Hydrologic Assessment of the Chequest Creek Watershed

August 2014

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

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Davis County Soil and Water Conservation District
Iowa Department of Natural Resources
Natural Resources Conservation Service
Soap Creek Watershed Board

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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, 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 local leaders, landowners and watershed residents in the Chequest Creek Watershed an understanding of the hydrology – movement of water – within the watershed.

The assessment begins by outlining trends and hydrologic conditions across Iowa, characterizes the conditions within the Soap and Chequest Creek Watersheds and compares local conditions to those in three other watersheds – the Middle Raccoon River, the Upper Cedar River and the Turkey River.

A hydrologic model of the Chequest Creek 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 and (2) implementing a system of distributed storage projects (ponds) across the landscape.

The focused hydrologic assessment provides watershed residents and local 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 Chequest Creek Watershed.

1. Iowa's Flood Hydrology

This chapter illustrates facts about Iowa's water cycle and flood hydrology across the state. Historical records for precipitation and streamflow are examined to describe how much precipitation falls, 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 Soap and Chequest Creek Watersheds, as well as that for the three other Iowa watersheds that are part of the Iowa Watersheds Project (see Figure 1.1).

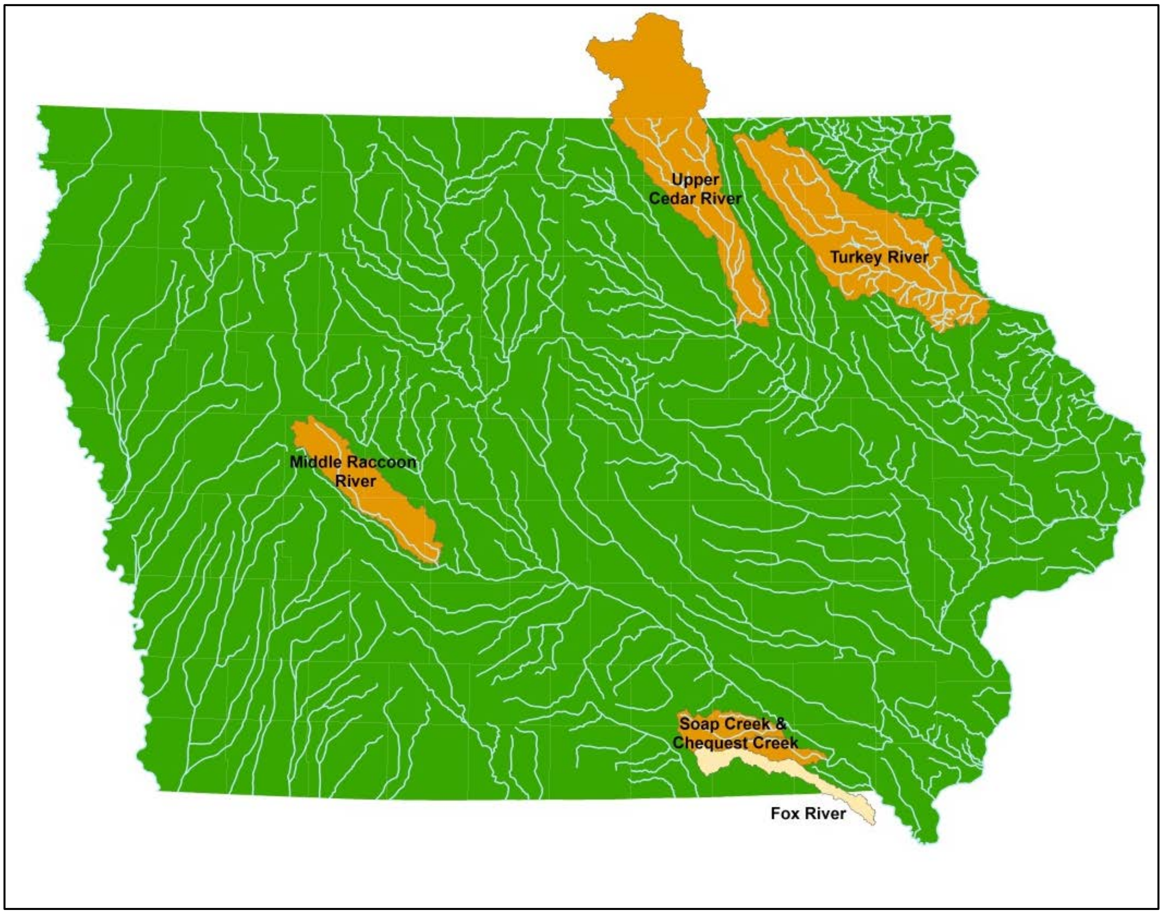


Figure 1.1. Iowa Watersheds Project study areas.

Soap and Chequest Creeks in the southern part of the state are located in the Southern Iowa Drift Plain landform region. Both of these creeks 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 of the adjoining Fox River as an indicator of the runoff characteristics in this portion of the state. The Turkey River (USGS 05412500 Turkey River at Garber) drains 1,545 square miles (mi^2), and includes portions of the Iowan Surface and karst topography of the Paleozoic Plateau. The Upper Cedar (USGS 05458500 Cedar River at Janesville) begins in Minnesota, and drains 1,661 mi^2 — mostly from the Iowan Surface landform. The Middle Raccoon River drains 375 mi^2 (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.

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 across its landscape 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 Watershed 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.

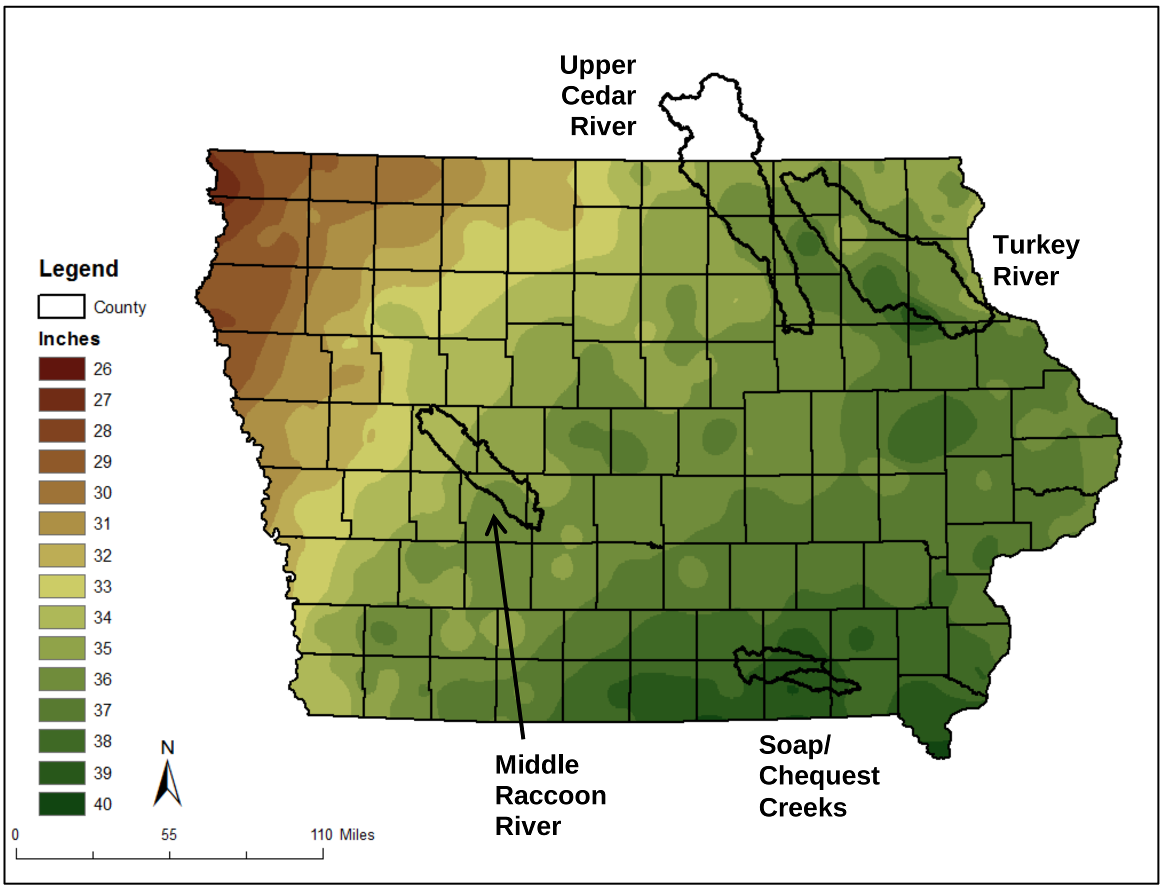


Figure 1.2. Average annual precipitation for Iowa. Precipitation estimates are based on the 30-year annual average (1981-2010) for precipitation gauge sites. Interpolation between gauge sites to an 800 m grid was done by the PRISM (parameter-elevation relationships on independent slopes model) method.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

ii. The Water Cycle in Iowa

Of the precipitation that falls in Iowa, a good portion evaporates into the atmosphere — either directly from lakes and streams, or by transpiration from crops and vegetation. What doesn't evaporate, flows through 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 precipitation (100% of the water in each watershed).

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

[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 of the adjoining Fox River as an indicator of the hydrology in this portion of the state.

This region of southeast Iowa consists of 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 of water into 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.

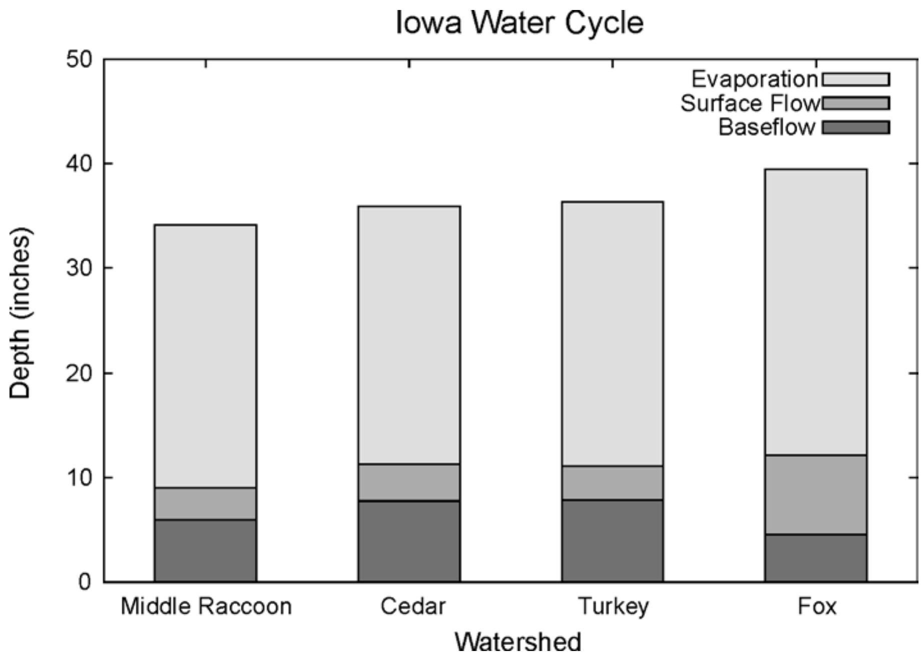


Figure 1.3. Iowa water cycle for four watersheds. The chart shows the partitioning of the average annual precipitation depth (in inches) into evaporation, surface flow, and baseflow components.[2]

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).

[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.

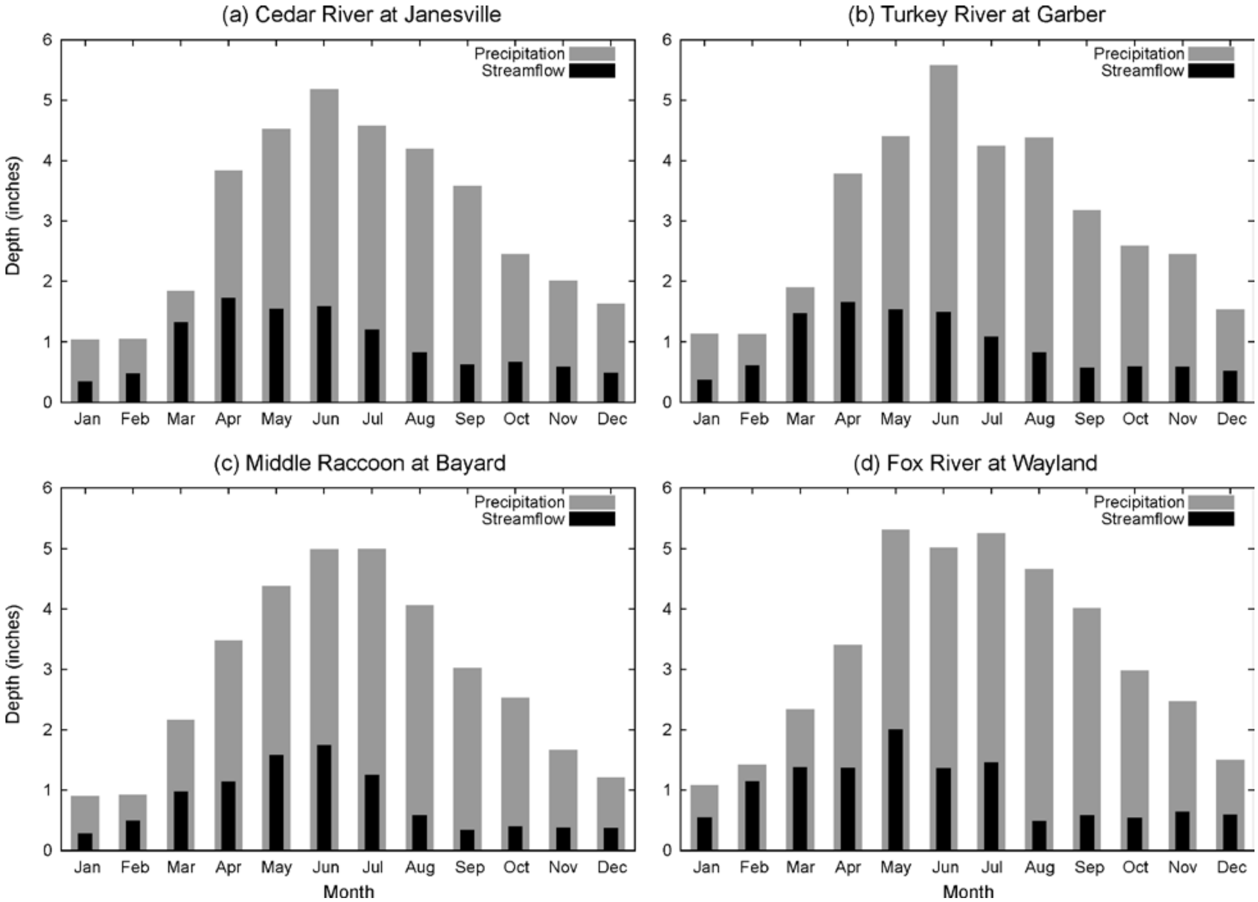


Figure 1.4. Monthly water cycle for four Iowa watersheds. The plots show the average monthly precipitation (in inches) and the average monthly streamflow (in inches). The average monthly estimates for precipitation and streamflow are based on the same 30-year period (1981-2010).

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.

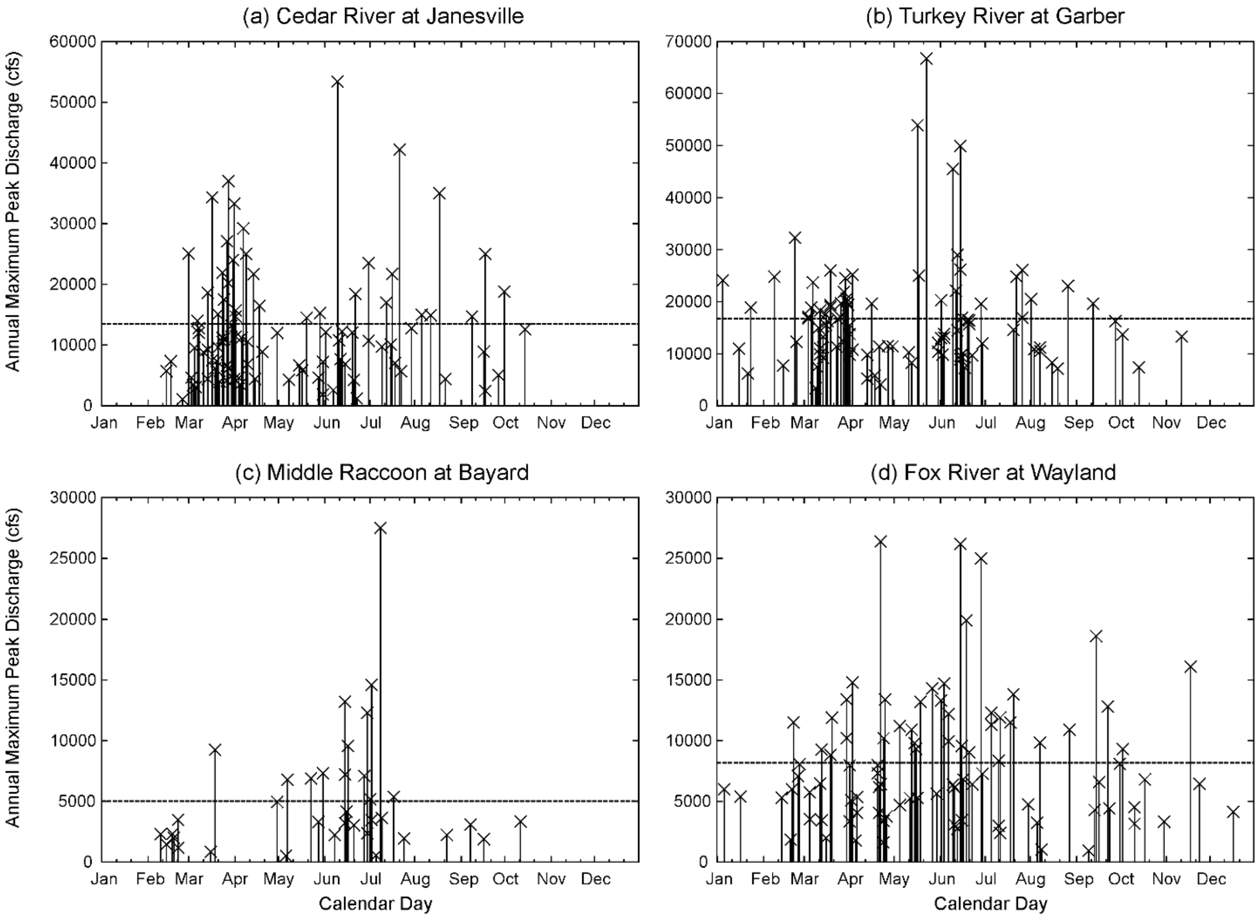


Figure 1.5. Annual maximum peak discharges and the calendar day of occurrence for four Iowa watersheds. The plots show all annual maximums for the period of record at four USGS streamgage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and (d) Fox River 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 flows 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).

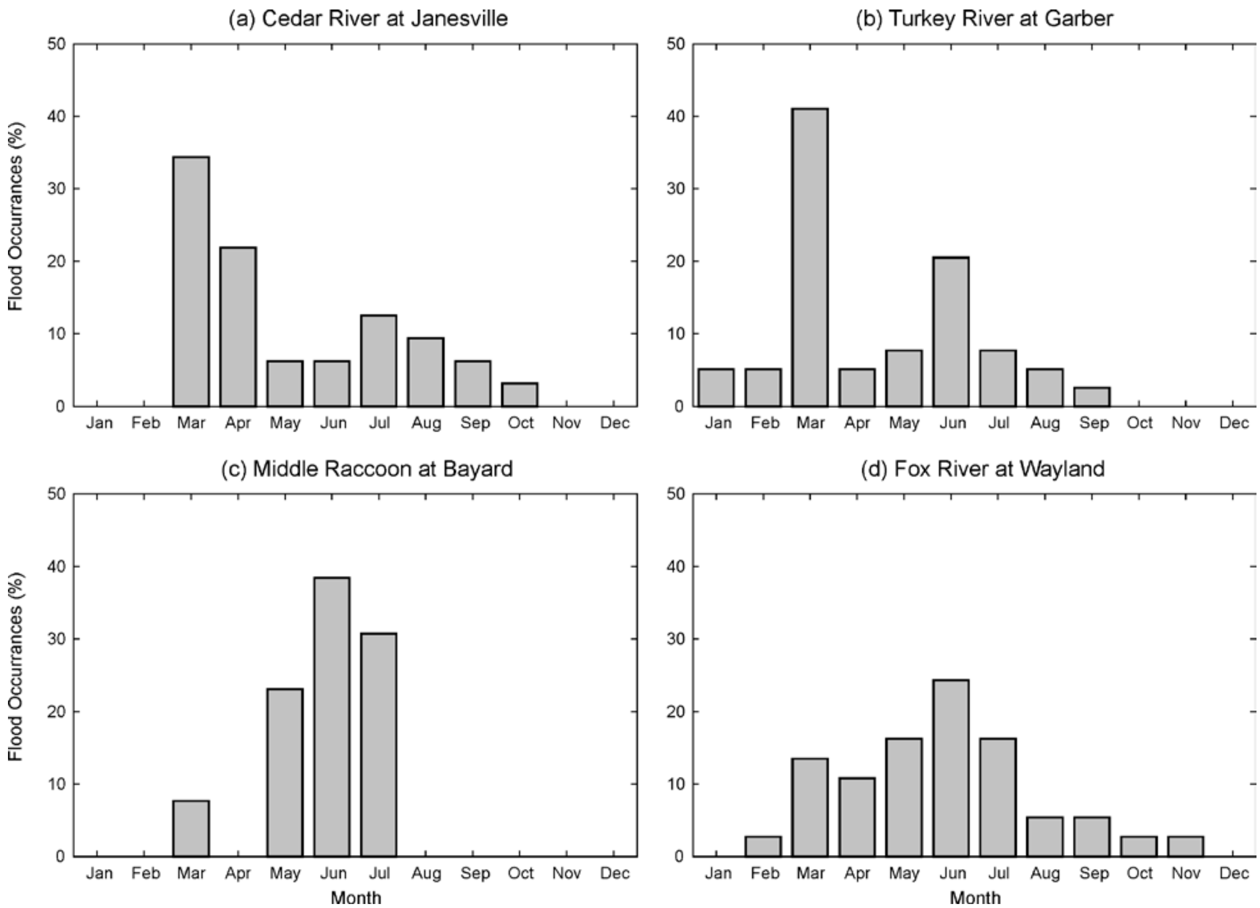


Figure 1.6. Flood occurrence frequency by month for four Iowa watersheds. The plots show the percent of peak annual discharges for a given month that exceed the mean annual flood at four USGS stream-gage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and (d) Fox River at Wayland.

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 in Iowa 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 hydrologic 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 the 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 agriculural state, a growing portion of its population resides in urban areas. The transition from agricultural to urban land uses has a profound impact on local hydrology, increasing the amount of runoff, the speed at which water moves through the landscape, and the magnitude of flood peaks. The factors that contribute to these increases (Meierdiercks et al., 2010) are the increase in the percentage of impervious areas within the drainage catchment and its location (Mejia et al., 2010), and the more efficient drainage of the landscape associated with the constructed drainage system — the surface, pipe, and roadway channels that add to the natural stream drainage system. Although traditional stormwater management practices aim to reduce increased flood peaks, urban areas have long periods of high flows that can erode 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 1.7 shows the results of the analysis for mean daily discharge for the four Iowa watersheds. Note the 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.

