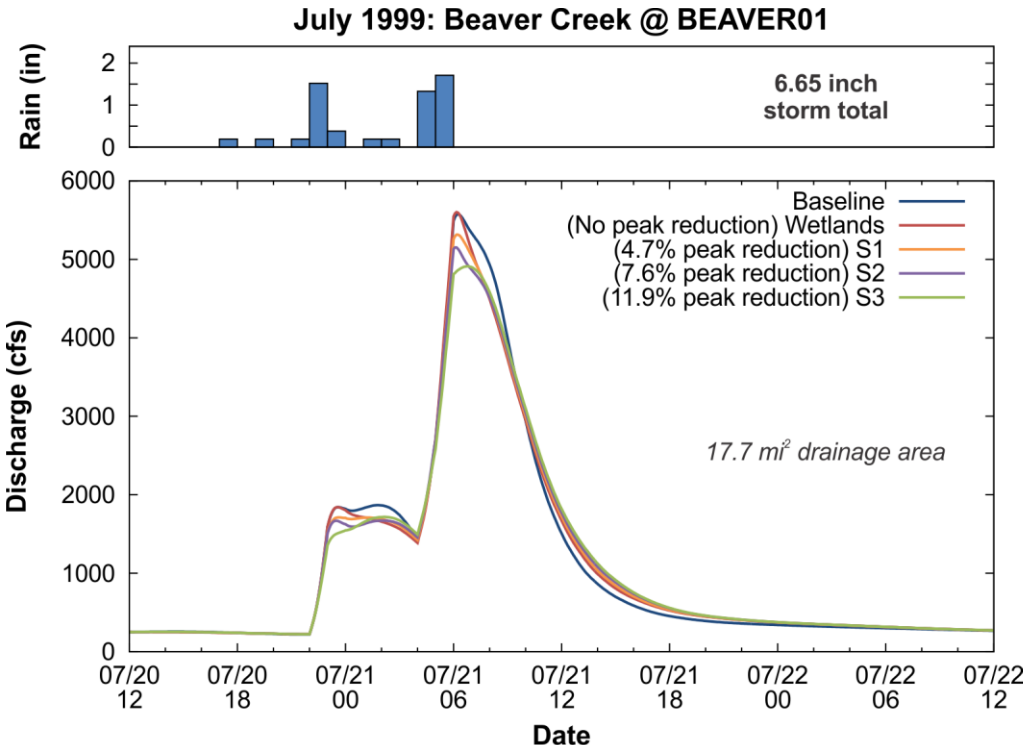


Figure 6.18: Flood hydrographs for the July 1999 event for Beaver Creek at the BEAVER01 stage sensor. Results are shown for the baseline (no wet- lands) and the Iowa Watersheds Project wetland simulation, as well as the three additional hypothetical wetland scenarios.

Based on a flood frequency analysis of the wetland scenarios, Table 6.7 shows the peak reduction at different return periods for the Beaver Creek outlet. As noted earlier (for Table 6.5), the peak reduction at the basin outlet is negligible for 25-year floods or higher with the constructed wetland projects. Yet even with the two-wetland scenarios S1, the peak reduction increases significantly for the 25-year (8.0%) and 50-year floods (5.3%). It increases even more for both the four-wetland S2 and the six-wetland S3 scenarios. Indeed, with the six-wetland scenarios, all locations on the Beaver Creek main stem would have a peak reduction of 14.4% or greater for the 25-year flood, and 10.1% or greater for the 50-year flood. However, we should note that the actual flood reduction potential for different return periods would depend on where the wetland structures were placed and how much storage is available at the location.

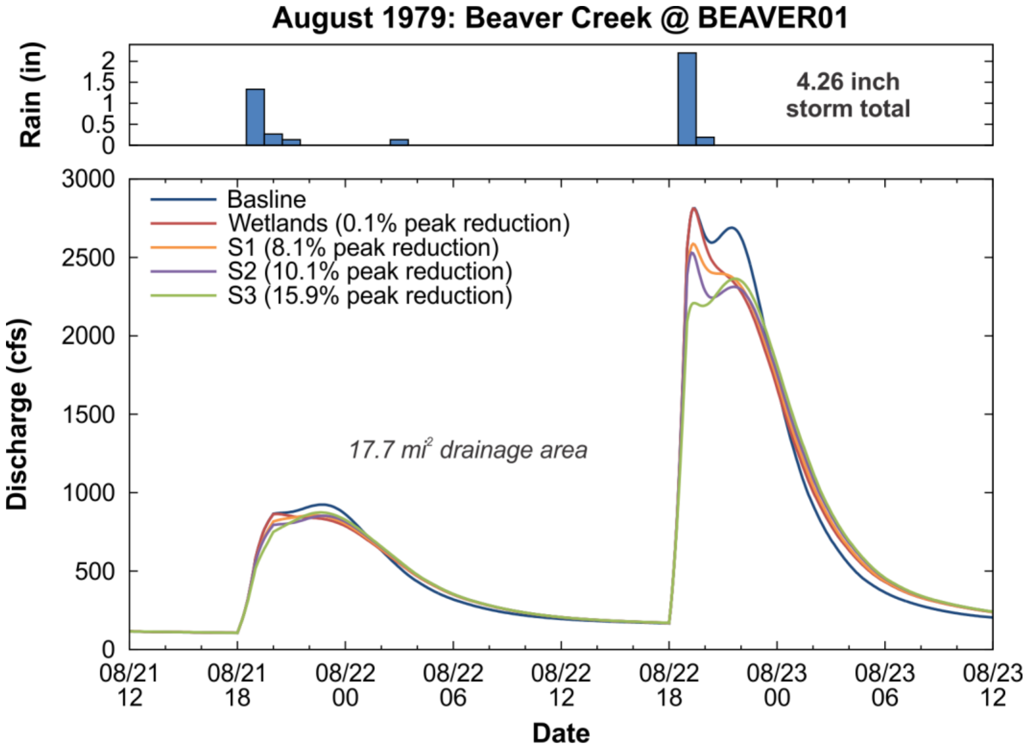


Figure 6.19: Flood hydrographs for the August 1979 event for Beaver Creek at the BEAVER01 stage sensor. Results are shown for the baseline (no wetlands) and the Iowa Watersheds Project wetland simulation, as well as the three additional hypothetical wetland scenarios.

Table 6.7: Peak reduction effect for the constructed wetlands and the hypothetical wetland scenarios for Beaver Creek at BEAVER01. Reductions (%) are shown for the 2-, 10-, 25-, and 50-year return periods. The average (%) is the average reduction based on all 65 ranked annual maximum events.

		Return Period			
Scenario	Average	2-year	10-year	25-year	50-year
Wetlands	3.3	7.3	2.9	0.4	-0.2
S1	7.0	5.8	8.4	8.0	5.3
S2	8.4	5.2	10.6	10.4	8.3
S3	9.4	3.9	10.6	15.5	12.5

d. Summary

We used the Beaver Creek HSPF model to examine flooding characteristics in the Beaver Creek Watershed. We created the model from the existing Cedar River HSPF model (RESPEC, 2007; Environmental Protection Agency, 2010). We extracted the model parameters representing different land uses and used them to simulate runoff in Beaver Creek. A network of stream reaches was then created to route water and simulate flows throughout the Beaver Creek Watershed. We also extended the weather inputs from 11 to 65 years. Based on the results from the 65-year simulation, we identified the top simulated flood events. Each was seen to produce widespread flooding throughout the watershed. In some cases, the simulated flooding is more severe along the Beaver Creek main stem. For others, flooding is more severe in the upstream and tributary areas.

We then used the Beaver Creek HSPF model to assess the performance of wetland projects in the watershed. We simulated the operation of the six Iowa Watersheds Project constructed wetlands and three existing wetlands continuously for the 65-year historical period. We found that the wetland projects significantly reduced flood peak discharges within the watershed. Figure 6.20 summarizes the peak reduction for the 25-year return period discharge (used here as a measure of a significant flood event). Peak reduction is large at the project outlets, ranging from about 22% at the Floyd County site 1 (with the largest upstream drainage area) to almost 90% at Chickasaw County site 3 (a small drainage area with two wetlands in series). Downstream of the wetland projects, the peak reduction diminishes (red diamonds on Figure 6.20). Still, it remains above 12% at all but the last two downstream locations. Near the Beaver Creek outlet, flood peaks are primarily caused by runoff coming from the lower watershed, where no wetland projects are located. As a result, the wetland projects have minimal peak reduction near the outlet for the largest floods.

