Hydrologic Assessment of the Middle Raccoon River Watershed

October 2014

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Table of Contents

List of Figures

List of Tables

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 – were formed locally to tackle local challenges with a unified watershed approach.

This assessment is part of the Iowa Watersheds Project, a project being undertaken in four watersheds across Iowa by the Iowa Flood Center located at IIHR—Hydroscience & Engineering on the University of Iowa campus, and is meant to provide the Middle South Raccoon River Watershed Management Authority, local leaders, landowners and watershed residents an understanding of the hydrology – movement of water – within the local watershed.

This assessment is part of the Iowa Watersheds Project, a project being undertaken in four watersheds across Iowa by the Iowa Flood Center located at IIHR—Hydroscience & Engineering on the University of Iowa campus and the respective watershed management authorities in each watershed.

A hydrologic model of the Middle Raccoon River watershed, using HEC-HMS, was used to identify areas in the watershed with high runoff potential and run simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed. Focus for the scenario development was placed 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.

The assessment is meant to provide local leaders, landowners and watershed residents in the Middle Raccoon River Watershed an understanding of the hydrology within the watershed and the potential impact of various hypothetical flood mitigation strategies. The hydrologic assessment provides watershed residents and community leaders an additional source of information and should be used in tandem with additional reports and watershed plans working to enhance the social, economic, and environmental sustainability and resiliency of the watershed.

1. Iowa's Flood Hydrology

This chapter illustrates some facts about Iowa's water cycle and flood hydrology. Historical records for precipitation and streamflow are examined to describe how much precipitation falls on Iowa watersheds, how that water moves through the landscape, when storms typically produce river flooding, and how Iowa's hydrology has changed over the past decades and century. As the context for this discussion, we examine the water cycle of the Middle Raccoon River Watershed, as well as that for the three other Iowa watersheds participating in the Iowa Watersheds Project (see Figure 1.1).

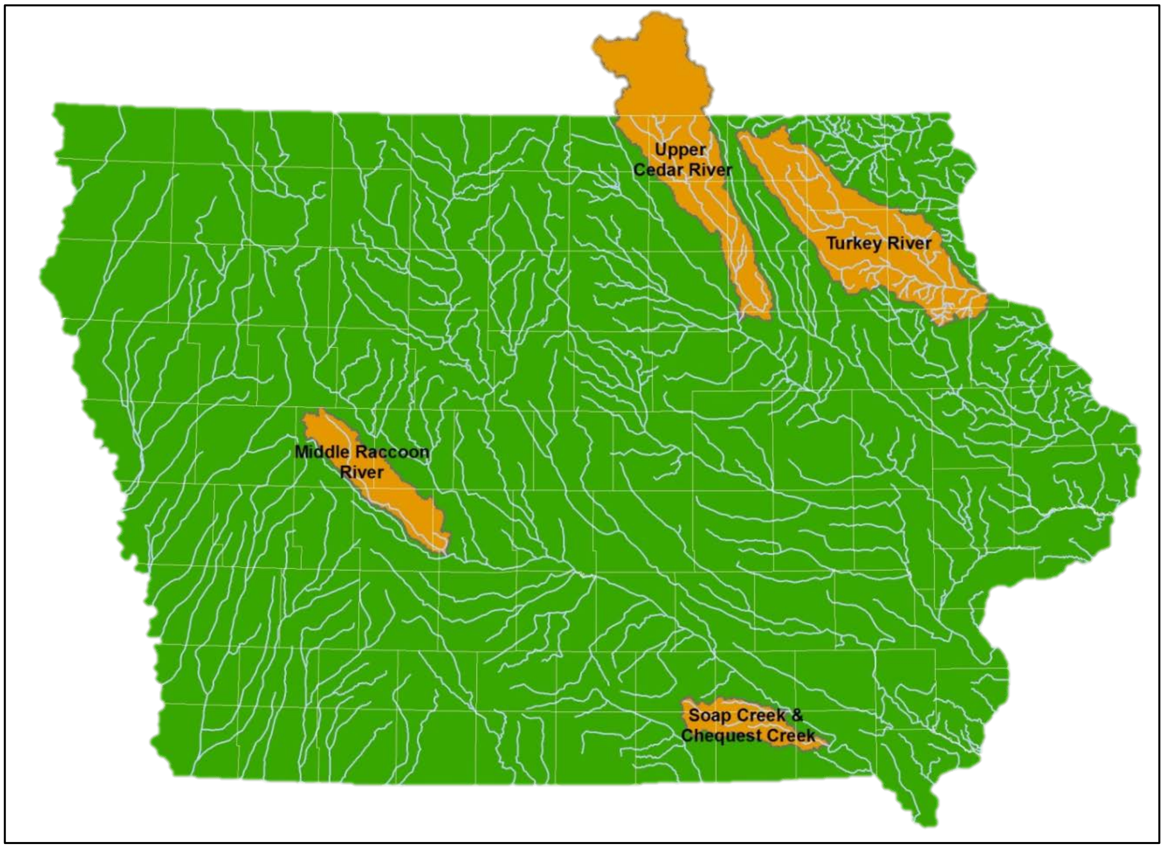


Figure 1.1. Iowa Watersheds Project Study Areas

The Upper Cedar begins in Minnesota, and drains 1,661 mi2 — mostly from the Iowa Surface landform (USGS 05458500 Cedar River at Janesville). The Turkey River (USGS 05412500 Turkey River at Garber) drains 1,545 mi2, and includes portions of the Iowa Surface and karst topography of the Paleozoic Plateau. The Middle Raccoon River drains 590 mi² (USGS 05483450 Middle Raccoon River near Bayard), and is located in the west-central part of the state. The upper part of the basin is located in flat terrain of the Des Moines Lobe, while the lower part is located within the Southern Iowa Drift Plain. Soap and Chequest Creeks in the southern part of the state are located in the Southern Iowa Drift Plain.

a. Hydrology in Iowa and the Iowa Watersheds Project Study Areas

i. Statewide Precipitation

Iowa's climate is marked by a smooth transition of annual precipitation from the southeast to the northwest (see Figure 1.2). The average annual precipitation reaches 40 inches in the southeast corner, and drops to 26 inches in the northwest corner. Of the four Iowa Watersheds Project study areas, Soap/Chequest along the southern border has the largest annual precipitation (38.8 inches), followed by the Turkey River (36.3 inches) and the Upper Cedar River (35.1 inches) in the northeast portion of the state, and then the Middle Raccoon (35.0 inches) in the western half of the state.

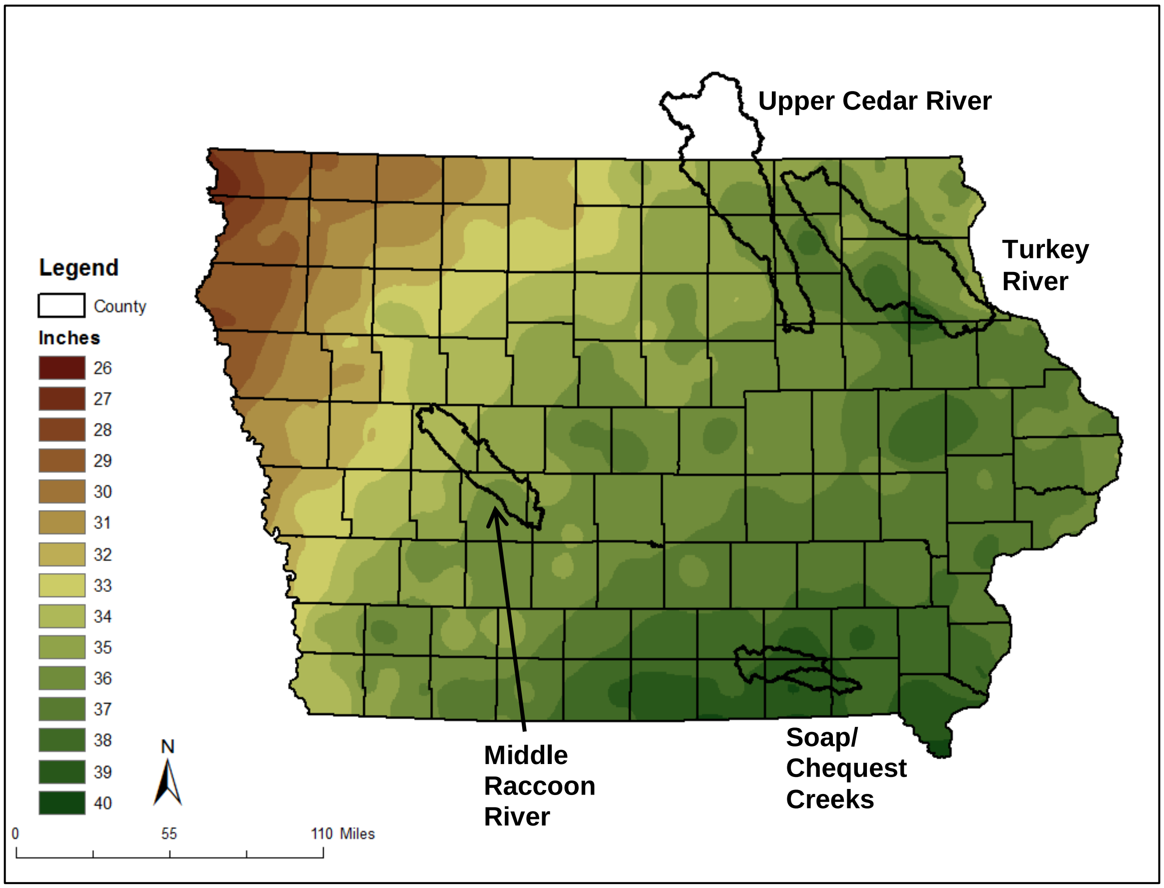


Figure 1.2. Average annual precipitation for Iowa. Precipitation estimates are based on the 30-year annual average (1981-2010) for precipitation gauge sites. Interpolation between gauge sites to an 800 m grid was done by the PRISM (parameter-elevation relationships on independent slopes model) method. (Data source: http://www.prism.oregonstate.edu/)

ii. The Water Cycle in Iowa

Of the precipitation that falls across the state, almost all of it evaporates into the atmosphere — either directly from lakes and streams, or by transpiration from crops and vegetation. What doesn't evaporate, drains into streams and rivers (see Table 1.1).

Table 1.1. Iowa water cycle for four watersheds. The table shows the breakdown of the average annual participation (100% of the water in each watershed).

	Precipitation (%)	*Evaporation (%)*	*Surface Flow (%)*	*Baseflow (%)*
Middle Raccoon	100	73.5	8.9	17.5
Upper Cedar	100	68.5	9.8	21.7
Turkey	100	69.4	9.0	21.6
Fox[1]	100	69.2	19.2	11.6

Evaporation

In Iowa, the majority of water leaves by evaporation; for the four Iowa watershed study areas, evaporation accounts for about 68% of precipitation in the Upper Cedar, and 69% in the Fox and Turkey Rivers. As one moves westward in the state, a larger fraction evaporates; for the Middle Raccoon, evaporation accounts for almost 74% of the precipitation

Surface Flow

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

Baseflow

The rest of the water that drains into streams and rivers takes a longer, slower path; first it infiltrates into the ground, percolates down to the groundwater, and then slowly moves towards a stream. The groundwater eventually reaches the stream, maintaining flows in a river even during extended dry periods. This portion of the flow is often called "baseflow".

A watershed's geology helps determine the partitioning of precipitation runoff into surface flow and baseflow. The Turkey River has the largest ratio of baseflow to surface flow (2.4): about 22% of precipitation leaves as baseflow, and 9% leaves as surface flow. Most likely, the karst limestone geology in portions of the watershed (with its enhanced surface drainage) contributes to a higher baseflow ratio. The ratio of baseflow to surface flow is slightly lower in the Upper Cedar (2.2), with its 22% baseflow and 10% surface flow, and the Middle Raccoon (2.0), with its 17% baseflow and 9% surface flow. For the Fox River, the partitioning is reversed; more water leaves as surface flow (19%) than as baseflow (12%), so its baseflow ratio is less than one (0.6). This region consists of

[1] Both Soap and Chequest Creek watersheds are ungauged, so historical records of streamflow are unavailable. However, the adjoining Fox River watershed, located directly south of Soap and Chequest Creek, has a long streamflow record (USGS 05495000 Fox River at Wayland, drainage area of 400 mi^2); we will use the flow records at the adjoining Fox River as an indicator of the hydrology in this portion of the state.

loess ridges and glacial till side slopes; steep slopes move water quickly to the valley, and those locations with flatter slopes typically contain high clay contents (42 to 48% in the subsoil) that limit infiltration in the ground. Figure 1.3 illustrates the water cycle components for the four Iowa watersheds, and clearly illustrates that the Fox is a more surface flow dominated river.

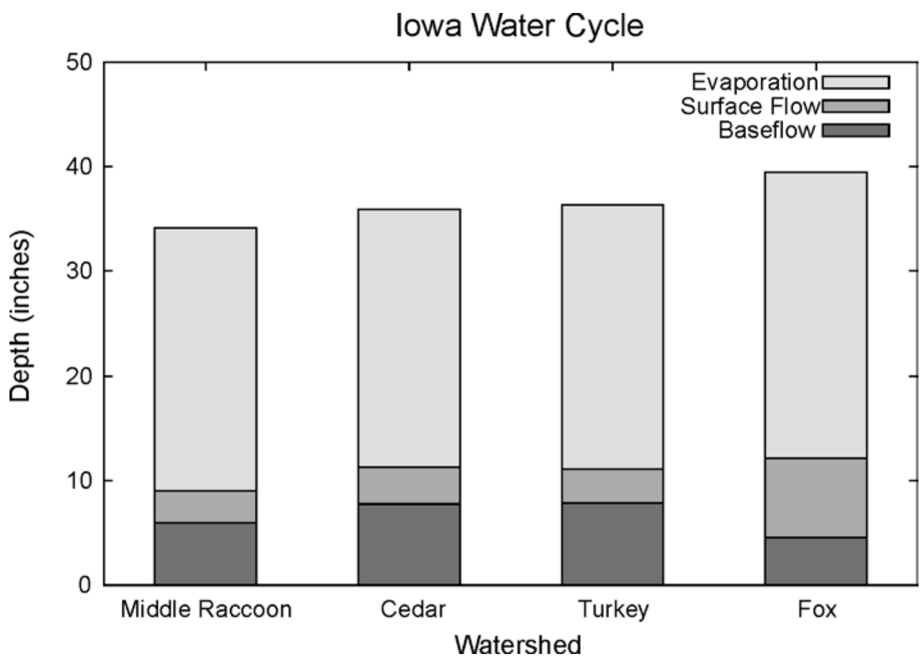


Figure 1.3. Iowa water cycle for four watersheds. The chart shows the partitioning of the average annual precipitation depth (in inches) into evaporation, surface flow, and baseflow components.[2]

[2] The average annual precipitation estimates are based on the 30-year averages for the state (see Figure 1.2). Flow records were obtained for USGS stream-gages for the same 30-year period (1981-2010); a continuous baseflow separation filter was used to estimate the surface flow and baseflow components. Evaporation was estimated by water budget analysis

iii. Monthly Water Cycle

Across the state, Iowa watersheds exhibit a similar cycle of average monthly precipitation and streamflow (see Figure 1.4). Precipitation is at its lowest in winter months; still, the precipitation is often in the form of snow, and can accumulate within the watershed until it melts (especially in the northernmost watersheds). Spring is marked by an increase in precipitation, the melting of any accumulated winter snow, and low evaporation before the growing season begins; these factors combine to produce high springtime streamflows.

Northern watersheds tend to see their peak average monthly streamflow in early spring (March or April), as snow accumulation and melt is more pronounced; southern watersheds tend to see their peak in late spring or summer (April and May). As crops and vegetation evaporate more and more water as we enter the summer months, moisture in the soil is depleted and the average monthly streamflow decreases (even though average monthly rainfall amounts are relatively high).

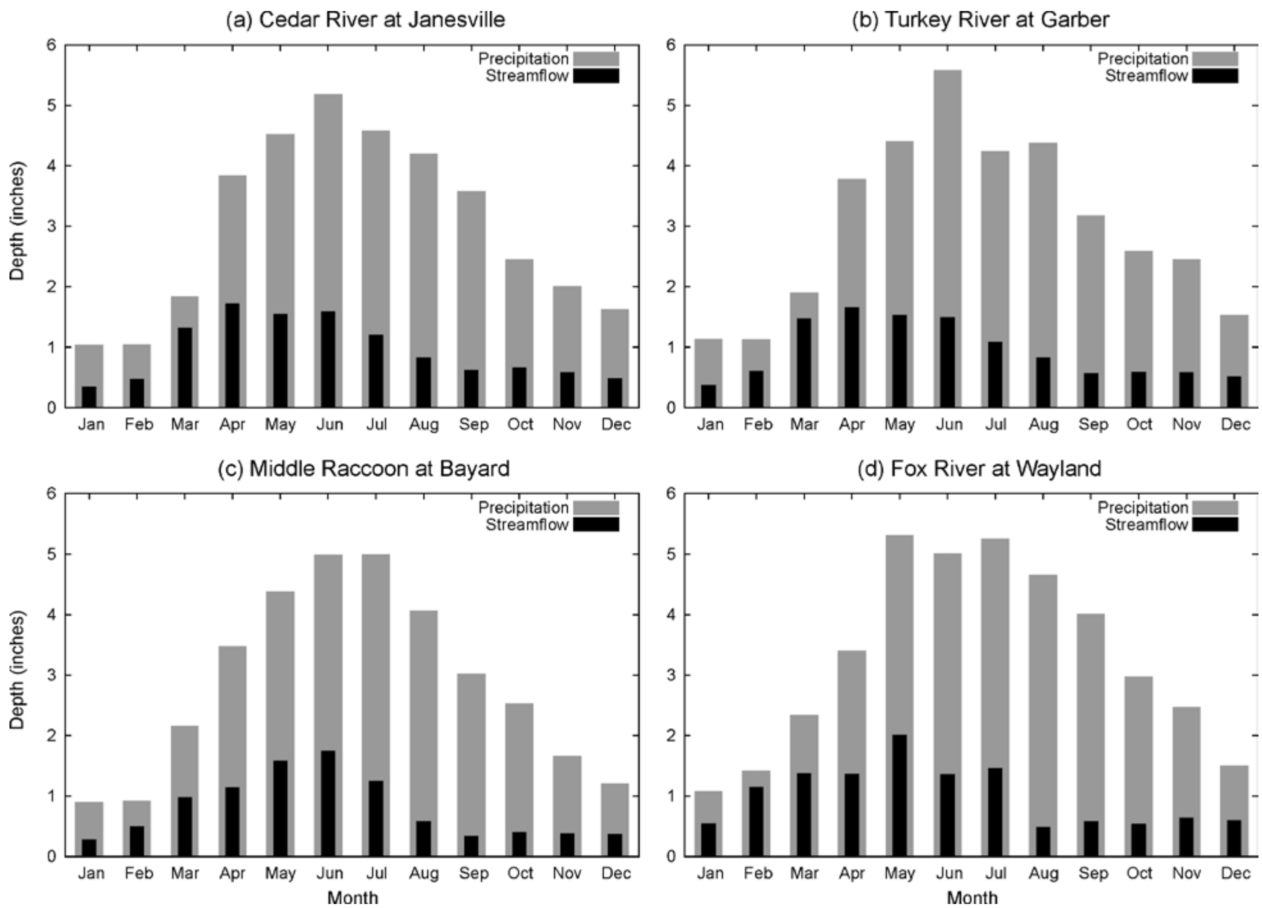


Figure 1.4. Monthly water cycle for four Iowa watersheds. The plots show the average monthly precipitation (in inches) and the average monthly streamflow (in inches). The average monthly estimates for precipitation and streamflow are based on the same 30-year period (1981-2010).

iv. Flood Climatology

The largest flows observed in Iowa's rivers follow a slightly different seasonal pattern. Figure 1.5 shows the annual maximum peak discharges (or the largest stream flow observed each year) and the calendar day of occurrence.

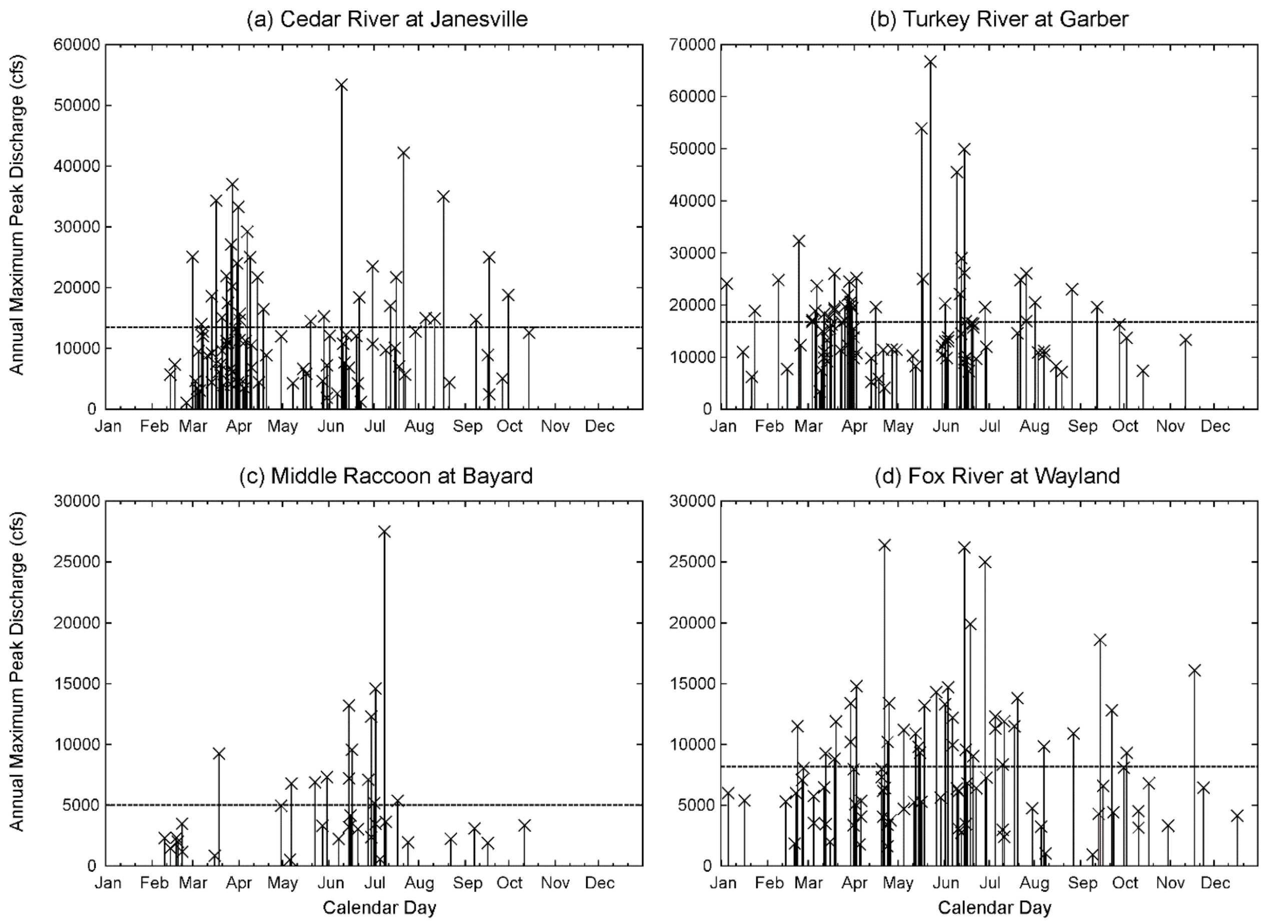


Figure 1.5. Annual maximum peak discharges and the calendar day of occurrence for four Iowa watersheds. The plots show all annual maximums for the period of record at four USGS stream-gage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and (d) Fox River at Wayland. The mean annual flood for each site is shown by the horizontal line.

For the northernmost watersheds (Cedar and Turkey), annual maximums often occur in March or April. These maximums may be associated with snow melt, rain on snow events, or heavy spring rains when soils are often near saturation. Still, the largest annual maximums all occurred in the summer season, when the heaviest rainstorms occur.

In contrast, the majority of all annual maximums occur in summer for the Middle Raccoon. For the Fox River, annual maximums are more evenly distributed throughout the year; as noted earlier, this river is surface flow dominated, and whenever heavy rainfall occurs during the year, large river flow can occur. Like the northernmost basins, both the Middle Raccoon and the Fox River see their largest annual maximums in the summer.

In addition to the annual maximums, Figure 1.5 also shows the mean annual flood for each river (the average of the annual maximums). For most rivers, the mean annual flood serves as a good approximate threshold for flooding. As can be seen, there are many years when the annual maximum peak discharge is not large enough to produce a flood. Figure 1.6 shows an estimate of the occurrence frequency for flood events (annual maximums that exceed the mean annual flood).

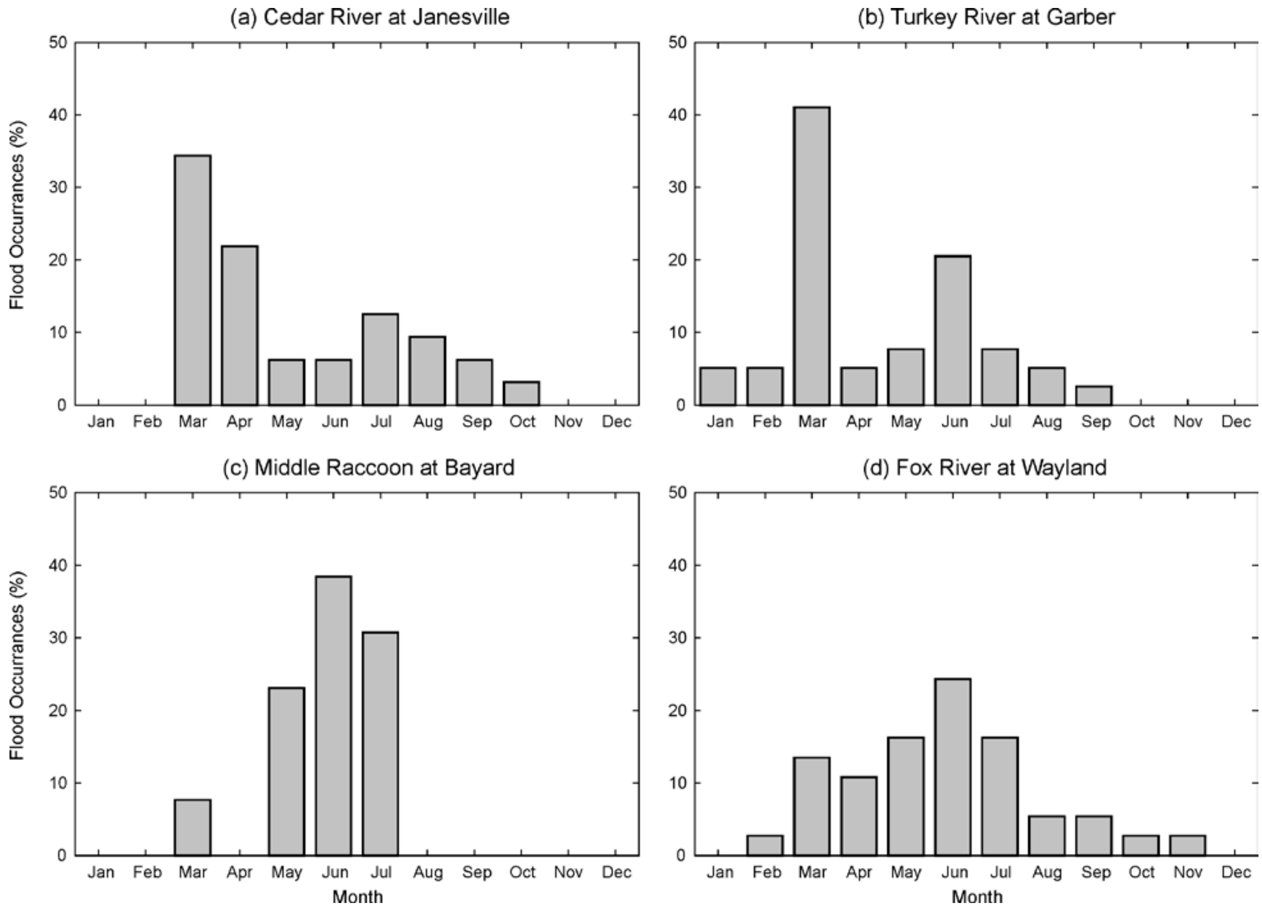


Figure 1.6. Annual maximum peak discharges and their month of occurrence for four Iowa watersheds. The plots show all annual maximums for the period of record at four USGS stream-gage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and (d) Fox River at Wayland. The mean annual flood for each site is shown by the horizontal line.

For the northernmost watersheds (Cedar and Turkey), the peak of flood occurrences is March. Both have a smaller secondary peak in summer. For the Middle Raccoon, nearly all the flood flows have occurred in late spring to early summer (May to July). Floods have occurred in all months except December and January in the Fox River watershed, although the peak flood occurrence is also in the late spring to early summer.

b. Hydrological Alterations and the Iowa Watersheds Project Study Areas

Although the hydrologic conditions presented for the Iowa Watersheds Project study areas illustrate the historical water cycle, the watersheds themselves are not static; historical changes have occurred that have altered the water cycle. In this section, we discuss the hydrological alterations of Iowa's watersheds, and look for evidence of these alterations in long-term streamflow records.

i. Hydrological Alterations from Agricultural-Related Land Use Changes

The Midwest, with its low-relief poorly-drained landscape, is one of the most intensively managed areas in the world (Pimentel, 2012). With European-descendent settlement, most of the land was transformed from low-runoff prairie and forest to higher-runoff farmland. Within Iowa, the land cover changes in the first decades of settlement occurred at an astonishing rate (Wehmeyer et al., 2011). Using land cover information obtained from well-documented studies in 1859, 1875, and 2001, Wehmeyer et al. (2011) estimated that the increase in runoff potential in the first thirty years of settlement represents the majority of predicted change in the 1832 to 2001 study period.

Still, other transformations associated with an agricultural landscape have also impacted runoff potential (see Table 1.2). For example, the introduction of conservation practices in the second half of the 20th century tend to reduce runoff, as suggested by a recent study of an Iowa watershed (Papanicolaou). The Conservation Reserve Program (CRP) originally began in 1950s. Many programs were established in 1970s to remove lands from agricultural production and establish native or alternative permanent vegetative cover; in an effort to reduce erosion and gulley formation, practices such as terraces, conservation tillages, and contour cropping were also encouraged. The Farm Bill of 1985 was the first act that officially established the CRP as we know it today, followed by expanded activities through the Bills of 1990, 1996, 2002, and 2008. The timeline of agriculture-driven land use changes and its impacts on local hydrology are summarized in Table 1.2.

Table 1.2. Agricultural-related alterations and hydrologic impacts.

Timeline	*Land use status, change & interventions*	*Hydrologic effect(s)*	*Source*
1830s - Prior	Native vegetation (tallgrass prairies and broad-leaved flowering plants) dominate the landscape	Baseflow dominated flows; slow response to precipitation events	Petersen (2010)
1830-1980	Continuous increase of agricultural production by replacement of perennial native vegetation with row crops 1940: <40% row crop (Raccoon) 1980: 75% row crop (statewide)	Elimination of water storage on the land; acceleration of the upland flow; expanded number of streams; increased stream velocity	Jones & Schilling (2011); Knox (2001)
1820-1930	Wetland drainage, stream channelization (straightening, deepening, relocation) leading to acceleration of the rate of change in channel positioning	Reduction of upland and in-stream water storage, acceleration of stream velocity	Winsor (1975); Thompson (2003); Urban & Rhoads (2003)
1890- 1960 2000-present	Reduction of natural ponds, potholes, wetlands; development of large-scale artificial drainage system (tile drains)	Decrease of water storage capacity, groundwater level fluctuations, river widening	Burkart (2010); Schottler et al. (2013)
1940-1980	Construction of impoundments and levees in Upper Mississippi Valley	Increased storage upland	Sayre (2010);
1950-present	Modernization/intensification of the cropping systems	Increased streamflow, wider streams	Zhang & Schilling (2006); Schottler et al. (2013)
1970-present	Conservation practices implementation: Conservation Reserve Program (CRP); Conservation Reserve Enhancement Program (CREP); Wetland Reserve Program (WRP)	Reduction of runoff and flooding; increase of upland water storage	Castle (2010); Schilling (2000); Schilling et al. (2008);
2002-present	62% of Iowa's land surface is intensively managed to grow crops (dominated by corn and soybeans up to 63% of total)	About 25% to 50% of precipitation converted to runoff (when tiling is present)	Burkart (2010)

ii. Hydrological Alterations Induced by Climate Change

Over periods ranging from decades to millions of years, Iowa has seen significant changes to its climate. Studies show that since the 1970s, Iowa and the Midwest have seen increases in annual and seasonal precipitation totals, and changes in the frequency of intense rain events and the seasonality of timing of precipitation (Takle, 2010). Large increases in runoff and flood magnitudes in the north central U.S. (including Iowa) have prompted scientific inquiries to unequivocally attribute these changes to driving factors (Ryberg et al., 2012). Although recent agricultural land use changes, such as the transition from perennial vegetation to seasonal crops, is an important driver (Schilling et al, 2008; Zhang and Schilling, 2006), other investigations show that climate-related drivers may be an equal or more significant contributor to recent hydrologic trends (Ryberg et al., 2012; Frans et al, 2013).

iii. Hydrological Alterations Induced by Urban Development

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

iv. Detecting Streamflow Changes in Iowa's Rivers

Hydrologic alterations in Iowa watersheds were tested through the analysis of changes in the long-term flow at the stream-gaging sites. The identification of statistically significant shifts in the flow time series was made using the approach developed by Villarini et al. (2011). Figure 7 shows the results of the analysis for mean daily discharge for the four Iowa watersheds. Note that stream-gage record for the Middle Raccoon River at Bayard does not begin until 1980, so analysis results are shown for the downstream stream-gage for the Raccoon River at Van Meter, where the record spans 96 years.

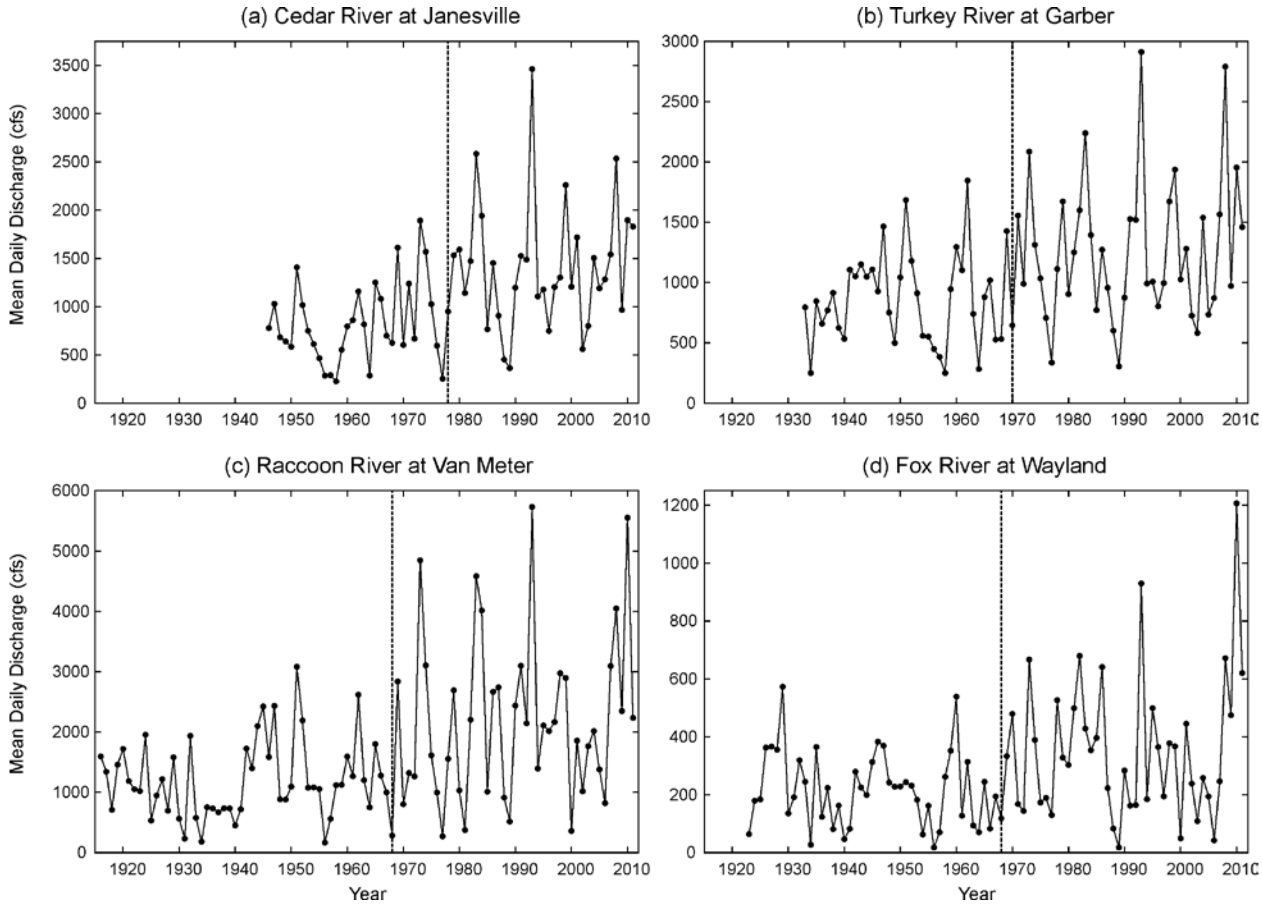


Figure 1.7. Time series of mean daily discharge for the period of record. An analysis was carried out to detect changes in the statistical characteristics of mean daily discharge; the vertical dashed lines indicate the location of any identified change point.

All four watersheds have statistically significant changes in mean daily discharge, occurring between 1968 and 1978. Streamflow since the 1970s is slightly higher than before, and its year to-year variability has increased noticeably. The trends seen in the Iowa Watersheds Project study areas are common among many Iowa watersheds. Similar outcomes are observed for a measure of low flows (the 5% daily discharge for the year); all the detected changes occur within the narrow period between 1968 and 1972. Changes in a measure of high flows (the maximum daily discharge for the year) are not as clear. No statistically significant changes were detected for two watersheds (Cedar and Turkey); for the Raccoon, changes were detected in 1943, and in 1978 for the Fox River. Still, the general tendencies observed for mean and low flows — increased flow amounts and greater variability in the last 40 years — are also observed for high flows, even if the changes are not statistically significant.

Overall, the evidence suggests that Iowa (and elsewhere in the Midwest) has experienced long-term changes in the nature of streamflow (around 1970). The reasons for these changes is still the subject of intense on-going research (e.g., Mora et al., 2013; Frans et al, 2013; Shawn et al., 2013; Yiping et al., 2013). Still, Iowans have all seen the impacts of increased and more highly variable flows; the widespread flooding in 1993 and 2008 mark two visible examples.

c. Summary of Iowa's Flood Hydrology

The hydrologic assessment begins by looking at the historical conditions within Iowa watersheds, and moves on to predicting their flooding characteristics. Ultimately, for watersheds to prevent flooding, large- and small-scale mitigation projects directed towards damage reduction will be proposed and implemented. In many instances, projects aim to change the hydrologic response of the watershed, e.g., by storing water temporarily in ponds, enhancing infiltration and reducing runoff, etc. Such changes have (and are designed to have) significant local water cycle effects; cumulatively, the effects of many projects throughout the watershed can also have impacts further downstream.

Still, it is important to recognize that all Iowa watersheds are undergoing alterations — changes in land use, conservation practices, increases in urban development, and changes in weather with a changing climate. Therefore, a watershed-focused strategy, which considers local interventions and their impacts on the basin as a whole, within the historical context of a changing water cycle, is needed for sound water resources planning.

2. Conditions in the Middle Raccoon River Watershed

This chapter provides an overview of the current Middle Raccoon River Watershed conditions including hydrology, geology, topography, land use, hydrologic/meteorologic instrumentation, as well as a summary of previous floods of record. Detailed maps of related material can be found in Appendix A.

a. Hydrology

The Middle Raccoon Watershed is comprised of 590 square miles in West Central Iowa. The Watershed encompasses approximately half the area of The South Raccoon River eight-digit Hydrologic Unit Code (HUC8) 07100007. It is made of Four HUC10's, and 15 HUC12's. The majority of the watershed boundary falls within four counties—Carroll, Greene, Guthrie, and Dallas. The main stem of the Middle Raccoon is located in the southern portion of the watershed and is fed by three primary tributaries from the north—Storm Creek, Willow Creek, and Mosquito Creek. The Middle Raccoon River drains to the South Raccoon River near Redfield, IA, and then flows east to meet the Des Moines River in Des Moines, IA.

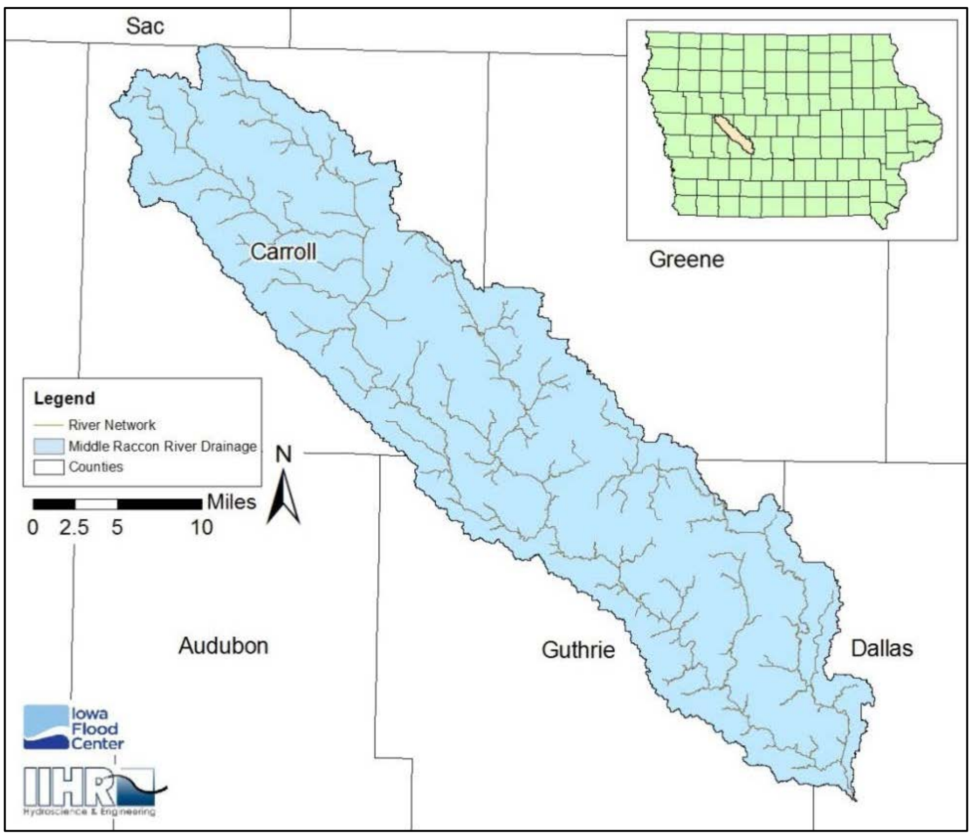


Figure 2.1. The drainage area for the Middle Raccoon River Watershed, part of the South Raccoon River HUC 07100007. The watershed drains 590 mi².

b. Geology and Soils

The Middle Raccoon River Watershed is split by two identified landform regions—the Des Moines Lobe and the Southern Iowa Drift Plain, each of which has a unique influence on the rainfall-runoff characterization of the watershed. The Southern Drift Plain Region of Southern Iowa covers 33% of the watershed and is characterized by numerous rills, creeks, and rivers which branch out across the landscape, shaping glacial deposits into steeply rolling hills and valleys. In contrast, the Des Moines Lobe Region of Central Iowa covers 67% of the watershed and is characterized by a poorly drained landscape of pebbly deposits, with broadly curved bands of ridges and knobby hills set among irregular ponds and wetlands, punctuating the otherwise subtle terrain (Iowa Geological & Water Survey, Iowa Department of Natural Resources, 2013).

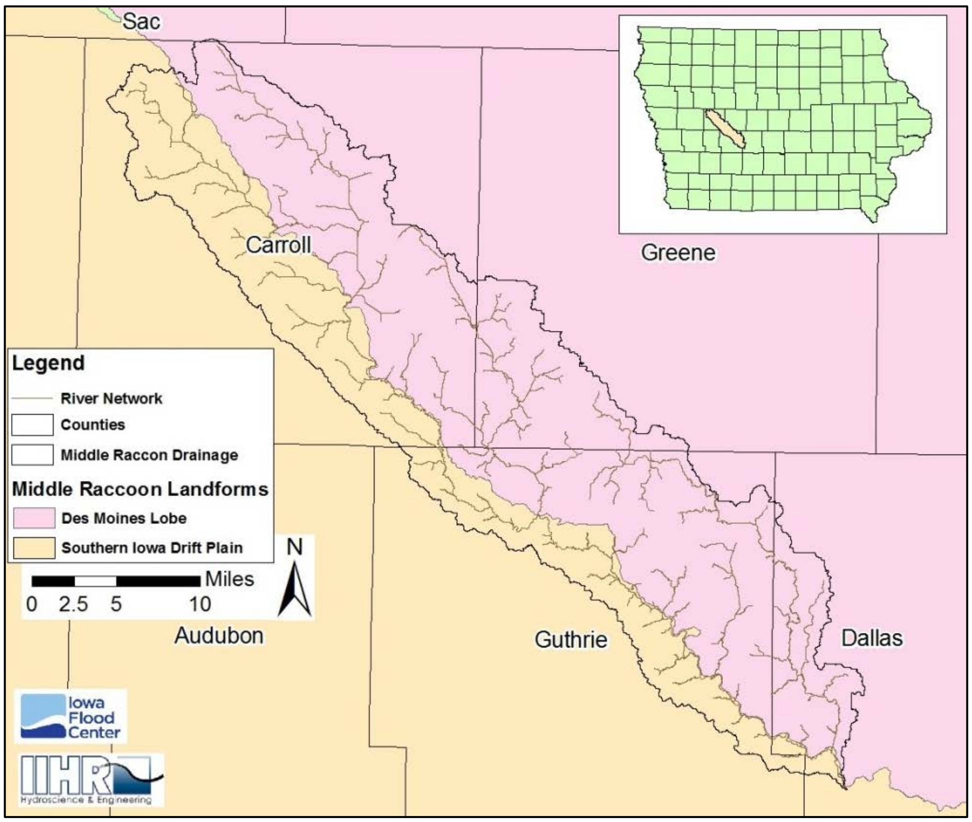


Figure 2.2. Defined landform regions of the Middle Raccoon River Watershed. The Southern Iowa Drift Plain is the south is characterized by the heavy relief. The flatter Des Moines Lobe is to the north.

The basin is composed primarily of moderately drained soils. Soils are classified into four Hydrologic Soil Groups (HSG) by the Natural Resources Conservation Service (NRCS) based on the soil's runoff potential. The four HSGs are A, B, C, and D, where A-type soils have the lowest runoff potential (highest infiltration capacity) and D-type have the highest runoff potential (lowest infiltration capacity). For reference, a sand or gravel would classify as an A-type soil whereas a clay or silt would classify as a C or D-type soil. In addition, there are dual code soil classes A/D, B/D, and C/D that are assigned to certain wet soils. In the case of these soil groups, the soil properties may be favorable to allow infiltration, but a shallow groundwater table (within 24 inches of the surface) typically prevents much infiltration from occurring (Hoeft, 2007). 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 or lowered, but the higher runoff potential of a D-type soil if it is not. Table 2.1 summarizes some of the properties generally true for each HSG A-D. This table is meant to provide a general description of each HSG and is not all inclusive. Complete descriptions of the Hydrologic Soil Groups can be found in USDA-NRCS National Engineering Handbook, Part 630 – Hydrology, Chapter 7.

Table 2.1. Soil properties and characteristics generally true for Hydrologic Soil Groups A-D.

Hydrologic Soil Group	*Runoff Potential*	*Soil Texture(s)*	*Composition*	*Minimum Infiltration Rate[1] (in/hr)*
A	Low	Sand, gravel	< 10% clay > 90% sand/gravel	> 5.67
B	Moderately low	Loamy sand, sandy loam	10-20% clay 50-90% sand	1.42-5.67
C	Moderately high	Loam containing silt and/or clay	20-40% clay <50% sand	0.14-1.42
D	High	Clay	>40% clay <50%	<0.14

[1] For HSG A-C, infiltration rates based on a minimum depth to any water impermeable layer and the ground water table of 20 and 24 inches, respectively.

Figure 2.3 shows the HSG distribution in the Middle Raccoon River Watershed, the watershed consists primarily of B(66%) and B/D(27%) type soils, therefore the majority of area considered moderately well-draining. The portion of the watershed deemed B/D, reflects a shallow groundwater table. A shallow groundwater table can result in increased runoff potential and greater reason to believe tile drainage practices are present to better agricultural production. Tile drain practices have further been confirmed in discussions with watershed stakeholders. The soils data from the USDA-NRCS Web Soil Survey (WSS) is available by county. The Counties of Sac, Carroll, Greene, Guthrie, and Dallas were downloaded and then merged using ArcGIS tools.

The HSG composition in the watershed is tabulated in Table 2.2.

Table 2.2. Hydrologic Soil Group distribution (by percent area) in the Middle Raccoon River Watershed.

Hydrologic Soil Group	*Portion of Watershed (%)*
A	0.4
A/D	0.0
B	66.4
B/D	27.1
C	5.3
C/D	0.5
D	0.2

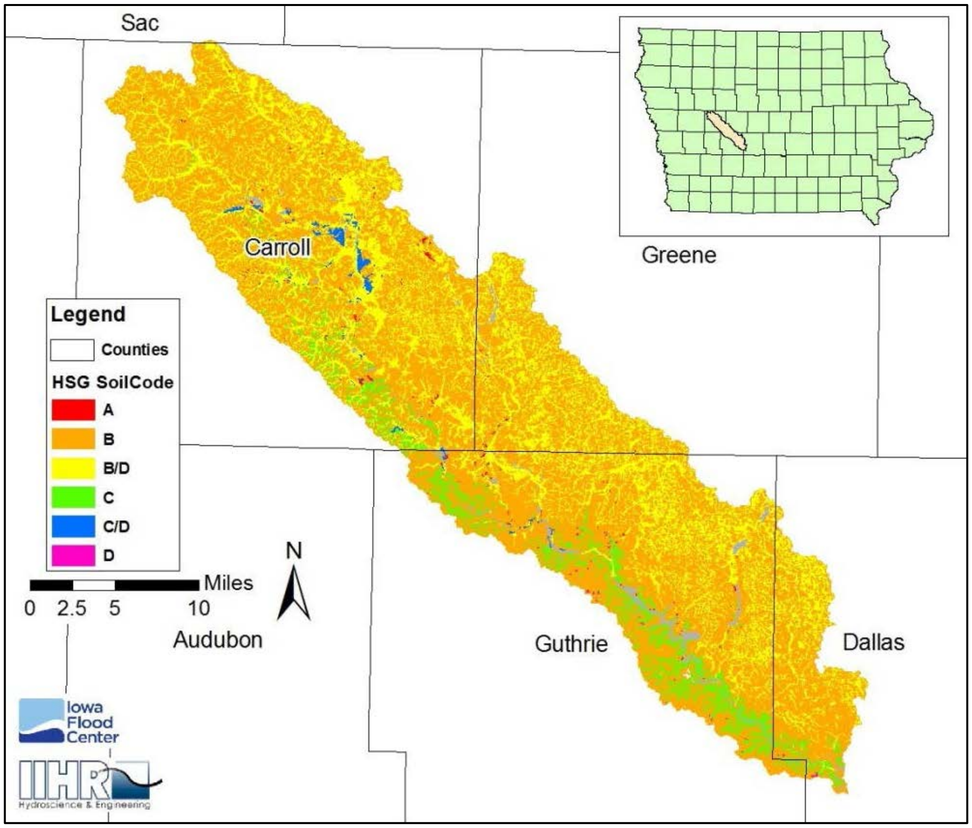


Figure 2.3. Soils of the Middle Raccoon River Watershed. Hydrologic Soil Group reflects the degree of runoff potential a particular soil has, with Type A (Red) representing the lowest runoff potential and Type D (Purple) representing the highest runoff potential. The dominate soil type in the basin is HSG B (66%).

c. Topography

The topography of the Middle Raccoon River Watershed is relatively flat, particularly in the Des Moines Lobe region, and consisting primarily of rolling hills and farm ground. Elevations range from 1,475 feet above sea level in the uppermost part of the watershed to 900 feet at its outlet (525 feet of relief). The terrain tends to be slightly steeper near the river channel and on the southern side of the Middle Raccoon River main stem, where the Southern Iowa Drift Plain Region is dominate. About 65% of the watershed has a slope of less than 5% and approximately 95% of the basin has a slope of less than 30%.

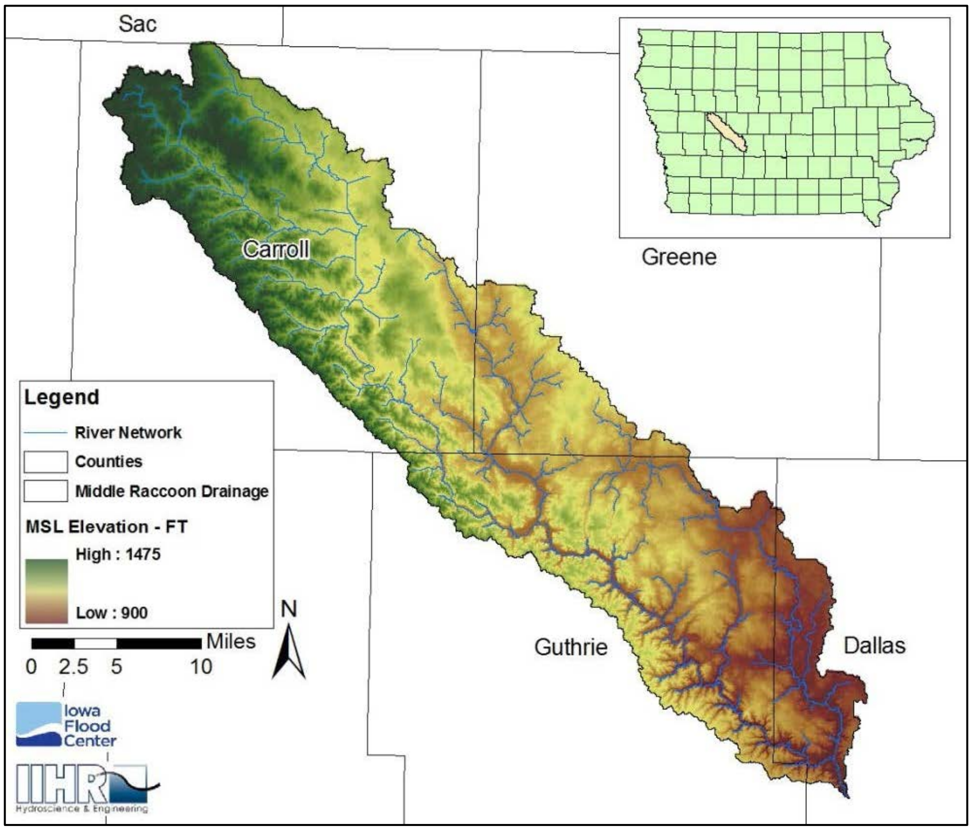


Figure 2.4. Topography of the Middle Raccoon River Watershed. The Middle Raccoon is a relatively flat basin ranging in elevation from 1475 ft to 900 ft.

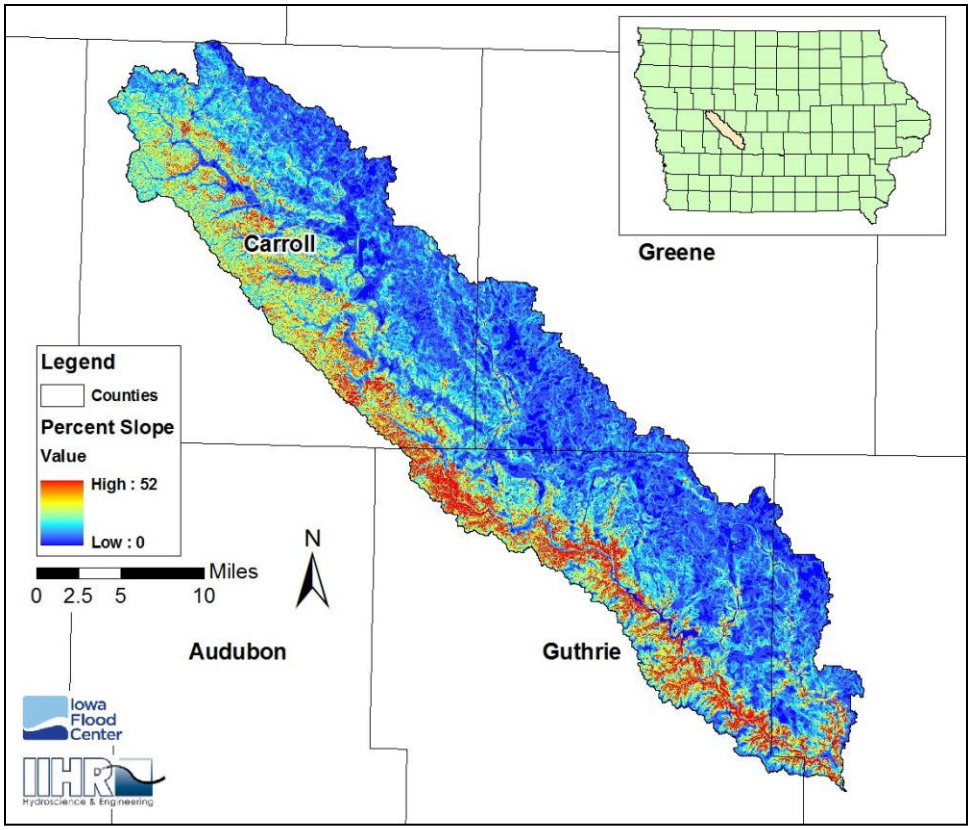


Figure 2.5. Land slope of the Middle Raccoon River Watershed. Slopes range from 0-52%.

d. Land Use

The Middle Raccoon River Watershed is predominantly agriculture, dominated by cultivated crops (corn/soybeans) at approximately 77% of the acreage, followed by pasture (9%), developed/commercial (7%), and forest (4%), per the 2006 National Land Cover Data (NLCD) Set. There are also several small towns located in the watershed—Carroll, Panora, Coon Rapids, Redfield, Lidderdale, and Bayard, among others.

