Hydrologic Assessment of the Soap Creek Watershed

October 2014

Iowa Flood Center | IIHR—Hydroscience & Engineering
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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 aftermath, a handful of Watershed Management Authorities –bodies consisting of representatives from municipalities, counties, and soil and water conservations districts – were formed locally to tackle local challenges with a unified watershed approach.

This assessment is part of the Iowa Watersheds Project, a project being undertaken in four watersheds across Iowa by the Iowa Flood Center located at IIHR—Hydroscience & Engineering on the University of Iowa campus, and is meant to provide local leaders, landowners and watershed residents in the Soap 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 Creek Watershed 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 Soap Creek Watershed, using HEC-HMS, was used to help understand the effect existing flood mitigation structures have on flood hydrology in the Soap Creek Watershed, to identify areas in the watershed with high runoff potential, and to run simulations to investigate the potential impact of additional flood mitigation strategies. Focus for the scenario development was placed on understanding the impacts of increased infiltration in the watershed.

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 Soap 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 participating in the Iowa Watersheds Project (see Figure 1.1).

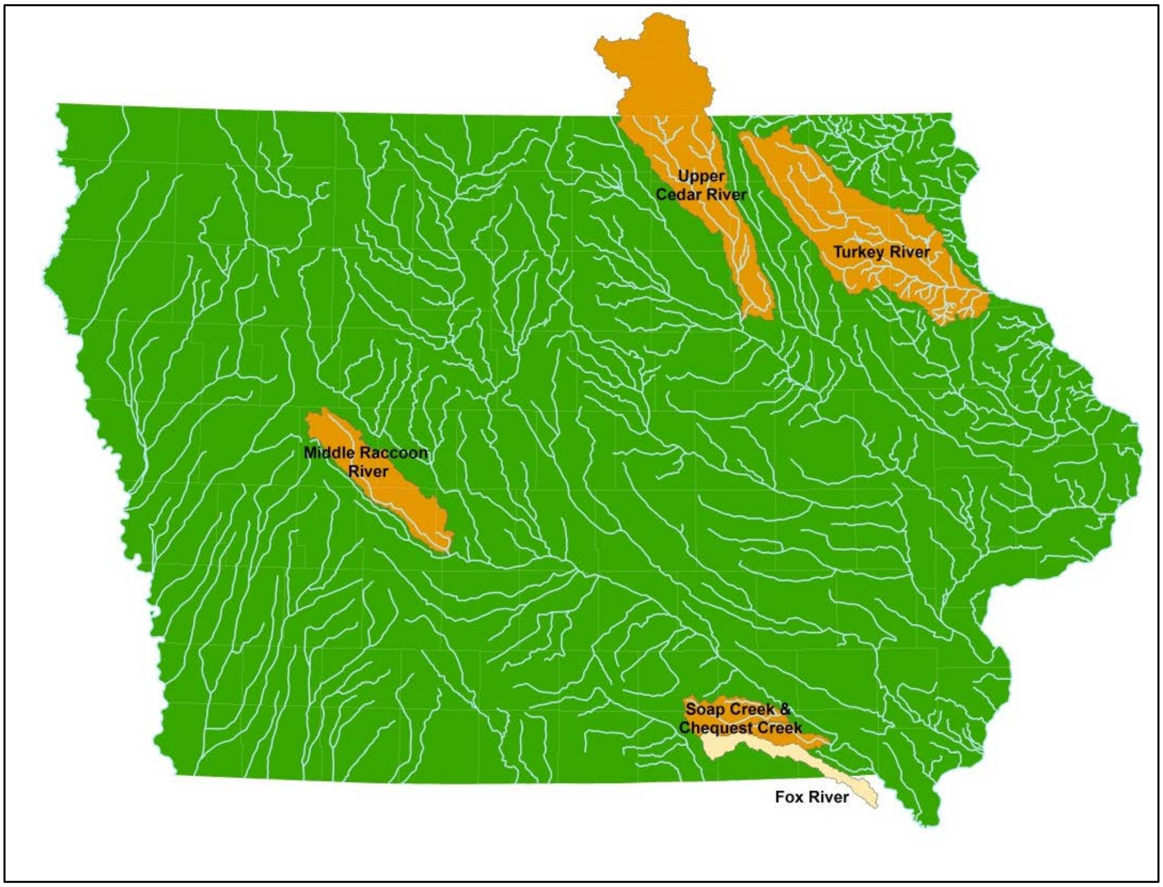

Figure 1.1. Iowa Watersheds Project study areas.

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

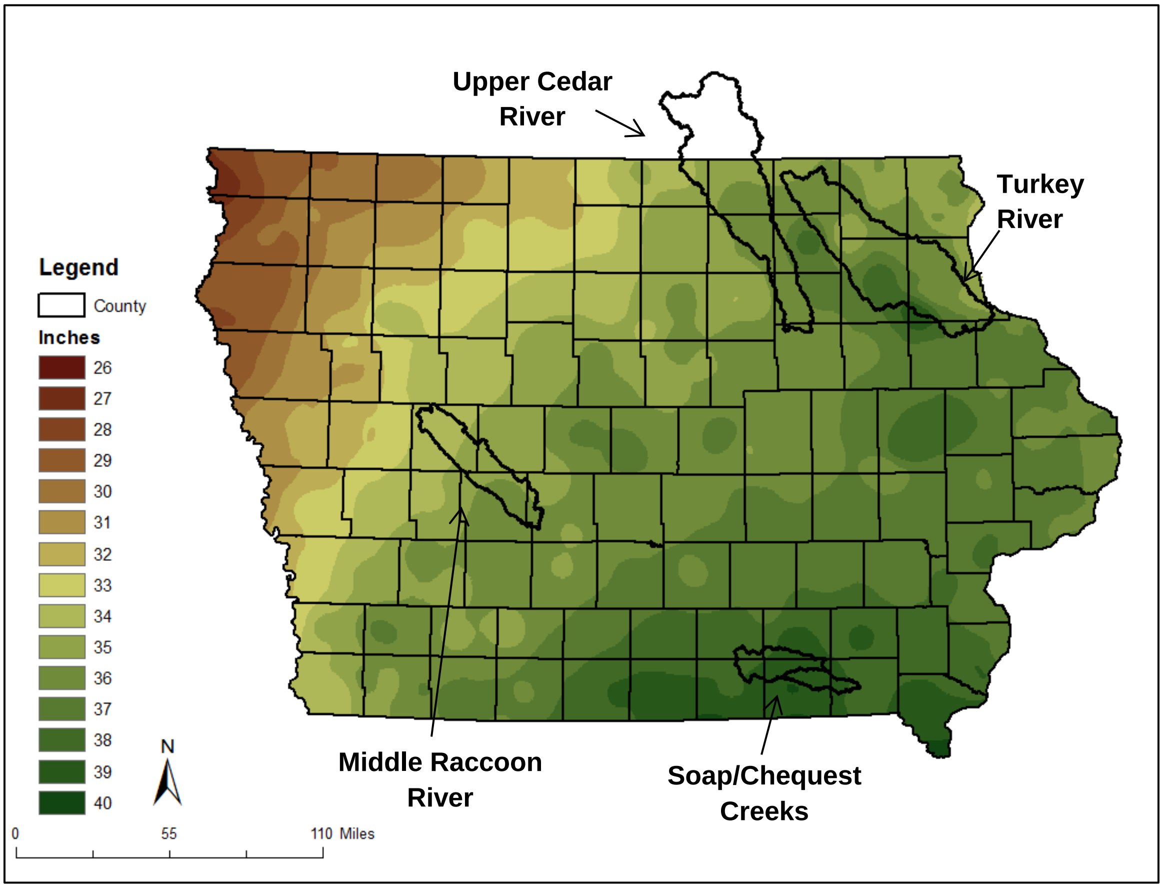

Figure 1.2. Average annual precipitation for Iowa. Precipitation estimates are based on the 30-year annual average (1981-2010) for precipitation gauge sites. Interpolation between gauge sites to an 800 m grid was done by the PRISM (parameter-elevation relationships on independent slopes model) method.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

ii. The Water Cycle in Iowa

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

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

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

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).

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

This region 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 in the ground. Figure 1.3 illustrates the water cycle components for the four Iowa watersheds, and clearly illustrates that the Fox is a more surface flow dominated river.

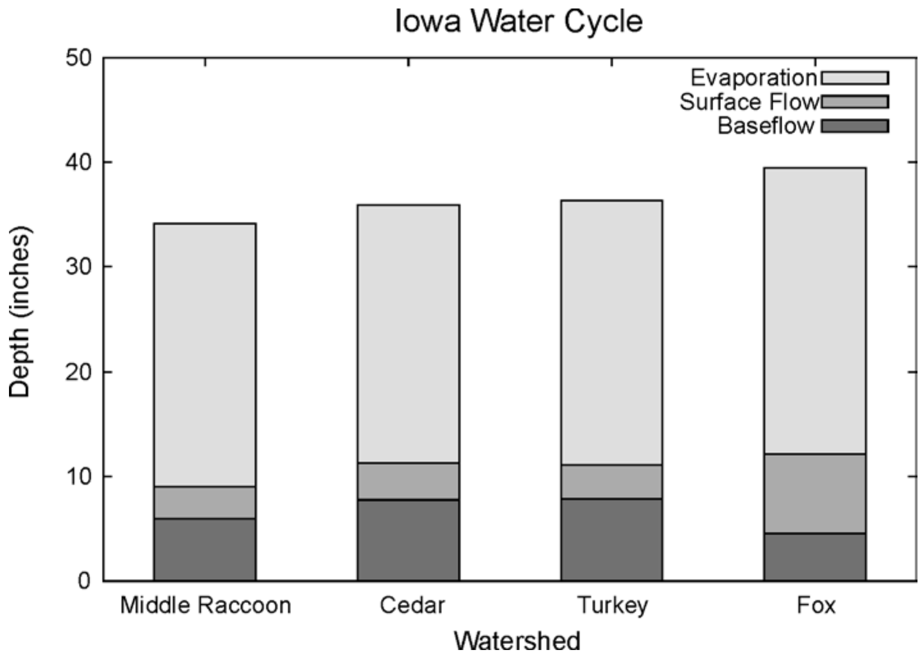


Figure 1.3. Iowa water cycle for four watersheds. The chart shows the partitioning of the average annual precipitation depth (in inches) into evaporation, surface flow, and baseflow components.[2]

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 (May and June). 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 streamgages 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.

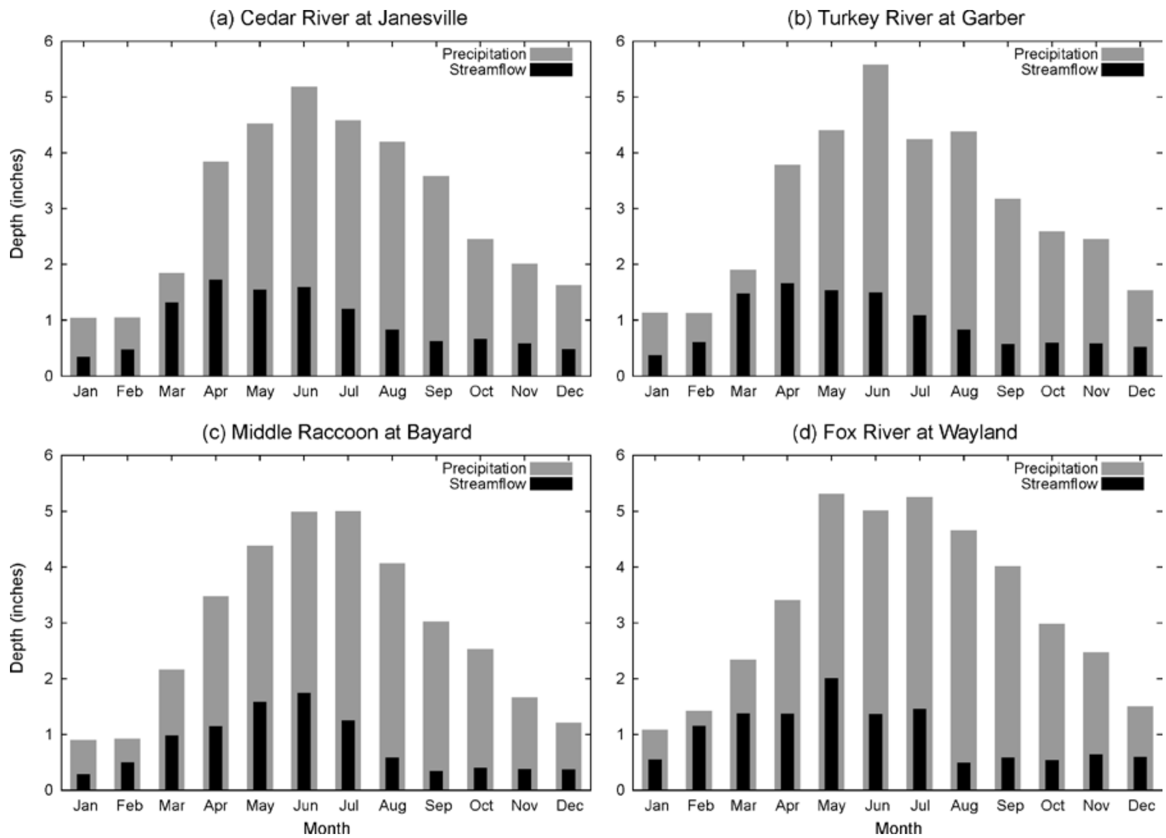


Figure 1.4. Monthly water cycle for four Iowa watersheds. The plots show the average monthly precipitation (in inches) and the average monthly streamflow (in inches). The average monthly estimates for precipitation and streamflow are based on the same 30-year period (1981-2010).

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.

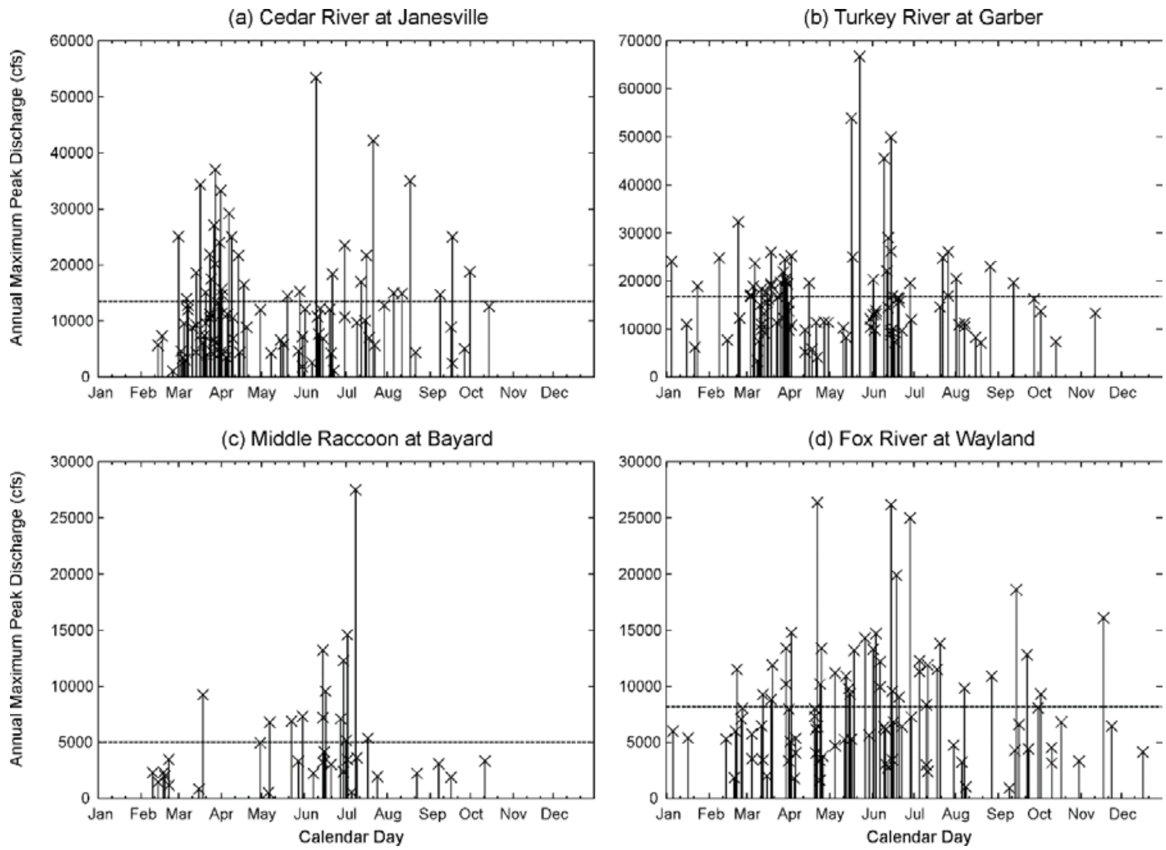


Figure 1.5. Annual maximum peak discharges and the calendar day of occurrence for four Iowa watersheds. The plots show all annual maximums for the period of record at four USGS streamgage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and (d) Fox River 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 flow can occur. Like the northernmost basins, both the Middle Raccoon and the Fox River see their largest annual maximums in the summer.

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

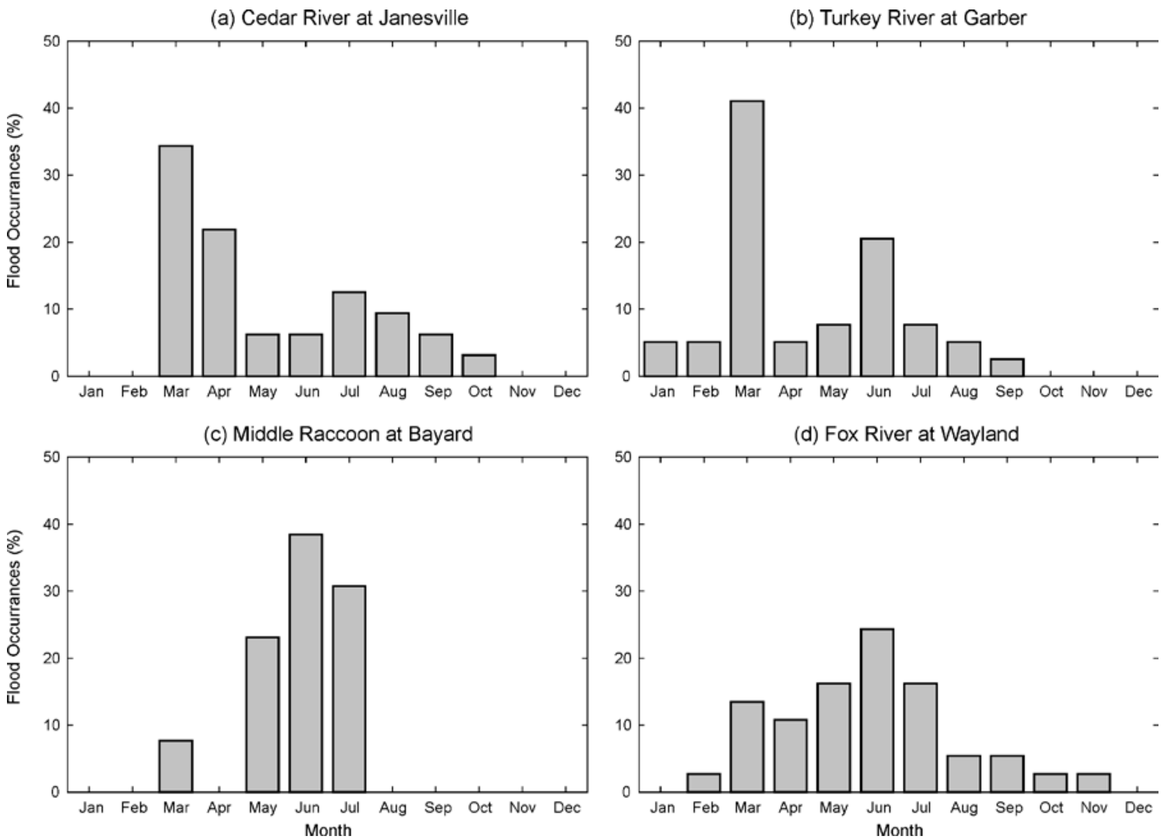


Figure 1.6. Flood occurrence frequency by month for four Iowa watersheds. The plots show the percent of peak annual discharges for a given month that exceed the mean annual flood at four USGS streamgage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and (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 hydrological alterations of Iowa’s watersheds, and look for evidence of these alterations in long-term streamflow records.

i. Hydrological Alterations from Agricultural-Related Land Use Changes

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

Still, other transformations associated with an agricultural landscape have also impacted runoff potential (see Table 1.2). For example, the introduction of conservation practices in the second half of the 20th century tend to reduce runoff, as suggested by a recent study of an Iowa watershed (Papanicolaou). The Conservation Reserve Program (CRP) originally began in 1950s. Many programs were established in 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 streamgage record for the Middle Raccoon River at Bayard does not begin until 1980, so analysis results are shown for the downstream streamgage for the Raccoon River at Van Meter, where the record spans 96 years.

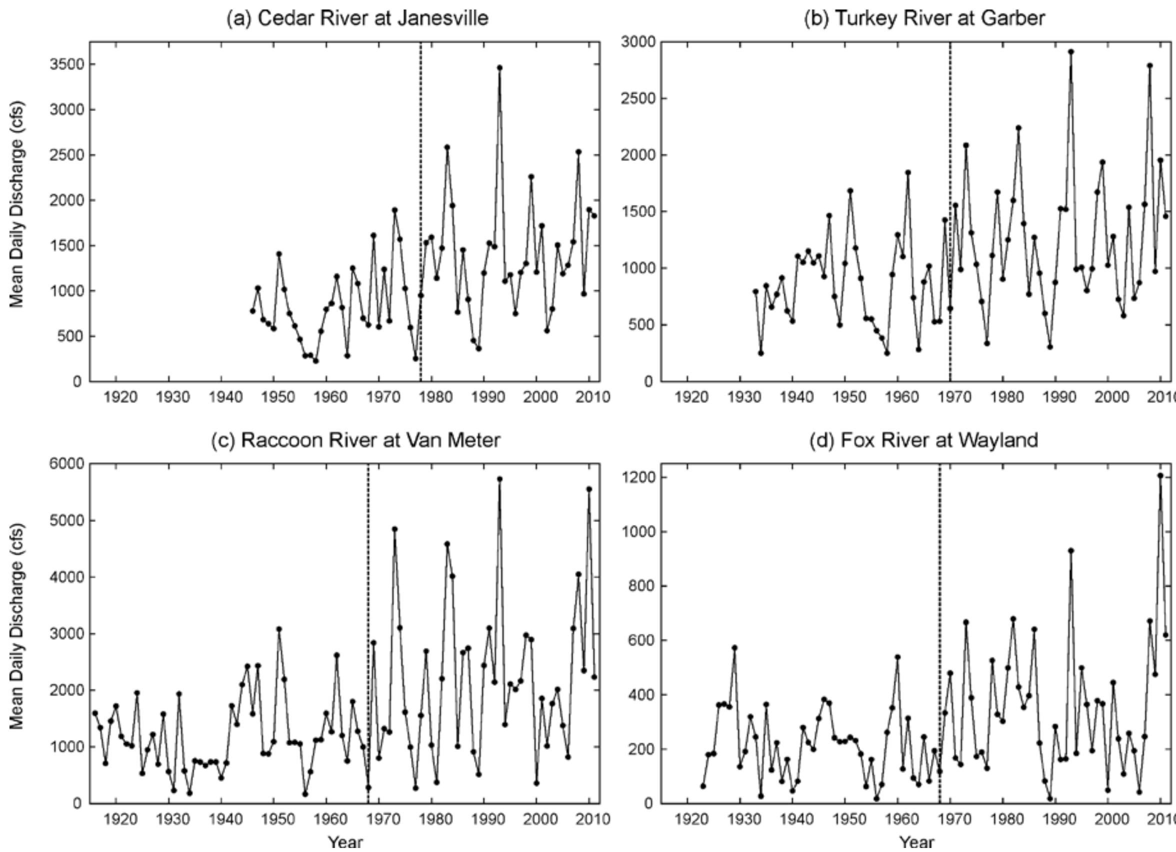


Figure 1.7. Time series of mean daily discharge for the period of record. An analysis was carried out to detect changes in the statistical characteristics of mean daily discharge; the vertical dashed lines indicate the location of any identified change point.