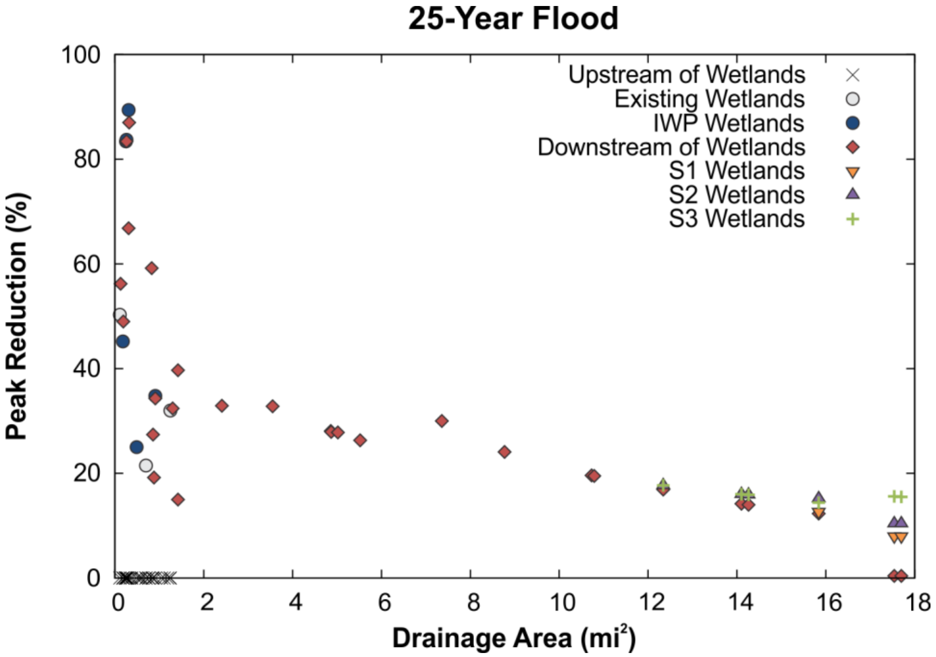


Figure 6.20: Peak reduction (%) for the 25-year return period peak discharge for all 59 simulated locations in the Beaver Creek Watershed. Locations upstream of projects (shown with an ×) are unregulated and have no peak reduction. Peak reductions at the wetlands (circles) and downstream (red diamonds) are shown as a function of their drainage area (in mi^2). Peak reductions are also shown for the three hypothetical wetland project scenarios: S1 (two wetlands added), S2 (four wetlands added), and S3 (six wetlands added). These scenarios add wetlands in the lower Beaver Creek tributaries, and their impact is shown only for the main stem locations where they have an effect (at 12.3 mi^2 or greater).

To further reduce peak discharges on the lower Beaver Creek main stem, we explored three hypothetical wetland project scenarios in the lower tributary areas. Figure 6.20 summarizes the results for the 25-year return period discharge. Adding two (S1), four (S2), or six (S3) wetland projects in the lower tributaries could increase peak reduction along the lower main stem. Given the effectiveness of the Iowa Watersheds Project and existing wetlands in the upper watershed (as seen in Figure 6.20), future investments in flood mitigation should be focused on the lower Beaver Creek Watershed to reduce main stem peaks near the outlet.

7. Summary and Conclusions

The Iowa Flood Center (IFC), a unit of the University of Iowa's IIHR— Hydroscience & Engineering (IIHR), has collaborated with the Upper Cedar Watershed Management Improvement Authority (WMIA) on Phase II of the Iowa Watersheds Project. Phase II involved the development and construction of flood mitigation projects in the Beaver Creek Watershed, a sub-watershed of the Upper Cedar River. In this report, IFC researchers evaluated the flood mitigation performance of proposed projects through monitoring and detailed hydrologic modeling. The team developed small-scale hydrologic simulations for the Beaver Creek Watershed using a more detailed representation of the watershed and flood mitigation strategies than was used in the Phase I study of the entire Upper Cedar River Watershed.

a. Monitoring Stations and Data Collection

Data collection before and after implementation of the watershed projects was especially critical for the Iowa Watersheds Project. In the Beaver Creek Watershed, we used monitoring equipment to quantify the benefits of constructed projects and to provide critical information to help Iowans make better informed decisions about the implementation, design, size, cost, and impact of additional watershed projects.

Since 2014, the Iowa Flood Center has been collecting data from three stream stage sensors and three rainfall/soil moisture platforms deployed in the Beaver Creek Watershed. The information from this deployed instrumentation network is made available to the public in real-time on the Iowa Flood Information System (IFIS) (http://ifis.iowafloodcenter.org/ifis), a user-friendly Google Maps interface.

In addition, IIHR has two water-quality sensors in the watershed to monitor the nutrient-reduction benefits of constructed projects. Sensors collect data in real-time, which is made available to the public through the Iowa Water-Quality Information System (Iowa WQIS) (http://iwqis.iowawis.org/). By incorporating hydrologic information with water-quality data, scientists, policy-makers, and interested stakeholders will be able to better understand how various hydrologic drivers impact the fate and transport of nutrients in Iowa's waterways.

b. Constructed Projects

In 2014, the Iowa Watersheds Project spent $1,500,000 to plan, design, and construct six wetlands in the Beaver Creek Watershed. The wetlands are designed to reduce flooding by increasing the storage capacity on the landscape; they provide a secondary benefit of improving water quality through nutrient processing. The wetlands also increase the aesthetic beauty of the land and create abundant habitat for wildlife. The constructed wetlands act as demonstration projects to promote the adoption of best management practices and provide education and outreach opportunities.

Volunteer landowners received 75% cost share assistance on constructed projects. The project designs follow Natural Resources Conservation Service (NRCS) specifications and guidelines and come with a 20-year maintenance agreement. The Upper Cedar River WMIA selected the project locations based on recommendations from the Floyd and Chickasaw County Soil & Water Conservation District offices and consultation with the Iowa Flood Center.

c. Evaluation of Project Performance

We evaluated the performance of the constructed wetland projects with two hydrologic models. The Beaver Creek HydroGeoSphere (HGS) model is a high-resolution physics-based model that simulates water storage and movement at almost 25,000 grid elements within the watershed. It can track the movement of water at the land surface and in the sub-surface (soils). The model also simulates flows in the six constructed wetlands and three other existing wetlands for design rainfall events and the June 2008 flood event. Since such a detailed model can take several days of computer time to simulate a year's worth of conditions, we also used a simpler model to evaluate project performance over a long historical period. The Beaver Creek Hydrological Simulation Program-FORTRAN (HSPF) model lumps the watershed area into five distinct land uses and makes predictions at 59 stream locations in the watershed. It accounts for water on the landscape continuously in time through a 65-year simulation period. We used historical weather records from nearby stations as input to drive the simulation.

Both hydrologic models demonstrate the effectiveness of the six Iowa Watersheds Project wetlands in reducing downstream flood peaks. Just downstream from the projects themselves, peak discharge reduction for design or historical events is significant, even for large flood events. The wetlands perform very well at around the 25-year return period, where peak reductions range from 20% to 90%. Even for more extreme events, such as the 100-year design rainfall, peak reductions ranged from 5% to almost 40%. As one moves downstream from the projects, the peak reduction effect diminishes. However, the constructed wetlands still significantly reduce flood magnitudes on tributaries and the Beaver Creek main stem locations. At the 25-year return period level, the peak reduction is almost 20% or greater in the upper Beaver Creek Watershed, where the wetland projects are located. Flood peaks on the lower main stem see less peak reduction, especially when water quickly runs off from unregulated tributaries in the lower watershed. Simulations in which hypothetical wetlands are added to the lower tributaries illustrate how additional investments in flood mitigation could enhance flood peak reduction in the lower watershed.

d. Concluding Comments

These watershed demonstration projects have taught us much about the movement of water through the landscape and serve as an essential step toward long-term recovery to improve Iowa's future flood resiliency. The hydrologic assessment, watershed plan, and project evaluation will guide future decision making to expand project implementation to other sub-watersheds in the Upper Cedar River Watershed. The watershed planning and project implementation conducted through the Iowa Watersheds Project will serve as leverage for the Upper Cedar River WMIA to seek additional funding for continued work toward its long term goals.

In January 2016, the U.S. Department of Housing and Urban Development (HUD) awarded $96.9 million to Iowa for a statewide watershed improvement program, the Iowa Watershed Approach

(IWA). The IWA will address issues associated with the devastating and dangerous floods Iowa communities experience year after year. The foundation of the IWA was built on the framework and success of the IWP, which served as a significant source of leverage for the state of Iowa to receive another round of HUD funding for a new five-year project.