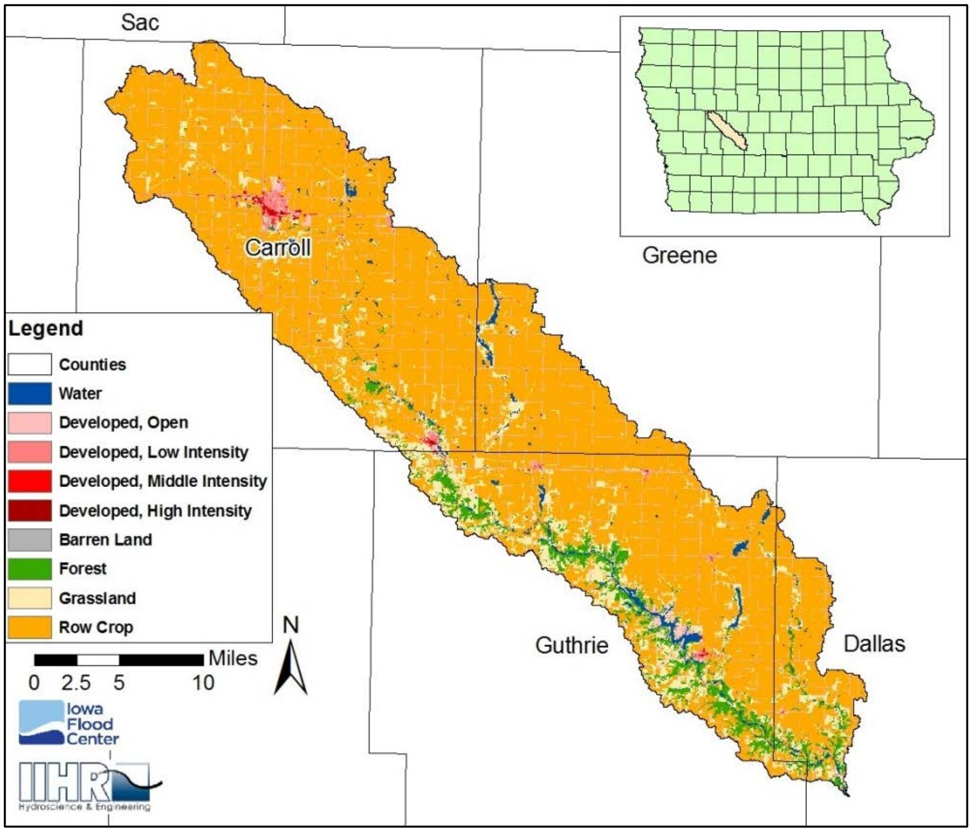


Figure 2.6. Land use composition in the Middle Raccoon River Watershed. Agriculture is the dominate land use, shown in orange.

e. Instrumentation/Data Records

The Middle River Watershed has instrumentation installed to collect and record stream stage, discharge, and precipitation measurements. There are two United States Geological Survey (USGS) owned stage & discharge gages, one USGS owned stage only gauge and three Iowa Flood Center (IFC) stream stage sensors located within the watershed. While the USGS gauges are owned by the USGS, they are maintained and operated by the Lake Panorama Association. There are four National Oceanic and Atmospheric Administration (NOAA) precipitation gauges within or near the watershed used for this study. Only rain gauges with a period of record longer than 25 years were considered. Table 2.3 and Figure 2.7 detail the period of record and location of the hydrologic and meteorologic instrumentation.

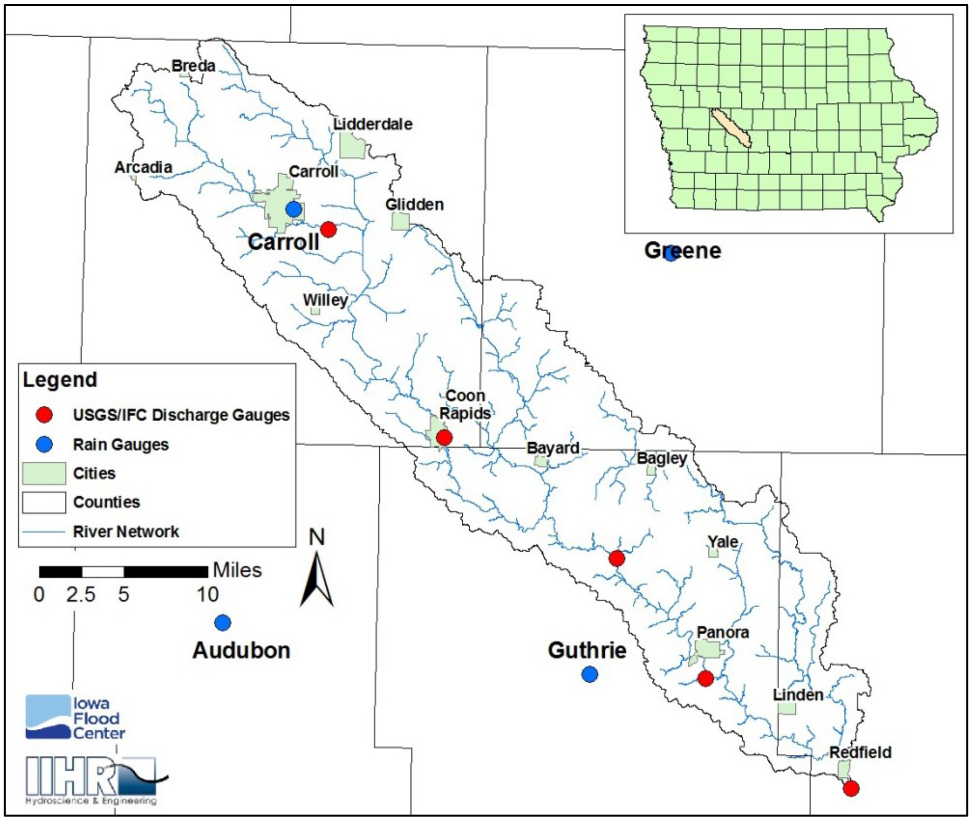


Figure 2.7. Meteorologic (4) and streamflow (5) gauges used in model development, calibration, and validation of the Middle Raccoon River Watershed model. Meteorologic gauges are shown in blue, streamflow in red.

Table 2.3. Periods of record for hydrologic/meteorologic instruments in the Middle Raccoon River.

Gage Type	*Location*	*Period of Record*
Stage/Discharge Gages (6)		
USGS Stage/Discharge	Middle Raccoon near Bayard (05483450)	1979- present
USGS Stage	Middle Raccoon at Lake Panorama (0583470)	1979- present
USGS Stage/Discharge	Middle Raccoon near Panora (05483600)	1958- present
IFC Stream Sensor (stage)	Middle Raccoon near Carroll MDDLRCCN03	2013- present
IFC Stream Sensor (stage)	Middle Raccoon near Coon Rapids MDDLRCCN02	2013-present
IFC Stream Sensor (stage)	Middle Raccoon near Redfield MDDLRCCN01	2013- present
Precipitation Gages (4)		
GHCND: USC00130385	Audubon	1883 - present
GHCND: USC00131233	Carroll	1883 - present
GHCND: USC00136566	Jefferson	1883 - present
GHCND: USC00133509	Guthrie Center	1895 - present

f. Floods of Record

There have been several noteworthy floods in the watershed over the past 25 years, with perhaps the most well-known being the flood of 1993. The memorable flood during the summer of 1993 struck much of the upper Midwest, and resulted in a stage of 29.02, shattering the prior high water mark by over 4 feet. Rainfall data from the storm of July 8-9, 1993 show that nearly 11 inches of rain fell on the upper reaches of the Middle Raccoon River and the surrounding watersheds. (Prestegaard et. al, 1994).

In total four floods, greater than 10,000 cubic feet per second, have been recorded at the USGS Middle Raccoon gauging station at Bayard, Iowa since 1973. These four flood peaks, June 03, 1973 – 14,600 cfs; June 30, 1986 – 12,300 cfs; July 09, 1993 – 27,500 cfs; and June 15, 2013 – 13,200 cfs are the four largest discharges observed during the continuous operation of this gauge. Flood details can be seen in Table 2.4.

The National Weather Service has not determined flood stages for the USGS gauges in the watershed. However, it has determined an action stage of 13 ft. This action stage was exceeded in all flood events tabulated above. The emergency spillway at Lake Panorama (El. 1048) has only activated in the Flood of 1993.

Table 2.4. Floods of record on the Middle Raccoon River at Bayard, IA.

Date	*Gauge Height/Stage (ft)*	*Peak Streamflow (cfs)*
July 03, 1973	21.63	14,600
June 30, 1986	24.70	12,300
July 09, 1993	29.02	27,500
June 15, 2013	24.94	13,200

3. Middle Raccoon River Hydrologic Model Development

This chapter summarizes the development of the hydrologic model used in the Phase I Hydrologic Assessment for the Middle Raccoon River Watershed. The modeling was performed using the United States Army Corps of Engineers' (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), Version 3.5.

HEC-HMS is designed to simulate rainfall-runoff processes of a watershed. It is applicable in a wide range of geographic areas and for watersheds ranging in size from small (a few acres) to very large (1,000 acres or more).

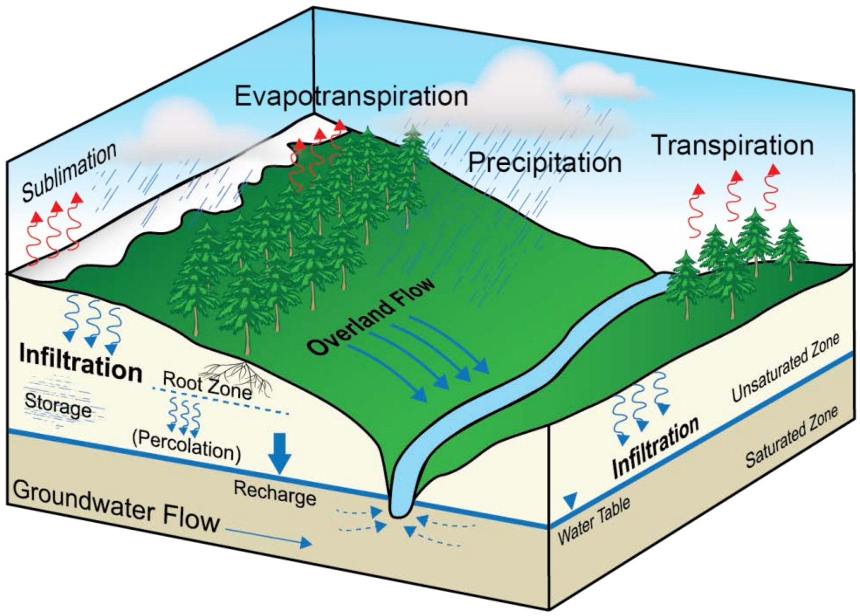


Figure 3.1. Hydrologic processes that occur in a watershed. HEC-HMS only considers precipitation, infiltration, and overland flow.

HMS is a mathematical, lumped parameter, uncoupled, surface water model. Each of these items will be briefly discussed. The fact that HMS is a mathematical model implies the different hydrologic processes are represented by mathematical expressions that were often empirically developed to best describe observations or controlled experiments. HMS is also a lumped parameter model, meaning physical characteristics of the watershed, such as land use and soil type, are "lumped" together into a single representative value for a given land area. Once these averaged values are established within HMS, the value remains constant throughout the simulation instead of varying over time. HMS is an uncoupled model, meaning the different hydrologic processes are solved independent of one another rather than jointly. In reality, surface and subsurface processes are dependent on one another and their governing equations should be solved simultaneously (Scharffenberg and Fleming, 2010). Finally, HMS is a surface water model, meaning it works best for simulating large storm events or when the ground is nearly saturated since overland flow is expected to dominate the partitioning of rainfall for both these cases.

The two major components of the HMS hydrologic model are the basin model and the meteorologic model. The basin model defines the hydrologic connectivity of the watershed, defines how rainfall is converted to runoff, and how water is routed from one location to another. The meteorologic model stores the precipitation data that defines when, where, and how much it rains over the watershed. Simulated hydrographs from HMS can be compared to discharge observations.

a. Model Development

The Middle Raccoon River Watershed as modeled and detailed herein is approximately 590 square miles (mi^2). The watershed was divided into 349 smaller units, called subbasins in HMS, with an average area of about 1.7 mi^2, but as large as 8.2 mi^2.

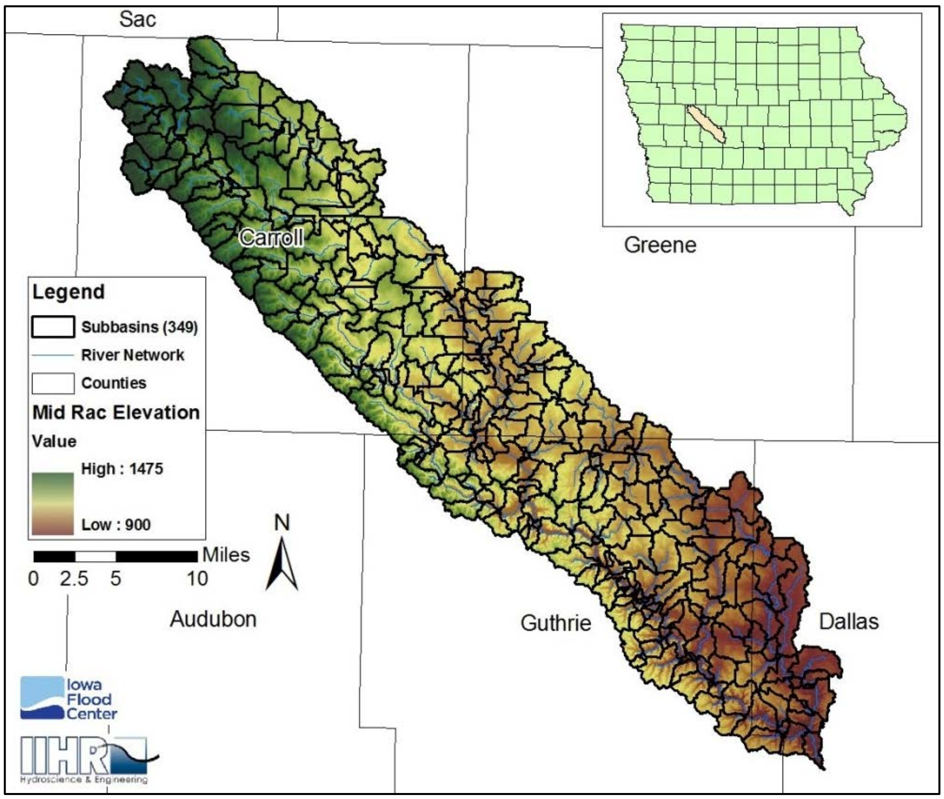


Figure 3.2. Subbasin delineation in the Middle Raccoon River HMS hydrologic model. Subbasins are smaller watershed units which unique parameters can be assigned, such as soil type and land use. The Middle Raccoon Model has 349 subbasins with an average size of 1.7 mi^2.

ESRI/ArcGIS, and Arc Hydro tools were used for terrain preprocessing, creating flow direction and flow accumulation grids, defining the stream network, and subbasin delineation. The stream network was defined to begin when the upstream drainage area was 4 square kilometers (1.16 mi^2), and subbasins were delineated such that a subbasin was defined upstream of all stream confluences. GIS-defined subbasins were further manually split to create an outlet pointat each USGS gage location, as well as the discharge point of two incorporated structures. In HMS, the averaging previously described for lumped parameter models is performed within the boundary of each subbasin and then each subbasin is assigned a single value for the parameter being developed.

i. Incorporated Structures

Two reservoirs, Lake Panorama and Bays Branch Lake, were incorporated in the HMS model. Lake Panorama is located in Guthrie County, northwest of Panora, Iowa. It drains approximately 440 mi^2, has a surface area of 1270 acres, and a normal storage of 19,700 acre-ft (Shive-Hattery, 1977). The Dam at Lake Panorama is controlled by a 100 foot long, 9.8 foot high, Bascule Gate (i.e. Hinge Crested Gate) and is operated by the Dam Supervisor. Since Lake Panorama is not intended for flood storage, the gate is designed to allow inflow to equal outflow, whenever possible. In order to mimic this gate operation in the model, the computed hydrograph at Bayard (the gauge directly upstream of Lake Panorama) was translated, via specified discharge, to the Bascule Gate location. Therefore, timing, peak flows, and total volumes from the Bayard Gauge location and the Bascule Gate location are identical. Since the supervisor uses the Bayard Gauge as one of the deciding factors in gate operation, this is a reasonable assumption and was confirmed by comparing the observed hydrograph at Bayard (upstream of Lake Panorama) to the observed hydrograph at Panora (downstream of Lake Panorama), Figure 3.3.

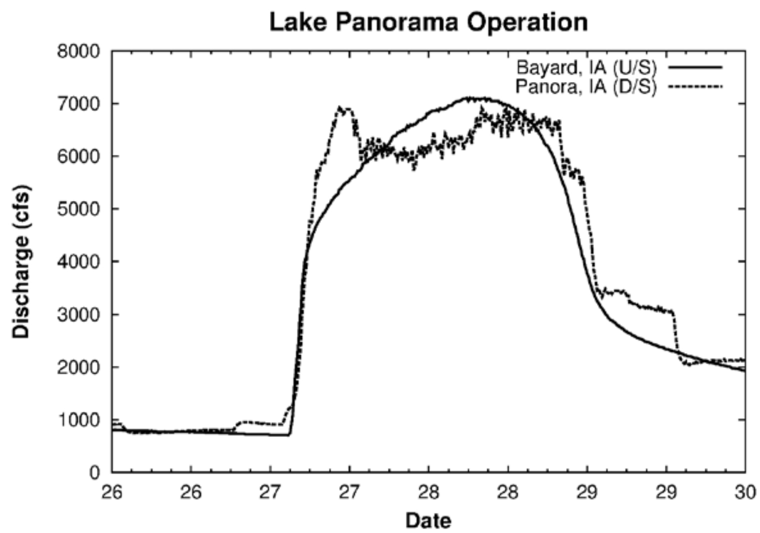


Figure 3.3. Hydrographs at both upstream of Lake Panorama (at Bayard) and downstream of Lake Panorama (at Panora) for the June, 2010 flood event. The figure shows how the upstream gauges are used to determine the discharge to be released from Lake Panorama.

Bays Branch is also located in Guthrie County but Northeast of Panora, Iowa. It drains approximately 15 mi^2, has a surface area of 272 acres, and a normal storage of 1,088 acre-feet (Hall, 2006) The Bays Branch Dam was modeled using the storage, elevation, and discharge relationships obtained from the Iowa Department of Natural Resources, Bays Branch Dam Safety Inspection Reports and is available in Appendix B. No existing farm ponds or other possible water storage structures were included in the baseline HMS model.

ii. Development of Model Inputs and Parameters

A brief overview of the data inputs used and assumptions that have been made to develop the HMS model are provided in the following paragraphs. Appendix C of this report provides more detailed information on the hydrologic model development.

Rainfall (Meteorological Model)

Stage IV radar rainfall estimates (NCEP/EMC 4KM Gridded Data (GRIB) Stage IV Data) were used as the precipitation input for simulation of actual rainfall events known to have occurred within the watershed. The Stage IV data set is produced by the National Center for Environmental Prediction (NCEP) by taking Stage III radar rainfall estimates produced by the 12 National Weather Service (NWS) River Forecast Centers across the Continental United States and combining them into a nationwide 4km x 4km (2.5mile x 2.5mile) gridded hourly precipitation estimate data set. Stage IV radar rainfall estimates are available from January 1, 2002 – present. Figure 3.4, shows an example of Stage IV radar rainfall estimates of cumulative rainfall during the event of June 13-15, 2013 in the Middle Raccoon River Watershed. This figure helps demonstrate the gridded nature of the radar rainfall estimate data, as well as the distributed nature of rainfall in time and space.

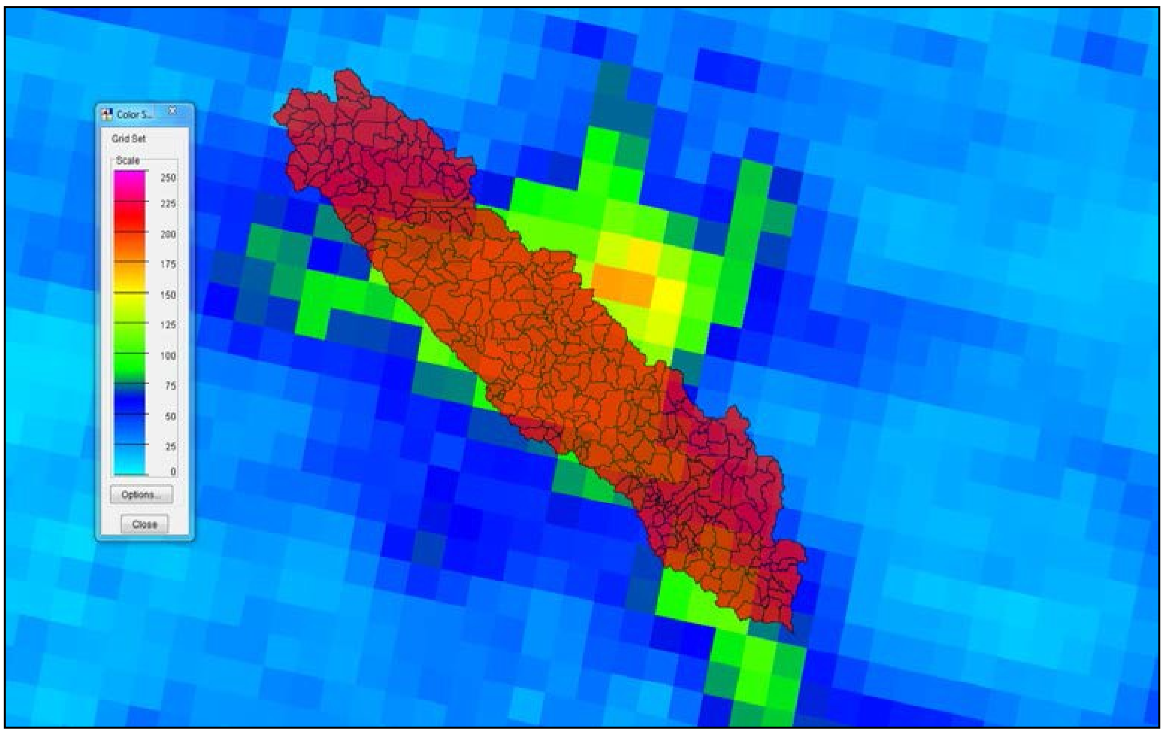


Figure 3.4. Demonstration of the gridded Stage IV radar rainfall product used in the Middle Raccoon River Watershed HMS model, June 13-15, 2013. Radar rainfall estimates are available for each hour at a spatial resolution of 2.5 miles x 2.5 miles and were used for calibration and validation of historical storm events. In the map, yellow corresponds with approximately 6 inches of rainfall.

Use of radar rainfall estimates provides increased accuracy of the spatial and time distribution of precipitation over the watershed and Stage IV estimates provide a level of manual quality control (QC) performed by the NWS that incorporates available rain gage measurements into the rainfall estimates. Actual storms using Stage IV data were the basis for model calibration and validation.

Hypothetical storms were developed for comparative analyses such as potential runoff generation, increased infiltration capacity through land use changes or soil improvements, and increased distributed storage within the watershed. These hypothetical storms apply a uniform depth of rainfall across the entire watershed with the same timing everywhere. Soil Conservation Service (SCS) Type-II distribution, 24-hour storms were used for all hypothetical storms. Point

Precipitation values (rainfall depths) for the 10, 25, 50, and 100-year average recurrence interval, 24 hour storms were derived using the online version of National Oceanic and Atmospheric Administration (NOAA) Atlas 14 – Point Precipitation Frequency Estimates (Perica et at., 2013). Point estimates were obtained for several locations throughout the watershed, these estimates remained fairly consistent. Therefore, point estimates at Carroll, IA were used since this was also the location of the GHCND rainfall gauge used for estimating antecedent moisture conditions.

Studies have been performed on the spatial distribution characteristics of heavy rainstorms in the Midwestern United States (Huff and Angel, 1992). Point precipitation frequency estimates are generally only applicable for drainage areas up to 10 square miles before the assumption of being uniformly distributed is no longer valid, thus for drainage areas between 10 and 400 square miles, relations have been established between point precipitation estimates and an areal mean precipitation approximation. Areal reduction factors based on storm duration and drainage area can be found in *Rainfall Frequency Atlas of the Midwest* (Huff and Angel, 1992). NOAA does not recommend adjusting point estimates to account for watershed size beyond 400 mi^2, as the dependence between the point and the areal values breaks down for watersheds larger than this.

For the comparative analyses that were performed in this modeling effort, an extrapolation was performed to get an areal reduction factor beyond 400 square miles. It is agreed that this depth of rainfall would not fall uniformly across a watershed this large, however to have reasonable rainfall depth estimates with a general relationship to the average recurrence interval 24-hour storms, the point rainfall estimates were reduced by a factor of 0.90 (the areal reduction factor for the 590 mi^2 drainage area at Redfield).

Table 3.1. Rainfall depths used for hypothetical scenario analyses. The 24 hour duration point rainfall estimates for the 10, 25, 50, and 100 year recurrence intervals were reduced by an areal reduction factor of 0.90.

24 Hour Hypothetical Design Storm (years)	*NOAA Point Precipitation (inches)*	*Areal Reduced Precipitation (inches)*
10	4.48	4.03
25	5.64	5.08
50	6.67	6.00
100	7.82	7.04

These values used in this modeling analysis should not be used for localized project design purposes. However, the process described for obtaining point estimates from NOAA Atlas 14 and applying the appropriate correction factor based on a specific project's drainage area (up to 400 square miles) is applicable.

Watershed (Basin Model)

Topography

Elevation data was obtained from the National Elevation Dataset (NED). The Digital Elevation Model (DEM) data was downloaded for the 5 counties in the watershed (DEM3MI05, DEM3MI14, DEM3MI25, DEM3MI37, DEM3MI39) of 3-meter resolution DEM's, covering the extent of the Middle Raccoon River Watershed. They were clipped to the watershed extents using ESRI ArcGIS, then merged into a single seamless DEM. NED data are distributed in geographic coordinates in units of decimal degrees, in conformance with the North American Datum of 1983 (NAD 83). All elevation values are in meters and are referenced to the North American Vertical Datum of 1988 (NAVD 88).

Runoff Volume

Soil Conservation Service (SCS) Curve Number methodology was used to determine the rainfall-runoff partitioning for the Middle Raccoon River Watershed HMS modeling. Curve Number (CN) serves as a runoff index and values range from 30-100. As the CN becomes larger, there is less infiltration of water into the ground and a higher percentage of runoff occurs. CN values are an estimated parameter based primarily on the intersection of a specific land use and the underlying soil type, not a measured parameter. General guidelines for curve numbers based on land use and soil type are available in technical references from the NRCS. The CNs assigned to each land use and soil type combinations for the Middle Raccoon River HMS model are shown below.

Table 3.2. Curve Numbers assigned to each land use and soil type combination. Area-weighted averaging was used to calculate a single Curve Number value for each subbasin. Curve Numbers range from 30-100 with higher values reflecting greater runoff potential.

		Hydrologic Soil Group			
NLCD 2006	*Description*	*A*	*B*	*C*	*D*
11	Open Water	100	100	100	100
90	Woody wetlands	100	100	100	100
95	Emergent herbaceous wetlands	100	100	100	100
21	Developed, open space	49	69	79	84
22	Developed, low intensity	57	72	81	86
23	Developed, medium intensity	81	88	91	93
24	Developed, high intensity	89	92	94	95
31	Bare rock/sand/clay	98	98	98	98
41	Deciduous forest	32	58	72	79
42	Evergreen forest	32	58	72	79
43	Mixed forest	32	58	72	79
52	Shrub	32	58	72	79
71	Grassland/herbaceous	49	69	79	84
81	Pasture/hay	49	69	79	84
82	Row crops	67	78	85	89

Soils that had been assigned a dual soil code (A/D, B/D, and C/D) were reassigned to the undrained condition since tile drainage conditions were represented using the Clark Unit Hydrograph transform method.

A CN grid was generated for the Middle Raccoon River Watershed using ESRI ArcGIS with the HEC-GeoHMS extension tools. These tools intersect the 2006 National Land Cover Data Set with digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WSS). Upon completion of producing the CN Grid, HEC-GeoHMS tools were used to perform area-weighted averaging within each subbasin to assign a composite CN to each subbasin.

The NRCS curve number methodology for rainfall-runoff partitioning accounts for precipitation losses due to initial abstraction, which is the initial amount of rainfall that must fall before any runoff begins (losses due to plant interception, soil wetting, and storage in surface depressions), and the amount of precipitation that is estimated to infiltrate into the ground during the simulation. The remaining precipitation is considered excess precipitation and is converted to runoff. Evaporation and transpiration (evapotranspiration) were neglected in the modeling as the focus is to simulate short duration, large rain events when evapotranspiration is thought to be a minimal component of the water balance. CN regeneration, in which the initial abstraction is reset after some time period, was not used since short duration; event-based storms were considered.

Antecedent Moisture Conditions

Rainfall-runoff partitioning for an area is also dependent on the antecedent soil moisture conditions (how wet the soil is) at the time rain falls on the land surface. In essence, the wetter the soil is, the less water is able to infiltrate into the ground and more rain is converted to runoff. Therefore, a methodology was needed to adjust subbasin CNs to reflect the initial soil moisture conditions at the beginning of a storm simulation in order to better predict direct runoff volumes.

To account for antecedent moisture conditions, a soil moisture proxy known as the 5-day Antecedent Moisture Condition (5-Day AMC) was used. Traditionally, 5-Day AMC is defined by the five day cumulative rainfall prior to the period of study, then based on the total amount of rainfall in those five days, it is broken into three levels—AMC I (dry), AMC II (normal/average), and AMC III (wet), Table 3.3. These three values statistically correspond to the 10%, 50%, and 90% cumulative non-exceedance probabilities of runoff depth, respectively (Hjelmfelt, 1982). Curve numbers are then altered to reflect the 5-Day AMC condition. They are shifted upwards during wet soil conditions, resulting is higher runoff generation, the opposite effect occurs during dry soil conditions. The subbasin curve numbers calculated for the HMS model represent the AMC II condition.

Table 3.3. The traditional definition for antecedent moisture conditions. (Chow et al., 1988)

5-Day AMC Group	*5-Day Cumulative Rainfall (inches)*
I	Less than 1.4
II	1.4 to 2.1
III	More than 2.1

Rainfalls in the Middle Raccoon River Watershed at the Carroll, IA rainfall gauge were analyzed to determine if rainfall volumes in the region fit the traditional definition of AMC I, II, and III. After classifying a 113 year record (1900-2013) in a series of 5-day antecedent moisture values at the NOAA GHCND Carroll, IA rainfall gauge, it was determined that AMC definitions for the Middle Raccoon would need to be modified to fit the hydrology seen in the watershed. To do this, new AMC I, II, and III values were calculated so that they reflected the 10%, 50%, and 90% cumulative non-exceedance probabilities of 5-day rainfall in the watershed. Between the new AMC conditions, I, II, & III moisture was assumed to act linearly in order to better account for AMC states between the three points. In this way, a continuous relationship describing the change in Curve Number based on 5-Day AMC was developed, as opposed to traditional NRCS methodology which allows only three discrete possibilities for Curve Number manipulation (the AMC I, II, and III Curve Numbers). Once it was determined what curve numbers were required for the optimal peak discharge correlation in the calibrated storms (independent of 5-Day AMC), the AMC II condition was shifted upwards 2.94%, and AMC I and II values were recalculated as per the method in Chow et al., 1988. This physically represents a slightly higher volume of runoff for the same moisture condition in a typically defined watershed. Figure 3.5 shows the existing NRCS definition for antecedent moisture conditions along with the changes described here and carried out for model calibration and validation.

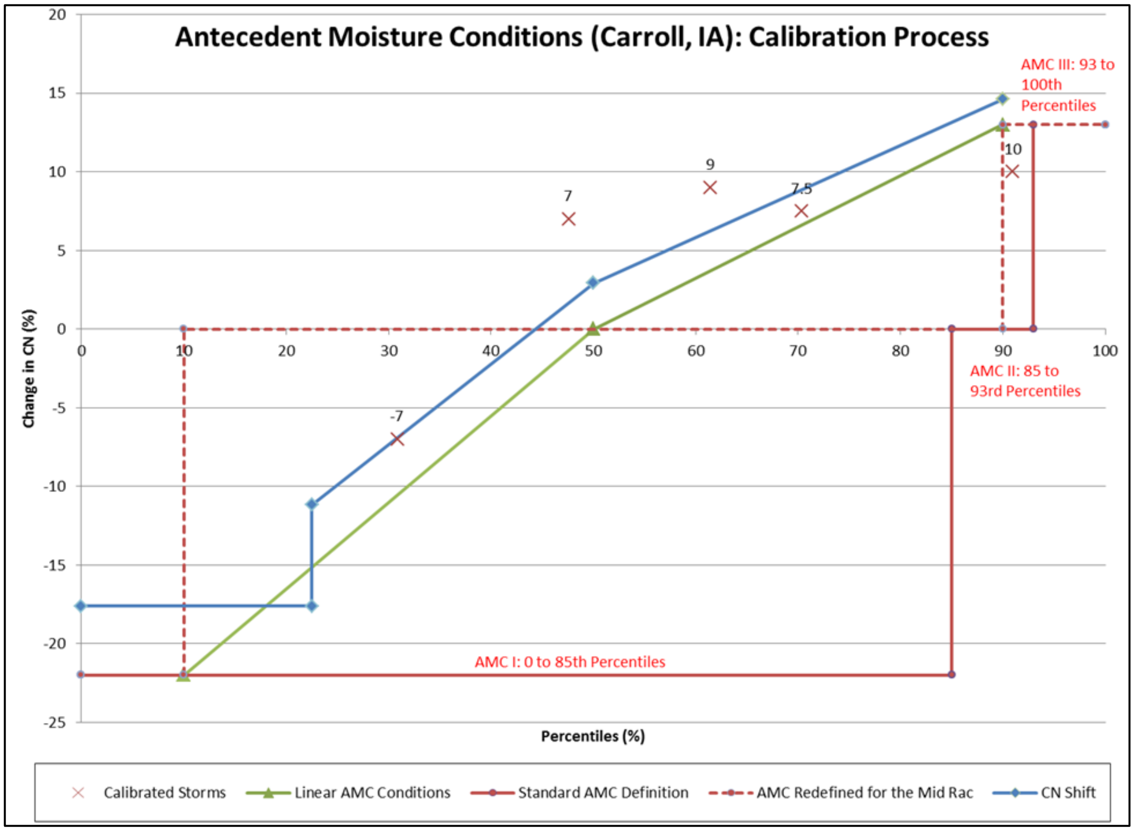


Figure 3.5. The redefinition of 5 day antecedent moisture based on rainfalls observed at Carroll, IA. The y-axis represents the change in curve number associated with AMC I, II, and III. The x-axis represents the percent chance of a given 5 day rainfall probability of nonexceedance, for example the 90th percentile would represent approximately a 2 inches in the 5 days leading up to a storm of interest. The final AMC/CN values used in HEC-HMS simulations were calculated using the blue line.

Runoff Hydrographs

The Clark and ModClark Unit Hydrograph methods were used to convert excess precipitation to a direct runoff hydrograph for each subbasin. The ModClark method requires the same grid used for radar rainfall, so this method was used for simulating historical storms used for calibration and validation while the traditional Clark method was used for hypothetical design storm analysis. Both methods account for translation (delay) and attenuation (reduction) of the peak subbasin hydrograph discharge due to the time it takes the excess precipitation to travel to the subbasin outlet and natural storage effects. The primary difference between the two methods is the traditional Clark Unit Hydrograph method uses a pre-developed time-area histogram while the ModClark method uses a grid-based travel time model to account for translation (lag) of the subbasin hydrograph. Both methods route the translation unit hydrograph through a linear reservoir to account for temporary storage effects.

Both unit hydrograph methods require two inputs, time of concentration and a time storage coefficient. The time of concentration is the time required for water to travel from the hydraulically most remote point in the subbasin to the subbasin outlet. This was estimated as 5/3 times the lag time, where lag time is the time difference between the center of mass of the excess precipitation and the peak of the runoff hydrograph. A scaling coefficient of 5/3 is a reasonable approximation according to SCS methodology (Woodward, 2010). Inputs required to determine the basin lag time for each subbasin include the subbasin slope, the length of the longest flowpath in the subbasin, and maximum potential retention (the maximum depth of water the soil can retain) in the subbasin, which is determined from the subbasin CN. ESRI ArcGIS tools were used for terrain analysis to identify subbasin slopes and the longest flowpaths. While time of concentration is a measure of lag due to travel time effects as water moves through the watershed, the time storage coefficient is a measure of lag due to natural storage effects in the subbasin (Kull and Feldman, 1998). Based on the literature, it can be estimated as a multiple of the time of concentration. Figure 3.5 illustrates the NRCS methodologies for runoff depth estimation and how this runoff depth is converted to discharge (using one of the Clark unit hydrograph methods).

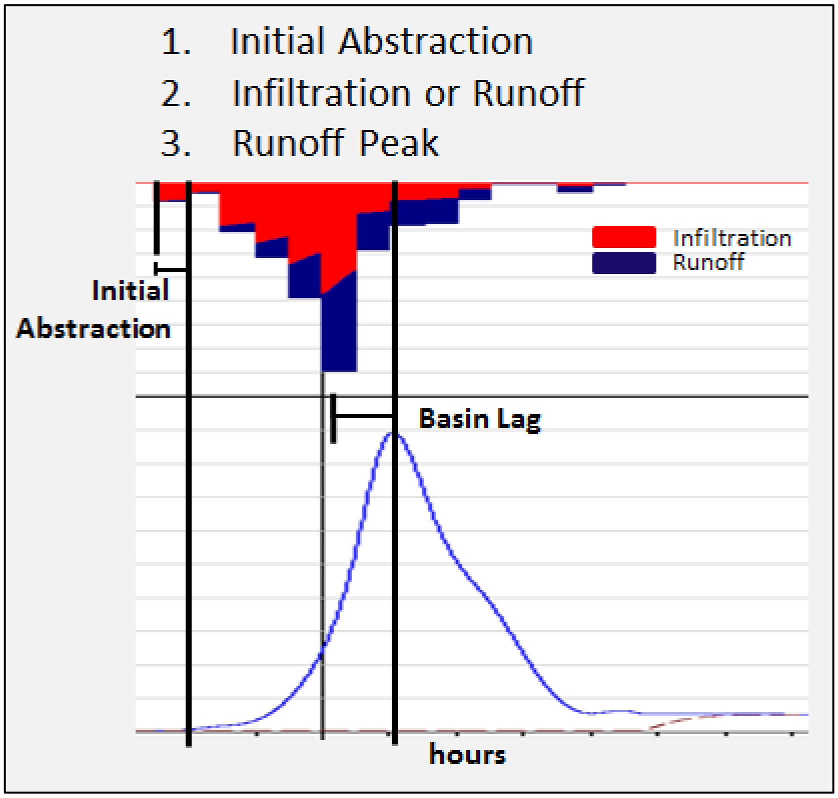


Figure 3.6. Subbasin runoff hydrograph conceptual model. This figure shows how rainfall is partitioned into a runoff depth (Curve Number method). The runoff depth is then converted to discharge using the Clark hydrograph method.

ArcGIS to HEC-HMS

Upon completion of GIS processing to prepare the basin topography data, establish the stream network, delineate the subbasins, and develop and assign the necessary parameters to describe the rainfall-runoff partitioning for each subbasin, HEC-GeoHMS tools were used to intersect the subbasins with the appropriate grid system (HRAP) to allow use of the Stage IV radar rainfall estimates. Lastly from ArcGIS, HEC-GeoHMS tools were used to create a new HMS project and export all of the data developed in ArcGIS to the appropriate format such that the model setup was mostly complete upon opening HMS for the first time. Once in the HEC-HMS user's interface, quality checks were performed to ensure the connectivity of the subbasins and stream network of the watershed were imported correctly.

Parameters Assigned in HEC-HMS

Baseflow

Baseflow was approximated by a first order exponential decay relationship for all historical storms. The USGS stage/discharge gages for the Middle Raccoon River near Bayard, IA were used to develop discharge-drainage area (cubic feet per second/per square mile) relationships to set initial conditions for streamflow prior to each actual storm event simulation. These unique initial conditions were applied to the appropriate corresponding subbasins within the HMS interface for each actual storm event simulation. A baseflow recession constant describing the rate of decay of baseflow per day and a threshold indicating when baseflow should be reactivated were also specified.

No baseflow was modeled for the hypothetical (design) storms as theses analyses are more concerned with the effects of how much direct runoff is produced. The contribution of baseflow during these design storm analyses is assumed to be relatively small compared to the amount of direct runoff produced.

Flood Wave Routing

Conveyance of runoff through the river network, or flood wave routing, was executed using the Muskingum routing method. Two inputs are required to use the Muskingum routing model in HMS – the flood wave travel time in a reach (K) and a weighting factor that describes storage within the reach as the flood wave passes through (X). The allowable range for the X parameter is 0-0.5 with values of 0.1-0.3 generally being applicable to natural streams. A value of 0.2 is frequently used in engineering practice and was used in this modeling analysis. Great accuracy in determining X may not be necessary because the results are relatively insensitive to the value of this parameter (Chow et. al, 1988). The flood wave travel time, K, is much more important and can be estimated by dividing the reach length by a reasonable travel velocity (1-5 feet per second, in general) as a starting point, but is generally best obtained by adjustment in the model calibration process using measured discharge records if available.

Flow routing through the Lake Panorama reservoir was executed using level pool routing. A level water surface is assumed and the methodology is derived from Conservation of Mass, similar to the Muskingum model. A specified discharge relationship was used along with an initial condition; specified discharges were gathered from the flows seen at the Bayard, IA USGS stream gauge location. Therefore, the discharges at the Bayard, IA USGS Gauge location and at the Lake Panorama Bascule Gate are identical in timing, and flow. This represents how the Dam Supervisor uses the Bayard, IA USGS stream gauge to determine flows approaching the dam, so he can release water accordingly.

Flow routing through Bays Branch Lake reservoir was also executed using level pool routing. A storage-outflow-discharge relationship was used along with an initial condition, from which HMS computes the outflow from the reservoir at each time step based on the known inflow and change in storage. All reservoirs or ponds incorporated into the model were assumed filled to the normal pool level at the beginning of each simulation.

b. Calibration

Model calibration is a process of taking an initial set of parameters developed for the hydrologic model through GIS and other means and making adjustments to them so that simulated results produced by the model match as close as possible to an observed time series, typically stream discharge at a gauging station. However, adjustments to parameters should not be made to great extremes just to manipulate the end results to match the observed time series. If this is necessary, the model does not reasonably represent the watershed and it is upon the modeler to change methods used within the model or find what parameter(s) might be needed to better represent the watershed's hydrologic response.

The Middle Raccoon River Watershed was calibrated to five storms events that occurred on April 2007, June 2008, June 2010, May 2013, and June 2013. Storms were selected based on their magnitude, time of year they took place, and based on the availability of Stage IV radar rainfall estimates and USGS discharge estimates. Large, high runoff storms occurring between May and September were selected so the impacts of snow, rain on frozen grounds, and freeze- thaw effects that exist during late fall to early spring conditions were minimized. Global adjustments were made to the runoff (CN) and timing (river routing and unit hydrograph) parameters to best match the simulated response to the observations at each of the USGS discharge gage locations. Although the simulated hydrographs at each of the USGS gage locations using the calibrated parameters are not perfect, they do predict several storms reasonably well. Additional calibration results are provided in Appendix C.

c. Validation

For model validation, the intent is to use the model parameters developed during calibration to simulate other events and evaluate how well the model is able to replicate observed stream flows. With several of the largest storms already having been selected for calibration or having occurred before the availability of Stage IV radar rainfall estimates (January 2002), the next best available storms were selected. Two storms were considered for model validation, July 2008 and August 2010.

As with calibration, the HMS model validation results are not perfect. Differences may be due to the size of the storms considered. Relative to the calibration events smaller storms, in terms of total runoff produced, were considered for validation. These smaller storms tend to have a greater subsurface flow component than larger storms since the ground is likely to have a greater capacity to infiltrate water, depending on antecedent moisture conditions. Because HMS is a surface water model, it struggles to simulate these types of conditions where surface flow is not the dominant partitioning of rainfall. Secondly, the storms occurred in or near the peak of the growing season when precipitation losses due to evapotranspiration and plant root uptake are at a maximum. This is reflected in the observations as most of the storms produce a small amount of runoff despite a substantial amount of rain, even with some storms having wetter than normal antecedent conditions. Lack of accounting for evapotranspiration losses in the HMS model may also contribute to runoff discrepancies.

Despite these differences, the HMS model did acceptable simulating the July 2008 flood that produced a discharge of 6,150 cfs at Bayard, IA, providing reassurance that the existing HMS model can reasonably simulate large runoff events where overland flow is expected to dominate the partitioning of rainfall. For the August 2010 event the model did an acceptable job simulating the peak flow of 2,890 cfs at Bayard, IA. However, timing of the peak was delayed nearly two days. Additional calibration results are provided in Appendix C.

4. Analysis of Watershed Scenarios

The HEC-HMS model of the Middle Raccoon River Watershed was used to identify areas in the watershed with high runoff potential and run simulations to help understand the potential impact of potential flood mitigation strategies in the watershed. Focus for the scenarios was placed on understanding the impacts of (1) increasing infiltration in the watershed and (2) implementing a system of distributed storages (ponds) across the landscape.

a. High Runoff Potential Areas

Identifying areas of the watershed with higher runoff potential is the first step in selecting mitigation project sites. High runoff areas offer the greatest opportunity for retaining more water from large rainstorms on the landscape and reducing downstream flood peaks.

In the HMS model of the Middle Raccoon River Watershed, the runoff potential for each subbasin is defined by the NRCS Curve Number (CN). The CN assigned to a subbasin depends on its land use and the underlying soils. The fraction of rainfall that is converted to runoff — also known as the runoff coefficient — is a convenient way to illustrate runoff potential. Areas with higher runoff coefficients have higher runoff potential. To evaluate the runoff coefficient, the runoff from each subbasin area is simulated with the HMS model for the same rainstorm; we chose a rainstorm with a total accumulation of 5.08 inches in 24 hours (25-year average recurrence interval).

Figure 4.1 shows the runoff coefficient as a percentage (from 0% for no runoff to 100% when all rainfall is converted to runoff). Since the subbasin areas shown were defined for numerical modeling purposes, the results were aggregated to more commonly used subbasin areas — namely, hydrologic units defined by the U.S. Geological Survey (USGS). The smallest hydrologic units, known as HUC 12 watersheds, are shown in Figure 4.2. Area-weighted average runoff coefficients were determined for each of the 15 HUC 12 watersheds in the Middle Raccoon basin. Areas in Iowa with the highest runoff potential are primarily located in the Des Moines Lobe portions of Carroll, and Greene counties. Runoff coefficients exceed 50% in many of these areas. Although agricultural land use dominates the entire watershed, it does even more so in these two counties which drives up the average Curve Number. From a hydrologic perspective, flood mitigation projects that can reduce runoff from these high runoff areas would be a priority.

Still, high runoff potential is but one factor in selecting locations for potential projects. Alone, it has limitations. For example, the two counties in Iowa with the highest runoff areas have very flat terrain; the average subbasin slopes are at or below the basin average. Flat terrain would make the siting of flood mitigation ponds more challenging. Indeed, there are many factors to consider in site selection. Landowner willingness to participate is essential. Also, existing conservation practices may be in place, or areas such as timber that should not be disturbed. Stakeholder knowledge of locations with repetitive loss of crops or road structures is also valuable in selecting locations.

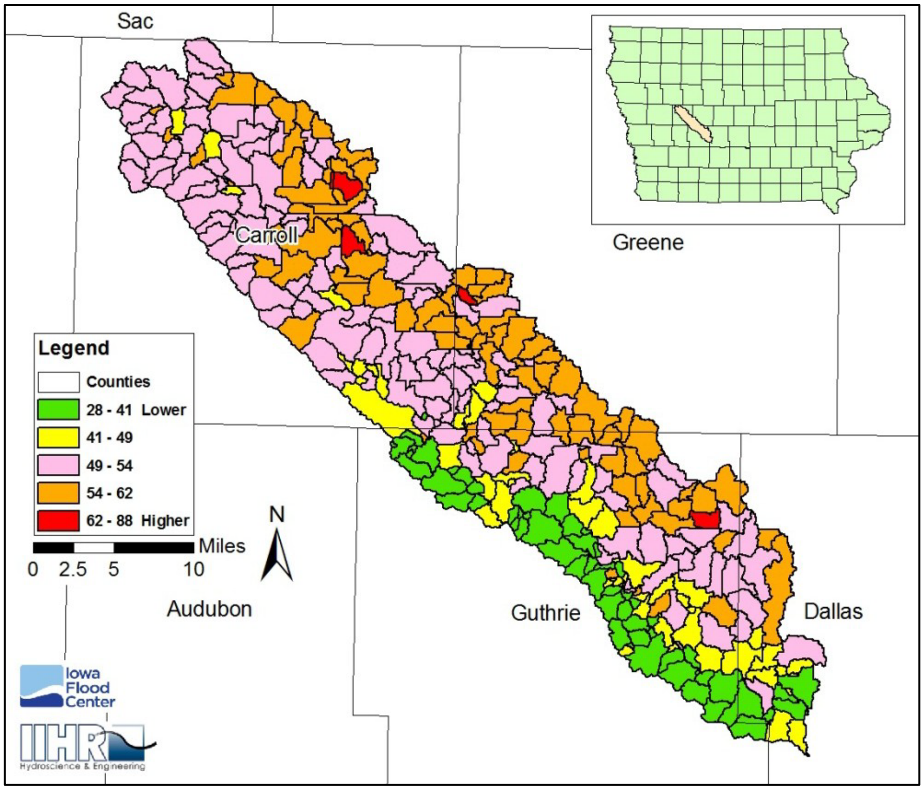


Figure 4.1. Runoff Potential Analysis for 25 yr – 24 hr storm (5.08" of rain) displayed by subbasin.

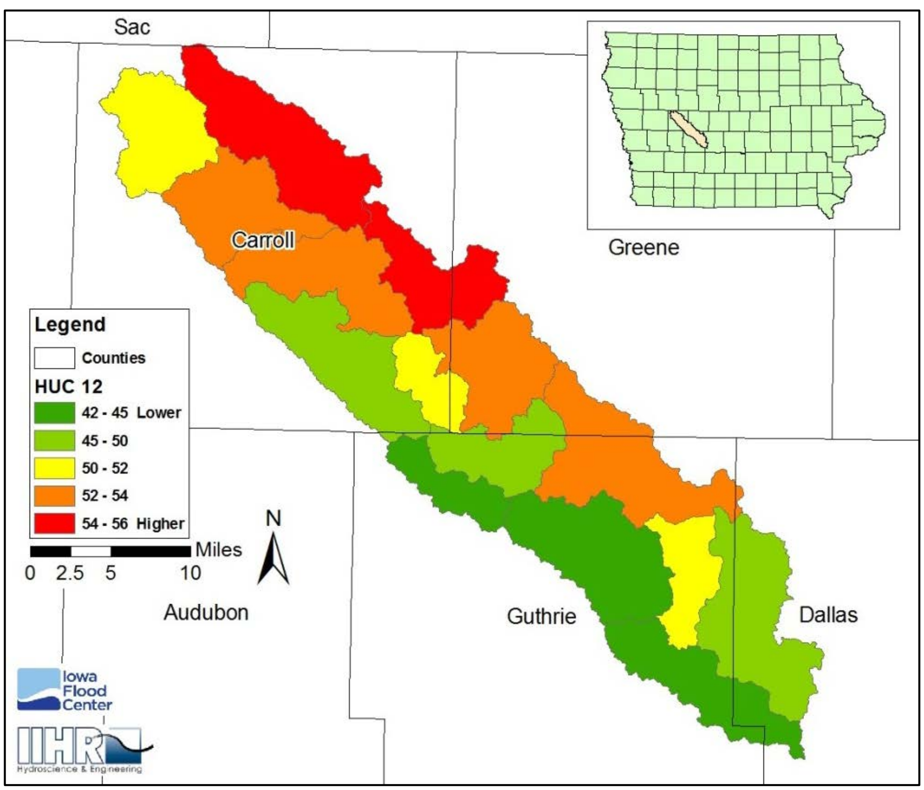


Figure 4.2. Runoff Potential Analysis for 25 yr – 24 hr storm (5.08" of rain) aggregated to HUC12 Boundaries. Similar to Figure 4.1, high potential runoffs are labeled in orange and red.

b. Mitigating the Effects of High Runoff with Increased Infiltration

Reducing runoff from areas with high runoff potential may be accomplished by increasing how much rainfall infiltrates into the ground. Changes that result in higher infiltration reduce the volume of water that drains off the landscape during and immediately after the storm. The extra water that soaks into the ground may later evaporate. Or it may slowly travel through the soil, either seeping deeper into the groundwater storage or traveling beneath the surface to a stream. Increasing infiltration has several benefits: If the infiltrated water reaches a stream, it arrives much later (long after the storm ends), and its late arrival keeps rivers running during long periods without rain.

In this section, we examine four alternatives for reducing runoff. The first is the conversion of row crop agriculture to forest. The second is the conversion of row crop agriculture back to native tall-grass prairie. The third is improving soil quality and the fourth is the application of the cover crop conservation practice. All four are hypothetical examples; they are meant to illustrate the potential effects on flood reduction. The examples are also not project proposals; they would neither be recommended or practically feasible. Still, the hypothetical examples do provide valuable benchmarks on the limits of flood reduction that are physically possible with runoff reduction.

i. Land Use Change

Land Use Change: Agriculture to Forest

An analysis was performed to quantify the impact of land use changes on the flood hydrology of the Middle Raccoon River Watershed. In this example, all current agricultural land use is converted to forest. Note that forest land use has the highest infiltration capacity that the landscape could reasonably support. Obviously, moving to this condition is unlikely to occur, but this scenario is an important benchmark to compare with any watershed improvement project considered.

To simulate the conversion to forest with the HMS model, the model parameters affecting runoff potential across the landscape (Curve Number) were adjusted to reflect the forest condition. Specifically, existing agricultural land use, which accounts for 77% of the watershed area, was redefined as forest. New SCS Curve Numbers, reflecting the lower runoff potential of forest, were assigned to each subbasin. It is important to note that other parameters estimated from Curve Numbers — such as the water flow travel time through the subbasin — were not adjusted. Thus, this scenario only considers the reduction in runoff volume resulting from the enhanced infiltration capacity of the forest; the attenuation and delay in the timing of the peak discharge that would be expected as well due to a much higher surface roughness and travel time is not considered. Following assignment of new subbasin Curve Numbers, the model was run for a set of design storms. Comparisons were made between current and forest simulations for the 10-, 25-, 50-, and 100-year return period 24-hour SCS design storms. Using design storms of different severity illustrates how flooding characteristics change during more intense rainstorms.

As expected, converting 77% of the watershed from row crop agriculture to forest has a significant effect on the flood hydrology. For the 10-year return period design storm (4.03 inches of rain in 24 hours), the simulated forest infiltrates 0.9 inches more into the ground than the current agricultural landscape. The additional infiltration increases to 1.1 inch for a 25-year storm, 1.3

inches for a 50-year storm, and 1.4 inches for a 100-year storm. As a result of increased infiltration across the landscape, the river response is dampened.

Figure 4.3 shows several locations in the watershed that were selected as points of reference for comparing flood flows for watershed improvement scenarios to current conditions. The two USGS stream-gages and the three IFC stage gauges in the watershed were selected as reference (index) points.

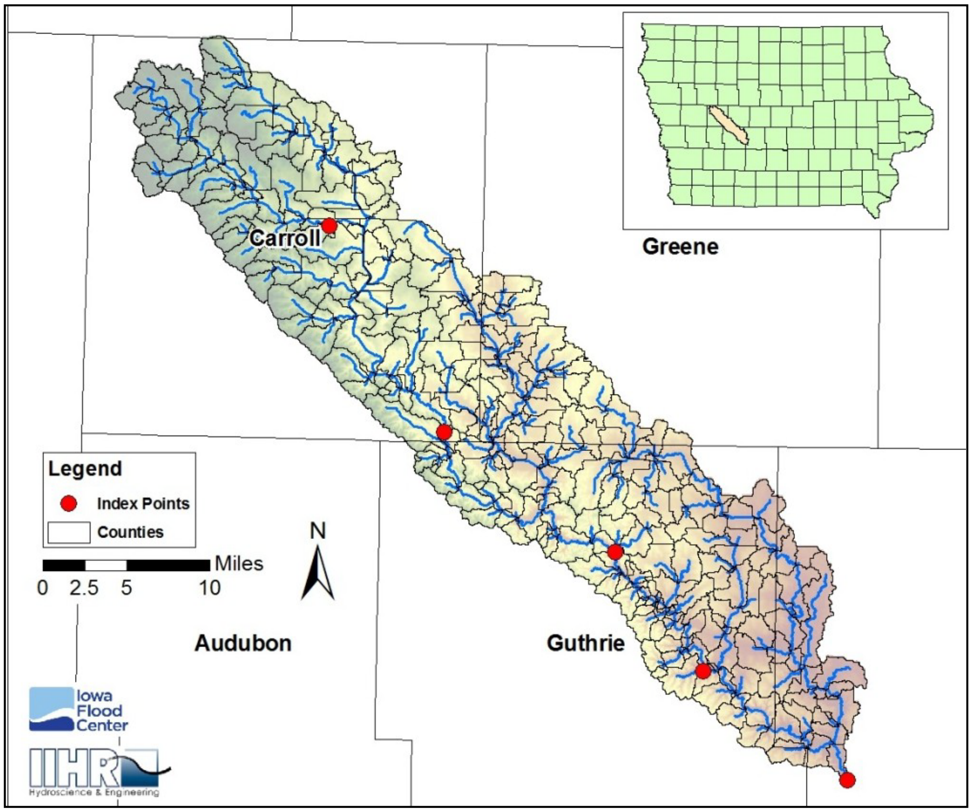


Figure 4.3. Index locations used for comparing watershed improvement scenarios to current conditions. The two USGS discharge gauges and the three IFC stage gauges served as points of reference to compare scenario results to existing conditions.