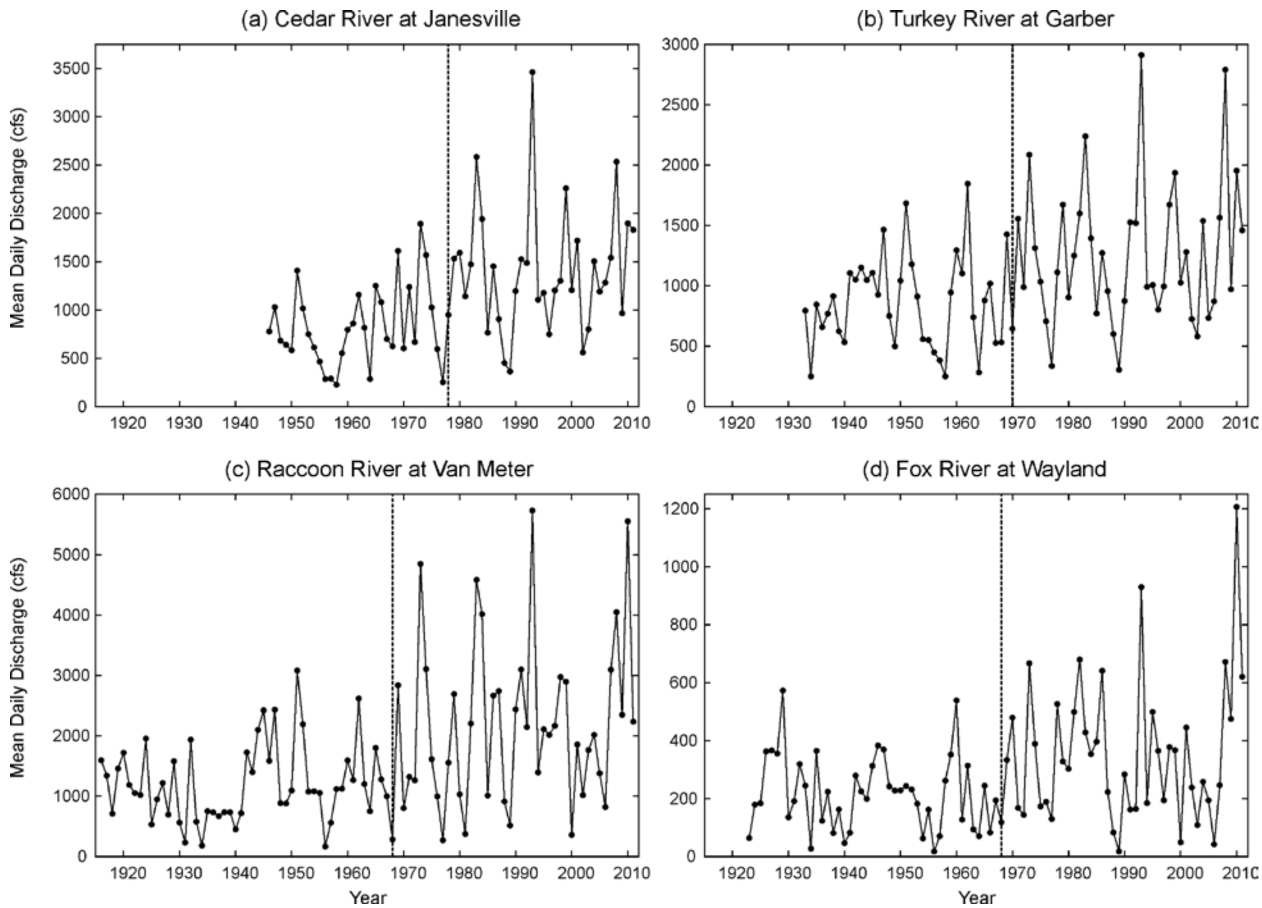


Figure 1.7. Time series of mean daily discharge for the period of record. An analysis was carried out to detect changes in the statistical characteristics of mean daily discharge; the vertical dashed lines indicate the location of any identified change point.

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

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 Chequest Creek Watershed

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

a. Hydrology

Chequest Creek's watershed, as defined by the boundary of ten-digit Hydrologic Unit Code (HUC10) 0710000912, has a drainage area of approximately 124 square miles. It is located in Southeast Iowa and is a sub-watershed within the Lower Des Moines River eight-digit Hydrologic Unit Code (HUC8 0710009).

The Chequest Creek watershed can be described as a narrow watershed, only about 7.5 miles at its widest. Chequest Creek has two headwater branches and flows west to east. The two branches come together in eastern Davis County and continue eastward discharging into the Des Moines River approximately four miles upstream of Keosauqua.

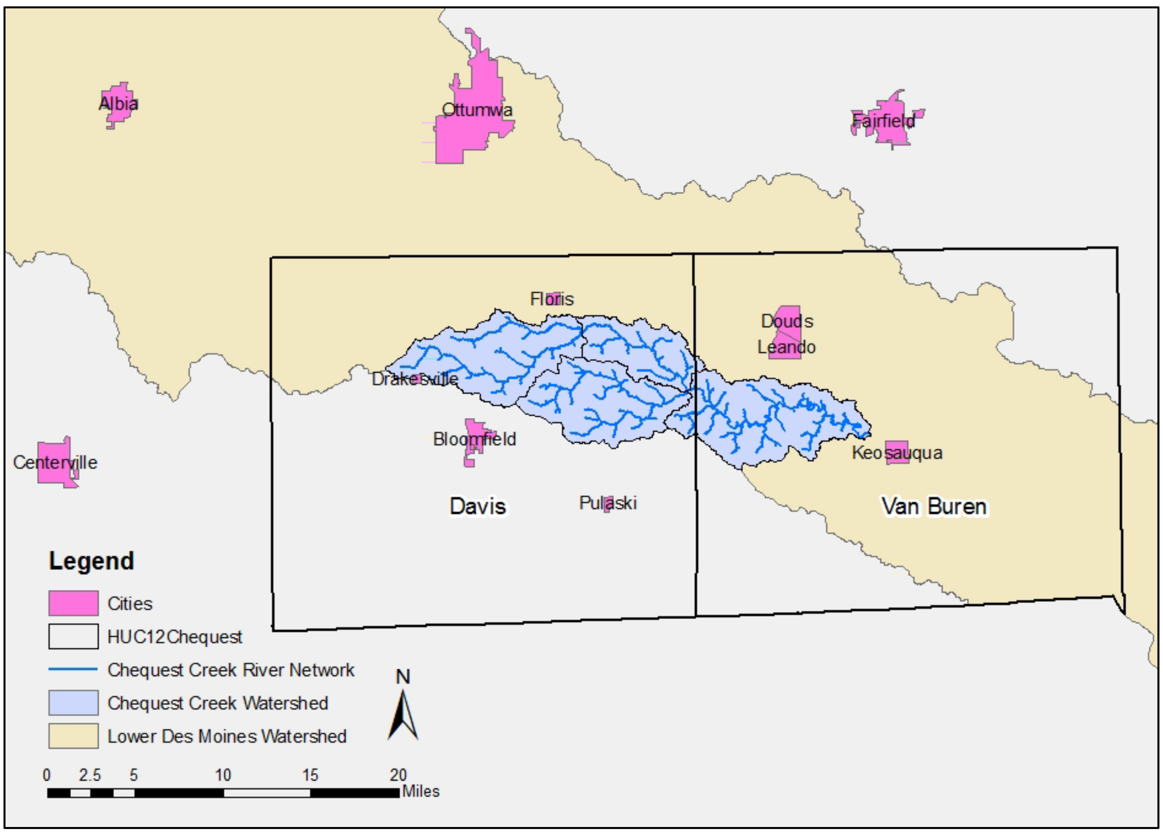


Figure 2.1. The Chequest Creek Watershed (HUC10 0710000912) drains approximately 124 mi^2.

Average annual precipitation for this region of Southeast Iowa is roughly 39 inches (PRISM, 1981-2010), with about 80% of the annual precipitation falling April through September. During this period, thunderstorms capable of producing torrential rain are possible with the peak frequency of intense storms occurring in June.

b. Geology and Soils

The entire Chequest Creek Watershed is located within the Southern Iowa Drift Plain (see Figure 2.2). This region is dominated by glacial deposits left by ice sheets that extended south into Missouri over half a million years ago. The deposits were carved by deepening episodes of stream erosion, only a horizon line of hill summits mark the once-continuous glacial plain. Numerous rills, creeks, and rivers branch across the landscape shaping the old glacial deposits into steeply rolling hills and valleys. A mantle of loess drapes the uplands and upper hill slopes (Iowa Geological & Water Survey, The Iowa Department of Natural Resources, 2014).

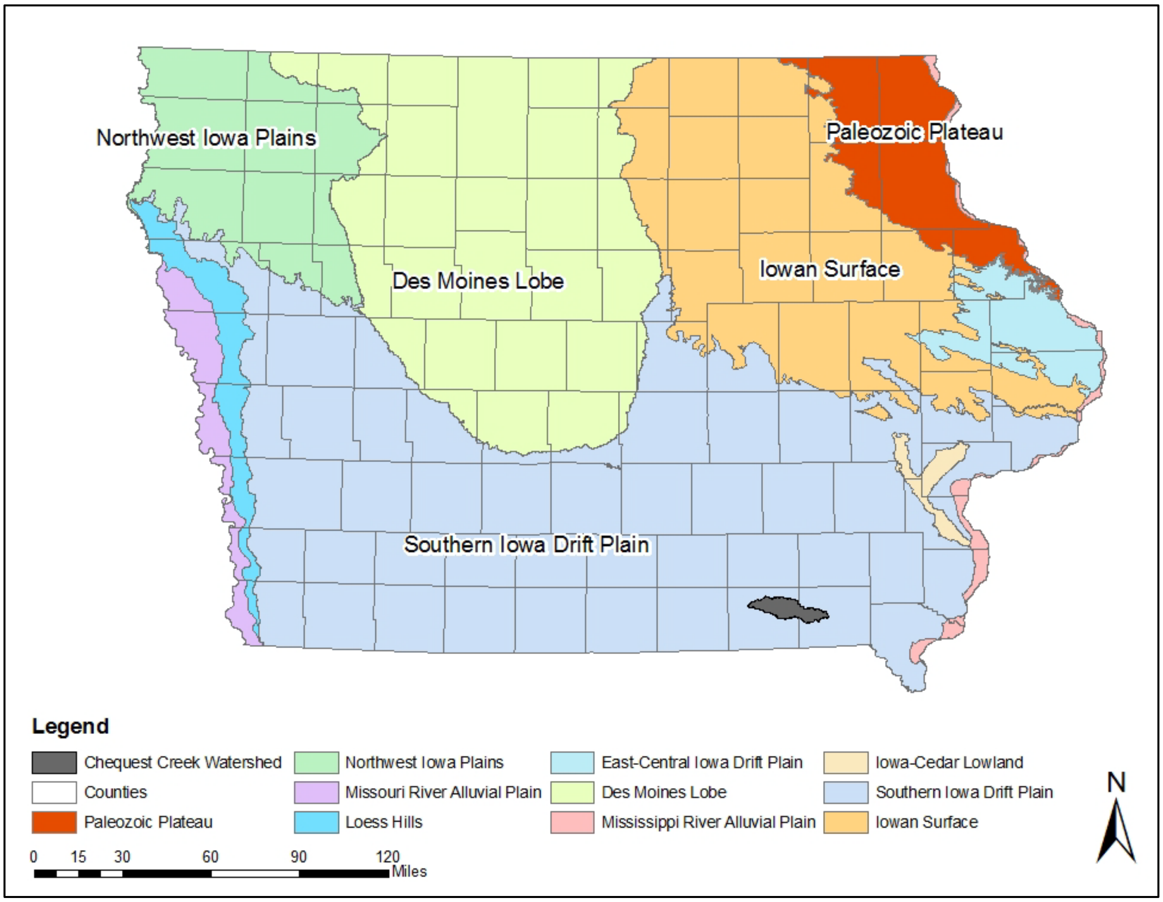


Figure 2.2. Landform regions of Iowa, Chequest Creek Watershed shown in Southeast Iowa.

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

Hydrologic Soil Groups can be found in USDA-NRCS National Engineering Handbook, Part 630 – Hydrology, Chapter 7.

The Southern Iowa Drift Plain in Southeast Iowa consists of Grundy, Haig, and Arispe soils on the headland ridges with slopes generally 9 percent or less. These soils typically contain 42 to 48 percent clay in the subsoil. Many of the side slopes that are steeper than 9 percent developed in glacial till. These soils classify as primarily HSG C and D type soils, resulting in areas that range from moderate to high runoff potential. The soil distribution of the Chequest Creek Watershed per digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WSS) is shown in Figure 2.4.

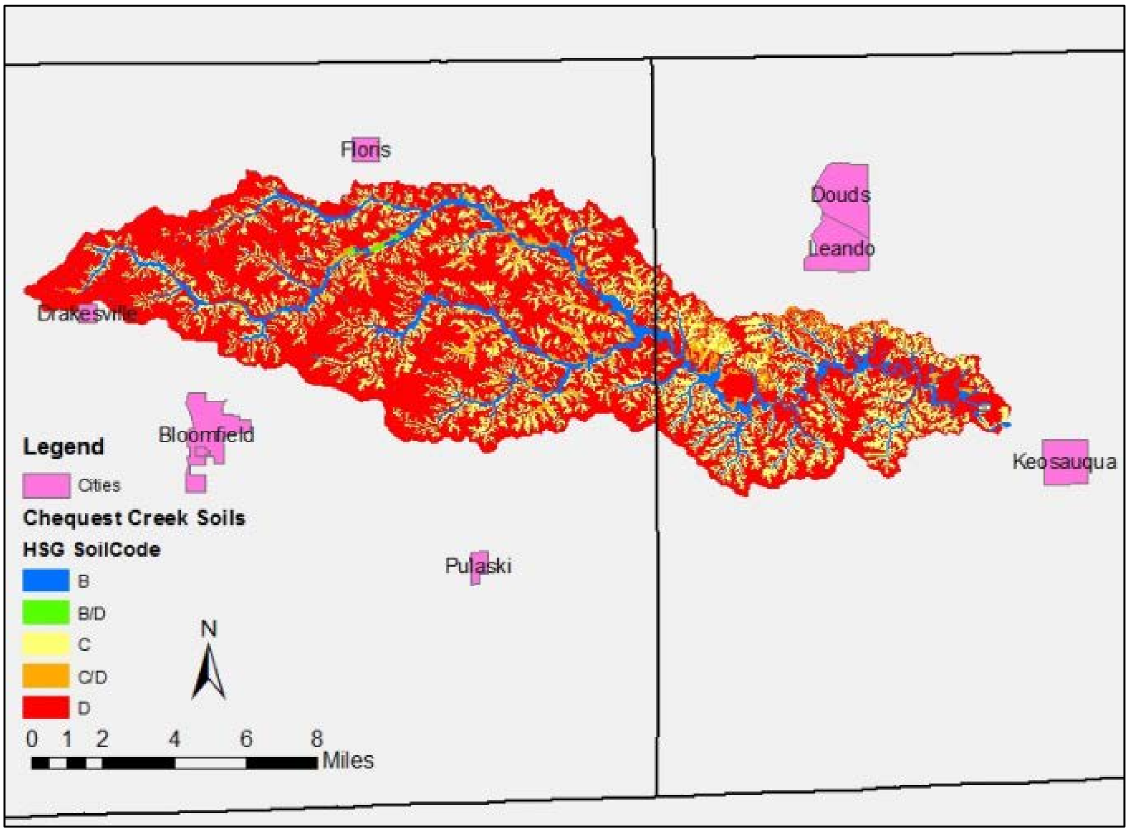


Figure 2.3. Distribution of Hydrologic Soil Groups in the Chequest Creek Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with A-type representing the lowest runoff potential and D-type representing the highest runoff potential.

The map illustrates the dominance of D-type soils in the headland areas and exposed C-type soils in the eroded rills of the watershed. Higher detailed soil distribution and watershed slope maps are included in Appendix A. Table 2.1 shows the approximate percentages by area of each soil type for the Southern Iowa Drift Plain in the Chequest Creek Watershed.

Table 2.1. Approximate Hydrologic Soil Group percentages by area in Chequest Creek.

Hydrologic Soil Group	*Runoff Potential*	*Percent of Watershed Area*
A	Low	0%
A/D		0%
B	Moderately Low	8.8%
B/D		0.1%
C	Moderately High	24.2%
C/D		3.8%
D	High	63.1%

c. Topography

Elevations range from approximately 900 feet above sea level in the uppermost part of the watershed to 505 feet at the outlet. The terrain, along with the underlying soils, makes the area well suited for water impoundments.

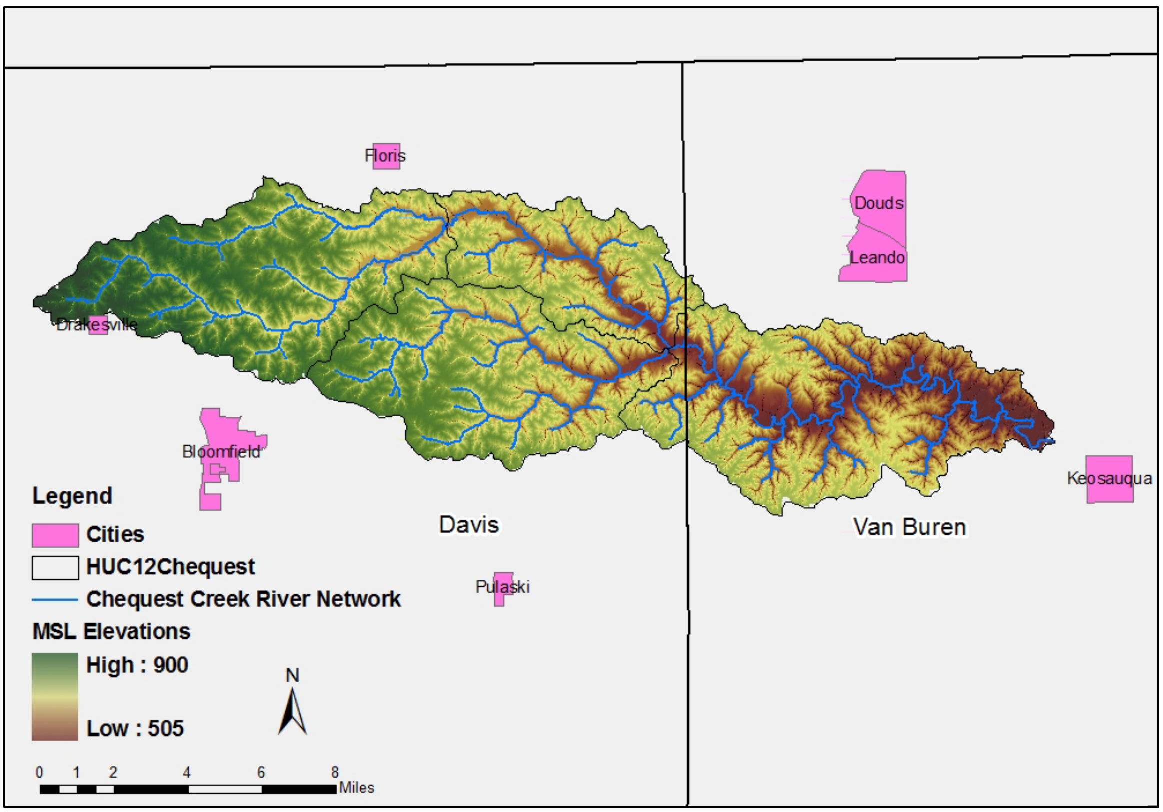


Figure 2.4. Topography of the Chequest Creek Watershed.

d. Land Use

Land use in the Chequest Creek Watershed is heavily agricultural, dominated by pasture/hay at approximately 47% of the acreage and row crop production at approximately 18%. The watershed consists of approximately 25% forested lands, with the remaining acreage consisting of 3% developed land and 1% open water and/or wetlands, per the 2006 National Land Cover Data (NLCD) Set. Approximately 90% of the land in the watershed is privately owned.

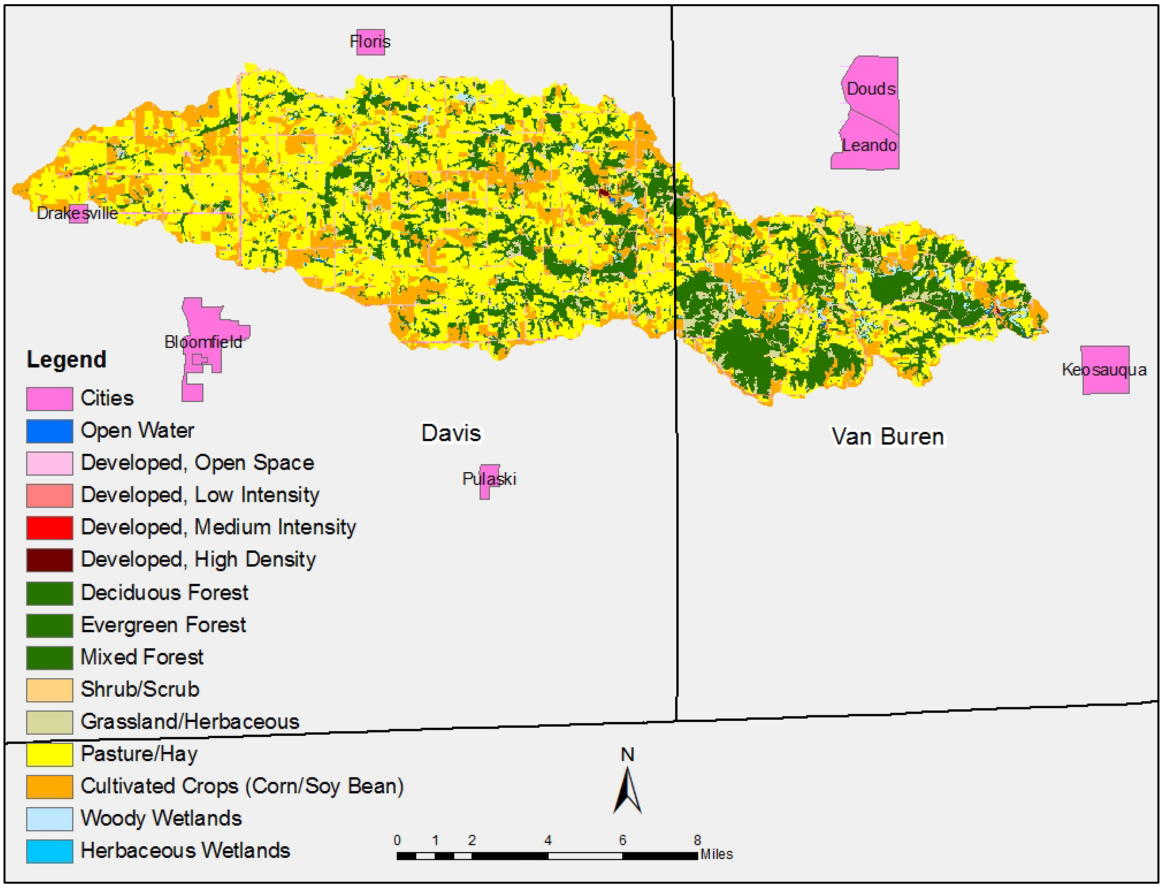


Figure 2.5. Land use composition in the Chequest Creek Watershed per the 2006 NLCD. Pasture/Hay is shown in yellow, forest is shown in green, and cultivated crops are shown in orange.

e. Instrumentation/Data Records

The Chequest Creek Watershed has historically had a limited data collection network. The following figure and tables detail the instrumentation.

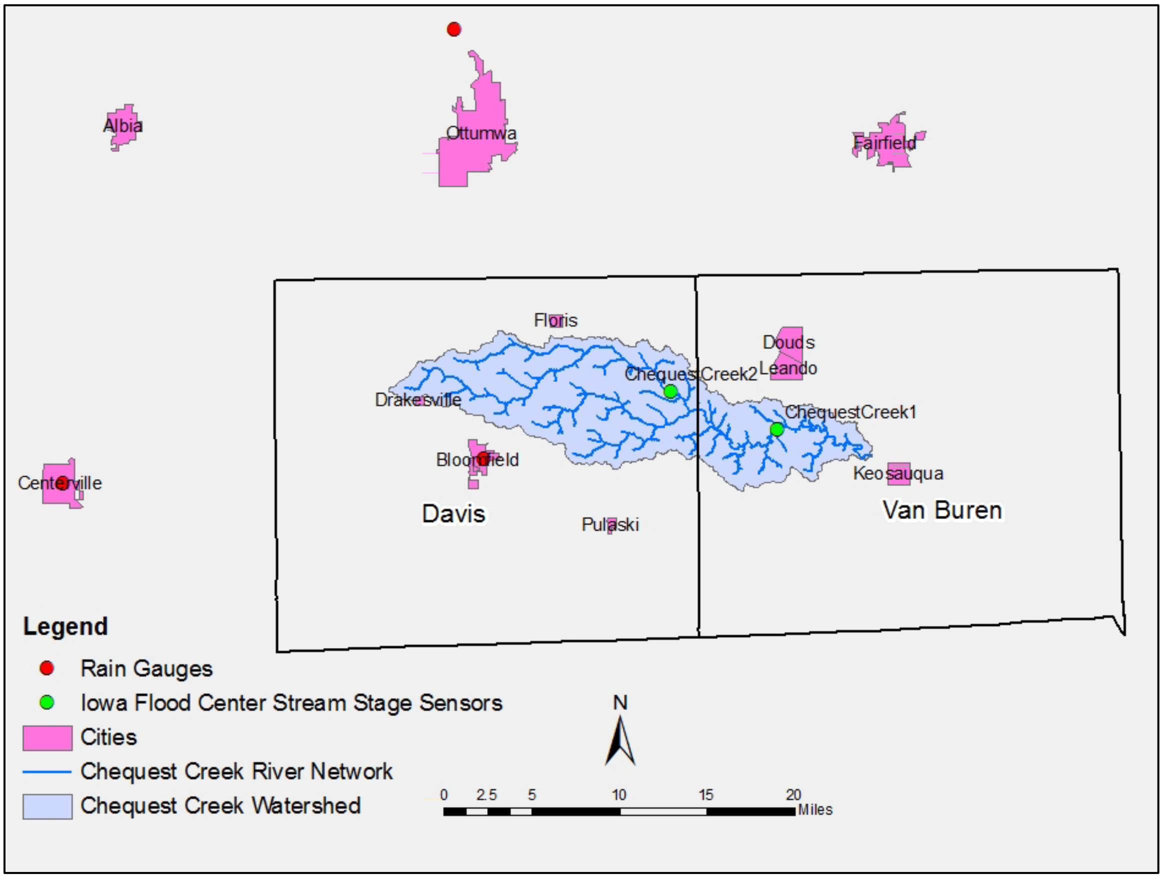


Figure 2.6. Hydrologic and meteorologic instrumentation in/near the Chequest Creek Watershed. Iowa Flood Center stream stage sensors (2) are shown in green while NOAA 15 minute/hourly and NOAA-partnered precipitation gages (3) are shown in red.