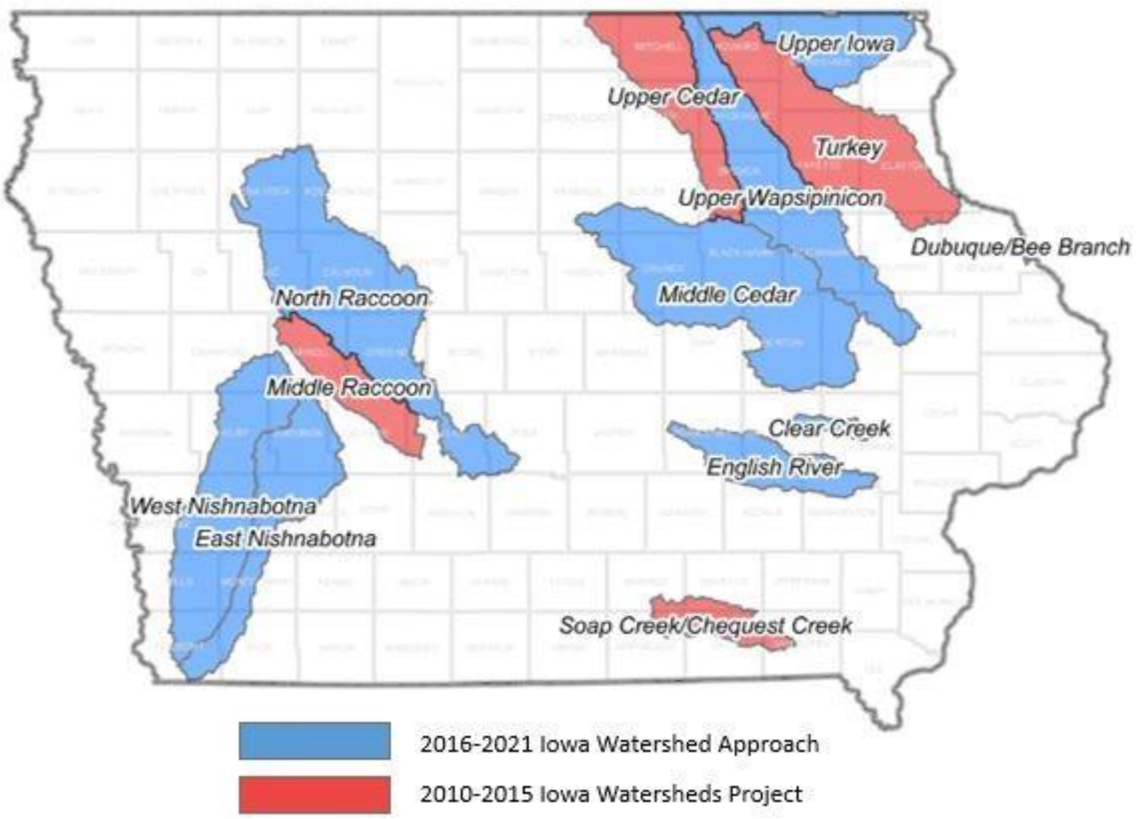


Figure 7.1: Location of watersheds selected for the Iowa Watersheds Project and the Iowa Watershed Approach.

The IWA project will work in nine new watersheds across the state: Bee Branch Creek in Dubuque, Upper Iowa River, Upper Wapsipinicon River, Middle Cedar River, Clear Creek, English River, North Raccoon River, West Nishnabotna River, and East Nishnabotna River. Each will have the opportunity to form a Watershed Management Authority (WMA), develop a hydrologic assessment and watershed plan, and implement projects to reduce the magnitude of downstream flooding and to improve water quality during and after flood events.

A video explaining the Iowa Watersheds Project and Iowa Watershed Approach can be accessed at https://www.youtube.com/watch?v=tODPRvs4ycU.

Appendix A – Wetland Project Elevation-Storage-Discharge Information

Project:	Floyd County Site 1 Wetland
Drainage Area:	460 acres
Description:	The principal spillway is a 24-inch pipe riser at 1131 ft MSL. The auxiliary spillway is a 40-foot crest at 1133 ft MSL (modeled as a broad crested weir).
Comment:	Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

Floyd County Site 1 Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1128	48,100	0	
1	1129	119,700	83,900	
2	1130	224,400	255,950	
3	1131	342,025	539,163	Principal
4	1132	433,235	926,793	
5	1133	537,150	1,411,985	Auxiliary
6	1134	642,360	2,001,740	Top of Dam

Floyd County Site 1 Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0.0	1128.0	1.104	0.000	0.00	
1.0	1129.0	2.748	1.926	0.00	
2.0	1130.0	5.152	5.876	0.00	
3.0	1131.0	7.852	12.377	0.00	Principal
3.5	1131.5	8.899	16.565	77.22	
4.0	1132.0	9.946	21.276	218.40	
4.5	1132.5	11.138	26.547	401.23	
5.0	1133.0	12.331	32.415	617.73	Auxiliary
5.5	1133.5	13.539	38.882	909.26	
6.0	1134.0	14.747	45.954	1264.84	Top of Dam
6.5	1134.5	15.905	53.617	1668.89	
7.0	1135.0	17.064	61.859	2114.90	

Project: Chickasaw County Site 2 Wetland

Drainage Area: 158 acres

Description: The principal spillway is a 24-inch pipe riser at 1153 ft MSL. The auxiliary spillway is a 40-foot crest at 1157 ft MSL (modeled as a broad crested weir).

Comment: Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

Chickasaw County Site 2 Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1148	37,80	0	
1	1149	13,670	8,725	
2	1150	25,720	28,420	
3	1151	42,210	62,385	
4	1152	62,025	114,503	
5	1153	89,010	190,020	Principal
6	1154	126,620	297,835	
7	1155	177,265	449,778	
8	1156	233,960	655,390	
9	1157	303,370	924,055	Auxiliary
10	1158	392,970	1,272,225	
11	1159	486,640	1,712,030	Top of Dam

Chickasaw County Site 2 Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0	1148	0.087	0.000	0.00	
1	1149	0.314	0.200	0.00	
2	1150	0.590	0.652	0.00	
3	1151	0.969	1.432	0.00	
4	1152	1.424	2.629	0.00	
5	1153	2.043	4.362	0.00	Principal
5.5	1153.5	2.475	5.492	8.26	
6	1154	2.907	6.837	23.38	
6.5	1154.5	3.488	8.436	27.69	
7	1155	4.069	10.325	31.99	
7.5	1155.5	4.720	12.523	33.27	
8	1156	5.371	15.046	34.55	
8.5	1156.5	6.168	17.930	35.64	
9	1157	6.964	21.213	36.73	Auxiliary
9.5	1157.5	7.993	24.953	74.49	
10	1158	9.021	29.206	142.72	
10.5	1158.5	10.097	33.986	230.75	
11	1159	11.172	39.303	334.82	Top of Dam
11.5	1159.5	12.247	45.157	452.80	
12	1160	13.322	51.550	583.10	

Project:	Chickasaw County Site 3 Wetland
Drainage Area:	196 acres (includes area upstream of Site 2)
Description:	The principal spillway is a 24-inch pipe riser at 1140 ft MSL. The auxiliary spillway is a 40-foot crest at 1145 ft MSL (modeled as a broad crested weir).
Comment:	Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

Chickasaw County Site 3 Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1134	1,040	0	
1	1135	4,400	2,720	
2	1136	9,720	9,780	
3	1137	18,900	24,090	
4	1138	31,370	49,225	
5	1139	52,875	91,348	
6	1140	70,720	153,145	Principal
7	1141	92,275	234,643	
8	1142	115,860	338,710	
9	1143	142,600	467,940	
10	1144	178,440	628,460	
11	1145	214,080	824,720	Auxiliary
12	1146	259,540	1,061,530	
13	1147	313,650	1,348,125	Top of Dam

Chickasaw County Site 3 Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0.0	1134.0	0.024	0.000	0.00	
1.0	1135.0	0.101	0.062	0.00	
2.0	1136.0	0.223	0.225	0.00	
3.0	1137.0	0.434	0.553	0.00	
4.0	1138.0	0.720	1.130	0.00	
5.0	1139.0	1.214	2.097	0.00	
6.0	1140.0	1.624	3.516	0.00	Principal
6.5	1140.5	1.871	4.389	10.55	
7.0	1141.0	2.118	5.387	21.09	
7.5	1141.5	2.389	6.514	22.91	
8.0	1142.0	2.660	7.776	24.73	
8.5	1142.5	2.967	9.182	26.04	
9.0	1143.0	3.274	10.742	27.34	
9.5	1143.5	3.685	12.482	28.51	
10.0	1144.0	4.096	14.427	29.67	
10.5	1144.5	4.506	16.578	30.74	
11.0	1145.0	4.915	18.933	31.81	Auxiliary
11.5	1145.5	5.436	21.521	69.57	
12.0	1146.0	5.958	24.369	137.80	
12.5	1146.5	6.579	27.504	225.80	
13.0	1147.0	7.200	30.949	329.84	Top of Dam
13.5	1147.5	7.822	34.704	447.80	
14.0	1148.0	8.443	38.770	578.10	

Project: Chickasaw County Site 4 Wetland

Drainage Area: 139 acres

Description: The principal spillway is a 24-inch pipe riser at 1140 ft MSL. The auxiliary spillway is a 40-foot crest at 1144 ft MSL (modeled as a broad crested weir).