Figure 4.4 compares the simulated flood hydrographs for the current agricultural landscape (baseline) to those for the forest landscape scenario for the 50-year return period 24-hour design storm (6.00 inches of rain in 24 hours). For four locations shown — from an upstream subbasin area (Carroll, IA) to the outlet of the Middle Raccoon River at Redfield — the river discharges and peak discharge rates are significantly less for a forest landscape. At Carroll, the smallest drainage area shown (73.8 square miles), about 1.6 additional inches of rainfall would infiltrate if this area were forest, resulting in a 44% reduction in its flood peak discharge. At downstream locations, the peak discharge reduction remains nearly uniform (between 40 and 42%), reflecting the relatively even distribution of agriculture throughout the watershed. Figure 4.5 summarizes the peak discharge for current conditions, the peak discharge for the hypothetical forest scenario, and the peak reduction effect, at all five index locations for the 50- year 24-hour design storm event.

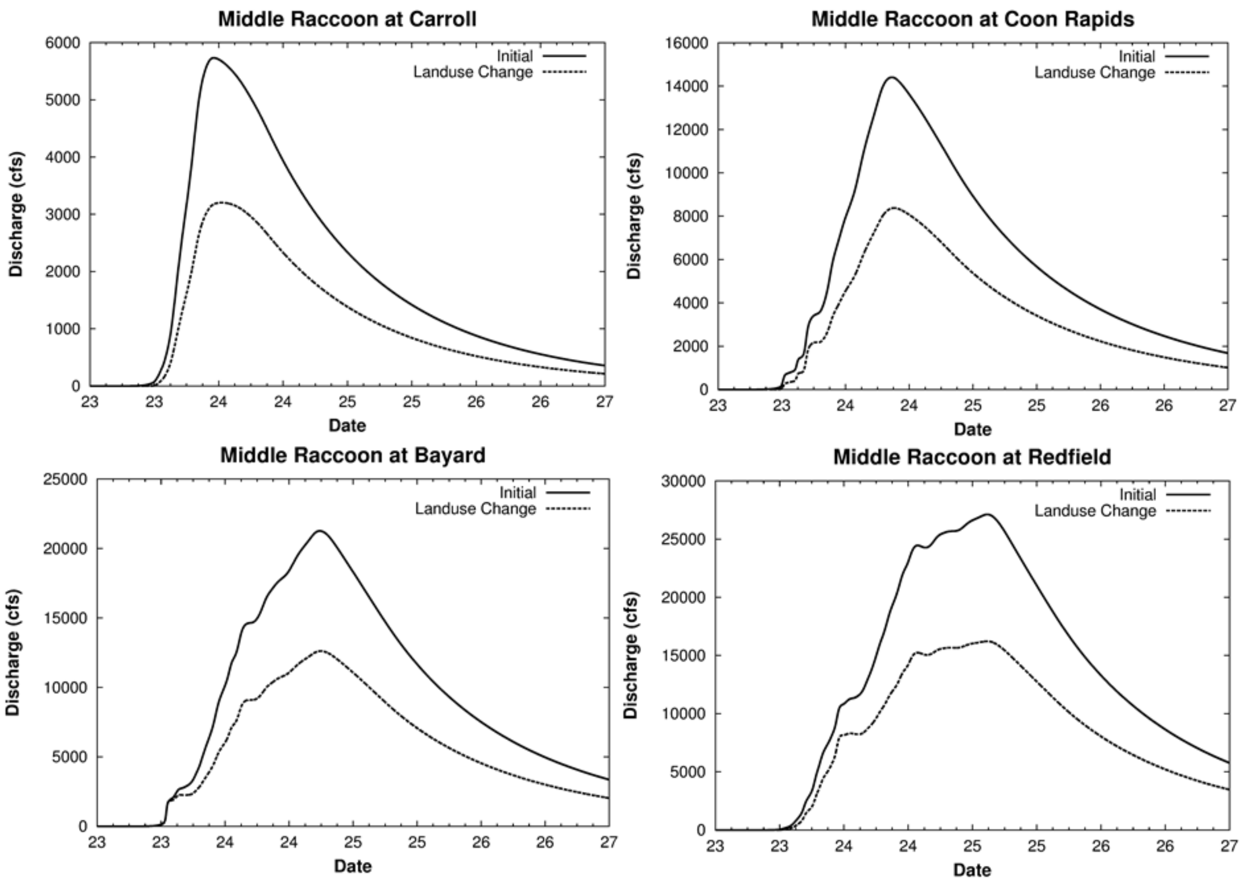


Figure 4.4. Hydrograph comparison at several locations for the increased infiltration scenario resulting from hypothetical land use changes (conversion of row crop agriculture to forest). Results shown are for the 50 year – 24 hour storm (6.00 inches of rain).

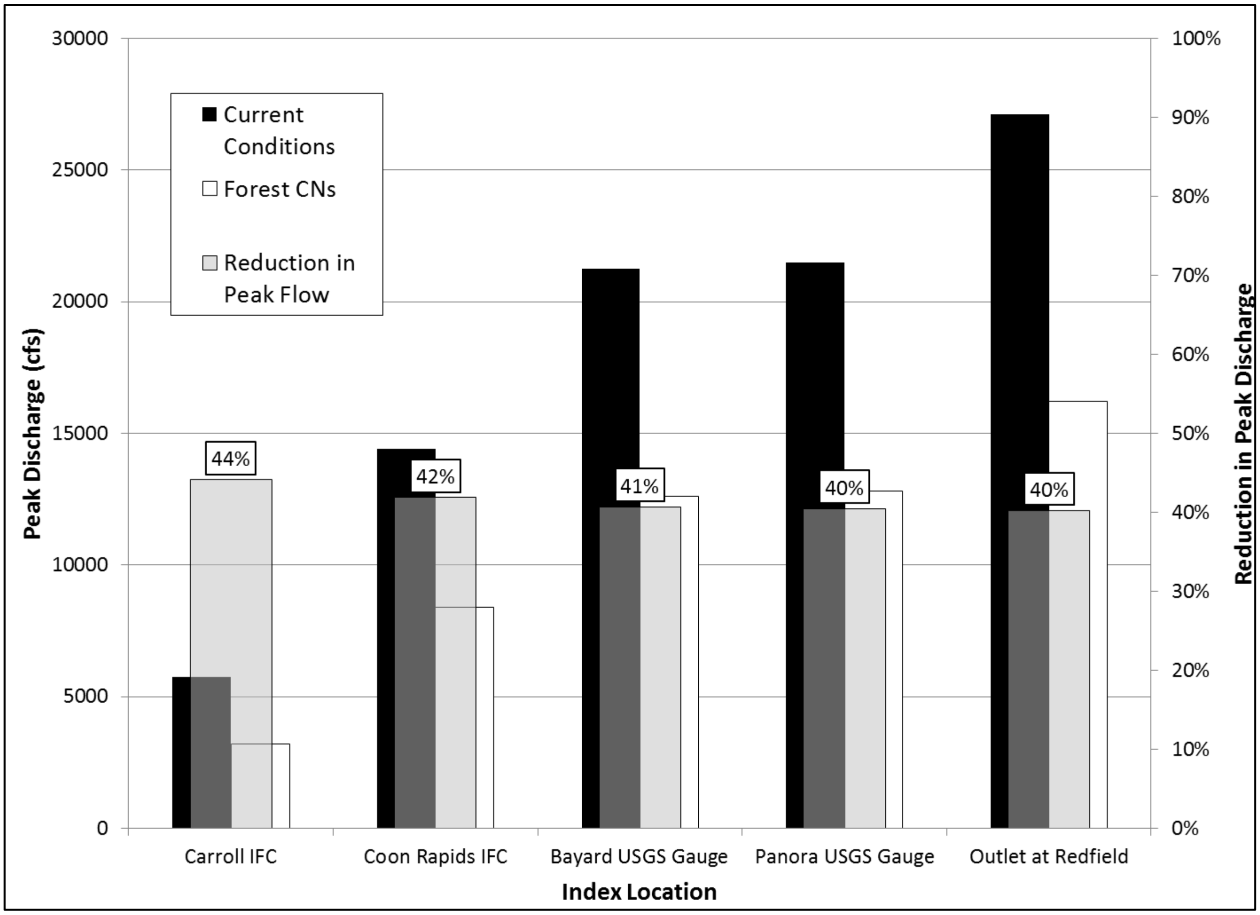


Figure 4.5. Percent reductions in peak flow for the increased infiltration scenario due to land use changes (conversion of row crop agriculture to forest). Peak flow reductions at five index locations progressing from upstream (left) to downstream (right) are shown for the 50-year 24-hour design storms (6.00 inches of rainfall).

Table 4.1 summarizes the percent reductions in peak discharge resulting from this hypothetical forest scenario at the five index locations for all the design storm events. The conversion of agriculture to forest results in peak discharge reductions of 36 to 56%. The peak reduction is largest for the smallest design storm (10-year return period), and decreases with larger rainfall amounts (up to the 100-year return period). In other words, the runoff reduction benefits of increased infiltration are greater for smaller rainfall events; still, for this forest scenario, there is still a significant peak reduction benefit for large floods. Note also that the percent reduction in peak discharge is fairly uniform at all locations. Again, this outcome reflects the relatively equal distribution of agricultural land throughout the watershed.

Table 4.1. Percent Reductions in peak discharge for agriculture to forest scenario.

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Index Location	10-YR (4.03 in)	25-YR (5.08 in)	50-YR (6.00 in)	100-YR (7.04 in)
Carroll IFC Gauge	56.1	49.0	44.1	39.7
Coon Rapids IFC Gauge	53.9	46.7	41.9	37.5
Bayard USGS Gauge	52.6	45.5	40.7	36.4
Panora USGS Gauge	52.4	45.2	40.4	36.2
Redfield IFC Gauge (Outlet)	52.1	44.9	40.2	35.9

Reducing peak flood discharge also reduces the peak water height (or stage) in a river during the flood. During a flood, the river stage is higher than the channel itself, so water flows out of the channel and inundates the surrounding floodplain. Hence, even small reductions in flood stage can significantly reduce the inundation area. For the peak discharge reductions in the agriculture to forest scenario, the corresponding reduction in flood stage is between 2.6 and 4.6 feet. This reduction was estimated for the USGS stream-gage locations, where the relationship between river stage and discharge — also known as a rating curve — has been measured.

Although a 2.6 to 4.6 foot reduction in flood stage would substantially reduce the flood inundation area, flooding still occurs in the forest simulation. For instance, based on the flood stage level reported by the National Weather Service at Bayard, water levels above action stage (13 feet) are expected for both the current agricultural and the forest landscapes for all rain events. Hence, conversion from agricultural to forest landscape does not eliminate flooding, but would reduce its severity and frequency.

Land Use Change: Agriculture to Native Prairie Tall-Grass

Much has been documented about the historical water cycle of the native tall-grass prairie of the Midwest. Some evidence suggests that the tall-grass prairie could handle up to six inches of rain without having significant runoff. The deep, loosely packed organic soils, and the deep root systems of the prairie plants, allowed a high volume of the rainfall to infiltrate into the ground. The water was retained by the soils instead of rapidly traveling to a nearby stream as surface flow. Once in the soils, much of the water was actually taken up by the root systems of the prairie grasses.

Similar to the previous scenario, an analysis was performed to quantify the impact of human-induced land use changes on the flood hydrology of the Middle Raccoon River Watershed. In this example, all current agricultural land use is converted to native tall-grass prairie with its much higher infiltration capacity. Obviously, returning to this pre-settlement condition is unlikely to occur. Still, this scenario is an important benchmark to compare between current conditions, to the most favorable hydrologic conditions historically seen in this area.

To simulate the conversion to native tall-grass prairie with the HMS model, the model parameters affecting runoff potential across the landscape were adjusted to reflect the tall-grass prairie condition. Specifically, existing agricultural land use, which accounts for 77% of the watershed area, was redefined as tall-grass prairie. New SCS Curve Numbers, reflecting the lower runoff potential of prairie, were assigned to each subbasin. It is important to note that other parameters estimated from Curve Numbers — such as the water flow travel time through the subbasin — were not adjusted. Thus, this scenario only considers the reduction in runoff volume resulting from the enhanced infiltration capacity of the native prairie; the attenuation and delay in the timing of the peak discharge that would be expected as well due to a much higher surface roughness and travel time is not considered. Following assignment of new subbasin Curve Numbers, the model was run for a set of design storms. Comparisons were made between current and tall-grass prairie simulations for the 10-, 25-, 50-, and 100-year return period 24-hour SCS design storms. Using design storms of different severity illustrates how flooding characteristics change during more intense rainstorms.

As expected, converting 77% of the watershed from row crop agriculture to native tall-grass prairie has a significant effect on the flood hydrology. For the 10-year return period design storm (4.05 inches of rain in 24 hours), the simulated tall-grass prairie infiltrates 0.7 inches more into the ground than the current agricultural landscape. The additional infiltration increases to 0.9 inch for a 25-year storm, 1.0 inches for a 50-year storm, and 1.1 inches for a 100-year storm. As a result of increased infiltration across the landscape, the river response is dampened.

Figure 4.6 compares the simulated flood hydrographs for the current agricultural landscape (Baseline) to those for a native tall-grass prairie landscape scenario for the 50-year return period, 24-hour design storm (6.00 inches of rain in 24 hours). For all four locations shown — from an upstream subbasin area (Carroll, IA) to the outlet of the Middle Raccoon River at Redfield — the river discharges and peak discharge rates are significantly less for a tall-grass prairie landscape. At Carroll, the smallest drainage area shown (73.8 square miles), about 1.2 additional inches of rainfall would infiltrate if this area were tall-grass prairie, resulting in a 34% reduction in its flood peak discharge. At downstream locations, the peak discharge reduction remains fairly uniform (30 to 32%), reflecting the relatively even distribution of agriculture throughout the watershed. Figure 4.7 summarizes the peak discharge for current conditions, the peak discharge for the hypothetical tall-grass prairie scenario, and the peak reduction effect, at all five index locations for the 50-year, 24-hour design storm event.

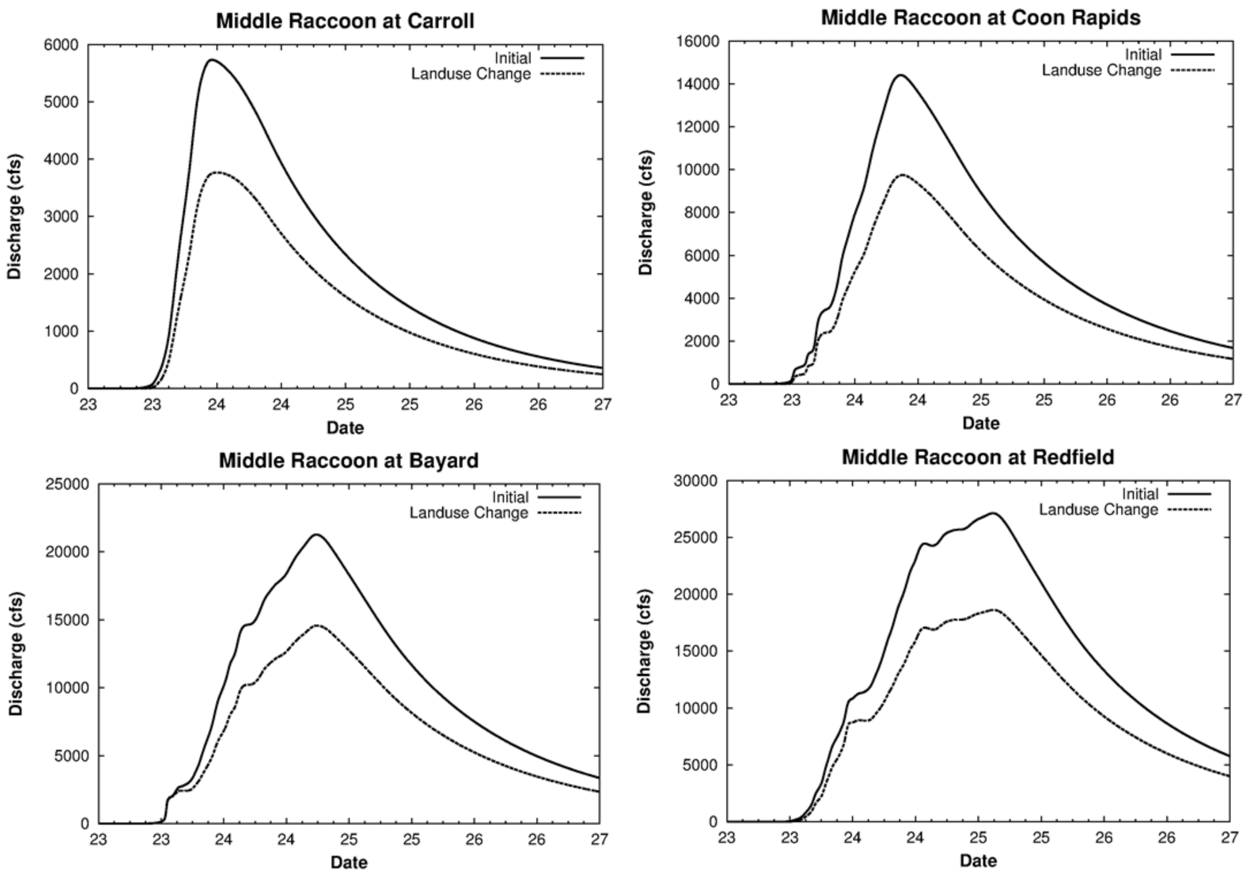


Figure 4.6. Hydrograph comparison at several locations for the increased infiltration scenario resulting from hypothetical land use changes (conversion of row crop agriculture to native tall-grass prairie). Results shown are for the 50 year – 24 hour storm (6.00 inches of rain).

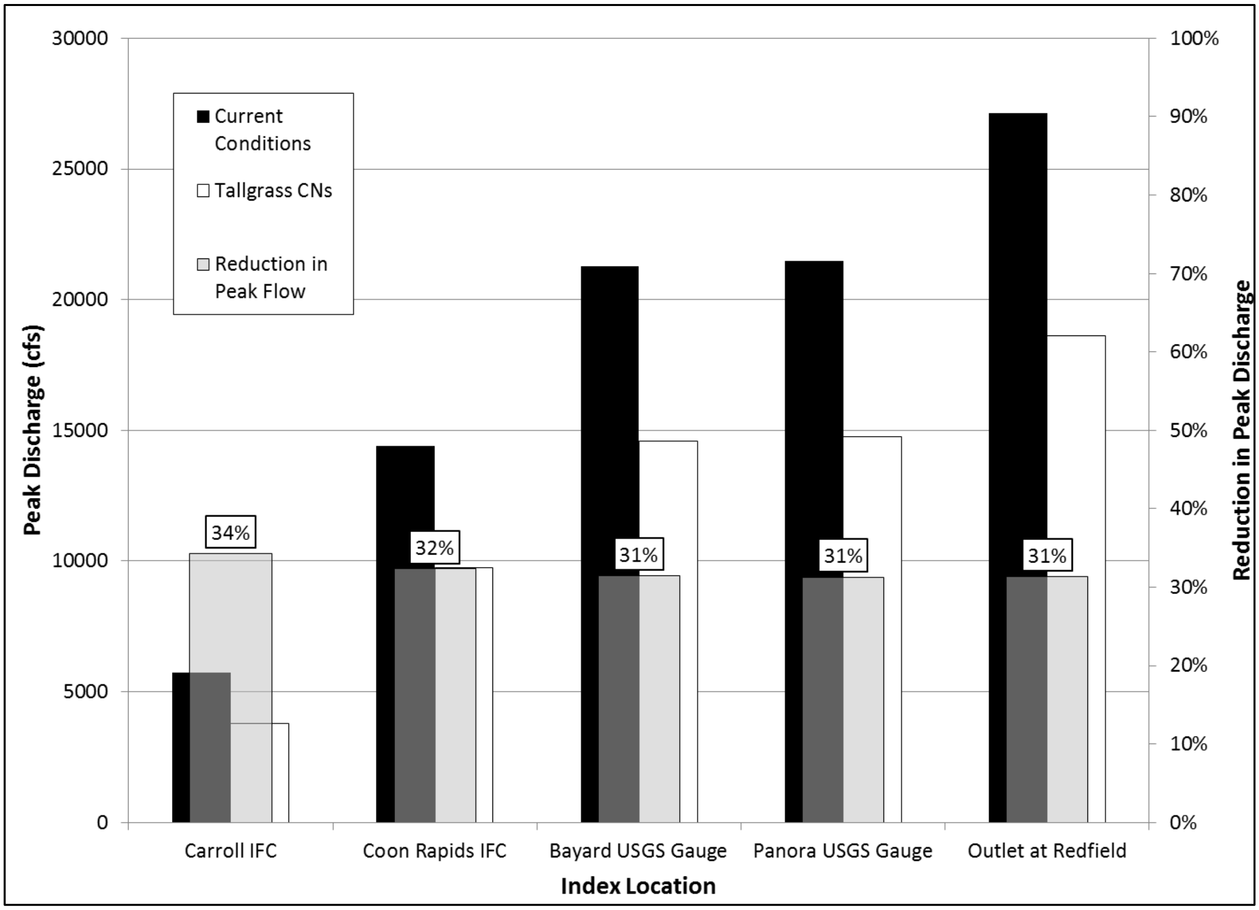


Figure 4.7. Percent reductions in peak flow for the increased infiltration scenario due to land use changes (conversion of row crop agriculture to native prairie). Peak flow reductions at five index locations progressing from upstream (left) to downstream (right) are shown for four different 24 hour, 50 year design storms (6.00 inches of rainfall).

Table 4.2 summarizes the percent reductions in peak discharge resulting from this hypothetical native tall-grass prairie scenario at the five index locations for all the design storm events. The restoration of native tall-grass prairie typically results in peak discharge reductions of 28 to 45%. As in the forest scenario, the peak reduction is largest for the smallest design storm (10- year return period), and decreases with larger rainfall amounts (up to the 100-year return period). Again, note also that the percent reduction in peak discharge is fairly uniform at all locations.

Table 4.2. Percent Reductions in Peak Discharge for Agriculture to Native Prairie Tall-grass Scenario.

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Index Location	10-YR (4.03 in)	25-YR (5.08 in)	50-YR (6.00 in)	100-YR (7.04 in)
Carroll IFC Gauge	44.8	38.5	34.3	30.5
Coon Rapids IFC Gauge	42.8	36.5	32.3	28.7
Bayard USGS Gauge	41.7	35.5	31.5	27.9
Panora USGS Gauge	41.5	35.3	31.3	27.7
Redfield IFC Gauge (Outlet)	41.6	35.4	31.3	27.8

Reducing peak flood discharge also reduces the peak water height (or stage) in a river during the flood. For the peak discharge reductions in the agriculture to tall-grass prairie scenario, the corresponding reduction in flood stage is between 1.9 and 3.5 feet. This reduction was estimated for the USGS stream-gage locations, where the relationship between river stage and discharge — also known as a rating curve — has been measured. Although a 1.9 to 3.5 foot reduction in flood stage would substantially reduce the flood inundation area, flooding still occurs in the native tall-grass prairie simulation. For instance, based on the flood stage level reported by the National Weather Service at Bayard, water levels above action stage (13 feet) are expected for both the current agricultural and the tall-grass prairie landscapes for all rain events. Hence, conversion from agricultural to tall-grass prairie does not eliminate flooding, but would reduce its severity and frequency.

ii. Soil Quality Improvements

Another way to reduce runoff is to improve soil quality. Here, soil quality refers to the infiltration capacity of the soil. Better soil quality (increased soil infiltration characteristics) effectively lowers the runoff potential of the soil. If soil quality throughout the Middle Raccoon River Watershed were improved, it could potentially reduce flood damages.

To simulate improved soil quality with the HMS model, we hypothesize that improvements translate to changes in the NRCS hydrologic soil group. As discussed previously, NRCS rates the runoff potential of soils with four hydrologic soil groups (A through D). Type A soils have the lowest runoff potential; type D soils have the highest runoff potential. The NRCS relies primarily on three quantities to assign a hydrologic soil group: saturated hydraulic conductivity (the rate water flows through the soil under saturated conditions), depth to an impermeable layer, and depth to the ground water table (Hoeft, 2007). Soils with a greater saturated hydraulic conductivity, or greater depth to an impermeable layer or ground water table, are assigned to a hydrologic soil group of lower runoff potential. To increase infiltration into the soil, one or more of these three quantities must be targeted. Obviously, the removal of all poorly draining soils throughout the watershed and replacement with higher infiltrating soils (like sands and gravels) is unrealistic. However, certain conservation and best management practices, such as increasing the organic material content in the soil and the introduction of cover crops, could aid in improving soil health to some degree.

In the HMS model of the Middle Raccoon River Watershed, the effects of improved soil health through conservation and best management practices are represented by changes in the NRCS hydrologic soil group. The most dominant soil type in the Middle Raccoon River watershed is Type B, which makes up 66% of the area. In this scenario, improved soil quality is assumed to improve these soils to Type A. New SCS Curve Numbers, reflecting the lower runoff potential with improved soil quality, were assigned to each subbasin. Then the model was run for a set of design storms. Comparisons were made between the current and improved soil quality simulation for the 10-, 25-, 50-, and 100-year return period 24-hour SCS design storms.

The soil improvement case — where all Type B soils improve to Type A — results in approximately 0.7 inches more infiltration than current soil conditions for the 10-year return period design storm. Additional infiltration increases to about 0.9 inches for the 25-year storm, 1.0 inches for the 50-year and 1.1 inches for the 100-year storms. Figure 4.8 compares the simulated flood hydrographs for the current soil condition (baseline) to those for the first soil improvement case scenario for the 50-year return period, 24-hour design storm (6.00 inches of rain in 24 hours). Type B soils are relatively evenly distributed throughout the watershed, so the percent reduction in peak flow does not vary greatly from the headwaters (27%) to the basin outlet at Redfield (26%) for the 50-year, 24-hour event. Figure 4.9 summarizes the peak discharge for current conditions, the peak discharge for the hypothetical soil quality improvement scenario, and the peak reduction effect, at all five index locations for the 50-year, 24-hour design storm event.

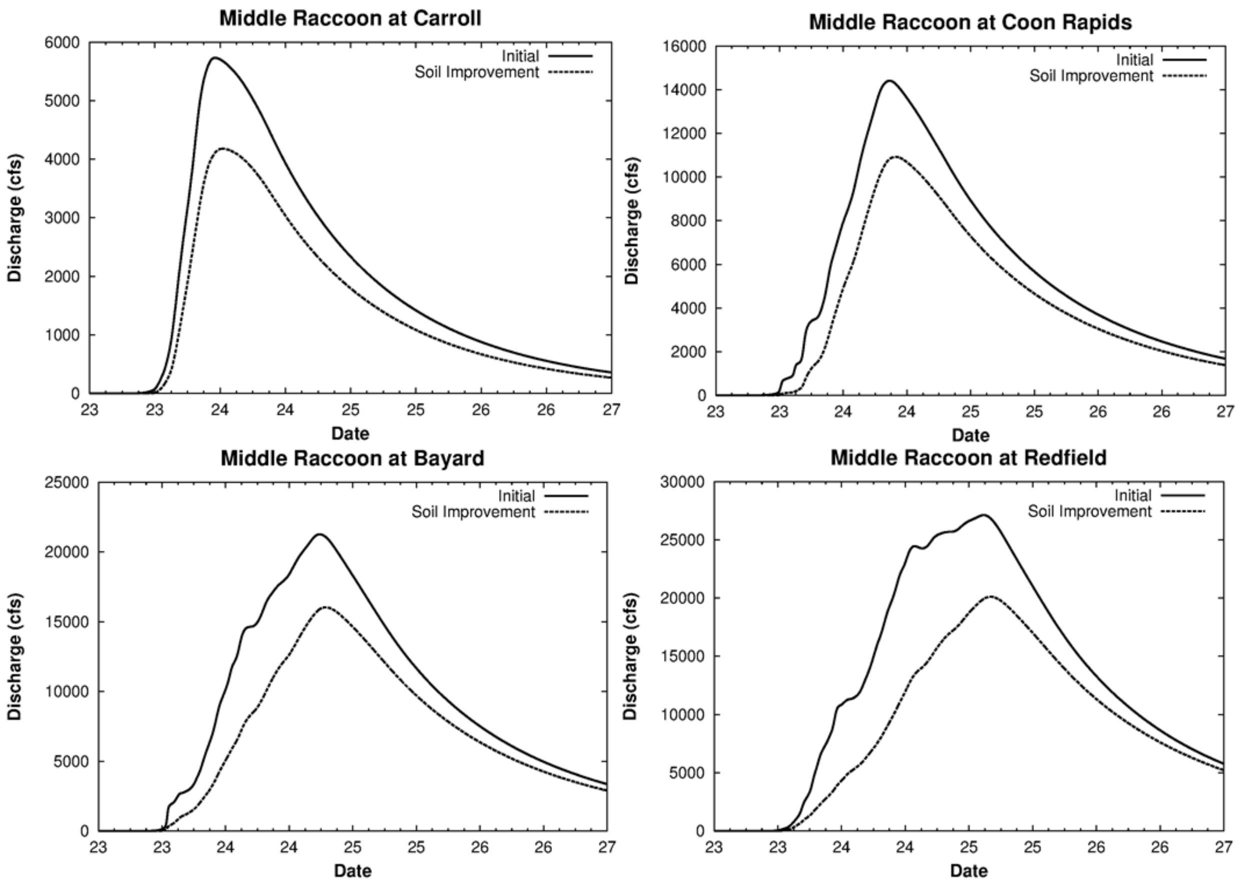


Figure 4.8. Hydrograph comparison at several locations for the increased infiltration scenario due to soil improvements. Improved soil quality was represented by converting all Hydrologic Group B to A. Results shown are for the 50 year – 24 hour storm (6.00 inches of rain).

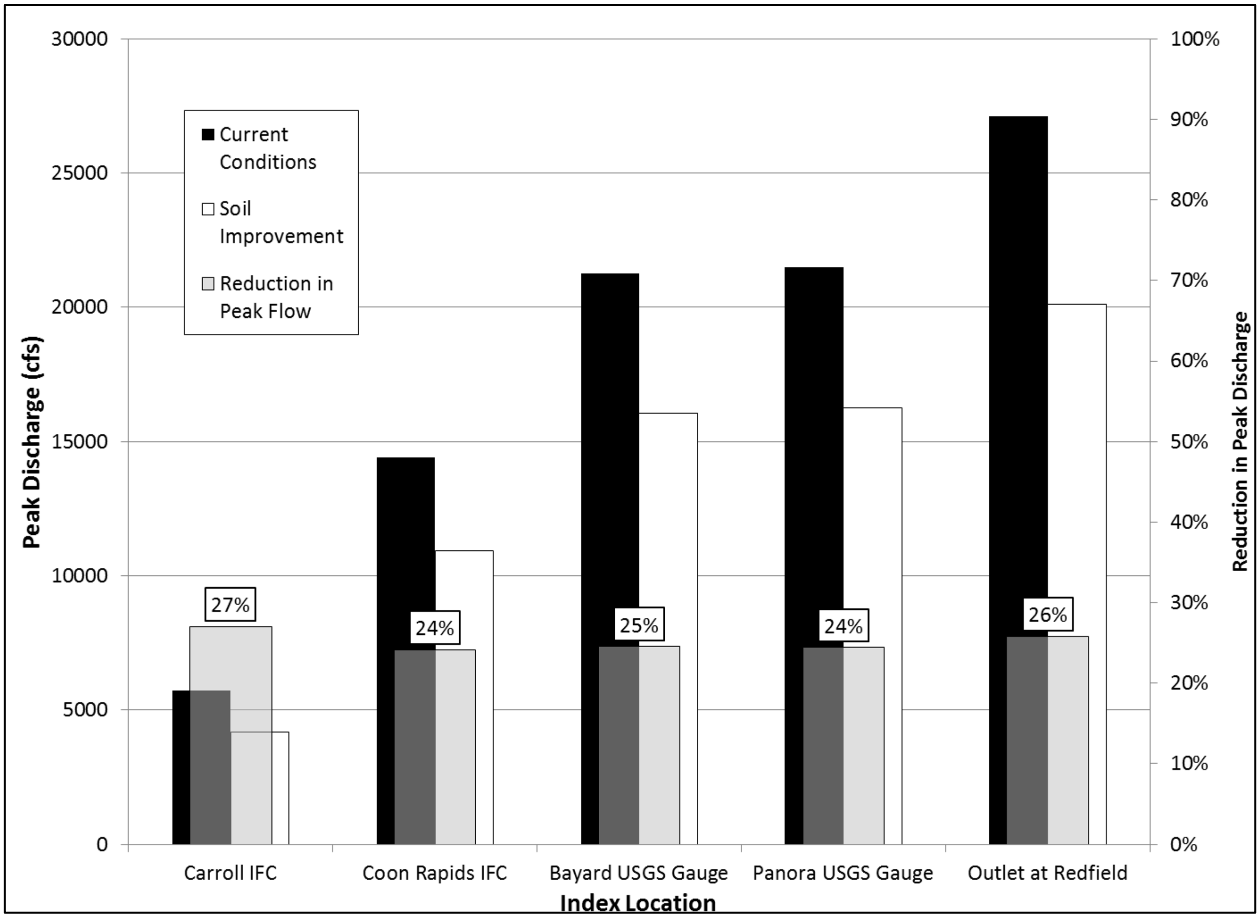


Figure 4.9. Percent reductions in peak flow for the increased infiltration scenario due to soil improvements. Improved soil quality was represented by converting all Hydrologic Soil Group B to A. Peak flow reductions at five index locations progressing from upstream (left) to downstream (right) are shown for four different 24 hour, 50 year design storm (6.00 inches of rainfall).

Table 4.3 summarizes the percent reductions in peak discharge resulting from this hypothetical soil quality improvement scenario at the five index locations for all the design storm events. Improving soil quality typically results in peak discharge reductions of 21 to 36%. As a result, flood stages are reduced by 1.6 to 2.6 feet. As in the two other enhanced infiltration scenarios, the peak reduction is largest for the smallest design storm (10-year return period), and decreases with larger rainfall amounts (up to the 100-year return period). This outcome reflects the landscape's diminished capacity to infiltrate additional water as rain rates increase. Also as seen before, the percent reduction in peak discharge is fairly uniform at all locations.

Table 4.3. Percent Reductions in Peak Discharge for Improved Soil Conditions Scenario

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Index Location	10-YR (4.03 in)	25-YR (5.08 in)	50-YR (6.00 in)	100-YR (7.04 in)
Carroll IFC Gauge	35.8	30.5	27.0	24.0
Coon Rapids IFC Gauge	32.4	27.5	24.2	21.4
Bayard USGS Gauge	33.0	27.9	24.6	21.7
Panora USGS Gauge	32.9	27.8	24.4	21.5
Redfield IFC Gauge (Outlet)	34.7	29.3	25.8	22.8

iii. Planting Cover Crops

While it is evident that the change of land use from the current agricultural state to that of forest or native prairie tall-grass land uses has a large impact on the reduction of peak flow, on the watershed wide scale it is neither an economically feasible or desirable scenario. However, there are other methods with which to increase infiltration without having to take the land entirely out of agricultural production. One common practice is to the use of cover crops. Cover crops, such as oats and rye, are typically grown between times of cash crops to fill a void in times which soil nutrients may otherwise be lost (Dabney, 1998). They affect the hydrology of a watershed by increasing hydraulic roughness, canopy and surface detention storage, and water infiltration rate (Dabney, 1998). For the purposes of this scenario we will focus on a covers crops ability to increase the water infiltration rate. This will be represented in the hydrologic model by a decrease in curve number.

Similar to the land use change scenarios, an analysis was performed to quantify the impact of applying uniform cover crops on the flood hydrology of the Middle Raccoon River Watershed. In this example, all current agricultural land use is assumed to use cover crops. It would be a rare or improbable case in which all the agriculturally productive land was planted with cover crop yet, this scenario will quantify the maximum reductions in peak flood discharge that could be expected for watersheds using cover crop conservation practices.

To simulate the application of cover crops with the HMS model, the model parameters affecting runoff potential across the landscape were adjusted to reflect hydrology of a watershed using cover crops. Specifically, existing agricultural land use, which accounts for 77% of the watershed area, was redefined as agriculture with cover crops. New SCS Curve Numbers, reflecting the lower runoff potential, were assigned to each subbasin. It is important to note that, as in the prior scenarios, other parameters estimated from Curve Numbers — such as the water flow travel time through the subbasin — were not adjusted. Thus, this scenario only considers the reduction in runoff volume resulting from the enhanced infiltration capacity of the cover crops; the attenuation and delay in the timing of the peak discharge that would be expected due to the increased canopy and surface detention, increased hydraulic roughness, and increase in evaporation and transpiration were not considered. Following assignment of new subbasin Curve Numbers, the model was run for a set of design storms. Comparisons were made between current and cover crop simulations for the 10-, 25-, 50-, and 100-year return period 24-hour SCS design storms. Using design storms of different severity illustrates how flooding characteristics change during more intense rainstorms.

As expected, assuming 77% of the watershed is using the cover crop conservation practice has a large impact of peak discharge. For the 10-year return period design storm (4.05 inches of rain in 24 hours), the simulated cover crops infiltrate 0.3 inches more into the ground than the current agricultural landscape. The additional infiltration generally increases to 0.3 inch for a 25-year storm, 0.4 inches for a 50-year storm, and 0.4 inches for a 100-year storm. As a result of increased infiltration across the landscape, the river response is slightly dampened.

Figure 4.10 compares the simulated flood hydrographs for the current agricultural landscape (Baseline) to those for a cover cropped landscape scenario for the 50-year return period, 24- hour design storm (6.00 inches of rain in 24 hours). For all four locations shown — from an upstream subbasin area (Carroll, IA) to the outlet of the Middle Raccoon River at Redfield, IA — the river discharges and peak discharge rates are less for a landscape using cover crops. At Carroll, the smallest drainage area shown (73.8 square miles), about 0.3 additional inches of rainfall would infiltrate if this area were using cover crops, resulting in a 9% reduction in its peak flood discharge. Downstream locations, remain fairly uniform (7 to 9%), reflecting the relatively even distribution of agriculture throughout the watershed. Figure 4.11 summarizes the peak discharge for current conditions, the peak discharge for the cover crop scenario, and the peak reduction effect, at all five index locations for the 50-year, 24-hour design storm event.

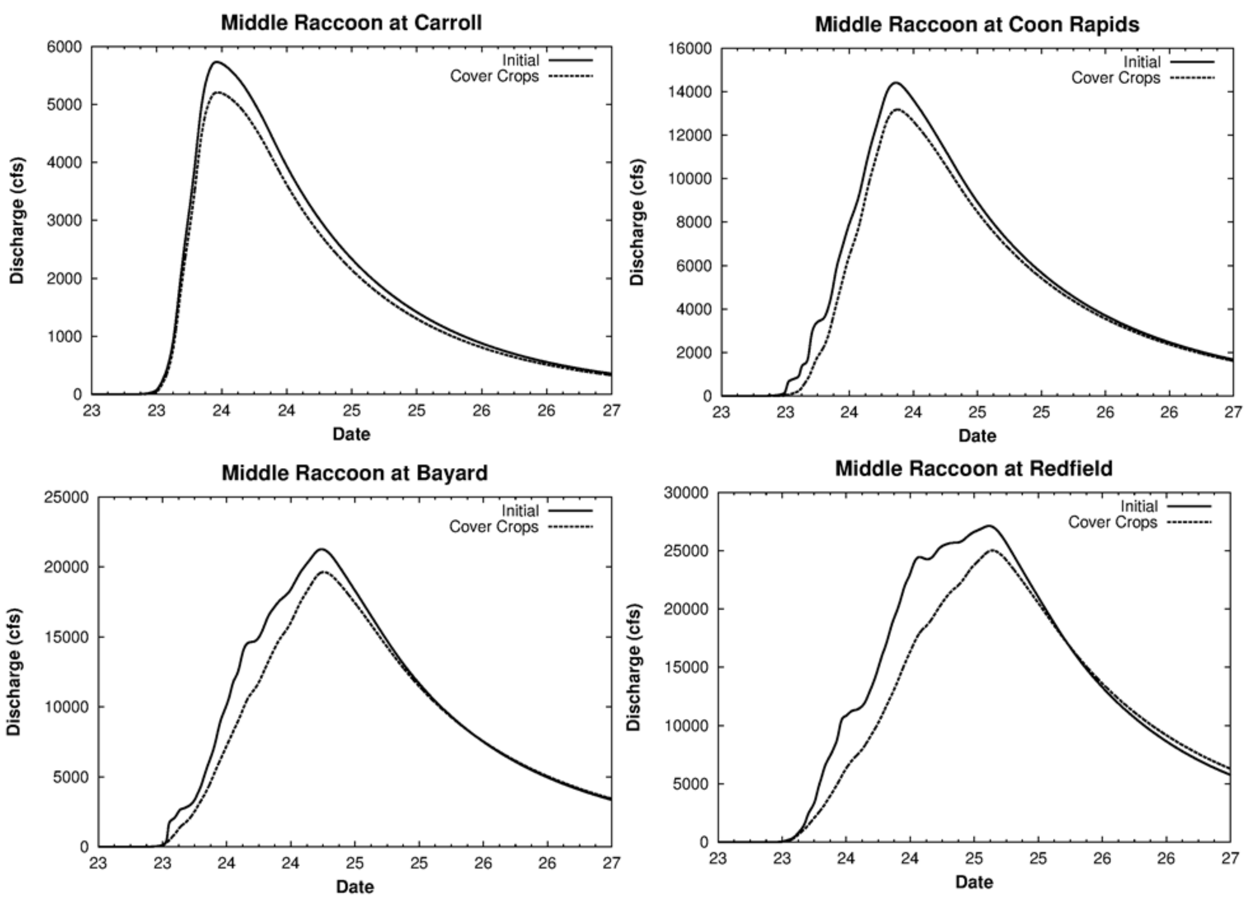


Figure 4.10. Hydrograph comparison at several locations for the increased infiltration scenario resulting from hypothetical conservation practice (conversion of row crop agriculture to agriculture using cover crops). Results shown are for the 50-year, 24-hour storm (6.00 inches).

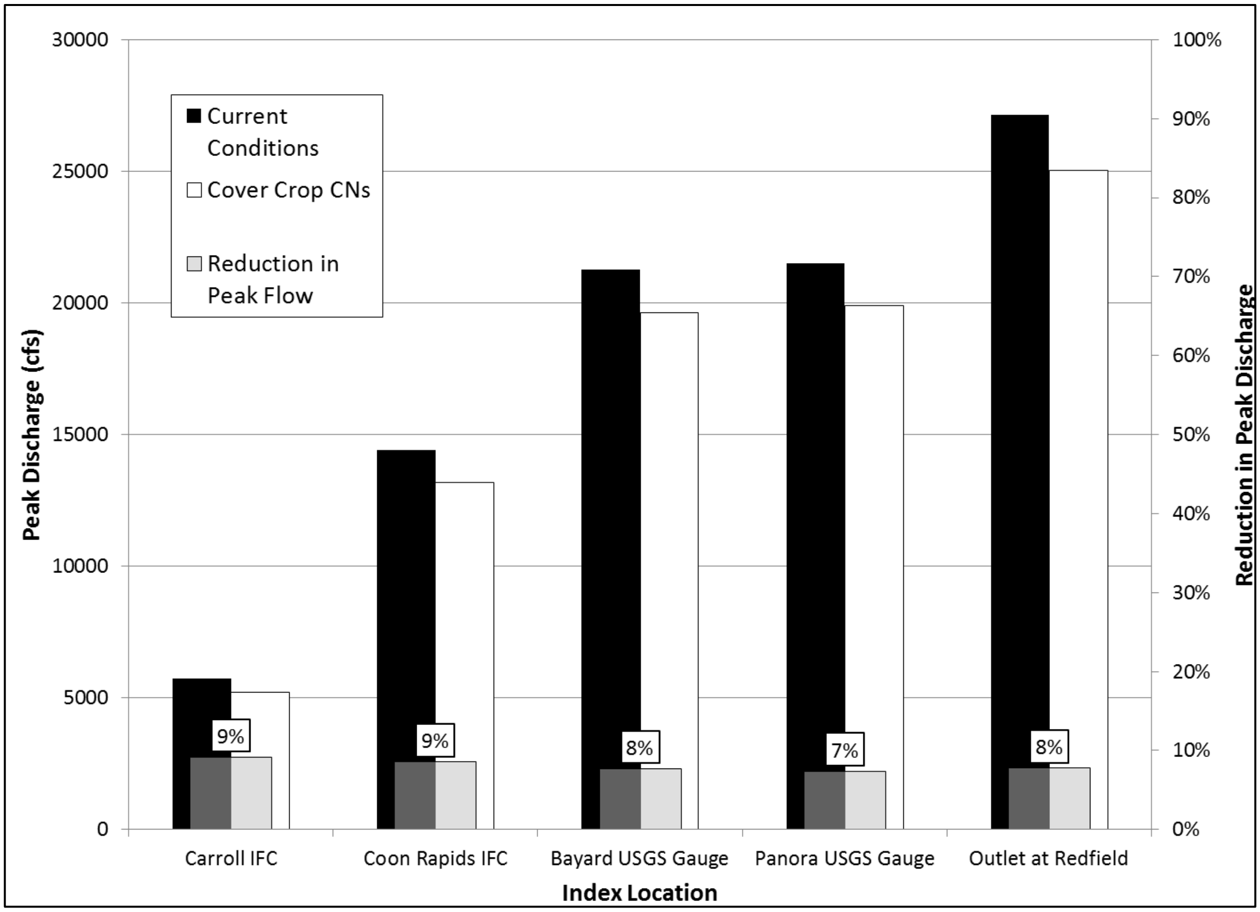


Figure 4.11. Percent reductions in peak flow for the increased infiltration scenario due to land use changes (conversion of row crop agriculture to agriculture using cover crops). Peak flow reductions at five index locations progressing from upstream (left) to downstream (right) are shown for the 50-year, 24- hour design storms (6 inches).

Table 4.4 summarizes the percent reductions in peak discharge resulting from this hypothetical cover crop scenario at the five index locations for all the design storm events. The cover crops typically result in peak discharge reductions of 6 to 13%. As in the other increased infiltration scenarios, the peak reduction is largest for the smallest design storm (10-year return period), and decreases with larger rainfall amounts (up to the 100-year return period). Again, note also that the percent reduction in peak discharge is fairly uniform at all locations.

Table 4.4. Percent reductions in peak discharge for the use of cover crops scenario.

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Index Location	10-YR (4.03 in)	25-YR (5.08 in)	50-YR (6.00 in)	100-YR (7.04 in)
Carroll IFC Gauge	12.8	10.5	9.4	7.9
Coon Rapids IFC Gauge	12.2	9.9	8.5	7.4
Bayard USGS Gauge	11.2	9.0	7.7	6.5
Panora USGS Gauge	10.9	8.7	7.4	6.2
Redfield IFC Gauge (Outlet)	11.5	9.2	7.8	6.5

Reducing peak flood discharge also reduces the peak water height (or stage) in a river during the flood. For the peak discharge reductions in the agriculture to agriculture with cover crops scenario, the corresponding reduction in flood stage is between 0.4 and 0.8 feet. This reduction was estimated for the USGS stream-gage locations, where the rating curves have been developed. Although a 0.4 to 0.8 foot reduction in flood stage would slightly reduce the flood inundation area, flooding still occurs. Again, based on the flood stage level reported by the National Weather Service at Bayard, water levels above action stage (13 feet) are expected for both the current agricultural and the agriculture with cover crops for all rain events. Hence, the addition of cover crops does not eliminate flooding, but would reduce its severity and frequency.

c. Mitigating the Effects of High Runoff with Flood Storage

Another way to mitigate the effects of high runoff is with distributed flood storage. Ponds provide the most common type of flood storage. In agricultural areas, ponds usually hold some amount of water at all times. However, ponds also have the capacity to store additional water during high runoff periods. This so-called flood storage can be used to reduce flood peak discharges.

Unlike the increased infiltration approaches for reducing runoff, storage ponds do not change the volume of water that runs off the landscape. Instead, storage ponds hold floodwater temporarily, and release it at a lower rate. Therefore, the peak flood discharge downstream of the storage pond is lowered. The effectiveness of any one storage pond depends on its size (storage volume) and how quickly water is released. By adjusting the size and the pond outlets, storage ponds can be engineered to efficiently utilize their available storage for large floods.

A system of ponds located throughout a watershed could be an effective strategy for reducing flood peaks at many stream locations. As an example, in the 1980s, landowners in southern Iowa came together to form the Soap Creek Watershed Board. Their motivation was to reduce flood damage and soil loss within the Soap Creek watershed. They adopted a plan that included the identification of locations for 154 distributed storage structures (mainly ponds) which could be built within the watershed. As of 2014, 132 of these structures have been built. (Wunsch, 2013)

In this section, the HMS model is used to simulate the effect of pond storage on flood peaks. For this hypothetical example, many ponds are distributed in tributary regions throughout the Middle Raccoon River watershed; because an actual storage pond design requires detailed site-specific information, a prototype pond design that mimics the hydrologic impacts of flood storage was used. Therefore, this example is not a proposed plan for siting a system of storage ponds, as it has not been determined whether suitable sites are available in the simulated locations. Still, this hypothetical example does provide a quantitative benchmark on the effectiveness of distributed flood storage and the flood reduction benefits that are physically possible.

i. Prototype Storage: Pond Design

Many ponds in Iowa have been constructed to provide flood storage. A pond schematic is illustrated in Figure 4.12. The pond is created by constructing an earthen embankment across the stream. A typical pond holds some water at all times (referred to as permanent pond 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 pond. Eventually, the water level reaches the emergency spillway. The emergency spillway is constructed as a means to release water rapidly so the flow does not damage or overtop the earthen embankment. Storage between the permanent pool and emergency spillway is referred to as the total flood storage.

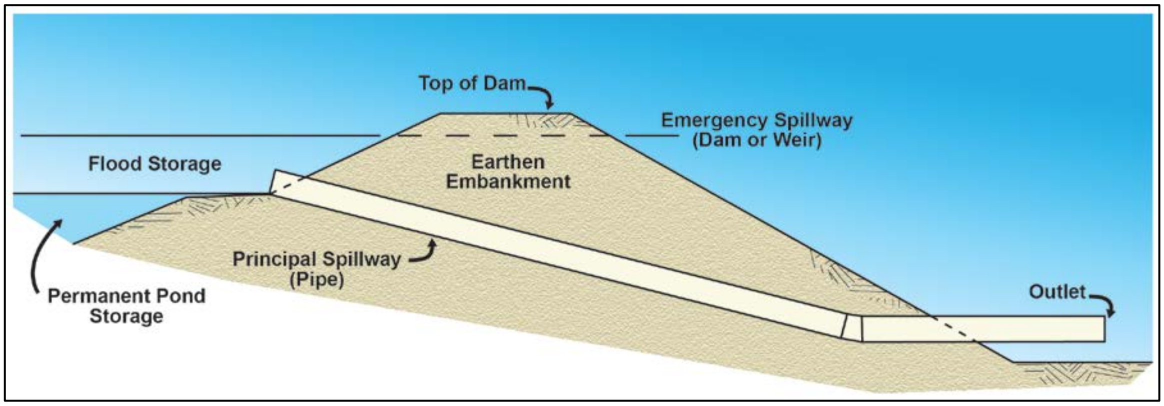


Figure 4.12. Prototype pond used for distributed flood storage analysis.

In addition to the typical pond design above, a second "dry" pond design was considered. A dry pond does not hold water under normal circumstances and, therefore, has no permanent pond storage. In this design, an additional 2-inch diameter outlet is set at the bottom of the pond so that, under normal conditions, inflow will roughly equal outflow. This allows for additional flood storage during times of high runoff, but also means that the pond will not serve additional purposes such as irrigation or watering animals. All of the other design characteristics in the dry pond scenario remained the same.

Prototype Pond Outlet and Emergency Spillway

Using information from ponds constructed in Soap Creek, as well as NRCS Technical References on pond design, a prototype pond outlet and emergency spillway were defined for the simulation experiments. In all cases, a 12-inch pipe outlet was assumed for the principal spillway, a 20 foot wide overflow opening was assumed for the emergency spillway, and the top of the dam was set two feet above the emergency spillway. In the case of dry ponds, an additional 2-inch pipe was considered at the pond bottom.

The elevation difference between the principal and emergency spillways varied; for the typical pond design, simulations were done with elevation differences of 3, 5, 7, and 10 feet. As the elevation difference increased, the available flood storage increased exponentially. Therefore, simulations for ponds with a 10 foot elevation difference have much more flood storage than those with a 3 foot difference. The elevations of the spillway in the pond designs were dependent upon the landform region where the pond was located. Due to its steeper topography, the Southern Iowa Drift Plain region needed higher emergency spillways to match the storage values seen in the flatter Des Moines Lobe region. Emergency spillways in the Southern Iowa Drift Plain were designed at 7 and 10 feet, while emergency spillways in the Des Moines Lobe were designed at 3 and 5 feet.

For the dry pond design, an additional 2 inch pipe was simulated in the Des Moines Lobe ponds; this pipe remained fixed at the bottom of the pond. Simulations were done with the emergency spillway set at 8 and 10 feet above the bottom of the pond. Therefore, the total pond volume did not change between the typical and dry pond designs. For example, in both designs, the total volume of the 3 foot typical pond and the 8 foot dry pond remained fixed at 62.8 acre-feet; only the amount of flood storage varied—26.8 acre-feet versus 34.2 acre-feet for the typical and dry ponds, respectively. In this way, the effects of two ponds were compared with roughly equivalent construction and operation costs, but serving different functions.

The amount of water released downstream by the pond depends on the water depth. The discharge from the principal spillway was determined using pipe flow hydraulic calculations. Once the water depth reached the emergency spillway, releases also included contributions from the emergency spillway. Discharge of the emergency spillway was determined using NRCS Technical References, assuming “C-Type” retardance, which was determined to be a reasonable design assumption (based on discussions with regional NRCS engineers). Discharge downstream began immediately in both ponds, since the typical pond is considered full (at the elevation of the principal spillway) prior to the rainfall event. However, it should be noted that more water would be released through the principal spillway, at the same relative elevation, in the dry pond design compared to the typical design. Since, the dry pond has an additional 2 inch pipe set five feet lower, discharge from the pipe began earlier in this design.

Prototype Pond Shape

Although pond design specifications and built ponds in Iowa provide a reasonable prototype for a pond outlet, the amount of water stored behind an earth embankment requires local knowledge of the topography behind the embankment. For hundreds of unique pond locations, the effort to compute a precise relationship between pond stage (water level) and water storage for each would be enormous. The effort would also be unwise, unless suitable sites for pond structures were selected in the first place (for each and every pond). As a compromise, the relationship between stage and storage at eight potential pond sites in the Middle Raccoon River watershed was analyzed, and the results were averaged to define a prototype pond shape.

The first step was to select several potential pond sites in the Middle Raccoon River watershed for topographic analysis. Figure 4.13 shows the subbasins in the HMS model. Of these, 160 were headwater basins. Headwater basins make good locations for flood storage ponds; they have relatively small drainage areas, and typical pond outlets (like the prototype above) can effectively reduce flood discharge at this scale. Hence, eight of the 160 headwater basins were selected as exploratory sites. These eight were scattered throughout the watershed and encompassed both geographic landform regions (four in the Des Moines Lobe and four in the Southern Iowa Drift Plain).

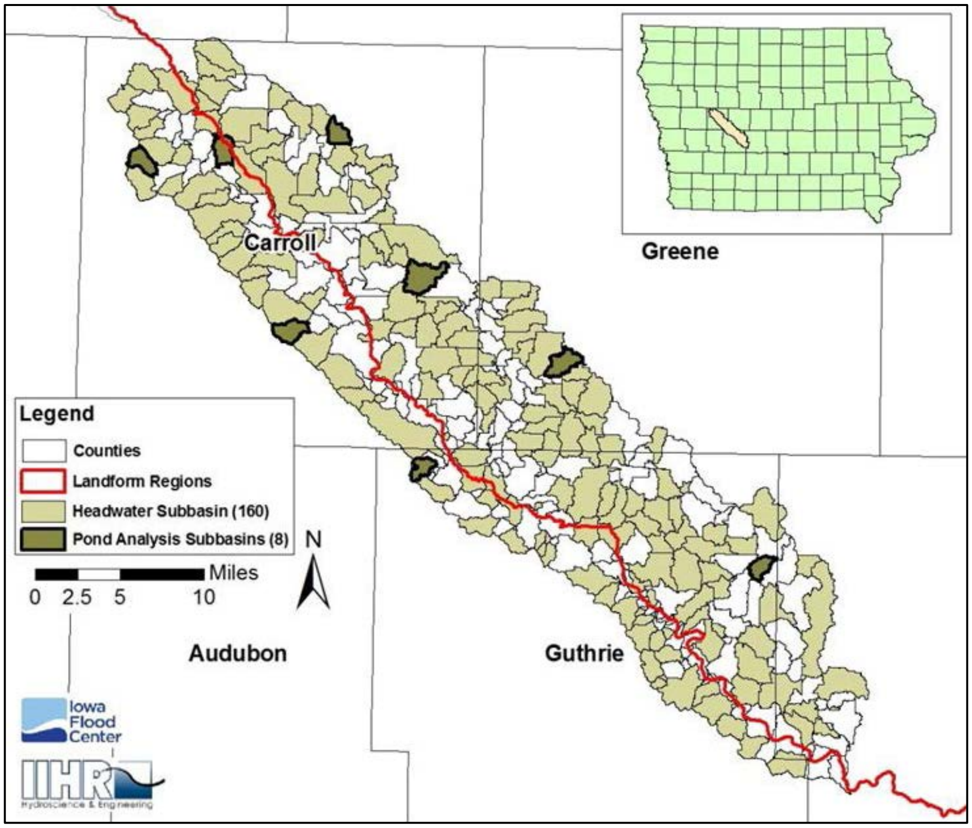


Figure 4.13. Subbasin locations selected for distributed flood storage analysis. Hypothetical ponds were placed in 160 headwater subbasin (beige) and eight of these subbasins (darkened) were used as exploratory sites to develop relevant pond characteristics needed for the HMS model.

In each of the eight subbasins, a location for a pond embankment was selected. Each site was selected based on sufficient topographic relief that would support the construction of a pond. Then, for a given water level, the volume of water that would be impounded behind the dam was computed. This calculation was done by ArcGIS 3D analyst, using the area and volume statistics tool and the 3 m^2 digital elevation model (DEM) of the local terrain. Once the pond location was defined, the tool could calculate volumes and areas for a given water surface elevation; the calculation was repeated for many different water levels. The final result — the storage volume in the pond for different water levels — is known as a stage-storage relationship.