Table 2.2. Stage/Discharge gages and precipitation gages in the Chequest Creek Watershed.

Gage Type	*Location*	*Period of Record*
IFC Stream Sensor (stage)	Chequest Creek 1, County V64, Van Buren County	2011 – present
IFC Stream Sensor (stage)	Chequest Creek 2, Wheat Ave, Davis County	2011 – present
NOAA 15 min/1 hr Precipitation	Ottumwa Industrial Airport	1948 – 2013
NOAA 15 min/1 hr Precipitation	Centerville, IA	1948 – 2013
NOAA-partnered Daily Precipitation	Bloomfield, IA	1906 - present

f. Floods of Record

With no historical gages in the Chequest Creek Watershed, peak flood discharges have not been established. However, Iowa Flood Center stream-stage sensors have collected data on two significant flooding events; the first, April 17-18, 2013, and the second, May 29-30, 2013. The flooding that occurred in April 2013 was set up by heavy rainfall watershed-wide in both Soap and Chequest Creeks. Rainfall in the Chequest Creek Watershed exceeded 3.5 inches across the entire drainage area, but as much as 5.2 inches is estimated to have fallen in the upper portion of the watershed in a 25 hour period from April 17 (3:00 a.m.) and April 18 (4:00 a.m.).

Rainfall over the month of May 2013 in the Chequest Creek Watershed can be characterized as periodic events following a west-to-east pattern with the flooding resulting from a week-long series of rainstorms tracking over the watershed from May 24-30. No single event was significant, but the cumulative impact of the repeated rainfall events on already wet conditions lead to many of the creeks leaving their banks for the second time in a little over a month. Rainfall estimates range from six inches in the upper portion of the watershed to four inches in the downstream.

As a result of the soil type in the Chequest Creek Watershed, a significant portion of rainfall is converted to runoff. This runoff impacts are further exacerbated due to the large percentage of steeply sloped landscape. These factors have and will continue to produce flash flooding so long as the watershed continues to receive similar rainstorm patterns.

3. Chequest Creek Hydrologic Model Development

This chapter summarizes the development of the model used in the Phase I Hydrologic Assessment for the Chequest Creek Watershed. The modeling was performed using the U.S. 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 very small (a few acres) to very large (the size of the Chequest Creek Watershed or larger). Figure 3.1 reviews the water cycle and major hydrologic processes that occur in a watershed.

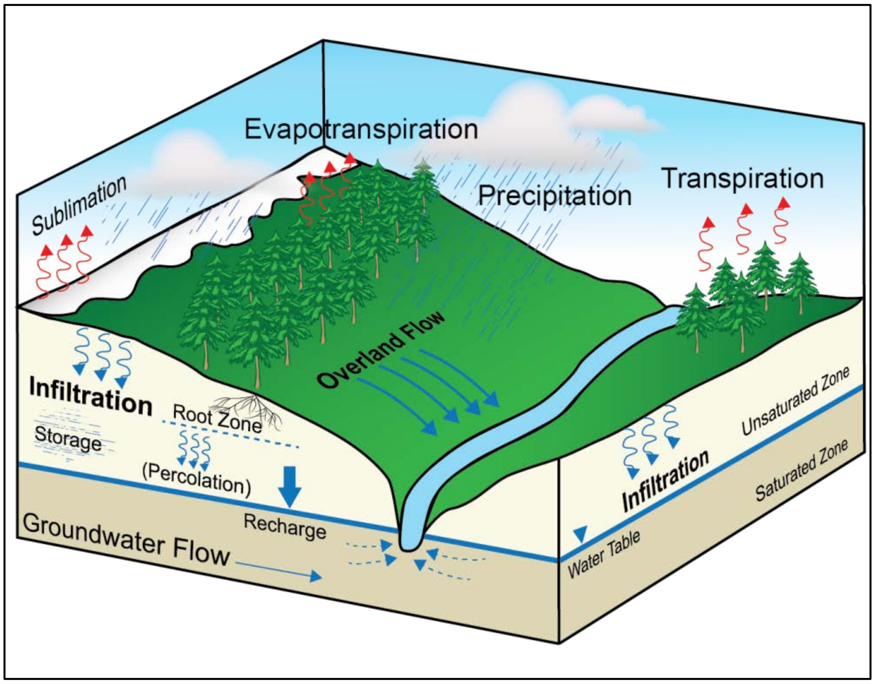


Figure 3.1. Hydrologic processes that occur in a watershed. Phase I modeling only considered the precipitation, infiltration, and overland components of the water cycle.

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 Chequest Creek Watershed as modeled and detailed herein is approximately 124 square miles. The watershed was divided into 267 smaller units, called subbasins in HMS, with an average area of each subbasin about 0.5 square miles but as large as 1.5 square miles. The subbasin delineation of the Chequest Creek Watershed implemented into HMS is shown in Figure 3.2.

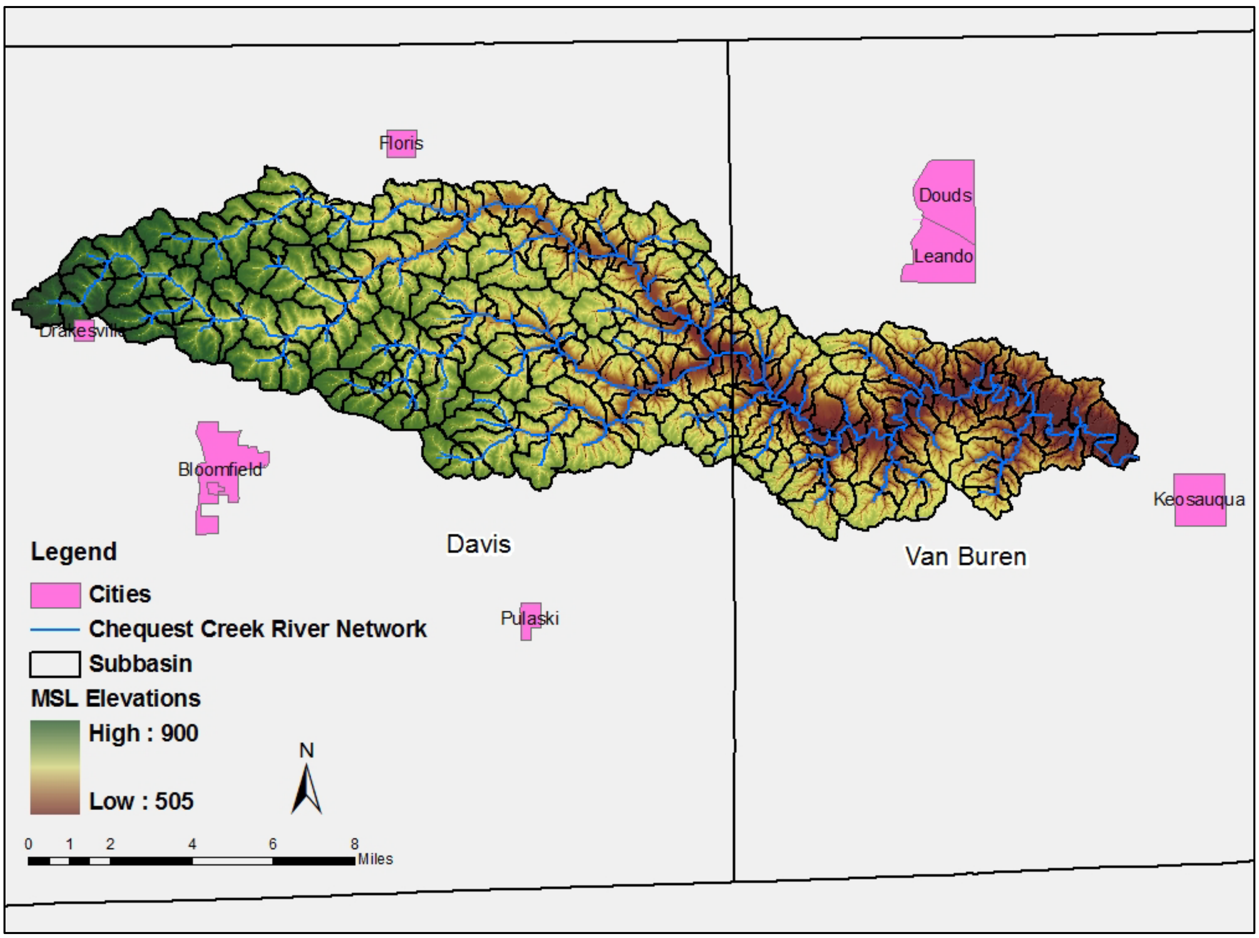


Figure 3.2. HMS subbasins developed for Chequest Creek. The watershed was divided into 267 subbasins for modeling.

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 0.387 mi^2 (1 km^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 point at the discharge point of thirteen NRCS ponds identified by Iowa Department of Natural Resources (IDNR) as having a dam requiring periodic inspection (refer to Chapter 3.a.i.). In HMS, area-weighted averaging is performed within the boundary of each subbasin to assign each subbasin a single value for the parameter being developed.

i. Incorporated Structures

Eleven of the thirteen NRCS ponds currently in the watershed were incorporated into the HMS model. Stage-storage-discharge relationships were obtained from the Bloomfield, Iowa NRCS field office or developed using partial design information obtained from the Iowa Department of Natural Resources' Office of Dam Safety in Des Moines, Iowa. England Dam and Crane Dam (1995) were not included as design information could not be obtained.

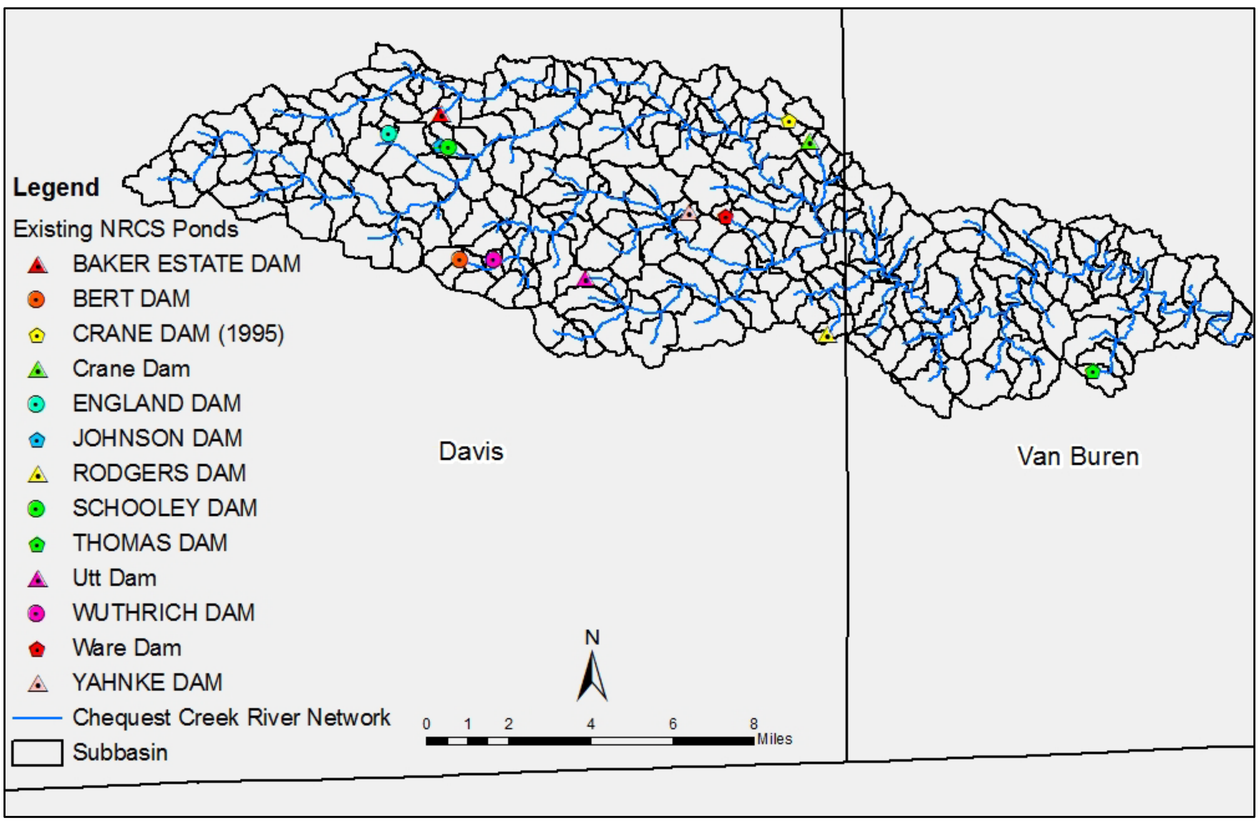


Figure 3.3. NRCS ponds in the Chequest Creek Watershed.

ii. Development of Model Inputs and Parameters

This section provides an overview of data inputs used and assumptions made to develop the HMS model.

Rainfall (Meteorological Model)

Stage IV radar rainfall estimates were used as the precipitation input for simulation of actual (historical) rainfall events known to have occurred within the watershed. The Stage IV data 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 4 km x 4 km (2.5 mile x 2.5 mile) gridded hourly precipitation estimate data set. These data are available from January 2002 – present.

Figure 3.4 shows an example of the Stage IV radar rainfall product. The cumulative rainfall estimated for each grid cell during a one hour period is shown (June 13, 2011, 8:00 p.m. - 9:00 p.m.). 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.

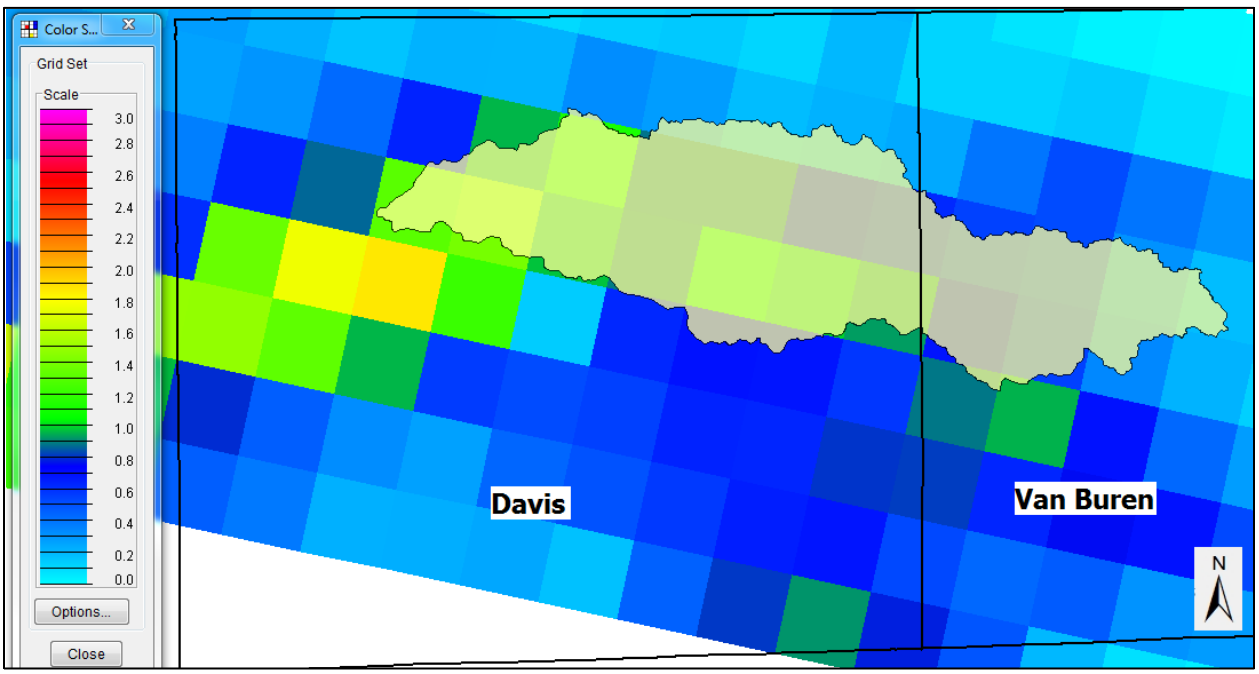


Figure 3.4. Demonstration of the gridded Stage IV radar rainfall product used as the precipitation input for historical storms in the Chequest Creek HMS model. The Stage IV product provides hourly rainfall estimates for each 4 km x 4 km grid cell. The scale shown refers to the depth of rainfall (in inches) estimated for a one hour period.

Use of radar rainfall estimates provides increased accuracy of the spatial and temporal distribution of precipitation over the watershed and Stage IV estimates provide a level of manual quality control 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, or 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 2-, 5-, 10-, 25-, 50-, and 100-year average recurrence interval, 24-hour storms were derived using the online version of NOAA Atlas 14 – Point Precipitation Frequency Estimates (NOAA, 2013). Point estimates were obtained for several locations in the vicinity of the Chequest Creek Watershed and the average resulted in a reasonable value to use watershed-wide for each average recurrence interval.

Studies have been performed on the spatial distribution characteristics of heavy rainstorms in the Midwest (Huff and Angel, 1992). Point precipitation frequency estimates are generally only applicable for drainage areas up to 10 mi^2 before the assumption of spatial uniformity is no longer valid. For drainage areas between 10 and 400 mi^2, 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 the *Rainfall Frequency Atlas of the Midwest* (Huff and Angel, 1992). NOAA does not recommend adjusting point estimates for watersheds much beyond 400 mi^2, as the dependence between the point and areal values breaks down for watersheds larger than this.

For the comparative analyses that were performed in this modeling effort, a single areal reduction factor was determined based on the 124 mi^2 drainage area at the model outlet. It is agreed that this depth of rainfall would not fall uniformly across a watershed this large; however, to have reasonable rainfall depth estimates for the average recurrence interval 24-hour storms in the Chequest Creek Watershed, the point rainfall estimates were reduced by a factor of 0.9375. Table 3.1 summarizes the point precipitation frequency estimates collected at the basin centroid for the 2-, 5-, 10-, 25-, 50-, and 100-year, 24-hour design storms, along with the areal reduced values used for the hypothetical analyses in HMS.

Table 3.1. Rainfall frequency estimates used for hypothetical watershed scenario analyses. The areal reduced values were used in HMS as the cumulative rainfall depths for the 24-hour design storms of different return period.

Hypothetical Storm	*NOAA Point Precipitation (inches)*	*Areal Reduced Precipitation (inches)*
2 year - 24 hour	3.21	3.0
5 year - 24 hour	4.01	3.76
10 year - 24 hour	4.73	4.43
25 year - 24 hour	5.81	5.45
50 year - 24 hour	6.70	6.28
100 year - 24 hour	7.65	7.17

Both the point and areal reduced precipitation estimates 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 mi^2) is applicable.

Watershed (Basin Model)

Topography

Elevation data was obtained from the Iowa Statewide Light Detecting and Ranging (LiDAR) dataset managed by the Iowa Department of Natural Resources. The five blocks of 3-meter resolution digital elevation models (DEMs) covering the extent of the Chequest Creek Watershed were downloaded, clipped to the needed extents using ArcGIS, then joined into a seamless DEM. The Iowa Statewide LiDAR data are distributed in geographic coordinates in units of decimal degrees, 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 Chequest Creek Watershed HMS modeling. The CN serves as a runoff index and typical 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. General guidelines for developing curve numbers based on land use and soil type are available in technical references from the U.S. Department of Agriculture – Natural Resource Conservation Service (USDA-NRCS), previously known as the SCS. The CNs assigned to each land use and soil type combination for the Chequest Creek HMS model are shown in Table 3.2 below.

Table 3.2. Curve Number assignment in the Chequest Creek Watershed based on land use and soil type.

2006 NLCD Code	*Description*	*HSG A*	*HSG B*	*HSG C*	*HSG D*
11	Open Water	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/Scrub	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
90	Woody Wetlands	100	100	100	100
95	Emergent Herbaceous Wetlands	100	100	100	100

For the Chequest Creek Watershed, a CN grid was generated using ESRI ArcGIS with the HEC-GeoHMS extension tools to intersect the 2006 National Land Cover Data Set with digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WSS). In preparing the digital soils data for CN grid development, soils that had been designated as dual code soils (A/D, B/D, and C/D) were assigned as 100% D-type soils due to a lack of agricultural tile drainage location records, as well as some of the dual code soils in the Chequest Creek Watershed occur in areas of timber and along river corridors less likely to have agricultural tile-drainage installed.

Upon completion of producing the CN Grid, HEC-GeoHMS tools were used to perform area-weighted averaging within each subbasin and subsequent assigning a composite CN to each subbasin.

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, when using SCS Curve Number methods to determine runoff volumes, determination of antecedent soil moisture content (AMC) and classification into the antecedent moisture classes AMC I, AMC II, and AMC III, representing dry, average, and wet conditions, is an essential matter for the application of the SCS Curve Number (Silveira et al., 2000) and Curve Numbers may need adjustment to accurately simulate runoff for dryer or wetter than normal conditions.

Runoff Hydrographs
The Clark and ModClark Unit Hydrograph methods were used to convert excess precipitation to a direct runoff hydrograph for each subbasin. The Clark Method was selected to account for the hydrologic impacts of tile drainage. 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 travel time of the excess precipitation to the subbasin outlet and temporary surface 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 hydrograph through a linear reservoir to account for temporary storage effects.

Both the Clark and ModClark 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 at 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. This is a reasonable approximation according to NRCS methodology (Woodward, 2010). Lag time is a function of land slope, longest flow path, and soil retention (represented through CN); these parameters were estimated for each subbasin in ArcGIS tools. 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).

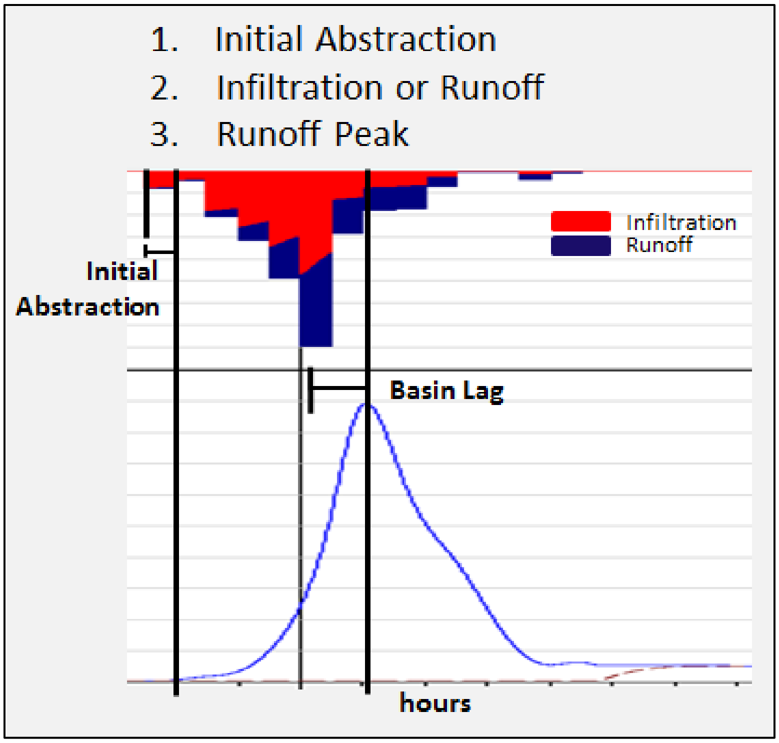


Figure 3.5. Subbasin runoff hydrograph conceptual model. This figure shows how rainfall is partitioned into a runoff depth using the NRCS Curve Number methodology which is then converted to discharge using either the ModClark or Clark unit hydrograph method.

ArcGIS to HEC-HMS

Upon completion of GIS processing to prepare the basin topography data, establish the stream network, delineate the subbasins, and develop/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.

<u>Parameters Assigned in HEC-HMS</u>

Baseflow

Baseflow was estimated using Flow Anywhere and Flow Duration Curve Transfer Statistical Methods developed by the United States Geological Survey (USGS) in cooperation with Iowa Department of Natural Resources (IDNR). The Flow Anywhere statistical method is a variation of the drainage-area-ratio method, which transfers same-day streamflow information from a reference streamgage to another location by using the daily mean streamflow at the reference streamgage and the drainage-area ratio of the two locations (Linhart et al., 2012). The Flow Anywhere method modifies the drainage-area-ratio method in order to regionalize the equations for Iowa and determine the best reference stream gage from which to transfer same-day streamflow information to the ungagged location. According to the USGS report, the Fox River at Wayland, Mo (0549500) gaging station was determined statistically to be best reference gage for estimating flows at ungagged locations in the Chequest Creek Watershed.