Comment: Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

Chickasaw County Site 4 Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1136	2,410	0	
1	1137	17,970	10,190	
2	1138	32,730	35,540	
2.01	1138.01	43,230	35,920	
3	1139	67,820	90,890	
4	1140	133,310	191,455	Principal
5	1141	148,350	332,285	
6	1142	169,900	491,410	
7	1143	202,330	677,525	
8	1144	241,170	899,275	Auxiliary
9	1145	288,500	1,164,110	
10	1146	339,740	1,478,230	Top of Dam

Chickasaw County Site 4 Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0	1136	0.055	0	0	
1	1137	0.413	0.234	0	
2	1138	0.751	0.816	0	
2.01	1138.01	0.992	0.825	0	
3	1139	1.557	2.087	0	
4	1140	3.06	4.395	0	Principal
4.5	1140.5	3.233	5.969	10.55	
5	1141	3.406	7.628	21.09	
5.5	1141.5	3.653	9.393	23.14	
6	1142	3.9	11.281	25.19	
6.5	1142.5	4.273	13.324	26.53	
7	1143	4.645	15.554	27.87	
7.5	1143.5	5.091	17.988	29.07	
8	1144	5.537	20.645	30.26	Auxiliary
8.5	1144.5	6.08	23.549	68.12	
9	1145	6.623	26.724	136.45	
9.5	1145.5	7.211	30.183	224.53	
10	1146	7.799	33.935	328.65	Top of Dam
10.5	1146.5	8.388	37.982	446.6	
11	1147	8.976	42.323	576.9	

Project:	Chickasaw County Site 5 Wetland
Drainage Area:	109 acres
Description:	The principal spillway is a 36-inch pipe riser at 1127 ft MSL. The auxiliary spillway is a 40-foot crest at 1129 ft MSL (modeled as a broad crested weir).
Comment:	Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

Chickasaw County Site 5 Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)
0	1123	5,240	0
1	1124	15,630	10,435
2	1125	28,390	32,445
2.01	1125.01	33,610	32,755
3	1126	55,530	76,879
4	1127	125,180	167,234
5	1128	148,500	304,074
6	1129	169,210	462,929
7	1130	195,170	645,119
8	1131	231,850	858,629

Chickasaw County Site 5 Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0	1123	0.12	0	0	
1	1124	0.359	0.24	0	
2	1125	0.652	0.745	0	
2.01	1125.01	0.772	0.752	0	
3	1126	1.275	1.765	0	
4	1127	2.874	3.839	0	Principal
4.5	1127.5	3.141	5.343	18.42	
5	1128	3.409	6.981	36.83	
5.5	1128.5	3.647	8.745	52.9	
6	1129	3.885	10.627	68.97	Auxiliary
6.5	1129.5	4.183	12.644	110.86	
7	1130	4.480	14.810	183.21	
7.5	1130.5	4.902	17.155	274.16	
8	1131	5.323	19.711	381.15	Top of Dam
8.5	1131.5	5.744	22.478	501.99	
9	1132	6.165	25.455	635.19	

Project:	Chickasaw County Site 6 Wetland
Drainage Area:	292 acres
Description:	The principal spillway is a 72-inch pipe riser at 1109 ft MSL. The auxiliary spillway is a 50-foot crest at 1112 ft MSL (modeled as a broad crested weir).
Comment:	Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

Chickasaw County Site 6 Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1103	1,160	0	
1	1104	12,830	6,995	
2	1105	33,310	30,065	
3	1106	63,615	78,528	
4	1107	93,660	157,165	
5	1108	123,780	265,885	
6	1109	167,910	411,730	Principal
7	1110	207,780	599,575	
8	1111	243,620	825,275	
9	1112	282,620	1,088,395	Auxiliary
10	1113	326,270	1,392,840	
11	1114	377,760	1,744,855	Top of Dam

Chickasaw County Site 6 Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0	1103	0.027	0.000	0	
1	1104	0.295	0.161	0	
2	1105	0.765	0.690	0	
3	1106	1.460	1.803	0	
4	1107	2.150	3.608	0	
5	1108	2.842	6.104	0	
6	1109	3.855	9.452	0	Principal
6.5	1109.5	4.312	11.494	37.15	
7	1110	4.770	13.764	74.29	
7.5	1110.5	5.181	16.252	142.21	
8	1111	5.593	18.946	210.13	
8.5	1111.5	6.040	21.854	280.82	
9	1112	6.488	24.986	351.51	Auxiliary
9.5	1112.5	6.989	28.355	411.86	
10	1113	7.490	31.975	510.28	
10.5	1113.5	8.081	35.868	631.69	
11	1114	8.672	40.056	773.15	Top of Dam
11.5	1114.5	9.263	44.540	931.92	
12	1115	9.854	49.320	1106.15	

Project:	CREP Site Floyd County 961502 B (Wohlers)
Drainage Area:	648 acres
Description:	The principal spillway 44-foot weir at 1127 ft MSL. The auxiliary spillway is a 25-foot crest at 1130 ft MSL (modeled as a broad crested weir).
Comment:	Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

CREP Site Floyd County 961502 B (Wohlers) Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1121	0	0	
1	1122	871	436	
2	1123	8,276	5,009	
3	1124	41,382	29,838	
4	1125	103,237	102,148	
5	1126	185,130	246,331	
6	1127	295,337	486,565	Principal
7	1128	393,782	831,124	
8	1129	503,118	1,279,574	
9	1130	652,964	1,857,615	Auxiliary
10	1131	787,822	2,578,008	Top of Dam

CREP Site Floyd County 961502 B (Wohlers) Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0.0	1121.0	0.000	0.000	0	
1.0	1122.0	0.020	0.010	0	
2.0	1123.0	0.190	0.115	0	
3.0	1124.0	0.950	0.685	0	
4.0	1125.0	2.370	2.345	0	
5.0	1126.0	4.250	5.655	0	
6.0	1127.0	6.780	11.170	0	Principal
6.5	1127.5	7.910	14.842	40.45	
7.0	1128.0	9.040	19.080	114.40	
7.5	1128.5	10.295	23.914	210.17	
8.0	1129.0	11.550	29.375	323.57	
8.5	1129.5	13.270	35.580	452.21	
9.0	1130.0	14.990	42.645	594.44	Auxiliary
9.5	1130.5	16.538	50.527	772.06	
10.0	1131.0	18.086	59.183	980.20	Top of Dam
10.5	1131.5	19.634	68.613	1211.47	
11.0	1132.0	21.182	78.817	1462.88	

Project:	CREP Site Floyd County 961502 D (Knapp)
Drainage Area:	548 acres
Description:	The principal spillway 30-foot weir at 1117 ft MSL. The auxiliary spillway is a 25-foot crest at 1120 ft MSL (modeled as a broad crested weir).
Comment:	Hydraulic design with AutoCAD Civil 3D Hydraflow Hydrographs Extension.

CREP Site Floyd County 961502 D (Knapp) Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1117	246,550	0	Principal
1	1118	327,700	287,125	
2	1119	422,968	662,459	
3	1120	530,996	1,139,441	Auxiliary
4	1121	642,074	1,725,976	Top of Dam

CREP Site Floyd County 961502 D (Knapp) Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0.0	1117.0	5.660	0.000	0	Principal
0.5	1117.5	6.591	3.063	32.88	
1.0	1118.0	7.523	6.591	93.00	
1.5	1118.5	8.616	10.626	170.85	
2.0	1119.0	9.710	15.208	263.04	
2.5	1119.5	10.950	20.373	367.61	
3.0	1120.0	12.190	26.158	483.24	Auxiliary
3.5	1120.5	13.465	32.572	631.94	
4.0	1121.0	14.740	39.623	809.00	Top of Dam
4.5	1121.5	16.015	47.312	1007.19	
5.0	1122.0	17.290	55.638	1223.62	

Project:	Wohlers Pond
Drainage Area:	69 acres
Description:	The principal spillway an 8-inch PVC pipe at 1120 ft MSL. The auxiliary spillway is a 10-foot crest at 1121.5 ft MSL (modeled as a broad crested weir).
Comment:	IFC created rating using orifice and weir flow equations.

Wohlers Pond Wetland: Elevation-area-storage data from design documentation.

Stage (ft)	Elevation (ft)	Area (ft^2)	Storage (ft^3)	
0	1111	0	0	
9	1120	117,612	--	Principal

Wohlers Pond Wetland: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Elev (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0.0	1111.0	0.00	0.000	0	
2.0	1113.0	0.60	0.600	0	
4.0	1115.0	1.20	2.400	0	
6.0	1117.0	1.80	5.400	0	
8.0	1119.0	2.40	9.600	0	
9.0	1120.0	2.70	12.150	0	Principal
9.5	1120.5	2.85	13.538	1.89	
10.0	1121.0	3.00	15.000	2.67	
10.5	1121.5	3.15	16.538	3.78	Auxiliary
11.0	1122.0	3.30	18.150	23.02	
11.5	1122.5	3.45	19.838	57.35	
12.0	1123.0	3.60	21.600	101.51	
12.5	1123.5	3.75	23.438	153.63	
13.0	1124.0	3.90	25.350	212.62	
13.2	1124.2	3.96	26.136	237.97	Top of Dam
14.0	1125.0	4.20	29.400	348.51	

Project: Hypothetical Wetlands for Scenarios

Drainage Area: Approximately 160 acres

Description: The principal spillway is a 24-inch pipe riser at a stage of 4 feet. The auxiliary spillway is a 40-foot crest at a stage of 6 feet (modeled as a broad crested weir).