The last step was to compare the different stage-storage relationships developed for the eight pond locations. The stage-storage relationships for similar projects constructed in the Soap Creek watershed were also examined. As expected, stage-storage relationships could be very different at different sites. Indeed, one would anticipate that pond storages for flat topography would be quite different from those for steep topography. As a result, different stage-storage relationships were discovered in the Des Moines Lobe (with its flatter terrain) compared to those in the Southern Iowa Drift Plain (with its steeper terrain). Therefore, two different stage- storage relationships were developed—one for the ponds in the flatter Des Moines Lobe, and another for the ponds in the steeper Southern Iowa Drift Plain. The stage-storage tables for all of the ponds used in distributed storage scenarios can be seen in Appendix B.

Prototype Pond Hydraulics

The pond shape defines the stage-volume relationship as water levels change in the pond. In contrast, the pond outlet defines the stage-discharge relationship for the pond. This information is combined to define the prototype storage-discharge hydraulic relationship needed in HEC- HMS for pond simulations.

In all, 6 different prototype pond storage discharge tables were used. First, for the typical pond designs, four sizes were considered. For the small pond scenario, the emergency spillway elevation was set to 3 feet above the primary spillway in the Des Moines Lobe and 7 feet above the primary spillway in the Southern Iowa Drift Plain; this resulted in a flood storage capacity of 23.8 acre-feet in the Southern Iowa Drift Plain and 26.8 acre-feet in the Des Moines Lobe. For the large pond scenario, the emergency spillway elevation was set to 5 feet above the primary spillway in the Des Moines Lobe and 10 feet above the primary spillway in the Southern Iowa Drift Plain; this resulted in a total flood storage capacity of 38.6 acre-feet in the Southern Iowa Drift Plain and 54.5 acre-feet in the Des Moines Lobe.

For the dry pond design, two sizes were considered. The design of these ponds was identical to the typical pond designs mentioned above, except an additional 2 inch outlet was set at the bottom of the pond. In these ponds, water was not stored under normal circumstances. This resulted in a larger total storage available for flood waters. For these scenarios, dry ponds were only assumed in the Des Moines Lobe landform region. This was due to the fact that the Des Moines Region is much flatter, and a dry pond in this location could reasonably be farmed during non-flood conditions. A dry pond in the Southern Iowa Drift Plain would have much steeper banks and would, therefore, not be conducive to farming practices, and could be seen as undesirable by land owners. For the small dry pond, the emergency spillway was set to 8 feet above the pond bottom in the Des Moines Lobe and 7 feet above the principal spillway in the Southern Iowa Drift Plain; this resulted in a total storage capacity 23.8 acre-feet in the Southern Iowa Drift Plain and 34.2 acre-feet om the Des Moines Lobe. For the large dry pond scenario, the emergency spillway elevation was set to 10 feet above the pond bottom in the Des Moines Lobe and 10 feet above the principal spillway in the Southern Iowa Drift Plain; this resulted in a flood storage capacity of 38.6 acre-feet in the Southern Iowa Drift Plain and 62.8 acre-feet in the Des Moines Lobe. The stage-storage-discharge relationships for all of the typical prototype pond scenarios are found in Appendix B.

Siting of Hypothetical Ponds

To examine the hypothetical impact that flood storage would have on the flood hydrology of the Middle Raccoon River watershed, prototype ponds were placed throughout the headwater subbasins (see again Figure 7.2). In the Soap Creek watershed, where flood storage is already used extensively, the average pond density was 1 built pond for every 1.9 square miles of drainage area. Therefore, for the flood storage simulations for the Middle Raccoon River watershed, it was decided to place pond structures in headwater subbasins at a density of 1 pond for every 2 square miles of drainage area.

The 160 headwater subbasins ranged in size from 0.1 to 8.2 square miles. Hence, all the subbasins contained between one and four ponds. For example, if a subbasin drainage area was 4.2 square miles, it would have two ponds (number of ponds was rounded to the nearest whole number). Furthermore, not all the area within a subbasin drained to a pond; some water would flow into the stream below the ponds and would not be temporarily stored. To handle these conditions in the

HMS model, it was first assumed that half the subbasin areas drain through a pond, and half do not. Next, for areas that drain through a pond, it was assumed that the water passes through only one pond (and not from one to the next and so on). This step was most efficiently accomplished in the model by creating a single aggregate pond. That is, if there were 3 ponds in a subbasin, it had the same aggregate effect of a single pond that had three times the storage and three times the outflow. So from an HMS modeling standpoint, the half of the subbasin that drained through a pond could more simply be routed through a single aggregated pond. In this way, the effects of the pond storage could be estimated, without having to specify the exact physical locations of any pond.

For the 160 headwater subbasins, a total of 198 prototype ponds were simulated. All the subbasins contained between 1 and 4 ponds. Figure 4.14 shows the 160 headwater subbasins, and the number of ponds assigned to each. In HMS, the 198 prototype ponds were represented by 160 aggregated ponds, one for each of the 160 subbasins. Overall, the ponds controlled flows from a total area of 175 square miles (or 30 percent of the watershed); in other words, 30 percent of the watershed area drained through the simulated prototype ponds.

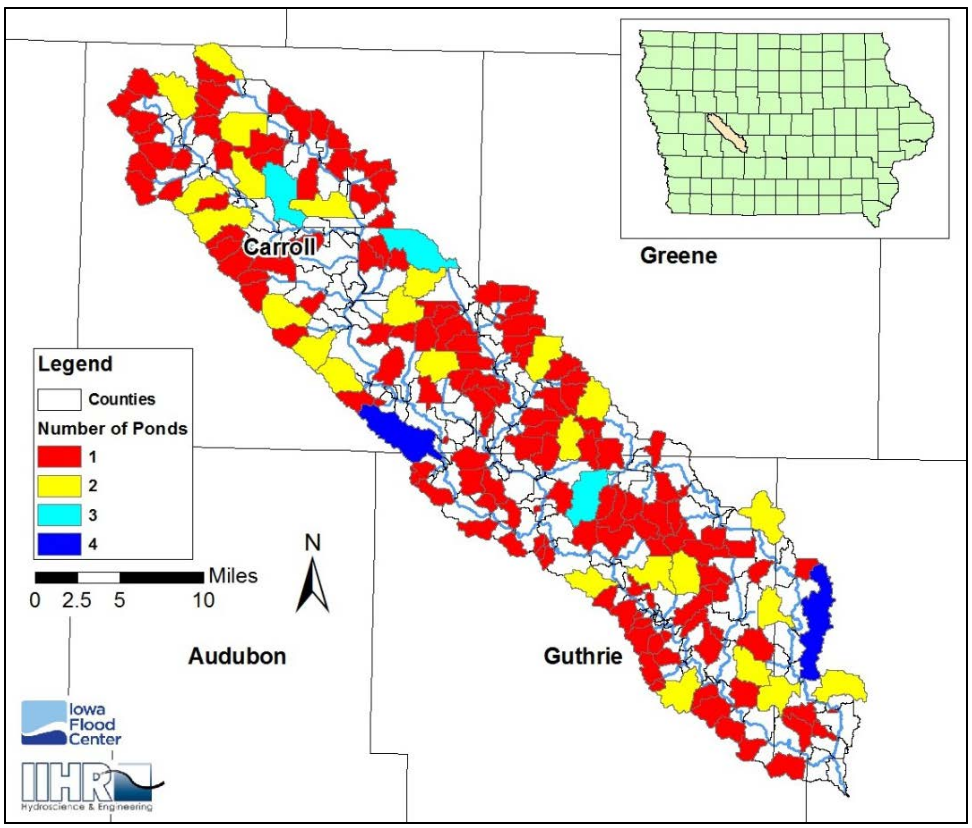


Figure 4.14. Headwater subbasins selected for distributed flood storage analysis and the number of prototype ponds assigned to each subbasin.

For the two USGS stream-gauges and the three IFC stream-gauges, the pond characteristics upstream of the locations are characterized in Table 4.5. Overall, the percentage of the upstream area controlled by ponds was relatively consistent; it ranged from approximately 30 percent for the Middle Raccoon River at Coon Rapids, Bayard, and Redfield, to a maximum of 35 percent for the Middle Raccoon River at Carroll. For the typical ponds, the small ponds had a total flood storage of 4,709 acre-feet; this amount of water placed over the upstream drainage area would have a water depth of 0.5 inches. Hence, the ponds could temporarily store roughly 0.5 inches of runoff from upstream of the ponds before filling completely. For large ponds, the total storage was 9,693 acre-feet; this is equivalent to roughly 1.0 inch.

For the dry ponds, the small ponds had a total storage of 6,051 acre-feet; this amount of runoff placed over the upstream drainage area would have a water depth of 0.6 inches. For large ponds, the total flood storage was 10,765 acre-feet; this is equivalent to roughly 1.2 inches. These average storage depths were relatively consistent for the upstream areas of the five locations.

Table 4.5. Pond characteristics for the distributed flood storage analysis at five index locations.

Location	*Drainage Area (mi^2)*	*Upstream Headwater Subbasins*	*Ponds Upstream*	*Drainage Area Upstream of Ponds (mi^2)*	*Watershed Area Upstream from Ponds*
Carroll	74	21	28	26	35%
Coon Rapids	217	58	72	66	30%
Bayard	382	110	132	116	30%
Panora	426	129	55	131	31%
Redfield	590	160	189	175	30%

Distributed Storage Simulations

The HMS model was run with ponds to simulate the effects of flood storage on peak discharges. Separate model runs were created for the typical pond design and the dry pond design; each pond design was broken into two separate scenarios—small and large ponds. For the small ponds scenario, in the case of the typical pond, each simulation started with all pond water levels at the principal spillway elevation; this assumed that the permanent storage was full as the storm began. For the dry pond, each simulation started with completely empty ponds (inflow equal to outflow). Comparisons were then made for the simulated flows without ponds in place (the existing baseline condition). Flood hydrographs were compared for the 10-, 25-, 50-, and 100-year return period 24-hour SCS design storms.

ii. Typical Pond Results

Small Typical Pond

Figure 4.15 compares the simulated flood hydrographs for the current no pond condition (baseline) to those with small prototype ponds for the 50-year return period 24-hour design storm (6.00 inches of rain in 24 hours). The smallest drainage area shown, at Carroll, IA, has a drainage area of 73.8 square miles. Twenty-eight prototype ponds were placed upstream. As a result, the peak discharge was reduced by 7 percent. The water runoff from this storm quickly filled the available storage and engaged the emergency spillway, so there was limited benefit from ponds of this size. There was only sufficient flood storage available to reduce the peak discharge from 5,733 cfs (with no ponds) to 5,338 cfs (with small ponds).

Even though the area upstream from ponds was very similar throughout the basin, the peak flow reduction was not. At Carroll, where the ponds upstream mostly lie in the Southern Iowa Drift Plain, the peak flow reduction was minimal. The smaller prototype ponds in the Southern Iowa Drift Plain filled faster than the larger ponds in the Des Moines Lobe. Even though a larger percentage of the watershed at Carroll drained through ponds, it had a smaller percentage of available storage. At Coon Rapids, the next index location downstream, the peak reduction was at a maximum (11%). At this location, a larger percentage of ponds upstream lie in the Des Moines Lobe. Even though the area controlled by ponds was very similar downstream, and the mix of ponds from the Southern Iowa Drift Plain and Des Moines Lobe were similar, the peak reduction gradually decreased downstream to the basin outlet at Redfield (6%). Generally speaking, the small typical pond design was not sufficiently sized to handle rainfalls of this magnitude.

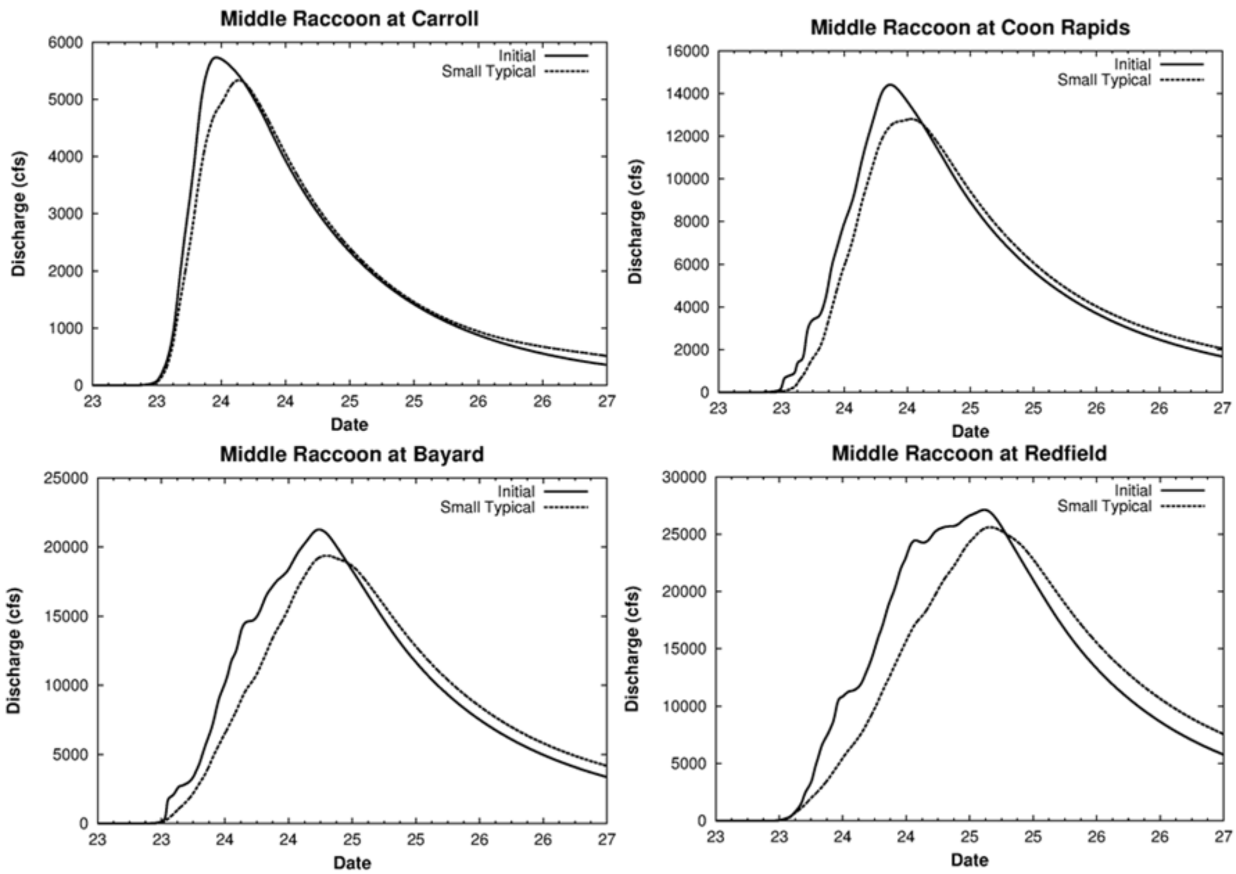


Figure 4.15. Comparisons of hydrographs with and without small ponds for the 50-year, 24-hour storm (6.00 inches). For the hydrographs shown, peak flow reduction ranges from 6-11%.

Figure 4.16 shows the peak discharge reductions at the two USGS discharge gauge locations and the three IFC discharge gauge locations for the small pond scenario (3 foot and 7 foot emergency spillway elevations) for the 50-year, 24-hour event (6.00 inches).

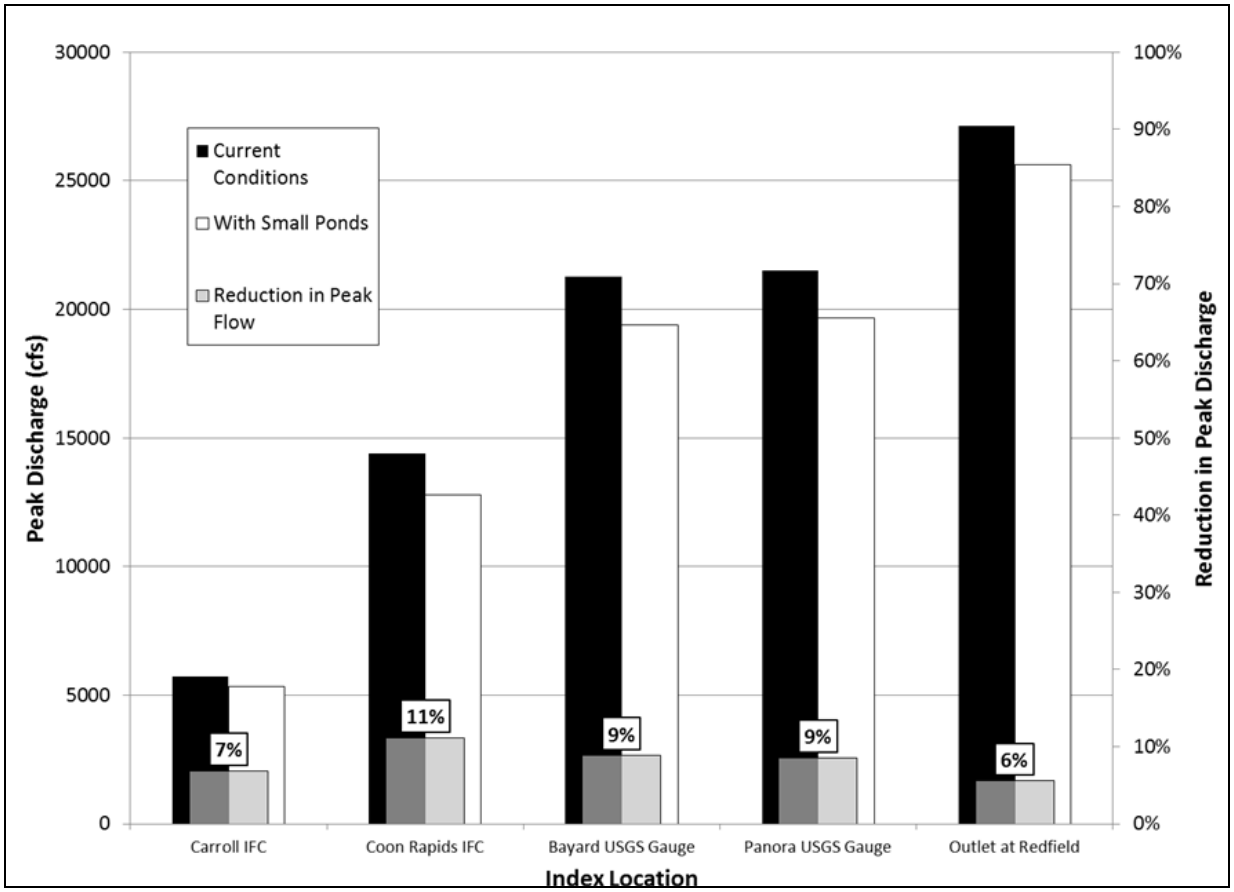


Figure 4.16. Peak discharge reductions for the small pond scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the 50-year, 24-hour design storm (6 inches).

Table 4.6 summarizes the percent reductions in peak discharge for the small typical pond scenario at the five index locations for all the design storm events. In this scenario, each pond in the Southern Iowa Drift Plain provided 23.8 acre-feet of flood storage and each pond in the Des Moines Lobe provided 26.8 acre-feet of flood storage, resulting in a total of 4,709 acre-feet of flood storage for the entire watershed. For the small ponds, the percent reduction was greatest for the 10-year return period flood, and decreased for larger floods; the small ponds fill rapidly for large floods, at which point little attenuation in flood peak was achieved. As noted above, the peak reduction effect varied with drainage area. It was typically larger for small drainage areas, where the location was closer to the headwater ponds, and decreased in the downstream direction. The one exception was the IFC gauge location at Carroll, for the 25- to 100- year events, where its upstream area was primarily in the Southern Iowa Drift Plains (where ponds are smaller and less flood storage is available). Otherwise, the peak reduction range was larger at smaller upstream locations; at Coon Rapids it varied from about 16 percent (10-year event) to 8 percent (100-year event), whereas at the downstream-most location of Redfield, it varied from 10 percent (10-year event) all the way to 4 percent (100-year event).

Table 4.6. Percent reduction in peak discharge using the typical small pond design (3 or 7 foot emergency spillway elevations).

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Location	*10–YR (4.03 inches)*	*25-YR (5.08 inches)*	*50-YR (6.00 inches)*	*100-YR (7.04 inches)*
Carroll IFC Gauge	18.0	10.3	6.9	4.6
Coon Rapids IFC Gauge	15.8	14.0	11.2	8.4
Bayard USGS Gauge	13.0	10.7	8.9	7.1
Panora USGS Gauge	12.7	10.3	8.6	6.9
Redfield IFC Gauge (Outlet)	9.8	7.0	5.6	4.3

Large Typical Pond

Figure 4.17 compares the simulated flood hydrographs for the current no pond condition (Baseline) to those with large prototype ponds for the 50-year return period 24-hour design storm (6.00 inches of rain in 24 hours). At Carroll twenty-eight prototype ponds were placed upstream. As a result, the peak discharge was reduced by 16 percent. The operation of the ponds is most evident at this size pond and at this location. Initially, water discharged from the subbasin without significant delay. Then, the rise in the discharge was halted, as water was stored in the ponds. After water began to flow over the emergency spillway, discharge increased rapidly again. The additional flood storage in this scenario reduced the peak discharge from 5,733 cfs (with no ponds) to 4,841 cfs (with large ponds).

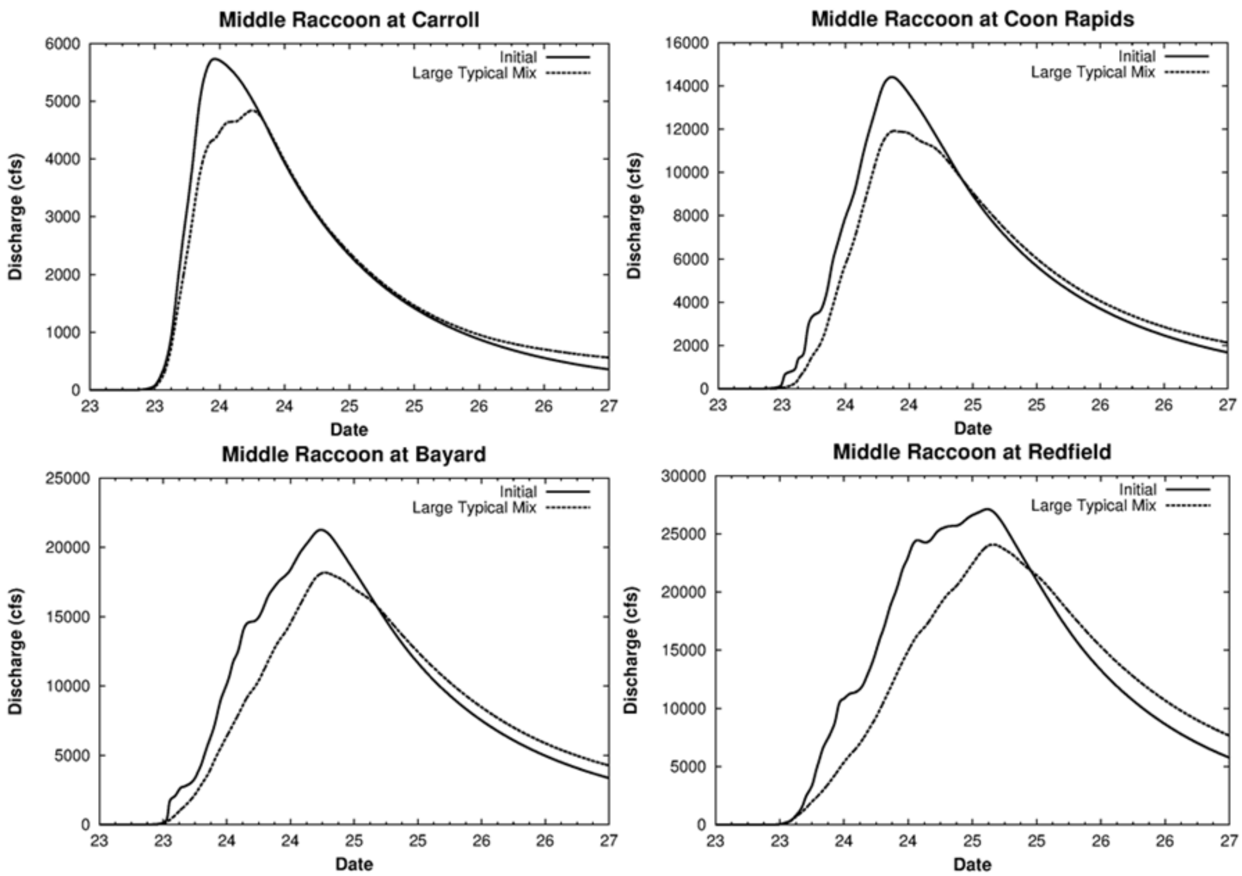


Figure 4.17. Comparisons of hydrographs with and without large ponds, for the 50-year, 24-hour storm (6.00 inches). For the hydrographs shown, peak flow reduction ranges from 11-17 percent.

Figure 4.18 shows the peak discharge reductions at the two USGS discharge gauge locations and the three IFC discharge gauge locations for the large pond scenario (5 foot and 10 foot emergency spillway elevations) for the 50-year, 24-hour event (6.00 inches).

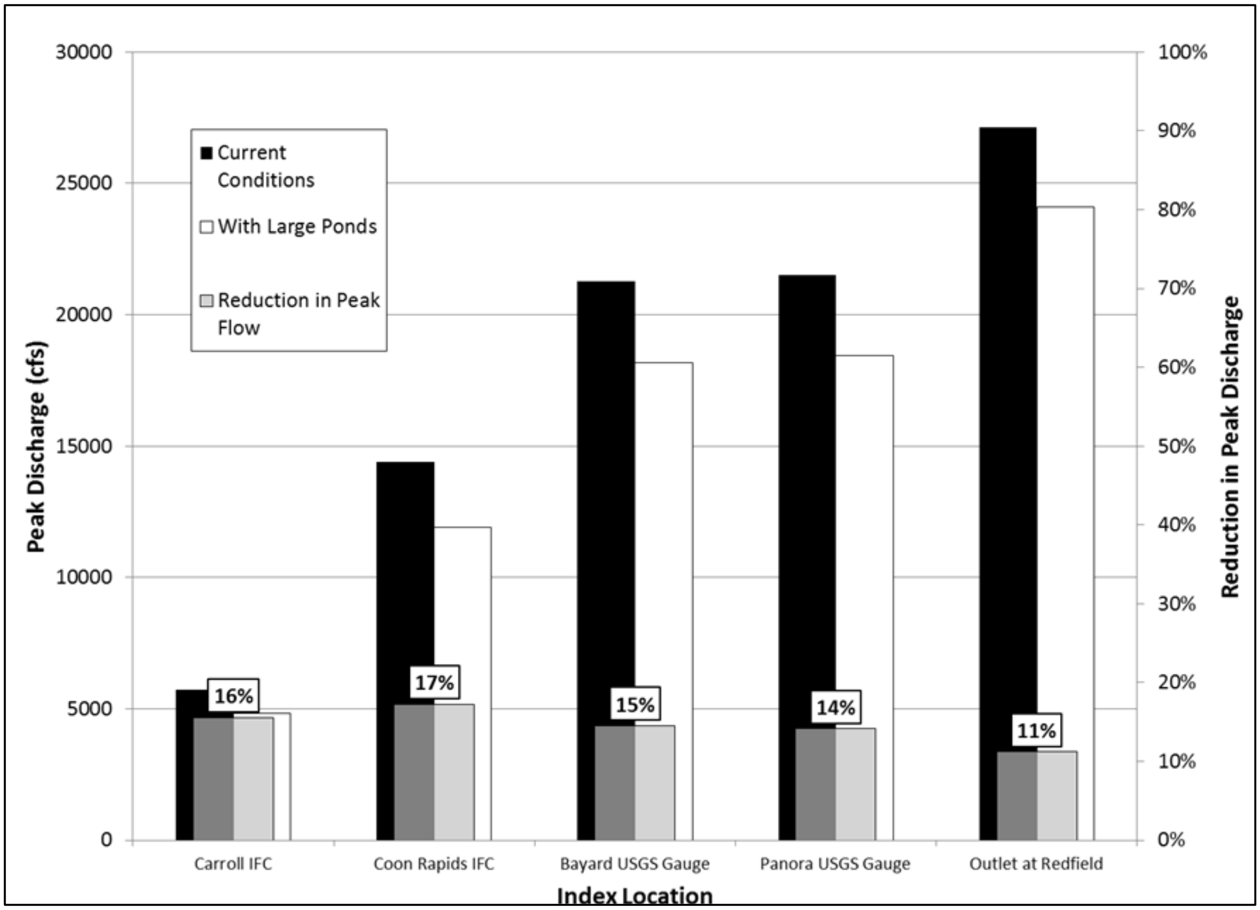


Figure 4.18. Peak discharge reductions for the large pond scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the 50-year, 24-hour design storm (6 inches).

Table 4.7 summarizes the percent reductions in peak discharge for the large pond scenario at the five index locations for all the design storm events. In this scenario, each pond provided 38.6 acre-feet of flood storage for the Southern Iowa Drift Plain and 54.5 acre-feet of total storage in the Des Moines Lobe Region, resulting in a total of 9,693 acre-feet of total storage for the entire watershed. With this additional flood storage, (approximately 2.1 times the small pond flood storage) the peak reduction increased. Percent reduction in peak flow remained relatively constant for the 10- and 25-year design storm events at the watershed outlet, yet it was a maximum at the 10-year event (15 percent). This was due to pond utilization of the potential flood storage to its maximum potential during this event (i.e. most ponds were relatively full but not engaging the emergency spillway). As expected, the peak reduction tended to be greater nearer to the headwater ponds (smaller drainage areas), and decreased for larger drainage areas downstream (with Carroll again being the exception). It should be noted that Carroll, IA had a maximum reduction for the 10-year and 25-year, 24-hour events; this was due to the ability of the smaller Southern Iowa Drift Plain ponds to store the 10-year and 25-year events when the spillway was raised to 10 feet. For the small pond designs, most emergency spillways were engaged much earlier.

Table 4.7. Percent reductions in peak discharge using the large typical pond design (5 foot and 10 foot emergency spillway elevations).

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Location	*10–YR (4.03 inches)*	*25-YR (5.08 inches)*	*50-YR (6.00 inches)*	*100-YR (7.04 inches)*
Carroll IFC Gauge	22.2	21.3	15.6	10.5
Coon Rapids IFC Gauge	19.7	17.9	17.3	15.9
Bayard USGS Gauge	17.5	16.1	14.5	12.8
Panora USGS Gauge	17.1	15.7	14.1	12.4
Redfield IFC Gauge (Outlet)	15.2	13.6	11.2	9.0

The maps in Appendix A show the percent reduction in peak flow with ponds, as compared to that without ponds, at the five index locations for the scenarios with small and large ponds. The maps also show each headwater basin and how well the ponds in the basins are utilized. The ponds in the Southern Iowa Drift Plain, south of the Middle Raccoon River main stem utilize their entire flood storage capacity at much smaller storm events. This is due to the topography in the region; therefore ponds in the Southern Iowa Drift Plain were designed to have a higher emergency spillway elevation.

To illustrate how effectively the ponds utilized their storage in the simulated flood events, the resulting peak discharge and potential stage reductions are shown in Table 4.8. Results are shown for the 10-, 25-, 50-, and 100-year return period 24-hour SCS design storms. For the 10- year return period design flood, the water level reached the emergency spillway elevation for 127 of the 160 (79 percent) of the small ponds (3 foot and 7 emergency spillway elevations). In contrast, the water level reached the emergency spillway for only 50 (31 percent) of the large ponds (5 foot and 10 foot emergency spillway elevations). As a result, nearly all of the flood storage was utilized in a 10-year flood for small ponds, with decreasing utilization for the large ponds. For the 25-year design flood, the water level reached the emergency spillway elevation for 145 of 160 small ponds (91 percent), and 115 of 160 large ponds (72 percent). By the 50-year and 100-year design floods, the water level reached the emergency spillway for the vast majority of all ponds, regardless of size.

Table 4.8. Reductions in stage at the USGS gauge locations due to the reduction in peak discharge for all typical pond scenarios.

	Reduction in Stage due to Reduction in Peak Discharge (ft)							
	Bayard, IA USGS Gauge				*Panora, IA USGS Gauge*			
Pond Size	*10-YR*	*25-YR*	*50-YR*	*100-YR*	*10-YR*	*25-YR*	*50-YR*	*100-YR*
Small	0.7	0.6	0.5	0.4	0.9	0.9	0.9	0.7
Large	1.0	0.9	0.9	0.8	1.2	1.4	1.6	1.4

iii. Dry Pond Results

The same distributed storage analysis was again run for the dry pond design. The dry ponds initially had no stored water since a 2-inch pipe was set at the lowest elevation in the pond. Therefore, dry ponds had a greater amount of total storage which could allow for greater potential peak flow reductions.

Small Dry Pond

Figure 4.19 compares the simulated flood hydrographs for the current no pond condition (Baseline) to those with small dry prototype ponds for the 50-year return period 24-hour design storm (6.00 inches of rain in 24 hours). The smallest drainage area shown, at Carroll, IA, has a drainage area of 73.8 square miles. Twenty-eight prototype ponds were placed upstream. As a result, the peak discharge was reduced by 7 percent. The limited amount of flood storage available in these ponds reduced the peak discharge from 5,733 cfs (with no ponds) to 5,339 cfs (with ponds).

Even though the area controlled was very similar throughout the basin, the peak flow reduction was not. At Carroll, where the ponds upstream mostly lie in the Southern Iowa Drift Plain, the peak flow reduction was minimal. The smaller prototype dry ponds in the Southern Iowa Drift Plain filled faster (and therefore engaged the emergency spillway much earlier) than the larger ponds in the Des Moines Lobe. Even though a larger percentage of the watershed at Carroll drained through ponds, it had a smaller percentage of available storage. At Coon Rapids, the next index location downstream, the peak reduction was at a maximum (11 percent). At this location, a larger percentage of ponds upstream lie in the Des Moines Lobe. Even though the area controlled by ponds was very similar downstream, and the mix of ponds from the Southern Iowa Drift Plain and Des Moines Lobe were similar, the peak reduction gradually decreased downstream to the basin outlet at Redfield (6 percent).

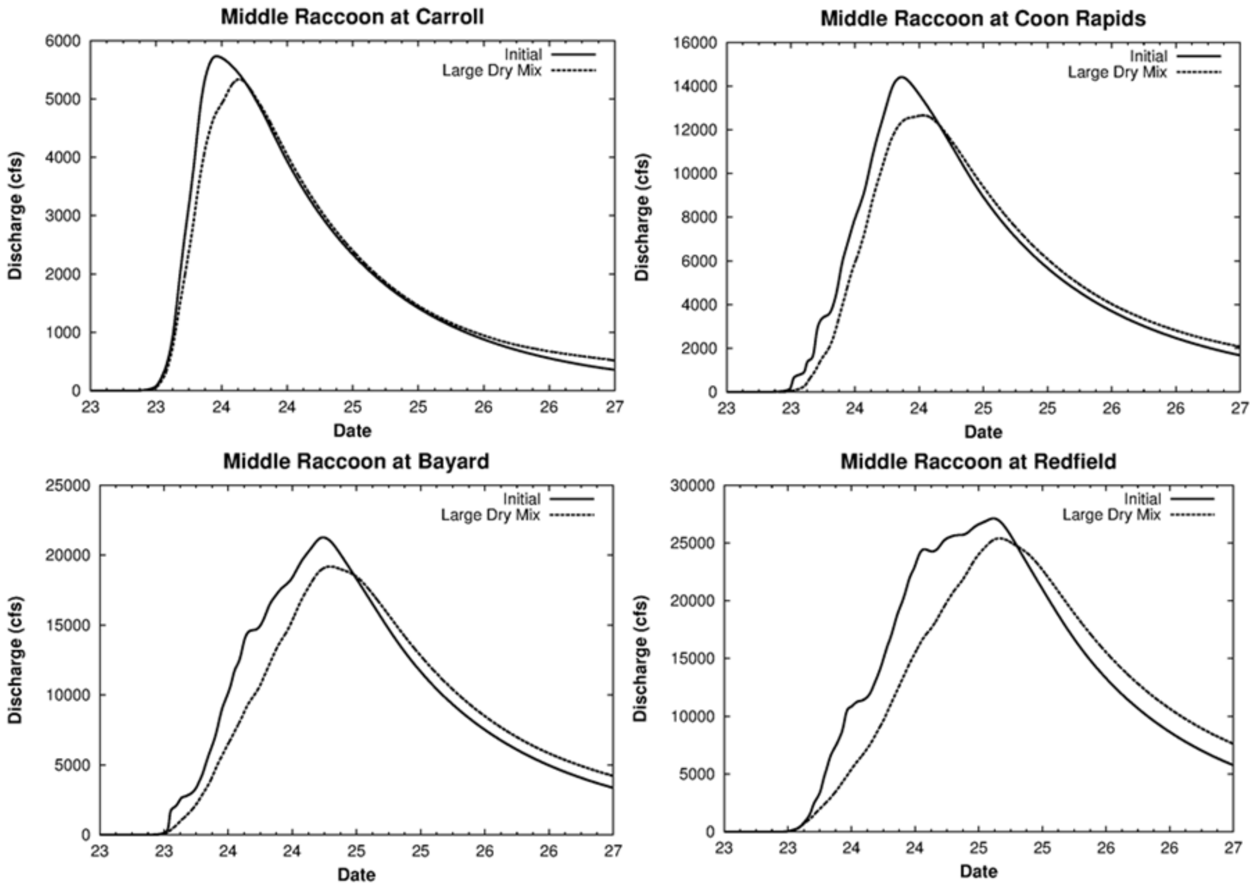


Figure 4.19. Comparisons of hydrographs with and without small dry ponds, for the 50-year, 24-hour storm (6.00 inches). For the hydrographs shown, peak flow reduction ranges from 6-12 percent.

Figure 4.20 shows the peak discharge reductions at the two USGS discharge gauge locations and the three IFC discharge gauge locations for the small dry pond scenario (7 foot and 8 foot emergency spillway elevations) for the 50-year, 24-hour event (6.00 inches).

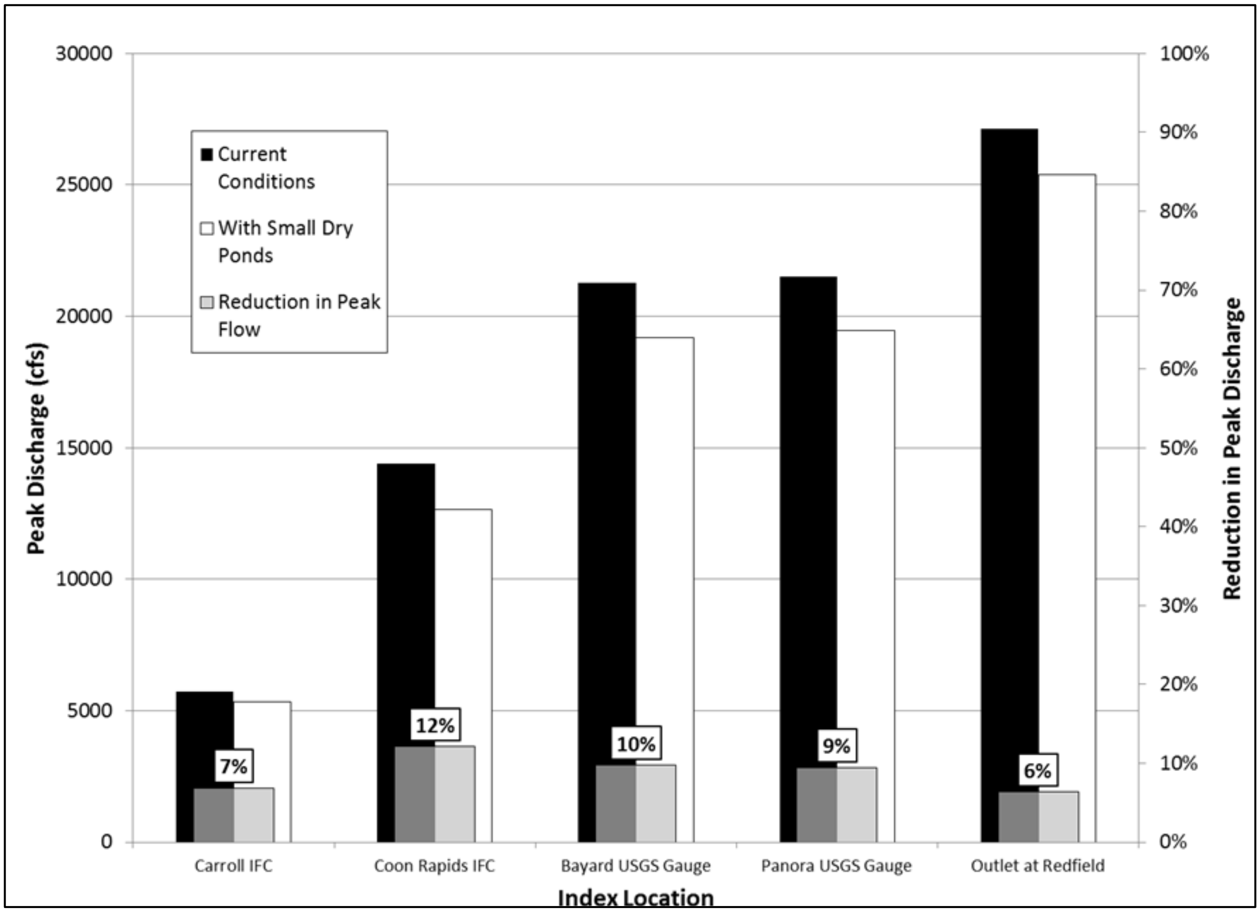


Figure 4.20. Peak discharge reductions for the small dry pond scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the 50-year, 24-hour design storm (6 inches).

Table 4.9 summarizes the percent reductions in peak discharge for the small dry pond scenario at the five index locations for all the design storm events. In this scenario, each pond in the Southern Iowa Drift Plain provided 23.8 acre-feet of flood storage and each pond in the Des Moines Lobe provided 34.2 acre-feet of flood storage, resulting in a total of 6,051 acre-feet of flood storage for the entire watershed. For the small dry ponds, the percent reduction was greatest for the 10-year return period flood, and decreased for larger floods; the small dry ponds filled rapidly for large floods, at which point little attenuation in flood peak was achieved.

As noted above, the peak reduction effect varied with drainage area. It was typically larger for small drainage areas, where the location was closer to the headwater ponds, and decreased in the downstream direction. The one exception was the IFC gauge location at Carroll where its upstream area was primarily in the Southern Iowa Drift Plains (where ponds are smaller and less flood storage is available). At Coon Rapids it varied from about 11 percent (10-year event) to 9 percent (50-year event), whereas at the downstream-most location of Redfield, it varied from 8 percent

(10-year event) all the way to 5 percent (50-year event). The increased storage in the small dry pond scenario increased peak flow reductions by an average of approximately 1 percent.

Table 4.9. Percent reduction in peak discharge using the small dry pond design (7 foot and 8 foot emergency spillway elevations).

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Location	*10–YR (4.03 inches)*	*25-YR (5.08 inches)*	*50-YR (6.00 inches)*	*100-YR (7.04 inches)*
Carroll IFC Gauge	18.6	10.1	6.9	5.0
Coon Rapids IFC Gauge	16.8	14.8	12.1	9.5
Bayard USGS Gauge	14.2	11.7	9.8	8.0
Panora USGS Gauge	13.8	11.4	9.5	7.7
Redfield IFC Gauge (Outlet)	11.1	8.1	6.4	5.0

Large Dry Ponds

Figure 4.21 compares the simulated flood hydrographs for the current no pond condition (Baseline) to those with large dry prototype ponds for the 50-year return period 24-hour design storm (6.00 inches of rain in 24 hours). At Carroll, IA, peak discharge was reduced by 16 percent. The increased amount of storage going from small dry ponds to large dry ponds decreased peak discharge by an additional 9 percent. These ponds reduced the peak discharge from 5,733 cfs (with no ponds) to 4,843 cfs (with large dry ponds).

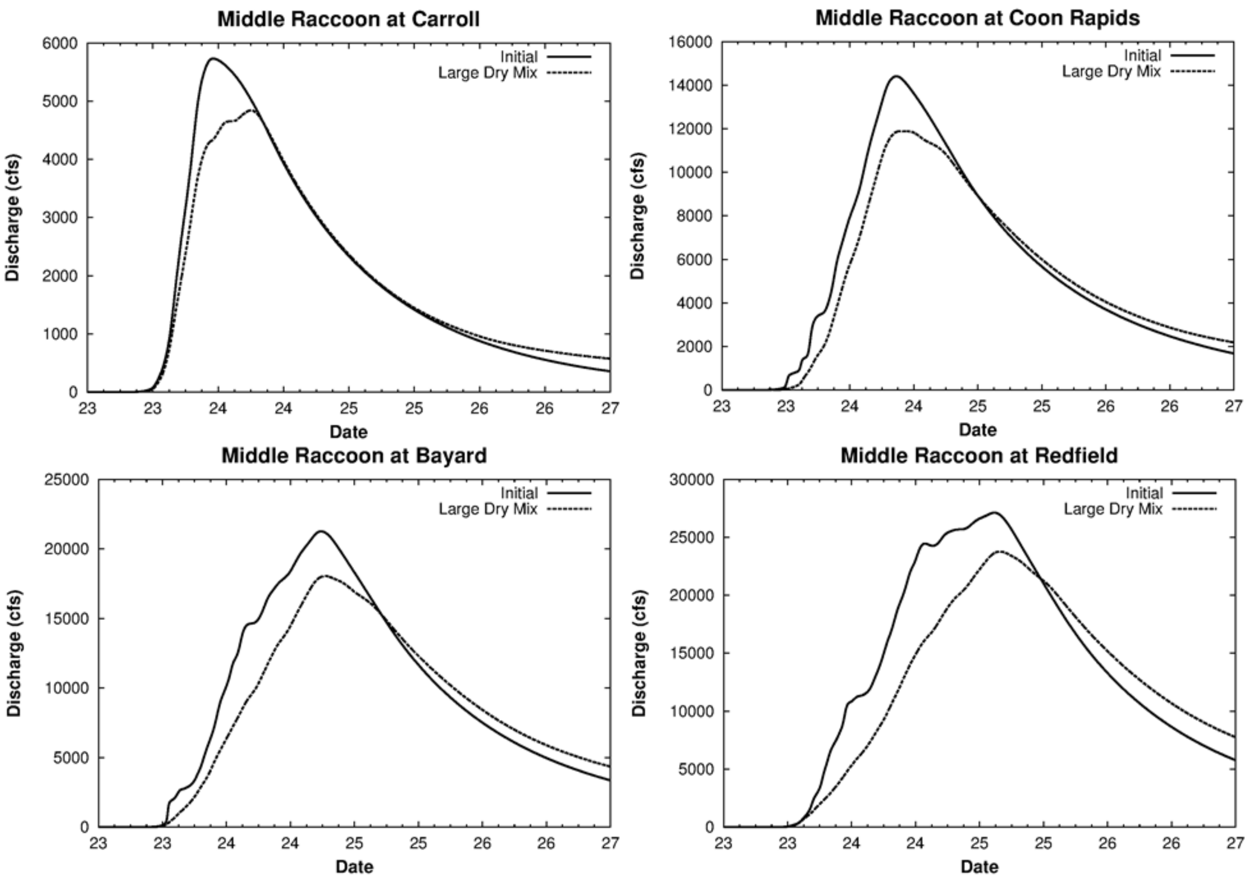


Figure 4.21. Comparisons of hydrographs with and without the large dry ponds, for the 50-year, 24-hour storm (6.00 inches). For the hydrographs shown, peak flow reduction ranges from 12-17%.

In the case of the large dry pond scenario, flow reductions seemed to be relatively uniform at all of the index locations throughout the Middle Raccoon River main stem. This was especially true for the 10-year and 25-year event. In these scenarios, the ponds upstream of Carroll, IA had sufficient capacity to retain the majority of runoff; this was not true for the other pond designs where discharge reductions at Carroll were minimal. For the 50-year event, percent reductions were more similar to those seen in the smaller pond scenarios with a reduction range from 16 percent at Carroll, IA to 12 percent at the watershed outlet (Redfield, IA).

Figure 4.22 shows the peak discharge reductions at the two USGS discharge gauge locations and the three IFC discharge gauge locations for the large dry pond scenario (10 and 12 foot emergency spillway elevations) for the 50-year, 24-hour event (6.00 inches).

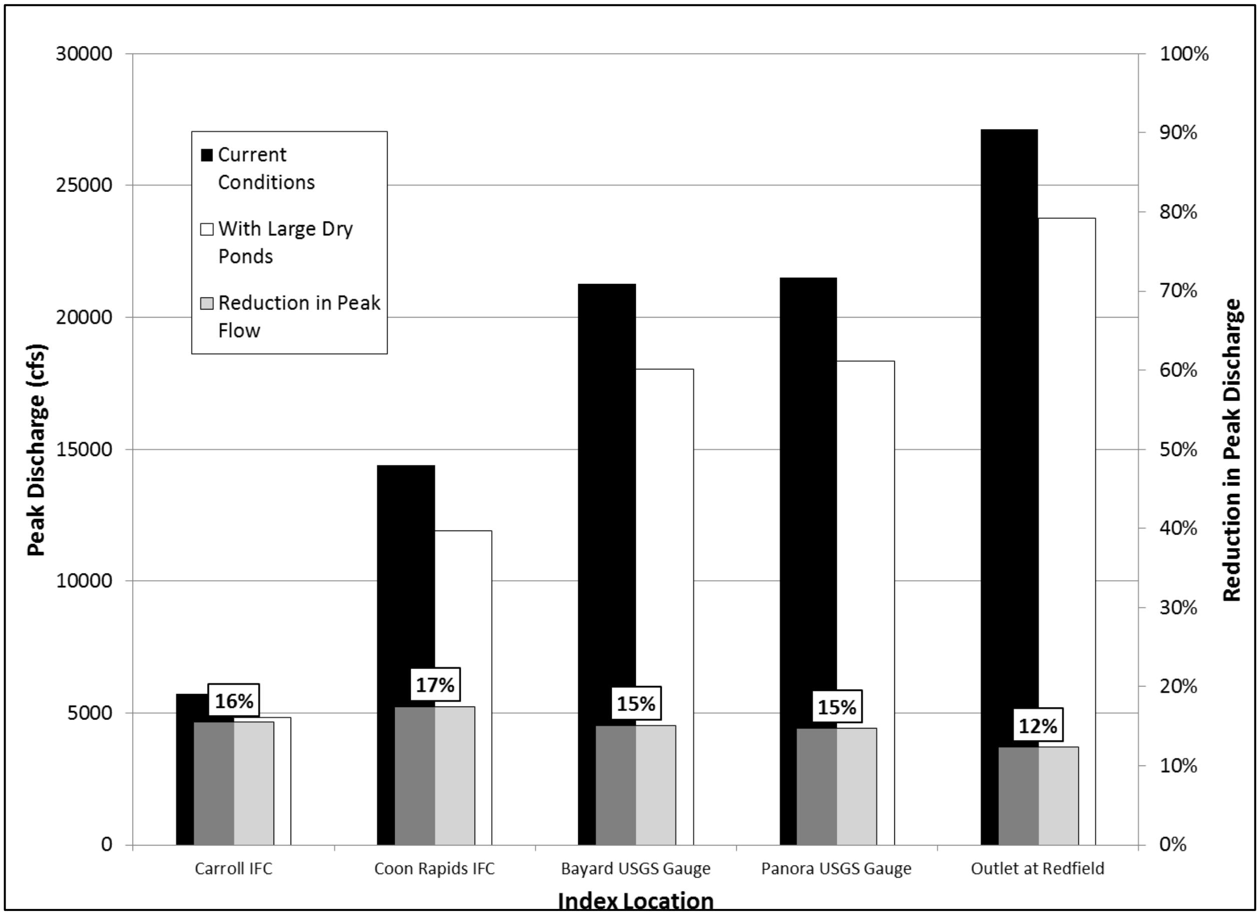


Figure 4.22. Peak discharge reductions for the large dry pond scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the 50-year, 24-hour design storm (6 inches).

Table 4.10 summarizes the percent reductions in peak discharge for the large pond scenario at the five index locations for all the design storm events. In this scenario, each pond provided 38.6 acre-feet of flood storage for the Southern Iowa Drift Plain and 62.8 acre-feet of flood storage in the Des Moines Lobe Region, resulting in a total of 10,765 acre-feet of flood storage for the entire watershed. With this additional flood storage (approximately 1.8 times the small dry pond flood storage), the peak reduction was again increased. Percent reduction in peak flow remained relatively constant for the 10- through 100-year design storm events at the watershed outlet, yet it was at a maximum at the 10-year event (15 percent). This was due to the ponds' utilization of the potential flood storage to its maximum potential (i.e. most ponds were relatively full but not engaging the emergency spillway). As expected, the peak reduction tended to be greater nearer to the headwater ponds (smaller drainage areas), and decreased for larger drainage areas downstream. In this case, Carroll no longer seemed to be the exception, at least in the smaller events. Table 4.10 shows that for the 10-year event, peak discharge reduction was at a maximum (22.6 percent) at Carroll, IA. The topography upstream of Carroll dictated that more elevation was needed between the pond bottom and emergency spillway in order to reduce the flows to the same capacity as the locations downstream.

Table 4.10. Percent reduction in peak discharge using the large dry pond design (10 foot emergency spillway elevation).

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Location	*10–YR (4.03 inches)*	*25-YR (5.08 inches)*	*50-YR (6.00 inches)*	*100-YR (7.04 inches)*
Carroll IFC Gauge	22.6	21.2	15.5	10.6
Coon Rapids IFC Gauge	20.5	18.2	17.5	16.0
Bayard USGS Gauge	17.7	16.2	15.1	13.7
Panora USGS Gauge	17.4	15.8	14.7	13.3
Redfield IFC Gauge (Outlet)	15.0	14.0	12.4	10.2

Maps in Appendix A show the percent reduction in peak flow with dry ponds, as compared to that without ponds, at the five index locations for the scenarios with small and large dry ponds.

To illustrate how effectively the dry ponds utilize their storage in the simulated flood events, the resulting peak discharge and potential stage reductions are shown in Table 4.11. Results are shown for the 10-, 25-, 50-, and 100-year return period 24-hour SCS design storms.

Table 4.11. Reductions in stage at the USGS gauge locations due to the reduction in peak discharge for all dry pond scenarios.

	Reduction in Stage due to Reduction in Peak Discharge (ft)							
	Bayard, IA USGS Gauge				*Panora, IA USGS Gauge*			
Pond Size	*10-YR*	*25-YR*	*50-YR*	*100-YR*	*10-YR*	*25-YR*	*50-YR*	*100-YR*
Small	0.8	0.7	0.6	0.5	1.0	1.0	1.0	0.8
Large	1.0	1.0	0.9	0.9	1.2	1.4	1.6	1.5

d. Mitigating the Effects of High Runoff with Infiltration and Storage

Small Blended Scenario

The HMS model was run with the ponds and cover crops to simulate the effects of the combination of flood mitigation methods on peak discharges. Two models were created for this scenario. The first blended the small typical pond design with the lowered cover crop practices curve numbers; the second blended the large typical pond design with the lowered cover crop practices curve numbers. Only the typical pond designs were used due to the assumption that they would be desirable for landowners, and therefore, would be a more realistic scenario. For the locations of the ponds, each simulation started with all pond water levels at the principal spillway elevation; this assumed that the permanent storage was completely utilized as the storm began. Comparisons were then made for the simulated flows without the blended flood mitigation practices in place (the existing baseline condition). Flood hydrographs were compared for the 10-, 25-, 50-, and 100-year return period; 24-hour SCS design storms.

Figure 4.23 compares the simulated flood hydrographs for the current no pond condition (Baseline) to those with the application of small blended flood mitigation practices for the 50- year return period, 24-hour design storm (6.00 inches of rain in 24 hours). The simulations used the small typical pond design specified in Chapter 7, where the emergency spillway is set at 7 feet above the principal spillway in the Southern Iowa Drift Plain and 3 feet above the principal spillway in the Des Moines Lobe. The smallest drainage area, shown at Carroll, IA, has a drainage area of 73.8 mi^2. There, the peak discharge was reduced by 17 percent. Ponds upstream of Carroll, IA were smaller due to the Southern Iowa Drift Plain topography; therefore, reductions there were not as significant as the downstream index locations. The results showed fairly uniform reductions of flows, ranging from 14 percent (at Redfield, IA) to over 21 percent (at Coon Rapids, IA). Figure 4.24 summarizes the peak discharge for current conditions, the peak discharge for the small blended practices scenario, and the percent peak reduction, at all five index locations for the 50-year, 24-hour design storm event.

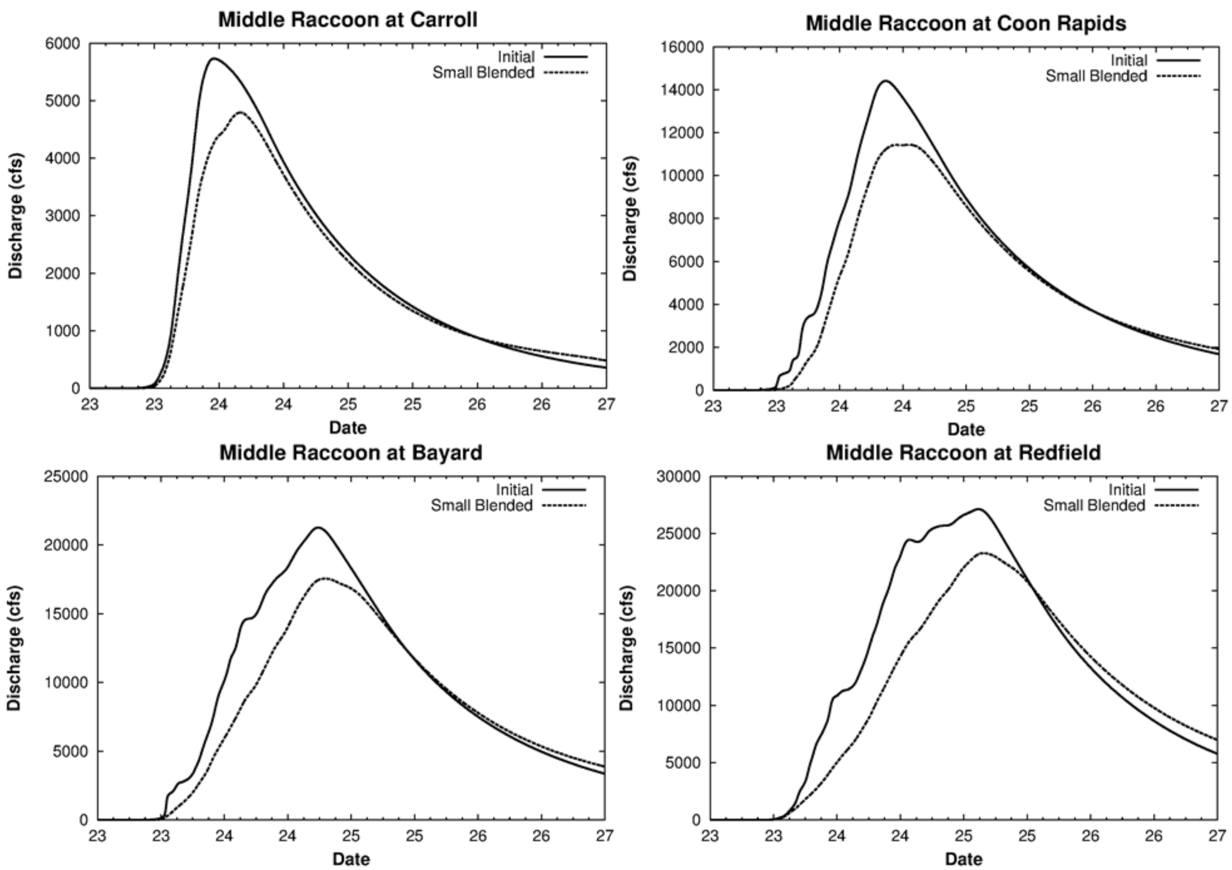


Figure 4.23. Comparisons of hydrographs with and without the small blended scenario for the 50-year, 24-hour storm (6.00 inches). For the hydrographs shown, peak flow reduction ranges from 14-21 percent.