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

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

c. Summary of Iowa's Flood Hydrology

The hydrologic assessment begins by looking at the historical conditions within Iowa watersheds, and moves on to predicting their flooding characteristics. Ultimately, for watersheds to prevent flooding, large- and small-scale mitigation projects directed towards damage reduction will be proposed and implemented. In many instances, projects aim to change the hydrologic response of the watershed, e.g., by storing water temporarily in ponds, enhancing infiltration and reducing runoff, etc. Such changes have (and are designed to have) significant local water cycle effects; cumulatively, the effects of many projects throughout the watershed can also have impacts further downstream. Still, it is important to recognize that all Iowa watersheds are undergoing alterations — changes in land use, conservation practices, increases in urban development, and changes in weather with a changing climate. Therefore, a watershed-focused strategy, which considers local interventions and their impacts on the basin as a whole, within the historical context of a changing water cycle, is needed for sound water resources planning.

2. Conditions in the Soap Creek Watershed

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

a. Hydrology

The Soap Creek Watershed as defined by the boundary of ten-digit Hydrologic Unit Code (HUC10) 0710000907 has a drainage area of approximately 258 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 Soap Creek Watershed falls within a portion of Appanoose, Davis, Monroe, and Wapello Counties. Soap Creek flows from west to east, with two headwater branches, North and South Soap Creek. These two branches come together in Davis County and flow continues eastward. Little Soap Creek traverses southern Wapello County and enters Soap Creek northeast of Floris, Iowa. Soap Creek then continues to its outlet, discharging into the Des Moines River approximately 12 miles southeast of Ottumwa.

Flow conditions are classified as intermittent on the lower 18 miles of Little Soap Creek (United States Department of Agriculture, 1988). Intermittent streams generally have flow occurring only during the wet season (50 percent of the time or less) (Mays, 2010). South Soap Creek is below Lake Sundown, and the lower end of the larger tributaries. Flow conditions in other channels are classified as ephemeral (United States Department of Agriculture, 1988). Ephemeral streams generally have flow occurring during and for short periods after storms. These streams are typical of climates without very well-defined streams (Mays, 2010). Two large recreational lakes are located in the watershed: Lake Sundown, a 470 acres private lake situated on South Soap Creek, and Lake Wapello, a 287 acres state-owned lake suited on Pee Dee Creek.

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

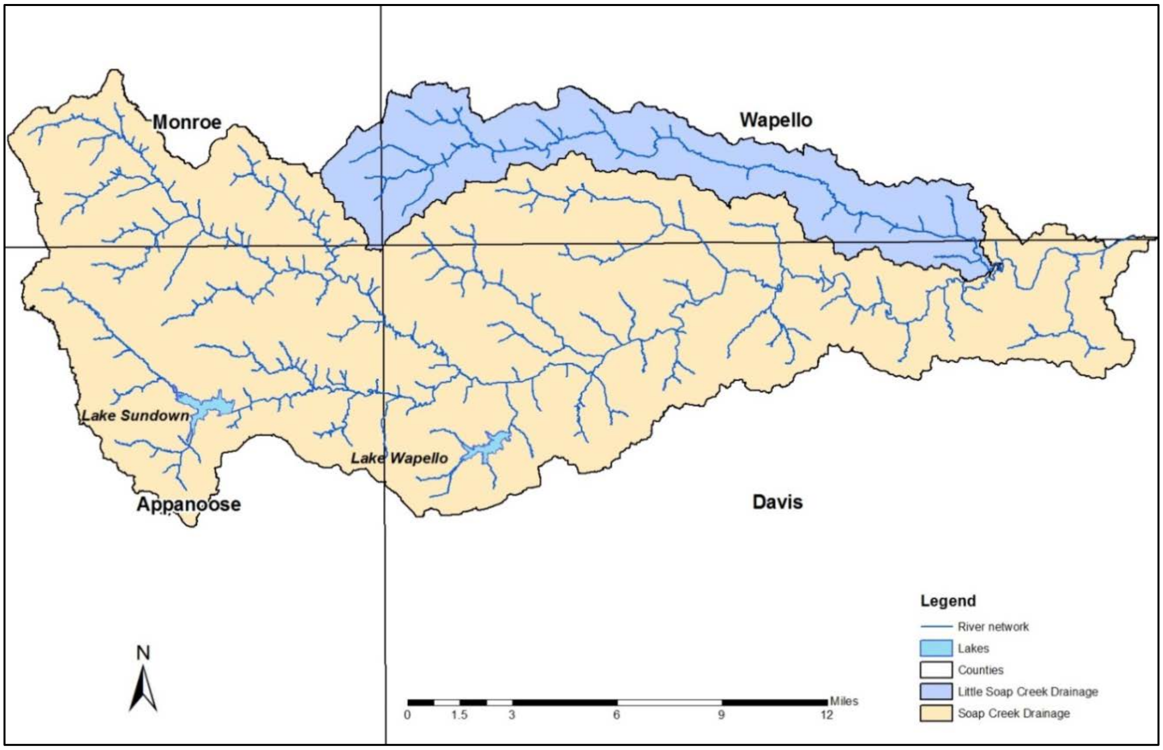


Figure 2.1. The Soap Creek Watershed (HUC10 0710000907) drains approximately 258 mi^2.

b. Geology and Soils

The entire Soap 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 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).

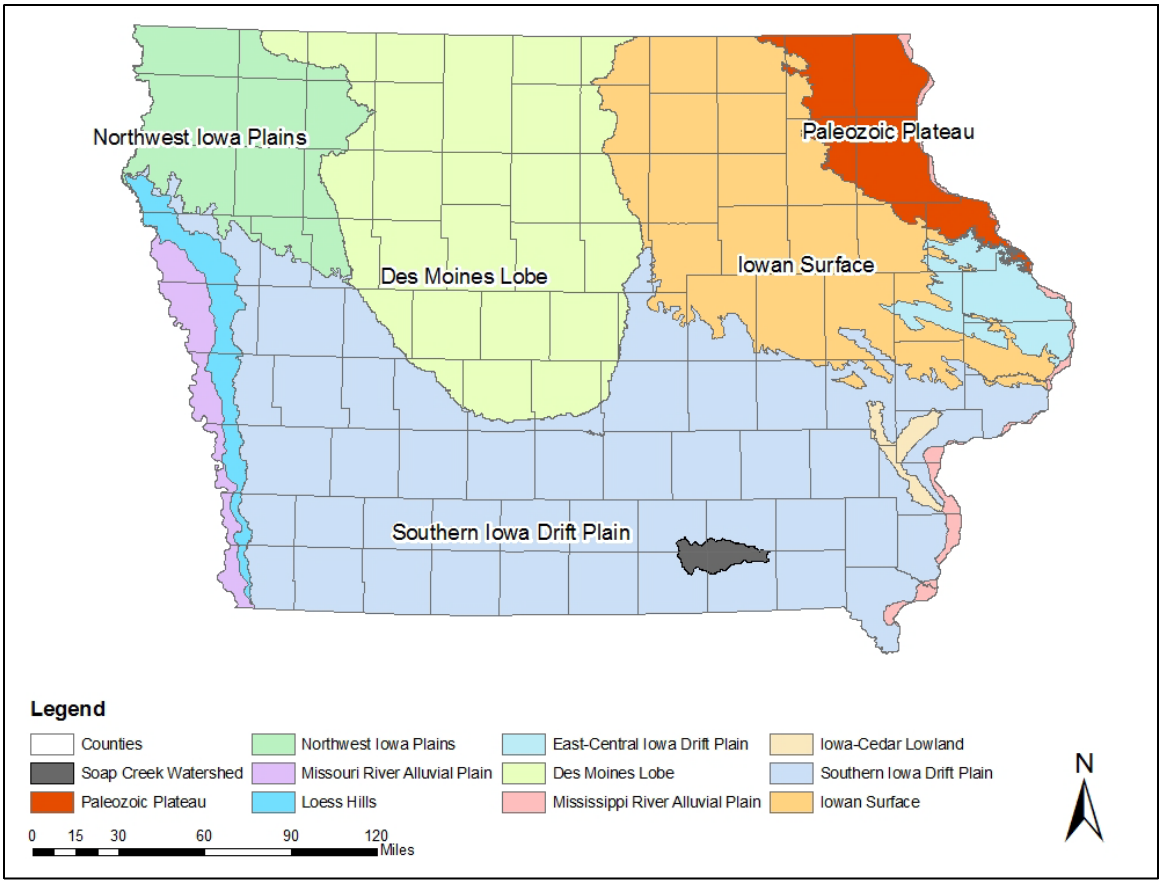


Figure 2.2. Land form regions of Iowa and the location of the Soap Creek Watershed.

Soils are classified into four Hydrologic Soil Groups (HSG) by the Natural Resources Conservation Service (NRCS) based on the soil's runoff potential. The four HSG's are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, there are dual code soil classes A/D, B/D, and C/D that are assigned to certain wet soils. The first letter applies to the drained condition and the second applies to the undrained condition. 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. Table 2.1 summarizes some of the properties generally true for each HSG A-D. This table is meant to provide a general description of each HSG and is not all inclusive. Complete descriptions of the Hydrologic Soil Groups can be found in USDA-NRCS National Engineering Handbook, Part 630 – Hydrology, Chapter 7.

Table 2.1. Summary of soil properties and characteristics generally true of Hydrologic Soil Groups A-D.

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

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

The soil distribution of the Soap Creek Watershed per digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WSS) is shown in Figure 2.3.

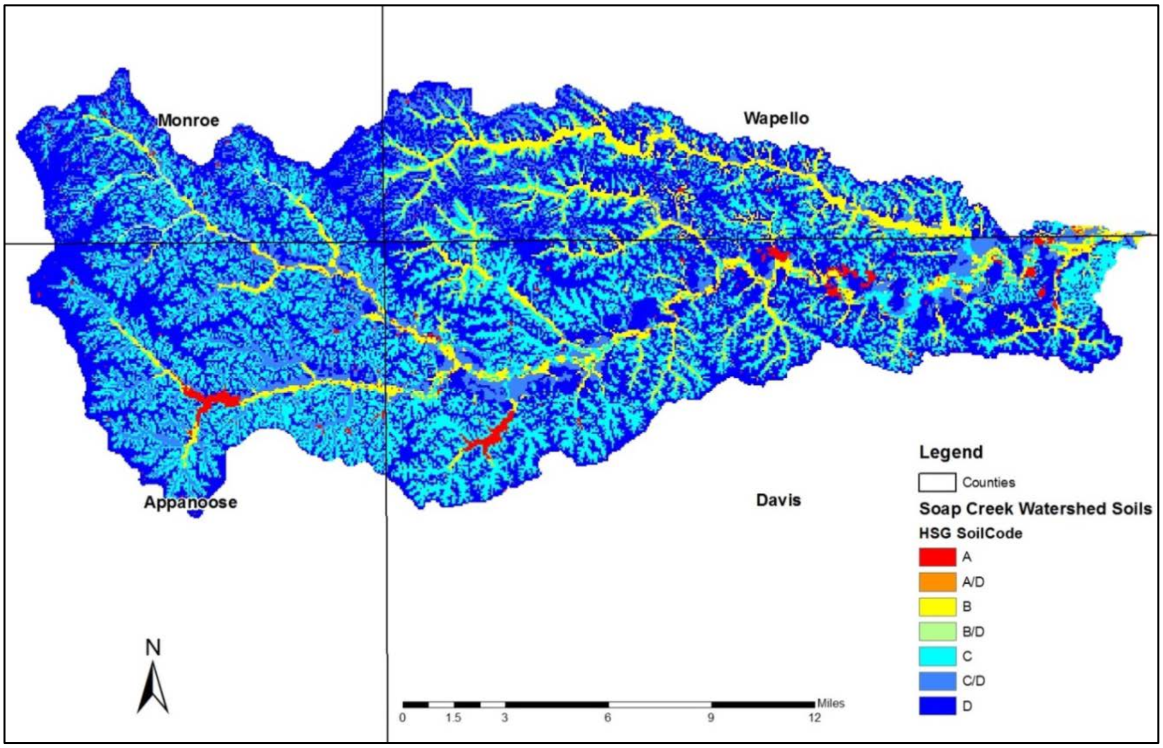


Figure 2.3. Soil Distribution of the Soap Creek Watershed. Hydrologic Soil Group reflects the degree of runoff potential a particular soil has, with Type A(Red) representing the lowest runoff potential and Type D (Dark Blue) representing the highest runoff potential. The dominant soil type in the basin is HSG D (48%).

The primary soil types are C, C/D and D (32.7%, 10.0% and 48.1%, respectively). These soils do not allow much water to infiltrate into the ground, resulting in the majority of areas considered high runoff potential. Table 2.2 shows the approximate percentages by area of each soil type for the Soap Creek Watershed.

Table 2.2. Hydrologic Soil Group distribution (by percent area) in the Soap Creek Watershed.

Soil Type (HSG)	*Runoff Potential*	*Approximate Area (%)*
A	Lower	~0
A/D		~0
B		8.9
B/D		0.3
C		32.7
C/D		10.0
D	Higher	48.1

c. Topography

The topography is characterized by irregular narrow ridges with steep slopes and narrow gullied valleys. Elevation ranges from 1,023 feet to 600 feet at the outlet (see Figure 2.4). Land slopes are between 0-161% (A flat surface is 0%, a 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger.) (see Figure 2.5).

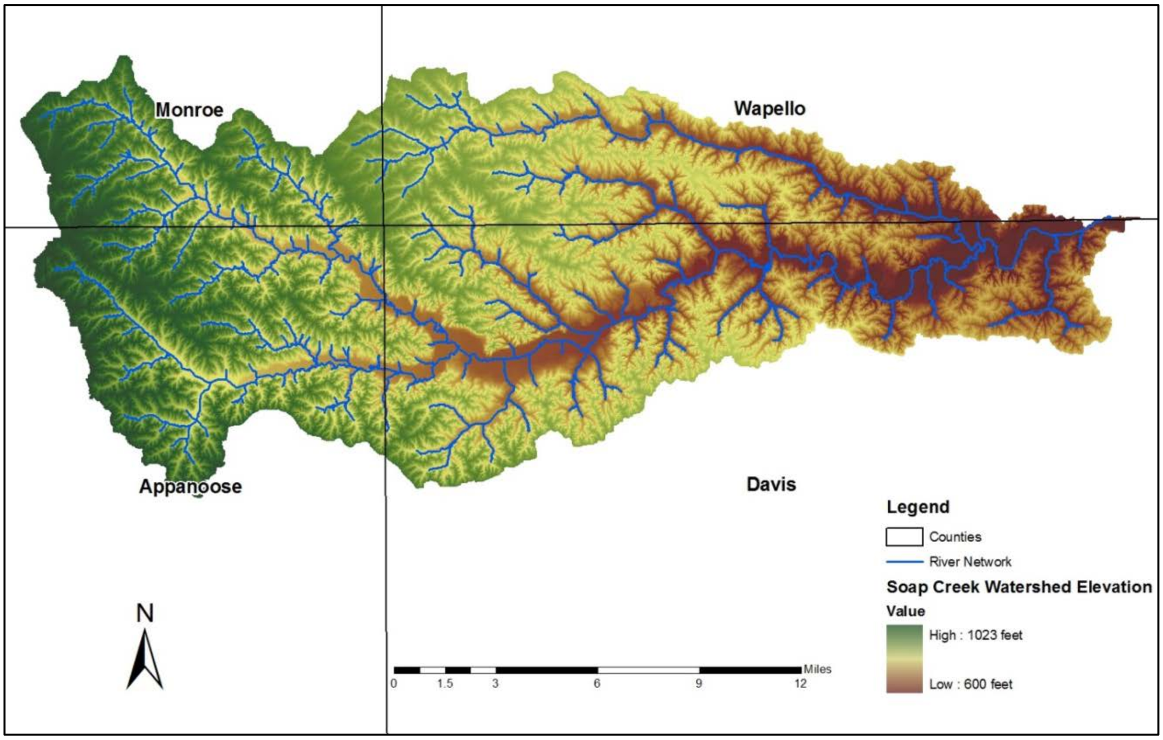


Figure 2.4. Topography of the Soap Creek Watershed. Elevations range from 1,023 feet to 600 feet.

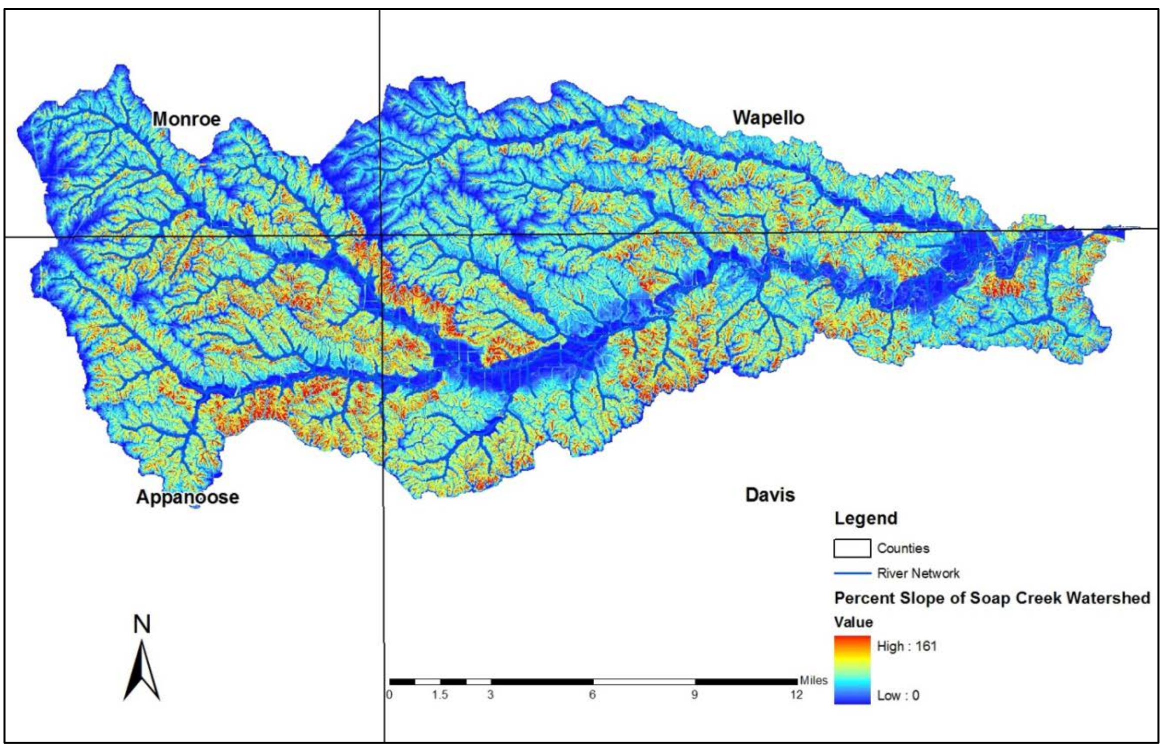


Figure 2.5. Slope of the Soap Creek Watershed, ranges from 0 to 161%.

d. Land use

The Soap Creek Watershed is comprised of approximately 35% pasture/hay and 35% deciduous forest, evenly distributed within the watershed (see Figure 2.6). Other major land use includes cultivated crops, grassland, and developed open space consisting of 14%, 5% and 3%. There are also several small cities in the watershed: Moravia, Blakesburg, Unionville, Udell and Floris. Approximately 90% of the land within the watershed is privately owned.

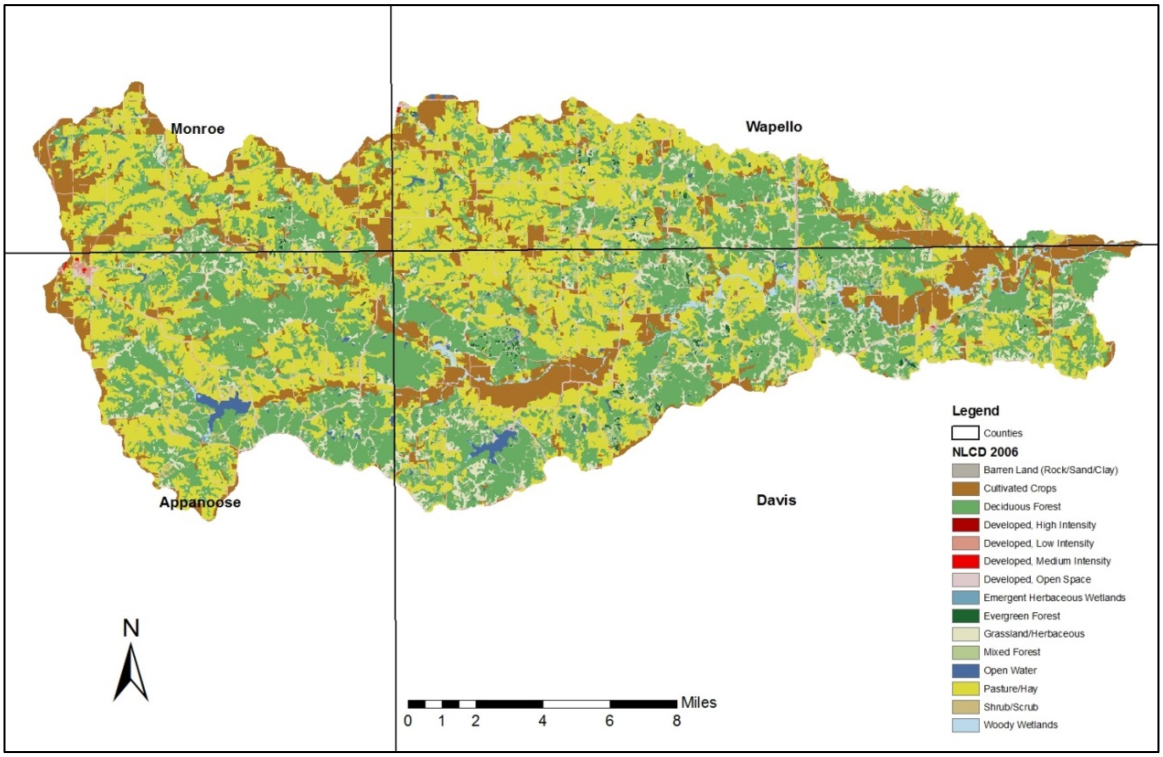


Figure 2.6. Land use composition in the Soap Creek Watershed.

e. Instrumentation/ data records

Soap Creek Watershed is gaged with only four Iowa Flood Center (IFC) stream-stage sensors. The IFC sensors provides a water level measurement every 15 minutes. In addition, there are four United States Geological Survey (USGS) operated stage/discharge gages and three National Oceanic and Atmosphere Administration (NOAA) 15 minute/hourly precipitation gages near the watershed. Figure 2.7 and Table 2.3 detail the period of record and location of the hydrologic and meteorologic instrumentation.

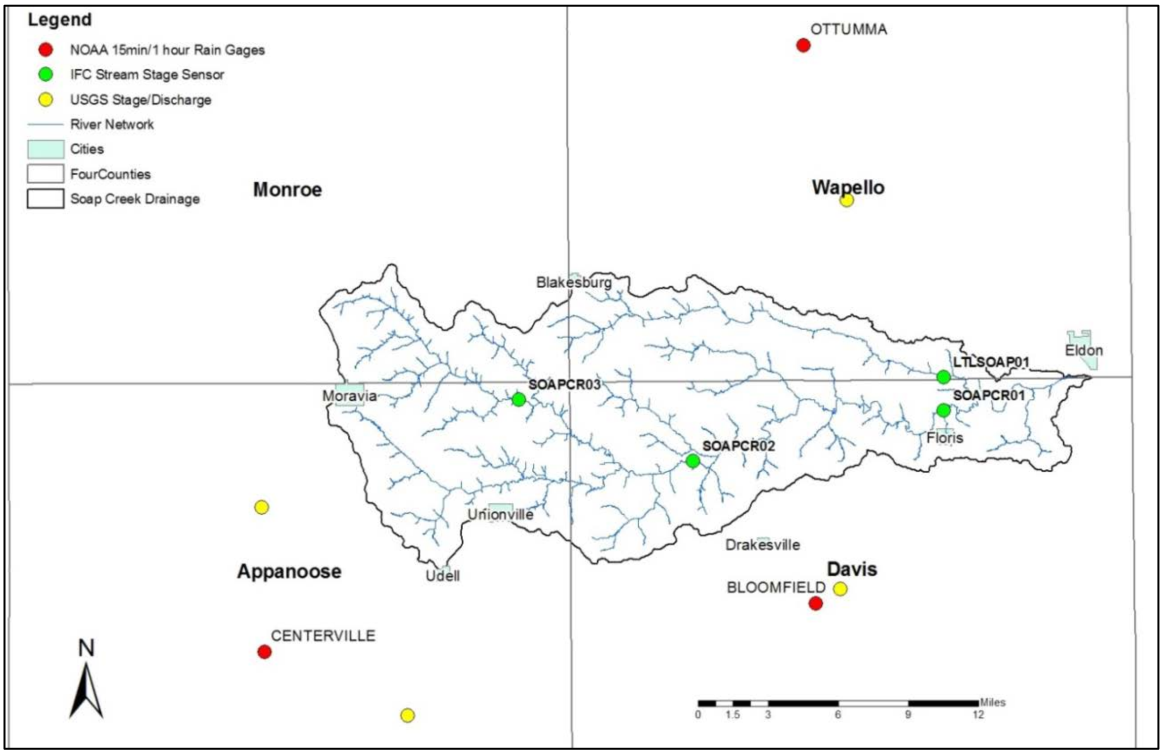


Figure 2.7. Hydrologic and meteorologic instrumentation in and around the Soap Creek Watershed.