Flood Wave Routing

Conveyance of runoff through the river network, or flood wave routing was executed using the Muskingum routing method. Three inputs are required to use the Muskingum routing method in HMS, the flood wave travel time in a reach (K), a weighting factor that describes storage within the reach as the flood wave passes through (X), and the ratio to peak, which describes at what discharge baseflow is once again the dominant source of streamflow after direct runoff ends. The allowable range for the X parameter is between 0 and 0.5. Generally, X ranges between a value of 0.1 and 0.3 for natural streams, with the value of 0.2 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/Maidment/Mays, 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. Ratio to peak can also be first estimated, but generally is best obtained by adjustment in the model calibration process as well.

b. Calibration and Validation

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 gaging station. However, adjustments to parameters shall 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.

As previously mentioned, Chequest Creek does not have instrumentation to determine stream discharges; therefore, a separate HEC-HMS model was completed for the upper portion of the adjacent Fox River to help understand the runoff characteristics of this region of Iowa. This technique is known as indirect calibration.

Calibration of the Fox River HEC-HMS Model

Stage IV radar rainfall estimates and the USGS Fox River at Bloomfield, IA gaging station were used in the Fox River model calibration efforts. Four storms that occurred between June 2008 and May 2013 were selected for calibration. Hydrographs for measured and simulated discharges for these storm events are provided in Appendix C.

Validation of the Fox River HEC-HMS Model

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. The large event that occurred April 17-19, 2013 and another smaller event from April 24-27, 2010 were used for validation. For the April 17-19, 2013 event, the model did well simulating the total runoff volume, but the peak flow was slightly underestimated. For the April 24-27, 2010 event, the HMS model simulated results underestimate the USGS discharge observation, both in magnitude of the peak flow and total runoff volume, even though the CNs were increased by 3.5% to reflect the wetter antecedent moisture conditions. Hydrographs for measured and simulated discharges for these storm events are also provided in Appendix C.

Transferring the Parameters to Chequest Creek

After finalizing the parameters for the Fox River HMS model, the knowledge gained was used to develop the runoff parameters for the Chequest Creek HMS model.

4. Analysis of Watershed Scenarios

The HEC-HMS model of the Chequest Creek was used to identify areas in the watershed with higher runoff potential and run simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed. Focus for the scenarios were placed on understanding the impacts of (1) increasing infiltration in the watershed and (2) implementing a system of distributed storage projects (ponds) across the landscape.

a. 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 Chequest Creek Watershed, the runoff potential for each subbasin is defined by the SCS 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 applied uniformly across the watershed with a total accumulation of 5.45 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 USGS. The smallest hydrologic units, known as HUC12 watersheds, are shown in Figure 4.2 with area-weighted average runoff coefficients determined for each of the four HUC 12 watersheds.

Areas in Chequest Creek with the highest runoff potential are primarily located in the headwater areas located in the Upper Chequest Creek HUC 12, followed by headwater areas located in the South Chequest HUC 12. Runoff coefficients mostly exceed 60% in these areas. Agricultural land use dominates these areas with little forested areas; however, this is not the sole reason they produce higher runoff. While agricultural land uses, including pasture/hay, do generally have higher runoff than forested ground, these areas also have the highest percentage of soils with very low infiltration rates (D-type HSG soils). 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. There are many factors to consider in site selection. Landowner willingness to participate is essential. Locations may have existing conservation practices in place or areas such as timber that should not be disturbed. Stakeholder knowledge of places with repetitive loss of crops or roads/road structures is also valuable in selecting locations. Lastly, the geology of the area may limit the effectiveness or even prohibit application of certain mitigation projects.

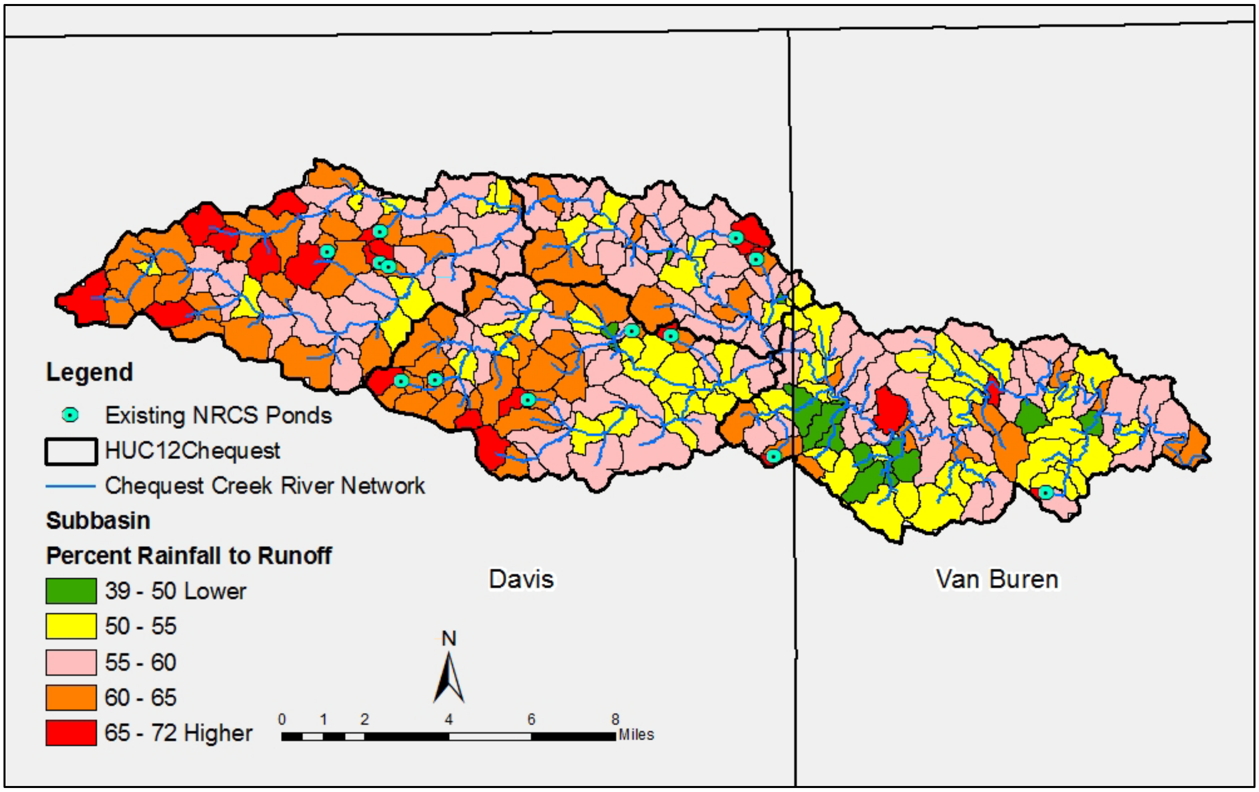


Figure 4.1. Runoff potential in the Chequest Creek Watershed. Runoff coefficients computed for each subbasin for the 25-year, 24-hour storm (5.45 inches of rain) are shown. Higher runoff coefficients are shown in red.

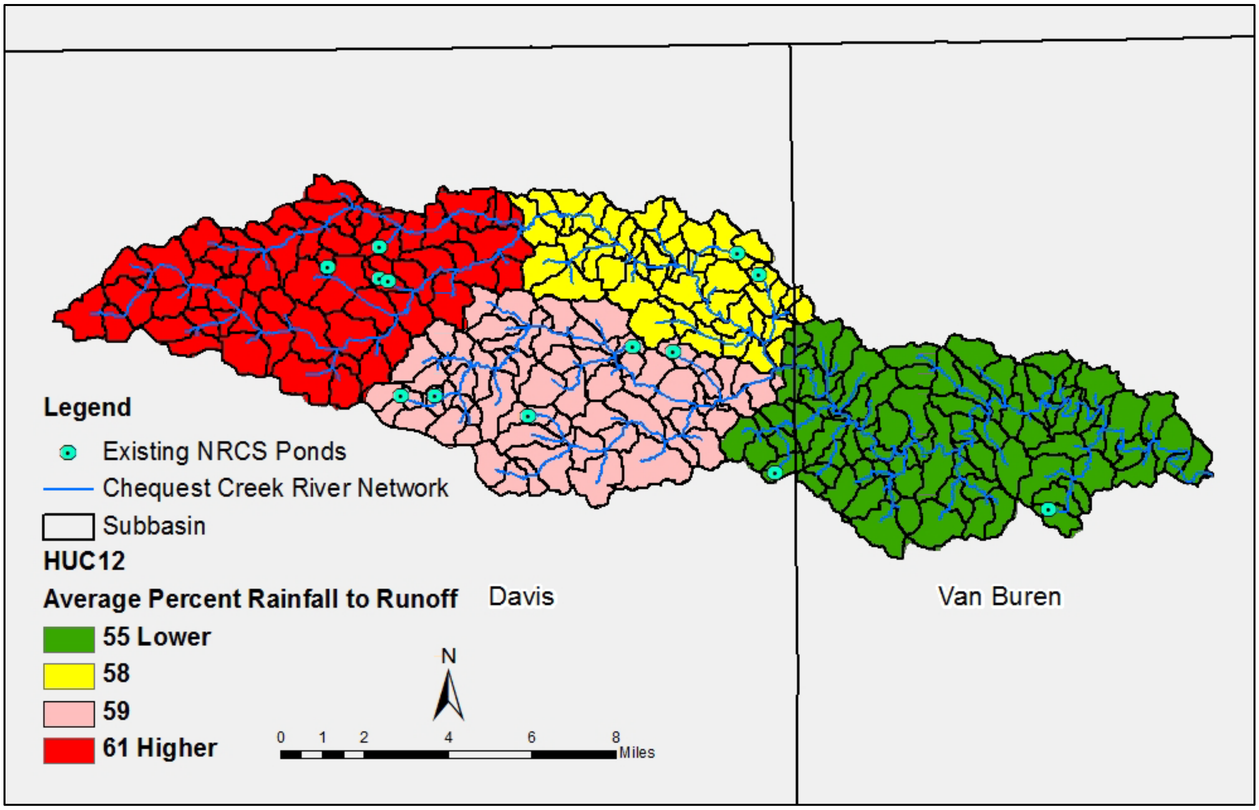


Figure 4.2. Runoff potential in the Chequest Creek Watershed. This figure shows the aggregated runoff coefficient calculated for each HUC 12 watershed for the 25-year, 24-hour storm (5.45 inches of rain).

b. Analysis of Flood Mitigation Strategies

Two potential strategies to lessen the flooding effects of runoff coming from areas identified as having high-runoff potential are to increase the amount of infiltration that occurs during larger precipitation events and construct a system of storage locations throughout the watershed (distributed storage).

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

A system providing distributed storage generally does not change the volume of water that runs off the landscape. Instead, storage ponds (Figure 4.3) hold floodwater temporarily and release it at a slower 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 the rate at which 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.

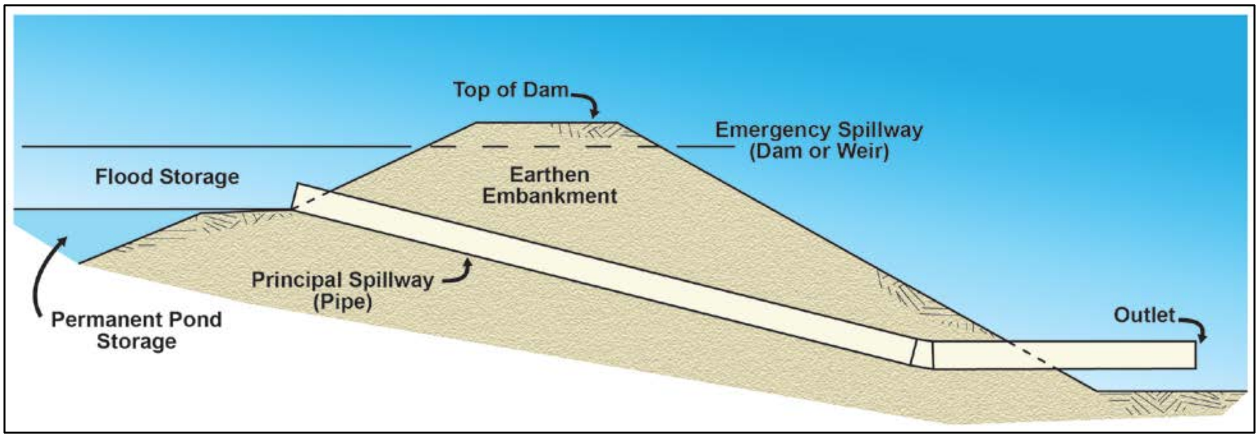


Figure 4.3. Schematic of a pond constructed to provide flood storage.

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

i. Mitigating the Effects of High Runoff with Increased Infiltration

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

Southeast Iowa is known to have higher clay content and low-infiltration soils that drive much of the runoff processes; however, a good portion of this area was once home to tall-grass prairie. Based on the root structure and increased organic material in the soil resulting from having a landscape with these plants, there historically would have been a slightly better infiltration rate and capacity to store water than can currently be found in the watershed.

Subbasins of the Upper Chequest and South Chequest HUC12 that were identified as being primarily agricultural, having D-type soils, and having a runoff coefficient of 55% or greater were selected (Figure 4.4) for the increased infiltration analysis.

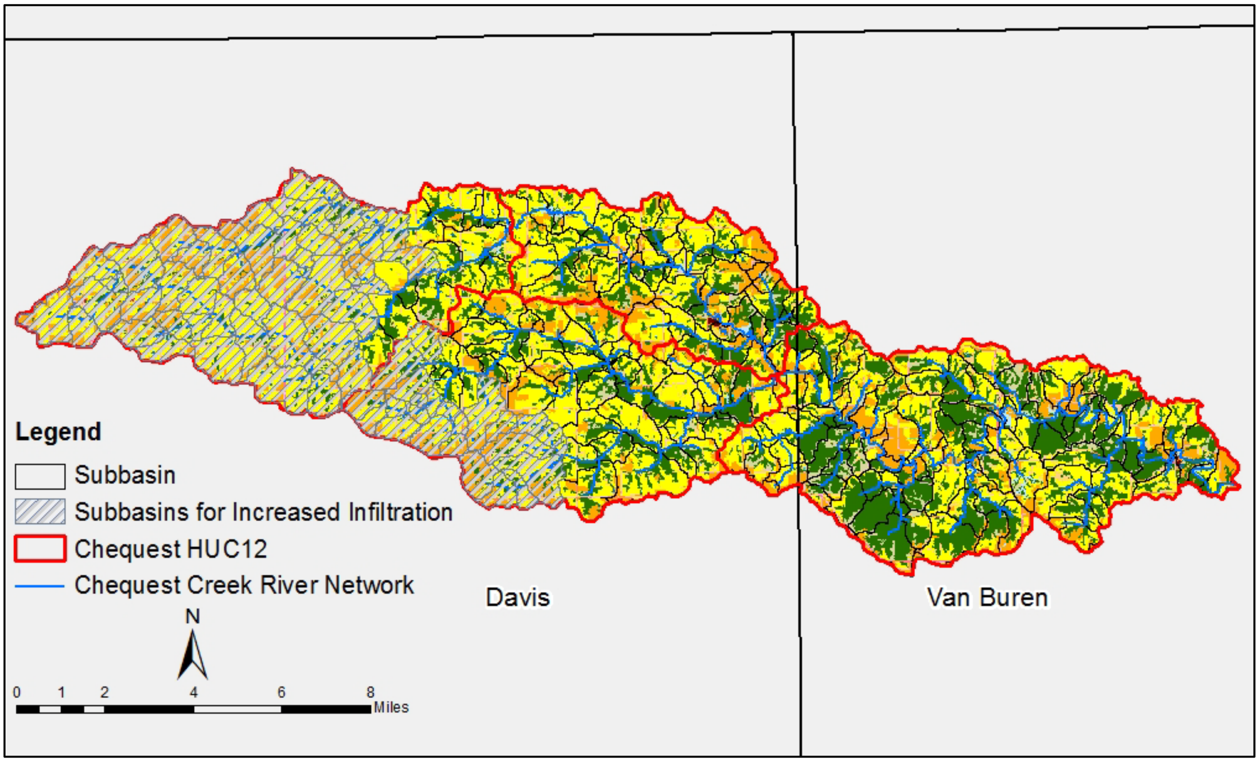


Figure 4.4. Subbasins selected for increased infiltration analysis. Colored background is 2006 NLCD land use (hay/pasture is yellow, forest is green, and row crop agriculture is orange).

Within these subbasins the composite Curve Numbers were adjusted to reflect conditions of looser-packed, higher organic content soils with good plant cover and a contoured landscape. The intent isn't to suggest all the selected land must be reverted back to tall-grass prairie, but rather make soil health improvements and promote terraced conservation practices on the current agricultural lands to promote more infiltration and hold more water across the landscape. A rainstorm was applied uniformly across the watershed; this time with a total accumulation of 6.28 inches in 24 hours (50-year average recurrence interval). In making Curve Number adjustments to the selected subbasins, an additional 0.333 inches of the total rainfall was infiltrated into the ground as compared to the existing conditions.

The effect of increased infiltration in the selected subbasins was evaluated at six reference points (Figure 4.5) within the watershed. Since there are no communities or USGS discharge gaging stations to select as reference points, reference points where located as follows:

1. Defined USGS HUC12 boundary between Upper Chequest/Middle Chequest
2. Defined USGS HUC12 boundary between Middle Chequest/Lower Chequest
3. Defined USGS HUC12 boundary between South Chequest/Lower Chequest
4. Defined USGS HUC12 boundary of Lower Chequest/outlet at Des Moines River)
5. Iowa Flood Center “CHEQ02” stream-stage sensor (upstream of rock quarry)
6. Iowa Flood Center “CHEQ01” stream-stage sensor

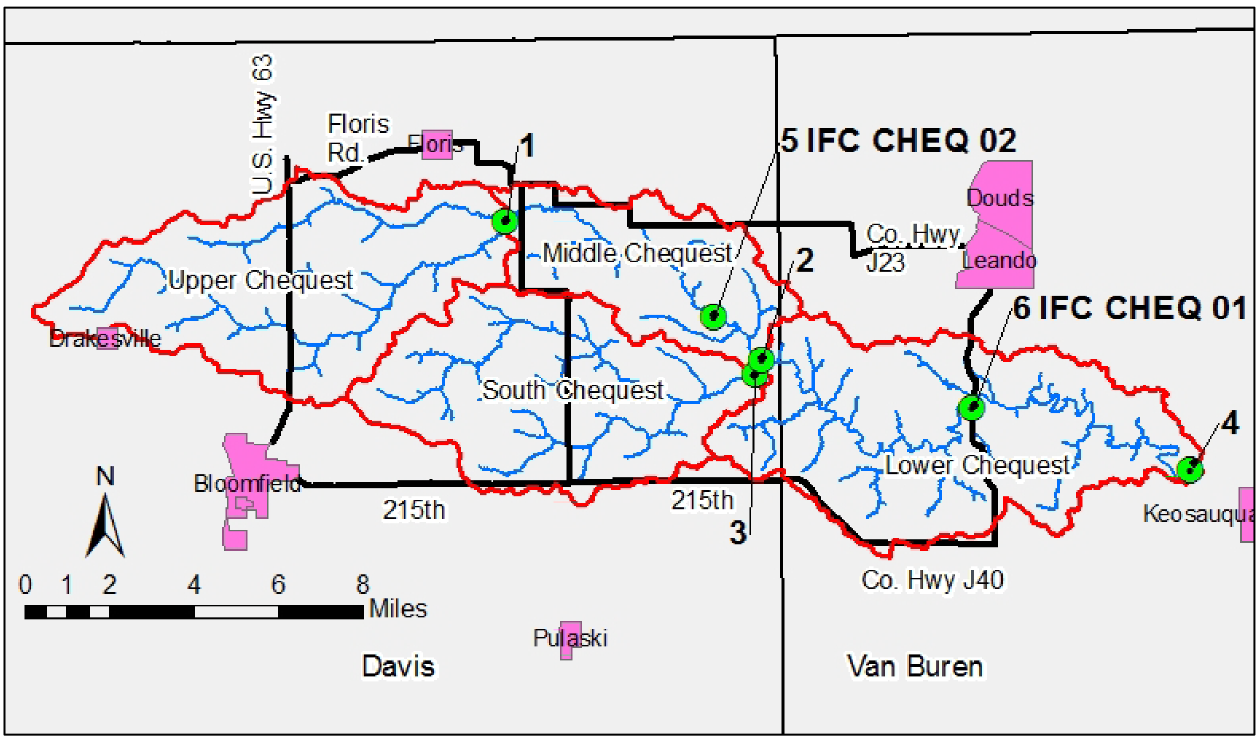


Figure 4.5. Location of the six reference points in the Chequest Creek Watershed.

Increasing infiltration in the selected subbasins produced reductions in peak discharges of 6.7% at Reference Point 1 (Upper Chequest, highest amount of land area with increased infiltration applied) and 3.1% at Reference Point 3. While applying the increased infiltration in just these two HUC12's, the effect of reducing the volume of runoff is observed throughout the watershed, with a 2% reduction in peak discharge at Reference Point 4 (outlet).

ii. Mitigating the Effects of High Runoff with Distributed Storage

The hypothetical distributed storage analysis performed using the Chequest Creek HMS model was based on information from projects in the adjacent Soap Creek Watershed. The Soap Creek Watershed Board formed in the 1980s as a result of landowners coming together to reduce flood damages and erosion within their watershed. They adopted a plan that included identifying the locations of 154 distributed storage structures (mainly ponds) to be built in the watershed. As of 2014, 132 of these structures are built.

The Soap Creek Watershed drains approximately 250 mi^2, equaling an average density of 1 built pond for approximately 2 mi^2 of drainage area. Further analysis of the Soap Creek structures shows that most were constructed as small structures in the headwater areas rather than large, high-hazard class structures on the main creek channel. When looking at the ponds in each HUC 12 within the Soap Creek Watershed (See Figure 4.6), pond density ranged from 1 pond per 0.8 mi^2 in the western portion of the watershed to 1 pond per 5.4 mi^2 in the middle of the watershed. The western portion of South Soap Creek has no constructed ponds in the draining area to Lake Sundown and in Middle Soap Creek there are no constructed ponds in the draining area to Lake Wapello. The average pond density in the headwater areas where the majority of the ponds have been constructed is approximately 1 pond per 1.4 mi^2.

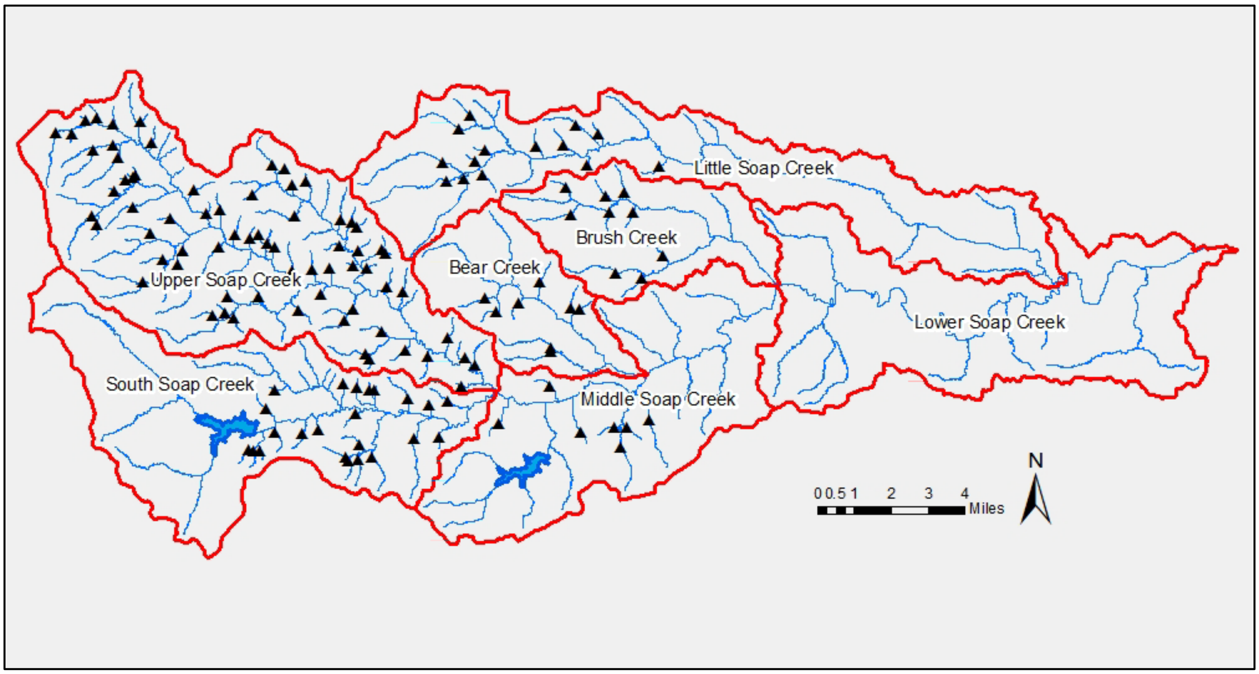


Figure 4.6. Pond placement in the Soap Creek Watershed. A total of 132 ponds were constructed between 1992 and 2014.