Comment: The stage-storage relationship was assumed to be the average stage-storage for the Chickasaw Sites 2 and 4. The same principal and auxiliary spillways used at those structure were assumed for the wetland outlets.

Hypothetical Wetlands for Scenarios: Elevation-storage-discharge information developed by IFC for hydrologic models.

Stage (ft)	Area (acre)	Storage (acre-feet)	Discharge (cfs)	
0	2.552	0.000	0	
0.5	2.854	1.351	8.26	
1	3.156	2.854	23.38	
1.5	3.571	4.536	27.69	
2	3.985	6.425	31.99	
2.5	4.496	8.545	33.27	
3	5.008	10.921	34.55	
3.5	5.629	13.580	35.64	
4	6.250	16.550	36.73	Principal
4.5	7.036	19.872	74.49	
5	7.822	23.587	142.72	
5.5	8.654	27.706	230.75	
6	9.486	32.240	334.82	Auxiliary
6.5	10.317	37.191	452.80	
7	11.149	42.558	583.10	Top of Dam

Appendix B – Top Simulated Flood Event Severity and Wetland Peak Reduction

We mapped the magnitude and extent of simulated flood events in the Beaver Creek Watershed using a *flood severity index*. The index is the ratio of the peak discharge to the mean annual flood at that location. Since the mean annual flood is a rough measure of the bankfull discharge, a flood severity of 1 or greater is an indicator of a flood. The flood severity index map for the largest simulated flood (July 1999) is shown in Figure 6.5. The flood severity index map for the second largest simulated flood (August 1979) is shown in Figure 6.6. Maps for the third (June 1998), fourth (August 1980), and fifth (August 1993) largest simulated events are shown below.

The nine wetland projects reduce peak discharge at their outlets and further downstream. The peak reduction for the largest simulated flood (July 1999) is shown in Figure 6.10. The flood severity index map for the second largest simulated flood (August 1979) is shown in Figure 6.13. Maps for the third (June 1998), fourth (August 1980), and fifth (August 1993) largest simulated events are shown below.

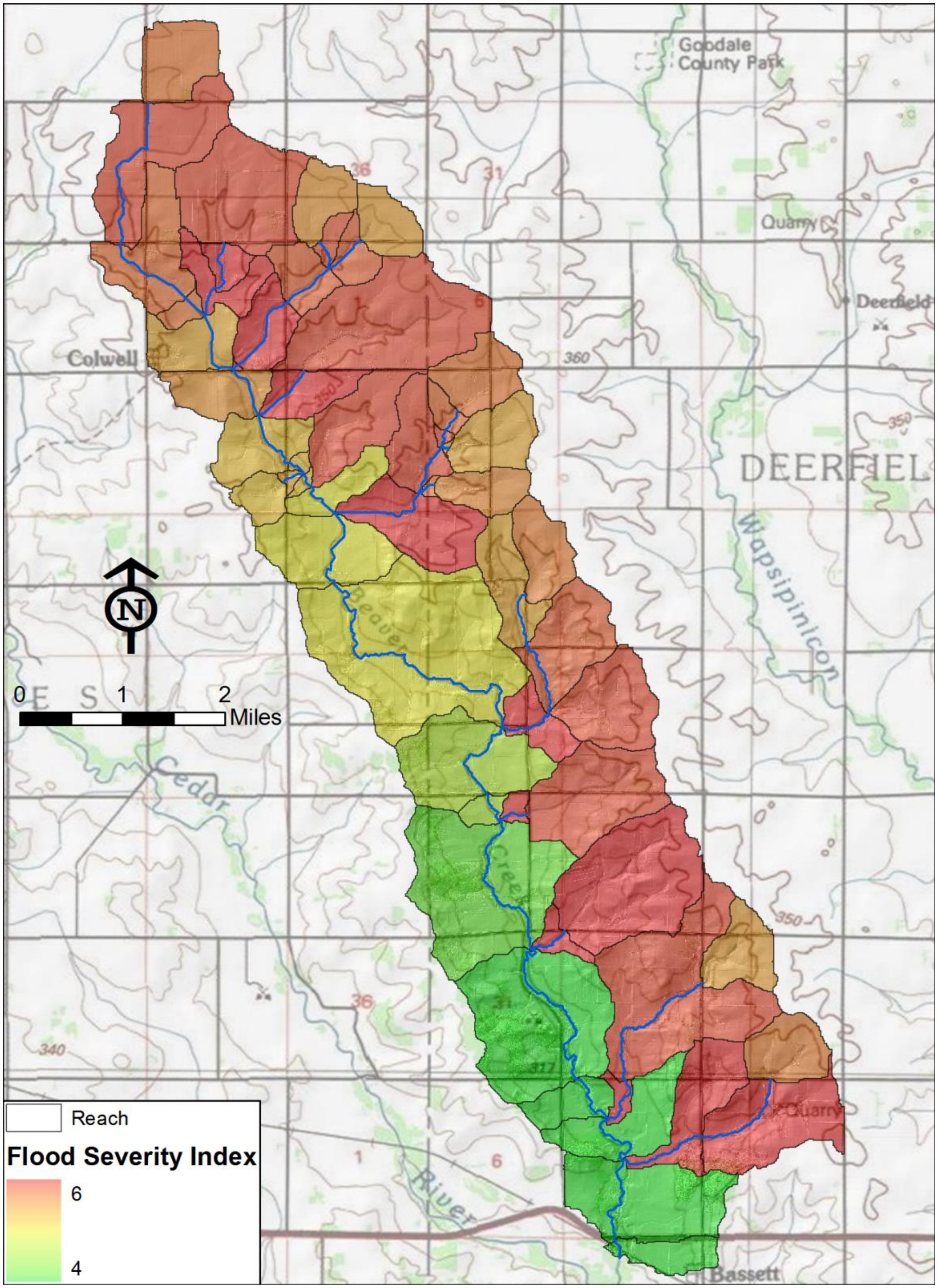


Figure B.1: Flooding intensity and extent for the June 1998 flood. The map shows the estimated flood severity index at each sub-basin outlet. Redder colors indicate a higher flood intensity.