Table 2.3. Stage/Discharge and Precipitation Gages in and around the Soap Creek Watershed.

Gage Type	*Location*	*Period of Record*
IFC Stream Stage Sensor - LTLSOAP01	Floris, IA	2012 - present
IFC Stream Stage Sensor - SOAPCR01	Floris, IA	2012 - present
IFC Stream Stage Sensor - SOAPCR02	Drakesville, IA	2012 - present
IFC Stream Stage Sensor - SOAPCR03	Unionville, IA	2012 - present
USGS Stage/Discharge - 05494300	Fox River at Bloomfield, IA	1906 - present
USGS Stage/Discharge - 06904010	Chariton River near Moulton, IA	1979 - present
USGS Stage/Discharge - 06903900	Chariton River near Rathbun,IA	1963 - 1969
USGS Stage/Discharge - 05489500	Des Moines River at Ottumwa, IA	1917 – present
NOAA 15 Min/Hourly Precipitation	Ottumwa Industrial Airport, IA	1948 – 2013
NOAA-partnered Daily Precipitation	Bloomfield, IA	1906 – present
NOAA 15 Minute/Hourly Precipitation	Centerville, IA	1948 – 2013

f. Floods of Record

Flooding from Soap Creek and its tributaries occurs nearly every year and more often in some reaches (United States Department of Agriculture, 1988). In 1986, Soap Creek flooded seven times, with major flooding occurring on April 30; rainfall of 2.5 to 4.0 inches over the upper end of the watershed caused the flooding (United States Department of Agriculture, 1988). Since there is no streamgage present within the Soap Creek Watershed, a historical record of flood peak discharges does not exist. However, since the installation of the four IFC stream stage senors in 2012, high water depths have been recorded three times: March 10, 2013; April 18, 2013 and May 29, 2013.

3. Soap Creek Hydrologic Model Development

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

The Hydrologic Modeling System (HMS) is designed to simulate the precipitation-runoff processes of a watershed. It is designed to be 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 Soap Creek Watershed or larger). Figure 3.1 reviews the water cycle and major hydrologic processes that occur in a watershed.

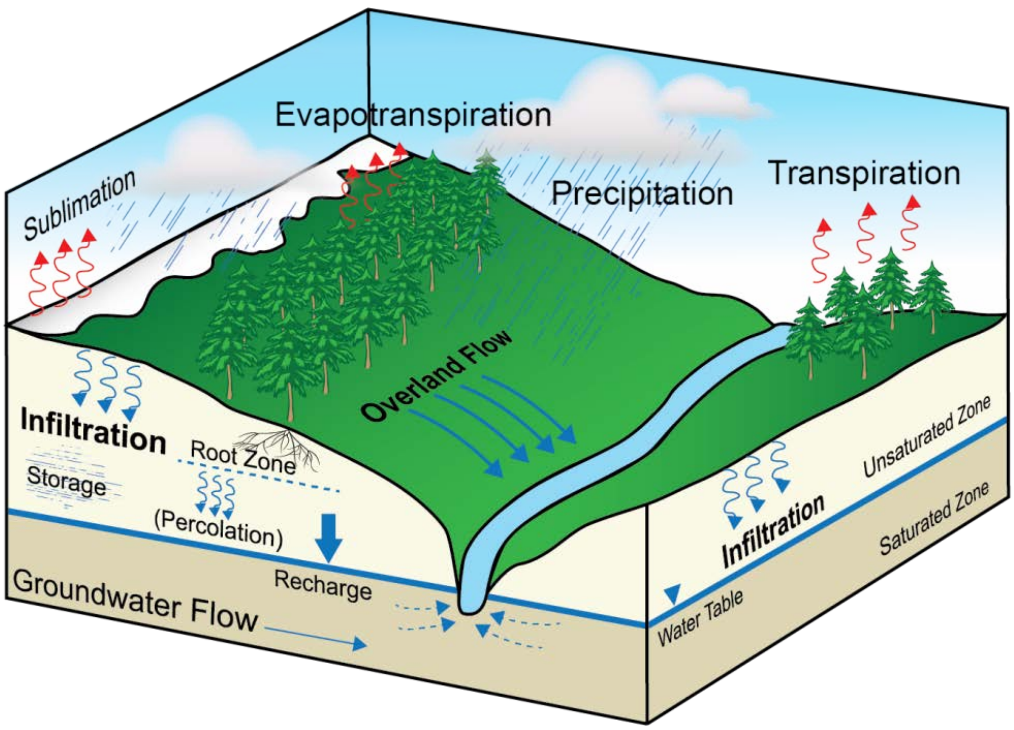


Figure 3.1. Hydrologic processes that occur in a watershed. Phase I modeling only considered the precipitation, infiltration, and overland components of the water cycle.

HMS is a mathematical, lumped parameter, uncoupled, surface water model. Each of these items will be briefly discussed, as each descriptor plays a role in the models' input demands, assumptions required, and final applicability for using the model's results. The fact that HMS is a mathematical model implies the different hydrologic processes (shown in Figure 3.1 above) are represented by mathematical expressions that were developed to best describe observations or controlled experiments. HMS is a lumped parameter model, meaning physical characteristics of the watershed, such as land use and soil type, are "lumped" together and averaged to produce 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 wet antecedent conditions where direct runoff and overland flow is expected to dominate the partitioning of rainfall.

The two major components of the hydrologic modeling within HMS are the basin model and the meteorological 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 meteorological model stores precipitation data that defines when, where and how much it rains over the watershed.

a. Model Development

In this project, two hydrologic models have been developed: one is for the Soap Creek Watershed, and another for the Fox River Watershed. Some HEC-HMS model parameters are best estimated by a trial-and-error “calibration” process, where the parameters are changed and the performance of the model is compared to observations. The Soap Creek Watershed has no USGS streamgages, so model parameters cannot be calibrated directly. In contrast, the Fox Creek Watershed has a historical record, and model parameters can be estimated by calibration. In this situation, calibration model parameters (for the Fox River) can be transposed for use in the model of the ungauged watershed (Soap Creek). Section3.b will explain more about this indirect calibration method and why the Fox River was selected. Since the hydrologic model for both the Soap Creek Watershed and Fox River Watershed were developed using the same method, we only provide the details of developing the Soap Creek Watershed model. The Soap Creek Watershed is approximately 258 squares miles. For modeling purposes, the entire watershed was divided into 642 smaller drainages areas, called subbasins in HMS; the average subbasin area is 0.39 square miles (250 acres), and the largest subbasin area is 3.9 square miles (2,500 acres). Figure 3.2 shows the subbasin delineation for use in the Soap Creek Watershed.

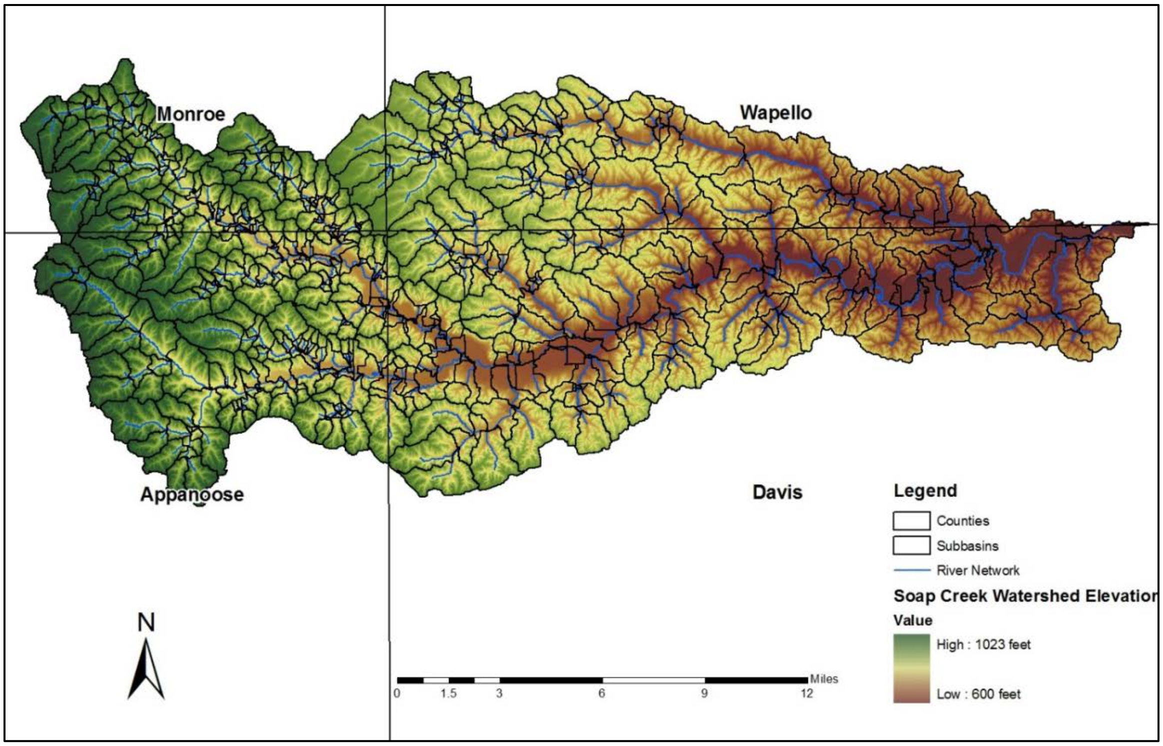


Figure 3.2. Subbasin delineation for use in the Soap Creek Watershed HMS hydrologic model. The watershed was divided into 642 subbasins to better define model parameters based on characteristics such as land use and soil type.

ESRI ArcGIS and Arc Hydro tools were used for preprocessing terrain, creating flow direction and flow accumulation grids, defining the stream network, and delineating subbasins. The stream network was defined to begin when the upstream drainage area was 0.39 square miles (250 acres), 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 each IFC stream stage sensor location, as well as the discharge point of any existing structures within watershed.

i. Incorporated Structures

In the 1980's, the Soap Creek Watershed Board was formed and a plan to distribute 154 flood mitigation structures (mainly ponds) was approved. Of 154 structures to be constructed in Soap Creek Watershed, 132 have been constructed as of 2013 (see Figure 3.3). All 132 structures were incorporated into the HEC-HMS model. Stage-storage-discharge relationships were obtained for each reservoir from Iowa Department of Natural Resource's Office of Dam Safety in Des Moines, Iowa and from regional NRCS offices. These 132 ponds have been built in several phases over the last 30 years (see Figure 3.4).

Additionally, two reservoirs, Lake Sundown and Lake Wapello, were incorporated into the HMS model. Even though these two large lakes were not designed or built for flood mitigation efforts, their ability to hold extra water during times of flooding cannot be neglected.

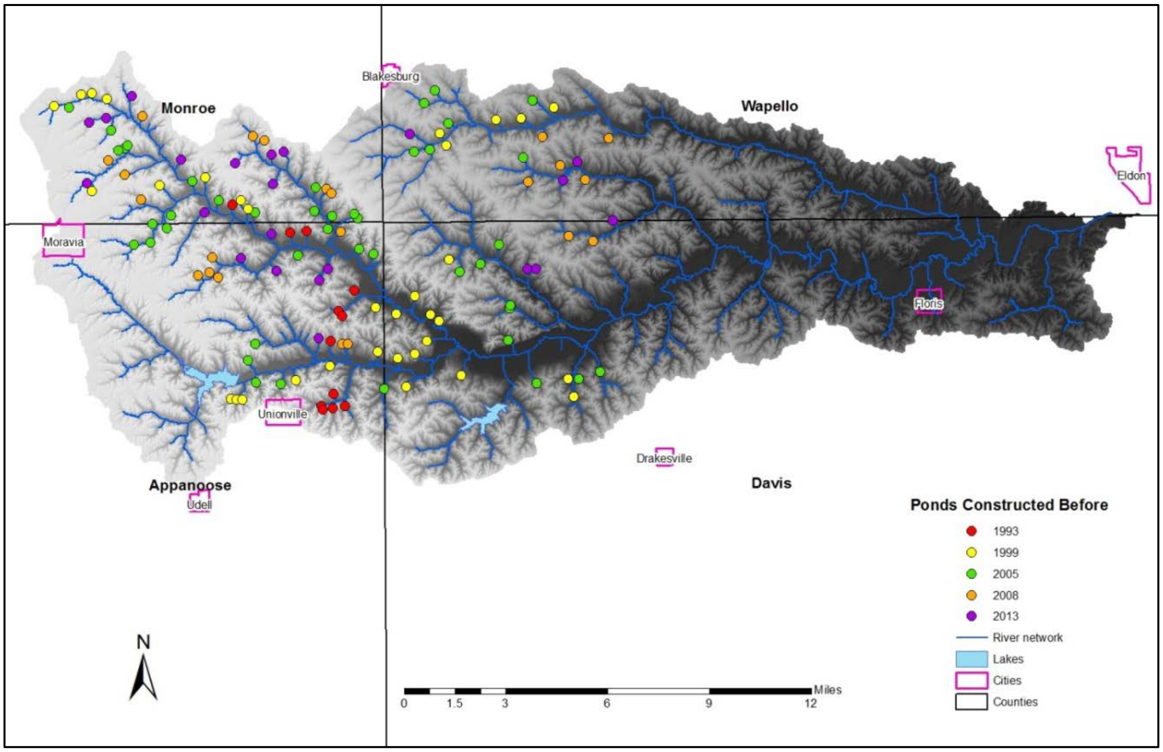


Figure 3.3. Construction progression of the 132 ponds that have been built in the Soap Creek Watershed.

ii. Development of Model Inputs

A brief overview of data inputs used and assumptions that have been made to develop the HMS model are provided in the following paragraphs.

Rainfall (Meteorological Model)

Stage IV radar rainfall estimates (NCEP/EMC 4KM Gridded Data (GRIB) Stage IV Data) were used as the precipitation input for simulation of recent actual rainfall events within the watershed. The Stage IV data set is produced by the National Center for Environmental Prediction (NCEP) by taking Stage III radar rainfall estimates produced by the 12 National Weather Service (NWS) River Forecast Centers across the continental United States and combining them into a nationwide 4 km x 4 km (2.5 mile x 2.5 mile) gridded hourly precipitation estimate data set. These data are available beginning in 2002 through the present.

Figure 3.5 shows an example of the Stage IV radar rainfall estimates of cumulative rainfall during a one hour period (April 17, 2013, 3 a.m. to 4 a.m.) in the Soap Creek Watershed. This figure helps demonstrate the gridded nature of the radar rainfall estimate data, as well as the distributed nature of rainfall in time and space during large storm events.

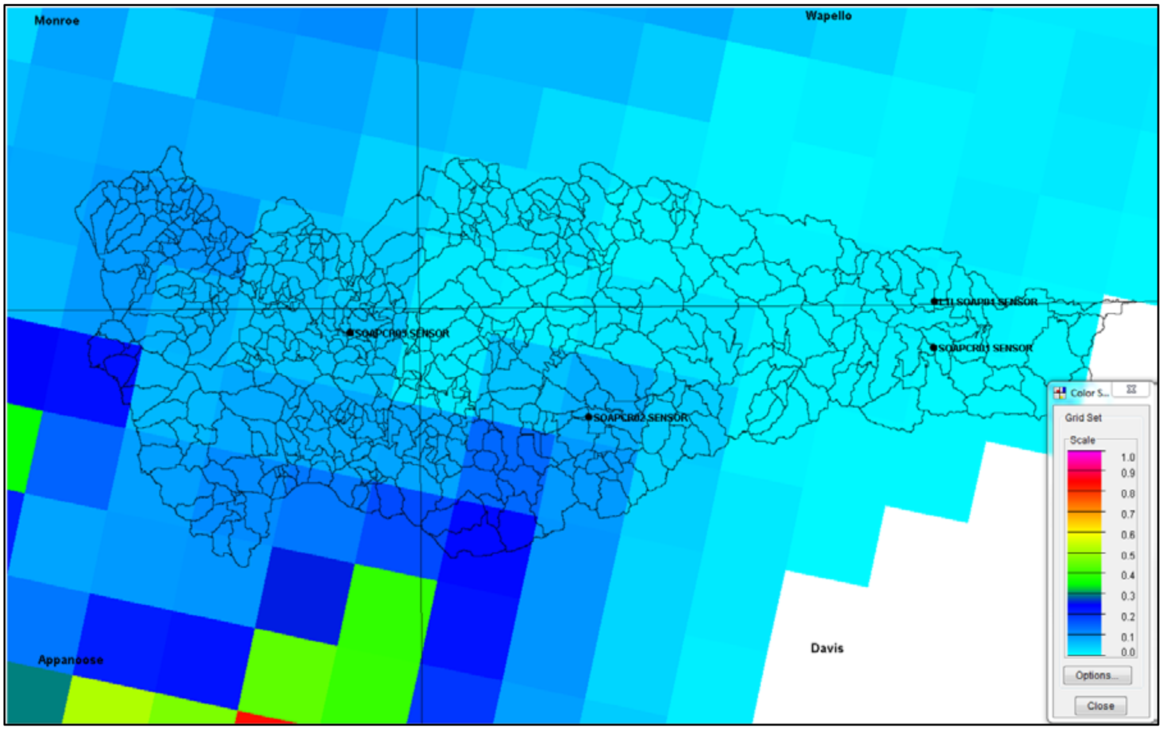


Figure 3.4. Demonstration of the gridded Stage IV radar rainfall product used in the Soap Creek Watershed HMS model. Radar rainfall estimates are available for each hour at a spatial resolution of 2.5 miles× 2.5 miles and were used for calibration and validation of historical storm events.

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 (QC) performed by the NWS that incorporates available rain gage measurements into the rainfall estimates. Actual storms using Stage IV data were the basis for model calibration and validation.

Hypothetical storms were developed for comparative analyses such as potential runoff generation, increased infiltration capacity through land use changes or soil improvements, and increased distributed storage within the watershed. These hypothetical storms apply a uniform depth of rainfall across the entire watershed with the same timing everywhere. Soil Conservation Service (SCS) Type-II distribution, 24-hour storms were used for all hypothetical storms. Point precipitation values (rainfall depths) for a 24-hour duration for recurrence intervals of 2, 5, 10, 25, 50, and 100-years were derived using the online version of National Oceanic and Atmospheric Administration (NOAA) Atlas 14 – Point Precipitation Frequency Estimates (Perica et al., 2013). The basin centroid was used as the point of reference for the point precipitation frequency estimates that were applied watershed wide for each average recurrence intervals storm.

Studies have been performed on the spatial characteristics of heavy rainstorms in the Midwestern United States (Huff and Angel, 1992). Point precipitation frequency estimates are generally only applicable for drainage areas up to 10 square miles; for drainage areas between 10 and 400 square miles, relations have been established between point precipitation estimates and an areal mean precipitation. 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). The point rainfall estimates were multiplied by an areal reduction factor of 0.92 (the areal reduction factor for the 258 mi^2 drainage area) for the Soap Creek Watershed.

Table 3.1. Rainfall depths used for hypothetical scenario analysis. The 24 hour duration point rainfall estimates for the 2, 5, 10, 25, 50, and 100 year recurrence intervals were reduced by an areal reduction factor of 0.92.

Hypothetical Storm	*NOAA Point Precipitation*	*Areal Reduced Precipitation*
2 year - 24 hour	3.19”	2.95”
5 year - 24 hour	3.94”	3.64”
10 year - 24 hour	4.65”	4.30”
25 year - 24 hour	5.71”	5.28”
50 year - 24 hour	6.57”	6.08”
100 year - 24 hour	7.52”	6.96”

Watershed (Basin Model)

The digital elevation model (DEM) that was used in Soap Creek was created using Light Detection and Ranging (LiDAR) technology. This tool is able to measure the distance from the emitting object to another surface by measuring the travel time of laser pulses (Sanborn, 2013). Four blocks of 1-meter resolution DEMs covering the extent of the Soap Creek Watershed were obtained from the Iowa Department of Natural Resources (IDNR). After averaging the 1-m resolution DEM to 3-m resolution, the DEMs were clipped to the needed extents using ESRI ArcGIS, and then the mosaic tool on the HEC-GeoDozer toolbar was used to join them into a seamless DEM. DEM data are distributed in geographic coordinates in units of decimal degrees, in conformance with the North American Datum of 1983 (NAD 83). All elevation values are in meters and are referenced to the North American Vertical Datum of 1988 (NAVD 88).

Soil Conservation Service (SCS) Curve Number methodology was used to determine the rainfall-runoff partitioning for the Soap Creek Watershed HMS modeling. Curve Number (CN) serves as a runoff index and values range from 34-100. As the CN becomes larger, there is less infiltration of water into the ground and a higher percentage of runoff occurs. CN values are an estimated parameter based primarily on the intersection of a specific land use and the underlying soil type, not a measured parameter. General guidelines for 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 watershed had fifteen different categories initially, but we reclassified them to ten to reduce the number of land use classes to make the task easier. Those land use class with similar characteristics were defined as one class. Table 3.2 shows the CNs assigned to each land use and soil type combination for the Soap Creek Watershed HMS model, and the how we reclassify the land use.

Table 3.2. Curve Numbers Assigned to Each Land Use/Soil Type Combination. Area-weighted averaging was used to calculate a single Curve Number value for each subbasin. Curve Numbers range from 34-100 with higher values reflecting greater runoff potential.

Original NLCD classification			*Soil Type*			
Number	*Description*	*Reclassification*	*A*	*B*	*C*	*D*
11	Open Water	1 – Wetlands	100	100	100	100
90	Woody Wetlands					
95	Emergent Herbaceous Wetlands					
21	Developed, Open Space	2 – Developed, Open	39	61	74	80
22	Developed, Low Intensity	3 – Developed, Low	61	75	83	87
23	Developed, Medium Intensity	4 – Developed, Medium	77	85	90	92
24	Developed, High Intensity	5 – Developed, High	89	92	94	95
31	Barren Land (Rock/Sand/Clay)	6 – Rock/Sand/Clay	98	98	98	98
41	Deciduous Forest	7 – Forest	44	65	76	82
42	Evergreen Forest					
43	Mixed Forest					
52	Shrub/Scrub	8 – Shrub	34	58	71	78
71	Grassland/Herbaceous	9 – Grassland, Pasture	49	70	80	87
81	Pasture/Hay					
82	Cultivated Crops	10 – Cultivated Crops	68	78	85	88

A CN grid was generated for the Soap Creek Watershed using ESRI ArcGIS with the HEC-GeoHMS extension tools to intersect the 2006 National Land Cover Dataset (NLCD) with digital soils data (SSURGO) available from the NRCS Web Soil Survey (WSS). Using the CN Grid, HEC-GeoHMS tools were then used to perform area-weighted averaging within each subbasin to assign a composite CN to each subbasin.

Using the NRCS Curve Number methodology for rainfall-runoff partitioning accounts for initial abstractions, the amount of precipitation that must fall before any runoff begins (losses due to plant interception, soil wetting, and storage in surface depressions), and continuing abstractions, the amount of precipitation that infiltrates into the ground. The remaining precipitation is considered excess precipitation and is converted to runoff. Evaporation and transpiration (evapotranspiration) were neglected, as the focus is on short-duration large rainfall events where evapotranspiration is a small component of the water balance.