For the Chequest Creek hypothetical distributed storage simulation, pond structures were only placed in headwater subbasins of the HMS model but distributed throughout the watershed. Fifty five (55) headwater subbasins were selected for analysis, ranging in size from approximately 0.4 to 1.5 mi^2, with an average size of 0.7 mi^2. This resulted in a pond density of 1 pond for every 2.25 mi^2 of drainage area mitigating runoff from approximately 31% of the total Chequest Creek Watershed area. See Figure 4.7 for the subbasins (colored bright purple) identified to have pond flood storage incorporated into the distributed storage simulation.

There certainly are opportunities to design and construct ponds at locations in subbasins that have not been identified in this analysis, as well as some identified may not work for ponds. The analysis is meant to provide a glimpse of the potential impact of a distributed storage system in the watershed.

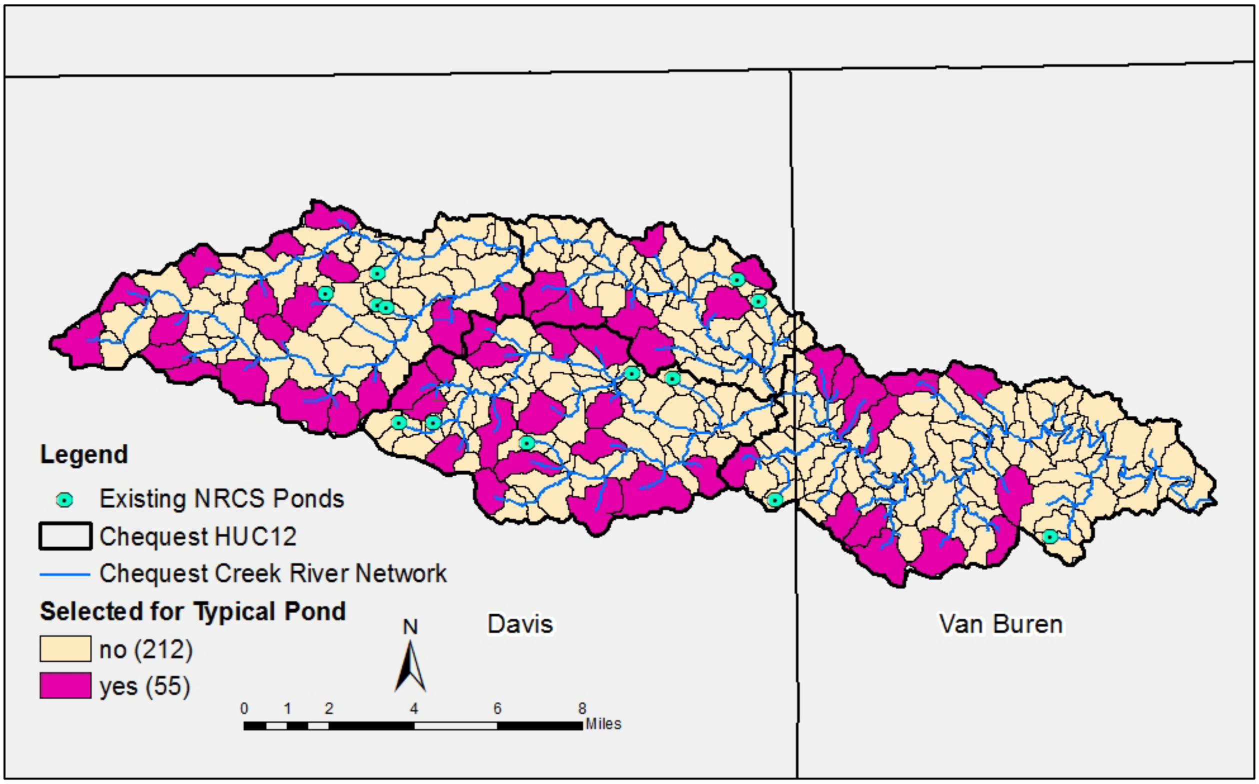


Figure 4.7. Headwater subbasins identified to have pond structures incorporated into the hypothetical distributed storage simulation.

For the analysis, a “typical” pond was developed for use in the Chequest Creek Watershed using the existing Soap Creek ponds and NRCS Technical References as guidance. The geometry of a “typical” pond consists of a 12-inch pipe outlet as the principal spillway with a 20-foot wide emergency spillway set at an elevation 5-foot above the pipe spillway. The top of the dam is then set 2-foot above the emergency spillway. Site topography will actually dictate the placement of the emergency spillway and the potential dam height. The stage-storage relationship of a pond also depends on local topography and is highly variable from site to site. The stage-storage relationship for the “typical” pond was developed by finding the average stage-storage values from all Soap Creek ponds that have a drainage area of 0.125 - 1.5 mi^2 (80 - 960 acres, 96 of 132 existing ponds). This relationship is representative of a pond with a permanent storage surface area of approximately 2-3 acres.

The stage-discharge relationship was determined from pipe flow calculations based on the elevation of stored water over the pipe spillway up until the activation of the emergency spillway. A combined outflow of pipe flow and flow through the emergency spillway was used. Discharge of the emergency spillway was determined using NRCS Technical References assuming C-Type retardance on the spillway.

Each subbasin identified for pond placement had one “typical” pond applied at that subbasin’s outlet. The “typical” pond stage-storage-discharge table is shown below. Additional information and can be found in Appendix B.

Table 4.1. Stage-Storage-Discharge relationship of the “typical” pond developed for the Chequest Creek hypothetical distributed storage simulation.

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	3.1	2.2	0	2.2
2	8.9	11.1	0	11.1
3	15.8	11.5	0	11.5
4	22.8	11.9	0	11.9
5 *Emergency Spillway*	30.9	12.3	0	12.3
5.5	35.2	12.5	14.0	26.5
6	40.2	12.6	40.0	52.6
6.5	44.5	12.8	80.0	92.8
7 *Top of Dam*	50.0	13.0	140.0	153
7.5	54.6	13.2	448.1	461.3
8	59.4	13.4	609.1	622.5
9	71.5	13.8	1,099.7	1,113.5

The effect of distributed storage was evaluated at the same six reference points used for the increased infiltration simulation (Figure 4.5). As anticipated, as you move further downstream in the watershed and a lesser percentage of the total area drains to a pond, the percent reduction of peak discharge decreases. However, this simulation applied 6.28 inches of rainfall (50-year average recurrence interval) in 24 hours over the entire watershed at once. This rainfall scenario is much less likely as the drainage area increases beyond the HUC 12 scale. Yet, even when applying rainfall volumes at an extreme rate, reduction in peak discharge was observed at all locations.

Reductions in simulated peak discharge from distributed storage in Chequest Creek were significantly greater than those from increased infiltration. Table 4.2 shows the simulated discharges and the reductions in peak discharges at the six locations.

Table 4.2. Peak discharge reduction at six reference points from current conditions to the hypothetical typical pond scenario using the 50 year – 24 hour storm (6.28 inches of rain in 24 hours).

Location	*Drainage area (sq. mi.)*	*# subbasins upstream with ponds*	*# of ponds*	*Peak Discharge: No ponds (cfs)*	*Peak Discharge: With ponds (cfs)*	*Peak discharge reduction*
Reference Point 1: Upper Chequest	34.8	18	18	10,106	7,984	21.0%
Reference Point 5: IFC CHEQ02	47.8	24	24	11,850	9,640	18.6%
Reference Point 2: Middle Chequest	53.2	25	25	12,323	10,095	18.1%
Reference Point 3: South Chequest	31.4	17	17	9,046	7,210	20.3%
Reference Point 6: IFC CHEQ01	106.3	52	52	20,197	17,962	11.1%
Reference Point 4: Lower Chequest (Outlet)	123.4	55	55	21,408	19,078	10.9%

Figure 4.8 shows the simulated with and without typical ponds hydrographs for Reference Point 1 (Upper Chequest HUC12) with a 21.0% reduction in peak discharge. Figure 4.9 shows the hydrographs for Reference Point 2 (Middle Chequest HUC12) with an 18.1% reduction in peak discharge. Figure 4.10 shows the hydrographs for Reference Point 6 (IFC CHEQ01) with an 11.1% reduction in peak discharge. With using the SCS Type-II design storm, the basin response is primarily driven by the largest hourly pulse of rain (2.7" in this case) that is applied at hour 12.

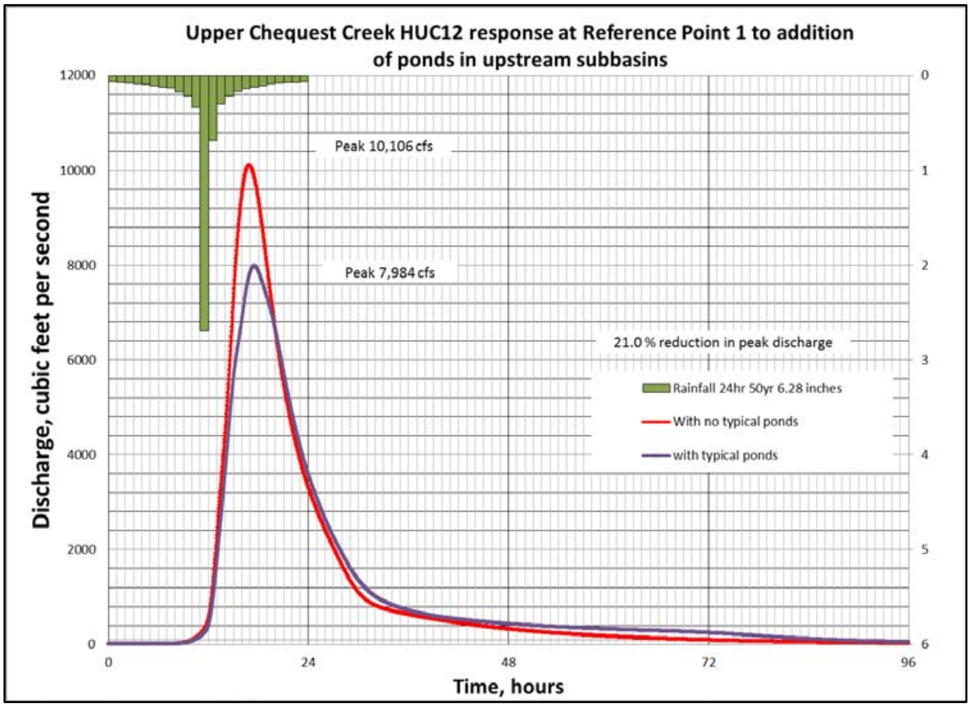


Figure 4.8. Hydrograph comparison for Chequest Creek at Reference Point 1 (Upper Chequest) with current conditions and the "typical" pond distributed storage scenario. Results are shown for the 50-year, 24-hour storm (6.28 inches of rain in 24 hours).

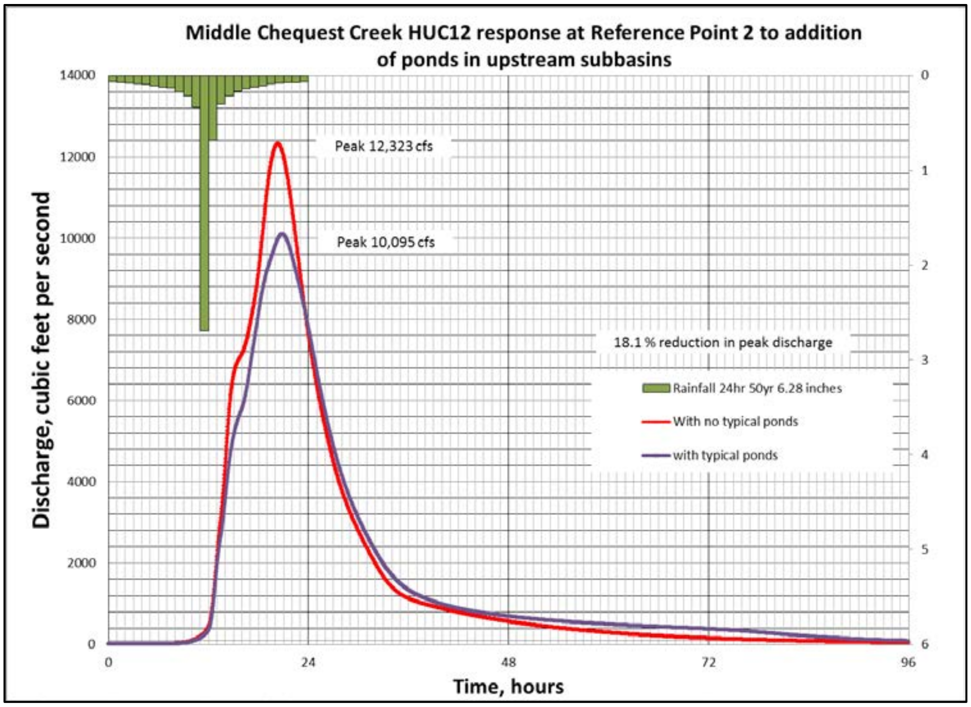


Figure 4.9. Hydrograph comparison for Chequest Creek at Reference Point 2 (Middle Chequest) with current conditions and the "typical" pond distributed storage scenario. Results are shown for the 50-year, 24-hour storm (6.28 inches of rain in 24 hours).

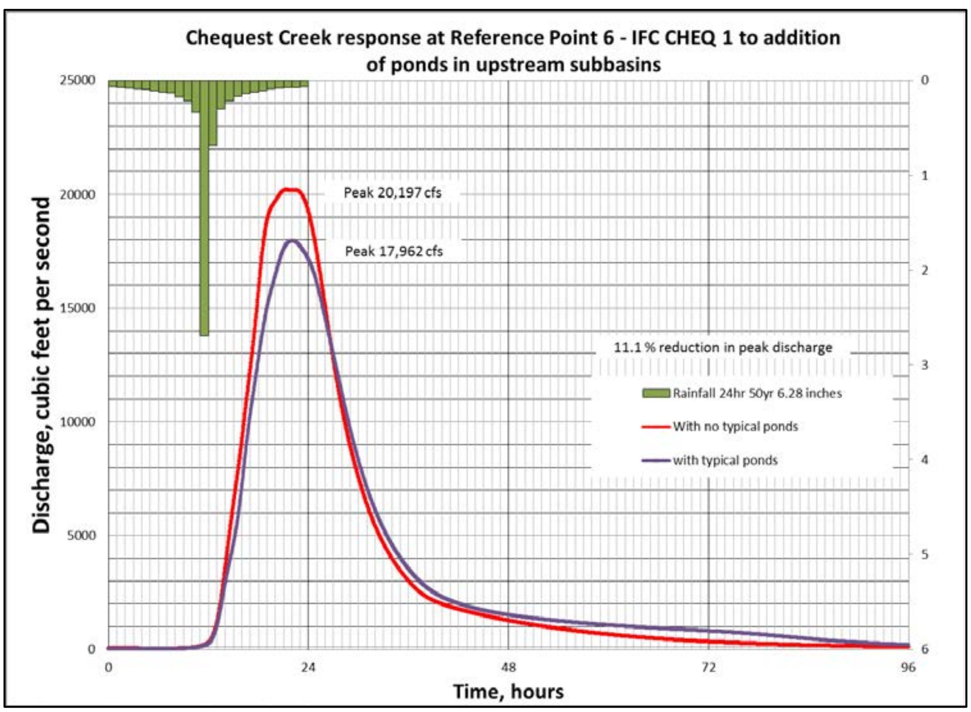


Figure 4.10. Hydrograph comparison for Chequest Creek at Reference Point 6 (IFC CHEQ01 Stream-Stage Sensor) with current conditions and the "typical" pond distributed storage scenario. Results are shown for the 50-year, 24-hour storm (6.28 inches of rain in 24 hours).

One can ask how might the hypothetical distributed storage scheme effect flood peaks from actual storm events. The answer is that the percent reduction in peak discharge depends on the location, rainfall amount, rainfall intensity, and timing of the rain storm. To pick a recent storm that caused significant flooding the watershed, the April 17-18, 2013 storm was applied to the "typical" ponds scenario and the baseline (no ponds) to assess the distributed storage system's performance.

The April 2013 storm was characterized by the entire Chequest Creek Watershed receiving more than three inches of rain during a 25 hour period with heavier rain falling in the upper portions of the watershed. The following rainfall estimates for each HUC 12 help describe the rainfall distribution. The Upper Chequest HUC 12 received the heaviest rainfall, ranging from 4.7-5.2 inches. South and Middle Chequest received approximately 3.6-4.0 inches of rain, and Lower Chequest ranged from 3.2-3.6 inches.

Unlike the concept of an SCS Type-II 24-hour design storm where rainfall starts out light, ramps up to having the majority of rain over a short time period in the middle of the storm, then tailing off, the April 2013 rainfall came from a series of short-duration, high-intensity thunderstorms repeatedly tracking over the same area. Figure 4.11 shows the simulated with and without ponds hydrographs for Reference Point 1 (Upper Chequest HUC 12) with an 11.0% reduction in peak discharge. As shown in Figure 4.11 which shows the rainfall applied to one subbasin in the Upper Chequest HUC 12 for this event, larger rain pulses came every few hours, with only one hour's rainfall exceeding 0.5 inches.

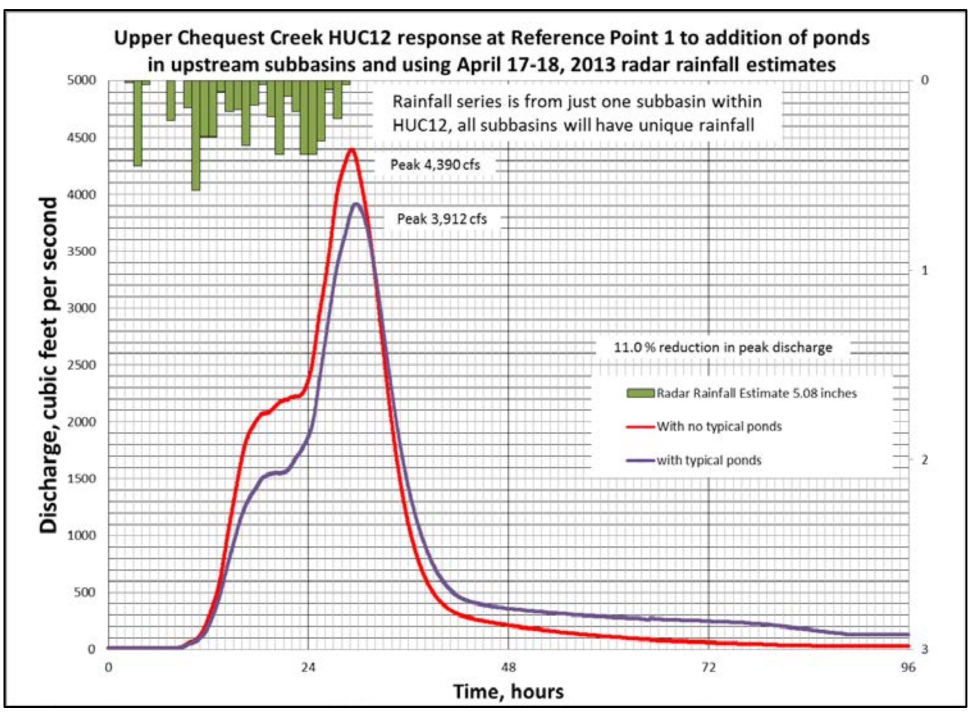


Figure 4.11. Hydrograph comparison for Chequest Creek at Reference Point 1 (Upper Chequest) with current conditions and the "typical" pond distributed storage scenario. Results are shown using the April 17-18, 2013 radar rainfall estimates. The rainfall series is from just one subbasin within the HUC12 (5.08 inches of rain in 25 hours).

Reference Point 2 (Middle Chequest HUC12), experienced a slight increase in the amount reduction in peak discharge to 13.2%, as the ponds in Middle Chequest were able to control additional rainfall. Reference Point 6 (IFC CHEQ01) in the Lower Chequest HUC 12 realized a 17.4% reduction in peak discharge which was obtained from both upstream benefit and detained locally in the additional ponds distributed in Lower Chequest HUC 12 subbasins.

Table 4.3. Peak discharge reduction at six reference points from current conditions to the hypothetical typical ponds scenario using the April 17-18, 2013 radar rainfall estimates.

Location	*Drainage area (sq. mi.)*	*# subbasins upstream with ponds*	*# of ponds*	*Peak Discharge no ponds (cfs)*	*Peak Discharge with ponds (cfs)*	*Peak discharge reduction*
Reference Point 1: Upper Chequest	34.8	18	18	4,396	3,912	11.0%
Reference Point 5: IFC CHEQ 2	47.8	24	24	5,166	4,516	12.6%
Reference Point 2: Middle Chequest	53.2	25	25	5,357	4,650	13.2%
Reference Point 3: South Chequest	31.4	17	17	2,910	2,179	25.1%
Reference Point 6: IFC CHEQ 1	106.3	52	52	8,852	7,313	17.4%
Reference Point 4: Lower Chequest (Outlet)	123.4	55	55	9,121	7,534	17.4%

If the hypothetical pond distributed throughout the Chequest Creek Watershed could replicate a stage-storage relationship developed based only on larger Soap Creek ponds, those with drainage areas of 0.5-1.5 mi^2 (320-960 acres), the flood storage provided in each pond could be increased by approximately 36%. This would likely increase the permanent storage surface area of the ponds to 4-5 acres. The stage-storage-discharge relationship is shown in Table 4.4.

Table 4.4. Stage-storage-discharge relationship for larger hypothetical ponds based on 0.5-1.5 mi^2 drainage areas.

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	6.1	2.2	0	2.2
2	14.9	11.1	0	11.1
3	25.2	11.5	0	11.5
4	36.4	11.9	0	11.9
5 *Emergency Spillway*	48.6	12.3	0	12.3
5.5	55.6	12.5	14.0	26.5
6	62.9	12.6	40.0	52.6
6.5	70.3	12.8	80.0	92.8
7 *Top of Dam*	77.7	13.0	140.0	153
7.5	85.4	13.2	448.1	461.3
8	93.1	13.4	609.1	622.5
9	101.76	13.8	1099.7	1113.5

The following table, Table 4.5, shows the same reference points as Table 4.2, however with the potential influence of the larger hypothetical ponds distributed in place of the smaller "typical" pond when using the 50-year, 24-hour storm (6.28 inches of rain in 24 hours).

Table 4.5. Peak discharge reduction at six reference points from current conditions to the larger hypothetical typical pond scenario using the 50 year – 24 hour storm (6.28 inches of rain in 24 hours).

Location	*Drainage area (sq. mi.)*	*# subbasins upstream with pond*	*# of ponds*	*Peak Discharge no ponds (cfs)*	*Peak Discharge with ponds (cfs)*	*Peak discharge reduction*
Reference Point 1: Upper Chequest	34.8	18	18	10,106	7,002	30.7%
Reference Point 5: IFC CHEQ02	47.8	24	24	11,850	8,725	26.4%
Reference Point 2: Middle Chequest	53.2	25	25	12,323	9,212	25.2%
Reference Point 3: South Chequest	31.4	17	17	9,046	6,303	30.3%
Reference Point 6: IFC CHEQ01	106.3	52	52	20,197	16,500	18.3%
Reference Point 4: Lower Chequest (Outlet)	123.4	55	55	21,408	17,588	17.8%

Figure 4.12 shows the simulated with and without ponds hydrographs for Reference Point 1 (Upper Chequest HUC 12) with a 30.7% reduction in peak discharge. Figure 4.13 shows the hydrographs for Reference Point 2 (Middle Chequest HUC12) with a 25.2% reduction in peak discharge. Figure 4.14 shows the hydrographs for Reference Point 6 (IFC CHEQ01). Once again, with using the SCS Type-II design storm, the basin response is primarily driven by the largest hourly pulse of rain (2.7" in this case) that is applied at hour 12.