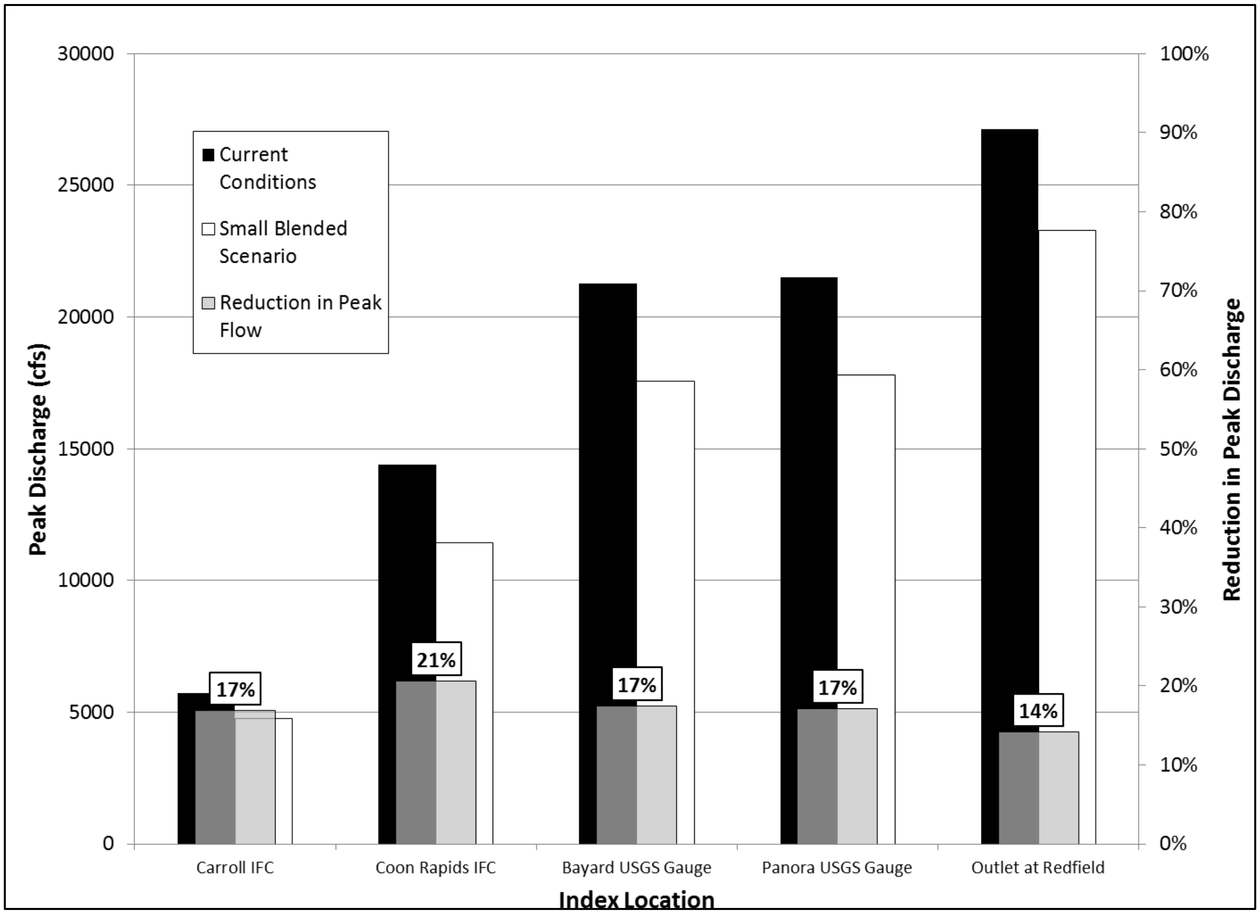


Figure 4.24. Peak discharge reductions for the small blended scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the 50-year, 24-hour design storm (6 inches).

Table 4.12 summarizes the percent reduction in peak discharge resulting from this hypothetical small blended scenario at the five index location for all the design storm events. The small blended scenario resulted in peak discharge reduction between 12 and 29 percent. For this scenario, the maximum flow reductions were found during the 10-year rainfall event. At this event, the ponds utilized their storage most efficiently. At the larger scaled drainage areas, the effects of the cover crop seem to dominate. Therefore, based on the results in previous sections, we expect increased infiltration to have its greatest impact during small design storms where the percentage of rainfall infiltrated is the greatest. The reduction in peak flow was relatively uniform at all locations for each event.

Table 4.12. Percent reduction in peak discharge using the small blended scenario.

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Index Location	*10-YR (4.03 in)*	*25-YR (5.08 in)*	*50-YR (6.00 in)*	*100-YR (7.04 in)*
Carroll IFC Gauge	29.3	21.9	16.9	12.7
Coon Rapids IFC Gauge	26.5	23.7	20.6	16.7
Bayard USGS Gauge	24.2	20.2	14.5	14.8
Panora USGS Gauge	23.8	19.8	17.1	14.4
Redfield IFC Gauge (Outlet)	21.5	16.9	14.2	11.8

Reducing peak flood discharge also reduced the peak water height (or stage) in a river during the flood. For the peak discharge reductions in the small blended flood mitigation practices, the corresponding reduction in flood stage was between 1.0 and 1.9 feet. This reduction was estimated for the USGS stream-gauge locations, where the rating curves have been developed. Although a 1.0 to 1.9 foot reduction in flood stage would slightly reduce the flood inundation area, flooding still occurs. Again, based on the flood stage level reported by the National Weather Service at Bayard, IA, water levels above action stage (13 feet) are expected for both the current conditions and small blended scenario. Hence, the addition of cover crops does not eliminate flooding, but would reduce its severity and frequency.

Large Blended Scenario

Figure 4.25 compares the simulated flood hydrographs for the current no pond condition (baseline) to those with the application of large blended flood mitigation practices for the 50- year return period, 24-hour design storm (6.00 inches of rain in 24 hours). The simulations used the small typical pond design specified in previous section, where the emergency spillway is set at 10 feet above the principal spillway in the Southern Iowa Drift Plain and 5 feet above the principal spillway in the Des Moines Lobe. The smallest drainage area shown at Carroll, IA has a drainage area of 73.8 mi^2. There, the peak discharge was reduced by 26 percent. In this scenario, the ponds upstream of Carroll, IA were much larger than in the small blended practices scenario; therefore, reductions there were at a maximum, while in the small blended scenario, they were not. The results showed fairly uniform reductions of flows, ranging from 20 percent (at Redfield, IA) to 26 percent (at Carroll, IA). Figure 4.26 summarizes the peak discharge for current conditions, the peak discharge for the large blended practices scenario, and the percent peak reduction, at all five index locations for the 50-year, 24-hour design storm event.

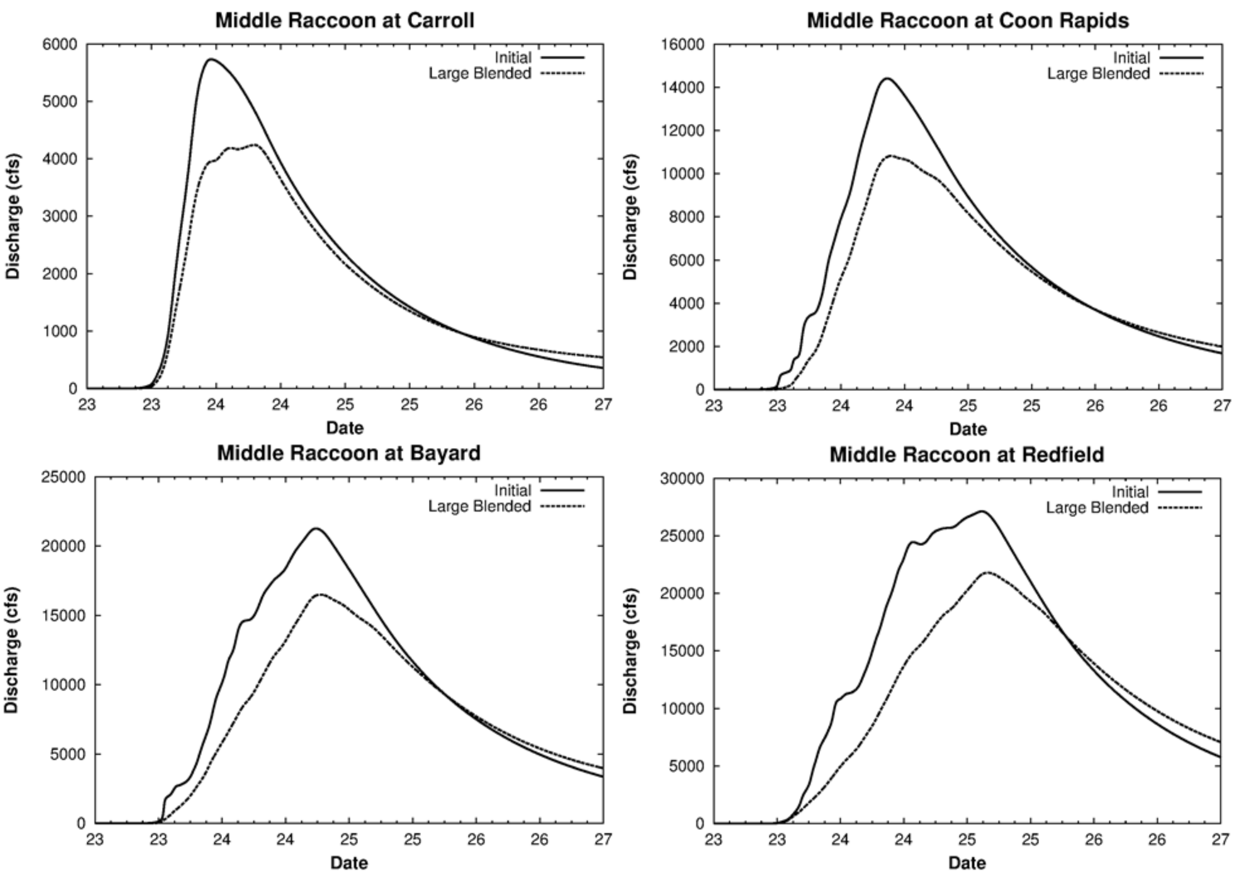


Figure 4.25. Comparisons of hydrographs with and without the large blended scenario for the 50-year, 24-hour storm (6.00 inches). For the hydrographs shown, peak flow reduction ranges from 20-26 percent.

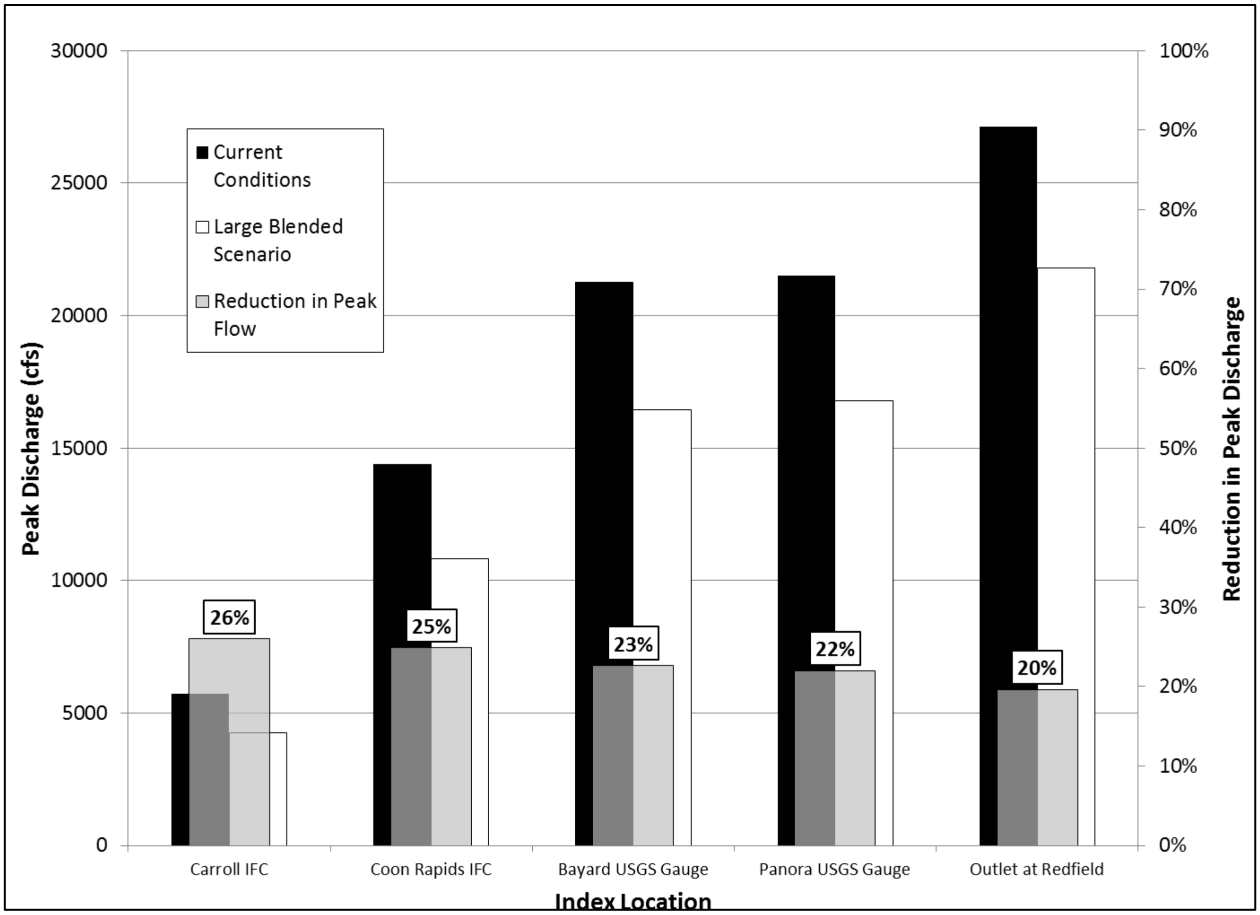


Figure 4.26. Peak discharge reductions for the large blended scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the 50-year, 24-hour design storm (6 inches).

Table 4.13 summarizes the percent reduction in peak discharge resulting from this hypothetical large blended scenario at the five index location for all the design storm events. The large blended scenario resulted in peak discharge reduction between 16 and 31 percent. For this scenario, the maximum flow reductions were found during the 10-year rainfall event. During this event, the ponds utilize their storage most efficiently. At the larger scaled drainage areas, the effects of the cover crop seem to dominate. Therefore, based on the results in increased infiltration sections, increased infiltration is anticipated to have its greatest impact during small design storms where the percentage of rainfall infiltrated is the greatest. The reduction in peak flow was relatively uniform at all locations for each event.

Table 4.13. Percent reduction in peak discharge using the large blended scenario.

	Percent Peak Discharge Reduction Based on Storm Return Period (%)			
Index Location	*10-YR (4.03 in)*	*25-YR (5.08 in)*	*50-YR (6.00 in)*	*100-YR (7.04 in)*
Carroll IFC Gauge	31.0	30.6	26.0	19.1
Coon Rapids IFC Gauge	29.0	26.7	24.9	23.1
Bayard USGS Gauge	26.7	25.1	22.6	19.9
Panora USGS Gauge	26.3	24.7	22.0	19.5
Redfield IFC Gauge (Outlet)	24.5	23.1	19.6	16.4

Reducing peak flood discharge also reduces the peak water height (or stage) in a river during the flood. For the peak discharge reductions in the large blended flood mitigation practices, the corresponding reduction in flood stage was between 1.3 and 2.5 feet. This reduction was estimated for the USGS stream-gauge locations, where the rating curves have been developed. Although a 1.5 to 2.5 foot reduction in flood stage would slightly reduce the flood inundation area, flooding still occurs. Again, based on the flood stage level reported by the National Weather Service at Bayard, IA, water levels above action stage (13 feet) are expected for both the current conditions and the small blended scenario. Hence, the addition of cover crops and large ponds does not eliminate flooding, but would reduce its severity and frequency.

For blended practices two scenarios were analyzed to represent a feasible mix of increased infiltration and distributed storage as flood control measures. The scenarios were created by combining the cover crop simulations and typical pond simulations that were previously developed. In HEC-HMS, the ponds are represented by a storage-discharge table that is reflective of the topographic conditions and pond hydraulics. The cover crops are represented with a reduced Curve Number which allow for more infiltration and less runoff. Since two practices were applied in these scenarios, peak flow reductions were shown to increase when compared to using a single practice. A maximum reduction of 31 percent was observed at Coon Rapids, IA during the 10-year SCS storm event and at Carroll, IA during the 25-year SCS storm event. Reductions were relatively uniform for all locations throughout the watershed, and relatively uniform for every storm event analyzed. From the analysis completed in previous sections, we know that increased infiltration is most effective at reducing peak discharge at small scale storm events, while distributed storage can be most effective at larger events (if the correct pond sizes are selected). Therefore, the blended scenario with cover crops and large typical ponds maximizes benefit at both the small and large design storms. This may be why we see the relatively uniform reduction in discharge.

The reductions seen in this scenario may best represent reductions that could be expected should the watershed adopt a basin wide flood mitigation strategy. Table 4.14 compares the reductions between the typical ponds only, the cover crops only, and the blended scenarios at the watershed outlet (Redfield, IA).

Table 4.14. Comparison of peak discharge reductions between distributed storage, cover crops, and blended scenarios.

	Percent Peak Discharge Reduction at Redfield, IA (%) (based on Storm Return Period)			
Scenario	*10-YR (4.03 in)*	*25-YR (5.08 in)*	*50-YR (6.00 in)*	*100-YR (7.04 in)*
Small Typical Pond Design Only	9.8	7.0	5.6	4.3
Large Typical Pond Design Only	15.2	13.6	11.2	9.0
Cover Crop Application Only	11.5	9.2	7.5	6.8
Small Blended Scenario	21.5	16.9	14.2	11.8
Large Blended Scenario	24.5	23.1	19.6	16.4

e. Evaluation of Flood Mitigation Strategies for Historical Rainfall Events: June 2008 and June 2013

The application of design storms, which apply uniform rainfall over the entire watershed, provided great value in predicting the effects of flood mitigation practices for the entire basin. Design storms are also easily applied for comparative analysis. However, it is unlikely that the Middle Raccoon River watershed would ever receive a uniform depth of rainfall along the entire 590 mi² region. For this reason, we examined the effects of the large typical pond application, and the large blended cover crops and typical pond application, previously discussed, on two historic rainfall events—the storms of June 2008 and June 2013. These two storms were chosen based upon their use in the calibration phase of modeling effort, for the large nature of the events, and because they occurred within the last decade. The recent time frame means the effects of these flooding events can still be easily remembered. Applying flood mitigation practices to real storm events, not only allows watershed stakeholders to better visualize the possible flood reduction benefit, but also provides insight as to how the practices would perform under a most probable non-uniform rainfall.

June 2008

The storm of June 8-12, 2008 was characterized by heavy rainfalls falling primarily in the northwest and southeast corners of the watershed. In these locations, rainfall totals reached approximately 4 inches. Lighter rainfalls fell in the central portion of the basin, averaging approximately 1 to 2 inches. Figure 4.27 shows the spatial variation of rainfall for this event, where green represents rainfalls of between 3 and 5 inches and blue represents rainfalls of between 1 and 3 inches. The combination of heavy rains and wet antecedent moisture conditions resulted in a modeled peak discharge of 8,806 cfs at the USGS gauge located in Bayard, IA.

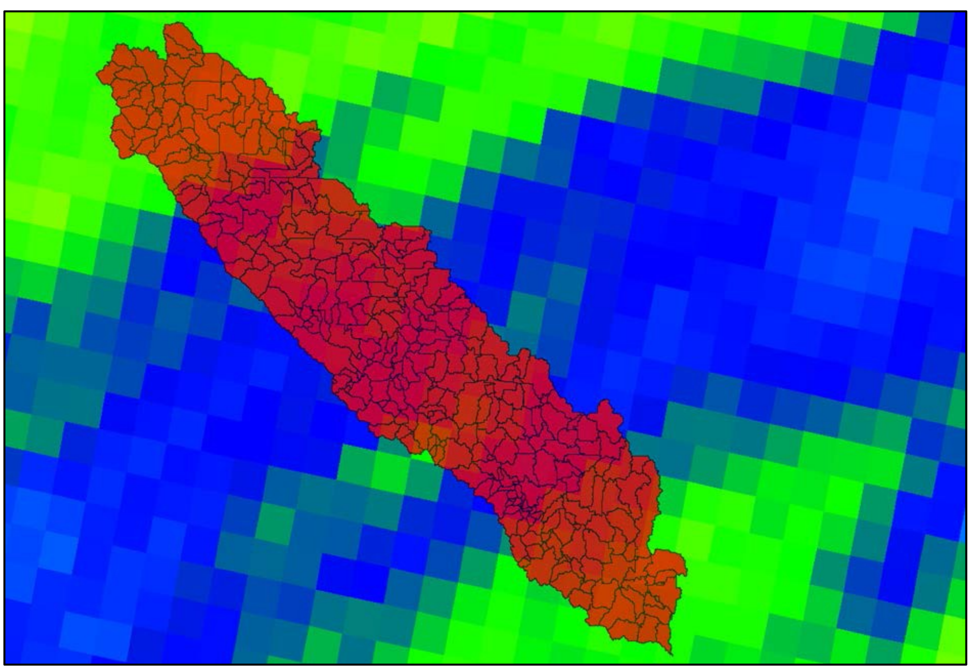


Figure 4.27. Spatial distribution of rainfall for the June 5-9, 2008 rainfall event.

Figure 4.28 compares the simulated flood hydrographs for the current no pond condition (baseline) to those with the application of the large typical pond flood mitigation practices for the

June 2008 rainfall event. The simulations used the large typical pond design specified in the previous sections, where the emergency spillway is set at 10 feet above the principal spillway in the Southern Iowa Drift Plain and 5 feet above the principal spillway in the Des Moines Lobe. The smallest drainage area shown at Carroll, IA has a drainage area of 73.8 mi². There, the peak discharge was reduced by 21 percent. Ponds upstream of Carroll, IA were more fully utilized than the ponds located downstream due to the heavier rainfalls experienced in the northwest corner of the watershed. For this reason, reductions at the Carroll, IA location were at a maximum for the watershed during this event. Downstream, the results showed steadily decreasing reductions of flows, ranging from 14 percent (at Redfield, IA) to 19 percent (at Coon Rapids, IA). Figure 4.29 summarizes the peak discharge for current conditions, the peak discharge for the large typical pond scenario, and the percent peak reduction, at all five index locations for the June 2008 rainfall event.

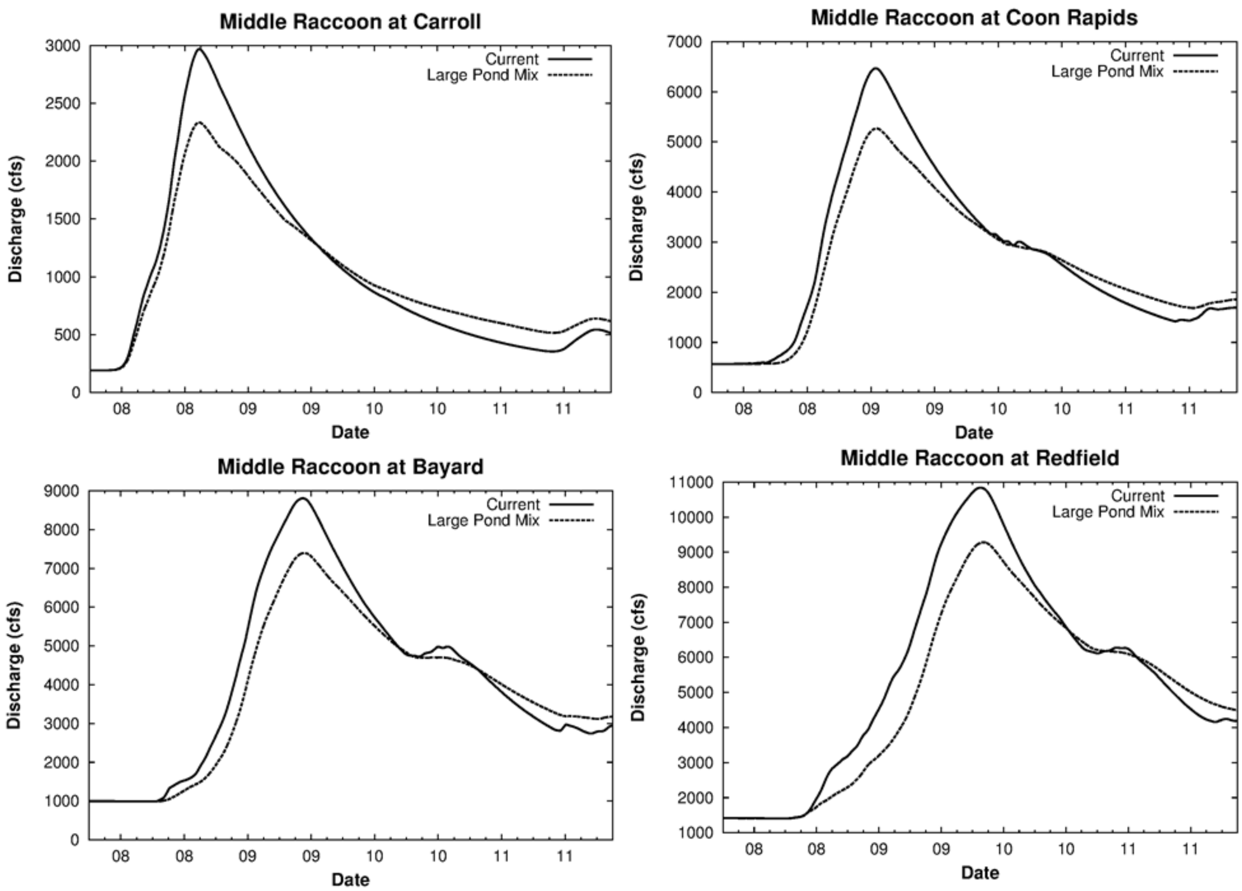


Figure 4.28. Comparisons of hydrographs with and without the large typical pond scenario for the June 2008 rainfall event. For the hydrographs shown, peak flow reduction ranges from 14-21 percent.

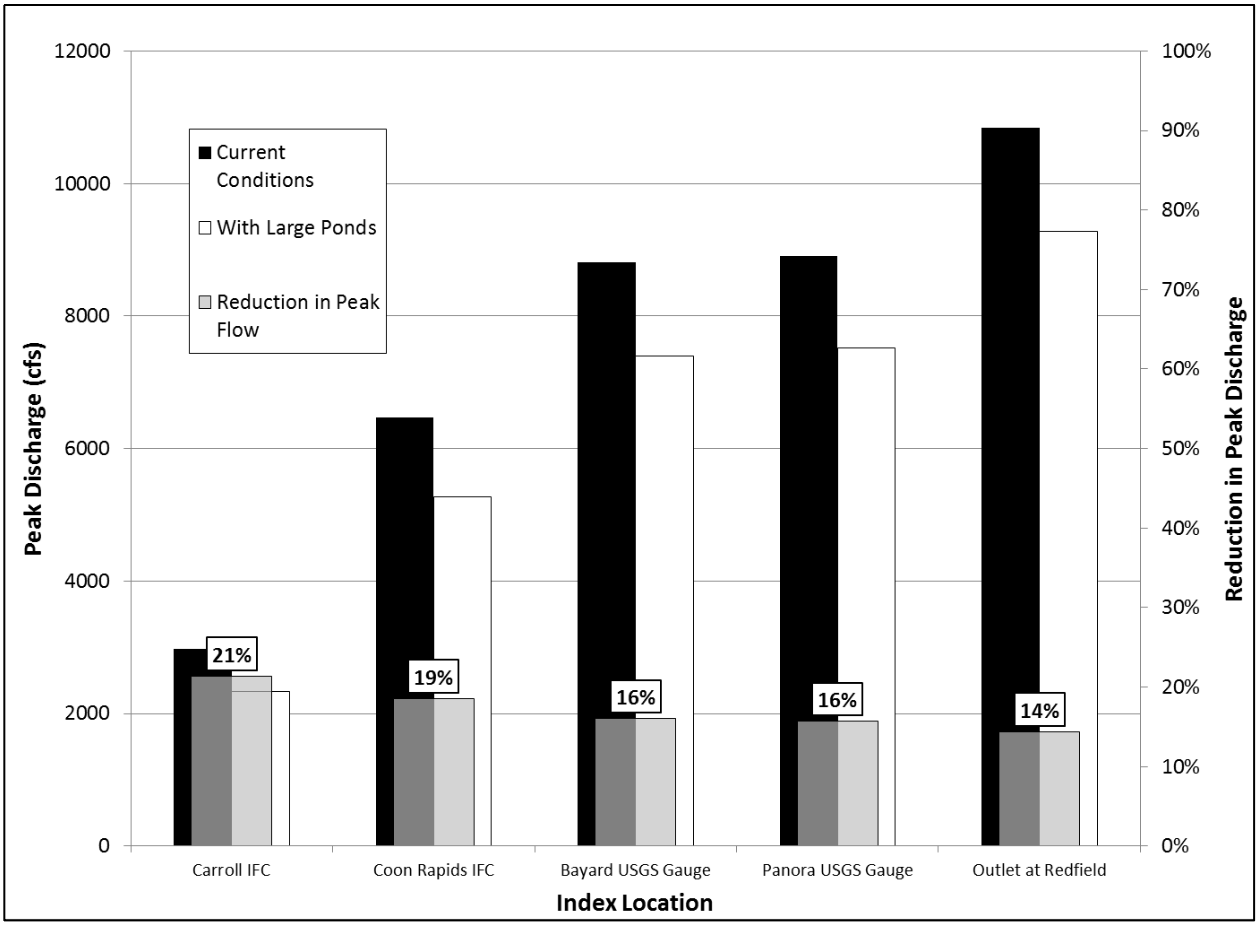


Figure 4.29. Peak discharge reductions for the large pond scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the June 2008 rainfall event.

Reducing peak flood discharge also reduces the peak water height (or stage) in a river during the flood. For the peak discharge reductions in the large pond flood mitigation practice, the corresponding reduction in flood stage was 0.8 feet at the USGS gauge location at Bayard, IA and 0.9 feet for the USGS gauge at Panora, IA. This reduction was estimated for the USGS stream-gauge locations, where the rating curves have been developed. Although a 0.8 and 0.9 feet reductions in flood stage would slightly reduce the flood inundation area, flooding still occurs. Based on the flood stage level reported by the National Weather Service at Bayard, IA, water levels above action stage (13 feet) are expected for both the current conditions and the large pond scenario. The addition of the large pond flood mitigation practice would not have eliminated the flood of 2008 in the Middle Raccoon River watershed. However, it would be reasonable to assume that a reduction in flood stage of approximately 1 foot may be capable of protecting some homes and properties which were inundated during this event.

Figure 4.30 compares the simulated flood hydrographs for the current no pond condition (Baseline) to those with the application of the large typical pond and cover crops flood mitigation practices for the June 2008 rainfall event. The simulations used the large typical pond design and cover crops specified in the previous section, where the emergency spillway is set at 10 feet above the principal spillway in the Southern Iowa Drift Plain and 5 feet above the principal spillway in the Des Moines Lobe. Cover crops were applied to every agricultural acre. The smallest drainage area shown at Carroll, IA has a drainage area of 73.8 mi². There, the peak discharge was reduced by 31 percent. Ponds upstream of Carroll, IA were more fully utilized than the ponds located downstream due to the heavier rainfalls experienced in the northwest corner of the watershed. For this reason, reductions at the Carroll, IA location were at a maximum for the watershed during this event. Downstream, the results showed steadily decreasing reductions of flows, ranging from 26 percent (at Redfield, IA) to 29 percent (at Coon Rapids, IA). Compared to the June 2008 storm using large ponds alone, the addition of cover crops created more uniform reductions in flow from the upstream most to downstream most index location. In general, the addition of cover crops reduced peak flows by an additional 10 percent when compared with large typical ponds alone. Figure 4.31 summarizes the peak discharge for current conditions, the peak discharge for the large typical pond with cover crops scenario, and the percent peak reduction, at all five index locations for the June 2008 rainfall event.

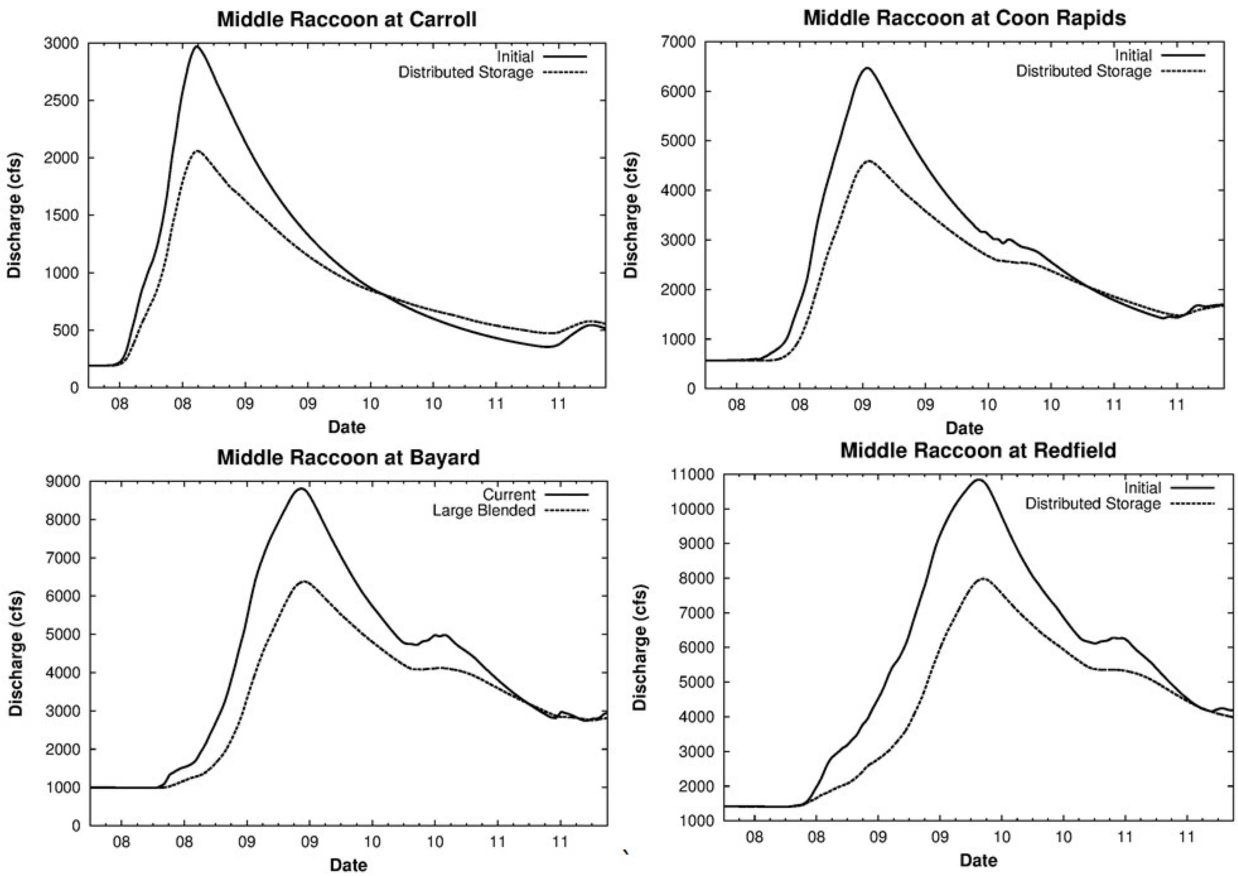


Figure 4.30. Comparisons of hydrographs with and without the large blended scenario for the June 2008 rainfall event. For the hydrographs shown, peak flow reduction ranges from 26-31 percent.

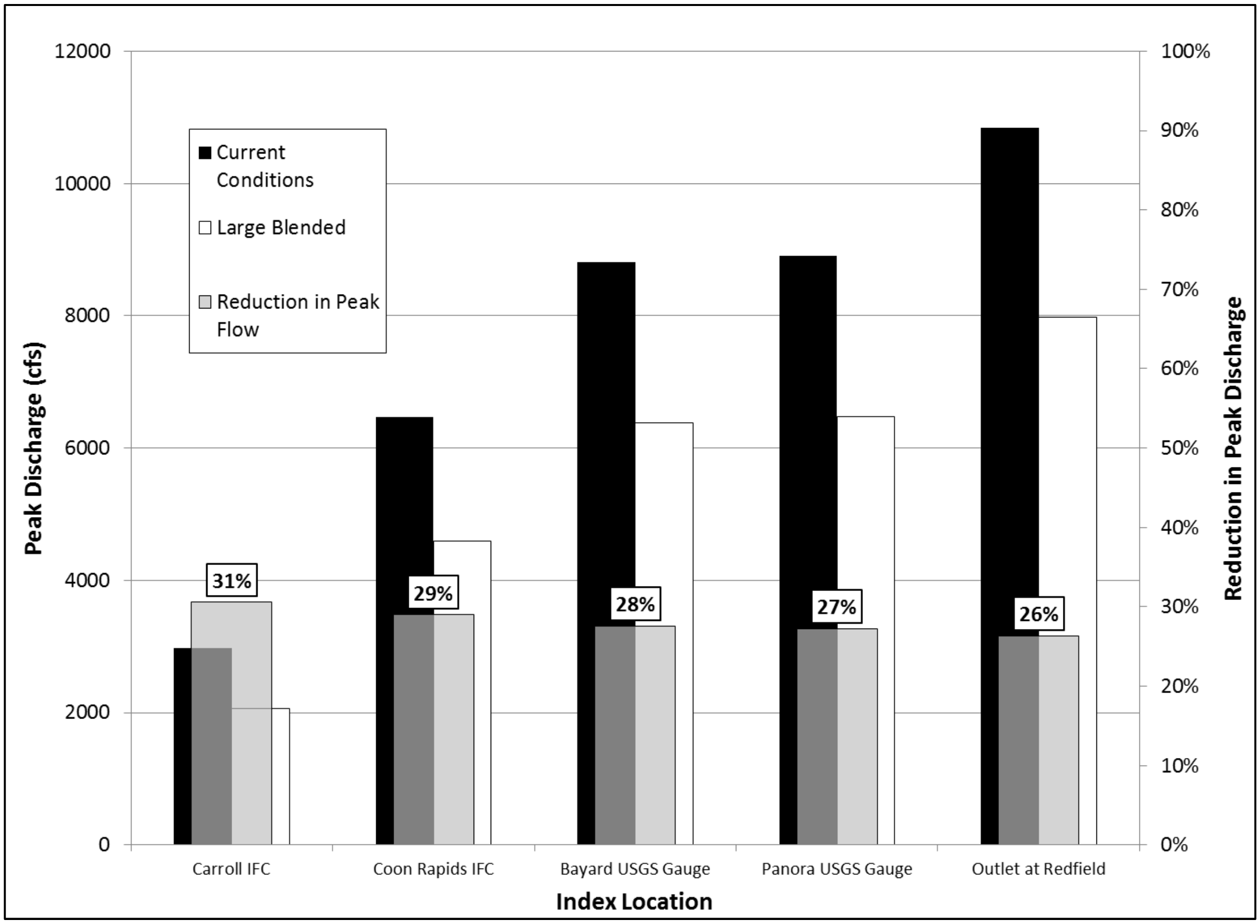


Figure 4.31. Peak discharge reductions for the large blended scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the June 2008 rainfall event.

For the peak discharge reductions in the large blended flood mitigation practice, the corresponding reduction in flood stage was 1.5 feet at the USGS gauge location at Bayard, IA and 1.7 feet for the USGS gauge at Panora, IA. This reduction was estimated for the USGS stream-gauge locations, where the rating curves have been developed. Although a 1.5 and 1.7 feet reductions in flood stage would slightly reduce the flood inundation area, flooding still occurs. Again, based on the flood stage level reported by the National Weather Service at Bayard, IA, water levels above action stage (13 feet) are expected for both the current conditions and the large pond scenario. The addition of the large blended flood mitigation practice would not have eliminated the flood of 2008 in the Middle Raccoon River watershed. However, it would be reasonable to assume that a reduction in flood stage of approximately 1.5 feet may be capable of protecting some homes and properties which were inundated during this event.

June 2013

The storm of June 13-17, 2013 was characterized by heavy rainfalls falling primarily in the center of the watershed. In this location, rainfall totals reached nearly 6 inches. Lighter rainfalls fell in the northern and southern portion of the basin, averaging approximately 1 to 4 inches in these locations. Figure 4.32 shows the spatial variation of rainfall for this event, where yellow represent rainfalls of greater than 6 inches, green represents rainfalls of between 3 and 5 inches, and blue represents rainfalls of between 1 and 3 inches. The heavy rains resulted in a modeled peak discharge of 10,970 cfs at the USGS gauge located in Bayard, IA.

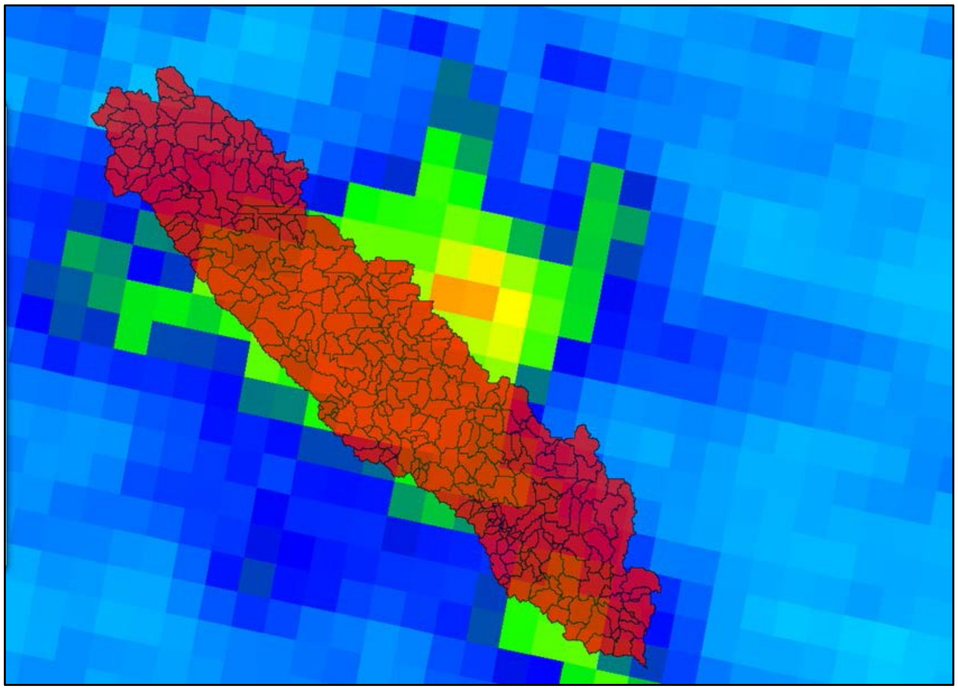


Figure 4.32. Spatial distribution of rainfall for the June 13-17, 2013 rainfall event

Figure 4.33 compares the simulated flood hydrographs for the current no pond condition (Baseline) to those with the application of the large typical pond flood mitigation practices for the June 2013 rainfall event. The simulations used the large typical pond design specified in previous sections, where the emergency spillway is set at 10 feet above the principal spillway in the Southern Iowa Drift Plain and 5 feet above the principal spillway in the Des Moines Lobe. The smallest drainage area shown at Carroll, IA has a drainage area of 73.8 mi². There, the peak discharge was reduced by 13 percent. Ponds upstream of Carroll, IA were not fully utilized due to very little rainfall in the area draining to Carroll. For this reason, reductions at the Carroll, IA location were at a minimum for the watershed. Downstream, the results showed a sharp increase in peak flow reduction where rainfalls were heaviest, ranging from 13 percent (at Carroll, IA) to 27 percent (at Redfield, IA). Figure 4.34 summarizes the peak discharge for current conditions, the peak discharge for the large typical pond scenario, and the percent peak reduction, at all five index locations for the June 2013 rainfall event.

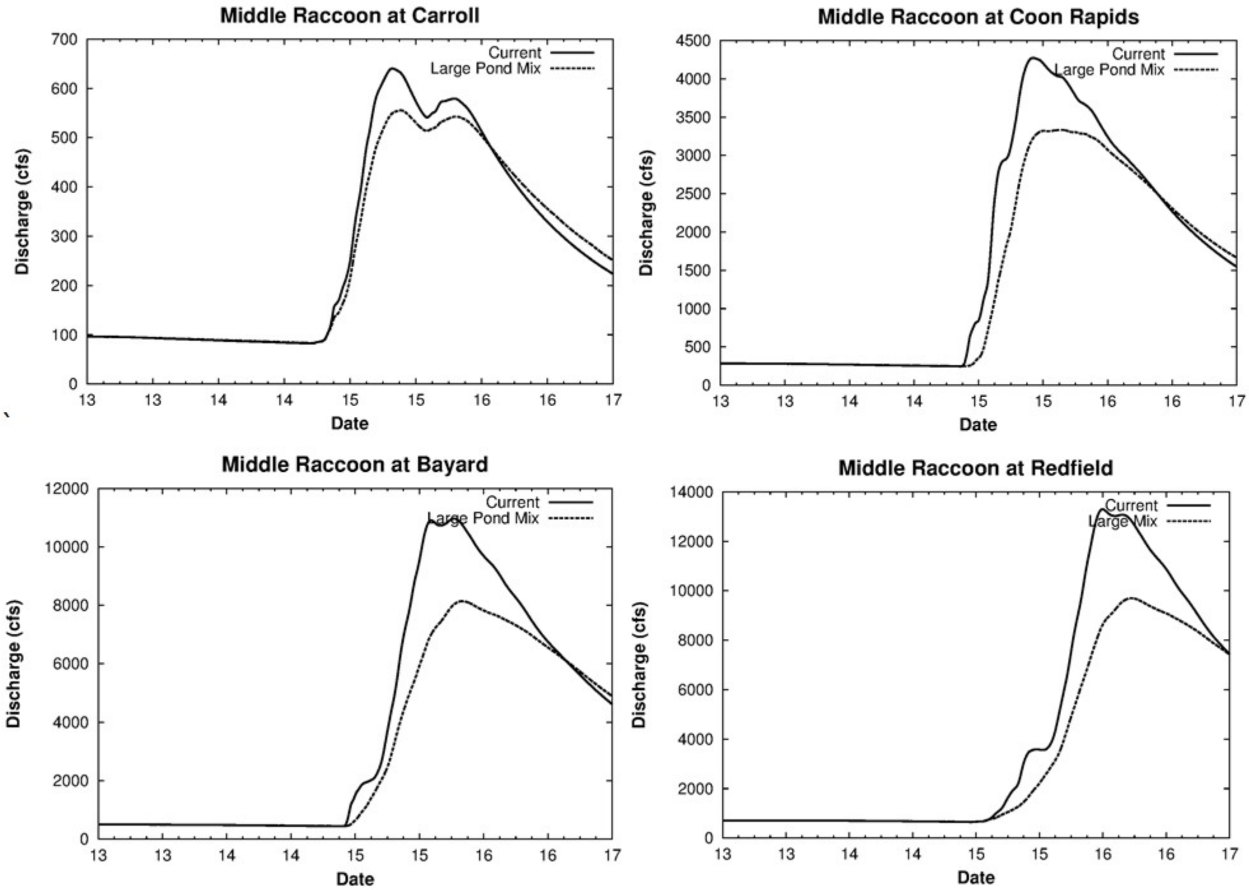


Figure 4.33. Comparisons of hydrographs with and without the large typical pond scenario for the June 2013 rainfall event. For the hydrographs shown, peak flow reduction ranges from 14-21 percent.

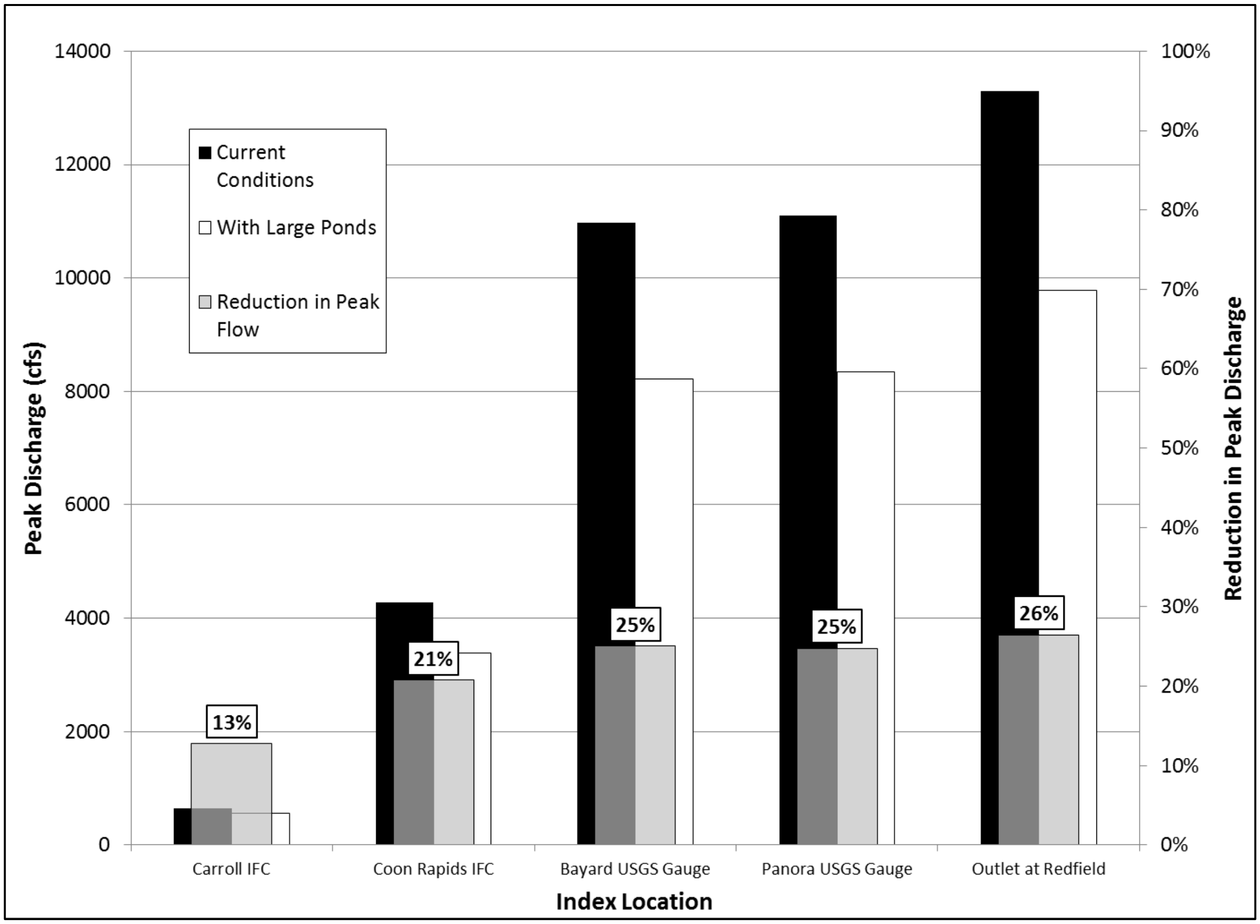


Figure 4.34. Peak discharge reductions for the large pond scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the June 2013 rainfall event.

Reducing peak flood discharge also reduces the peak water height (or stage) in a river during the flood. For the peak discharge reductions in the large pond flood mitigation practice, the corresponding reduction in flood stage was 1.5 feet at the USGS gauge location at Bayard, IA and 1.7 feet for the USGS gauge at Panora, IA. This reduction was estimated for the USGS stream-gauge locations, where the rating curves have been developed. Although a 1.5 and 1.7 feet reductions in flood stage would slightly reduce the flood inundation area, flooding still occurs. Again, based on the flood stage level reported by the National Weather Service at Bayard, IA, water levels above action stage (13 feet) are expected for both the current conditions and the large pond scenario. The addition of the large pond flood mitigation practice would not have eliminated the flood of 2013 in the Middle Raccoon River watershed. However, it would be reasonable to assume that a reduction in flood stage of approximately 1.5 foot may be capable of protecting some homes and properties which were inundated during this event.

Figure 4.35 compares the simulated flood hydrographs for the current no pond condition (Baseline) to those with the application of the large typical pond and cover crops flood mitigation practices for the June 2013 rainfall event. The simulations used the large typical pond design and cover crops specified in previous sections, where the emergency spillway is set at 10 feet above the principal spillway in the Southern Iowa Drift Plain and 5 feet above the principal spillway in the Des Moines Lobe. Cover crops were applied to every agricultural acre. The smallest drainage area shown at Carroll, IA has a drainage area of 73.8 mi². There the peak discharge was reduced by 30 percent. Ponds upstream of Carroll, IA were not fully utilized; however, a large increase in peak flow reduction can be seen when comparing this practice to the large typical pond practice for this event. This was due to a large increase in the percentage of rainfall being absorbed into the soil using the cover crop practices for the small amount of rainfall which fell in the Carroll, IA drainage area. However, peak flow reduction was still at a minimum at Carroll, IA during this event. Downstream, the results varied, based upon the spatial location of rainfall, ranging from 30 percent (at Carroll, IA) to 34 percent (at Redfield, IA). Compared to the June 2013 storm, using large ponds along with the addition of cover crops, more uniform reductions in flow were created from the upstream most to downstream most index location. In general, the addition of cover crops reduced peak flows by an additional 8 percent when compared with large typical ponds alone. Figure 4.36 summarizes the peak discharge for current conditions, the peak discharge for the large typical pond with cover crops scenario, and the percent peak reduction, at all five index locations for the June 2013 rainfall event.

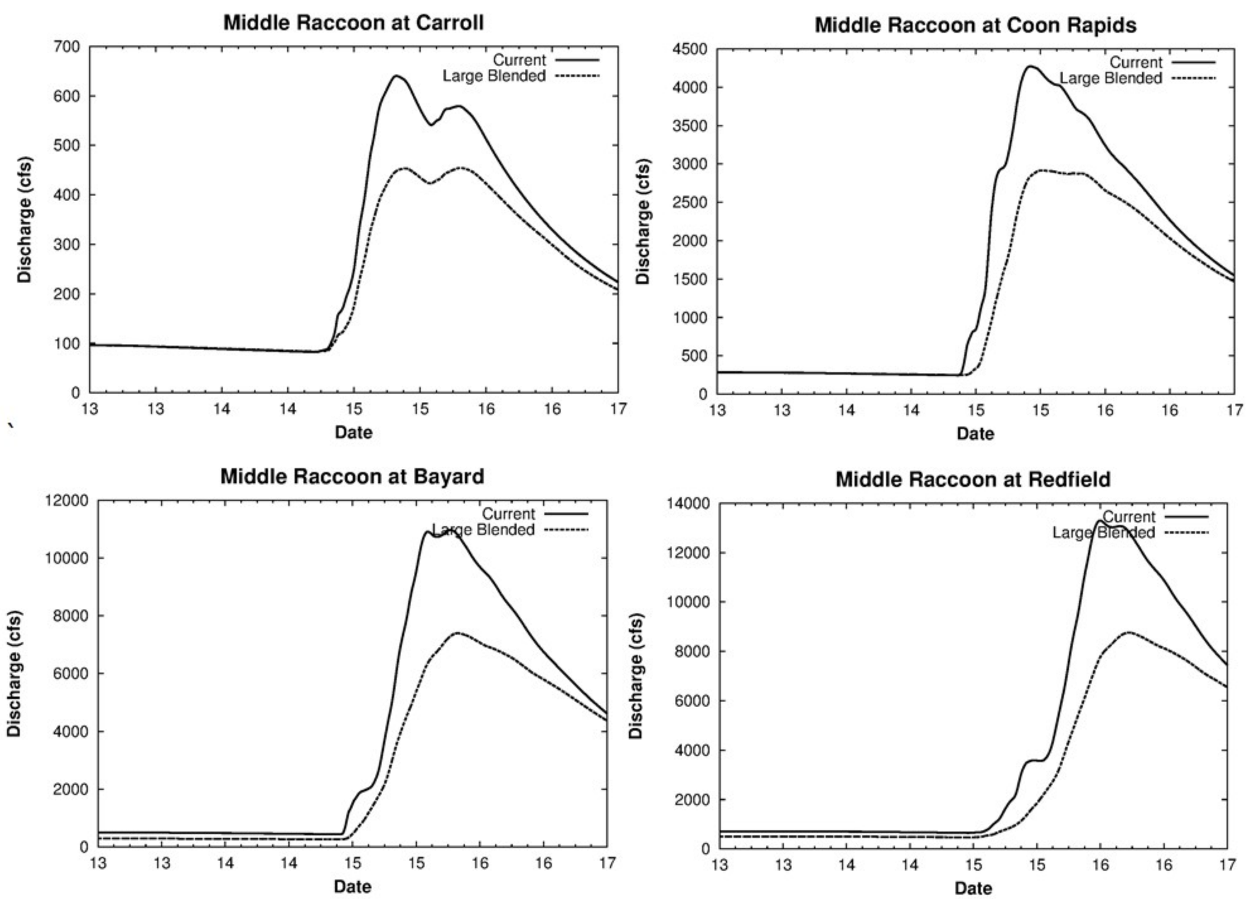


Figure 4.35. Comparisons of hydrographs with and without the large blended scenario for the June 2013 rainfall event. For the hydrographs shown, peak flow reduction ranges from 30-34 percent.