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; as a result, more rain is converted to runoff. Therefore, a methodology was needed to adjust subbasin CNs to reflect the initial soil moisture conditions at the beginning of a storm simulation in order to better predict runoff volumes.

To account for antecendent moisture conditions (AMC) at the beginning of a simulation in the HMS, antecedent rainfall is used as soil moisture proxy. The traditional NRCS methodology attempts to account for different initial soil moisture conditions by defining CNs for three moisture conditions: AMC I (dry), AMC II (average or normal), or AMC III (wet), which correspond to the 10%, 50%, and 90% cumulative non-exceedance probabilities of runoff depth, respectively (Hjelmfelt, 1982). CNs are either increased (AMC III) or decreased (AMC I) from the average or normal condition (AMC II) based on the antecedent rainfall for five days total prior to the simulated event. The subbasin CNs calculated for the HMS model represents the AMC II condition.

Instead of using the 5-day antecedent rainfall total (which applies equal weight to each of the five days preceding a storm to describe soil moisture conditions), a more flexible antecedent precipitation (API) was used as a soil moisture proxy. The API is calculated uses a temporal decay constant that allows more weight to be applied to precipitation that fell closer in time to event of interest (Beck et al., 2009). Basin average daily API values were computed over a 43 year period (1970 to 2013) using records from NOAA hourly/daily precipitation station at Bloomfield. Like the traditional NRCS method, API analysis in this case has two parts, one is for the dormant season, and another one is growing season. In this case, the growing season refers to the months from April 1st to October 31st, while the dormant season includes the months from November 1st to March 31st. Since all the events used for both calibration and validation happened between April and August, we only needed the API for growing season in this case.

The CN was related to API so that appropriate CN adjustments could be made in the HMS model to reflect soil wetness conditions at the beginning of a simulation. First, we assume that the AMC I, II, and III CN classes represent the 10%, 50%, and 90% cumulative non-exceedance probabilities (or percentiles) of API. Using the computed API percentile for a historical storm event, an adjusted CN can then be found by linear interpolation (between the three ordered pairs containing the AMC I, II, and III CNs and the corresponding 10, 50, and 90th API percentiles). In this way, a continuous relationship between the CN the API (soil moisture proxy) for the event was developed. In contrast, the traditional NRCS methodology which allows only three discrete value for CN (the AMC I, II, and III CNs), based on the 5-day antecedent rainfall. Figure 3.5 illustrates the traditional NRCS methodology with its discrete CN values, and the continuous relationship between CN and API.

The method was further refined by calibration with four historical events for the Fox River Watershed. Calibration consisted of adjusting the initial subbasin CN estimates (for AMC II) to obtain the best correlation between simulated and observed peak discharge for each event. The percentage CN adjustment for these four events are plotted versus their corresponding API percentile in Figure 3.5. Since the calibrated CN adjustments tend to be less than that predicted by the original API percentile – CN curve, the curve was shifted downward by 2.67%. The adjusted API percentile – CN curve represents the final relationship used to adjust CNs for historical storm events.

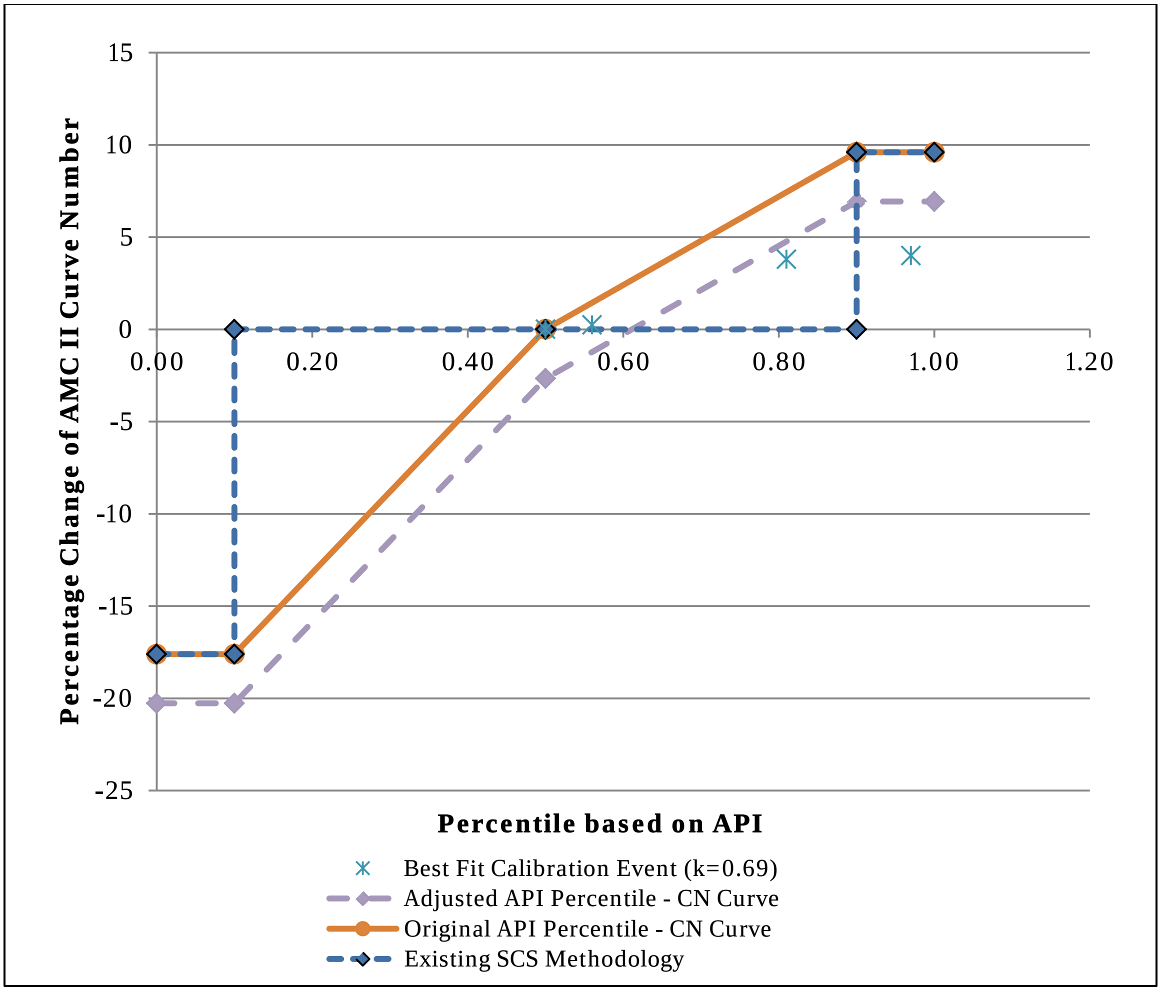


Figure 3.5. Accouting for antecedent moisture conditions in the Fox River Watershed HMS model. Precipitation gage records were used to quantify the soil wetness prior to historical event and corresponding precent change in Curve Number was applied to each subbasin Curve Number to reflect those conditions.

Runoff Hydrographs

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

Both of these methods required the estimation of two parameters: the time of concentration and the storage coefficient; both have units of time. The time of concentration is defined as the maximum travel time in the subbasin. The storage coefficient is used in the linear reservoir to account for storage effects. The time of concentration can generally be estimated knowing the lag time which describes the time difference between the center of mass of the excess precipitation and the peak of the runoff hydrograph. The time of concentration is 1.67 times the lag time, which is a reasonable approximation according to SCS methodology (Mays, 2010). The storage coefficient can be estimated with empirical equations (as some multiple of the time of concentration) and adjusted through calibration.

Inputs required to determine the basin lag time include the subbasin slope (in percent), the length of the longest flowpath for the subbasin (in feet), and maximum potential retention (in inches) in the subbasin, which is determined from the subbasin CN. ESRI ArcGIS tools were used for terrain analysis to identify subbasin slopes and the longest flow paths. The following graphic illustrates the SCS methodologies as applied for runoff volume estimation and conversion of the excess precipitation into a runoff hydrograph.

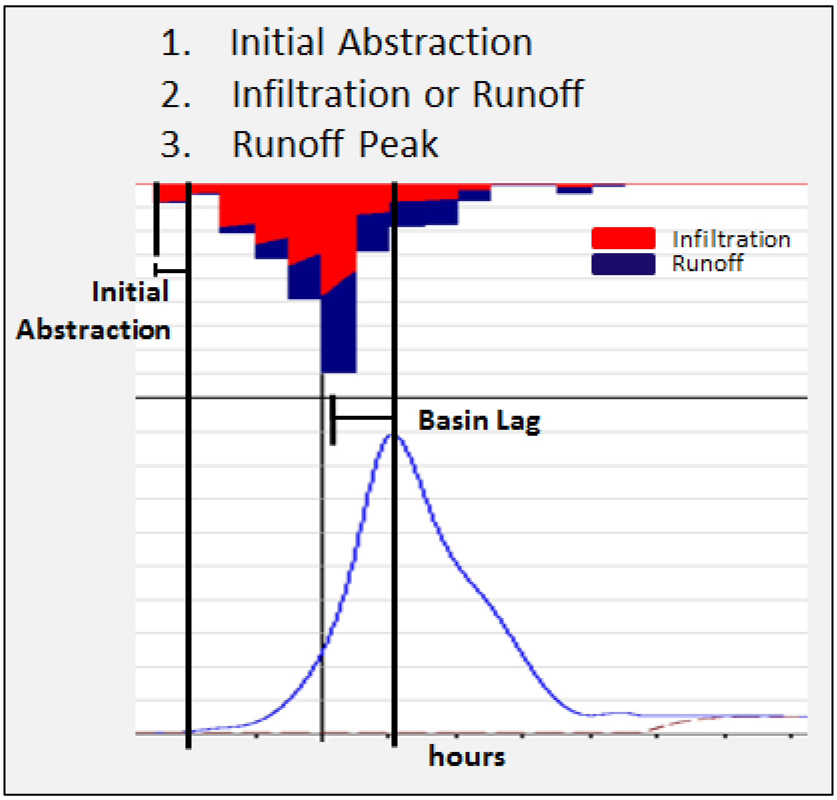


Figure 3.6. Subbasin runoff hydrograph conceptual model. This figure shows rainfall is partitioned into runoff using the SCS Curve Number methodology and converted to a runoff hydrograph.

ArcGIS to HEC-HMS

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

Parameters Assigned in HEC-HMS

Baseflow

Baseflow for the Soap Creek Watershed and the Fox River Watershed were computed using different methods. For the Soap Creek Watershed, where are no USGS streamgages, Flow Anywhere and Flow Duration Curve Transfer Statistical Methods developed by USGS in cooperation with Iowa Department of Natural Resources were used to compute daily mean streamflow at ungaged locations. 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. The method uses the daily mean streamflow at the reference streamgage, and the drainage-area ratio of the predicted and reference 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 an ungaged location. According to the USGS report, the Fox River at Wayland, Mo (0549500) streamgage was determined statistically to be best reference gage for estimating flows at ungaged locations in Soap Creek Watershed. Because most large floods in Iowa happen during the warm season, the HEC-HMS model simulations must represent warm season conditions. Therefore, the daily mean average streamflow of May-October, 2013 was computed and used for the baseflow separation. After separating baseflow from streamflow, several typical baseflow periods were averaged to get the initial baseflow for the Soap Creek Watershed (0.0049 cubic meter per second/per square meter). This initial baseflow was used for the hypothetical (design) storm simulation of the Soap Creek Watershed.

For the Fox River Watershed, baseflow was approximated by a first order exponential decay relationship for all historical storms. The USGS stream-gage for the Fox River at Bloomfield, IA (05494300) was used to develop discharge-drainage area (cubic feet per second/per square mile) relationships to set initial conditions for streamflow prior to each actual storm event simulation. These unique initial conditions were applied to the appropriate corresponding subbasins within the HMS interface for each actual storm event simulation. A baseflow recession constant describing the rate of decay of baseflow per day and a threshold indicating when baseflow should be reactivated were also specified.

Flood Wave Routing

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

b. Calibration and Validation

Calibration and validation of the models are necessary before using them in the research or real-world applications. Successful calibration requires an accurate and reliable historical record of both rainfall and stream data. However, because of no streamgage is present in the Soap Creek Watershed, the HEC-HMS model was not calibrated using historical data directly. In order to calibrate the hydrological model components without discharge records, an indirect calibration was performed. The concept of indirect calibration indicates that the parameters of hydrological models for a watershed with scarce or no discharge records can be estimated using regional information (Bárdossy, 2007). An assumption made when using this method is that watersheds with similar characteristics show a similar hydrological behavior. The calibration of Soap Creek Watershed involves four main processes:

Selecting a Similar Watershed

The Fox River Watershed is being used in this study since it has similar characteristics as the Soap Creek Watershed. The Fox River Watershed is also located within the Southern Iowa Drift Plain and adjacent to the Soap Creek Watershed. Additionally, the distribution of soil type and land use in these two watersheds are also similar (see comparison tables listed in Appendix C).

Calibration of Fox River HEC-HMS Model

Stage IV radar rainfall estimates and the USGS streamgage on the Fox River at Bloomfield, Iowa were used to calibrate the Fox River model. Four storms that occurred between June 2008 and May 2013 were selected for calibration. Storms were selected based on their magnitude, time of year, and the availibility of Stage IV radar rainfall estimates and USGS discharge estimates. Large, high runoff storms occurring between May and August were selected so the impacts of snow, rain on frozen grounds, and the freeze-thaw effects that exist during late fall to early spring conditions were minimized. Hydrographs for measured and simulated discharge are provided in Appendix C.

Validation of 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. With several of the largest storms already having been selected for calibration or having occurred before the availability of Stage IV radar rainfall estimates (January 2002), the next best available storms were selected. The small storm event of the April 24-27, 2010 and a large event that occurred April 17-19, 2013 were used for validation.

As with calibration, the HMS model validation results are not perfect. 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 was increased by 3.5% to reflect the wetter antecedent moisture conditions. For the April 17-19, 2013 event the model did a nice job simulating the total runoff volume, but the peak flow was slightly underestimated. More details about the calibration results are provided in Appendix C.

Transposing the parameters

After finalizing a set of parameters for the Fox River Watershed HMS model, these parameters were transferred to the Soap Creek Watershed model accordingly. The strategy used in this study partially follows transposition method by using some optimized parameters from the Fox River Watershed directly without any change, such as the recession constant of baseflow. Other parameters were changed based on the Soap Creek Watershed's own characteristics, such as the velocity of the flow. For instance, with the Soap Creek Watershed having steeper slopes, direct runoff flows faster within the Soap Creek Watershed than the Fox River Watershed. In this case, instead of using the velocity from the Fox River Watershed directly, we computed the ratio of the flow velocities from these two watersheds based on their land slopes and then came up with the flow velocity in the Soap Creek Watershed. Table C.4 in Appendix C provides the initial and calibrated parameters for the Fox River Watershed and parameters for the Soap Creek Watershed.

4. Analysis of Scenarios/Model Results

The HEC-HMS model for the Soap Creek Watershed was used to understand the effects of existing ponds, 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 strategies was placed on understanding the impacts of increasing infiltration in the watershed.

a. Effects of Existing Ponds

One strategy to lessen the effects of runoff is to construct a system of storage locations throughout the watershed (distributed storage). The most common type of flood storage is a pond. In agricultural areas, ponds usually hold some water all the time. However, ponds also have the ability to store extra water during high runoff periods. This so-called flood storage can be used to reduce flood peak discharges.

Unlike approaches for reducing runoff, storage ponds do not change the volume of water that runs off the landscape. Instead, storage ponds (Figure 4.1) 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 how quickly water is released. By adjusting the size and the pond outlets, storage ponds can be engineered to efficiently utilize its available storage for large floods and lessen downstream flood damages.

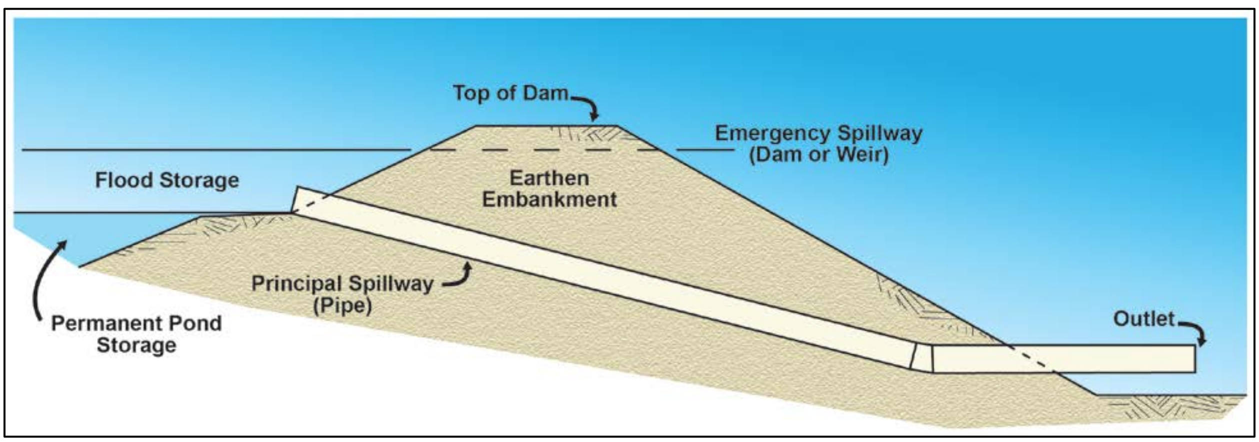


Figure 4.1. Schematic of a pond constructed to provide flood storage.

Storage ponds typically 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 outlet, water will pass through the pipe, leaving the pond, but at a calculated 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.

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

The design data for each constructed pond was gathered from the state NRCS office in Des Moines. When modeling ponds in HEC-HMS, the model needs a stage-storage-discharge relationship for each one. Table 4.1 shows an example relationship input to HEC-HMS for one of the ponds (Project 26-32).

Table 4.1. Stage-Storage-Discharge table for Project 26-32.

Stage (ft)	*Storage (ac-ft)*	*Discharge (ft^3/s)*
796.0	0.00	0.00
797.0	0.10	2.73
798.0	1.32	4.67
799.0	3.31	4.81
800.0	5.48	4.96
801.0	7.90	5.09
802.0	10.67	5.23
803.0	13.78	5.36
803.5	15.51	5.43
804.0	17.23	15.82
804.5	19.12	48.30
805.0	21.01	110.82
805.5	23.07	190.22
806.0	25.12	293.34
806.5	27.34	427.02
807.0	29.55	598.14
807.5	31.93	813.66
808.0	34.30	1080.62
809.0	39.40	1581.43
810.0	44.87	2239.52
811.0	50.70	3077.97

The HMS model was run quantify the effects of pond flood storage on peak discharges within the Soap Creek Watershed. Separate model runs were made using the following pond scenarios:

No ponds, Pond built before 1993, Ponds built before 1999, Ponds built before 2005, Ponds built before 2008, and Ponds built before 2013. Four index points shown in the Figure 4.2 were chosen as locations for evaluating the flood peak reduction effects of the ponds. Tables 4.2 – 4.5 show the area upstream of each index point, the area upstream of ponds for each index point, and the percentage of the area that is upstream. The tables also show the peak flow reduction at different index points for different pond scenarios for the 25-year return period 24-hour design storm (5.28 inches). The nearest cross streets to the Index Points are also provided in the table for reference.

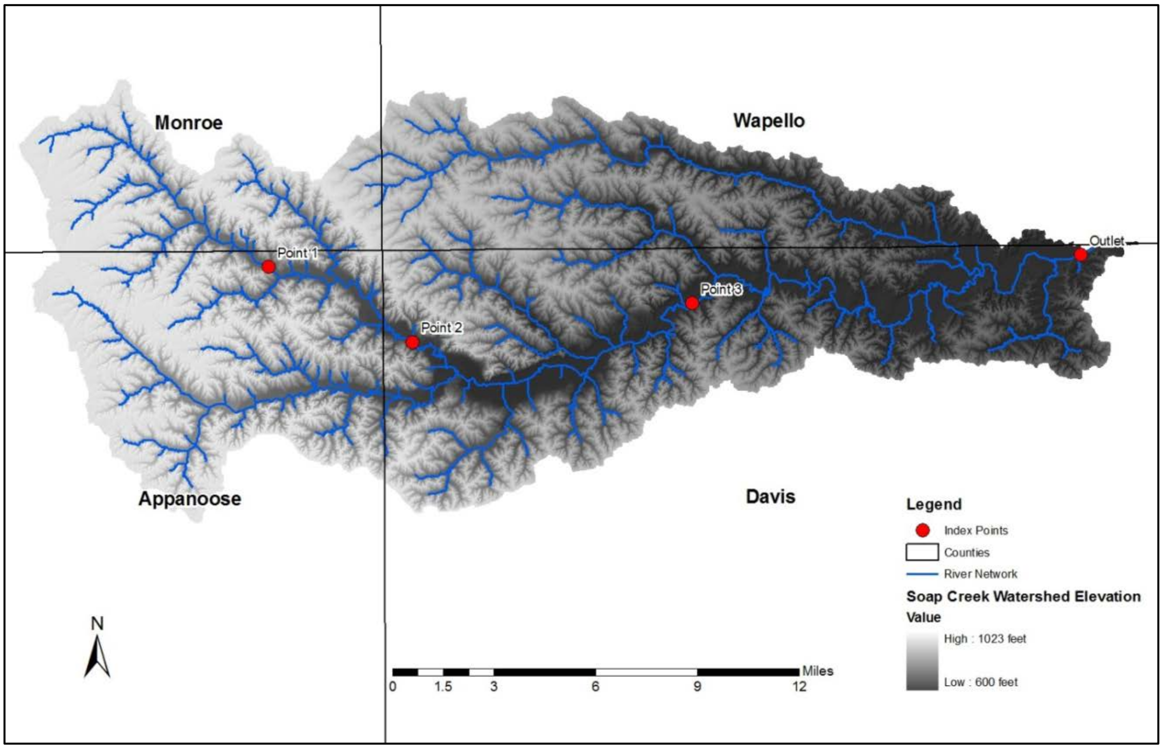


Figure 4.2. Four index locations used for comparing watershed improvement scenarios to current conditions. Nearest road intersections to each Index Point are provided in the tables below.

Table 4.2. Upstream area for Index Point 1 and peak flow reduction for the 25-year 24-hour storm (5.28 inches in 24 hours).

Point 1 402nd St/310th Ave – S4 T70N R16W		Upstream Area - 17,738 acres		
	Protected Area (acre)	*Protected Area*	*Peak Flow (cfs)*	*Peak Flow Reduction*
No ponds	0	0%	9,122	0.0%
Before 1993	131	0.7%	9,072	0.5%
Before 1999	2,103	11.9%	8,437	7.5%
Before 2005	5,178	29.2%	6,925	24.1%
Before 2008	5,951	33.5%	6,441	29.4%
Current	9,363	52.8%	5,446	40.3%

Table 4.3. Upstream area for Index Point 2 and peak flow reduction for the 25-year 24-hour storm (5.28 inches in 24 hours).

Point 2 Asteria Blvd/ 134th – S18 T70N R15W		Upstream Area - 33,821 acres		
	Protected Area (acre)	*Protected Area*	*Peak Flow (cfs)*	*Peak Flow Reduction*
No ponds	0	0%	15,323	0.0%
Before 1993	1,242	3.7%	15,139	1.2%
Before 1999	4,116	12.2%	14,454	5.7%
Before 2005	8,461	25.0%	12,682	17.2%
Before 2008	11,108	32.8%	11,290	26.3%
Current	15,994	47.3%	9,832	35.8%

Table 4.4. Upstream area for Index Point 3 and peak flow reduction for the 25-year 24-hour storm (5.28 inches in 24 hours).

Point 3 Jewel Avenue – S10 T70N R14W		Upstream Area - 94,705 acres		
	Protected Area (acre)	*Protected Area*	*Peak Flow (cfs)*	*Peak Flow Reduction*
No ponds	0	0%	27,263	0.0%
Before 1993	2,892	3.1%	25,967	4.8%
Before 1999	9,538	10.1%	24,879	8.7%
Before 2005	19,520	20.6%	22,036	19.2%
Before 2008	22,264	23.5%	20,709	24.0%
Current	27,577	29.1%	19,247	29.4%

Table 4.5. Upstream area for the Soap Creek Outlet and peak flow reduction for the 25 year 24-hour storm (5.28 inches in 24 hours).