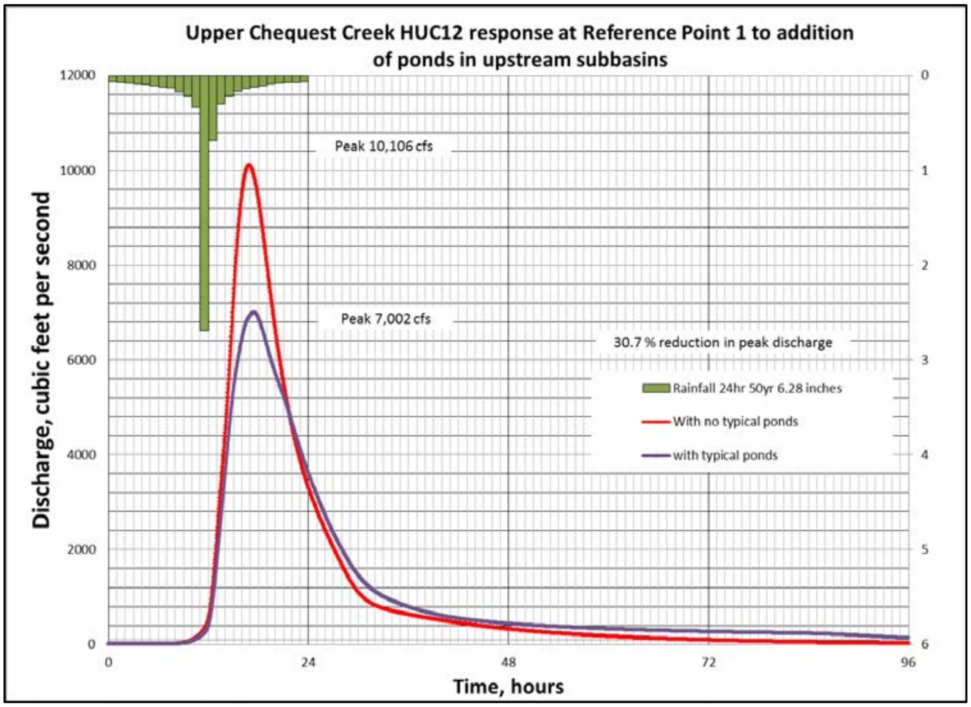


Figure 4.12. Hydrograph comparison for Chequest Creek at Reference Point 1 (Upper Chequest) with current conditions and the larger hypothetical distributed storage ponds scenario. Results are shown for the 50-year, 24-hour storm (6.28 inches of rain in 24 hours).

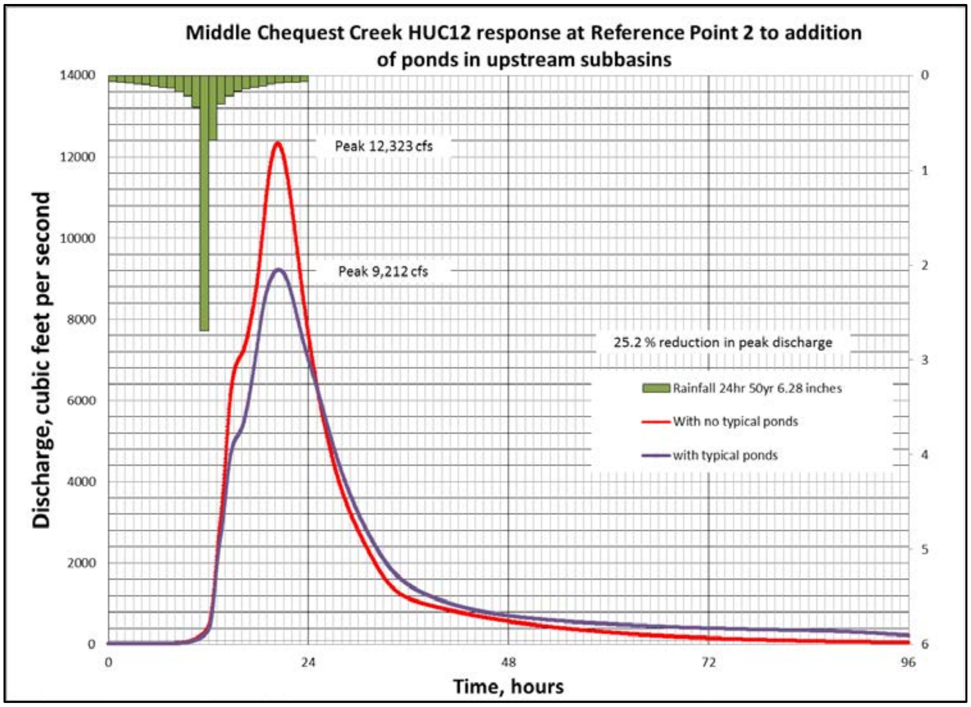


Figure 4.13. Hydrograph comparison for Chequest Creek at Reference Point 2 (Middle Chequest) with current conditions and the larger hypothetical distributed storage ponds scenario. Results are shown for the 50-year, 24-hour storm (6.28 inches of rain in 24 hours).

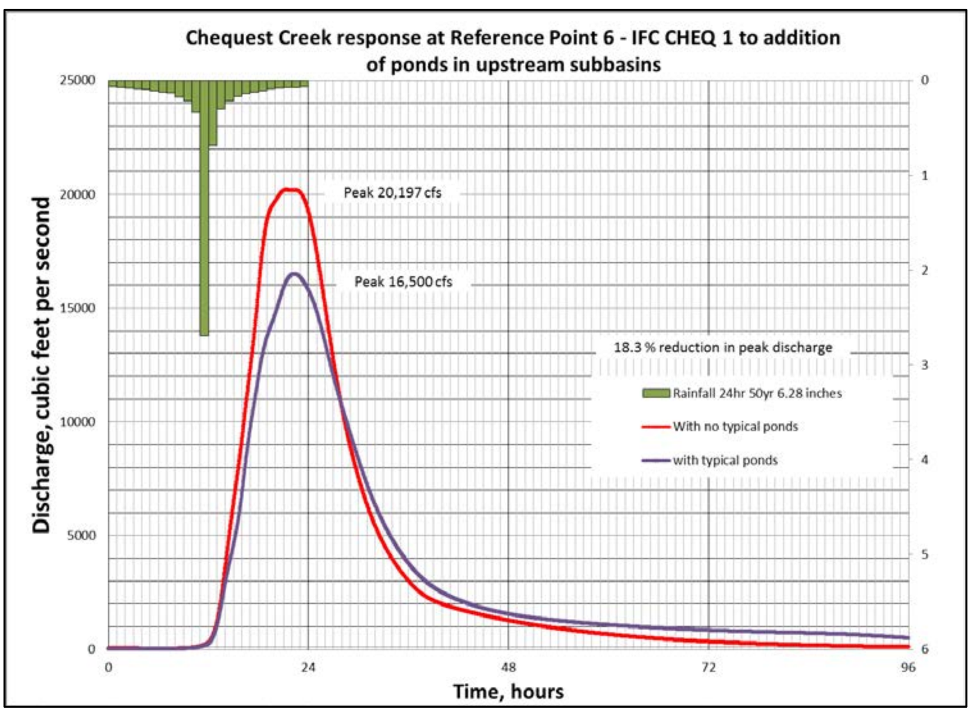


Figure 4.14. Hydrograph comparison for Chequest Creek at Reference Point 6 (IFC CHEQ01 Stream-Stage Sensor) with current conditions and the larger hypothetical distributed storage ponds scenario. Results are shown for the 50-year, 24-hour storm (6.28 inches of rain in 24 hours).

Lastly, the April 17-18, 2013 storm was applied to the with and without larger hypothetical ponds scenarios to assess the hypothetical distributed storage's performance. Figure 4.15 again shows the rainfall that was applied to one subbasin in the Upper Chequest HUC12 and the resulting hydrographs.

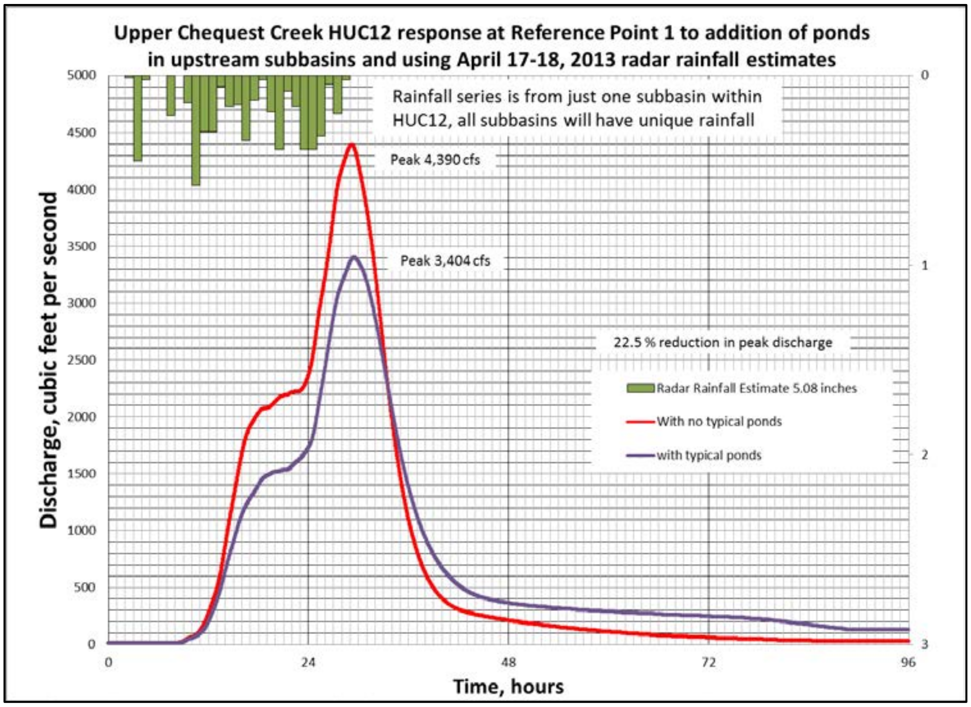


Figure 4.15. Hydrograph comparison for Chequest Creek at Reference Point 1 (Upper Chequest) with current conditions and the hypothetical distributed storage scenario. Results are shown from using the April 17-18, 2013 radar rainfall estimates. The rainfall series is from just one subbasin within the HUC12 (5.08 inches of rain in 25 hours).

Table 4.6 shows the simulated discharges and the reductions in peak discharges at the six locations for the April 2013 flooding event with larger hypothetical ponds distributed across the watershed.

Table 4.6. Percent reduction in peak discharge by location from current conditions to the larger hypothetical ponds scenario using the April 17-18, 2013 radar rainfall estimates.

Location	*Drainage Area (sq. mi.)*	*# subbasins upstream with pond*	*# of ponds*	*Peak Discharge no ponds (cfs)*	*Peak Discharge with ponds (cfs)*	*Peak discharge reduction*
Reference Point 1: Upper Chequest	34.8	18	18	4,396	3,404	22.5%
Reference Point 5: IFC CHEQ02	47.8	24	24	5,166	3,927	24.0%
Reference Point 2: Middle Chequest	53.2	25	25	5,357	4,078	23.9%
Reference Point 3: South Chequest	31.4	17	17	2,910	1,974	32.2%
Reference Point 6: IFC CHEQ01	106.3	52	52	8,852	6,458	27.0%
Reference Point 4: Lower Chequest (Outlet)	123.4	55	55	9,121	6,702	26.5%

When the “typical” pond stage-storage-discharge relationship is used in the distributed storage simulation, there is an estimated reduction in peak discharge at all of the reference points. Additionally, there was a significant increase in the peak discharge reduction when switching to the larger pond stage-storage-discharge relationship.

5. Summary and Conclusions

This hydrologic assessment of the Chequest Creek Watershed is part of the Iowa Watersheds Project, a project being undertaken in four Iowa watersheds by the Iowa Flood Center located at IIHR—Hydroscience & Engineering at the University of Iowa. The assessment is meant to provide an understanding of the hydrology – or movement of water – within the watershed and the potential of various hypothetical flood mitigation strategies.

a. Chequest Creek Water Cycle and Watershed Conditions

The water cycle of the Chequest Creek Watershed was examined using historical precipitation and streamflow records (adjacent Fox River streamflow records used). The average annual precipitation for the Chequest Creek Watershed is 38.8 inches. Of this precipitation amount, 69.2% (26.8 inches) evaporates back into the atmosphere and the remaining 30.8% (12 inches) runs off the landscape into the streams and rivers. The majority of the runoff amount occurs as surface flow (62.1% or 7.45 inches), and the rest occurs as baseflow (37.9% or 4.55 inches). The Soap and Chequest (Fox) Watersheds are the only watersheds in the Iowa Watersheds Project that have higher surface flow than baseflow, this is a result of the soil type and the landform region of southeast Iowa. Average monthly streamflow peaks in May, and decreases slowly through the summer growing season. For this area, annual maximum streamflows are evenly distributed through the year; as noted earlier, this river is surface flow dominated, and whenever heavy rainfall occurs during the year, large river flows can occur. Still, the largest floods on record tend to occur in the summer season.

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

The Chequest Creek Watershed is located within the Southern Iowa Drift Plain. This region is dominated by glacial deposits left by ice sheets that extended south into Missouri over 500,000 years ago. The deposits were carved by deepening episodes of stream erosion so that only a horizon line of hill summits marks the once-continuous glacial plain. Numerous rills, creeks, and rivers branch out across the landscape shaping the old glacial deposits into steeply rolling hills and valleys. A mantle of loess drapes the uplands and upper hill slopes (Iowa Geological & Water Survey, The Iowa Department of Natural Resources, 2014).

b. Chequest Creek Hydrologic Model

The U.S. Army Corp of Engineers' (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was used to develop a flood prediction model for the Chequest Creek Watershed. First, the watershed was divided into 267 subbasins with an average area of 0.5 mi^2. An indirect model calibration method was used for the Chequest Creek Watershed, using the adjacent Fox River Watershed as the donor watershed due to no discharge gaging stations within Chequest Creek. Model calibration and validation was completed using actual (historical) rainfall events, with radar rainfall estimates used as the precipitation input for simulation. For the analysis of watershed scenarios, 24-hour duration design storms (an NRCS Type-II distribution) with rainfall accumulations equal to the 25- and 50-year return period basin-average depths were used as the precipitation input.

The SCS Curve Number (CN) methodology was used to determine the rainfall-runoff partitioning in the HMS model. The CN method accounts for precipitation losses due to initial abstractions and infiltration during the rainstorm. CN values are estimated based on land use and underlying soil type, and the areal-weighted average CN is assigned to each subbasin as an initial parameter estimate. The Clark Unit Hydrograph method was used to convert excess precipitation into a direct runoff hydrograph for each subbasin. Baseflow was estimated using Flow Anywhere and Flow Duration Curve Transfer Statistical Methods developed by the United States Geological Survey (USGS) in cooperation with Iowa Department of Natural Resources (IDNR). The Flow Anywhere statistical method is a variation of the drainage-area-ratio method, which transfers same-day streamflow information from a reference streamgage to another location by using the daily mean streamflow at the reference streamgage and the drainage-area ratio of the two locations (Linhart et al., 2012). The Flow Anywhere method modifies the drainage-area-ratio method in order to regionalize the equations for Iowa and determine the best reference streamgage from which to transfer same-day streamflow information to the ungagged location. According to the USGS report, the Fox River at Wayland, Mo (0549500) gaging station was determined statistically to be best reference gage for estimating flows at ungagged locations in the Chequest Creek Watershed. Lastly, conveyance of runoff through the river network, or flood wave routing, was executed using the Muskingum routing method.

c. Watershed Scenarios for the Chequest Creek Watershed

To better understand the flood hydrology of the Chequest Creek Watershed and to evaluate potential flood mitigation strategies, the HEC-HMS model of the watershed was used in several ways. Runoff potential was assessed throughout the basin using the HMS model's representation of storm runoff generation from the landscape. Locations with agricultural land use (mainly pasture/hay) and low-infiltration soils have the highest runoff potential and might serve as the primary target areas for flood mitigation planning.

To quantify the potential effects of flood mitigation strategies, the HEC-HMS model was used to simulate river flows throughout the Chequest Creek Watershed. Two strategies are considered — increasing infiltration and storing floodwaters temporarily in ponds throughout the watershed to reduce downstream discharges. The effects of these strategies were simulated for significant design flood events — those resulting from a 50-year average recurrence interval 24-hour design rainfall. This event corresponds to rainfall of 6.28 inches in 24 hours over the entire watershed. The results for these strategies were compared to simulations of flows for the existing watershed condition. Although each scenario simulated is hypothetical and simplified, the results provide valuable insights on the relative performance of each strategy for flood mitigation planning. Additional analyses were performed using radar rainfall estimates of recent storms that caused significant flooding in the watershed.

i. Increased Infiltration in the Watershed

Much has been documented about the historical hydrology of the native tall-grass prairie, with evidence suggesting the tall-grass prairie could handle up to six inches of rain without having significant runoff. This is a result of the deep, loosely-packed, organic-rich soils and the deep root systems of the prairie plants that allowed a high volume of the rainfall to infiltrate into the ground. Southeast Iowa is known to have higher-clay content, lower-infiltration soils that drive much of the runoff processes in the Chequest Creek Watershed; however, a good portion of this area was once home to tall-grass prairie. Based on the root structure and increased organic material in the soil resulting from a landscape with these plants, there would have been slightly better infiltration rates and a capacity to hold more water than what can be found in the watershed today.

The subbasins of the Upper Chequest Creek HUC 12 and the subbasins in the headwater region of the South Chequest HUC 12 that were identified as being primarily agricultural with little timber on D-type soils and having a runoff coefficient of 55% or greater were selected to simulate increased infiltration. The intent isn't to suggest all the selected land be converted back to tall-grass prairie, but rather make soil health improvements and promote terraced conservation practices on the current agricultural lands to promote more infiltration and hold more water on the landscape.

Increasing infiltration in the selected subbasins produced reductions in peak discharges of 6.7% in a headwaters HUC12 (Reference Point 1, Upper Chequest) and 3.1% at a point further downstream (Reference Point 3). While applying the increased infiltration in just these 2 HUC 12s, the effect of reducing the volume of runoff is observed throughout the watershed, with a 2% reduction in peak discharge at the Chequest Creek outlet (Reference Point 4).

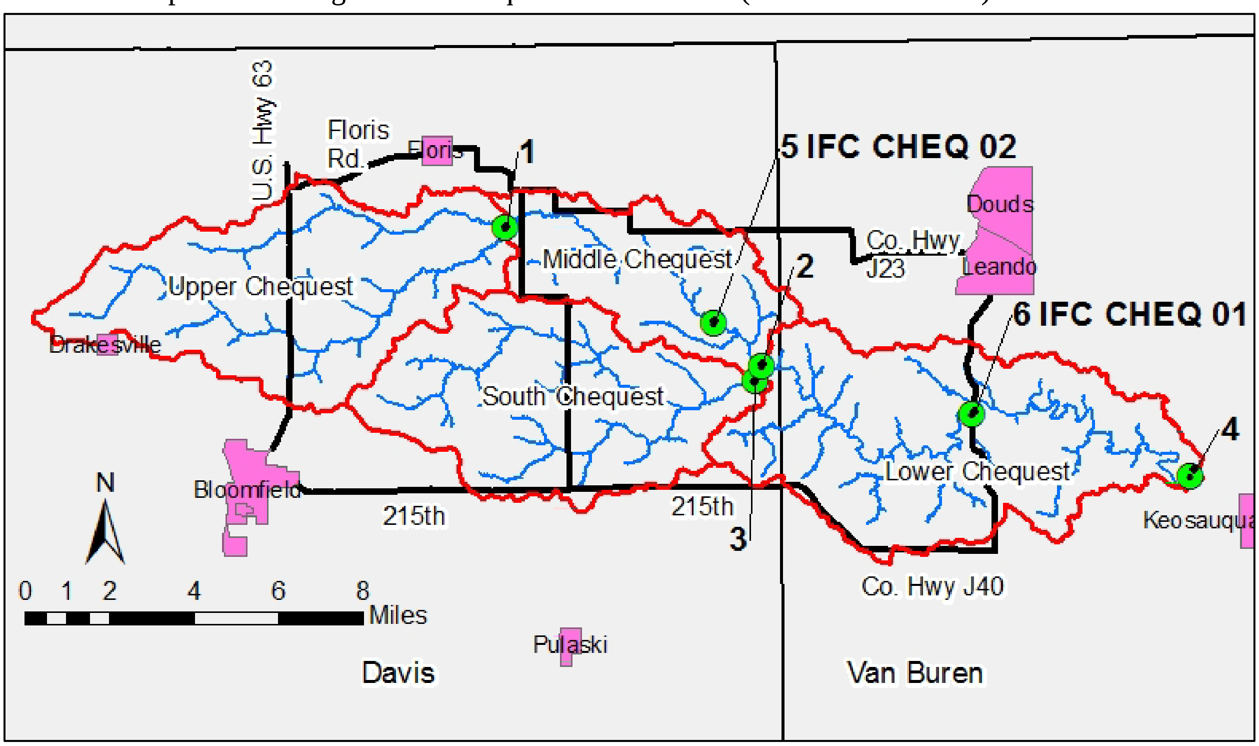


Figure 5.1. Location of the six reference points in the Chequest Creek Watershed.

ii. Increased Storage on the Landscape

In some ways, using ponds to temporarily store floodwaters is an attempt to replace the loss of water that was once stored in the soils in the pre-agricultural landscape. In the hypothetical scenario a "typical" pond was incorporated into the HEC-HMS model and when using a SCS Type-II 50-year 24-hour design storm, simulated peak discharge reductions ranged from 21% in the upper portion of the Chequest Creek Watershed to roughly 11% at the outlet. This approach does however apply the rainfall uniformly across the entire watershed at the same time, which generally does not occur as the area becomes larger. Thus, applying radar rainfall estimates from previous storms can help overcome this when trying to analyze the potential benefits of a hypothetical distributed storage scheme.

However, the percent of reduction realized in peak discharge is going to depend on the location, rainfall amount, rainfall intensity, and timing of the rain storm. Each storm is going to be somewhat different. Applying the radar rainfall estimates for April 17-18, 2013 led to simulated peak flood reduction of 11% in the upper portion of the Chequest Creek Watershed (Upper Chequest HUC12) receiving the most rainfall and approximately 25% reduction in the upper portion (South Chequest HUC12) that didn't receive as much rain. The simulated reduction of peak discharge at the model's outlet at the Des Moines River was 17.4%.

Both the 50-year 24-hour design storm and the April 17-18, 2013 radar rainfall estimates were used to evaluate the potential additional reduction in peak discharge if the "typical" pond were replaced with a larger hypothetical pond; one that provides approximately 36% more flood storage potential. With the design storm, simulated peak discharges were reduced by approximately 30% in the upstream HUC12's of the watershed (Upper and South Chequest) to about 18% at the outlet at the Des Moines River. With radar rainfall estimates, reductions in peak discharge were roughly 22% and 32% respectively for Upper and South Chequest HUC12's, and 26.5% at the model's outlet.

d. Concluding Remarks

Figure 5.2 summarizes the relative effectiveness of each flood mitigation strategy considered for reducing peak discharges in the Chequest Creek Watershed (125 mi^2). Based on the simulated results and the known geology of the Chequest Creek Watershed, distributed storage will lead to much higher reductions in peak discharge within the watershed; however, any opportunity to increase infiltration will still provide benefit. Conservation practices that promote improved soil health and contour practices such as terracing that allow additional water to infiltrate into the soil should be encouraged where possible.

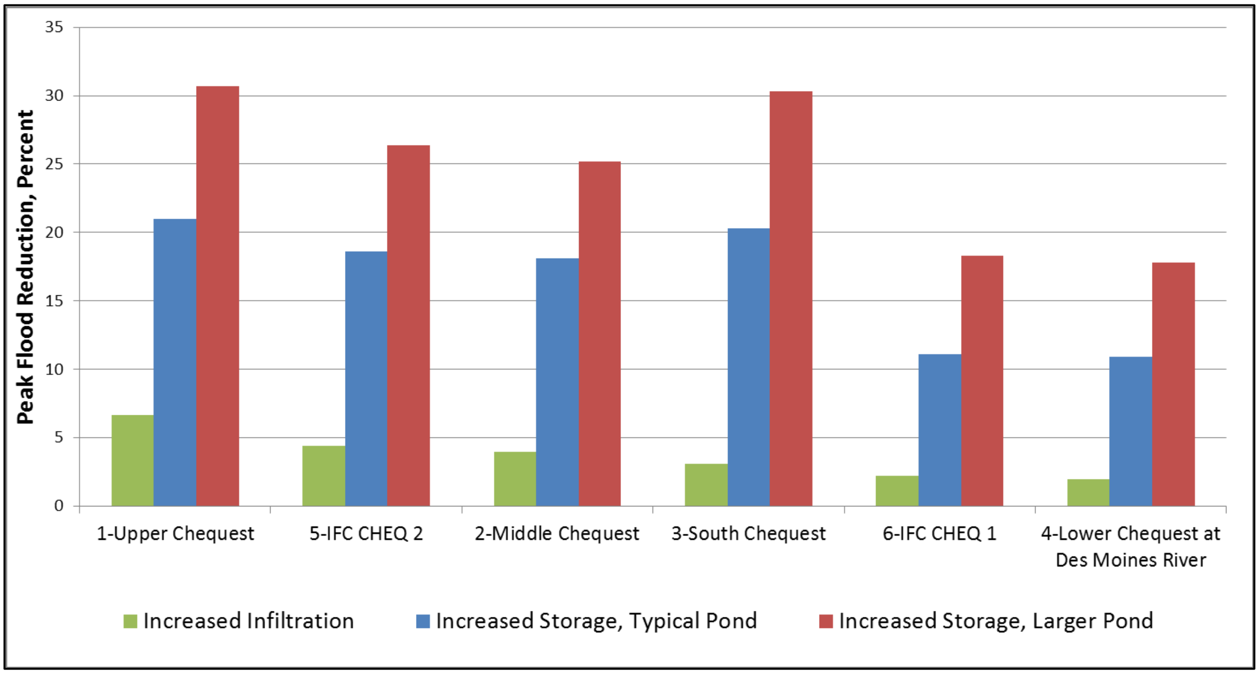


Figure 5.2. Comparison of the relative impact of the flood mitigation scenarios for reducing peak discharges in the Chequest Creek Watershed.