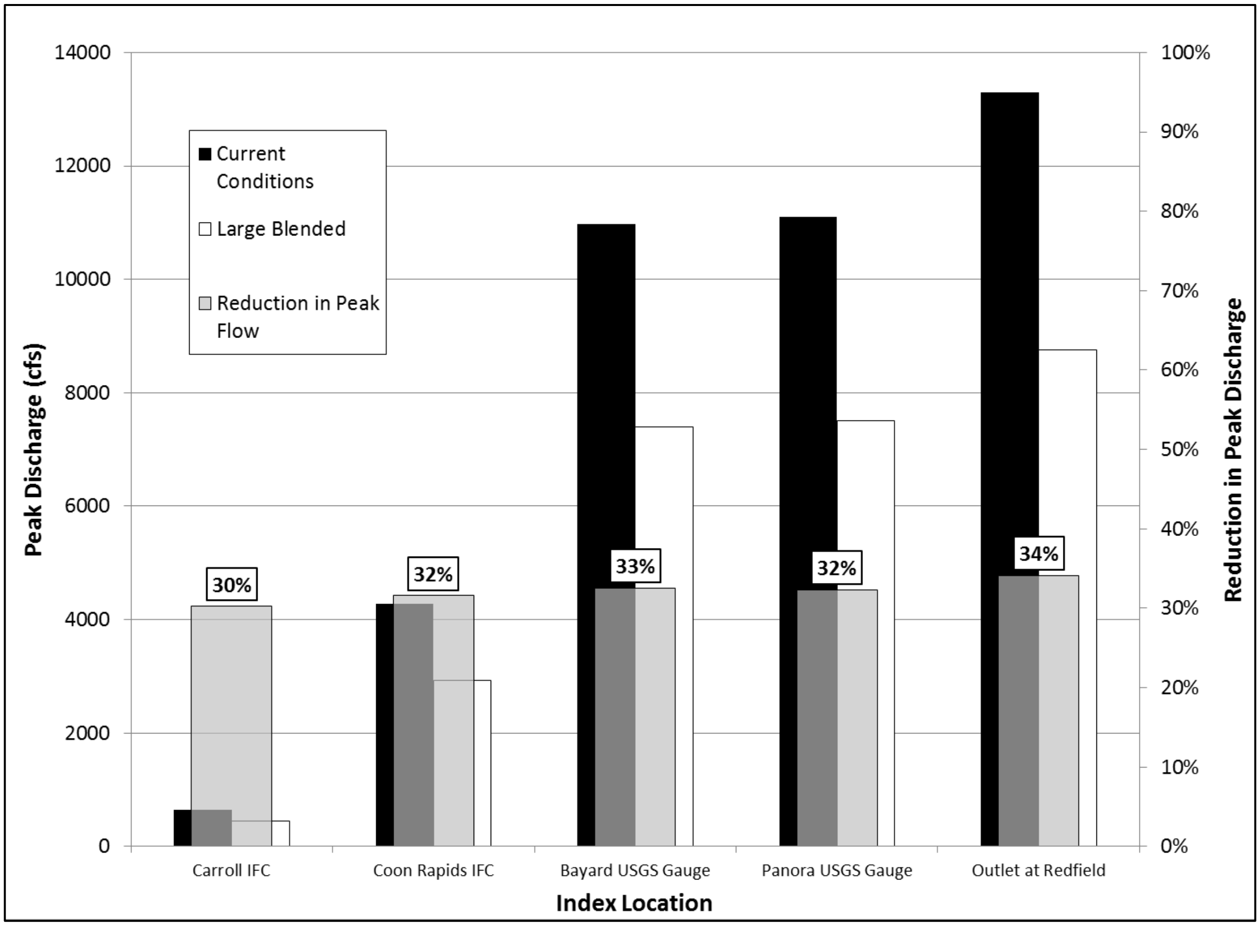


Figure 4.36. Peak discharge reductions for the large blended scenario. Results are shown at five index points moving from upstream (left) to downstream (right) for the June 2013 rainfall event.

For the peak discharge reductions in the large blended flood mitigation practice, the corresponding reduction in flood stage was 1.9 feet at the USGS gauge location at Bayard, IA and 2.3 feet for the USGS gauge at Panora, IA. This reduction was estimated for the USGS stream-gauge locations, where the rating curves have been developed. Although a 1.9 and 2.3 feet reductions in flood stage would slightly reduce the flood inundation area, flooding still occurs. Again, based on the flood stage level reported by the National Weather Service at Bayard, IA, water levels above action stage (13 feet) are expected for both the current conditions and the large pond scenario. The addition of the large blended flood mitigation practice would not have eliminated the flood of 2013 in the Middle Raccoon River watershed. However, it would be reasonable to assume that a reduction in flood stage of approximately 2 feet may be capable of protecting some homes and properties which were inundated during this event.

Two historic rainfall events were analyzed to represent the impact of flood mitigation practices on the watershed during times of past flooding. The scenarios were created using the large typical pond design and the addition of cover crops were applied in some simulations. In HEC- HMS, the ponds are represented by a storage-discharge table that is reflective of the topographic conditions and pond hydraulics. The cover crops are represented with a reduced Curve Number which allow for more infiltration and less runoff. A maximum peak flow reduction of 31 percent was found during the June 2008 event at Carroll, IA. A maximum peak flow reduction of 34 percent was found during the June 2013 event at Redfield, IA. Reductions were more varied for the simulations run with the ponds only, and more uniform when using the combination of both ponds and cover crops. From the analyses completed in previous sections, we know that increased infiltration is most effective at reducing peak discharge at small scale storm events, while distributed storage can be most effective at larger events (if the correct pond sizes are selected). The 2008 rainfall event was roughly equivalent to a 10-year rainfall in the northern portion of the watershed; therefore, most ponds were utilized, but the emergency spillway was not engaged. The June 2013 rainfall event was roughly equivalent to a 25-year rainfall in the center of the watershed; therefore, a number of ponds in the center of the basin were fully utilized and the emergency spillway was engaged. Pond utilization figures can be seen in Appendix A. Had flood mitigation practices been in place during these events, the simulations show that they could have had a significant impact on flooding throughout the basin.

5. Summary and Conclusions

To better understand the flood hydrology of the Middle Raccoon River watershed, and to evaluate potential flood mitigation strategies, the HEC-HMS model of the watershed was used in several ways. We first assessed the runoff potential throughout the basin, using the HEC-HMS model's representation of runoff generation. Locations with agricultural land use, and moderate to poorly drained soils, have the highest runoff potential; mitigating the effects of high runoff from these areas is a priority for flood mitigation planning. Note that other land uses – particularly urban development in towns and cities – may have even higher runoff. But because their size is small compared to that of the HEC-HMS modeled subbasins (the basic element for runoff simulation), individual communities are not identified by this technique (only individual subbasins, which may include a small portion of urban land, are identified). Still, typical strategies employed to manage urban storm water are needed in these communities (e.g., storm water detention and low-impact development practices).

To quantify the potential effects of flood mitigation strategies, the HEC-HMS model was used to simulate river flows throughout the Middle Raccoon River watershed. Five strategies were considered — enhancing local infiltration though changes in land-use (from agriculture to forest or native tall-grass prairies), enhancing local infiltration though improvements in soil quality, enhancing local infiltration using conservation practices (cover crops), storing floodwaters temporarily in ponds throughout the watershed, and a combination of cover crops and ponds all to reduce downstream discharges. The effects of these strategies were simulated for significant design flood events – those resulting from a 10-, 25-, 50-, and 100-year return period, 24-hour design storm rainfall. These events correspond to rainfall amounts of 4.03, 5.08, 6.00, and 7.04 inches in 24 hours over the entire Middle Raccoon River watershed. Scenarios were also run for the historic rainfall events of June 2008 and June 2013. The results for these strategies were compared to simulations of flows for the existing watershed condition. Although each simulated scenario was hypothetical and simplified, the results provide valuable insights on the relative performance of each strategy for flood mitigation planning.

Increased Infiltration in the Watershed: Land Use Changes

From the simulated results, enhancing local infiltration through changes in land use was found to have the most significant impact on runoff. The model predicts that the changes from an agricultural to a forest or native tall-grass prairie landscape would increase infiltration during large storms between 0.7 inches (tall-grass prairie, 10-year event) to 1.4 inches (forest, 100-year event). The increased infiltration results in peak flow reductions between 28 percent (tall-grass, 100-year event) and 56 percent (forest, 10-year event). This means the conversion of the native landscape to agricultural land uses, which has been occurring since the mid-19th century, has resulted in a significant reduction in the infiltration capacity, and more runoff. Obviously, converting the entire landscape back to forest or tall-grass prairie (as was simulated) is not a practical or an economically desirable strategy. Still, from a hydrologic point of view, targeted projects that enhance infiltration by land-use change could be an effective part of the watershed's flood mitigation efforts.

Increased Infiltration in the Watershed: Improving Soil Quality

Even without changes to land use, the storage capacity of the soils could be better utilized by improving soil quality to enhance infiltration. The hypothetical improved soil quality scenario suggests that it is a slightly less effective strategy than land use change. The improved soil quality scenarios predict an increased infiltration during large storms between 0.7 inches (for the 10-year design event) to 1.1 inches (100-year design event). The increased infiltration results in peak flow reductions between 21 percent and 36 percent. In locations where the land use must remain the same, such increases in infiltration (and the resulting downstream reduction in flood flows) are very significant. For the Middle Raccoon River watershed, where agricultural land use will continue to dominate for the foreseeable future, efforts to improve soil quality can also be an effective part of a watershed-wide flood mitigation strategy.

Increased Infiltration in the Watershed: Application of Cover Crops

Hydrology is altered when cover crops are applied to heavily agricultural landscapes during a crop's dormant season. Cover crops act to increase infiltration by the prevention of surface sealing, increased available water storage capacity, and increased soil macroporosity, (Dabney, 1998). The hypothetical cover crop application results in the least drastic reductions in peak discharge reductions and stage reductions. However, less drastic results were expected in this scenario since they did not require large scale changes to the watershed's primary agricultural function. This scenario may, therefore, be the most feasible of the four increased infiltration scenarios. The application of cover crops scenario predicts an increased infiltration during large storms between 0.2 inches (for the 10-year event) to 0.4 inches (for the 100-year event). The increases in infiltration result in peak discharge reductions between 6 percent (for 100-year design event) and 13 percent (for the 10-year design event). Since the application of cover crops between cash crop seasons has become more popular in recent years, and the removal of agricultural land to tall-grass prairie or forest is not realistic on a large scale, this cover crop scenario can provide input as to the upper bounds of expected peak flow reduction, should every tillable acre apply this conservation practice. The results of this scenario show that, while not as effective as other increased infiltration techniques, the application of cover crops can still be part of a basin-wide flood mitigation strategy.

Increased Storage on the Landscape: Typical Ponds

In some ways, using ponds to temporarily store floodwaters is an attempt to replace the loss of water that was stored in soils during a pre-agricultural landscape. In the hypothetical scenarios involving pond storage, between 4,709 acre-feet and 9,693 acre-feet of flood storage was added to the Middle Raccoon River watershed. For the watershed, the added storage depth ranges from 0.5 inches (using small ponds) to 1.0 inches of rainfall for drainage areas upstream of the ponds (using large ponds). Compared to the extra water that was removed by infiltration in the previous scenario simulations, the amount of storage replaced by ponds is much smaller. As a result, the overall flood peak reduction with storage ponds is less than predicted for the other scenarios. However, compared to the infiltration scenarios, flood storage is more realisticallyachievable. In this scenario peak discharges were reduced between 4 percent (small pond) and 22 percent (large ponds).

As a flood mitigation strategy, ponds are very effective in reducing flood peaks immediately downstream of their headwater sites. Further downstream, floodwaters originating from locations throughout the watershed arrive at vastly different times; some areas are controlled by ponds, others are not. As a result, as one moves further downstream in the watershed, the flood peak reduction of storage dampens and reductions are less.

Increased Storage on the Landscape: Dry Ponds

Another way to consider the temporary storage of water floodwaters is to design ponds that do not maintain a permanent pool. This means that during times of normal flow, the ponds in this scenario would not hold water. By adding and an outlet (2 inch pipe) at the pond bottoms, the water stored in the permanent pool in the typical pond design scenario, becomes flood storage in the dry pond design scenario. Over the entire Middle Raccoon River watershed, this adds approximately 1,000 acre-feet of flood storage. In this scenario, a willing land owner would be trading other functions of the pond, such as watering animals and irrigation, for flood storage. This may not be as appealing, and may require extra incentive. However, the dry pond scenarios show that, under most conditions, the extra storage provides an increased benefit in peak flow reductions. Peak discharge in these scenarios was reduced between 5 percent (small dry pond) to 23 percent (large dry pond).

Blended Practices: Increased Infiltration and Distributed Storage

One last set of scenarios was run to get an approximation for peak flow reduction, should the watershed adopt a flood mitigation plan that incorporated both distributed storage and increased infiltration. In HEC-HMS, the cover crop increased infiltration scenario (where every agricultural acre was converted to agricultural plus the application of cover crops) was combined with the typical pond scenarios. The typical pond design was used, due to the increased expectation of landowner willingness. The two flood mitigation strategies applied in this scenario were assumed to be a likely part of any flood mitigation strategy. Therefore, it can give an approximation for realistic peak flow reductions that the watershed could expect from adopting such a plan. Peak flow reductions for this scenario ranged from 12 percent (Small Blended storm at Redfield, IA) to 31 percent (Large Blended at Carroll, IA). Flow reductions remained relatively consistent for the entire range of design storms considered. This is likely due to the fact that increased infiltration has its greatest impact at smaller design storm events, and distributed storage can have its greatest effect at larger design storm events. The mixing of the practices results in flow reductions that never vary more than 8 percent from the upstream most to downstream most locations, and under most design storms variations were far lower. Compared to cover crops only and typical ponds only, the blended practices have a much larger impact on peak discharges, up to 11 percent. While reductions in peak discharge describe the hydrologic impact of the simulated scenarios, the most important factor is how that peak discharge reduction translates to a decrease in river stage.

Historical Rainfall Events

In addition to analyzing the effects of flood mitigation practices on peak discharge using design storms, we also took into consideration the effects of these practices on historic rainfall events. In particular, two events were simulated June 2008, and June 2013 both using the Large Typical Pond scenario and the Large Blended Practices scenario. By analyzing actual past rainfall events, we were able to get a sense of how well these practices would have performed in non- uniform, past rainfall events. It also gave us an idea as to how much peak flow reduction we can expect in future large flooding events. As expected, the reduction in peak discharge for these events was highly dependent on the spatial distribution of rainfall. For June 2008, the majority of rain fell on the northwest portion of the watershed, so this is where peak flow reductions were at a maximum. For June 2013, the majority of rainfall fell on the center of the watershed, so similarly this is where peak flow reductions were at a maximum. For both events the large blended scenarios outperformed the large typical pond scenarios by an average peak flow reduction of 8 percent. Reductions in peak flows for June 2008 ranged from 14 percent (Large typical ponds at Redfield, IA) to 31 percent (Large blended at Carroll, IA). Reductions in peak flows for June 2013 ranged from 13 percent (Large typical ponds at Carroll, IA) to 34 percent (Large blended at Redfield, IA).

Reductions in Flood Stage

While reductions in peak discharge describe the hydrologic impact of the simulated scenarios, the most important factor is how that peak discharge reduction translates to a decrease in river stage. Table 5.1 summarizes the effects of all the flood mitigation scenarios analyzed in terms of their stage reduction at the USGS gauges at Bayard and Panora for the design storms.

Table 5.1. Stage reductions (ft) for all hypothetical flood mitigation simulations using design storms.

	Reduction in Stage due to Reduction in Peak Discharge (ft)							
	Bayard, IA USGS Gauge				*Panora, IA USGS Gauge*			
Scenario	*10-YR*	*25-YR*	*50-YR*	*100-YR*	*10-YR*	*25-YR*	*50-YR*	*100-YR*
Ag to Forest	3.5	3.1	2.9	2.6	4.1	4.3	4.6	4.6
Ag to Tallgrass	2.6	2.3	2.1	1.9	3.1	3.3	3.5	3.4
Soil Improvement	2.0	1.7	1.6	1.4	2.4	2.6	2.7	2.6
Addition of Cover Crops	0.6	0.5	0.5	0.4	0.8	0.8	0.8	0.6
Ponds - Small	0.7	0.6	0.5	0.4	0.9	0.9	0.9	0.7
Ponds - Large	1.0	0.9	0.9	0.8	1.2	1.4	1.6	1.4
Dry Ponds - Small	0.8	0.7	0.6	0.5	1.0	1.0	1.0	0.8
Dry Ponds - Large	1.0	1.0	0.9	0.9	1.2	1.4	1.6	1.5
Small Ponds & Cover Crops	1.4	1.2	1.1	1.0	1.4	1.8	1.9	1.6
Large Ponds & Cover Crops	1.5	1.5	1.4	1.3	1.9	2.3	2.5	2.3

Table 5.2 summarizes the effects of the flood mitigation scenarios when used in the June 2008 and June 2013 historic rainfall events. With the decreases in stage and flow shown in this report also comes a potential decrease in sediment and nutrient transport. Extreme rainfall events (greater than 90th percentile) in the intensively drained and heavily farmed Midwestern landscapes have been shown to be responsible for over 50 percent of Nitrate exports and over 80 percent of Phosphorous exports (Royer et. al, 2006). To truly predict the reductions in nutrients and

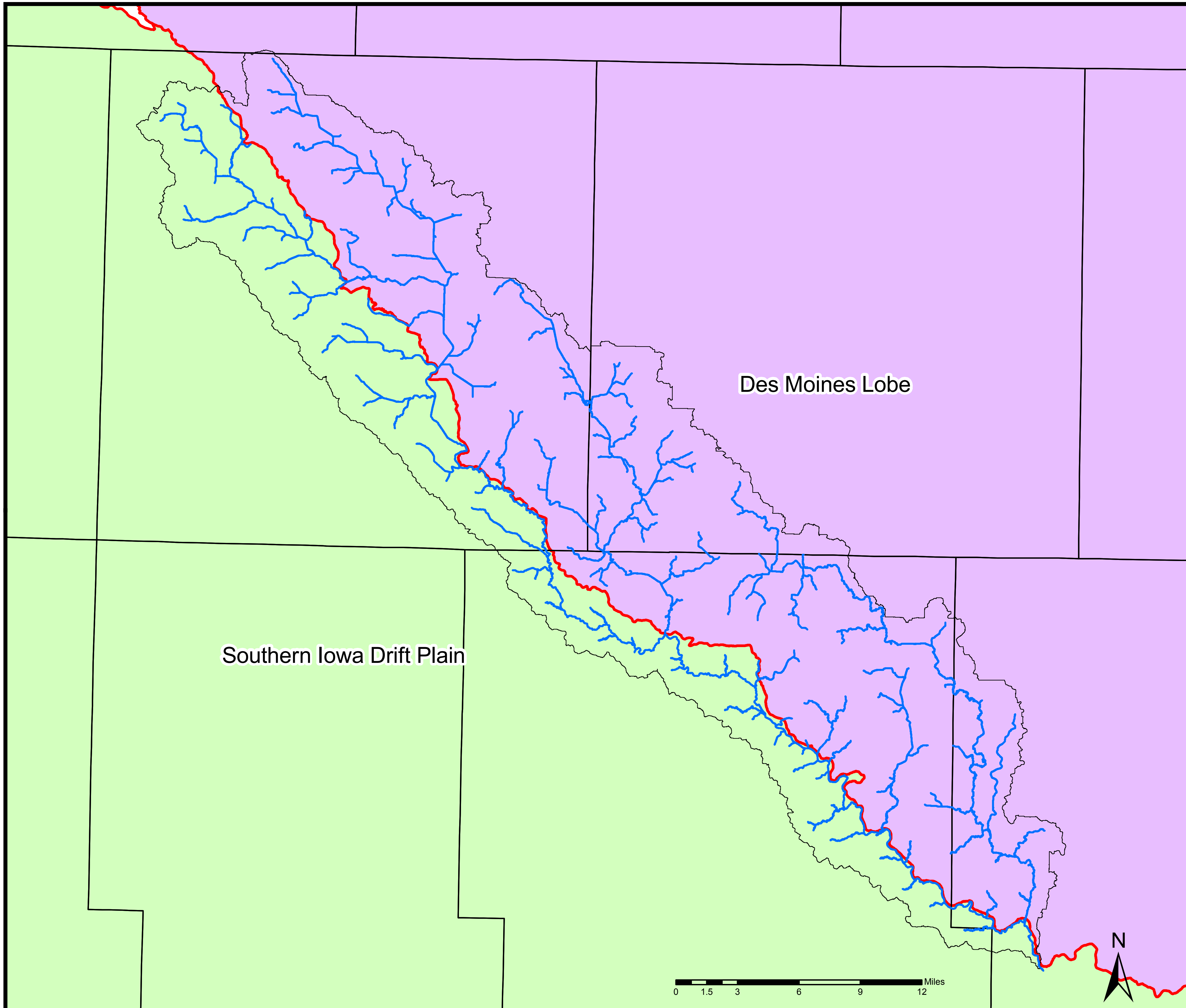
sediments associated with the flood mitigation practices simulated in this study, more detailed modeling should be performed.

Table 5.2. Stage reductions (ft) for 2008 and 2013 simulations using design storms.

	Reduction in Stage due to Reduction in Peak Discharge (ft)			
	Bayard, IA USGS Gauge		*Panora, IA USGS Gauge*	
Scenario	*June 2008*	*June 2013*	*June 2008*	*June 2013*
Ponds – Large	0.8	1.5	0.9	1.7
Large Ponds & Cover Crops	1.5	1.9	1.7	2.3

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

Appendix A – Middle Raccoon River Maps



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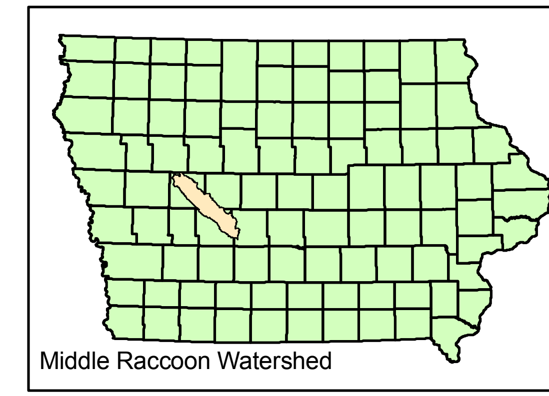
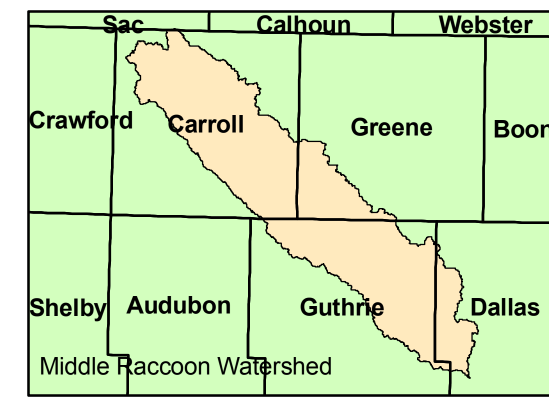




Middle Raccoon River Watershed
Landform Regions

Legend
River
Iowa Counties

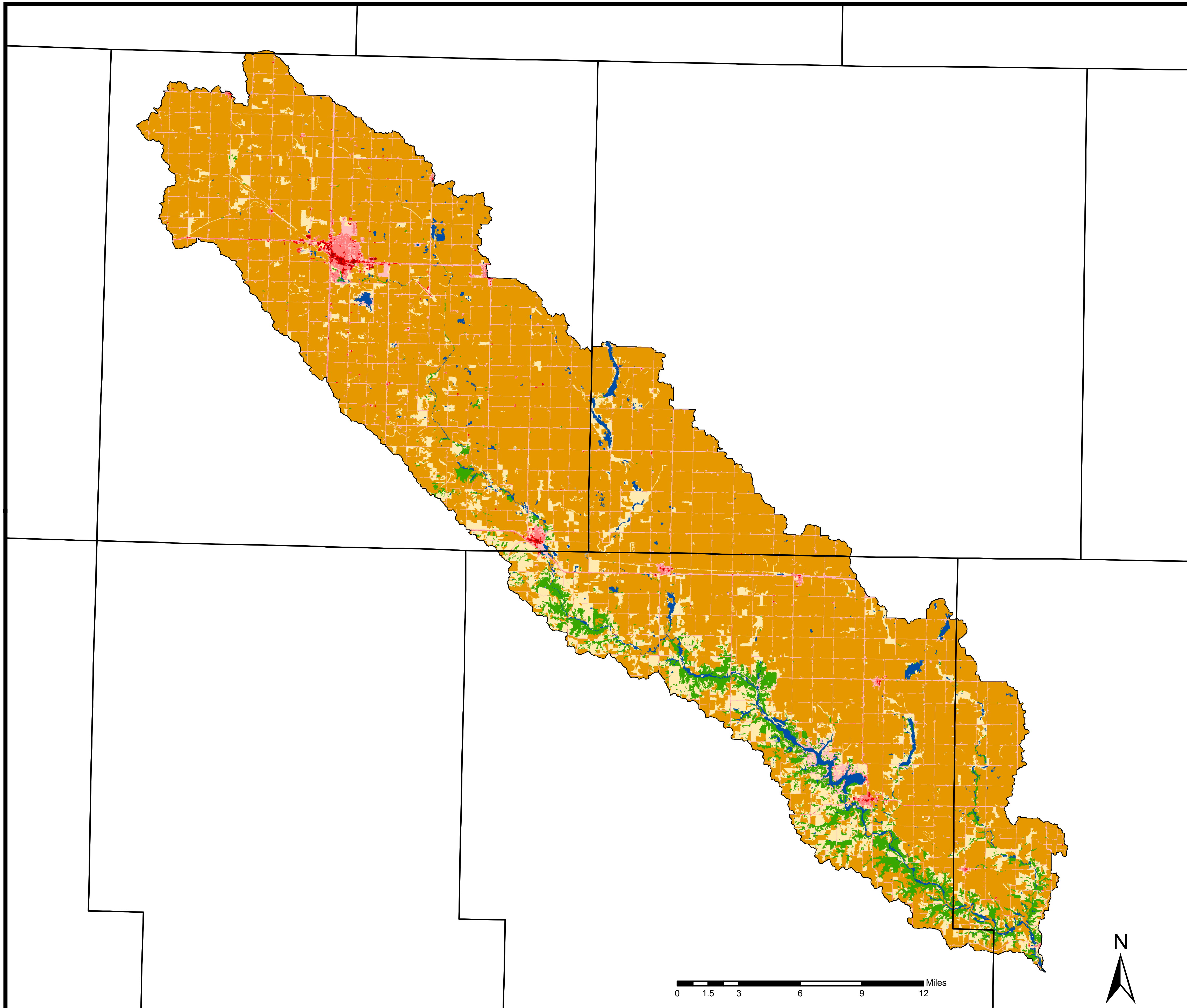
LANDFORMS
Des Moines Lobe
Southern Iowa Drift Plain

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:
Iowa Geologival & Water Survey, Iowa DNR (2009-2010).

Figure: A.1



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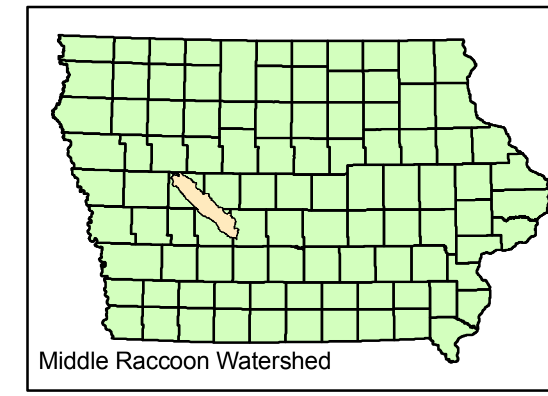
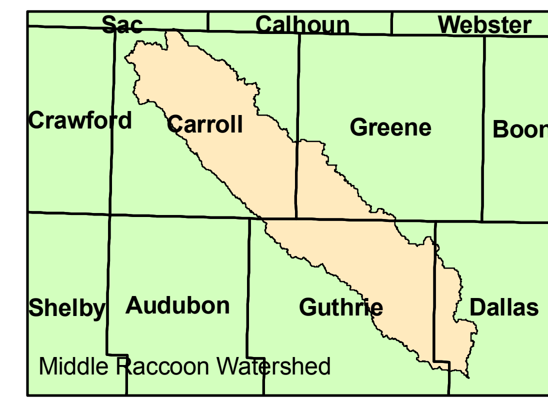




Middle Raccoon River Watershed

Land Cover

Legend

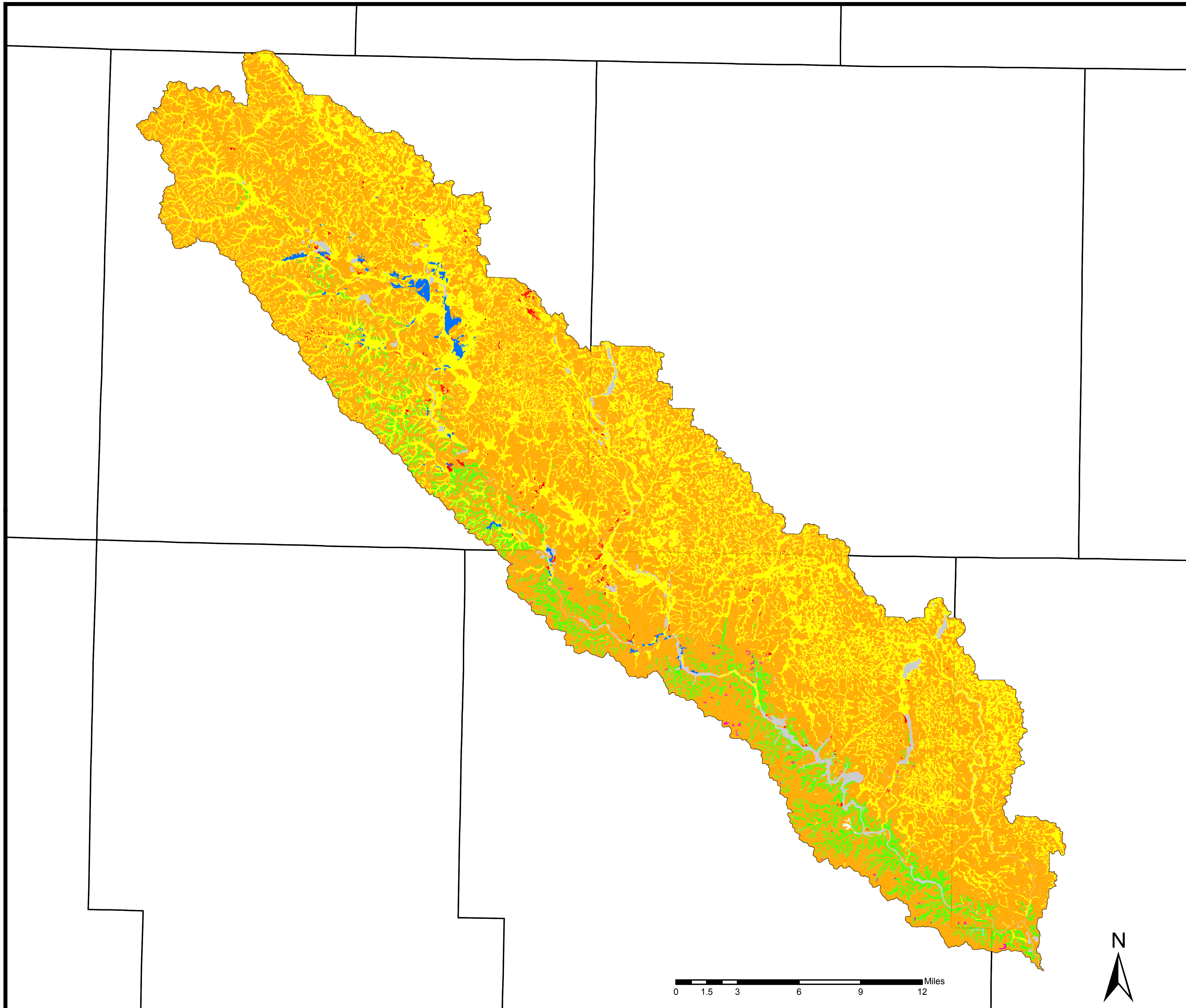
- Iowa Counties
- Water
- Developed, Open
- Developed, Low Intensity
- Developed, Middle Intensity
- Developed, High Intensity
- Barren Land
- Forest
- Grassland
- Row Crop

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:
National Land Cover Dataset, USGS (2006)

Figure: A.2



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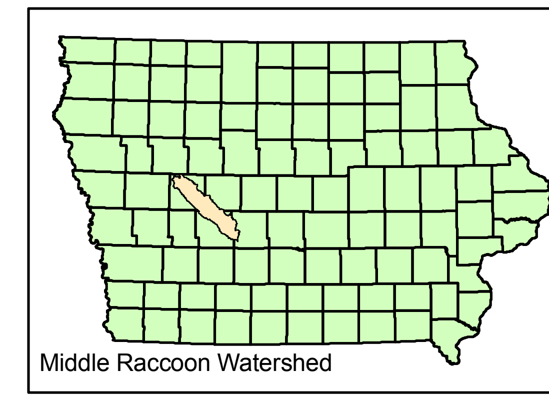
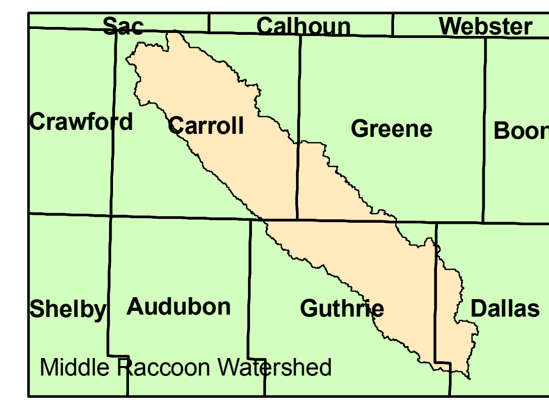




Middle Raccoon River Watershed
Soil Type

Legend

Iowa Counties

Hydrologic Soil Group

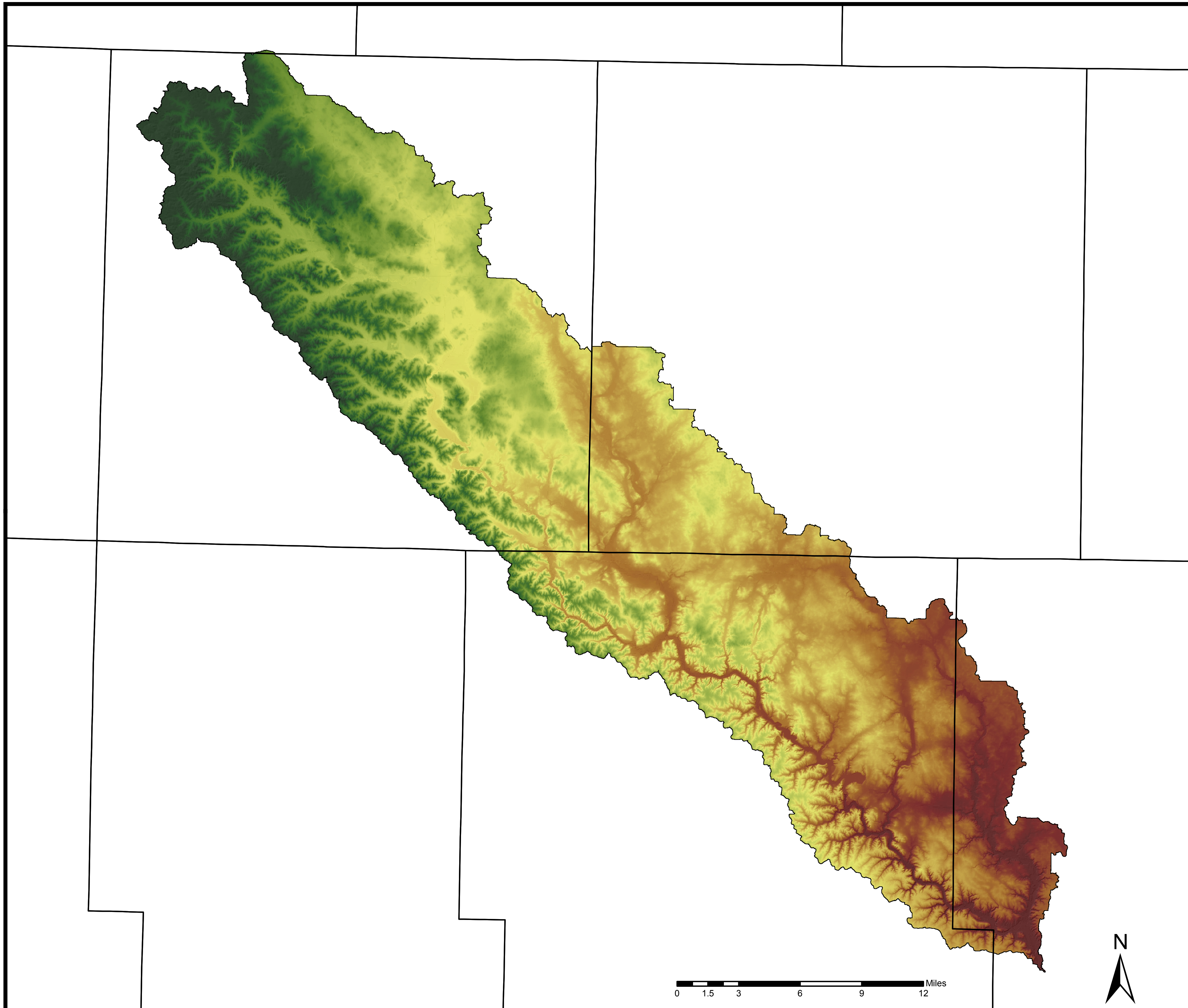
- A
- B
- B/D
- C
- C/D
- D

Date: May 2014

By: William Klingner, E.I., CFM

Data Sources:
Soil Survey (SSURGO) Geographic Database, NRCS (2012)

Figure: A.3



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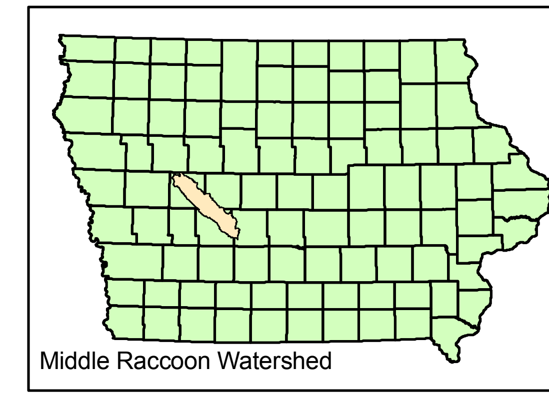
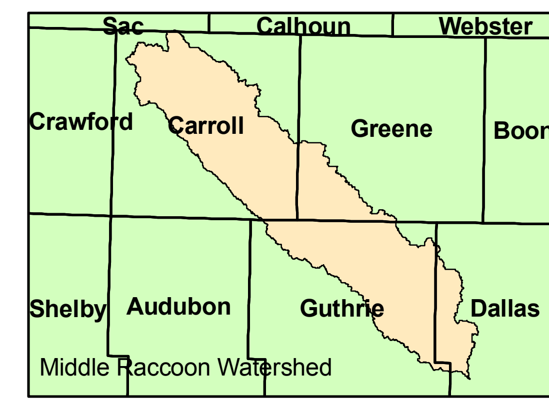




Middle Raccoon River Watershed
Elevation (Feet)

Legend

Iowa Counties

DEM Elevation (ft)

High : 1475

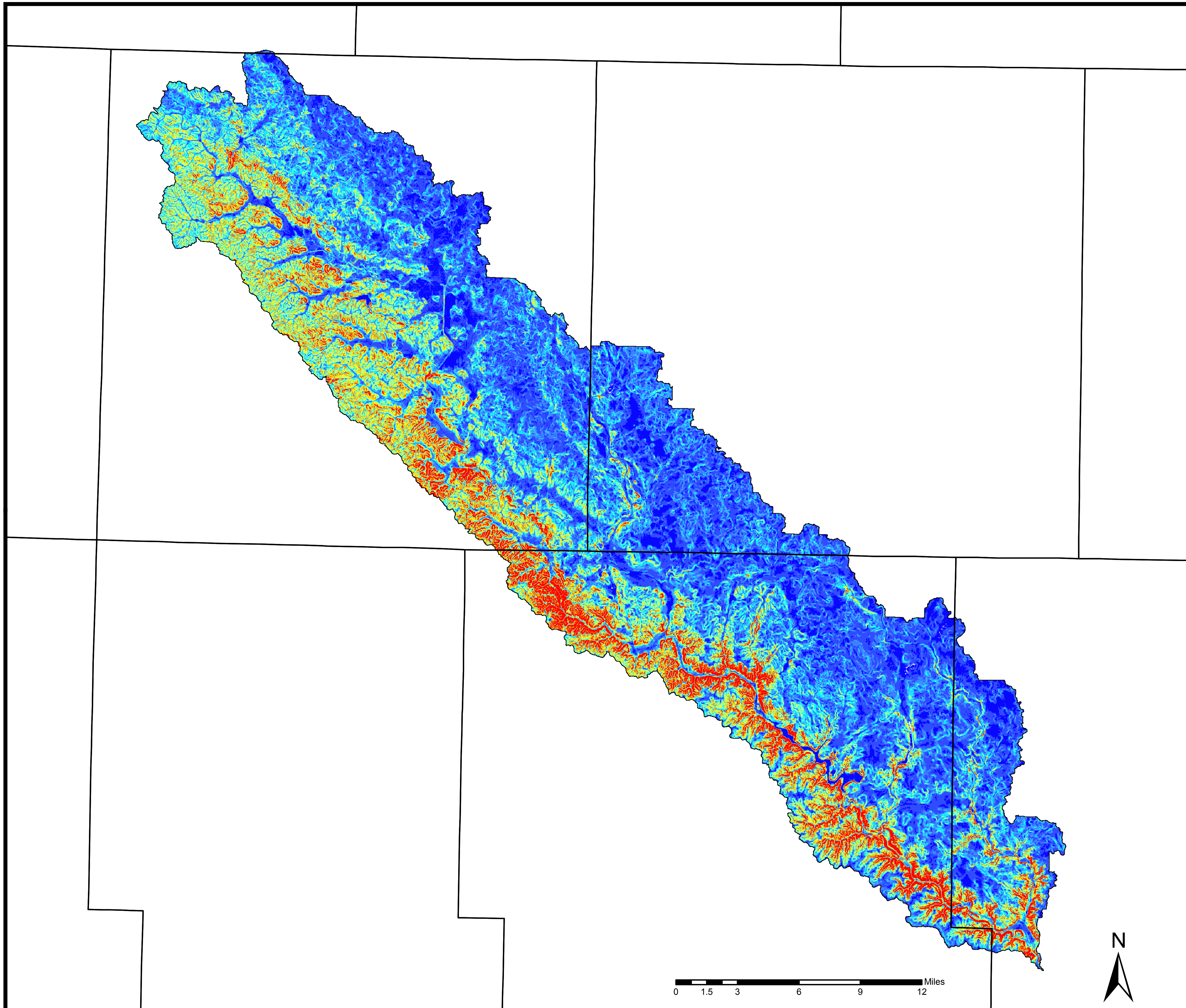
Low : 900

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:
National Elevation Dataset (3m)
USGS (2009)

Figure: A.4



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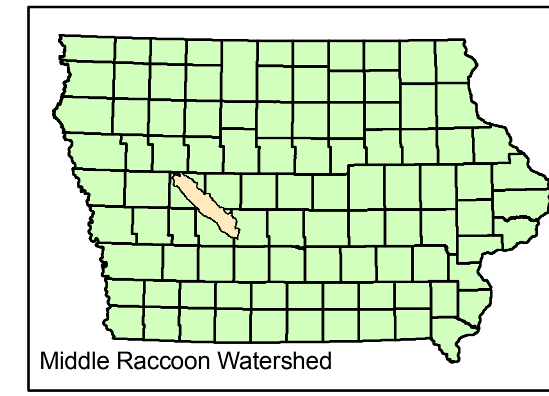
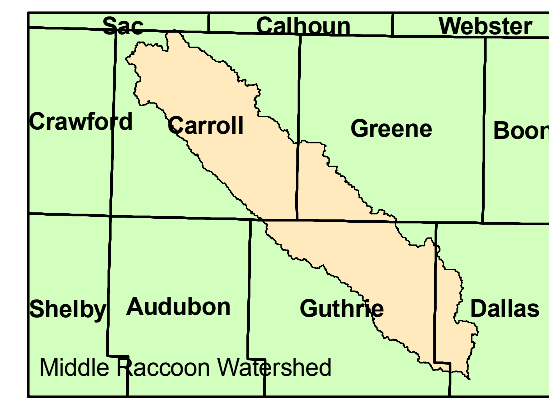




Middle Raccoon River Watershed

Percent Slope

Legend

Iowa Counties

Percent Slope

Value

High : 52

Low : 0

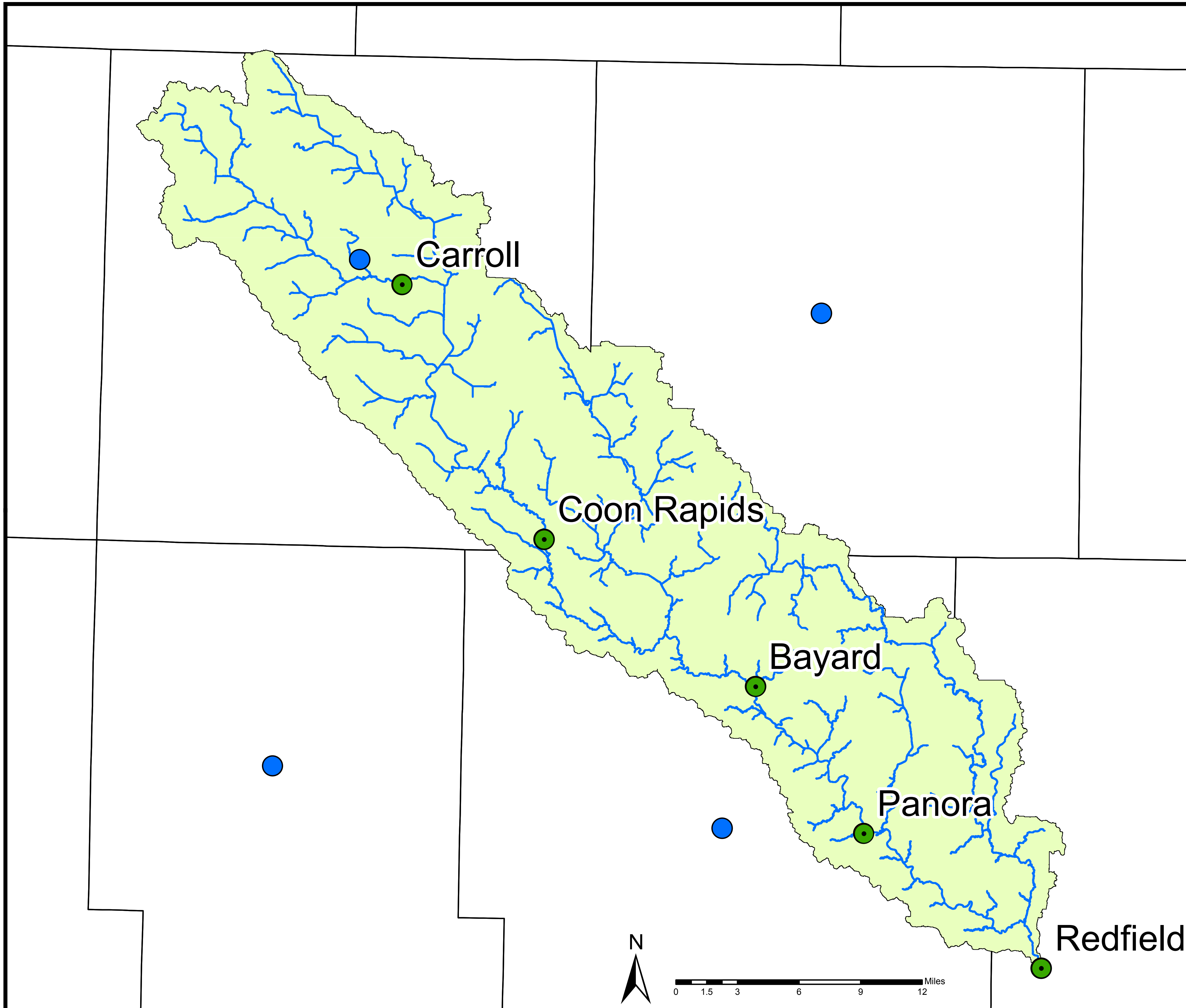
Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Iowa Department of Natural Resources, 2008
30 Meter Integer GRID

Figure: A.5



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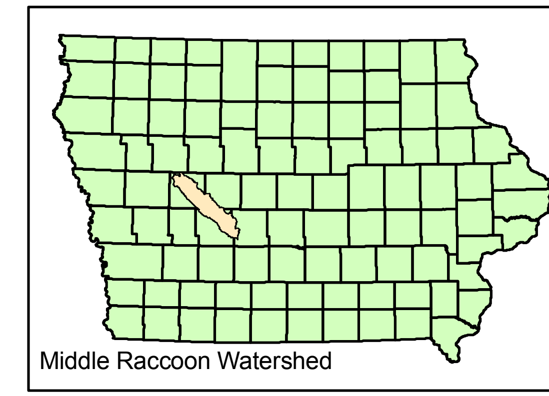
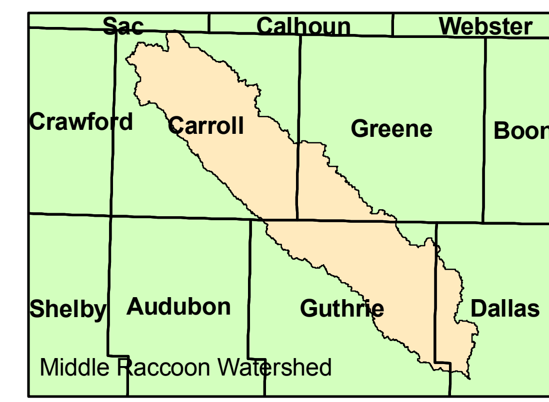




Middle Raccoon River Watershed
Hydrologic and Meteorologic Stations

Legend

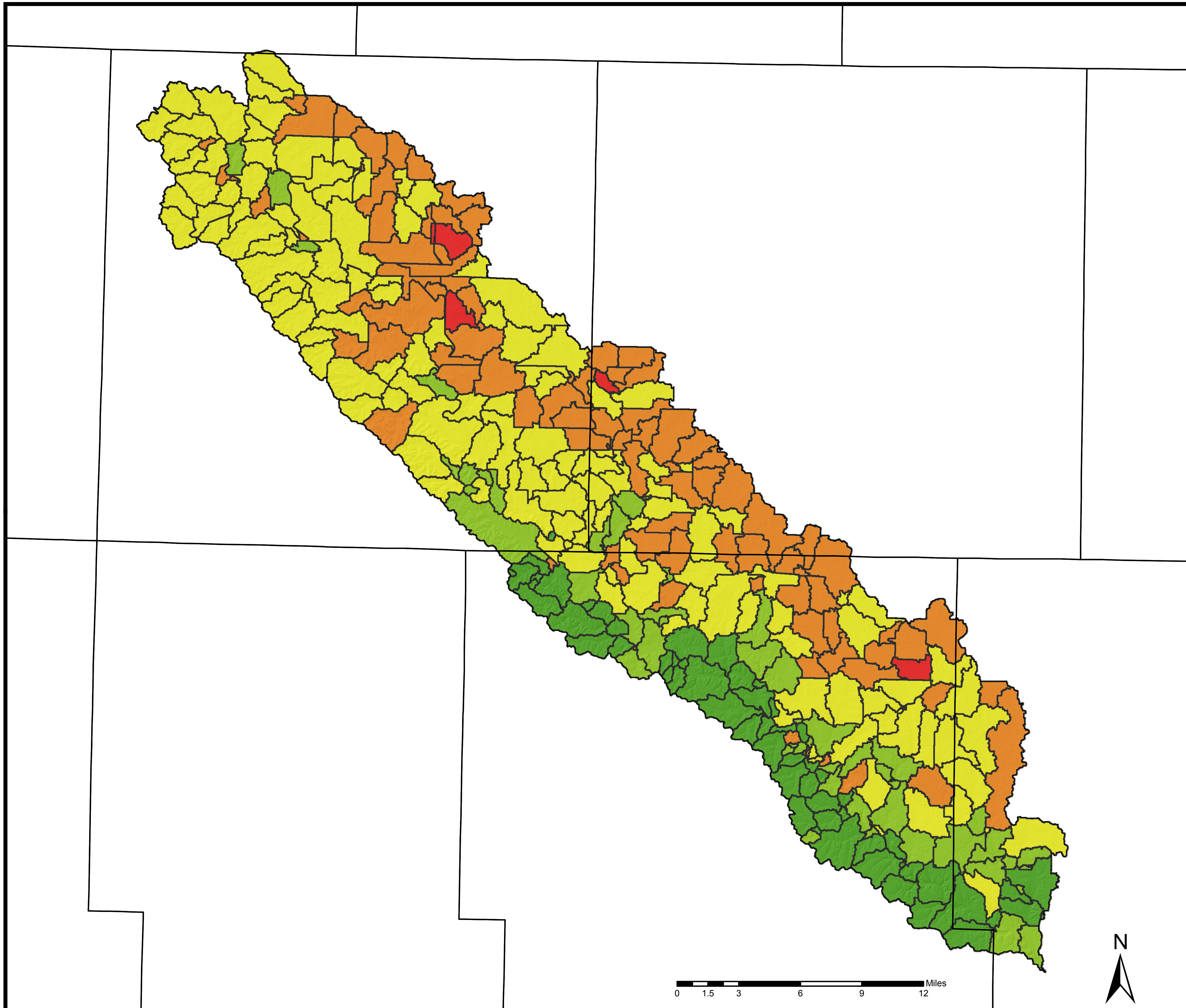
- IFC Gauges
- USGS Gauges
- GHCND Rain Gauges
- River
- Iowa Counties

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.6



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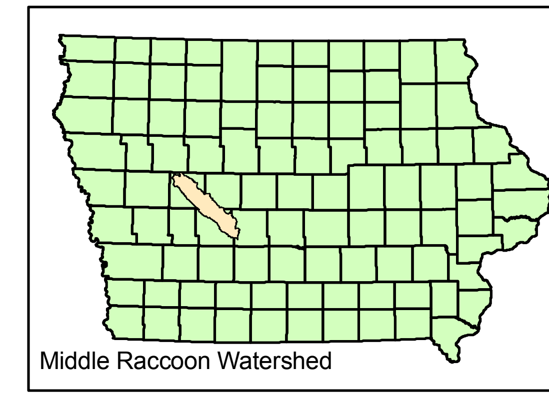
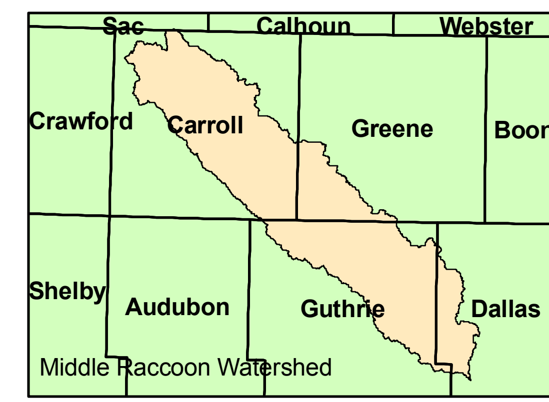