Outlet		Upstream Area (acre) - 161,143		
	Protected Area (acre)	*Protected Area*	*Peak Flow (cfs)*	*Peak Flow Reduction*
No ponds	0	0.0%	37,674	0.0%
Before 1993	2,892	1.8%	36,198	3.9%
Before 1999	10,268	6.4%	34,612	8.1%
Before 2005	25,235	15.7%	30,674	18.6%
Before 2008	30,781	19.1%	29,078	22.8%
Current	39,208	24.3%	27,228	27.7%

Figure 4.3 shows the how peak flow reduction changes for the 25-year 24-hour storm with pond construction. As ponds are built, a greater percentage of the upstream area must drain through a pond (see Table 4.2). As the percentage of protected area upstream increases at each index point, the peak flow reduction increases as well. A similar trend is seen at all four index

locations; as the percentage of protected area increases, there tends to be a proportional increase in the peak flow reduction.

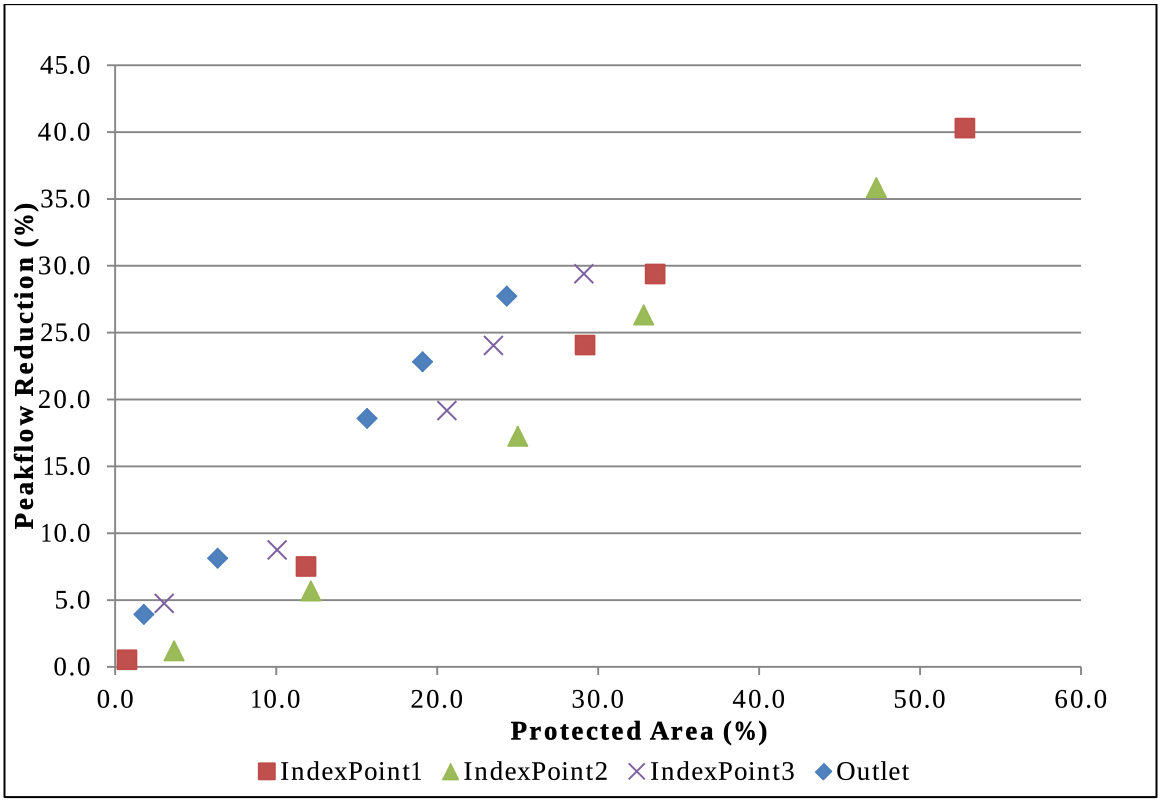


Figure 4.3. Peak flow reduction for percentage of the area that is upstream of the ponds at different index point for 25-year 24-hour design storm (5.28 inches).

Other comparisons were then made for the simulated flows assuming no ponds in place (the baseline condition). Flood hydrographs were compared for the 10-, 25-, 50-, and 100- year return period 24-hour SCS design storms.

Figure 4.4 compares the simulated flood hydrographs for the no ponds conditions (Without Ponds) to those with 132 built ponds (With Ponds) for the 25-year return period 24-hour design storm (5.28 inches of rain in 24 hours). For the hydrograph shown, peak flow reduction ranges from 28-40%. The percent reduction is greatest for the index point 1, which is located in the upper half of the watershed, and decreases towards the outlet.

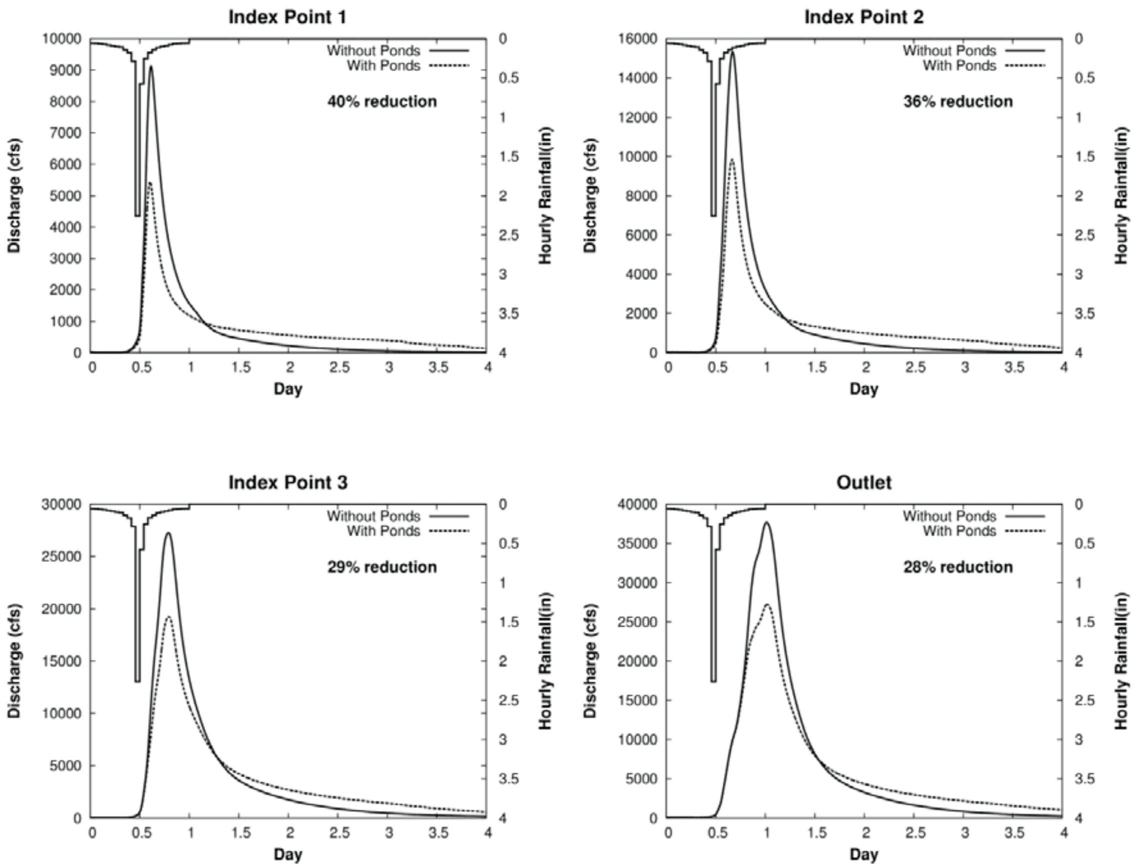


Figure 4.4. Comparison of hydrographs with 132 ponds and without ponds for the 25-year 24-hour design storm (5.28 inches).

Figure 4.5 shows the peak discharge reductions at the four index points for four different 24-hour design storms (10-year, 25-year, 50-year and 100-year), comparing the no pond and 132 built ponds conditions. As noted above, the peak flow reduction effect varies with drainage area. It is typically larger for small drainage areas, where the location is closer to the headwater ponds, and decreases in the downstream direction. Still, the figure shows that the percent of peak flow reduction at each index point is nearly the same for all the simulated flood events. At the Index Point 1, the peak flow reductions are around 40% for the four design storms, whereas at the outlet, they are near 27%.

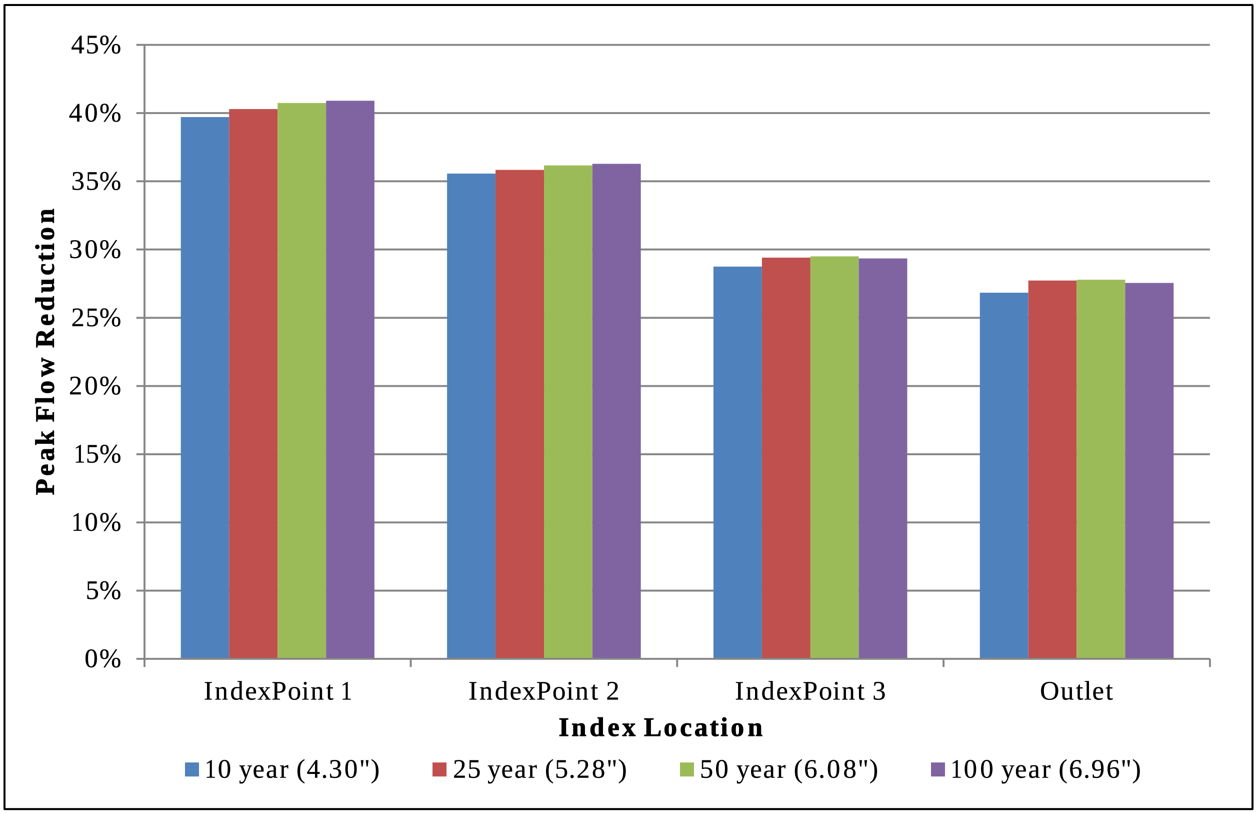


Figure 4.5. Peak discharge reductions for the model with ponds built before 2013. Results are shown at four index locations moving from upstream (left) to downstream (right) for four different 24 hour design storms.

To illustrate how effectively the ponds utilize their storage in the simulated flood events, a pond storage and pond usage map was created for each design storm (Figure 4.6 to Figure 4.13). Results are shown for the 10-, 25-, 50, and 100-year return period 24-hour SCS design storms.

The pond storage maps show the maximum volume of water storage divided by the upstream drainage. Reporting the pond storage as a depth makes it easier to determine what fraction of the precipitation for the storm is stored by the pond. The pond usage maps show the maximum volume of water storage divided by the pond's flood storage. A red circle symbol (see the legend of pond usage map) indicates that the pond usage is more than 100%, which means the water level is reached the emergency spillway elevation or even higher.

Figure 4.6 shows the pond storage map for the 10-year design storm (4.30 inches in 24 hours). Many of the ponds hold at least 1 inch of the total accumulation at their peak; this corresponds to about 23% of the total precipitation for the storm. Figure 4.7 shows pond usage map for the 10-year design storm. For the 10-year storm, only 4 of the 132 ponds reach their maximum designed storage. This indicates that the ponds have the potential to hold much more water.

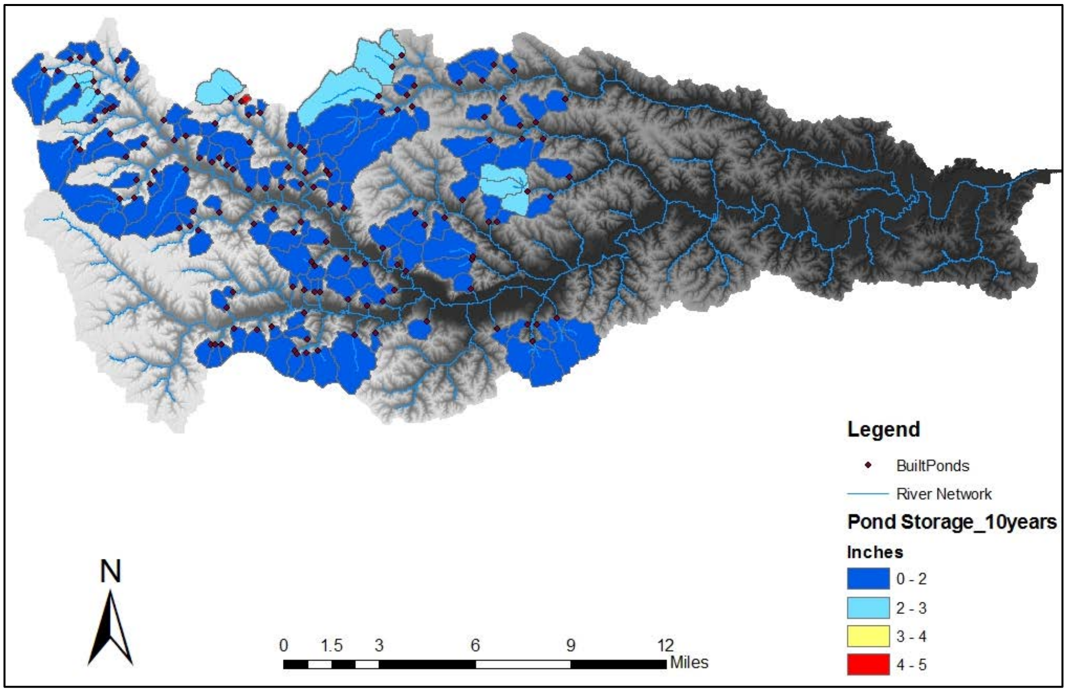


Figure 4.6. Peak Storage for the ponds built before 2013 (132 total) for the 10-year 24-hour design storm (4.30 inches).

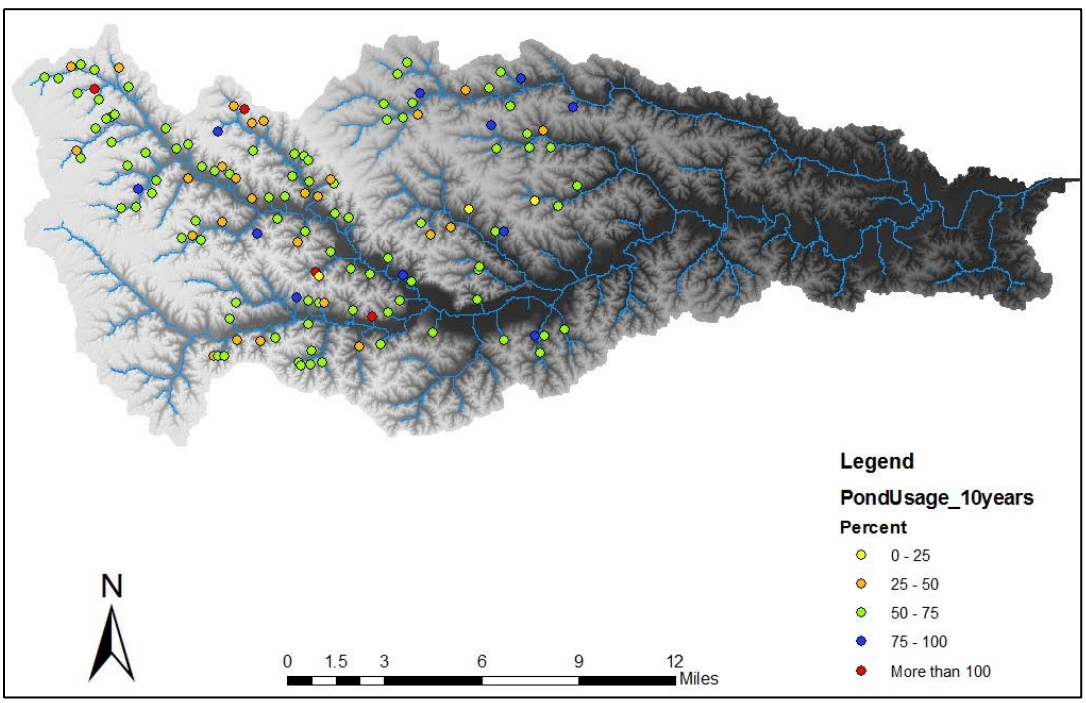


Figure 4.7. Percentage of storage used for the 10-year 24-hour design storm per pond (4.30 inches).

The results for the 25-year design storm (5.28 inches in 24 hours) are shown in Figure 4.8 and Figure 4.9. Figure 4.8 shows a larger percentage precipitation stored by the ponds; several are storing as much as 2-3 inches of rain (40 - 55% of the total rainfall). Figure 4.9 shows 25 of 132 ponds reached maximum flood storage.

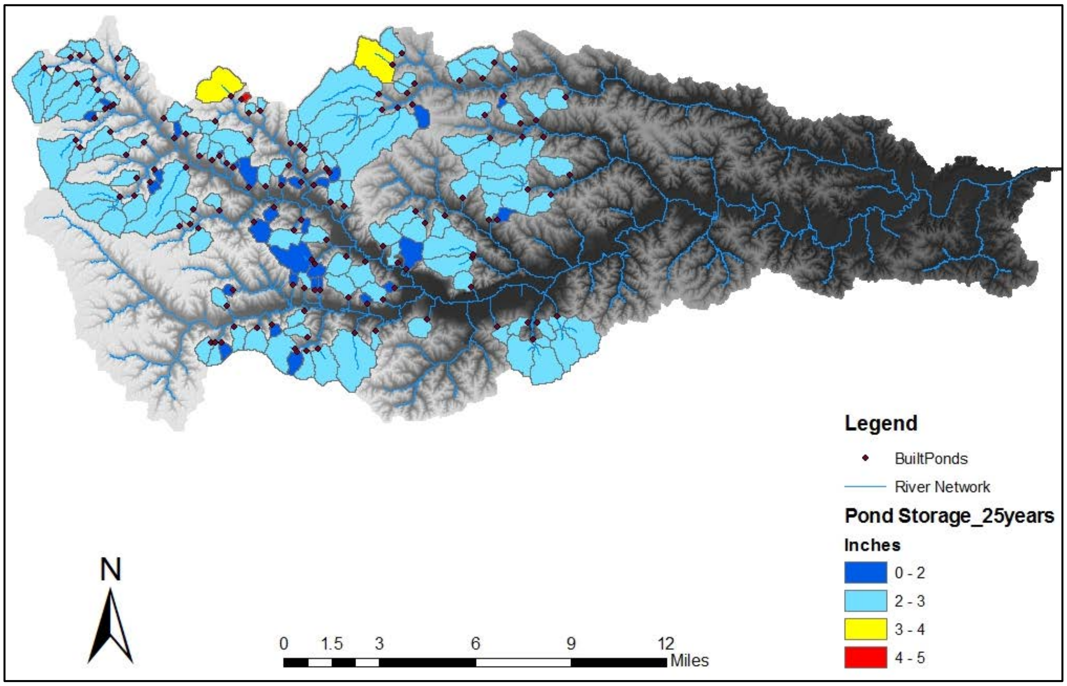


Figure 4.8. Peak Storage for ponds built pre-2013 for the 25-year 24-hour design storm (5.28”).

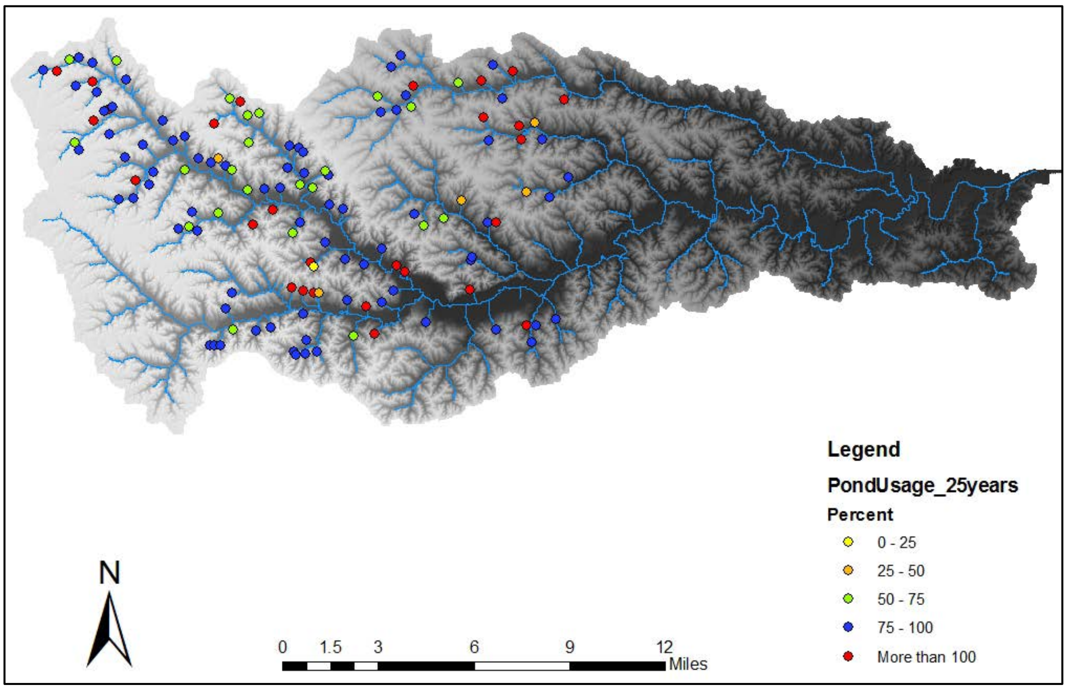


Figure 4.9. Percentage of storage used for the 25-year 24-hour design storm per pond (5.28”).

For the 25-year design storm (6.08 inches in 24 hours), Figure 4.10 shows many of the ponds hold at least 3 inches of the total accumulation during the peak, or about half of the total precipitation. Figure 4.11 shows 88 of 132 ponds (67%) reached their maximum flood storage.