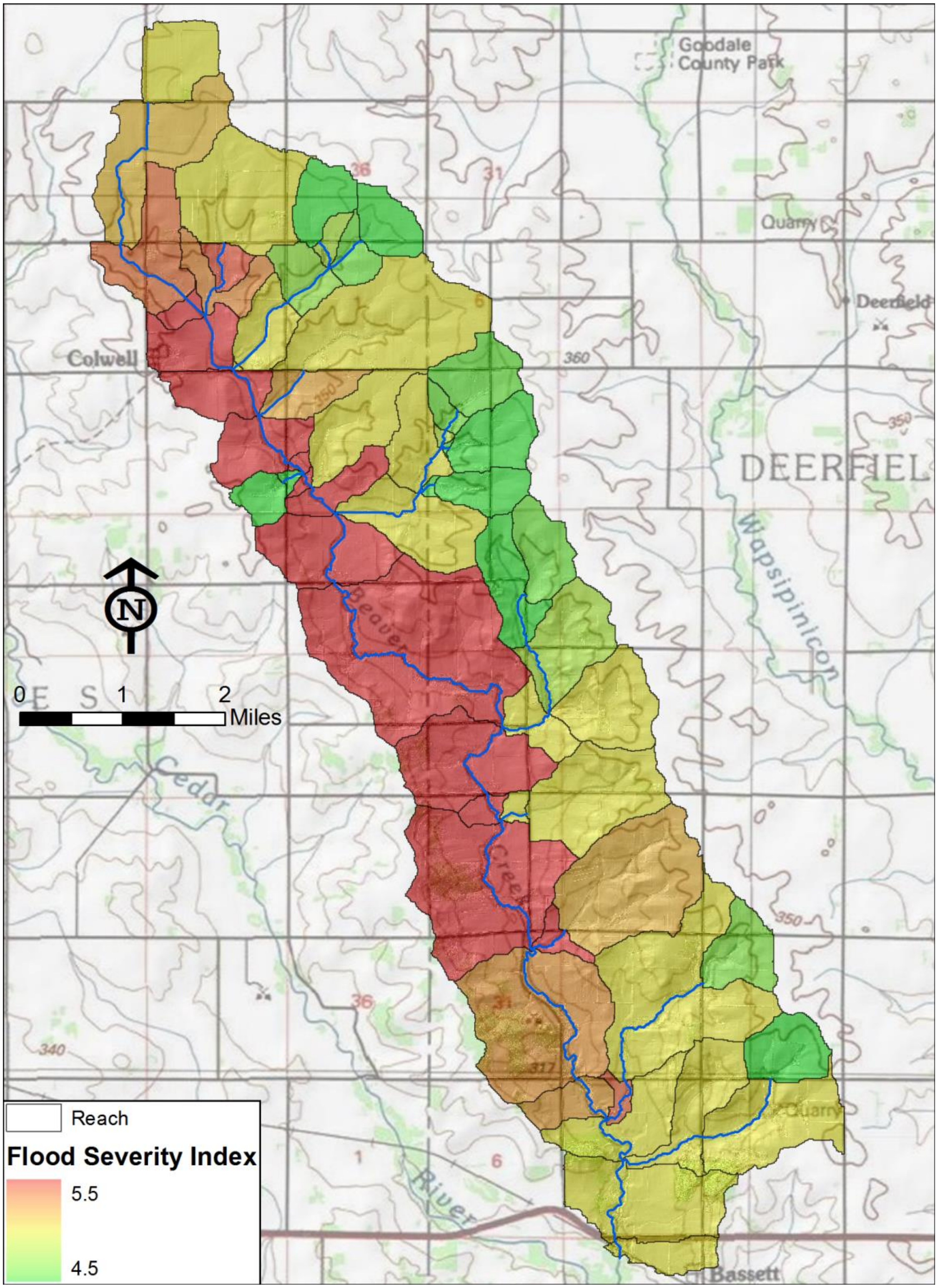


Figure B.2: Flooding intensity and extent for the August 1980 flood. The map shows the estimated flood severity index at each sub-basin outlet. Redder colors indicate a higher flood intensity.

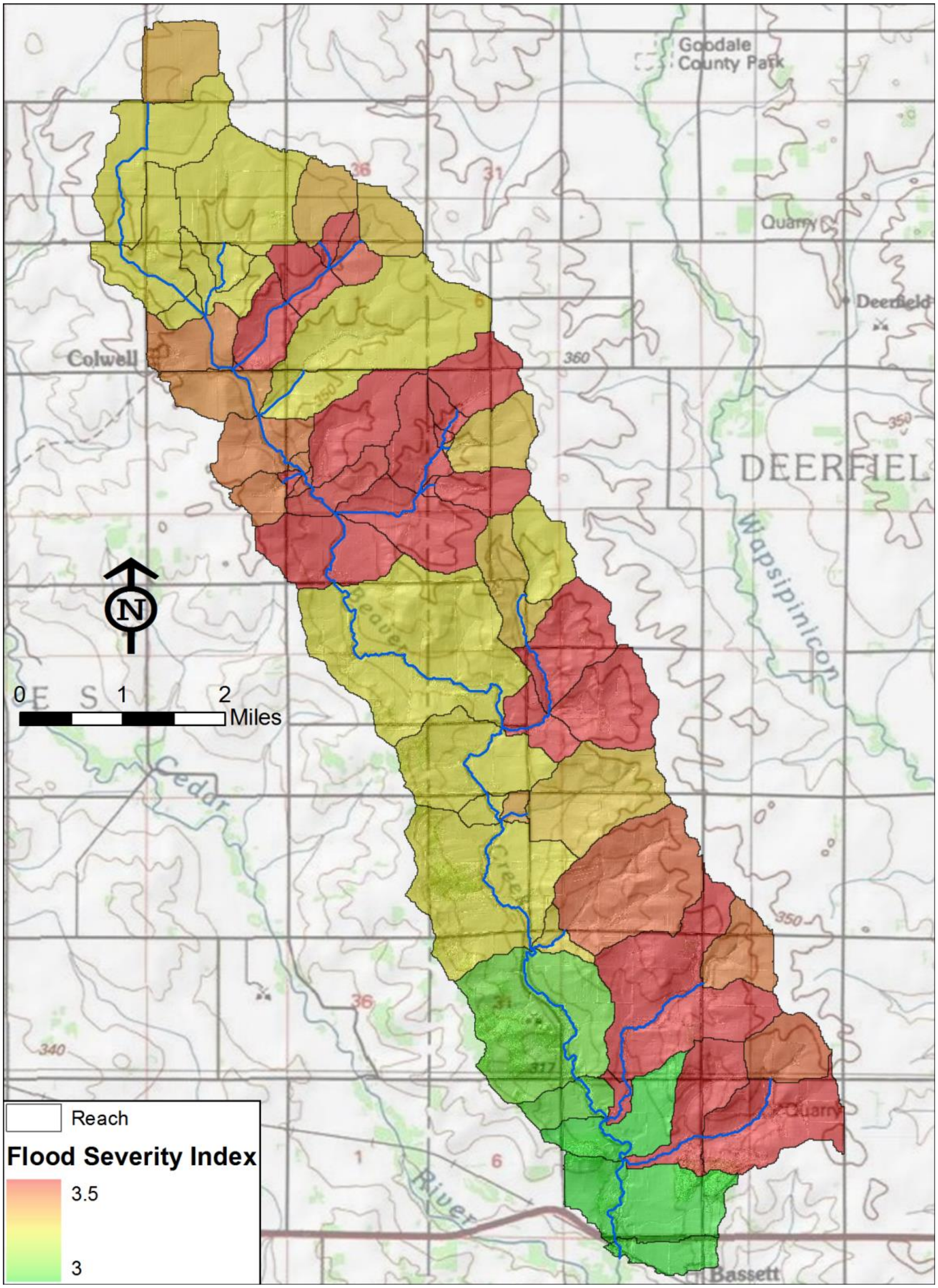


Figure B.3: Flooding intensity and extent for the August 1993 flood. The map shows the estimated flood severity index at each sub-basin outlet. Redder colors indicate a higher flood intensity.

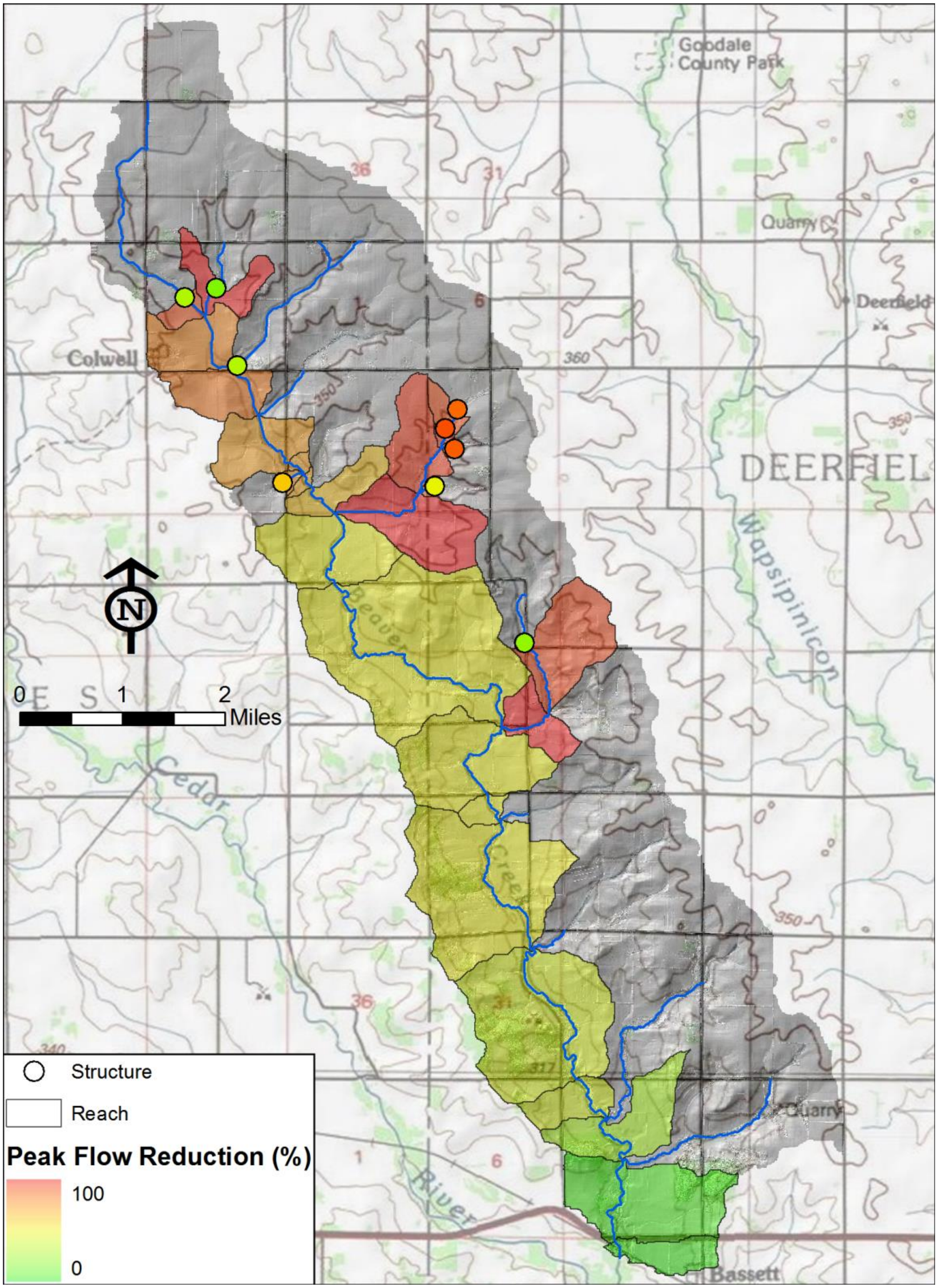


Figure B.4: Peak reduction (%) for the June 1998 flood with the nine wetland projects. The map shows the estimated peak reduction at each sub-basin outlet compared to the baseline simulation without wetlands. Redder colors indicate a higher peak reduction.