Middle Raccoon River Watershed

Subbasins of High Runoff Potential

Legend

Iowa Counties

Subbasin Runoff Analysis

Low Runoff

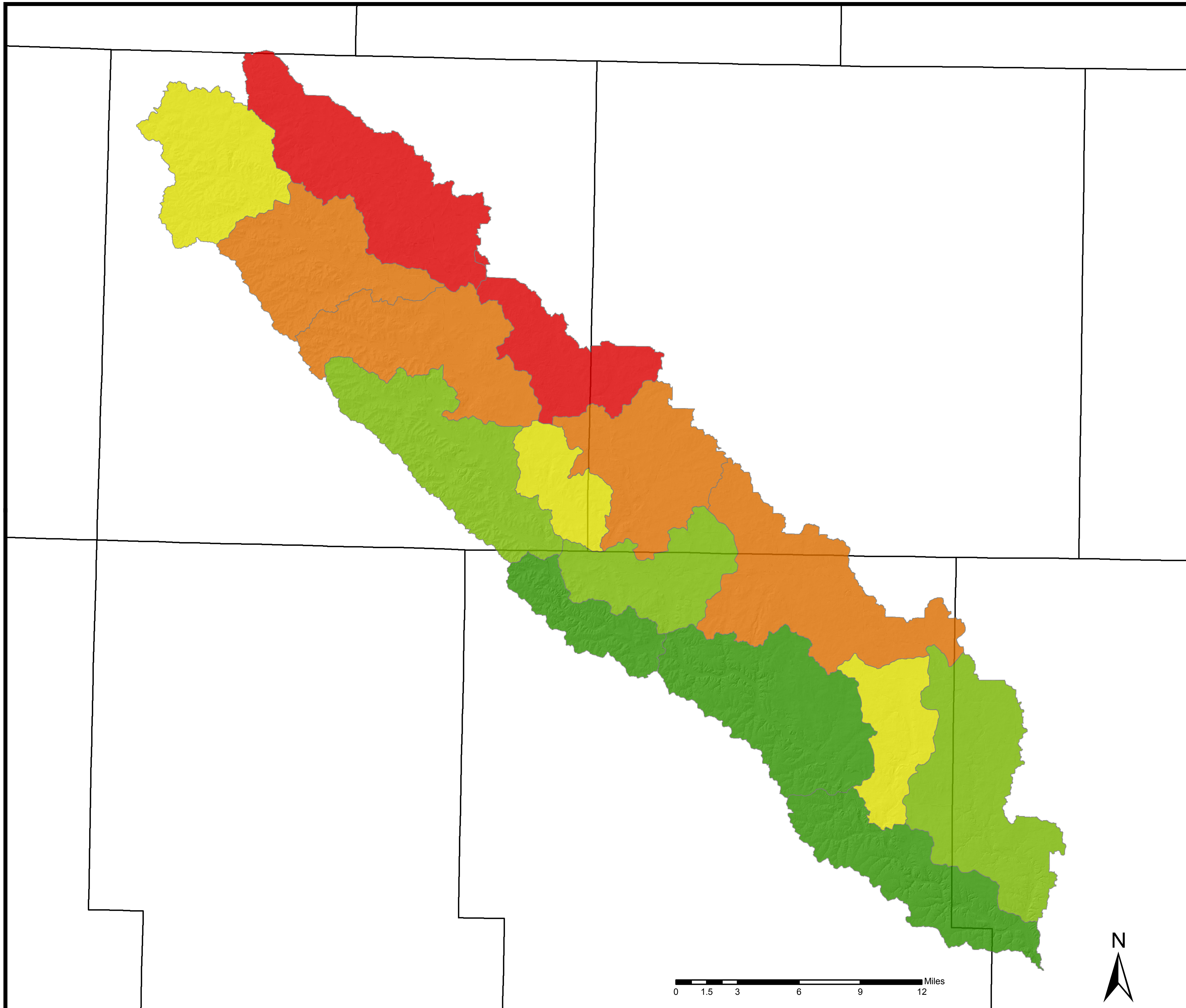
High Runoff

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.7



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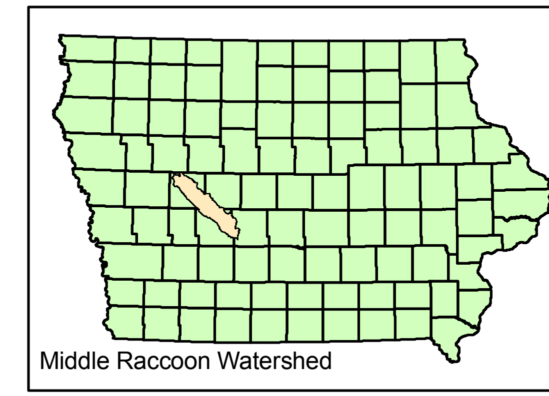
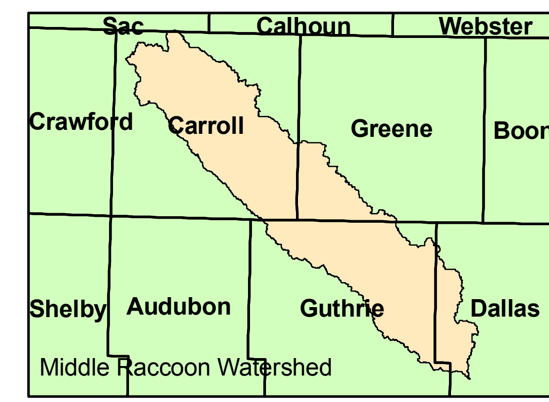




Middle Raccoon River Watershed

Areas of High Runoff - HUC 12

Legend

Iowa Counties

HUC 12 % Excess Precipitation

Low Runoff

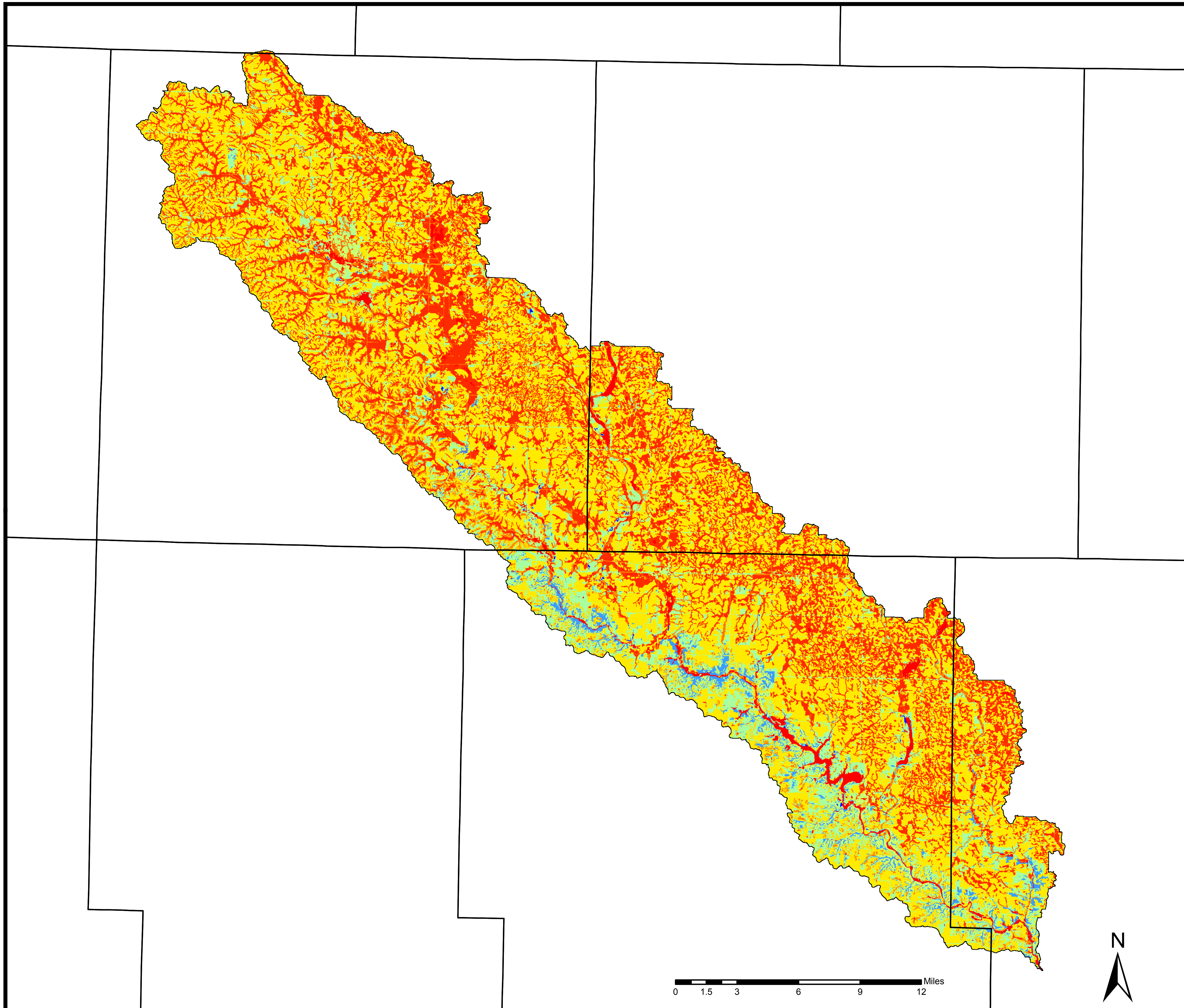
High Runoff

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.8



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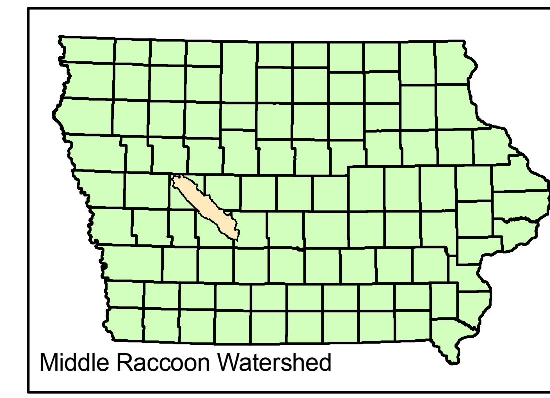
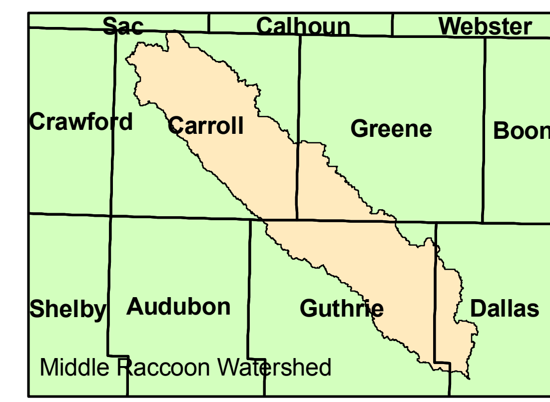




Middle Raccoon River Watershed
Original Curve Number Grid

Legend

Iowa Counties

Curve Number

Value

High : 100

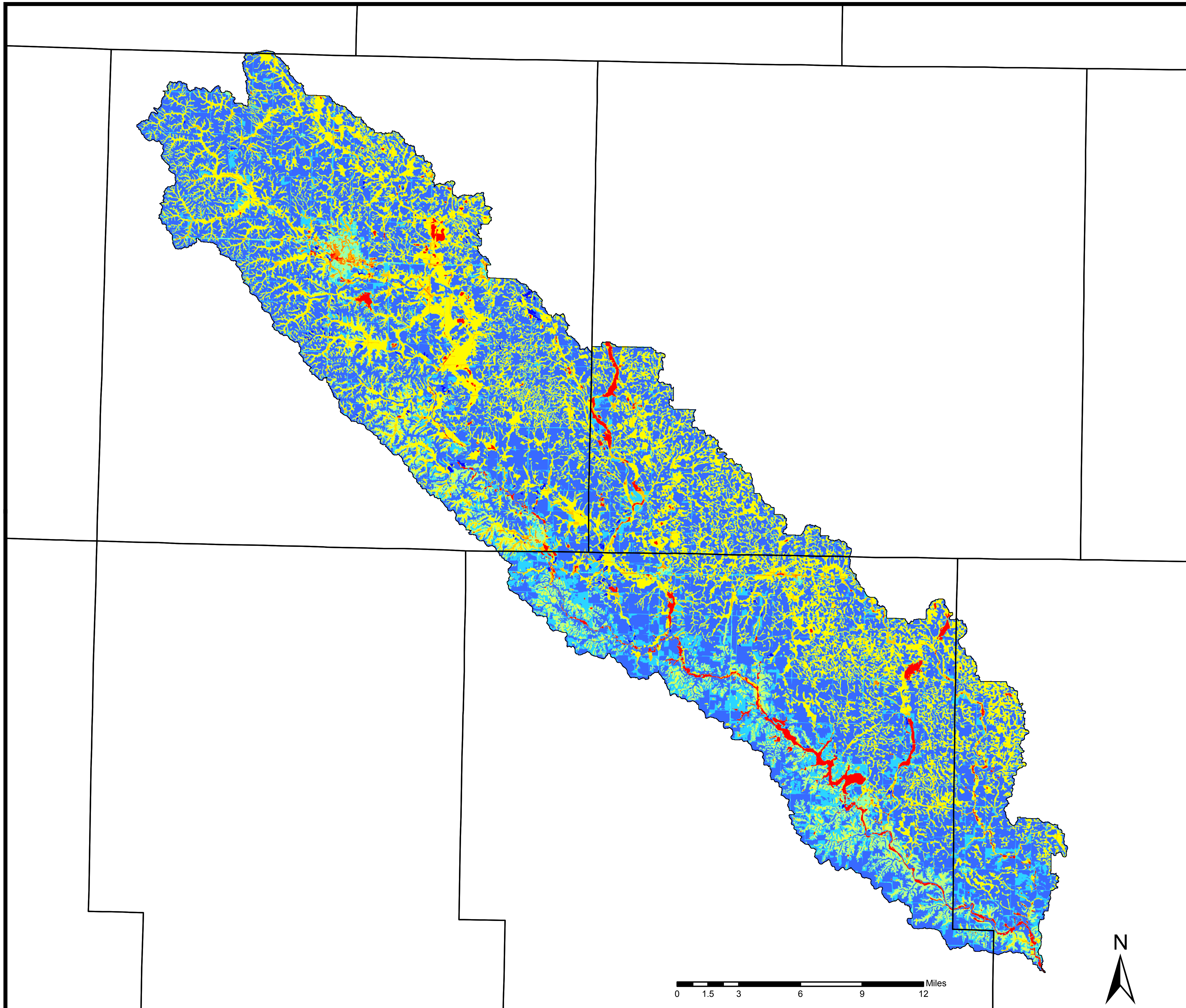
Low : 32

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.9



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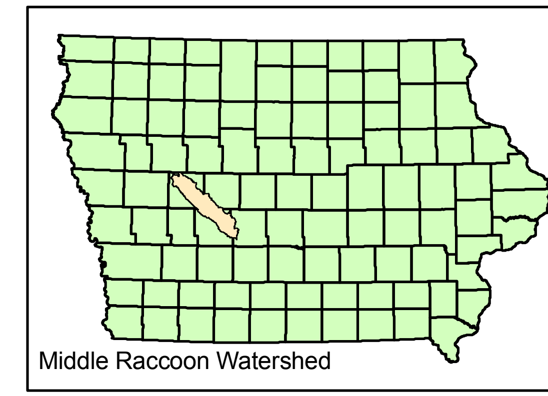

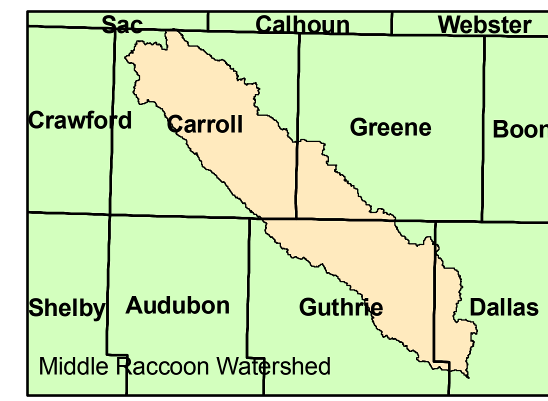

Middle Raccoon River Watershed

Forest Curve Number Grid

Legend

Iowa Counties

CN - Forest

Value

High : 100

Low : 32

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.10

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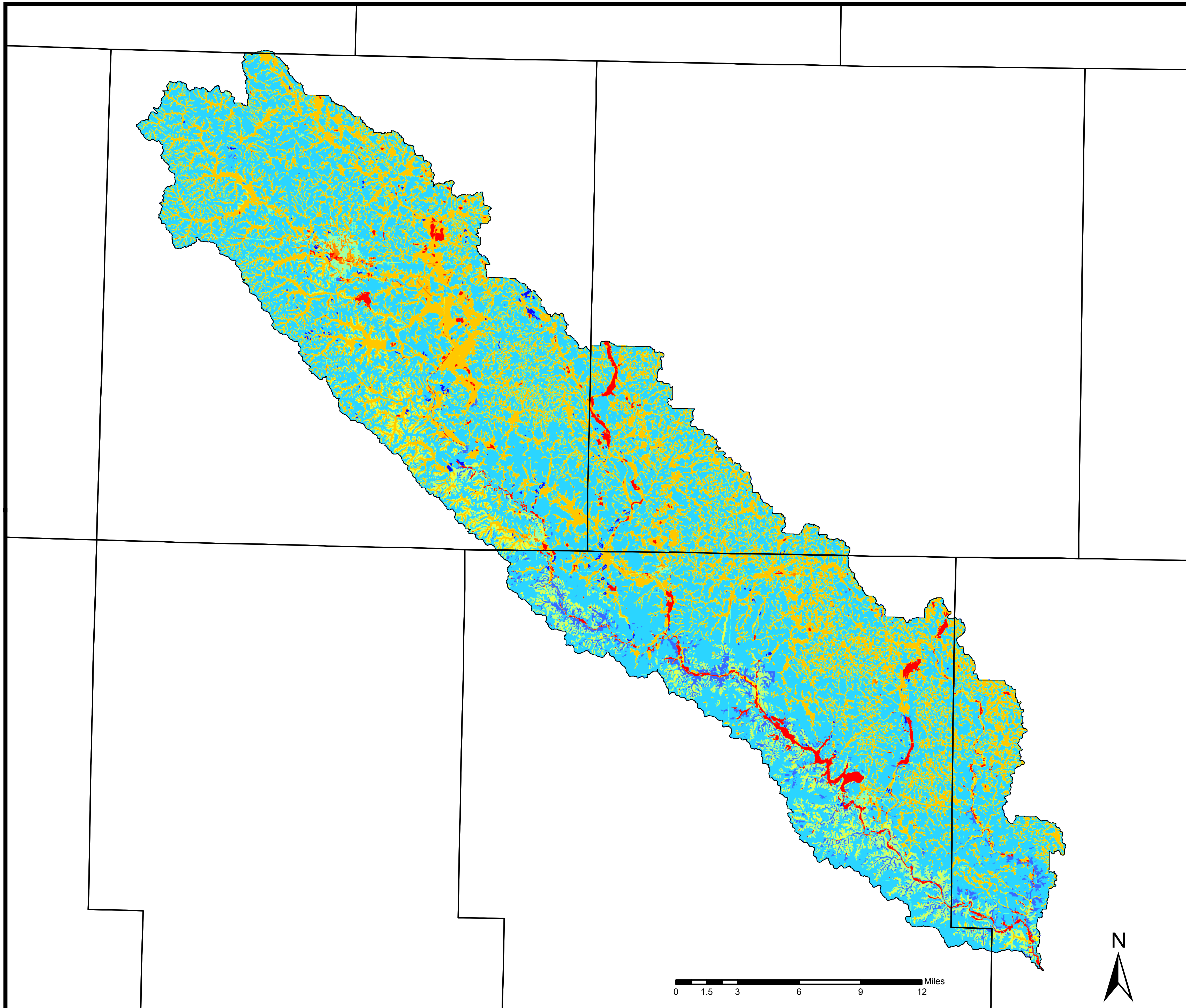
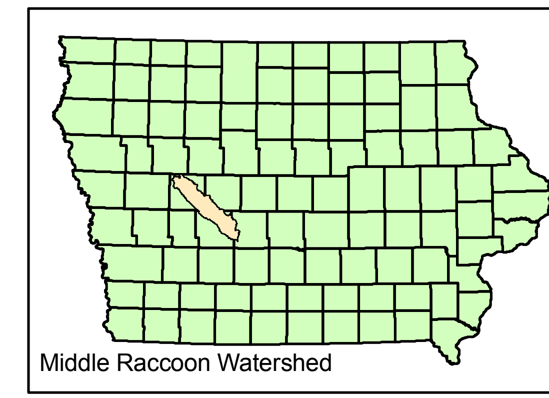
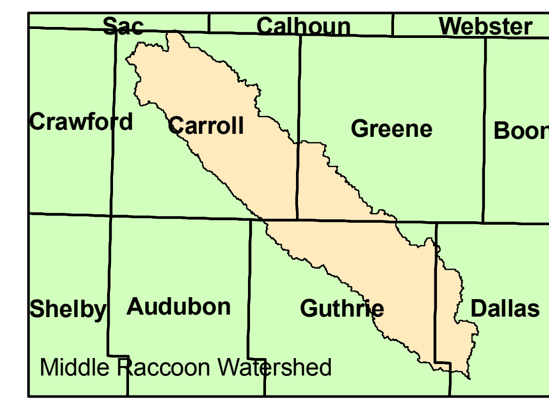






Middle Raccoon River Watershed

Tall-Grass Curve Number Grid

Legend

Iowa Counties

CN - Tall-Grass

Value

High : 100

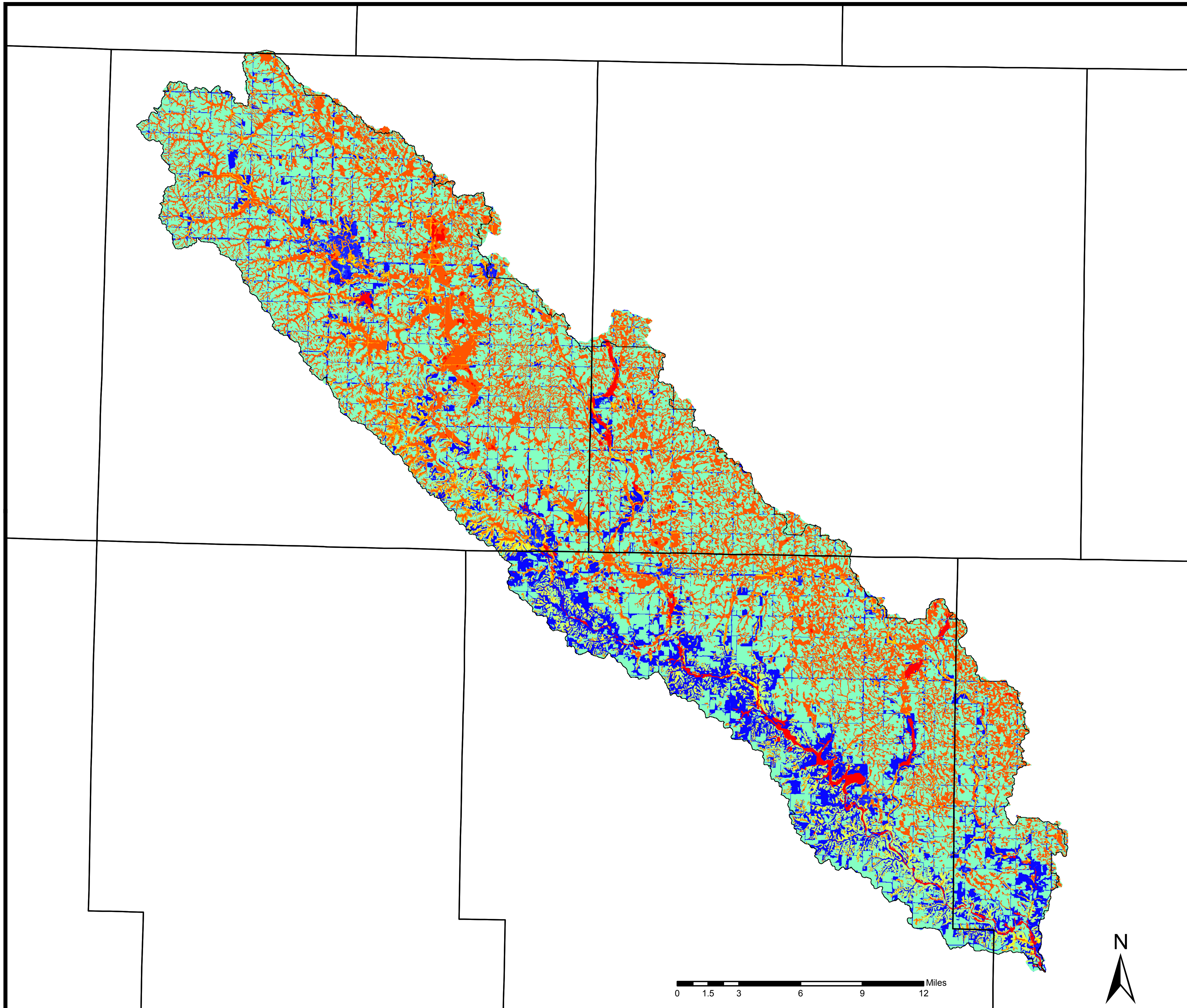
Low : 32

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.11



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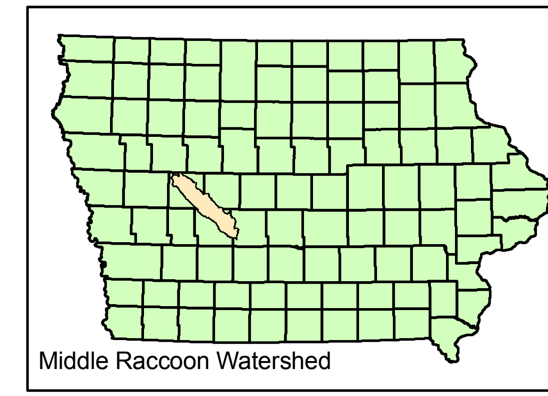
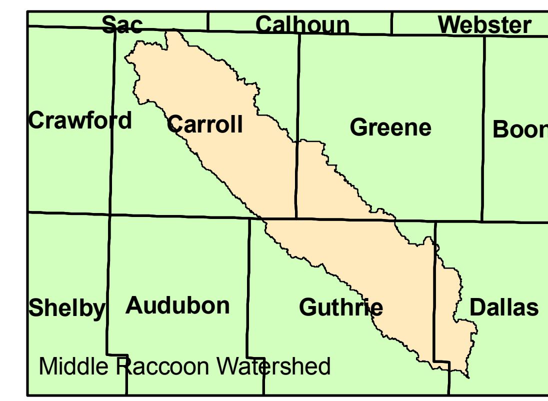




Middle Raccoon River Watershed

Soil Improvement Curve Number Grid

Legend

Iowa Counties

CN - Soil Improvment

Value

High : 100

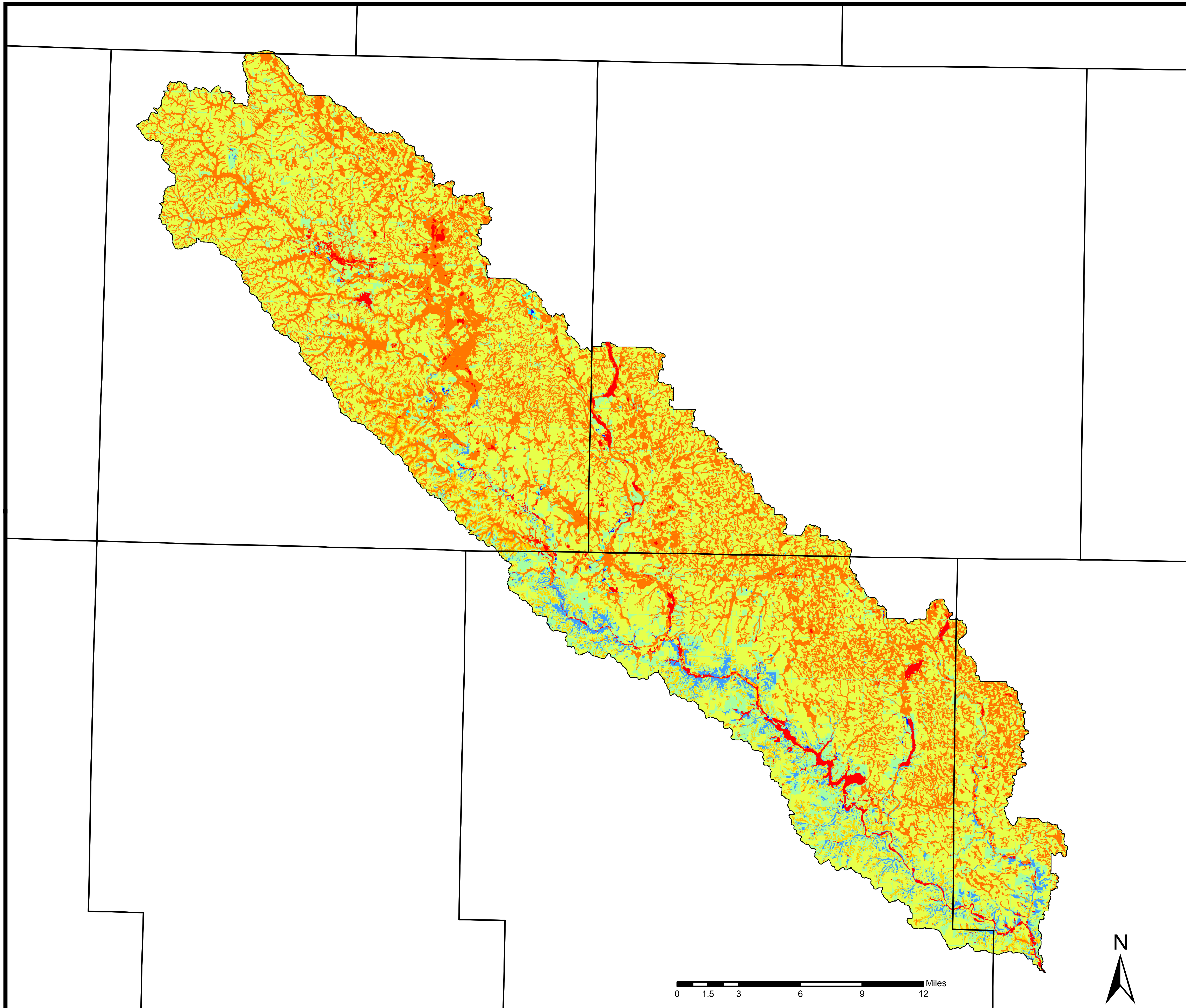
Low : 32

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.12



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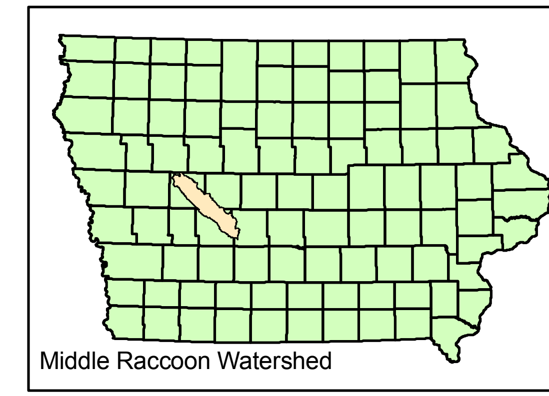
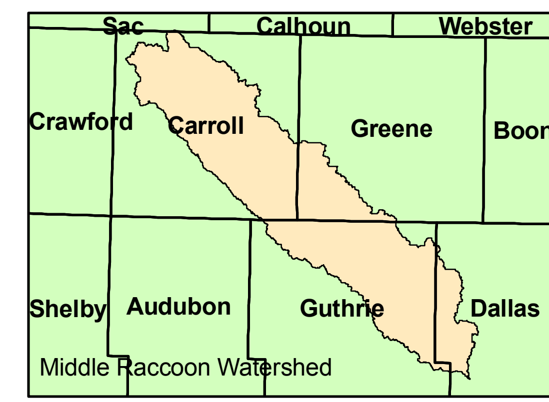




Middle Raccoon River Watershed
Cover Crop Curve Number Grid

Legend

Iowa Counties

CN - Cover Crops

Value

High : 100

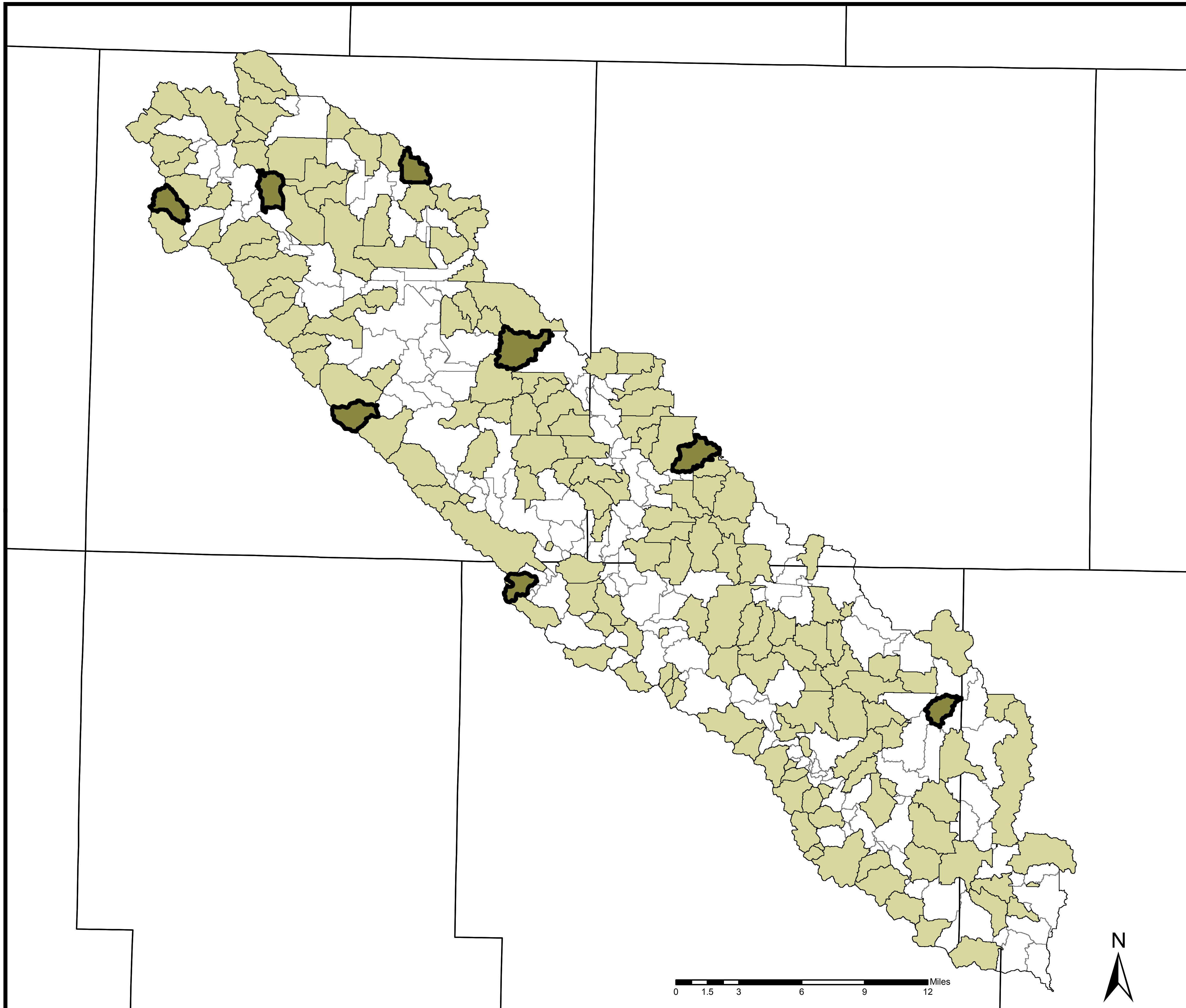
Low : 32

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.13



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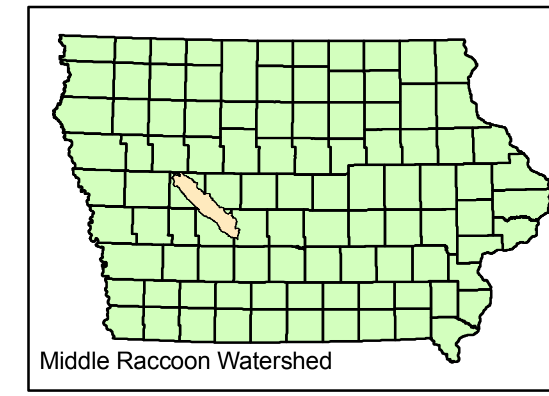
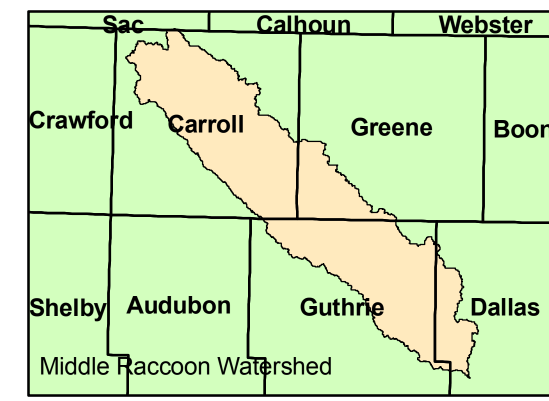




Middle Raccoon River Watershed
Head Water Subbasins

Legend

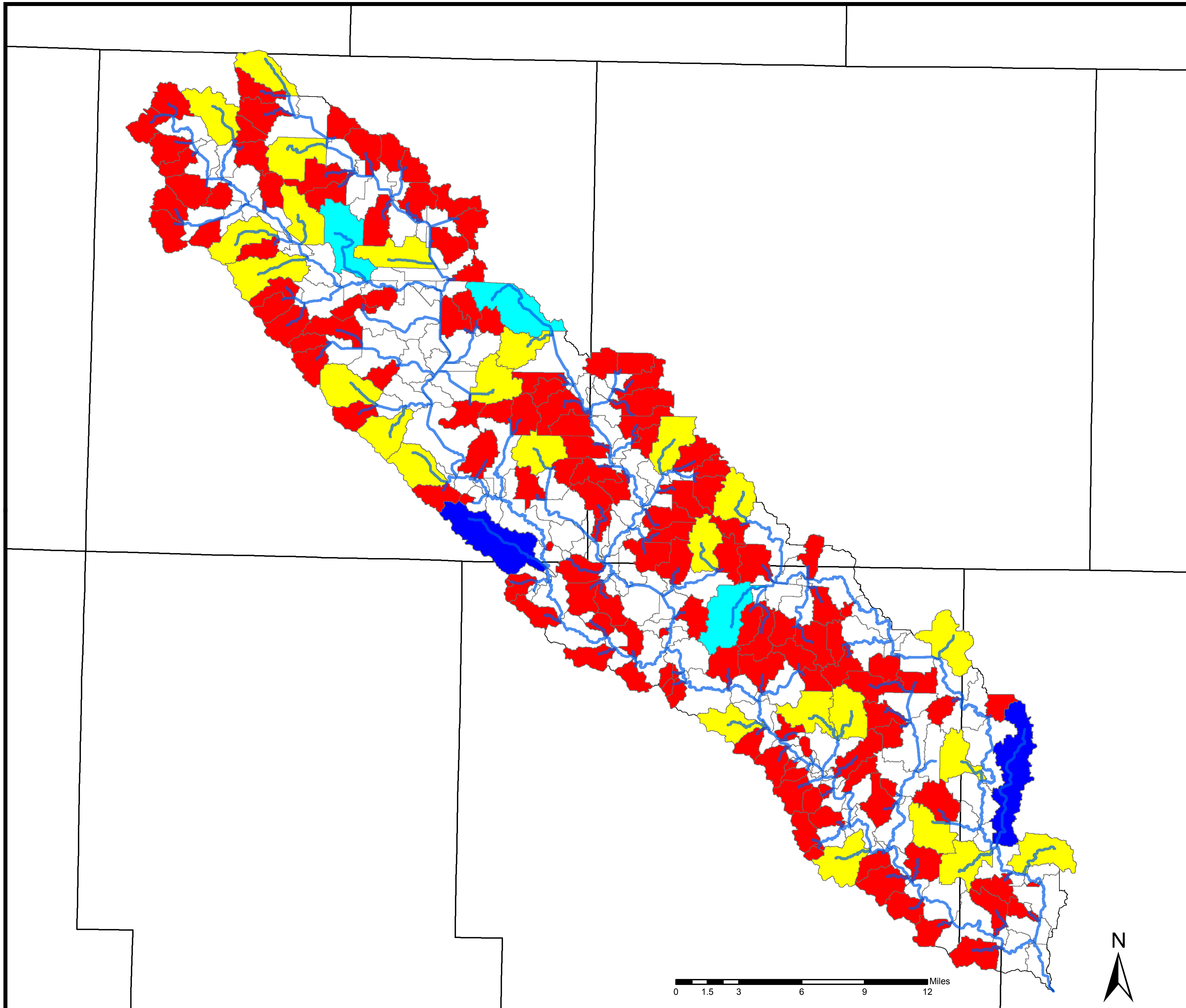
- Iowa Counties
- Non Headwater Subbasins (189)
- Headwater Subbasins (160)
- Topographic Analysis Subbasins (8)

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure A.14



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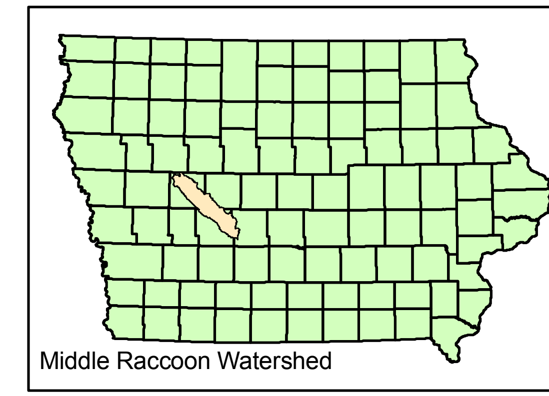

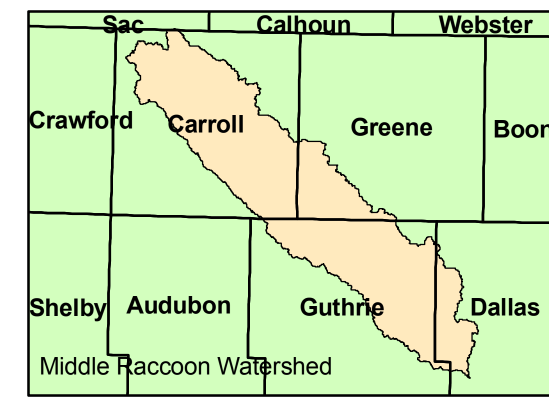

Middle Raccoon River Watershed
Prototype Pond Assignments

Legend

Iowa Counties

Number of Ponds

1
2
3
4

Date: May 2014

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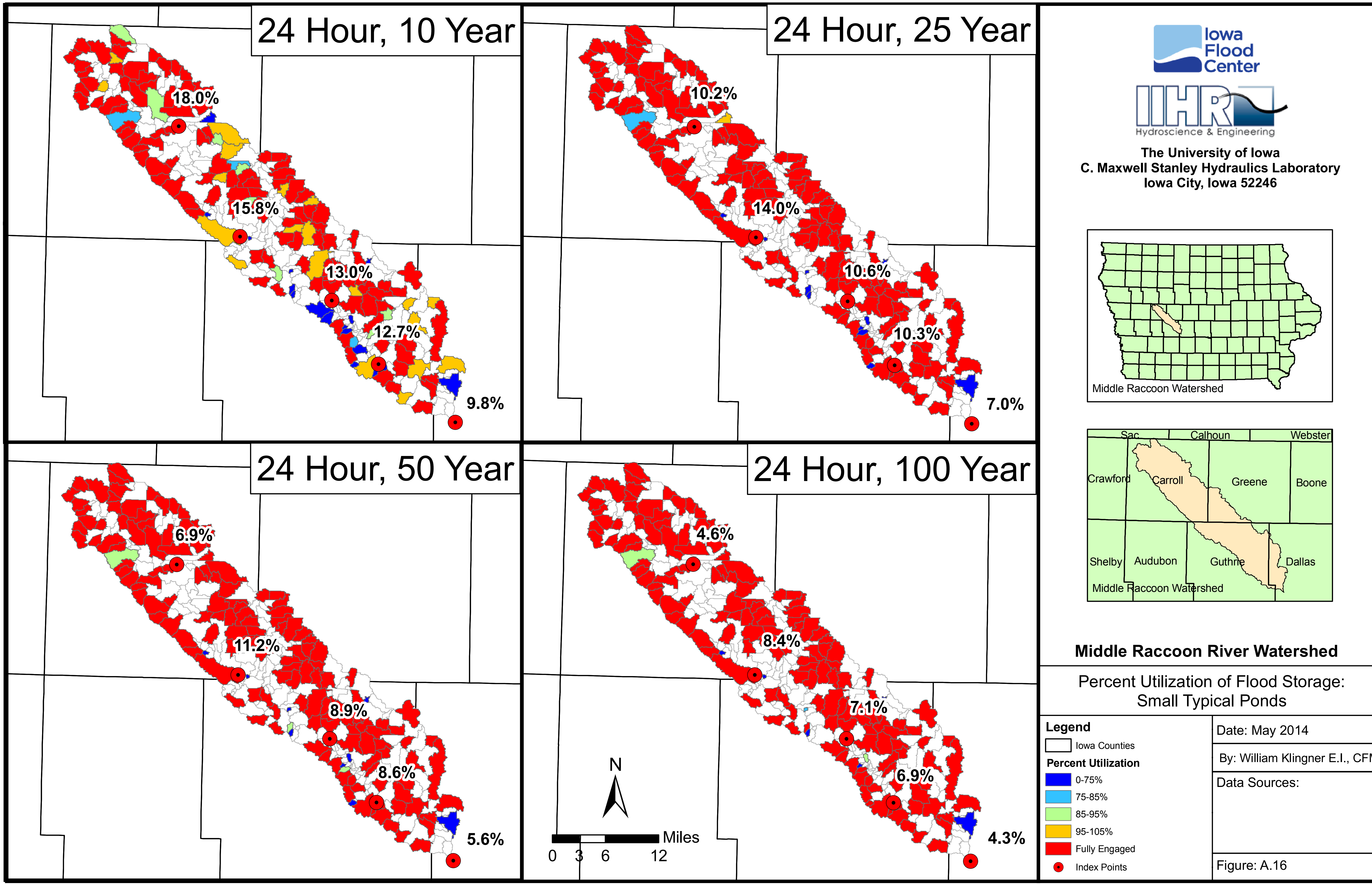
Data Sources:

Figure: A.15


24 Hour, 10 Year
18.0%
15.8%
13.0%
12.7%
9.8%
24 Hour, 25 Year
10.2%
14.0%
10.6%
10.3%
7.0%
24 Hour, 50 Year
6.9%
11.2%
8.9%
8.6%
5.6%
24 Hour, 100 Year
4.6%
8.4%
7.1%
6.9%
4.3%
N
Miles
0 3 6 12
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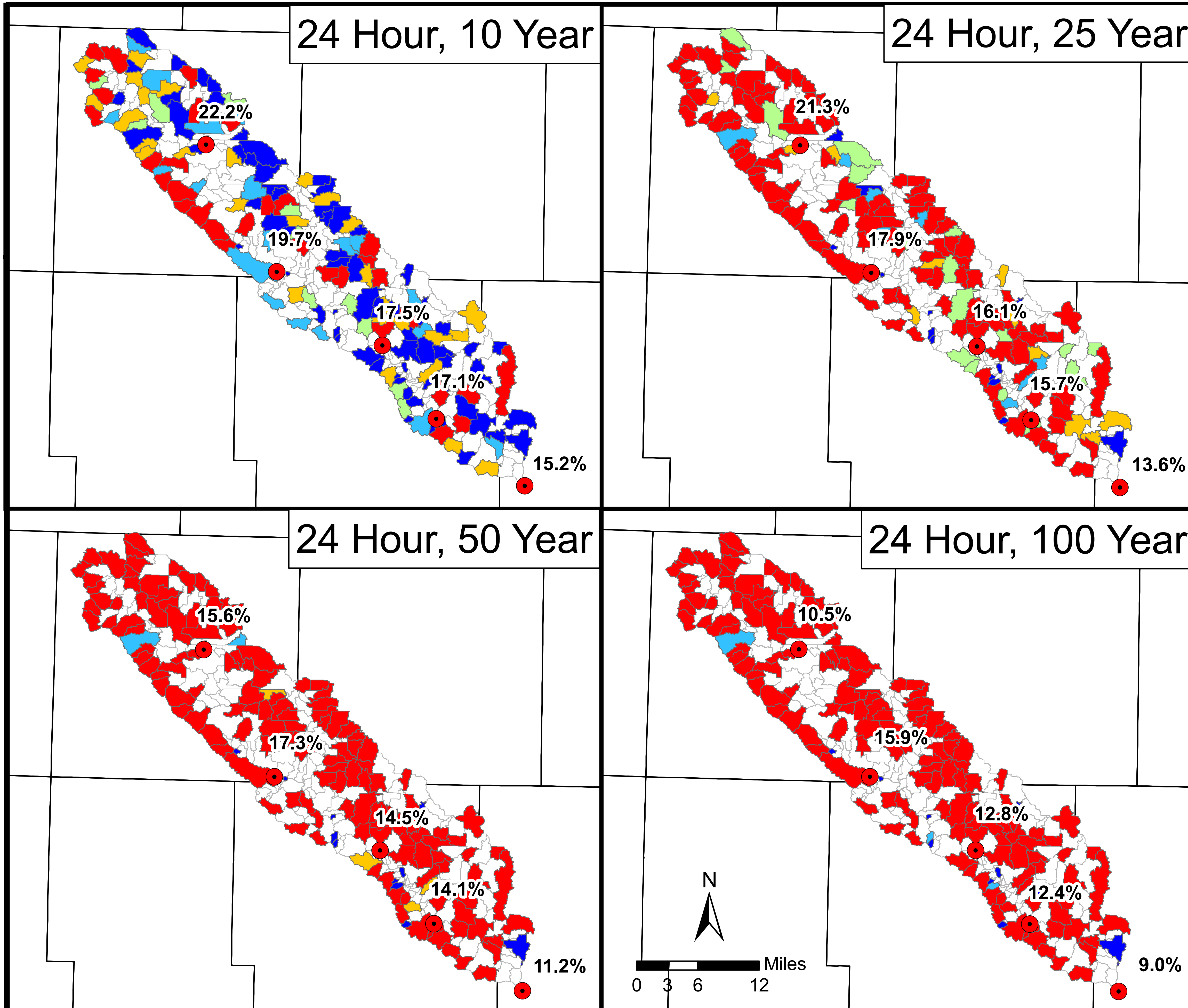
Middle Raccoon Watershed
Sac
Calhoun
Webster
Crawford
Carroll
Greene
Boone
Shelby
Audubon
Guthrie
Dallas
Middle Raccoon Watershed
Middle Raccoon River Watershed
Percent Utilization of Flood Storage:
Small Typical Ponds
Legend
Iowa Counties
Percent Utilization
0-75%
75-85%
85-95%
95-105%
Fully Engaged
Index Points
Date: May 2014
By: William Klingner E.I., CFM
Data Sources:
Figure: A.16



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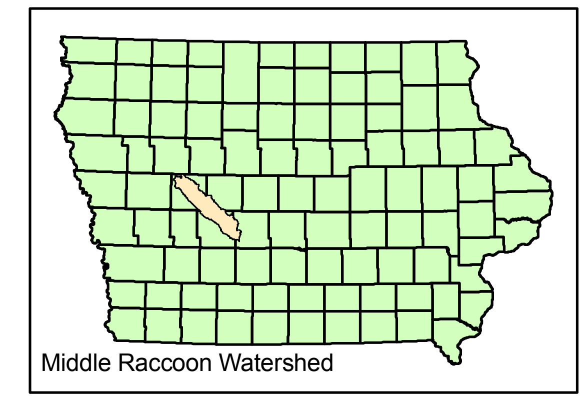
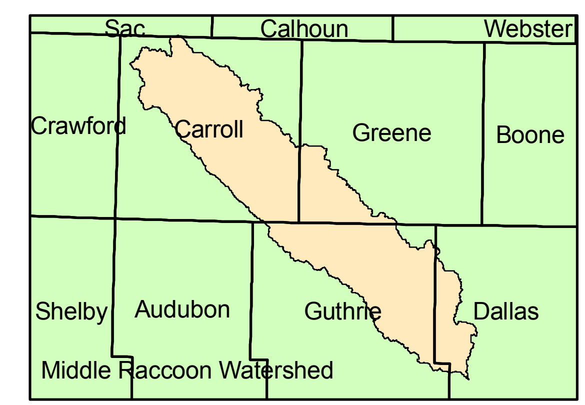




Middle Raccoon River Watershed

Percent Utilization of Flood Storage:
Large Typical Ponds

Legend

Iowa Counties

Percent Utilization

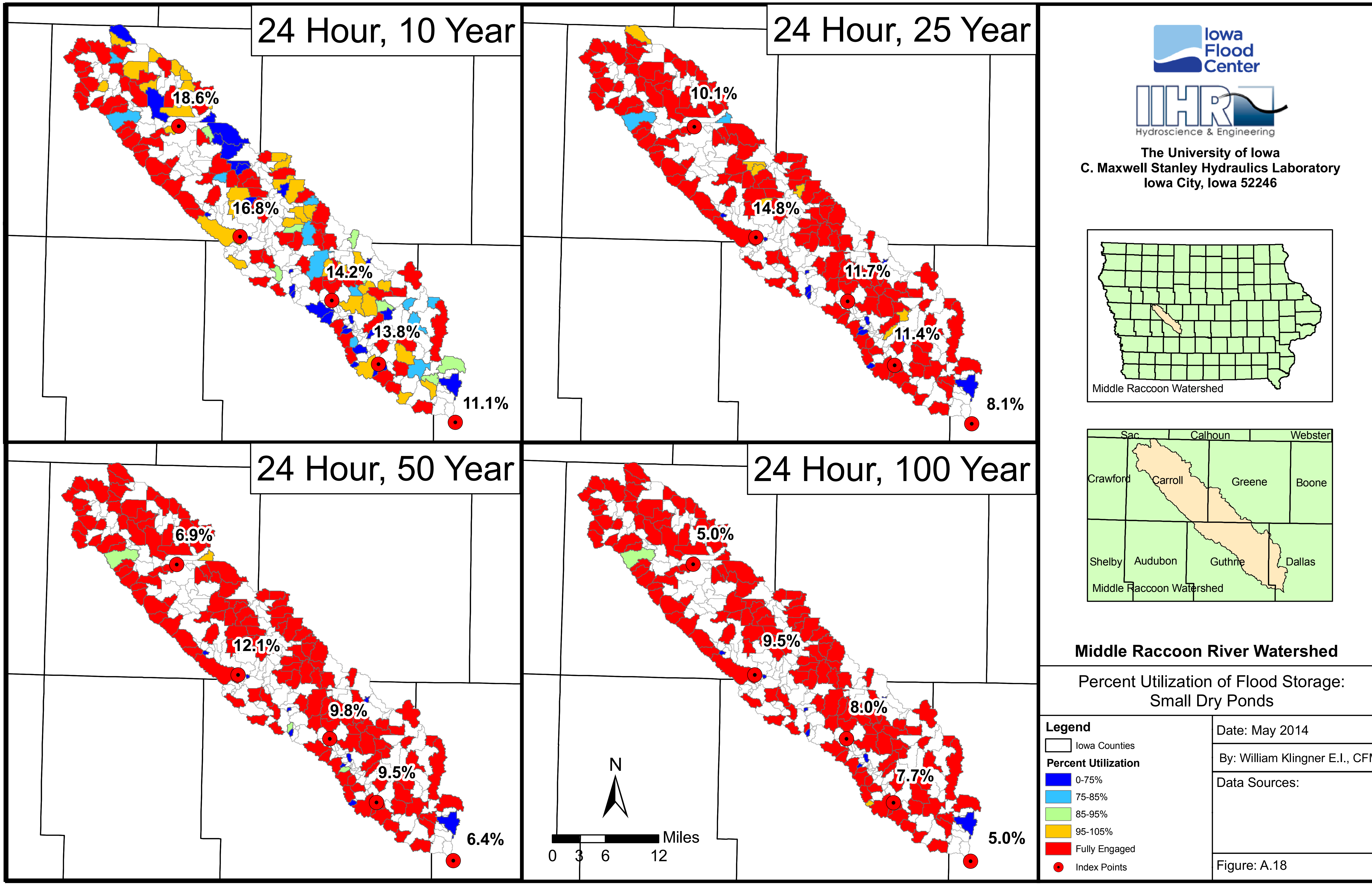
- 0-75%
- 75-85%
- 85-95%
- 95-105%
- Fully Engaged
- Index Points

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.17


24 Hour, 10 Year
18.6%
16.8%
14.2%
13.8%
11.1%
24 Hour, 25 Year
10.1%
14.8%
11.7%
11.4%
8.1%
24 Hour, 50 Year
6.9%
12.1%
9.8%
9.5%
6.4%
24 Hour, 100 Year
5.0%
9.5%
8.0%
7.7%
5.0%
N
0 3 6 12 Miles
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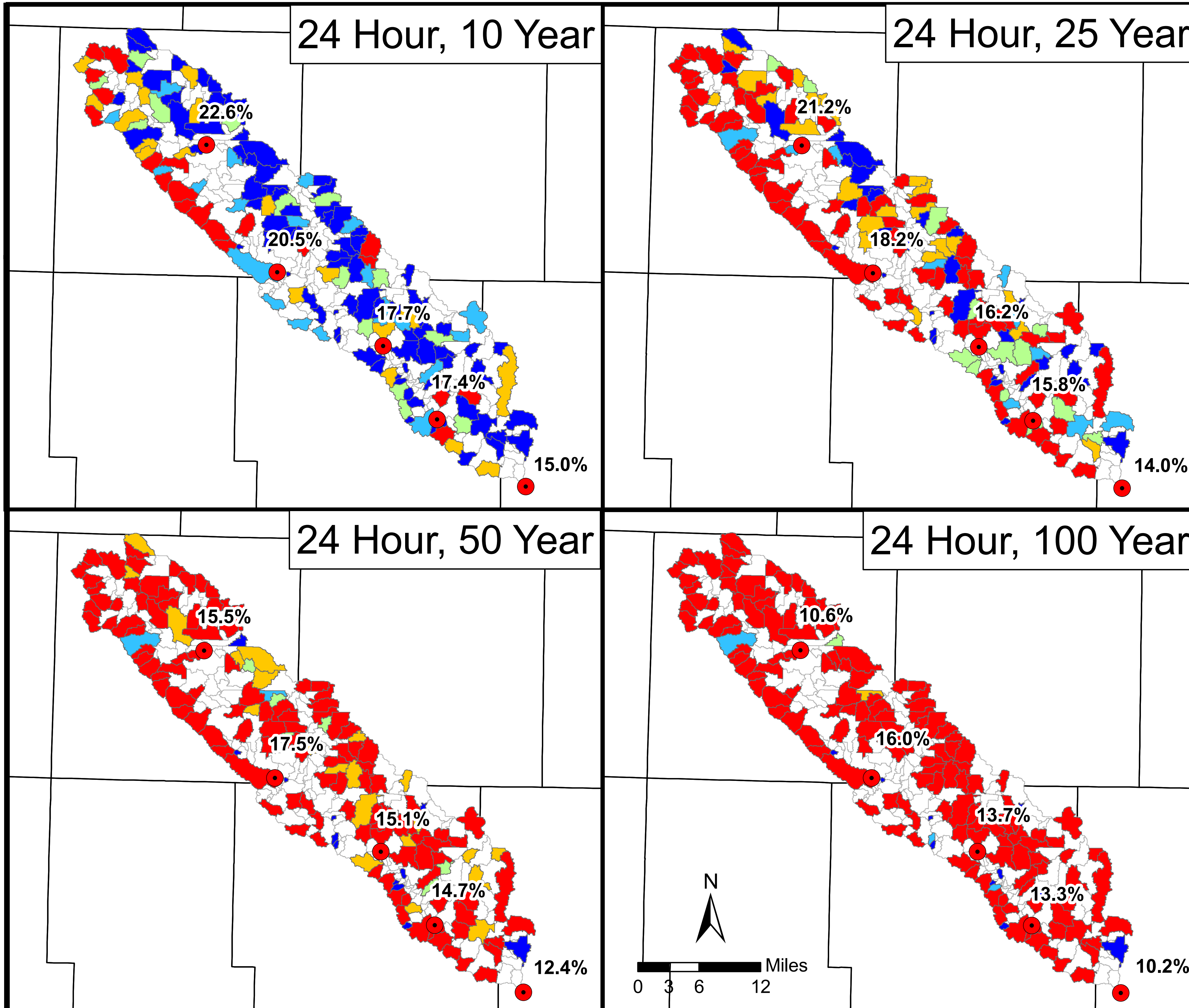
Iowa City, Iowa 52246
Middle Raccoon Watershed
Sac
Calhoun
Webster
Crawford
Carroll
Greene
Boone
Shelby
Audubon
Guthrie
Dallas
Middle Raccoon Watershed
Middle Raccoon River Watershed
Percent Utilization of Flood Storage:
Small Dry Ponds
Legend
Iowa Counties
Percent Utilization
0-75%
75-85%
85-95%
95-105%
Fully Engaged
Index Points
Date: May 2014
By: William Klingner E.I., CFM
Data Sources:
Figure: A.18