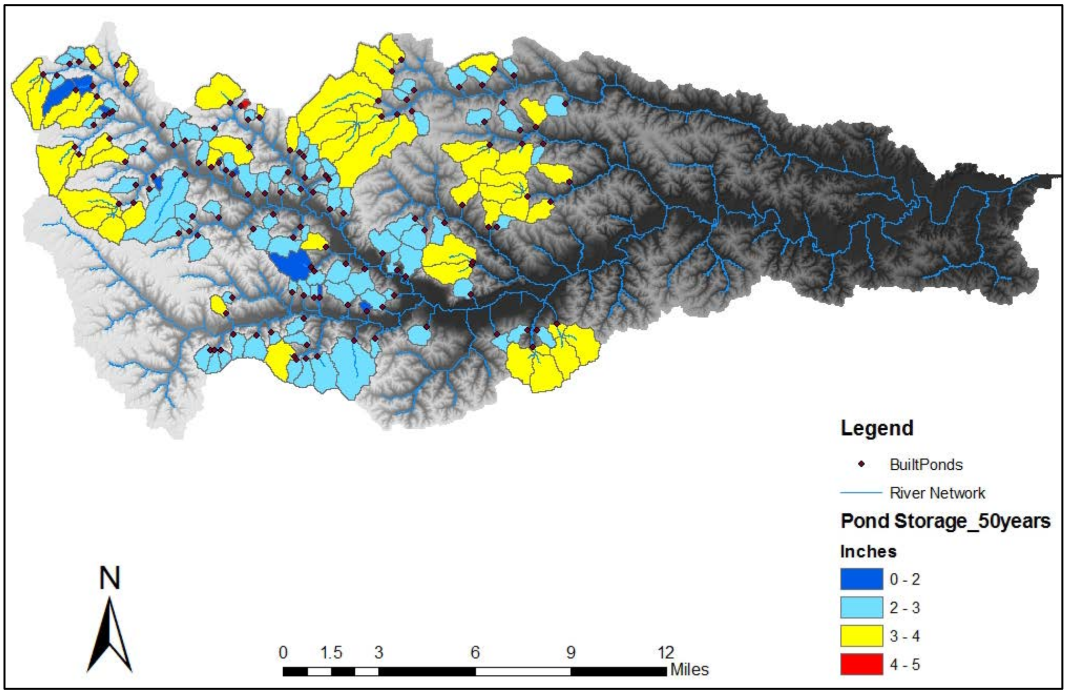


Figure 4.10. Peak Storage for the ponds built before 2013 (132 total) for the 50-year 24-hour design storm (6.08 inches).

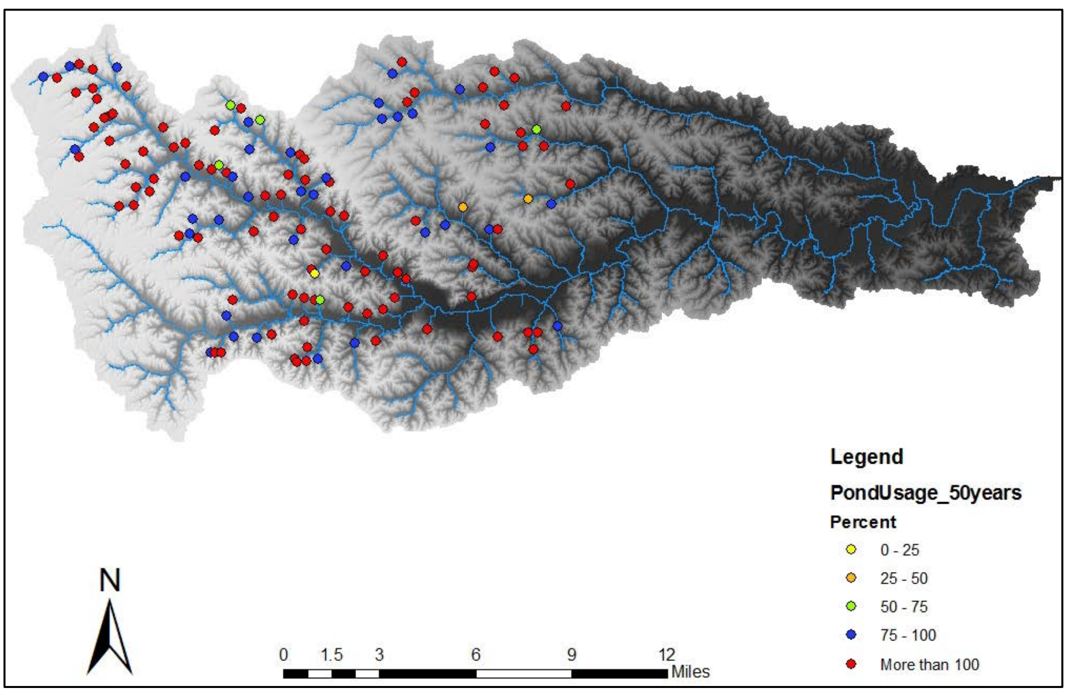


Figure 4.11. Percentage of storage for the 50-year 24-hour design storm per pond (6.1 inches).

The 100-year storm (6.96 inches in 24 hours) was the largest design storm simulated; it shows the effects the distribution of ponds have on a major flood. Figure 4.12 shows many of the ponds hold at least 3.0 inches of rain at their peak, and some can hold 4-5 inches of rain. Figure 4.13 indicates almost all ponds reached their maximum flood storage (121 out of 132 ponds). This number shows the system nearing its total capacity and in heavier rains, the ponds would not likely be able to hold back much more precipitation as effectively.

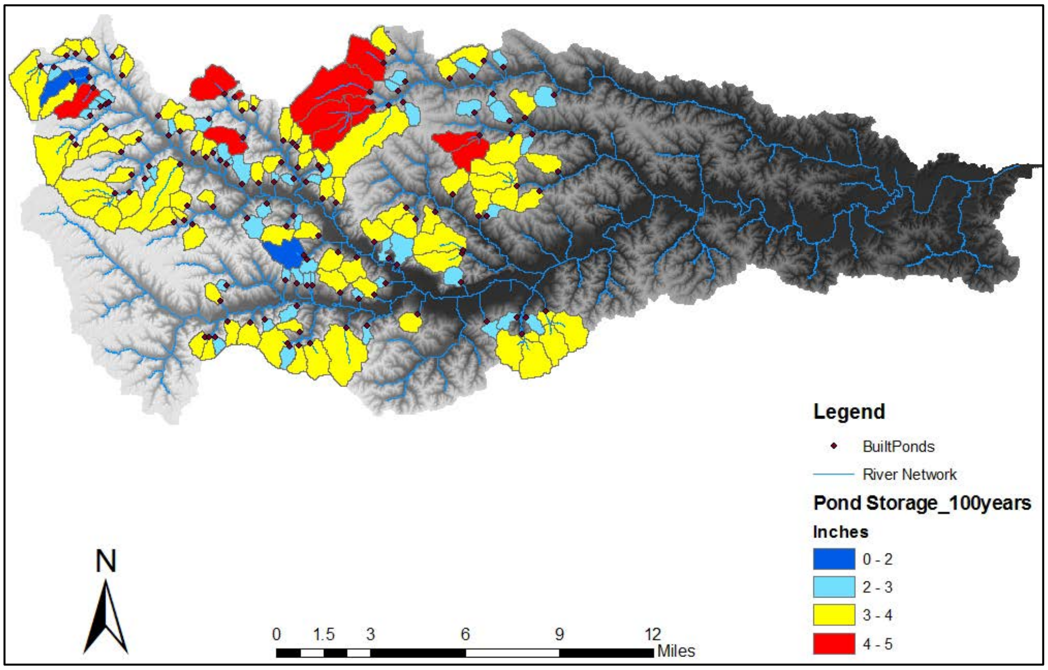


Figure 4.12. Peak Storage for the ponds built before 2013 (132 total) for the 100-year 24-hour design storm (6.96 inches).

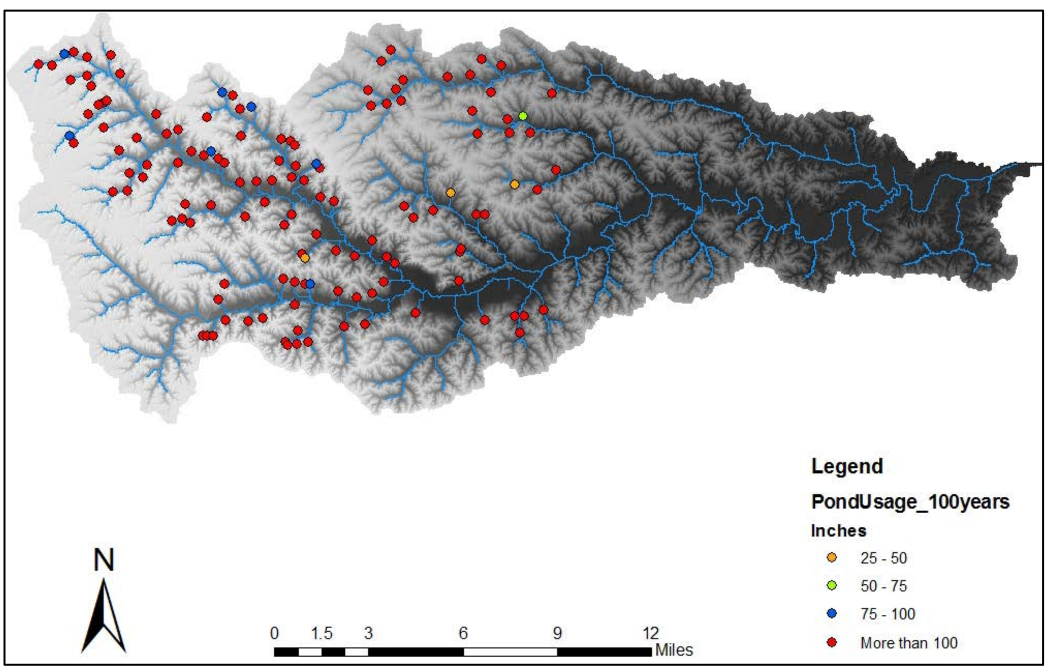


Figure 4.13. Percentage of storage used for the 100-year 24-hour design storm per pond (6.96 inches).

b. Area of high runoff potential

A sensible first step to implementing additional projects in the watershed — targeted towards reducing flood peaks and minimizing runoff — is to identify areas of the watershed with higher runoff potential. We define runoff potential by the percentage of that rainfall that is converted to runoff for each subbasin. This runoff potential is related to the SCS Curve Number, which depends on the land use and soils in the subbasin.

To evaluate the runoff potential, the runoff from each subbasin is simulated with the HMS model for the same rainstorm; we chose a rainstorm with a total accumulation of 5.28 inches in 24 hours (25-year average recurrence interval). Figure 4.14 shows the runoff potential analysis by subbasin and Figure 4.15 shows the runoff potential aggregated to the HUC 12 boundaries with the Soap Creek Watershed. As the figures show, almost all of the areas show more than 50% of the rainfall being converted to runoff. Even though the two dominant land uses within the Soap Creek Watershed are forest (35%) and pasture/hay (35%), the entire watershed still has very high runoff potential because of the soil type. As mentioned before, a majority of the soil within the Soap Creek Watershed is classified as hydrologic soil group C, C/D, and D, which are all poorly drained 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. For example, landowner willingness to participate is essential. Also, existing conservation practices may be in place, or areas such as timber that should not be disturbed. Stakeholder knowledge of places with repetitive loss of crops or roads/road structures is also valuable in selecting locations.

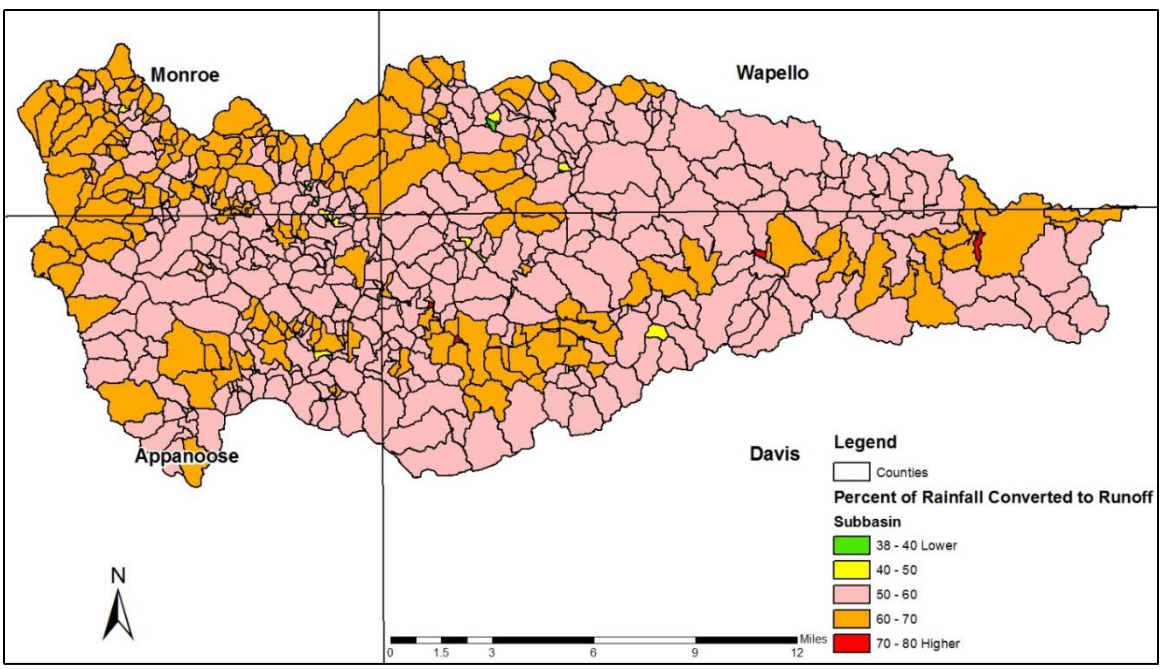


Figure 4.14. Runoff Potential Analysis Displayed by Subbasin Boundaries for the 25-year 24 hour storm (5.28 inches).

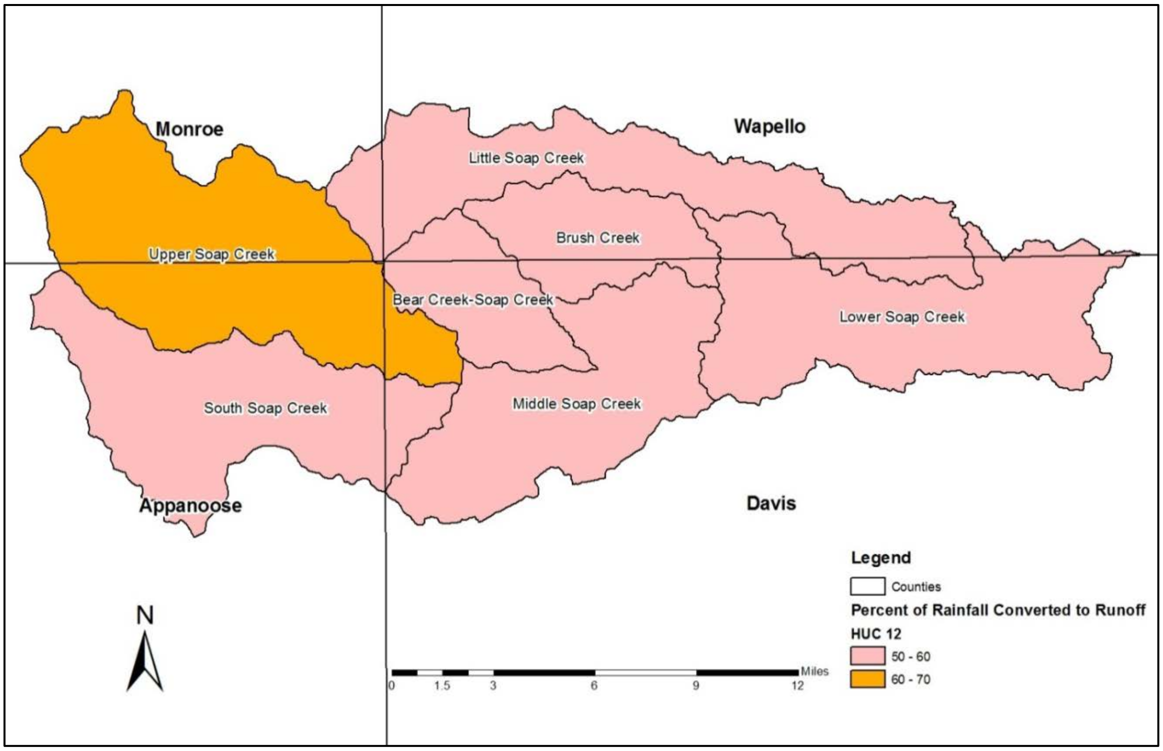


Figure 4.15. Runoff Potential Analysis Aggregated to HUC12 Boundaries for the 25-year 24 hour storm (5.28 inches).

c. Mitigating the Effects of High Runoff with Increased Infiltration

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

In this section, we examine two alternatives for reducing runoff. One is the conversion of row crop agriculture back to native tall-grass prairie within the Soap Creek Watershed, the other is improving soil quality. Both are hypothetical examples and are meant to illustrate the potential effects on flood reduction.

i. Hypothetical Increased Infiltration within the Watershed: Land Use Change

An analysis was performed to quantify the impact of human-induced land use changes on the flood hydrology of the Soap Creek Watershed. In this example, all lands currently used for cultivated crops are converted to native tall-grass prairie with its much higher infiltration characteristics. Obviously, returning to this pre-settlement condition is unlikely to occur. Still, the scenario provides an important benchmark to compare with any watershed improvement project considered.

Two methods to simulate the conversion to native tall-grass prairie with the HMS model were considered; for both, the model parameters affecting runoff potential across the landscape (Curve Number) were first adjusted to reflect the tall-grass prairie condition. Specifically, existing agriculture land use, which accounts for 14% of the watershed area, was redefined as tall-grass prairie. New SCS Curve Numbers, reflecting the lower runoff potential of prairie, was assigned to each subbasin. For the first method, only changes to the Curve Numbers were used. Thus, this method only considers the reduction in runoff volume resulting from the improved infiltrating characteristics of the native prairie. However, changing land use can also alter how long it takes water to flow over the landscape. Therefore, for the second method, we also considered the effects of slower travel times across a prairie landscape, and the resulting attenuation and delay in the timing of speak discharge that would be expected within the higher roughness of the prairie surface. To do this, in addition to changes to the Curve Numbers, model parameters affecting the travel time of runoff - the time of concentration and storage coefficient - were altered to reflect a prairie landscape.

Following the assignment of new subbasin model parameters, the HMS model was run for a set of design storms. Comparisons were made between current and tall-grass prairie simulations for the 10-, 25-, 50-, and 100- year return period 24-hour SCS design storms. Using design storms of different severity illustrates how flooding characteristics change during more intense rainstorms. The same four index points were used for comparison.

For the first method of representing a prairie landscape, Figure 4.16 compares simulated flood hydrographs for the current agriculture landscape (Baseline) to those for a native tall-grass prairie landscape (Scenario) for the 50-year return period 24-hour design storm (6.08 inches of rain in 24 hours). For all four locations shown (from upstream to the outlet of Soap Creek), a change to a prairie has little effect; the flood hydrographs and peak discharge rate are nearly the same for both cases (indeed, it difficult to distinguish between the two hydrographs in the plots). Overall, the percent reduction in peak discharge is less than 1% at all these index points. The minimal difference for a prairie landscape is a result of the soil types within the Soap Creek Watershed. About 58% of the Soap Creek Watershed is type D and about 33% is type C. For type C and D soils, the Curve Number for a prairie landscape is not much less than for existing landscape. Overall, the adjusted Curve Numbers for the prairie landscape decrease by only 0.4 % compared to the original Curve Numbers.

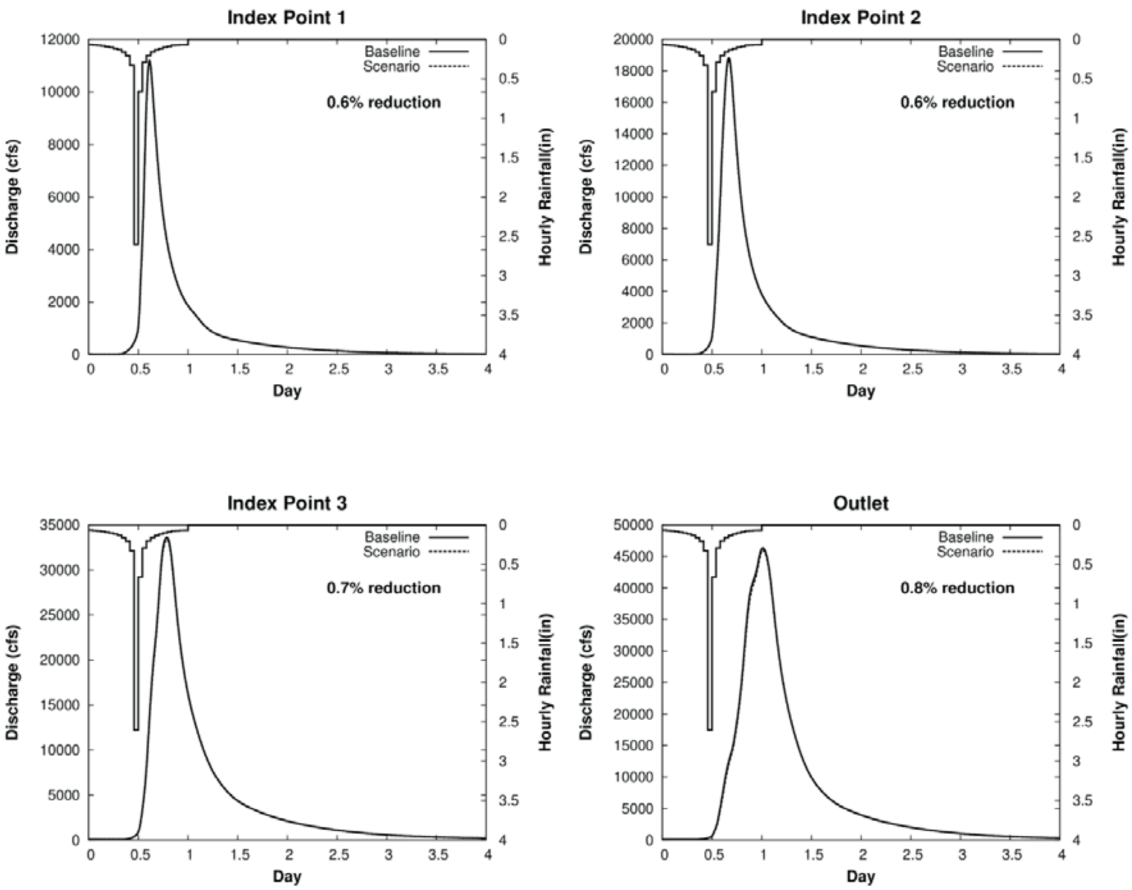


Figure 4.16. Hydrograph comparison at several locations for the increased infiltration scenario resulting from hypothetical land use changes (conversion of row crop agriculture to native prairie). Results shown are for the 50-year 24 hour storm (6.08 inches of rain).

Figure 4.17 shows the percent reductions in peak discharge resulting from this hypothetical tall-grass prairie at four index locations for four design storms. The restoration of native tall grass typically results in peak discharge reduction around 1%. The peak reduction is largest for the smallest design storm (10-year return period), and decreases with larger rainfall amounts (up to the 100- years return period). In other words, the runoff reductions benefits of increased infiltration are greater for smaller rainfall events. Note also that the percent reduction in peak discharge is fairly uniform at all locations. This outcome reflects the relatively equal distribution of agricultural land throughout the watershed.