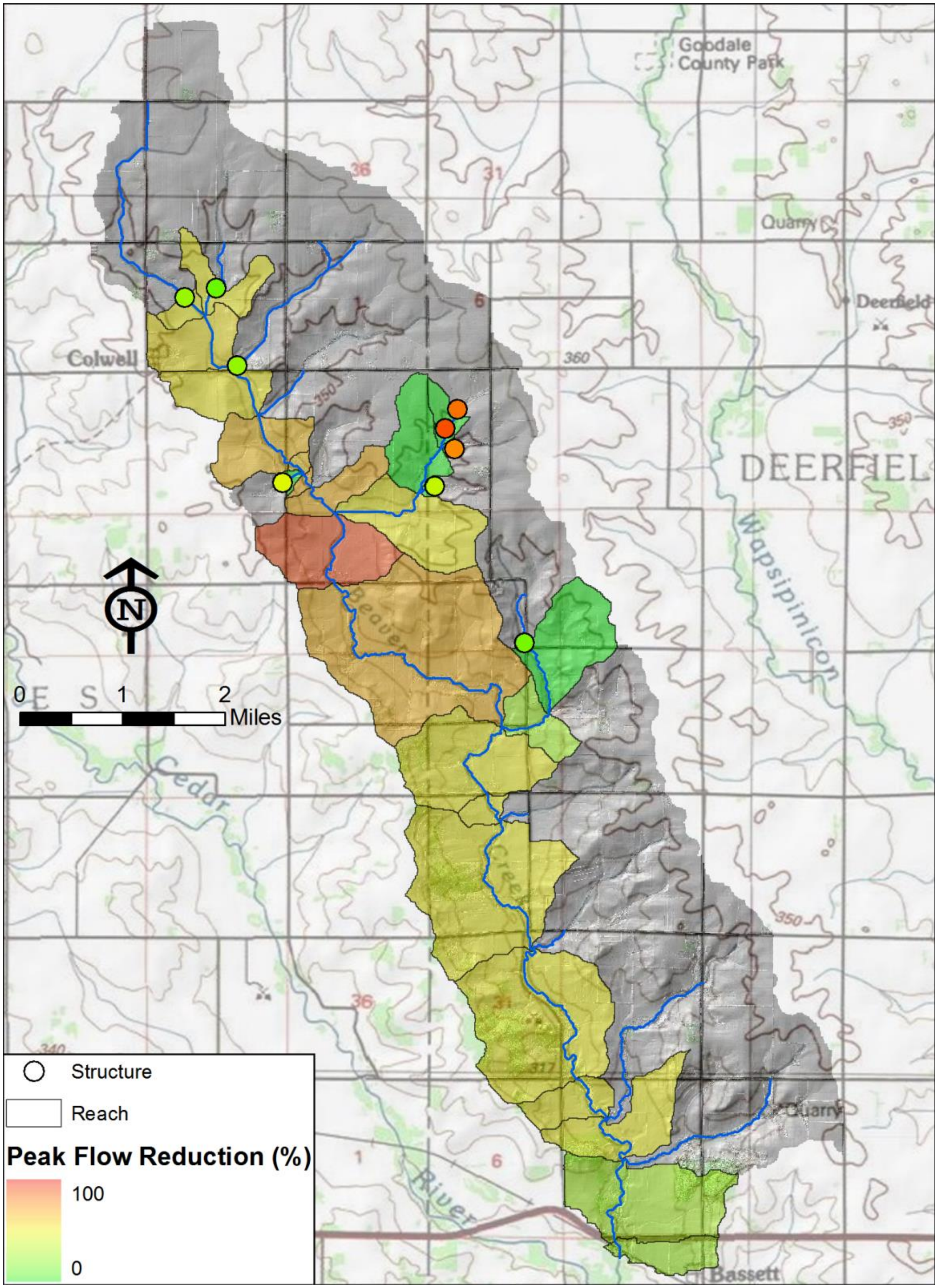


Figure B.5: Peak reduction (%) for the August 1980 flood with the nine wetland projects. The map shows the estimated peak reduction at each sub-basin outlet compared to the baseline simulation without wetlands. Redder colors indicate a higher peak reduction.

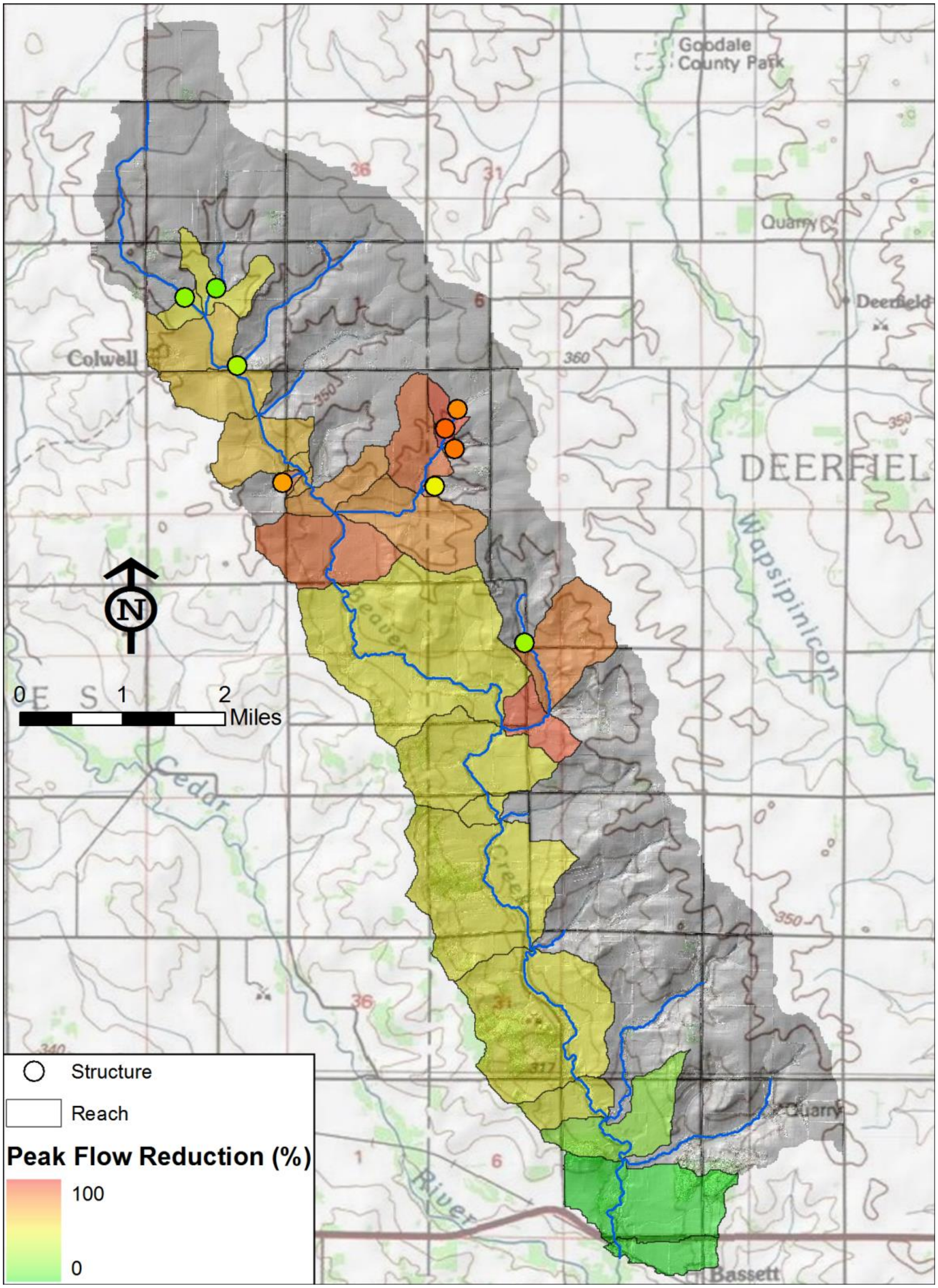


Figure B.6: Peak reduction (%) for the August 1993 flood with the nine wetland projects. The map shows the estimated peak reduction at each sub-basin outlet compared to the baseline simulation without wetlands. Redder colors indicate a higher peak reduction.