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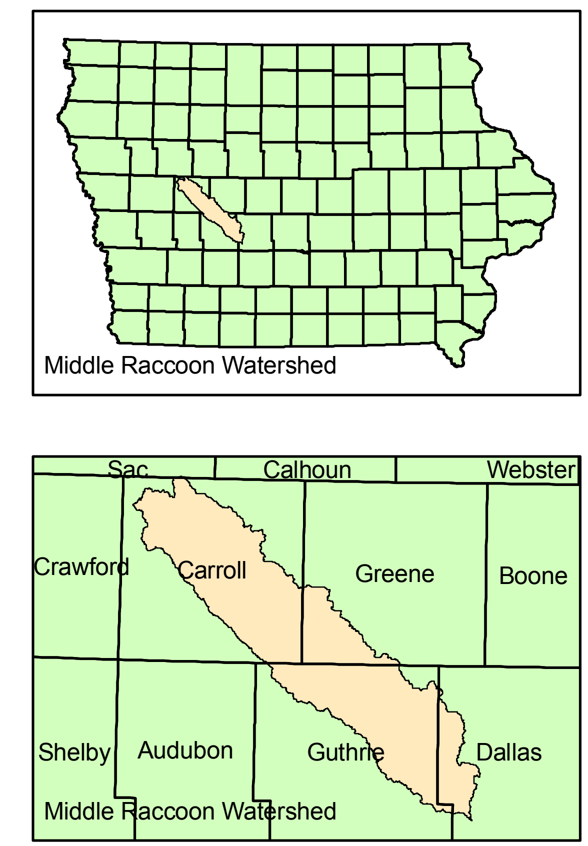


Middle Raccoon River Watershed

Percent Utilization of Flood Storage:
Large Dry Ponds

Legend

Iowa Counties

Percent Utilization

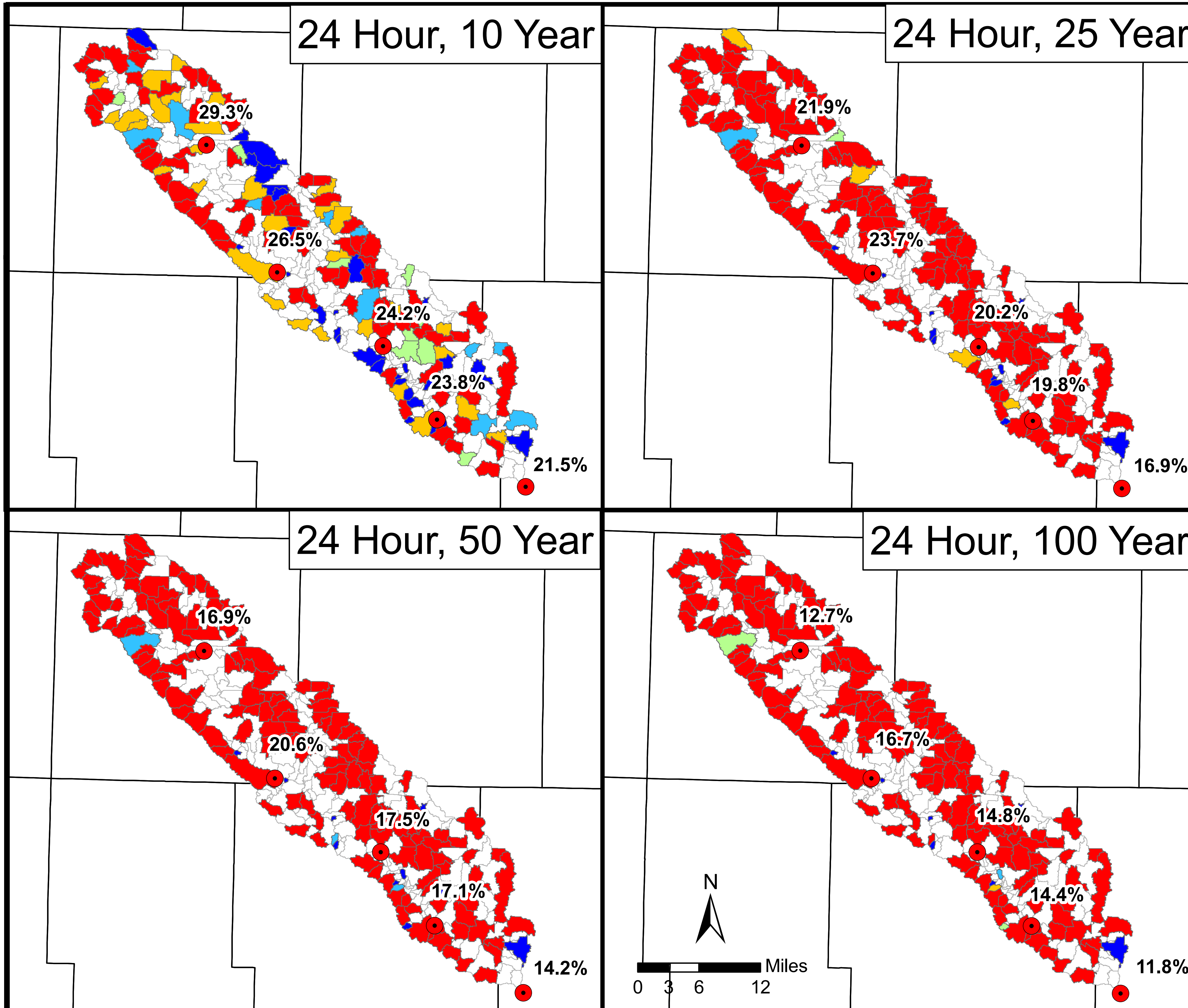
- 0-75%
- 75-85%
- 85-95%
- 95-105%
- Fully Engaged
- Index Points

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.19



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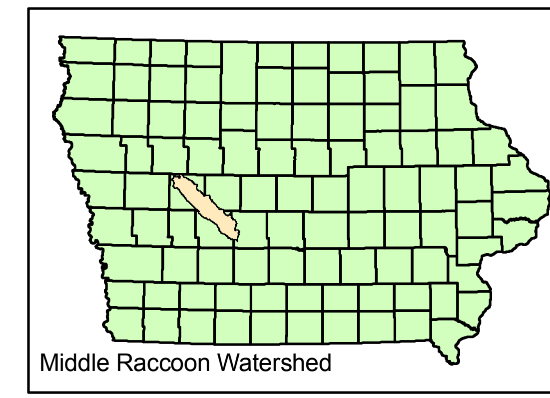
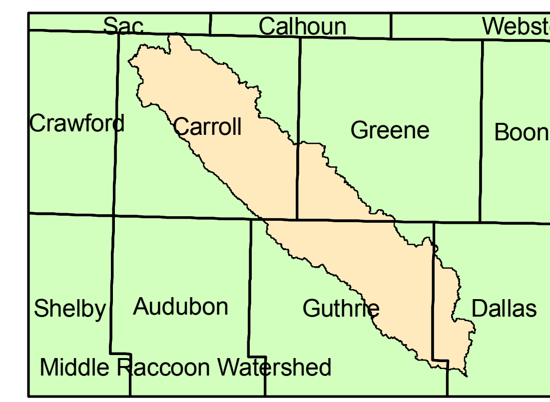




Middle Raccoon River Watershed

Percent Utilization of Flood Storage:
Small - Blended Practices

Legend

Iowa Counties

Percent Utilization

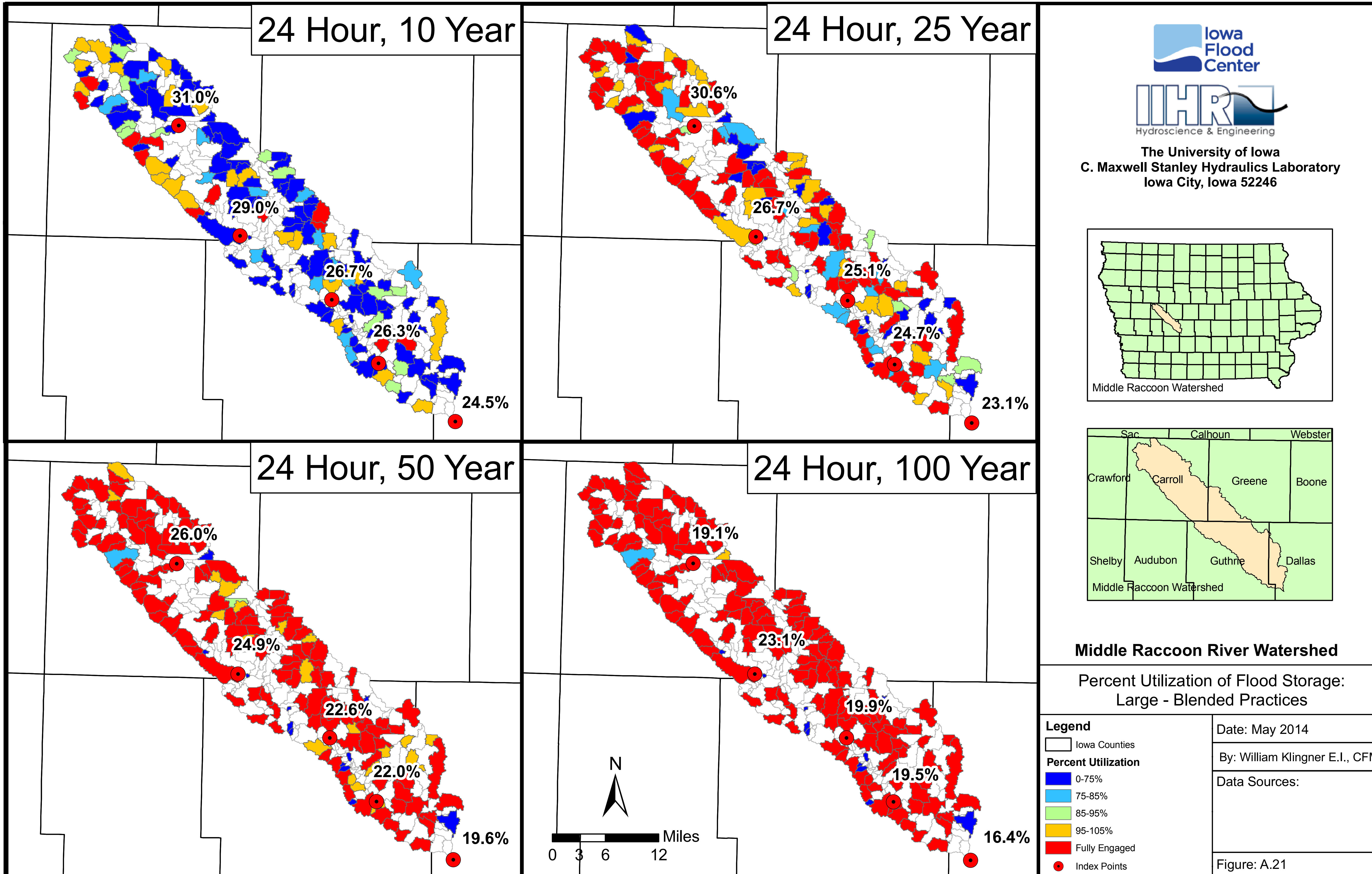
- 0-75%
- 75-85%
- 85-95%
- 95-105%
- Fully Engaged
- Index Points

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.20


24 Hour, 10 Year
31.0%
29.0%
26.7%
26.3%
24.5%
24 Hour, 25 Year
30.6%
26.7%
25.1%
24.7%
23.1%
24 Hour, 50 Year
26.0%
24.9%
22.6%
22.0%
19.6%
24 Hour, 100 Year
19.1%
23.1%
19.9%
19.5%
16.4%
N
Miles
0 3 6 12
Iowa Flood Center
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Middle Raccoon Watershed
Sac
Calhoun
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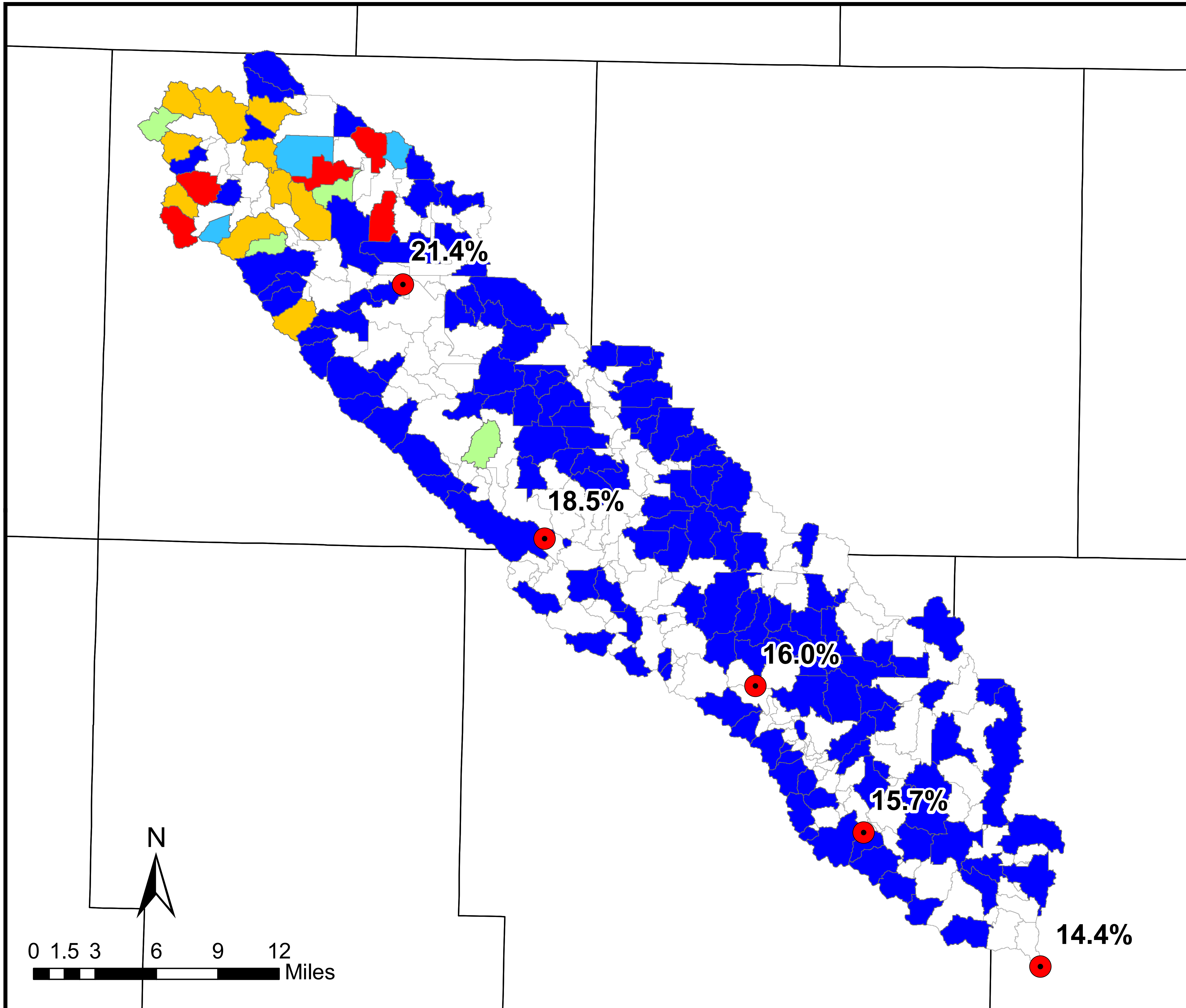
Carroll
Greene
Boone
Shelby
Audubon
Guthrie
Dallas
Middle Raccoon Watershed
Middle Raccoon River Watershed
Percent Utilization of Flood Storage:
Large - Blended Practices
Legend
Iowa Counties
Percent Utilization
0-75%
75-85%
85-95%
95-105%
Fully Engaged
Index Points
Date: May 2014
By: William Klingner E.I., CFM
Data Sources:
Figure: A.21



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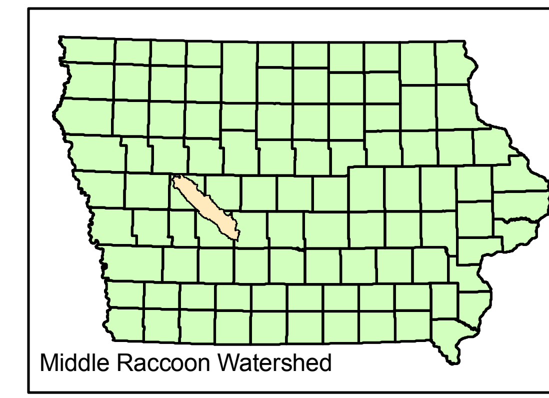
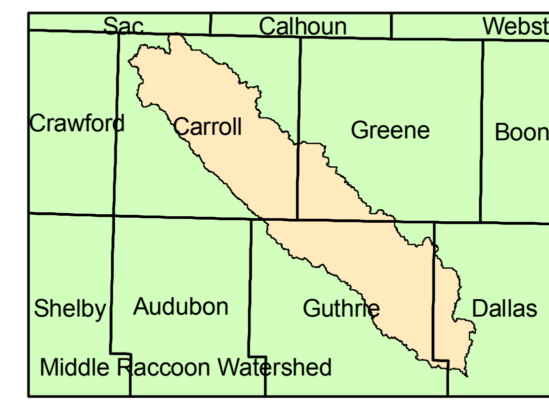




Middle Raccoon River Watershed

Percent Utilization of Flood Storage June '08:
Large Typical Ponds

Legend

Iowa Counties

Percent Utilization

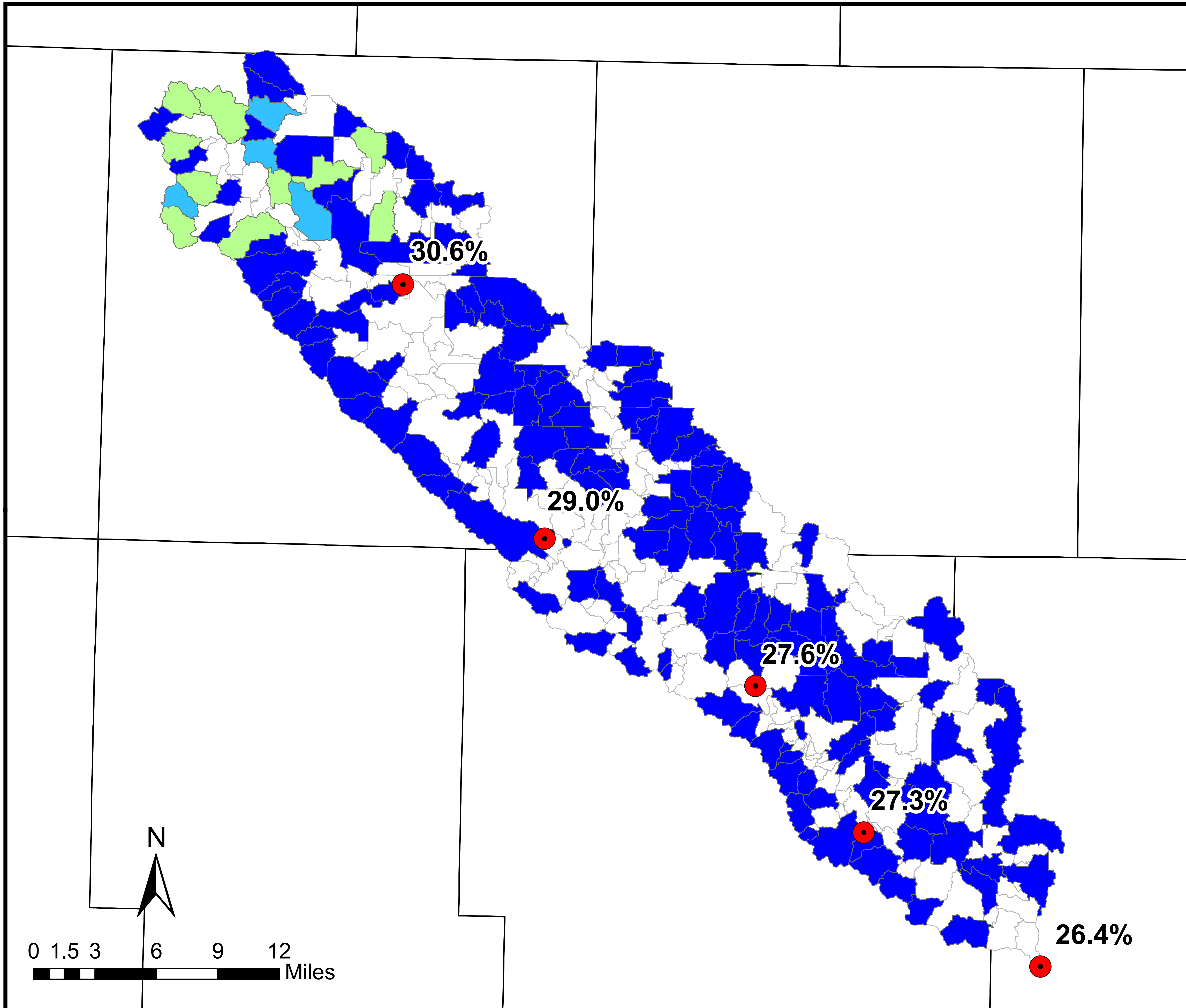
- 0-75%
- 75-85%
- 85-95%
- 95-105%
- Fully Engaged
- Index Points

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.22



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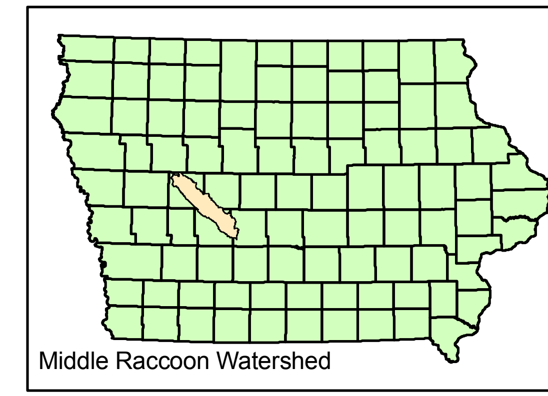
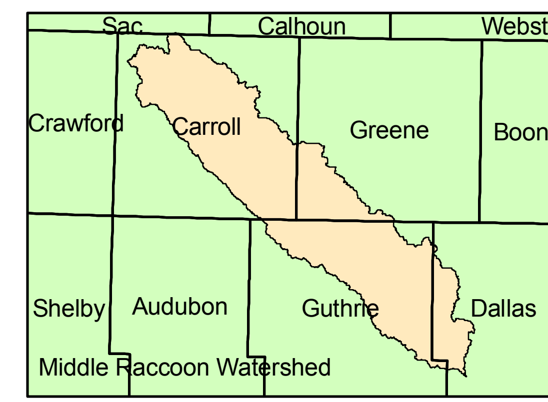




Middle Raccoon River Watershed

Percent Utilization of Flood Storage June '08:
Large - Blended Practices

Legend

Iowa Counties

Percent Utilization

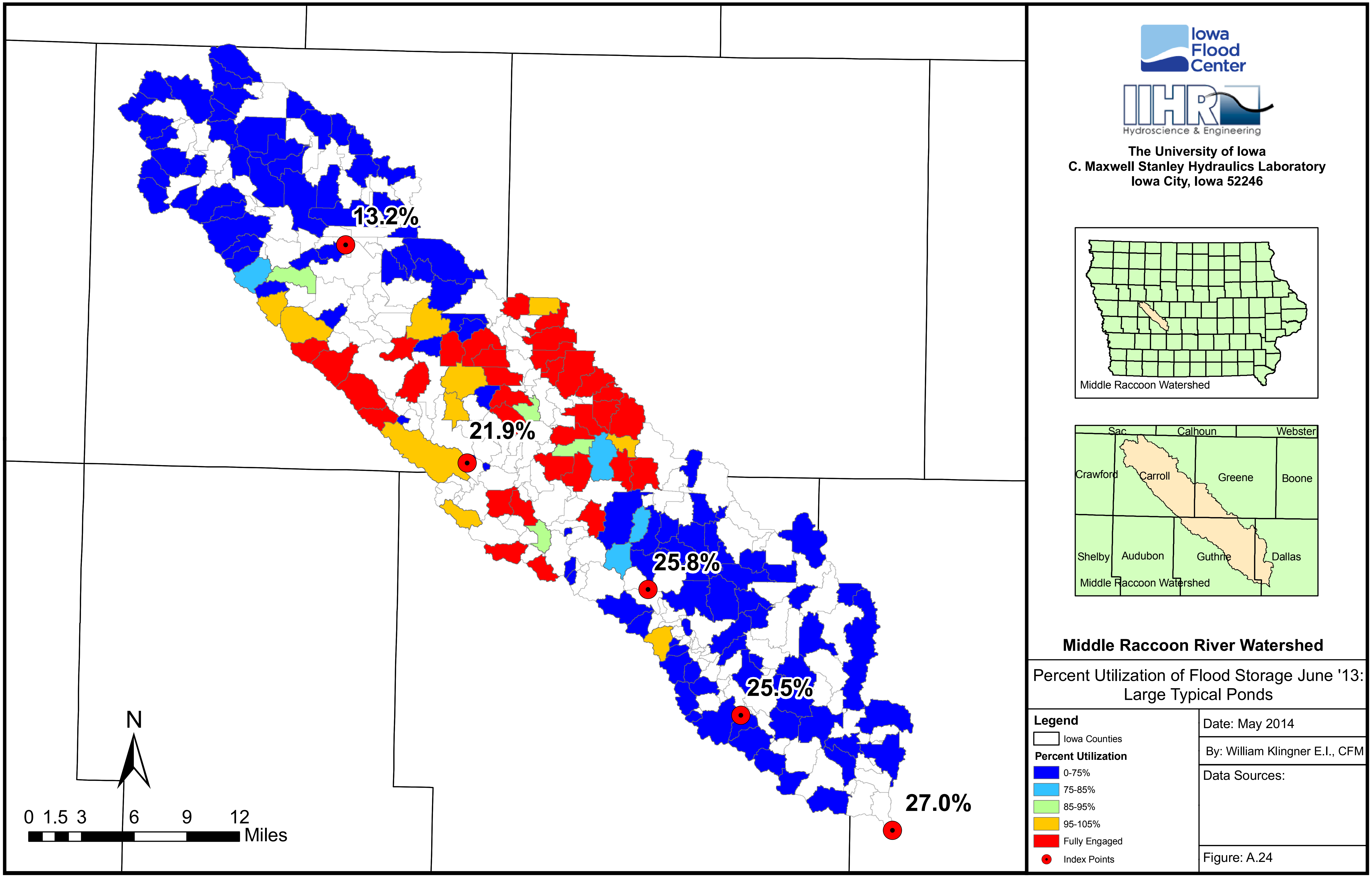
- 0-75%
- 75-85%
- 85-95%
- 95-105%
- Fully Engaged
- Index Points

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.23


13.2%
21.9%
25.8%
25.5%
27.0%
N
0 1.5 3 6 9 12
Miles
Iowa Flood Center
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The University of Iowa
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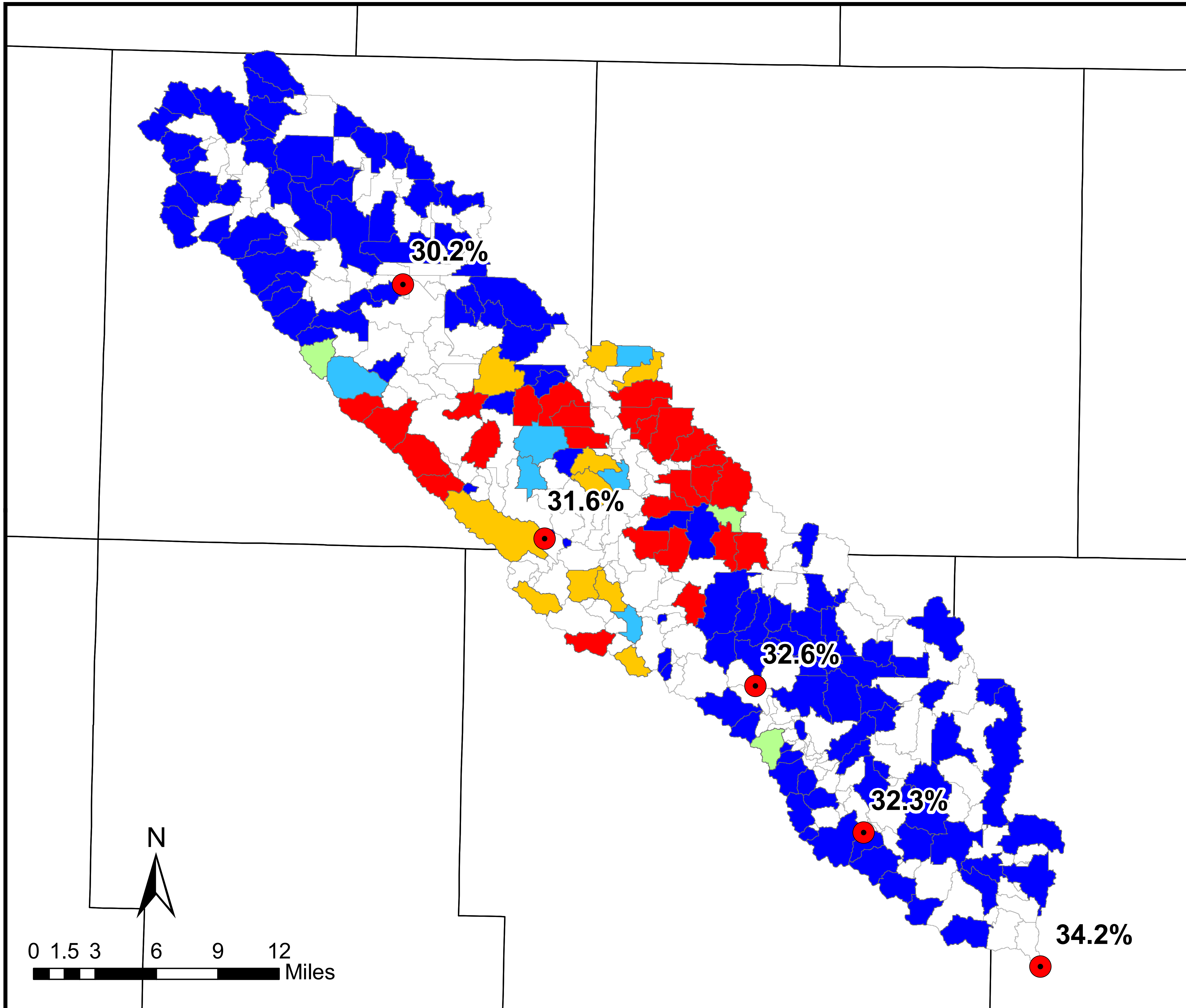
Crawford
Carroll
Greene
Boone
Shelby
Audubon
Guthrie
Dallas
Middle Raccoon Watershed
Middle Raccoon River Watershed
Percent Utilization of Flood Storage June '13:
Large Typical Ponds
Legend
Iowa Counties
Percent Utilization
0-75%
75-85%
85-95%
95-105%
Fully Engaged
Index Points
Date: May 2014
By: William Klingner E.I., CFM
Data Sources:
Figure: A.24



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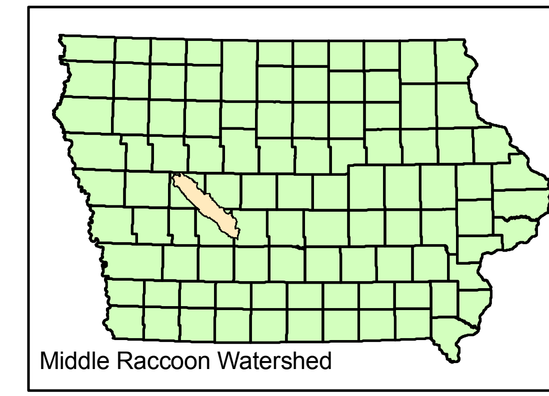

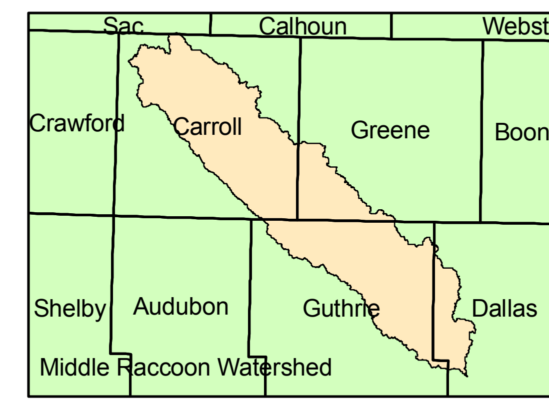

Middle Raccoon River Watershed

Percent Utilization of Flood Storage June '13:
Large - Blended Practices

Legend

Iowa Counties

Percent Utilization

- 0-75%
- 75-85%
- 85-95%
- 95-105%
- Fully Engaged
- Index Points

Date: May 2014

By: William Klingner E.I., CFM

Data Sources:

Figure: A.25

Appendix B – Incorporated Structures

Existing Structures

Lake Panorama – Discharges translated from discharges at Bayard, IA USGS stream gage location to water released at the Lake Panorama Bascule Gate, via specified discharge. Therefore hydrographs at Bayard and hydrographs being released from Lake Panorama are identical.

Table B. 1. Bays Branch Lake Stage-Storage-Discharge Table

Elevation (ft)	*Storage (ac-ft)*	*Discharge (cfs)*
1040	1088	0
1041	1338	125
1042	1588	375
1043	1838	750
1044	2088	1125
1045	2343	1525
1046	2608	1950
1047	3128	2700

Hypothetical Ponds Stage-Storage-Discharge Tables

Table B.2. Small Size Pond Scenario, Des Moines Lobe Region

Elevation Above Primary Spillway (ft)	*Storage (ac-ft)*	*2" Pipe Outflow*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*
0	0	0	0	0
1	5.9	2.2	0	2.2
2	15.3	11.1	0	11.1
3	26.8	11.5	0	11.5
3.5	33.2	11.7	14	25.7
4	40.0	11.9	40	51.9
4.5	47.1	12.1	80	92.1
5	54.5	12.3	140	152.3
5.5	62.2	12.45	448.1	460.5
6	70.2	12.6	609.1	621.7
6.5	78.4	12.8	1099.7	1112.5
7	86.9	13	1370.6	1383.6
7.5	95.7	13.2	1787.9	1801.1
8	104.6	13.4	2107.6	2121.0
8.5	113.8	13.6	2492.4	2506.0
9	123.2	13.8	2833.8	2847.6
10	142.5	14.1	3567.3	3581.4

Table B.3. Small Size Pond Scenario, Southern Iowa Drift Plain Region

Elevation Above Primary Spillway (ft)	*Storage (ac-ft)*	*2" Pipe Outflow*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*
0	0	0	0	0
1	1.7	2.2	0	2.2
2	4.3	11.1	0	11.1
3	7.5	11.5	0	11.5
4	11.1	11.9	0	11.9
5	15.0	12.3	0	12.3
5.5	17.1	12.45	0	12.4
6	19.3	12.6	0	12.6
6.5	21.5	12.8	0	12.8
7	23.8	13.0	0	13.0
7.5	26.1	13.2	14	27.2
8	28.5	13.4	40	53.4
8.5	31.0	13.6	80	93.5
9	33.5	13.8	140	153.7
9.5	36.0	14.0	448.1	462.0
10	38.6	14.1	609.1	623.2
10.5	41.3	15.6	1099.7	1115.3

Table B 4. Large Pond Scenario, Des Moines Lobe Region

Elevation Above Primary Spillway (ft)	*Storage (ac-ft)*	*2" Pipe Outflow*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*
0	0	0	0	0
1	5.9	2.2	0	2.2
2	15.3	11.1	0	11.1
3	26.8	11.5	0	11.5
4	40.0	11.9	0	11.9
5	54.5	12.3	0	12.3
5.5	62.2	12.45	14	26.4
6	70.2	12.6	40	52.6
6.5	78.4	12.8	80	92.8
7	86.9	13.0	140	153.0
7.5	95.7	13.2	448.1	461.3
8	104.6	13.4	609.1	622.5
9	123.2	15.64	1099.7	1115.3

Table B.5. Large Size Pond Scenario, Southern Iowa Drift Plain Region

Elevation Above Primary Spillway (ft)	*Storage (ac-ft)*	*2" Pipe Outflow*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*
0	0	0	0	0
1	1.7	2.2	0	2.2
2	4.3	11.1	0	11.1
3	7.5	11.5	0	11.5
4	11.1	11.9	0	11.9
5	15.0	12.3	0	12.3
5.5	17.1	12.45	0	12.4
6	19.3	12.6	0	12.6
6.5	21.5	12.8	0	12.8
7	23.8	13.0	0	13.0
7.5	26.1	13.2	0	13.2
8	28.5	13.4	0	13.4
8.5	31.0	13.6	0	13.6
9	33.5	13.8	0	13.8
9.5	36.0	14.0	0	13.9
10	38.6	14.1	0	14.1
10.5	41.3	15.6	14	29.6
11	44.0	16.9	40	56.9
11.5	46.7	17.4	80	97.4
12	49.5	18.0	140	157.9
13	55.2	19.0	609	628.0

Table B.6. Small dry pond stage-discharge relationship in the Des Moines Lobe Region.

Elevation Above Primary Spillway (ft)	*Storage (ac-ft)*	*2" Pipe Outflow*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0	0
1	0.1	0.9	0	0	0.9
2	0.8	1.3	0	0	1.32
3	2.3	1.6	0	0	1.6
4	5.2	1.9	0	0	1.9
5	9.5	2.1	0.00	0	2.1
6	15.6	2.3	2.20	0	4.5
7	23.7	2.5	11.10	0	13.6
8	34.2	2.6	11.50	0	14.1
9	47.1	2.8	11.90	40	54.7
10	62.8	2.9	12.30	140	155.3
11	81.4	3.1	12.60	609	624.8

Table B.7. Large dry pond stage-discharge relationship in the Des Moines Lobe Region.

Elevation Above Primary Spillway (ft)	*Storage (ac-ft)*	*2" Pipe Outflow*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0	0
1	0.1	0.9	0	0	0.9
2	0.8	1.3	0	0	1.3
3	2.3	1.6	0	0	1.6
4	5.2	1.9	0	0	1.9
5	9.5	2.1	0	0	2.1
6	15.6	2.3	2.2	0	4.5
7	23.7	2.5	11.1	0	13.6
8	34.2	2.6	11.5	0	14.1
9	47.1	2.8	11.9	0	14.7
10	62.8	2.9	12.3	0	15.3
11	81.4	3.1	12.6	40	55.7
12	103.3	3.2	13.0	140	156.2
13	128.5	3.4	13.4	609	625.9

Appendix C – Model Development Parameters

Calibration

The April 2007 storm was characterized by a rainfall depth of approximately 3.25 inches, an antecedent moisture condition in the 31st percentile, and a peak discharge of 5,890 cfs at Bayard, IA. Dry conditions were present before the storm, rainfall the five previous days amounted to 0.1 inches at Carroll, IA. CNs in the HMS model were reduced to reflect these dry conditions (average CN -7.6%) and the model did a reasonable job simulating this particular storm as the simulated peak flow is only 7% underestimated, the timing of the peak flow is approximately two hours late and the runoff volume is underestimated by 18%. Underestimation of runoff volume may be due to the inaccuracies in radar rainfall estimates but the very dry conditions before the storm would suggest a greater initial abstraction would need to be overcome to produce runoff and a lesser amount of rainfall would be converted to runoff.

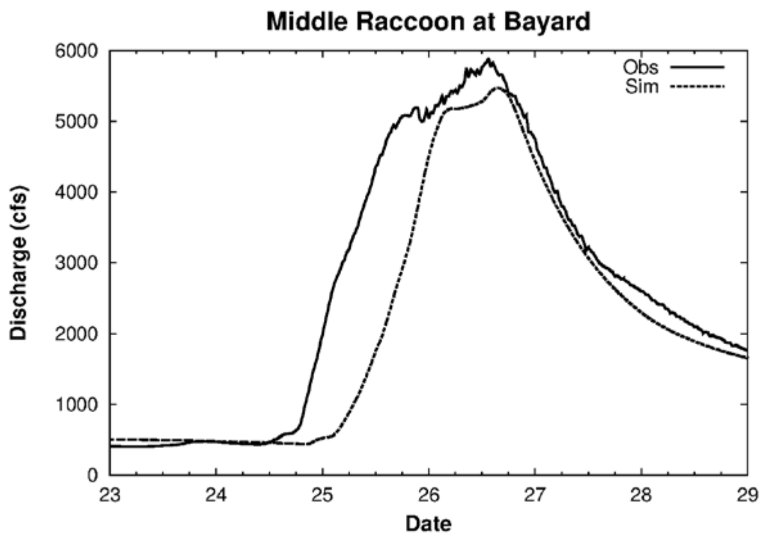

Figure C. 1. Observed and simulated hydrographs at Bayard, IA USGS stream gauge location. Run for the April 2007 rainfall event with post calibration parameters.

The June 2008 storm was characterized by a rainfall depth of approximately 3.1 inches, an antecedent moisture condition in the 91st percentile, and a peak discharge of 7,190 cfs at Bayard, IA. Very wet conditions were present before the storm, rainfall the five previous days amounted to 1.9 inches at Carroll, IA. CNs in the HMS model were increased to reflect these wet conditions (average CN +15.9%), the simulated peak flow was 22% overestimated, the timing of the peak flow is approximately 10 minutes early and the runoff volume is overestimated by 1%. The difference in peak flows may be due to the very wet antecedent moisture condition, which accounted for the greatest increase in curve number seen in any of the calibrated event. The model tends to be more accurate as antecedent moisture conditions move closer to the average.

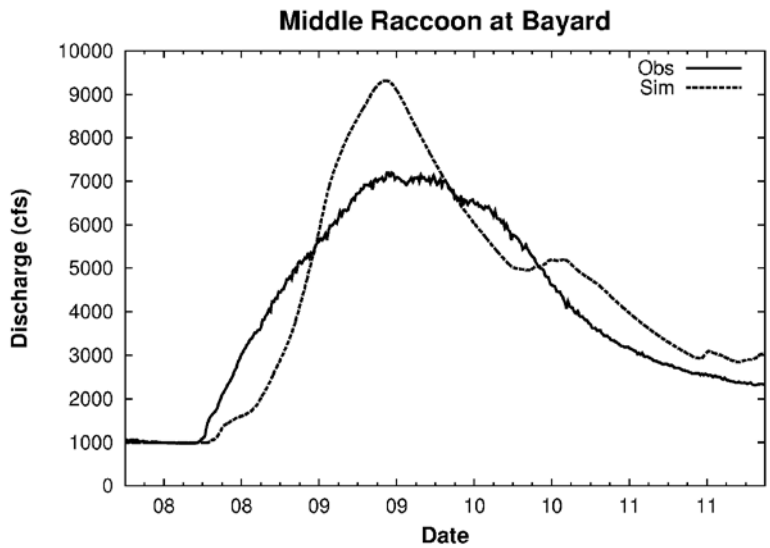

Figure C. 2. Observed and simulated hydrographs at Bayard, IA USGS stream gauge location. Run for the June 2008 rainfall event with post calibration parameters.

The June 2010 storm was characterized by a rainfall depth of approximately 2.7 inches, an antecedent moisture condition in the 61st percentile, and a peak discharge of 7,100 cfs at Bayard, IA. Wet conditions were present before the storm, rainfall the five previous days amounted to 0.6 inches at Carroll, IA. CNs in the HMS model were increased to reflect these wet conditions (average CN +6.6%), the simulated peak flow is was 16% underestimated, the timing of the peak flow is approximately 3 hours late and the runoff volume is underestimated by 23%. Differences in the hydrographs could be due to the abnormally "flashy" response observed in this storm.

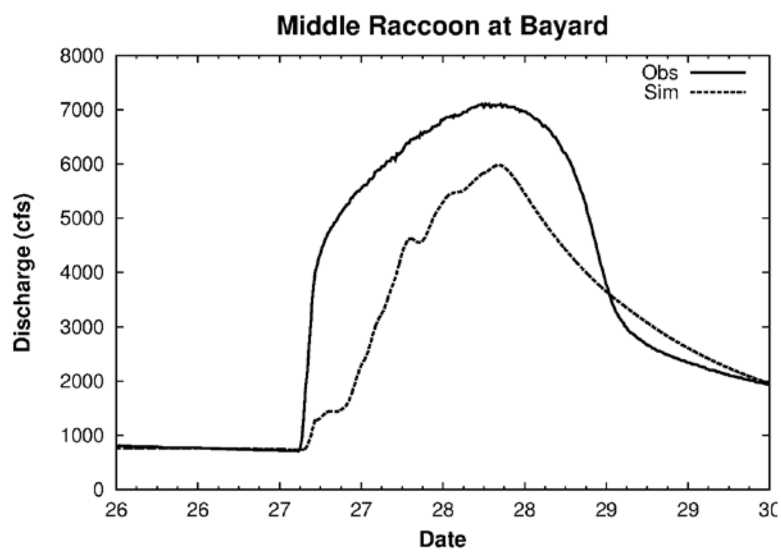

Figure C. 3. Observed and simulated hydrographs at Bayard, IA USGS stream gauge location. Run for the June 2010 rainfall event with post calibration parameters.

The May 2013 storm was characterized by a rainfall depth of approximately 2.8 inches, an antecedent moisture condition in the 70th percentile, and a peak discharge of 8,030 cfs at Bayard, IA. Wet conditions were present before the storm, rainfall the five previous days amounted to 0.8 inches at Carroll, IA. CNs in the HMS model were increased to reflect these wet conditions (average CN +9.5%), the simulated peak flow is was 6% overestimated, the timing of the peak flow is approximately 4 hours early and the runoff volume is overestimated by 23%. The calibrated parameters seemed to do a reasonable job in reflecting the hydrologic response to this storm.

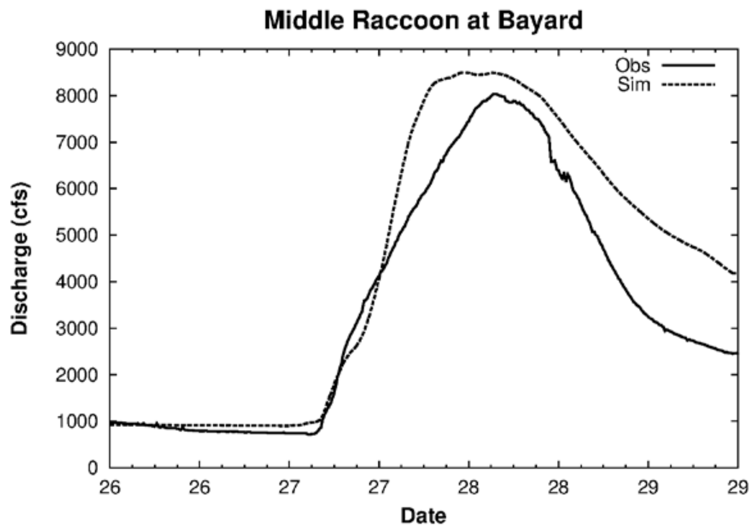

Figure C. 4. Observed and simulated hydrographs at Bayard, IA USGS stream gauge location. Run for the May 2013 rainfall event with post calibration parameters.

The June 2013 storm was characterized by a rainfall depth of approximately 2.5 inches, an antecedent moisture condition in the 48th percentile, and a peak discharge of 13,200 cfs at Bayard, IA. Average conditions were present before the storm, rainfall the five previous days amounted to 0.3 inches at Carroll, IA. CNs in the HMS model were slightly increased to reflect these conditions (average CN +1.6%), the simulated peak flow was 17% underestimated, the timing of the peak flow is within 5 minutes of the observed flow, the runoff volume is overestimated by 8%. The calibrated parameters seemed to do a reasonable job in reflecting the hydrologic response to this storm.

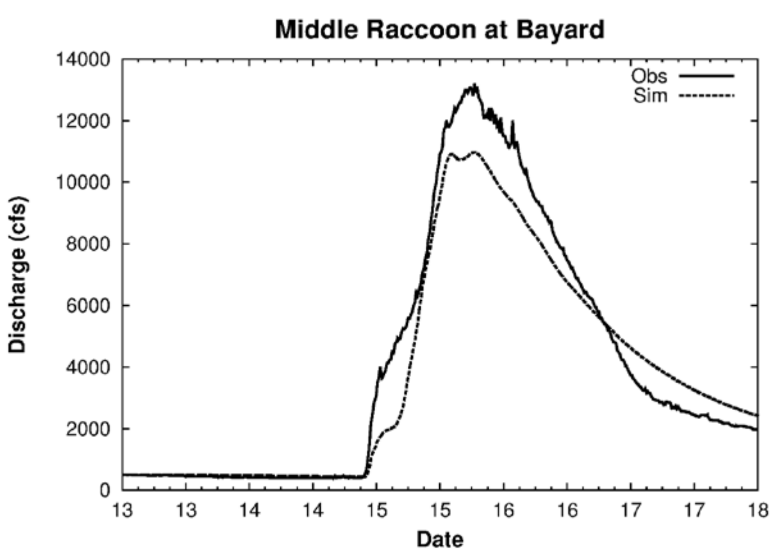

Figure C.5. Observed and simulated hydrographs at Bayard, IA USGS stream gauge location. Run for the June 2013 rainfall event with post calibration parameters.

The model was not calibrated to fit one storm perfectly. Instead parameters were altered in an attempt to reflect a variety of historic rainfall events that varied in intensity, season, and antecedent moisture conditions. The efforts of this multi-storm approach to calibration and validation can be seen in Figure C.6. While none of the peak flows calibrated matched the peak flow observed at the Bayard, IA USGS gauge location exactly; they all did a reasonable job of estimating flows within a realistic range for the magnitude of rainfall events simulated.

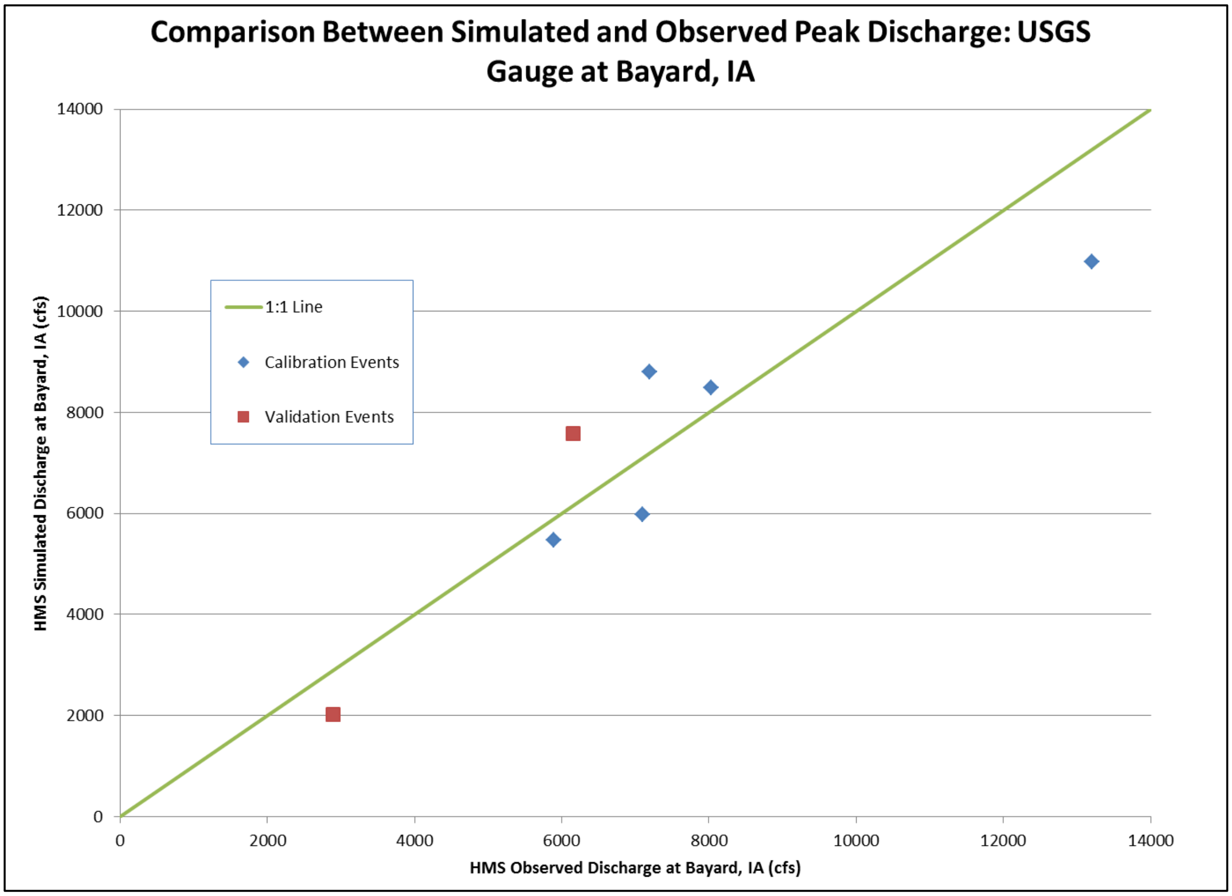

Figure C.6. Calibration and validation summary: Comparison of the simulated discharges (y-axis) and observed discharges (x-axis).

Validation

In validation the model overestimated the wet antecedent moisture (79th percentile) July 2008 event and underestimated the very dry (0-22nd percentile, i.e. 0 inches) August 2010 event. Both of these events had lower observed peak discharges when compared with the calibrated events. Although a reasonable simulated response is sought for all storm sizes, greater precedence is placed on more accurately modeling large events since they typically pose a greater threat in terms of flooding. Furthermore, larger events tend to be more surface flow dominated while smaller events are likely to have a greater subsurface flow component, so it makes some sense why HMS, a surface water model, does better modeling larger events.

The July 2008 validation storm was characterized by a peak discharge of 6,150 cfs at the Bayard, IA USGS gauge location. Wetter than normal conditions were present before the storm, 1.1 inches of rainfall in the 5 days prior or the 79th percentile. The wet initial conditions increased the curve number and allowed more rainfall to be converted to runoff. This increase in curve number increased peak discharge to a level that better represented discharges, when compared with the uncalibrated parameters. That being said, the simulation still overestimated peak discharge by 23% and volumes by 31%. Validation for this storm showed that using calibrated parameters better reflected the observed conditions when compared with uncalibrated parameters.

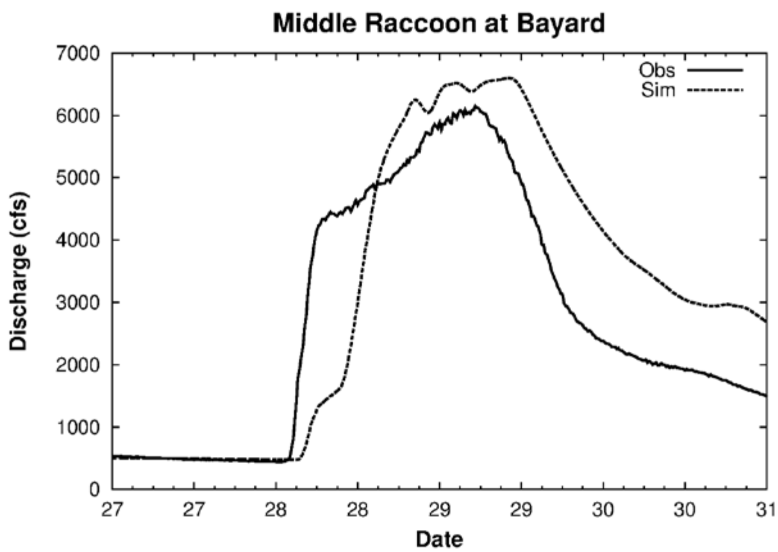

Figure C. 7. Observed and simulated hydrographs at Bayard, IA USGS stream gauge location. Validation for the July 2008 rainfall event, run with post calibration parameters.

The August 2010 validation storm was characterized by a peak discharge of 2,890 cfs at the Bayard, IA USGS gauge location, by far the smallest event simulated. Much dryer than normal conditions were present before the storm, 0 inches of rainfall in the 5 days prior or the 0-22nd percentile. The very dry initial conditions decreased the curve number and allowed less rainfall to be converted to runoff. In this event peak discharges were underestimated and the timing of the peak flow was late by approximately two day. The simulation still underestimated peak discharge by 30% and volumes by 11%. Difference in the observed and simulated hydrographs may be due to the smaller nature of this event, the model tends to more accurately predict large, high surface flow events. That being said, the model performed better using the calibrated parameters when compared with the uncalibrated parameters.

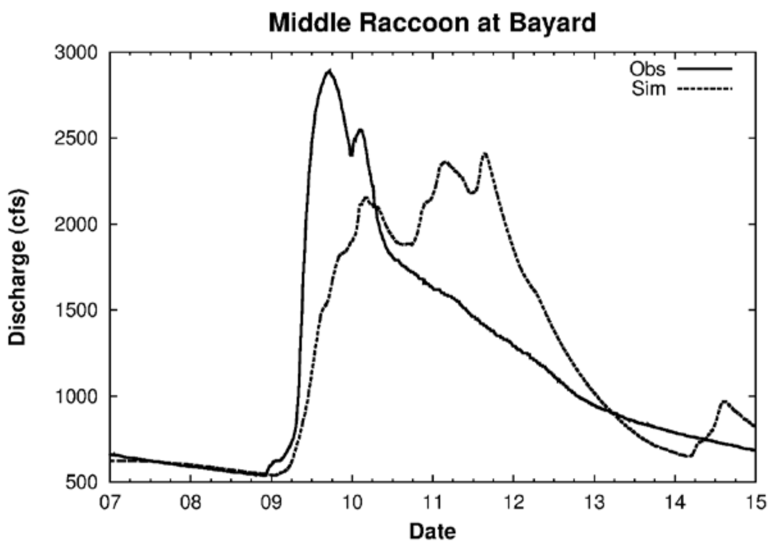

Figure C.8. Observed and simulated hydrographs at Bayard, IA USGS stream gauge location. Validation for the August 2010 rainfall event, run with post calibration parameters.

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