Figure 5.3 shows the percent reduction in peak discharge at six points of interest for both the "typical" pond stage-storage relationship and the larger pond scenario. Figure 5.4 shows the peak flow reduction for the "typical" and larger pond scenarios using the April 2013 radar rainfall estimates.

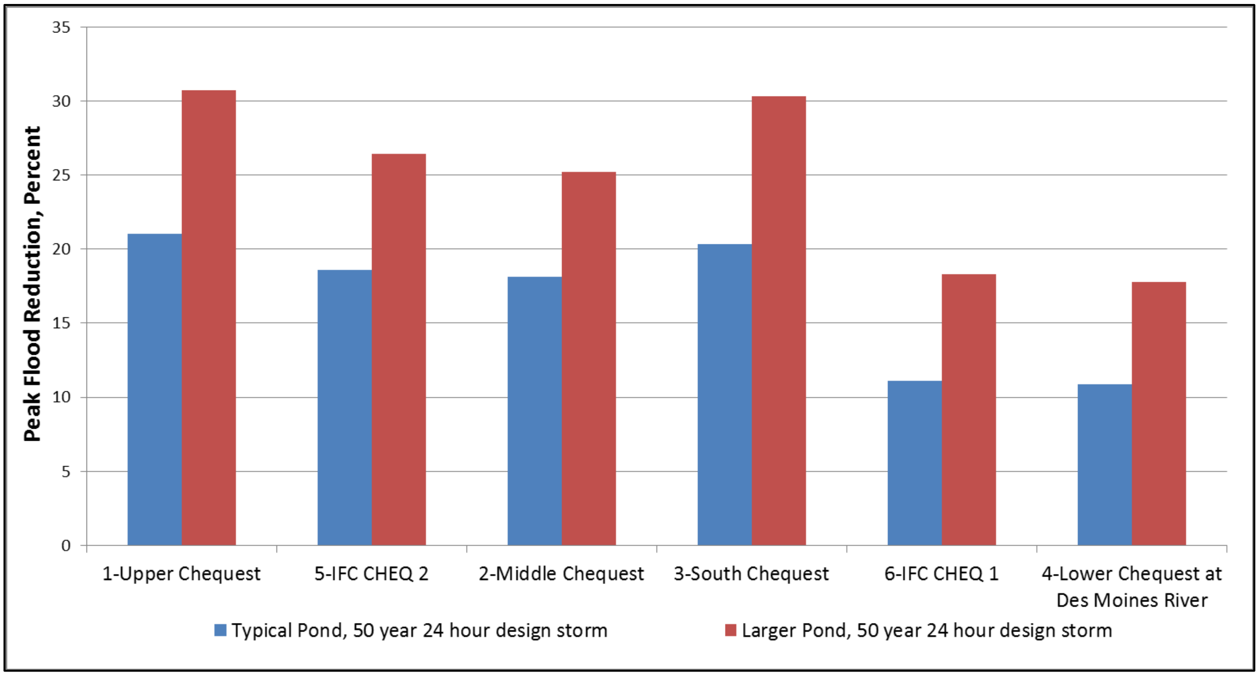


Figure 5.3. Relative impact of the distributed storage scenarios for reducing peak discharges in the Chequest Creek Watershed. Results are using 50-year, 24-hour design storm (5.67").

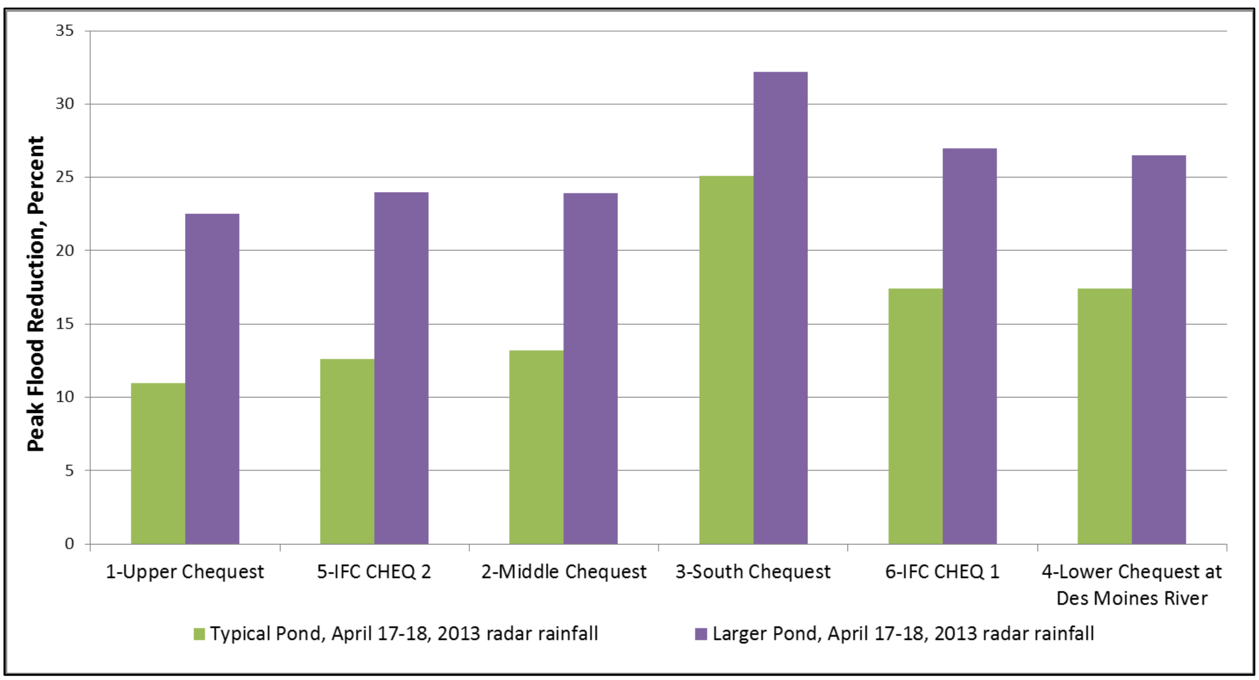
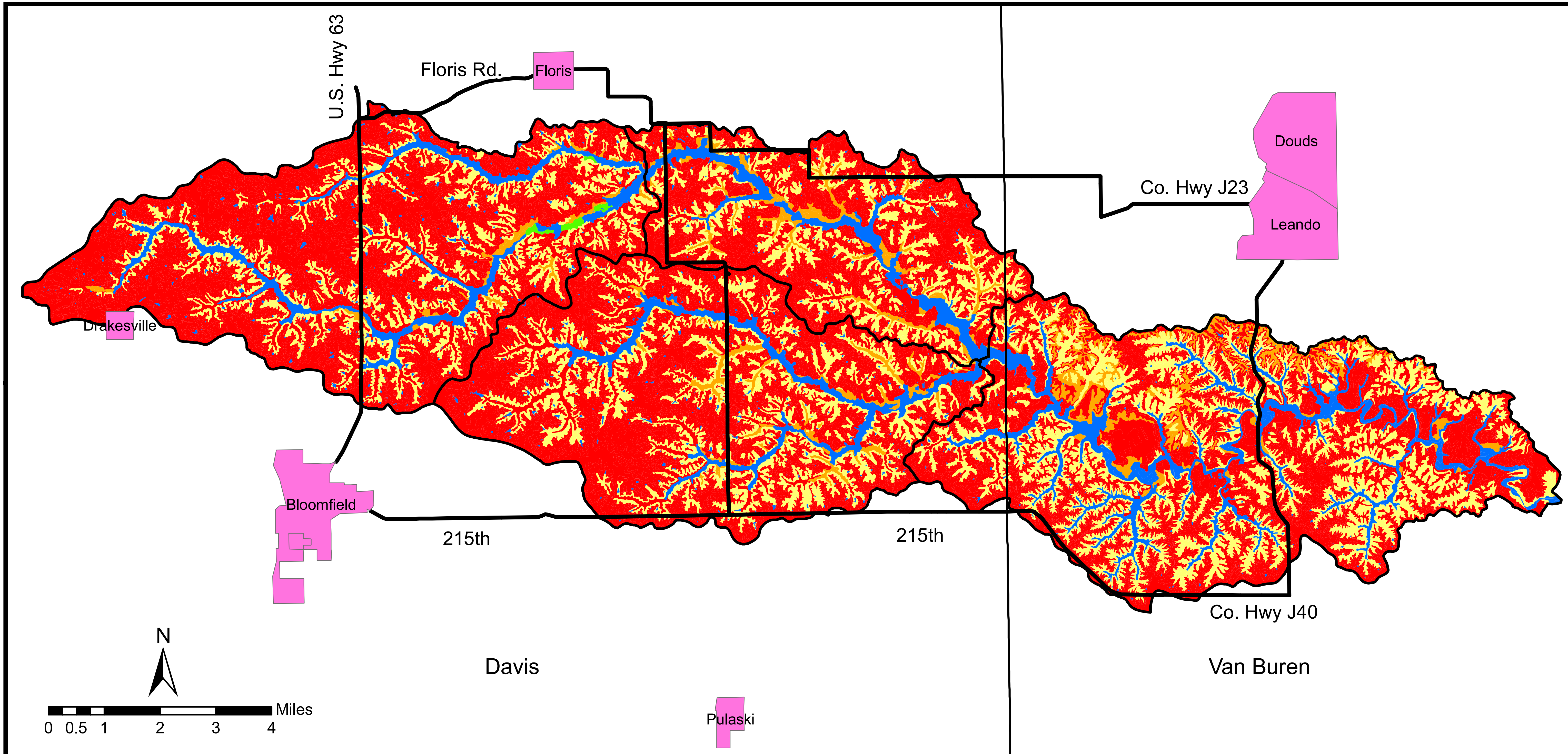


Figure 5.4. Comparison of the relative impact of the distributed storage scenarios for reducing peak discharges in the Chequest Creek Watershed. Results are using April 17-18, 2013 radar rainfall estimates.

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

Appendix A – Maps



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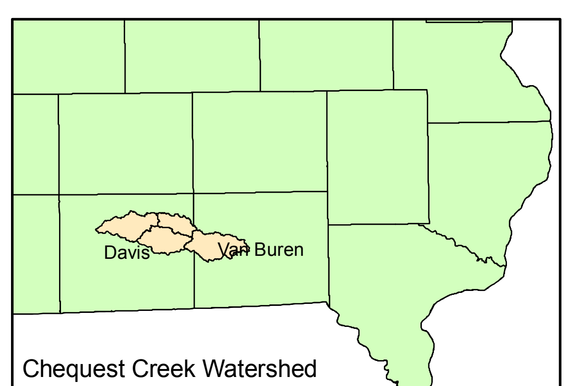
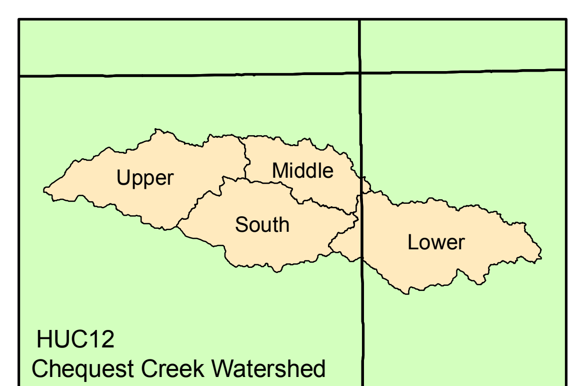




Chequest Creek Watershed
Watershed Soils

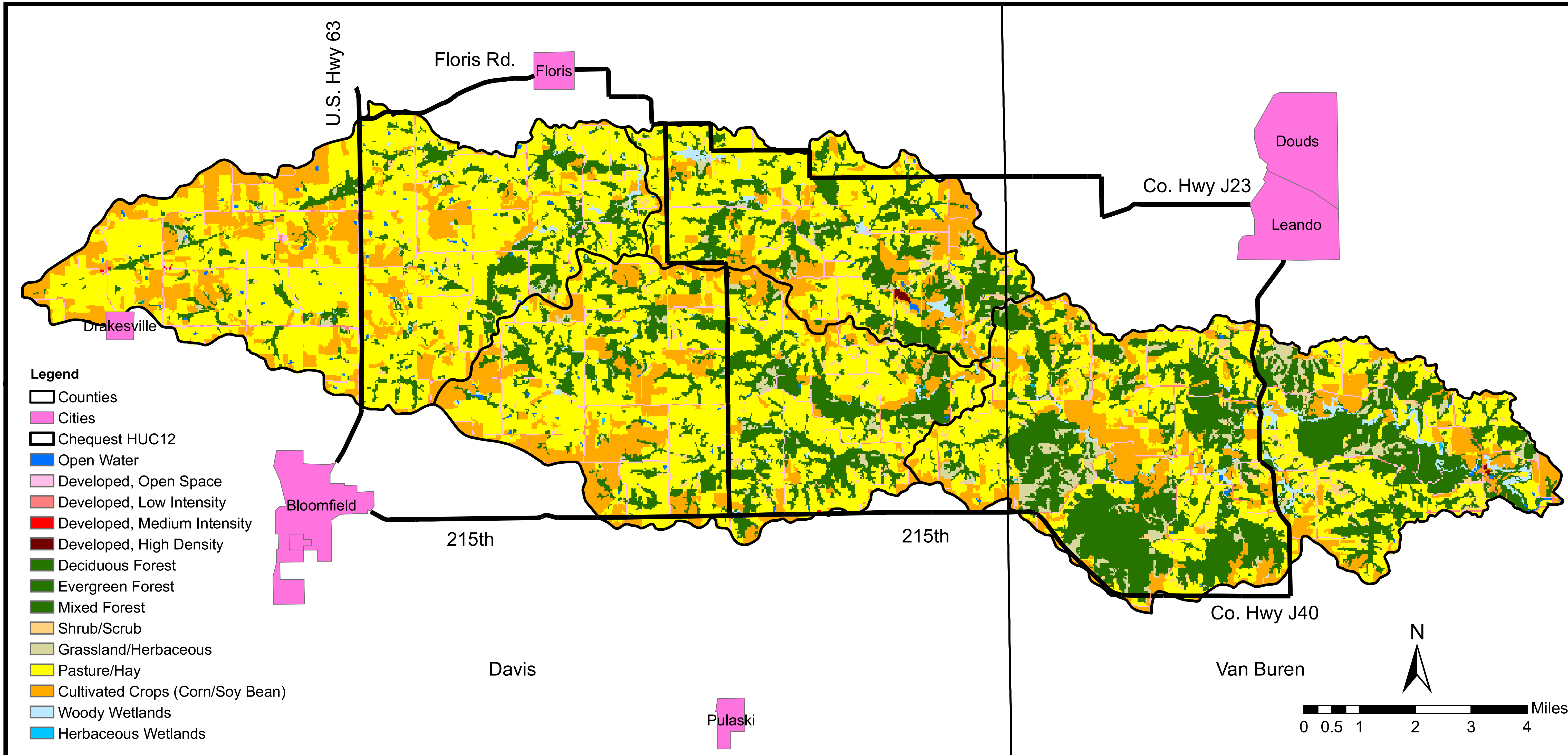
Legend
Chequest HUC12
Chequest Creek Soils
HSG SoilCode
- B
- B/D
- C
- C/D
- D

Date: 4/21/2014

By: Tony Loeser

Data Sources:
USDA-NRCS Web Soil Survey (WSS) SSURGO Dataset. 2012.

Figure A-1



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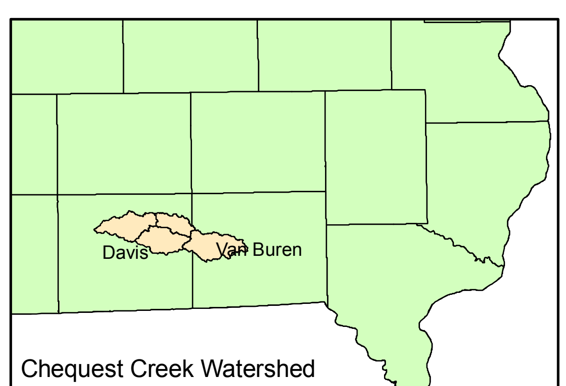
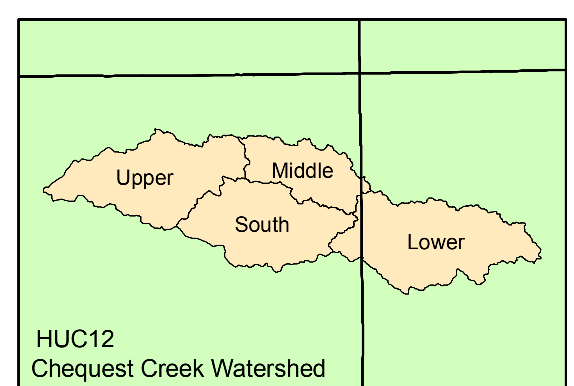




Chequest Creek Watershed
Land Use

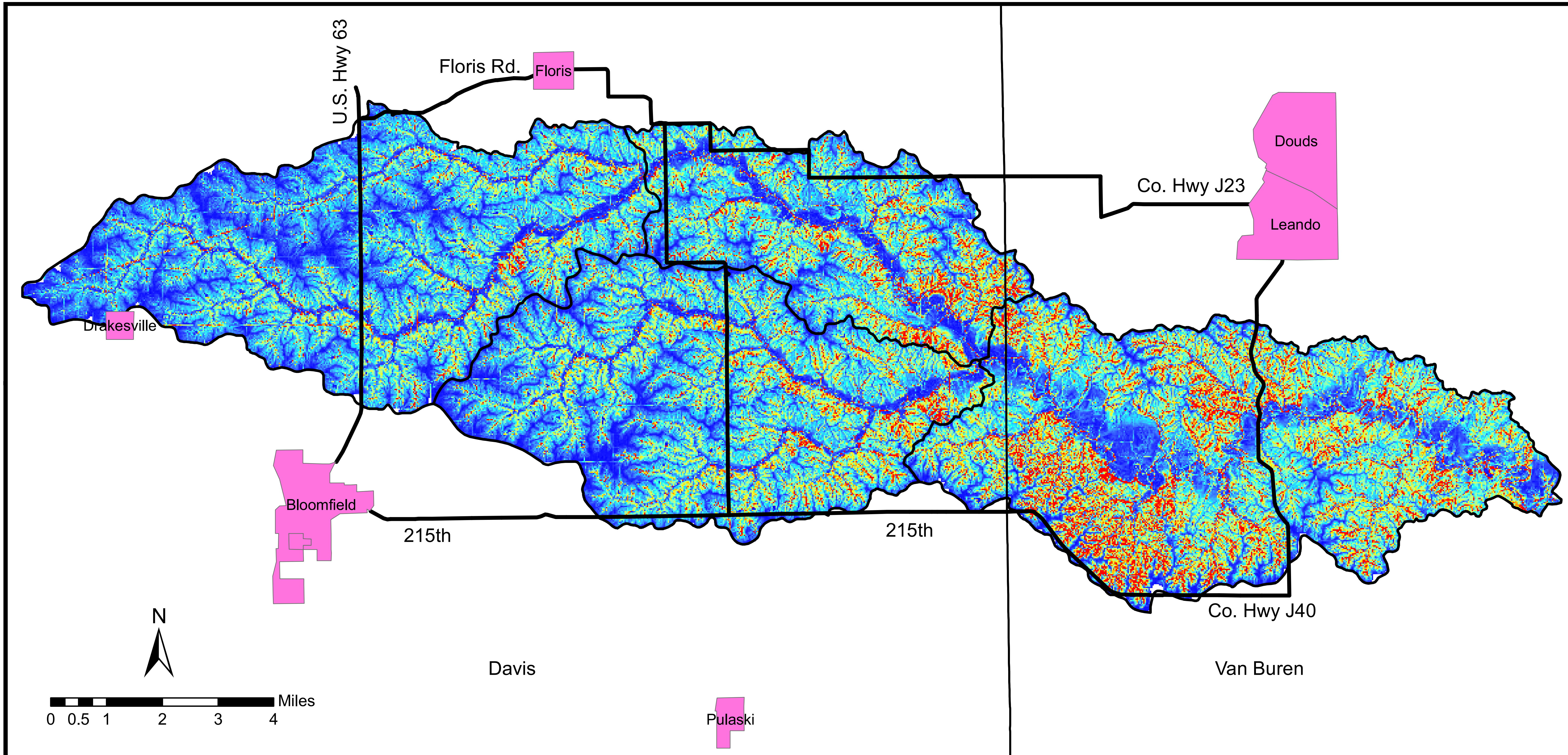
For Legend, see lower left of map panel.

Date: 4/21/2014

By: Tony Loeser

Data Sources:
National Land Cover Dataset (NLCD). 2006.

Figure A-2



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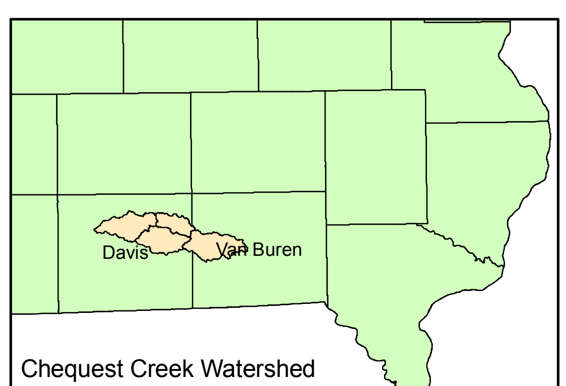
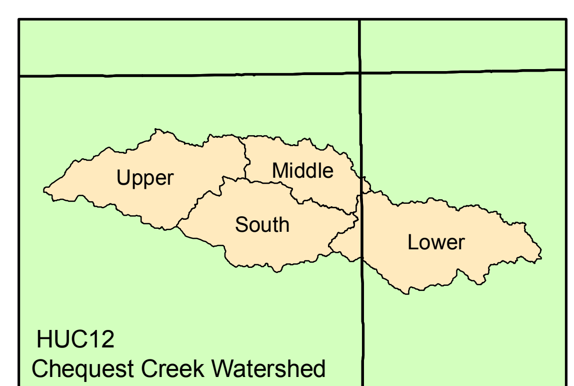




Chequest Creek Watershed
Watershed Slopes

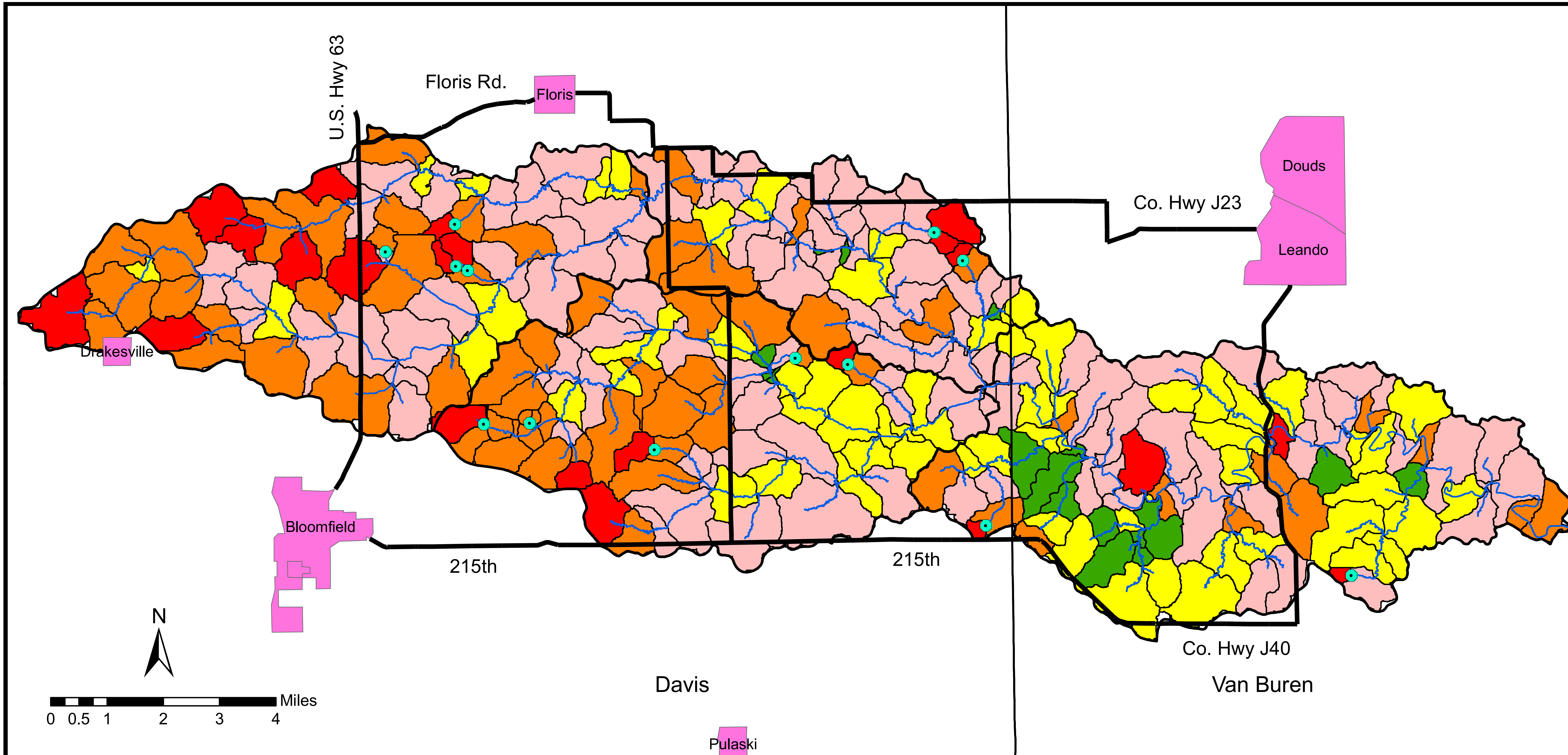
Legend
Counties
Chequest HUC12
Value
Higher
Lower

Date: 4/21/2014

By: Tony Loeser

Data Sources:
LiDAR Datasets. 2010.
Iowa Geological and Water Survey. DNR.