Appendix C – References

Ajami, H., M. F. McCabe, and J. P. Evans, 2015: Impacts of model initialization on an integrated surface water-groundwater model. *Hydrological Processes*, 29 (17), 3790–3801, doi:10.1002/hyp.10478.

Benning, J., D. Herzmann, C. Ingels, and A. Wilke, 2013: Agriculture and Weather Variability in the Corn Belt: Northeast Iowa. SustainableCorn.org: Crops, Climate, Culture, and Change, Iowa State University, USDA-NIFA Award No. 2011-68002-30190, URL http://sustainablecorn.org/Weather-and-Ag/Pubs/IA-Northeast.pdf.

Bicknell, B., J. Imhoff, J. Kittle, Jr., T. Jobes, and A. Donigian, Jr., 2005: HSPF Version 12.2 User's Manual. AQUA TERRA Consultants, Mountain View, Calif., in cooperation with the Office of Surface Water, U.S. Geological Survey, Reston, Virginia, and the National Exposure Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia.

Bradley, A. A., A. KC, N. P. Leach, and R. Tokuhisa, 2015: Hydrologic Modeling of the English River Watershed. IIHR Technical Report No. 494, Iowa Flood Center, IIHR–Hydroscience & Engineering.

Brunner, P. and C. T. Simmons, 2012: HydroGeoSphere: A fully integrated, physically based hydrological model. *Ground Water*, 50 (2), 170–176, doi: 10.1111/j.1745-6584.2011.00882.x.

Donigian, A., Jr., D. Baker, D. Haith, and M. Walter, 1983: HSPF Parameter Adjustments to Evaluate the Effects of Agricultural Nest Management Practices. U.S. Environmental Protections Agency, Environmental Research Laboratory, Athens, Georgia, EPA Contract No. 68-03-2895, PB- 83-247171.

Donigian, A., Jr., J. Imhoff, B. Bicknell, and J. Kittle, Jr., 1984: Application Guide for the Hydrological Simulation Program - FORTRAN. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, EPA/600/3-84-066.

Environmental Protection Agency, 2010: Cedar River Watershed Total Maximum Daily Load. Report, EPA Region 7.

Fry, J., et al., 2011: Completion of the 2006 National Land Cover Database for the conterminous United States. *Photogrammetric Engineering and Remote Sensing*, 77 (9), 858–864.

High Plains Regional Climate Center, 2015: Crop coefficients for corn. URL http://www.hprcc.unl.edu/awdn.php.

Hoyt, W. G., and others, 1936: Studies of relations of rainfall and run-off in the United States. U.S. Geological Survey, Water-Supply Paper 772, Washington, D.C.

Hutchinson, K. and D. Christiansen, 2013: Use of the Soil and Water Assessment Tool (SWAT) for Simulating Hydrology and Water Quality in the Cedar River Basin, Iowa, 2000-10. U.S. Geological Survey Scientific Investigations Report 2013-5002, 36 pp.

Iowa Flood Center, 2014: Hydrologic Assessment of the Upper Cedar River Watershed. IIHR Technical Report No. 489, IIHR–Hydroscience & Engineering.

Iowa Geological and Water Survey, 2010: One meter digital elevation model of Iowa. Iowa Department of Natural Resources, URL https://programs.iowadnr.gov/nrgislibx/.

Iowa Geological and Water Survey, 2013: Landform Regions of Iowa. Iowa Department of Natural Resources, URL http://www.igsb.uiowa.edu/browse/landform.htm.

Iowa Geological and Water Survey, 2015: Geosam. URL https://geosam.iihr.uiowa.edu/home.

Iowa State University, 2015: Legacy ISU AgClimate Network. URL https://mesonet.agron.iastate.edu/agclimate/.

Kang, S. Z., B. J. Gu, T. S. Du, and J. H. Zhang, 2003: Crop coefficient and ratio of transpiration to evapotranspiration of winter wheat and maize in a semi-humid region. *Agricultural Water Management*, 59 (3), 239–254, doi:10.1016/s0378-3774(02)00150-6.

Kristensen, K. J. and S. E. Jensen, 1975: A model for estimating actual evapotranspiration from potential evapotranspiration. *Nordic Hydrology*, 6 (3), 170–188.

Li, Q., A. J. A. Unger, E. A. Sudicky, D. Kassenaar, E. J. Wexler, and S. Shikaze, 2008: Simulating the multi-seasonal response of a large-scale watershed with a 3D physically-based hydrologic model. *Journal of Hydrology*, 357 (3-4), 317–336, doi:10.1016/j.jhydrol.2008.05.024.

Love, J. T. and T. P. Whitney, 2008: The Cedar River basin pathogen total maximum daily load – A case study for watershed-scale total maximum daily loads. American Society of Civil Engineers, World Environmental and Water Resources Congress 2008 Ahupua'a, CC-325A TMDLs and Non-Point Sources.

McDonald, J., 1961: On the ratio of evaporation to precipitation. *American Meteorological Society Bulletin*, 42 (3), 185–189.

Natural Resource Conservation Service, 2004a: Chapter 11 Snowmelt. Part 630 Hydrology, National Engineering Handbook. U.S. Department of Agriculture. URL http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch11.pdf.

Natural Resource Conservation Service, 2004b: Soil moisture/soil temperature pilot project. U.S. Department of Agriculture.

Natural Resource Conservation Service, 2009: Chapter 7 Hydrology. Part 630 Hydrology, National Engineering Handbook. U.S. Department of Agriculture. URL http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch7.pdf.

Natural Resource Conservation Service, 2015: Soil Climate Analysis Network (SCAN). U.S. Department of Agriculture, URL http://www.wcc.nrcs.usda.gov/scan/.

Perica, S., D. Martin, D., S. Pavlovic, I. Roy, M. St. Larent, C. Trypaluk, D. Unruh, M. Yekta, and G. Bonnin, 2013: NOAA Atlas 14, Precipitation- Frequency Atlas of the United States. National Weather Service, URL http://hdsc.nws.noaa.gov/hdsc/pfds/index.html, 297 pp.

PRISM Climate Group, 2016: Oregon State University, URL http://prism.oregonstate.edu.

RESPEC, 2007: Work plan for the Cedar River Basin Project. RSI-WP-01, Prepared by RESPEC, Rapid City, SD, for Iowa Department of Natural Resources, Des Moines, IA.

Sanford, W. E. and D. L. Selnick, 2013: Estimation of evapotranspiration across the conterminous United States using a regression with climate and land-cover data 1. *Journal of the American Water Resources Association*, 49 (1), 217–230, doi:10.1111/jawr.12010.

Schaefer, G. L., M. H. Cosh, and T. J. Jackson, 2007: The USDA Natural Re- sources Conservation Service Soil Climate Analysis Network (SCAN). *Journal of Atmospheric and Oceanic Technology*, 24 (12), 2073–2077, doi:10.1175/2007JTECHA930.1.

Schilling, K. E., 2005: Relation of baseflow to row crop intensity in Iowa. *Agriculture Ecosystems & Environment*, 105 (1-2), 433–438, doi:10.1016/j. agee.2004.02.008.

Schilling, K. E., M. K. Jha, Y.-K. Zhang, P. W. Gassman, and C. F. Wolter, 2008: Impact of land use and land cover change on the water balance of a large agricultural watershed: Historical effects and future directions. *Water Resources Research*, 44 (7), W00A09, doi:10.1029/2007WR006644.

Schilling, K. E. and R. D. Libra, 2003: Increased baseflow in Iowa over the second half of the 20th century. *Journal of the American Water Resources Association*, 39 (4), 851–860, doi:10.1111/j.1752-1688.2003.tb04410.x.

Schlesinger, W. H. and S. Jasechko, 2014: Transpiration in the global water cycle. *Agricultural and Forest Meteorology*, 189, 115–117, doi:10.1016/j. agrformet.2014.01.011.

Shuttleworth, W., 1993: *Evaporation*, Chapter 4, Handbook of Hydrology, D.R. Maidment (editor), 4.1–4.53. McGraw-Hill, New York.

Soil Survey Staff, 2014: Gridded Soil Survey Geographic (gSSURGO) Database for the United States of America and the Territories, Commonwealths, and Island Nations served by the USDA-NRCS. U.S. Department of Agriculture, Natural Resources Conservation Service, URL https://gdg.sc.egov.usda.gov/.

Wang, L. X., et al., 2013: The effect of warming on grassland evapotranspiration partitioning using laser-based isotope monitoring techniques. *Geochimica Et Cosmochimica Acta*, 111, 28–38, doi:10.1016/j.gca.2012.12.047.

Witzke, B. J., J. L. Anderson, and J. P. Pope, 2010: Estimated depth to bedrock of Iowa as a 110-meter pixel, 32-bit imagine format raster dataset. Iowa Department of Natural Resources, OFM-2010-1.