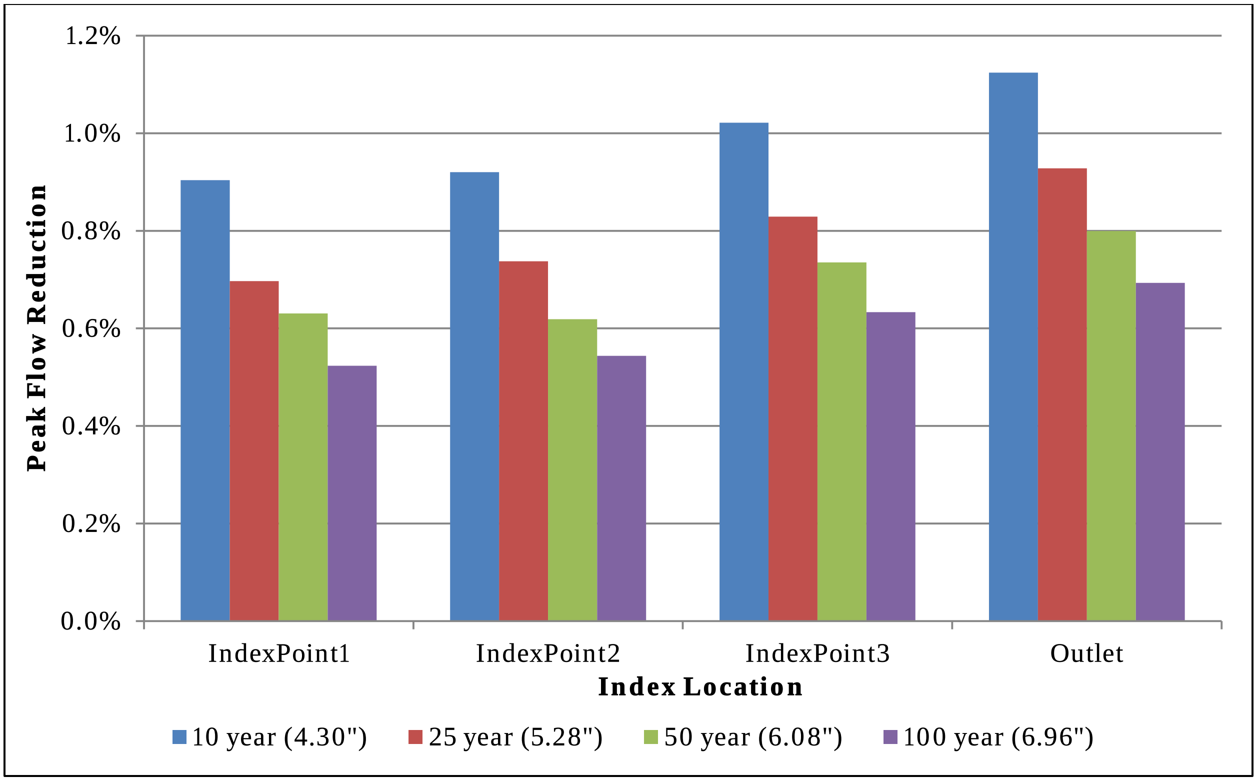


Figure 4.17. Percent reductions in peak flow for the increased infiltration scenario due to land use changes (conversion of row crop agriculture to native prairie). Peak flow reductions at four index points progressing from upstream (left) to downstream (right) are shown for four different 24 design storms.

The first method of representing a prairie landscape considers changes in runoff potential only. However, the second method considers both changes in runoff and the slower travel times of a prairie landscape. Figure 4.18 and 4.19 shows similar comparisons to the current agricultural landscape for the second method. The results are almost the same as for the first method. For the 50-year design storm (see Figure 4.18), the peak reduction effect is slightly higher upstream. At Index Point 1, when water travels more slowly across the prairie landscape (the second method compared to the first), the peak flow reduction increase from 0.6 to 1.0%. However, as the slower moving water accumulates at downstream locations, the significance of changing the travel time decreases. As a result, at the outlet, the peak reduction effect simulated by the methods is virtually identical. The same trends are also observed for both smaller (10- and 25-year) and larger (100-year) design storm events (see Figure 4.19).

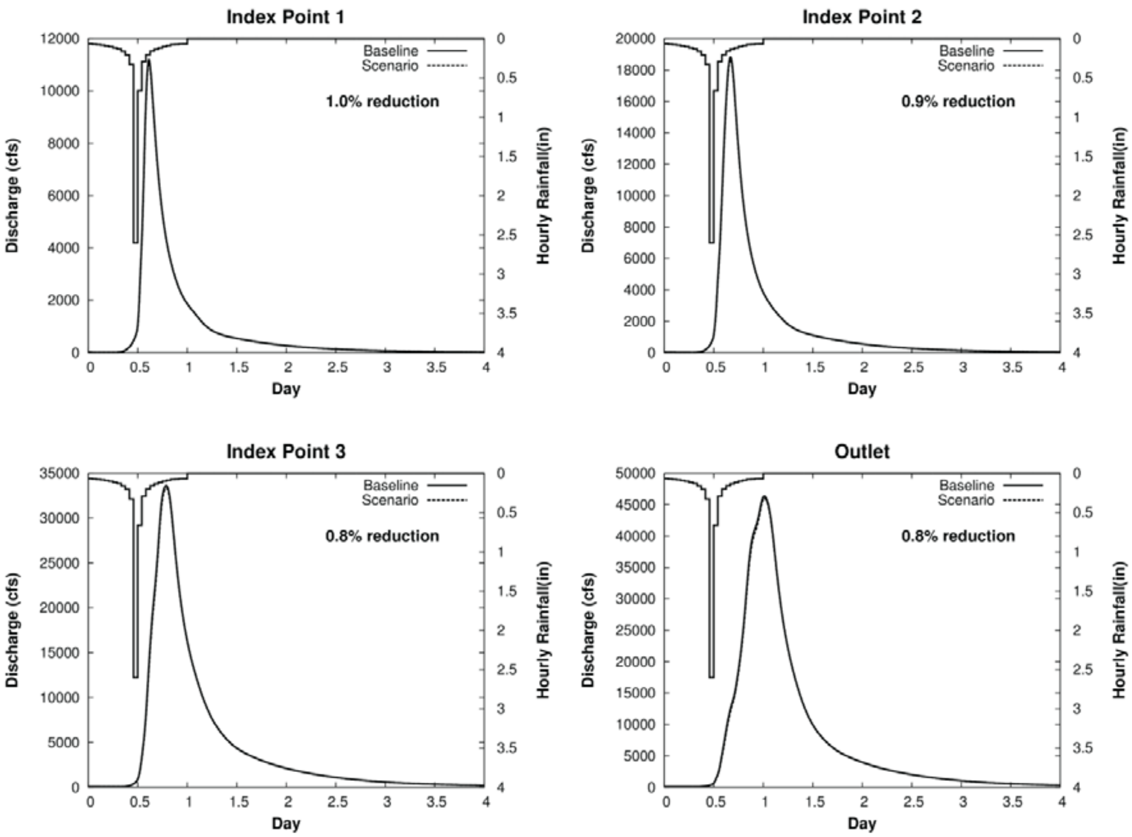


Figure 4.18. Hydrograph comparison at several locations for the increased infiltration scenario resulting from hypothetical land use changes (conversion of row crop agriculture to native prairie). Results shown are for the 50-year 24 hour storm (6.08 inches of rain).

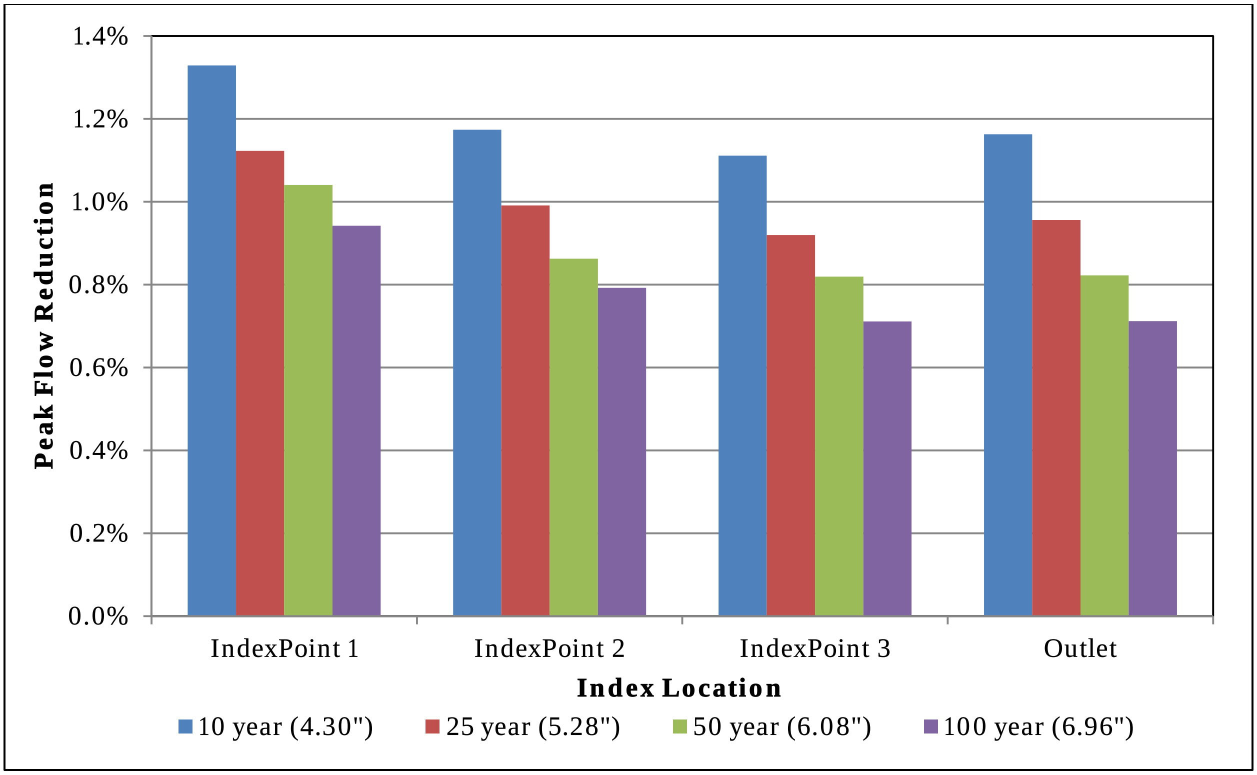


Figure 4.19. Percent reduction in peak flow for increased infiltration scenario due to land use changes (adjust other parameters estimated by CNs). Peak flow reduction at four index locations progressing from upstream (left) to downstream (right) are shown for four different 24 hour design storms.

ii. Hypothetical Increased Infiltration within the Watershed: Improving Soil Quality

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

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

In the HMS model of the Soap Creek Watershed, the effects of improved soil quality through conservation and best management practices are represented by changes in the NRCS hydrologic soil group. The most dominant soil type in the Soap Creek Watershed is Type D (including A/D, B/D, C/D), which makes up 58.4% of the area. In this case, improved soil quality is assumed to improve all Type D soils (clay) to Type C (loam containing silt and/or clay). Therefore, a new Curve Number grid was generated based on this new soil type, and was assigned to each subbasin. Then the model was run for a set of design storms. Comparisons were made between current and improved soil quality scenarios for the 10-, 25-, 50-, and 100- year return period 24-hour SCS design storm. As in the case of the prairie land use change, two methods were used to represent changes in soil quality; the first method considers changes in runoff potential only, and the second method considers both changes in runoff and travel times with soil improvement.

For the first method, Figure 4.20 compares the simulated flood hydrographs for the current soil condition (baseline) to those for the soil improvement case (scenario) for the 50-year return period 24-hour design storm (6.08 inches of rain in 24 hours). For the 50-year design storm, the simulated soil condition infiltrates 0.33 inches more water into the ground than the current condition. For all four index locations shown – from upstream (Index 1) to the outlet of Soap Creek – the peak discharge reduction is relatively uniform (8.7% to 10.6%). The outcome reflects the relatively even distribution of Type D soils throughout the watershed. Figure 4.21 shows the percent reductions in peak flow resulting from the first soil improvement case at four index locations for all four design storms. The peak flow reduction is greatest for smaller storms, and decreases systematically as storm rainfall increases. For the 10-year design storm, the peak reduction is between 12.1 and 14.7%. For the 100-year design storm, the peak reduction drops to between 7.8 and 9.2%.

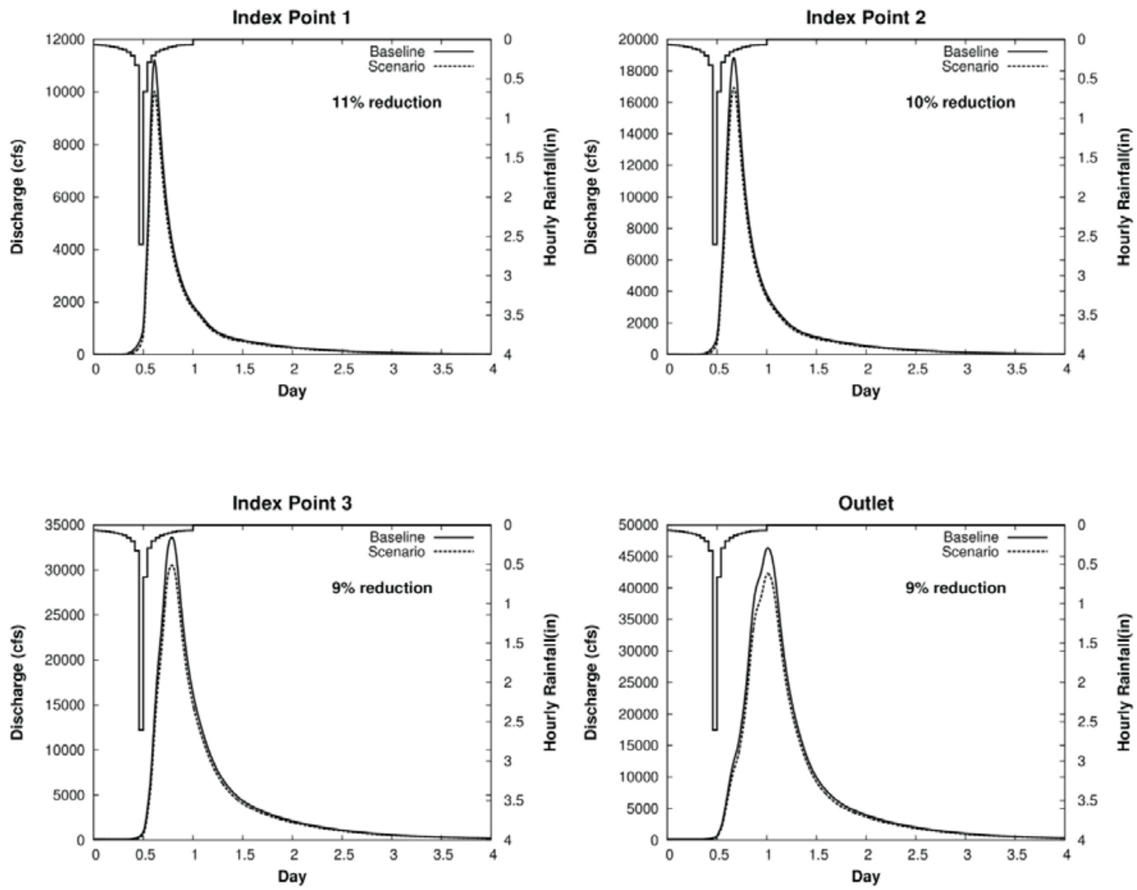


Figure 4.20. Hydrograph comparison at several locations for the increased infiltration scenario due to soil improvements (changes in runoff potential only). Improved soil quality was represented by converting all Hydrologic Group D (includes A/D, B/D and C/D) to C. Results shown are for the 50-year 24 hour storm (6.08 inches of rain).

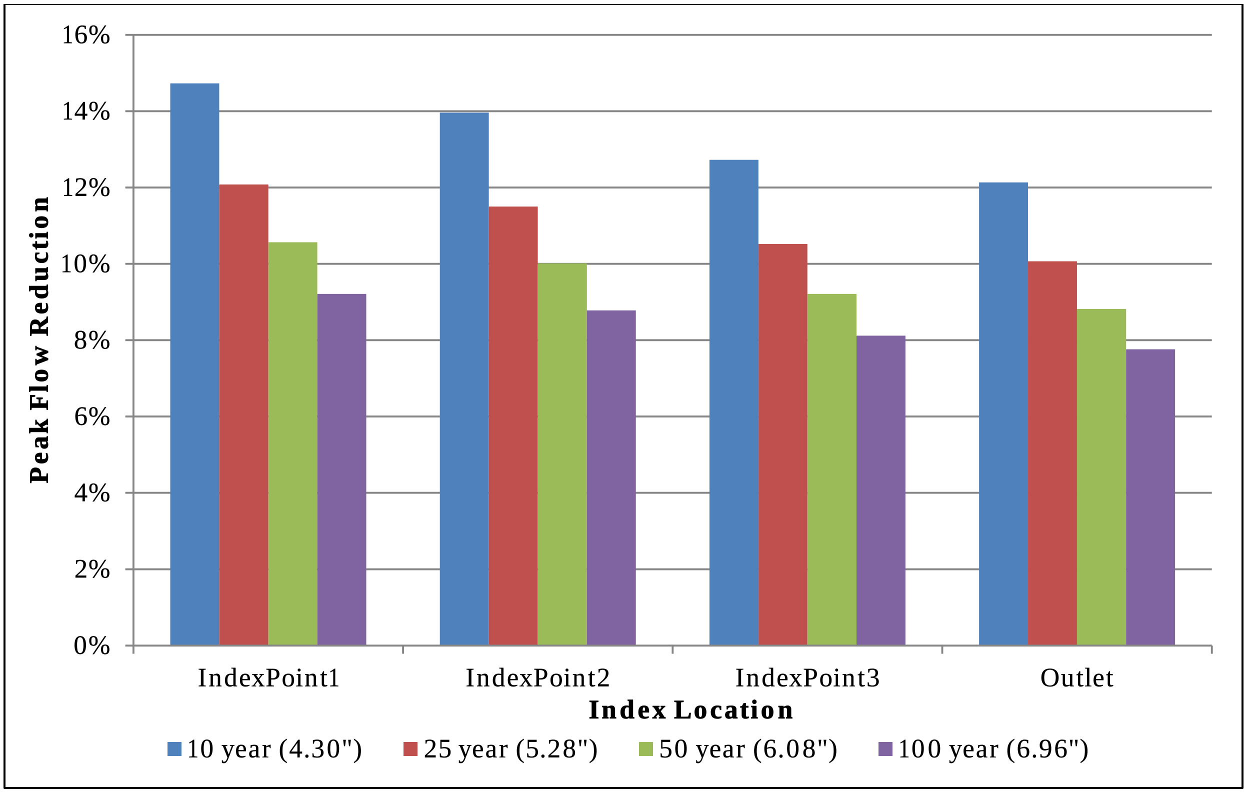


Figure 4.21. Percent reductions in peak flow for the increased infiltration scenario due to soil improvements (changes in runoff potential only). Improved soil quality was represented by converting all Hydrologic Group D (also includes A/D, B/D and C/D) to C. Peak flow reductions at four locations progressing from upstream (left) to downstream (right) are shown for four different 24 hour design storms (6.08 inches).

Figure 4.22 and 4.23 show the comparison results created by the second method, which accounts for both changes in runoff potential and travel times with soil quality improvements. Similar to the results seen for the change to a prairie landscape, adding the effects of travel time to the simulation has a small impact at upstream locations only. As Figure 4.22 shows, the peak flow reduction at Index Point 1 increases from 10.5 to 16.4%. There is also a slight reduction at Index Point 2. However, at the two downstream locations, the slower moving water produces no significant peak flow reduction. The same trends are also observed for both smaller (10- and 25-year) and larger (100-year) design storm events (see Figure 4.23).

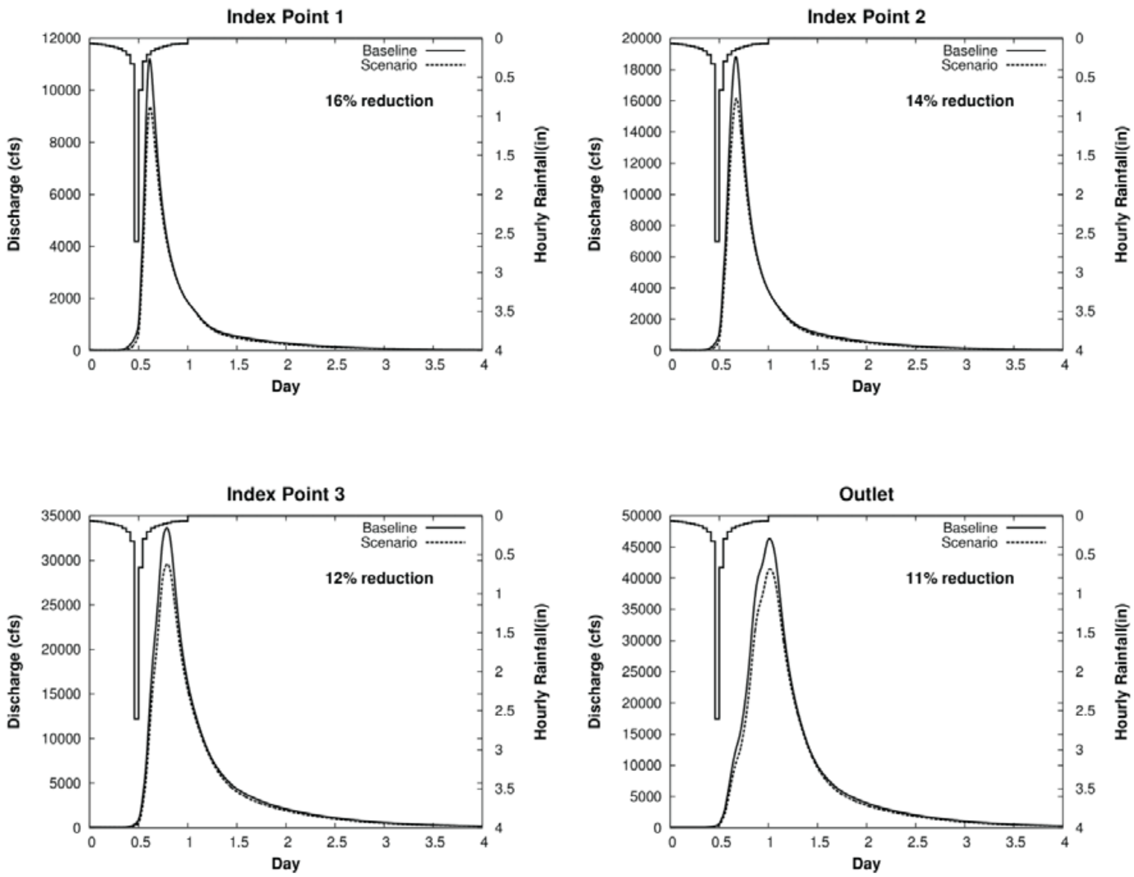


Figure 4.22. Hydrograph comparison at several locations for the increased infiltration scenario due to soil improvements (changes in runoff potential and travel times with soil quality improvements). Improved soil quality was represented by converting all Hydrologic Group D (includes A/D, B/D and C/D) to C. Results shown are for the 50-year 24 hour storm (6.08 inches of rain).

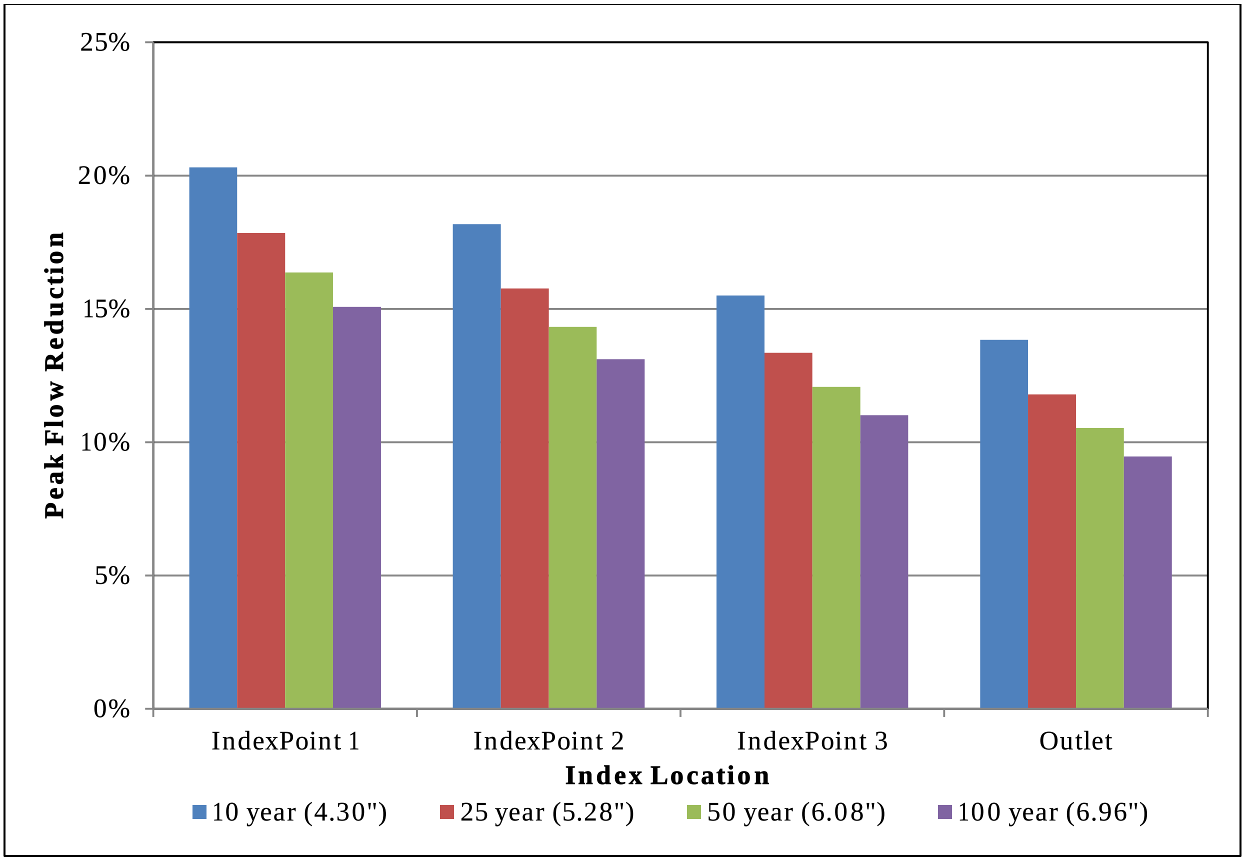


Figure 4.23. Percent reductions in peak flow for the increased infiltration scenario due to soil improvements (changes in runoff potential and travel times with soil quality improvements). Improved soil quality was represented by converting all Hydrologic Group D (including A/D, B/D and C/D) to C. Peak flow reductions at four locations progressing from upstream (left) to downstream (right) are shown for four different 24 hour design storms (6.08 inches).