Figure A-3



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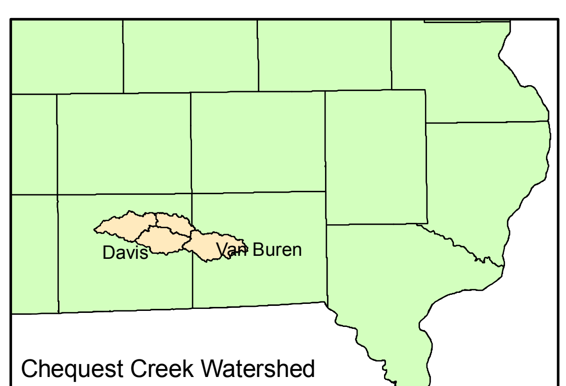
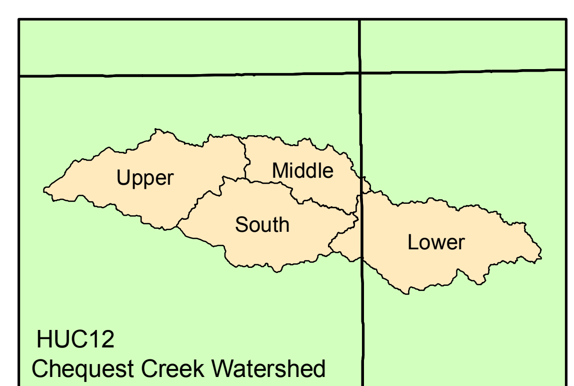




Runoff Potential Analysis
Percent of Rainfall Converted to Runoff

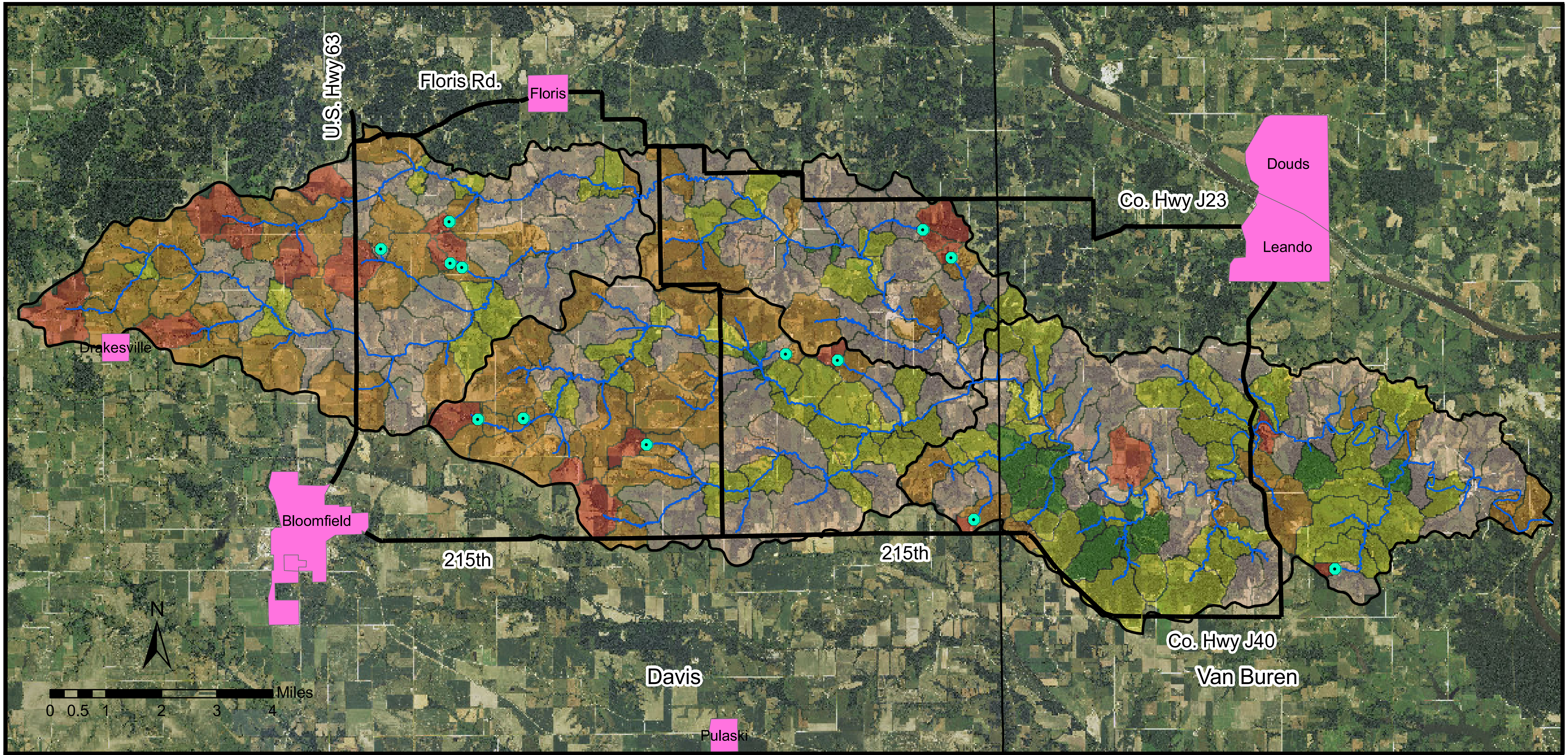
Legend
Existing NRCS Ponds
Chequest HUC12
Percent Rainfall to Runoff
38.8 - 49.8
49.9 - 55.5
55.6 - 60.2
60.3 - 64.9
65.0 - 72.4

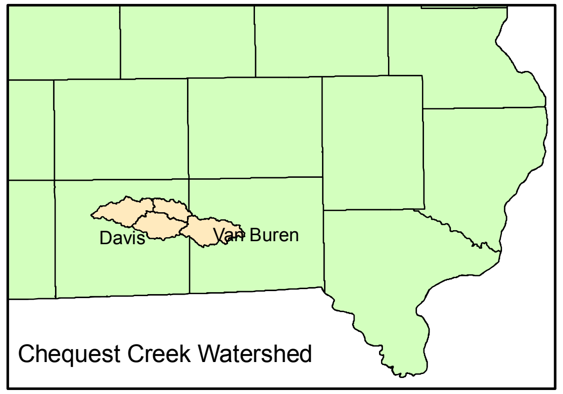
Date: 4/21/2014

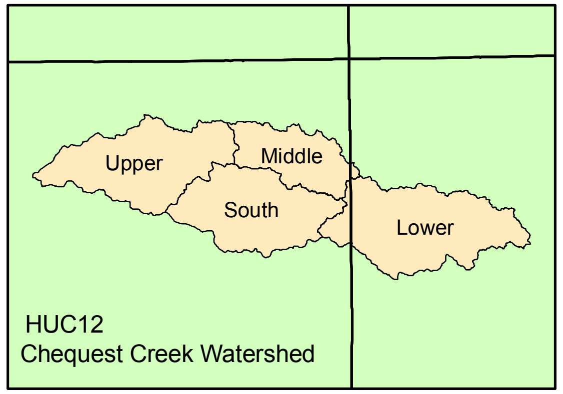
By: Tony Loeser

Data Sources:
Iowa Flood Center
HEC-HMS Model

Figure A-4







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Runoff Potential Analysis

Percent of Rainfall Converted to Runoff

Legend

Existing NRCS Ponds
Chequest HUC12

Percent Rainfall to Runoff

- 38.8 - 49.8
- 49.9 - 55.5
- 55.6 - 60.2
- 60.3 - 64.9
- 65.0 - 72.4

Date: 4/21/2014

By: Tony Loeser

Data Sources:
Iowa State WMS
2013 NAIP
Aerial Photograph

Figure A-5

Appendix B – Incorporated Structures

Table B.1. Typical Pond Stage-Storage-Discharge Data

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	3.1	2.2	0	2.2
2	8.9	11.1	0	11.1
3	15.8	11.5	0	11.5
4	22.8	11.9	0	11.9
5 *Emergency Spillway*	30.9	12.3	0	12.3
5.5	35.2	12.5	14.0	26.5
6	40.2	12.6	40.0	52.6
6.5	44.5	12.8	80.0	92.8
7 *Top of Dam*	50.0	13.0	140.0	153.0
7.5	54.6	13.2	448.1	461.3
8	59.4	13.4	609.1	622.5
9	71.5	15.6	1099.7	1115.3

Table B.2. Larger Pond Stage-Storage-Discharge Data

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	6.1	2.2	0	2.2
2	14.9	11.1	0	11.1
3	25.2	11.5	0	11.5
4	36.4	11.9	0	11.9
5 *Emergency Spillway*	48.6	12.3	0	12.3
5.5	55.6	12.5	14.0	26.5
6	62.9	12.6	40.0	52.6
6.5	70.3	12.8	80.0	92.8
7 *Top of Dam*	77.7	13.0	140.0	153.0
7.5	85.4	13.2	448.1	461.3
8	93.1	13.4	609.1	622.5
9	101.8	15.6	1099.7	1115.3

Appendix C – Calibration and Validation Hydrographs (Fox River Indirect Calibration)

Calibration Storm Events

The June 2008 storm was characterized by a basin wide average rainfall depth of approximately 3.93 inches and a peak discharge of 8871.1 cfs at Bloomfield. Wet conditions were present before the storm, as the API was 0.80 inches corresponding to the 0.81 percentile. CNs in the HMS model were increased by 4.8% to reflect these wet conditions and the model did a reasonable job simulating this particular storm. The simulated peak was overestimated by 5.6%, the timing of the peak flow is approximately one hour later, and the runoff volume is underestimated by 6.2%. The average simulated runoff coefficient (precipitation excess per total precipitation) was 0.61.

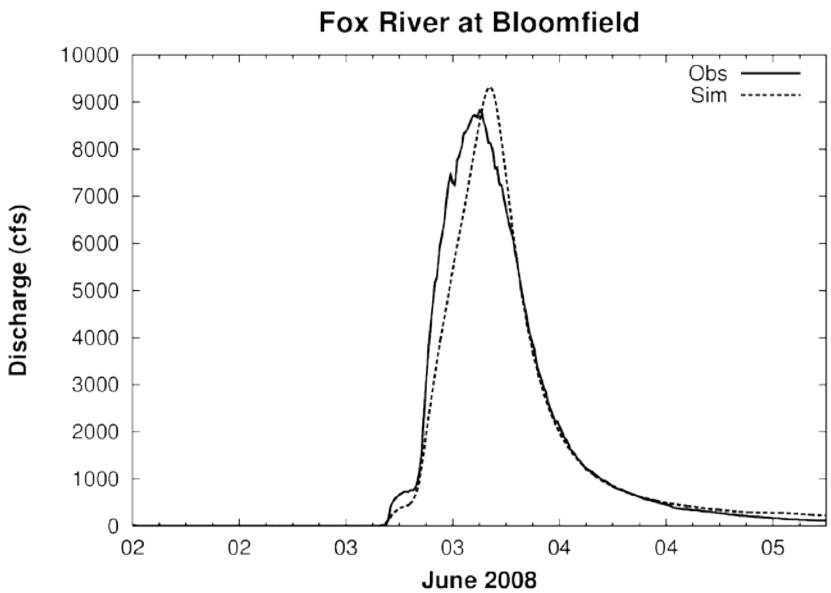

Figure C.1. Observed and simulated hydrographs at Bloomfield. Run for the June 2008 rainfall event with post calibration parameters.

The July 2009 storm was characterized by a basin wide average rainfall depth of 2.0 inches and a peak discharge of 4288.7 cfs at Bloomfield. Even though wetter conditions were present before the storm, as the API was 0.33 inches corresponding to the 0.56 quantile, CNs in the HMS model were decreased by 1.1 % according to the shifted API Quantile-CN curve. The simulated peak flow was 8.6 % underestimated, the timing of the peak flow is approximately 3 hours late, and the runoff volume was underestimated by 12.2%. The simulated runoff coefficient was 0.37.

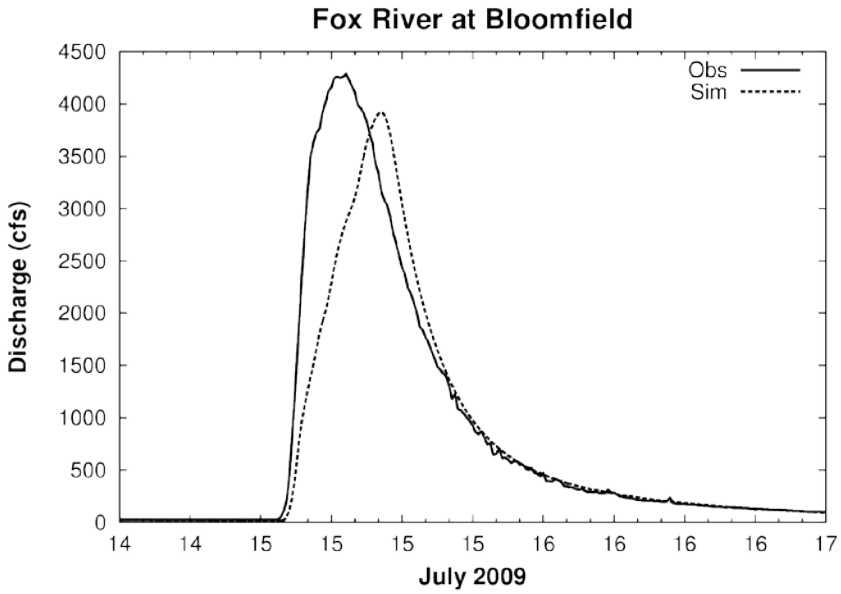

Figure C.2. Observed and simulated hydrographs at Bloomfield. Run for the July 2009 rainfall event with post calibration parameters.

The August 2009 storm was characterized by a basin wide average rainfall depth of 2.74 inches and an observed peak discharge of 5978.5 cfs at Bloomfield. Wet conditions were present before the storm, as the API was 0.27 inches corresponding to the 0.503 percentile. CNs in the HMS were decreased by 2.59 % according to the shifted API Quantile-CN Curve. The simulated peak flow was 14.3% underestimated, the timing of the peak flow is approximately 1 hour late, and the runoff volume is underestimated by 29.6 %. The simulated runoff coefficient was 0.47.

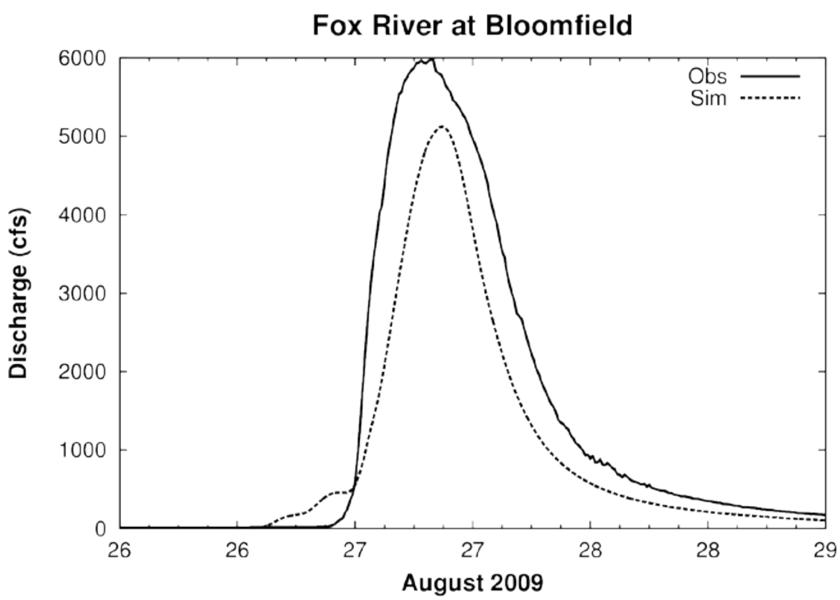

Figure C.3. Observed and simulated hydrographs at Bloomfield. Run for the August 2009 rainfall event with post calibration parameters.

The May 2013 storm was characterized by a basin wide average rainfall depth of 2.81 inches and a peak discharge of 6879.4 cfs at Bloomfield. Wetter than normal conditions were present before the storm, as the API was 2.14 inches corresponding to the 0.97 quantile. CNs in the HMS model were increased by 6.96% to reflect wetter conditions. The simulated peak flow was overestimated by 15.0 % while the runoff volumes are nearly identical. The timing of the peak flow was approximately 2 hours early. The simulated runoff coefficient was 0.54.

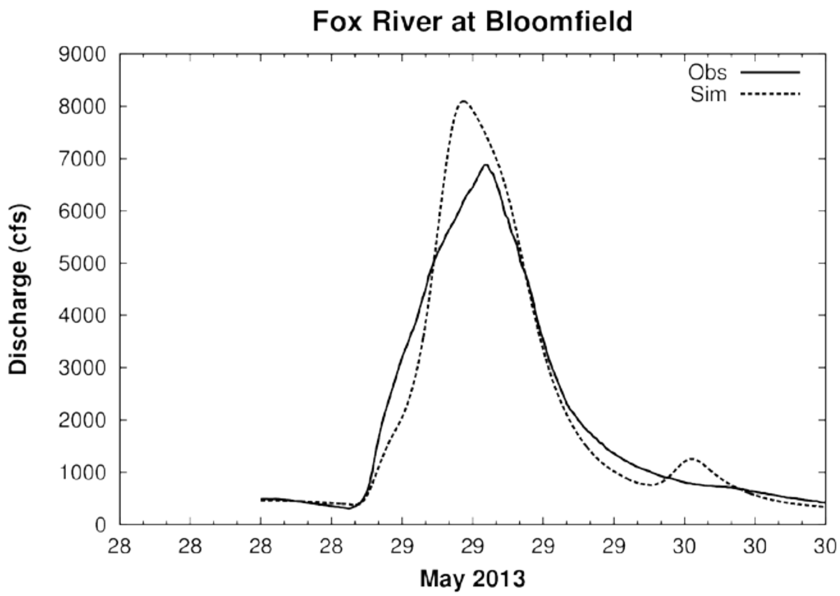

Figure C.4. Observed and simulated hydrographs at Bloomfield. Run for the May 2013 rainfall event with post calibration parameters.

Validation Storm Events

The April 2010 validation storm was characterized by a basin wide average rainfall depth of 1.69 inches and a peak discharge of 5,219cfs at Bloomfield. Wetter than normal conditions were present before the storm, as the API was 0.62 inches corresponding to the 0.75 quantile. The CNs were increased by 3.3% to reflect the wet antecedent moisture condition. Despite more amount of rain being converted to runoff as the wet antecedent moisture conditions suggested, the simulated peak flow and total runoff volume were significantly underestimated in the model (underestimation of peak flow and runoff volume at Bloomfield by 31.3 % and 43.5%, respectively). The simulated runoff coefficient was 0.87.

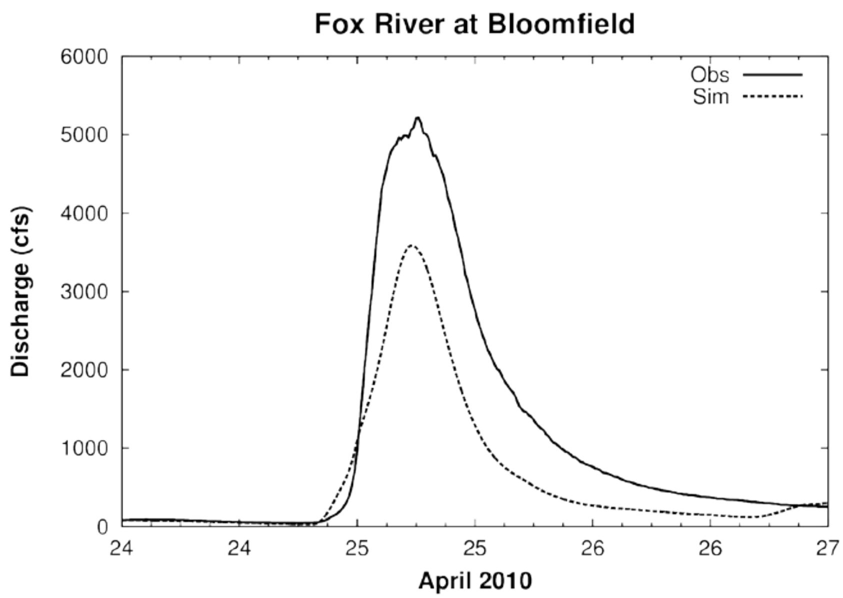

Figure C.5. Observed and simulated hydrographs at Bloomfield. Validation for the April 2010 rainfall event, run with post calibration parameters.

Figure C.6 depicts the simulated and observed hydrographs generated by the April 2013 validation storm. The April 2013 storm was characterized by a basin wide average rainfall depth of 4.96 inches and a peak discharge of 12,300 cfs at Bloomfield. Wet conditions were present before the storm, as the API was 0.65 inches corresponding to the 0.76 quantile, so CNs were increased by 3.5% from the base AMC II condition. As the result, the overall fit of the model is very well, especially the falling limb. The peak flow was underestimated by 10.5% while the volume was overestimated 5.7%. The simulated storm achieved the peak magnitude about 2 hours earlier than the observed one. The simulated runoff coefficient was 0.76.

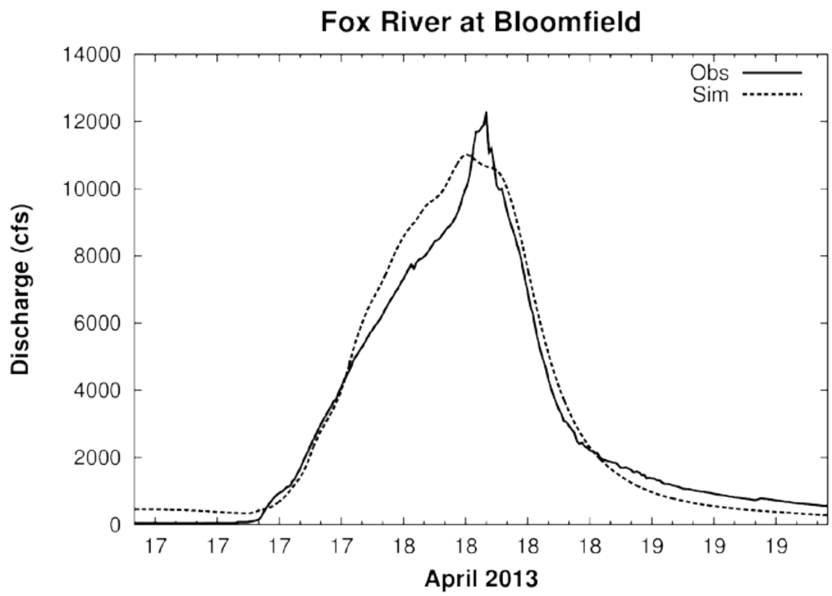

Figure C.6. Observed and simulated hydrographs at Bloomfield. Validation for the April 2013 rainfall event, run with post calibration parameters.

Table C. 1. The initial and calibrated parameters for the Fox River Watershed and parameters for the Chequest Creek Watershed.

Parameters	*Initial Value (Fox River)*	*Calibrated Value (Fox River)*	*Transferred Value (Chequest Creek)*
Ratio to peak	0.10	0.06	0.06
Recession Constant	0.90	0.25	0.25
Muskingum K	Based on 0.7 m/s velocity	Based on 1.3 m/s velocity	Based on 1.3 m/s velocity
Curve Number	Initial curve number generated from GIS	Values vary based on antecedent moisture condition	2.67% decrease overall
Storage Coefficient	2X time of concentration	3X time of concentration	3X time of concentration

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