5. Summary and Conclusions

This hydrologic assessment of the Soap Creek Watershed is part of the Iowa Watershed 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. The assessment is meant to provide local leaders, landowners and watershed residents in the Soap Creek Watershed an understanding of the hydrology - or movement of water - within the watershed, and potential of various hypothetical flood mitigation strategies.

a. Soap Creek Water Cycle and Watershed Conditions

The water cycle of the Soap Creek Watershed was examined using historical precipitation and streamflow records. The average annual precipitation for the Soap Creek Watershed is 38.8 inches. The Soap Creek Watershed is ungaged, so historical records of streamflow are unavailable. However, the adjoining Fox River Watershed, located directly south of Soap Creek, has a long stream record. We use the flow records at the adjoining Fox River as an indicator of the hydrology in this portion of the state. For the Fox River Watershed, evaporation accounts for about 69% of precipitation and the remaining 31% runs off the landscape into the streams and river. The Fox River has a baseflow ratio less than 1 (0.6): about 19% of precipitation leaves surface flow, and 12% leaves as baseflow. The annual maximum peak discharge can occur in almost any month of the year.

The water cycle has changed due to land use and climate changes. The largest change occurred in the late 1800s when the landscape was transformed from low-runoff prairie and forest to higher-runoff farmland. Since the 1970s, Iowa has seen increases in precipitation, changes in timing of precipitation, and change in the frequency of intense rain events. Streamflow records in Iowa (including the one for the Fox River) suggest that average flows, low flows, and perhaps high flows have all increased and become more variable since the late 1960s or 1970s; however, the relative contributions of land use and climate changes are difficult to sort out.

The entire Soap Creek Watershed is located within the Southern Iowa Drift Plain which is dominated by glacial deposits left by ice sheets that extended south into Missouri over 500,000 years ago. Soils of the watershed have high runoff potential: the primary soil types are C, C/D, and D (32.7%, 10.0% and 48.1%, respectively). The topography is characterized by irregular narrow ridges with steep slopes and narrow gullied valleys. Slope are between 0-161% (A flat surface is 0%, a 45 degree surface is 100%). The Soap Creek Watershed is comprised of approximately 35% pasture/hay and 35% deciduous forest, evenly distributed within the watershed. Flooding from Soap Creek and its tributaries occurs nearly every year and more often in some reaches (United Sates Department of Agriculture, 1988).

b. Soap Creek Watershed Hydrologic Model

The U.S. Army Corp of Engineers' (USAE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was used to develop a flood prediction model for the Soap Creek Watershed. First, the watershed was divided in 642 smaller units, called subbasins, with an average area of about 0.39 square miles. Since the Soap Creek Watershed is ungaged, the HEC-HMS model was not calibrated and validated using historical data directly. Instead, a model for the adjoining Fox River Watershed was calibrated using its streamgage data (at Bloomfield), and then its parameters were transposed to the Soap Creek Watershed model. For the analysis of watershed scenarios, 24-hour duration design storms (an NRCS Type-II distribution) with rainfall accumulations equal to the 10-, 25-, 50-, and 100-year return period basin-average depths were used as the precipitation input.

The NRCS Curve Number (CN) methodology was used to determine the rainfall-runoff partitioning the Soap Creek Watershed HMS modeling. The CN methodology 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. Clark Unit Hydrograph methods were selected for converting excess precipitation into a direct runoff hydrograph for each subbasin to better account for the impacts of tile drainage. Baseflow was simulated with actual (historical) rainfall events for model calibration and validation, as well as the analysis of watershed scenarios with hypothetical design storms. Conveyance of runoff through the river network, or flood wave routing, was executed using the Muskingum routing method.

Model calibration adjusts the initial set of model parameters so that simulated results match observed discharges at gaging stations more closely for historical events. As noted before, we only calibrated and validated the HEC-HMS model for the Fox River Watershed. Four storms that occurred between June 2008 and May 2013 are selected for calibration. The small storm event of the April 2010 and a large event that occurred April 2013 were used for validation. After finalizing a set of parameters for the Fox River Watershed HMS model, these parameters were transferred to Soap Creek Watershed model accordingly.

c. Watershed Scenarios for the Soap Creek Watershed

To better understand the flood hydrology of the Soap Creek Watershed, and to evaluate potential flood mitigation strategies, the HEC-HMS model of the watershed was used in several ways. We first assessed the flood mitigation effects of the ponds that have been constructed within the watershed. We simulated conditions without ponds, and for conditions representing the state of pond construction from 1993 to today. Simulations of flows throughout the basin were made for the 10-, 25-, 50- and 100-year recurrence interval 24-hour design rainfall. These events correspond to rainfall amount of 4.30, 5.28, 6.08 and 6.96 inches in 24 hours over the entire Soap Creek Watershed.

Before considering additional strategies for flood mitigation, we assessed the runoff potential throughout the basin using the HMS model's representation of storm runoff generation from the landscape. Locations with agricultural land use and moderately to poorly drained soils have the highest runoff potential; mitigating the effects of high runoff from these areas is a priority for flood mitigation planning. Note that other land uses — particularly urban development in towns and cities — may have even higher runoff. But because their size is small compared to that of the HMS model's subbasins (the basic element for runoff simulation), individual communities are not identified by this technique (only individual subbasins, which may include a small portion of urban land, are identified). Still, typical strategies employed to manage urban stormwater are needed in these communities (e.g., stormwater detention and low-impact development practices).

To quantify the potential effects of increasing infiltration as a flood mitigation strategy, we considered two hypothetical scenarios. The first scenario increases infiltration by changing land use. In this case, the agricultural lands within the Soap Creek Watershed (about 36 square miles) were changed to native tall-grass prairie, which has a greater infiltration capacity. The second scenario increases infiltration by changing soil quality. Improving soil quality also increases the infiltration and storage capacity of the soils. The effects of these two strategies were also simulated for significant design flood events – those resulting from a 10-, 25-, 50- and 100-year recurrence interval 24-hour design rainfall. 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.

Figure 5.1 summarizes the relative effectiveness of each flood mitigation strategy considered for reducing peak discharge. The outlet was selected as the location for comparison, and the relative impact of each strategy from highest to lowest is shown for both the 10-year, 24-hour design storm (4.30 inches of rain in 24 hours) and the 25-year, 24 hour design storm (6.96 inches of rain in 24 hours) simulation. A brief summary of each flood mitigation strategy and concluding remarks are provided in the following sections.

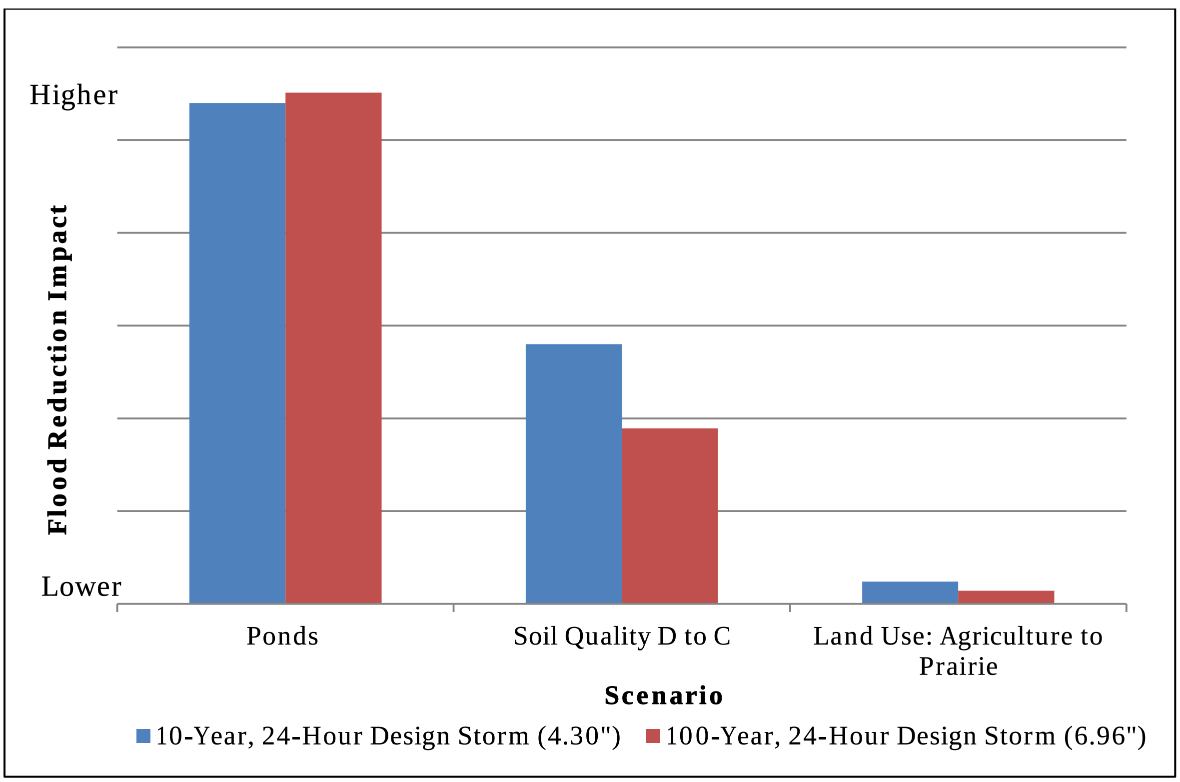


Figure 5.1. Comparison of the relative impact of the flood mitigation scenarios for reducing peak discharge at the outlet of the Soap Creek. The ponds had the greatest flood reduction while restoration of native prairie has the lowest impact for both 10-year, 24-hour design storm (4.30 inches of rain in 24 hours) and 100-year, 24-hour (6.96 inches of rain in 24 hours).

i. Effects of Existing Ponds

The simulation results for the pond scenarios demonstrate their efficiency and effectiveness as a flood mitigation strategy. The ponds are very effective in reducing flood peaks throughout the watershed. They are most effective in reducing flood peaks immediately downstream of with locations. At downstream locations, floodwaters originating from locations throughout the watershed arrive at vastly different times; some areas are upstream by ponds, others are not. The result is that the storage effect from areas upstream of ponds is spread out in time, instead of being concentrated at the time of highest flows. Hence, as one moves further downstream in the watershed, the flood peak reduction of storage ponds slowly diminishes. Owing to their hydraulic design, the ponds were equally effective in reducing peak discharge for the smallest (10-year) and largest (100-year) design storm simulated. Peak reductions ranged from 40% at the upstream-most site, to about 28% at the outlet. For the 100-year design storm, almost all the ponds (121 out 132) would completely utilize all their flood storage, and have flows over their emergency spillways. Therefore, one could anticipate that for floods much larger than the 100-year design storm, the peak reduction effect of the system of ponds might start to decrease from what was simulated.

ii. Increased Infiltration in the Watershed: Land Use Change

From the simulation results, changing agricultural lands to native tall-grass prairie is not an effective strategy for reducing peak flows in the Soap Creek Watershed. Simulated peak flow reductions ranged from about 0.7% (at the outlet) to about 1.2% (at an upstream location). Only a relatively small portion of the current landscape has an agricultural land use, and the basin's soils have naturally high runoff potential; as a result, changes of agricultural lands to tall-grass prairie are not predicted to significantly enhance infiltration. Still, for very small drainages within the Soap Creek Watershed where the land use is predominately agricultural, there could be beneficial localized reductions in peak flows with upstream changes to prairie land use.

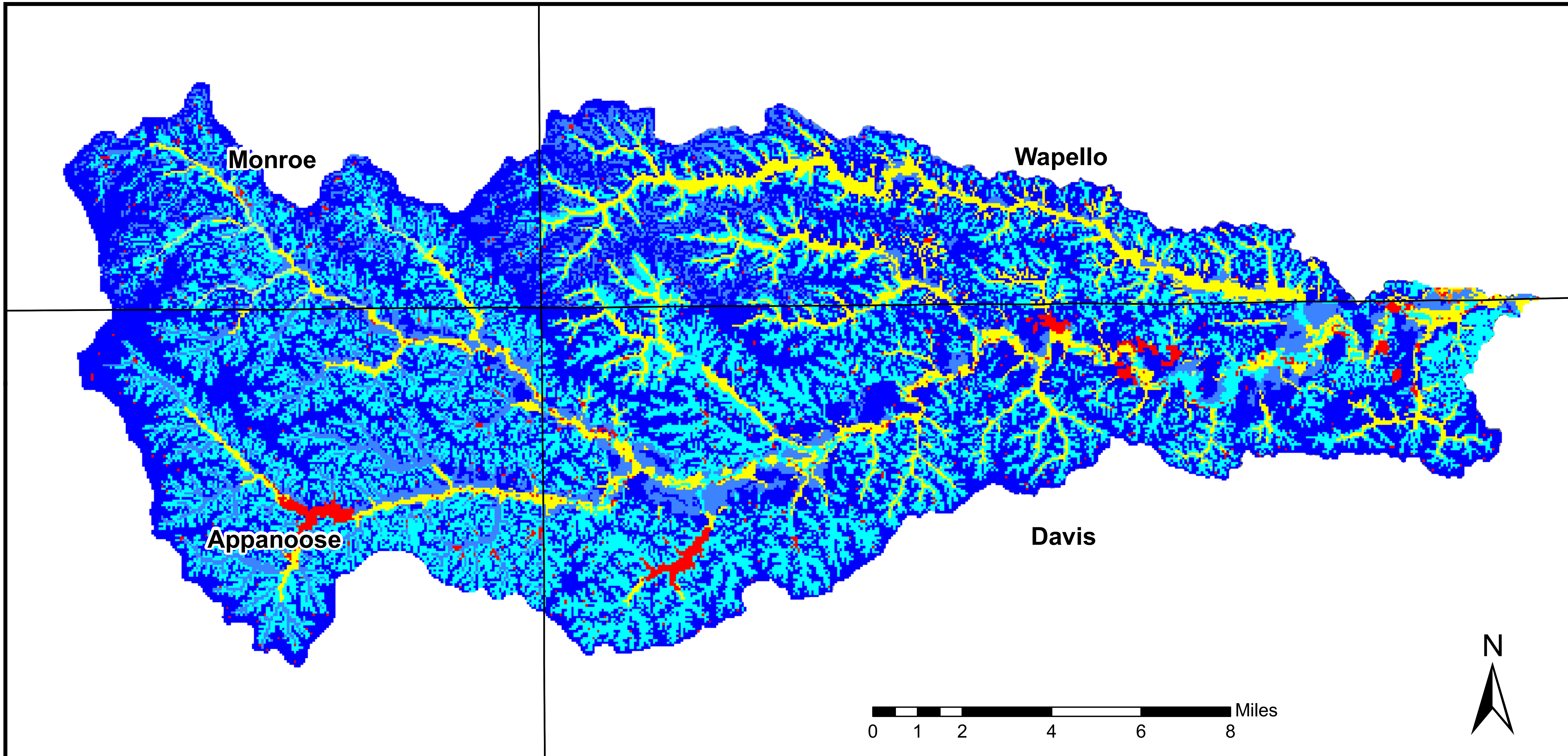
iii. Increased Infiltration in the Watershed: Improving Soil Quality

Even without changes to land use, the storage capacity of the soil could be better utilized by improving soil quality to enhance infiltration. The hypothetical improved soil quality scenario suggests that it is a much more effective strategy than land use change. For the 50-year design storm, the improved soil quality scenarios predict an increased infiltration by 0.36 inches. The peak flow reduction effect of improved soil quality is greatest for smaller storms, and decreases systematically as storm rainfall increases. For the 10-year design storm, the peak reduction is between 13.8 and 20.3%. For the 100-year design storm, the peak reduction drops to between 9.5 and 15.1%. For the Soap Creek Watershed, with its current mix of forest, undeveloped, and agricultural lands, efforts to improve soil quality could be an effective part of a watershed-wide flood mitigation strategy.

d. Concluding Remarks

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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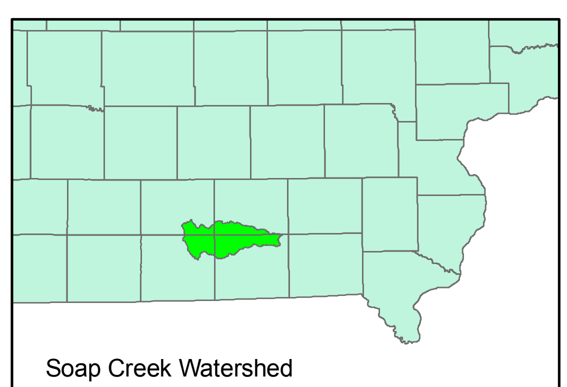
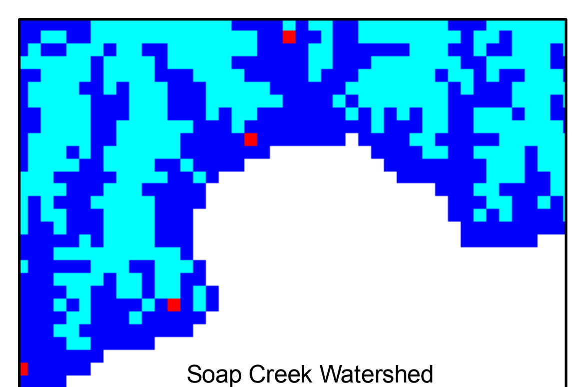




Soap Creek Watershed
Soil

Legend

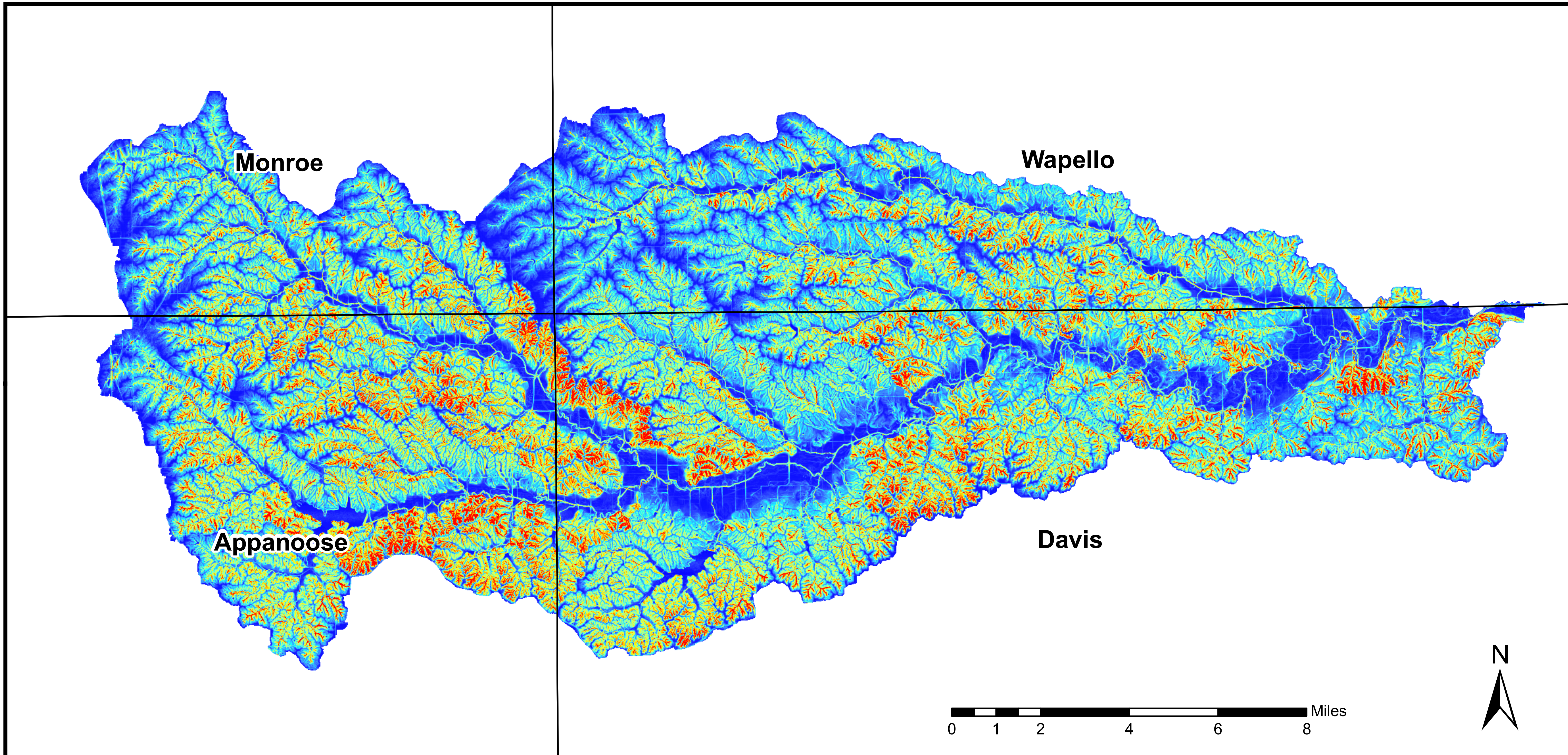
Hydrologic Soil Type
- A
- A/D
- B
- B/D
- C
- C/D
- D

Date: 04/25/2014

By: Jingyun Sun

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

Figure A-1



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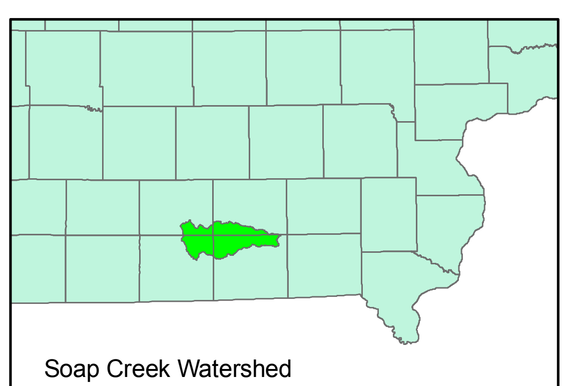
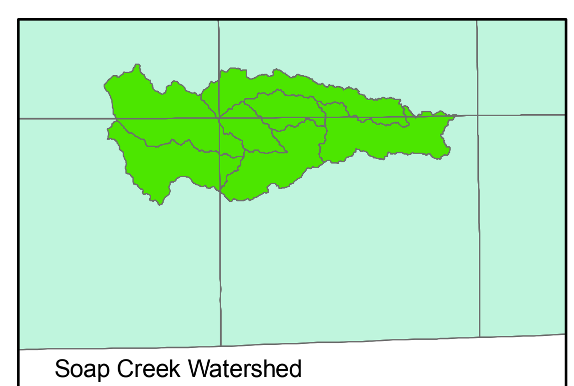




Soap Creek Watershed
Watershed Slope

Legend

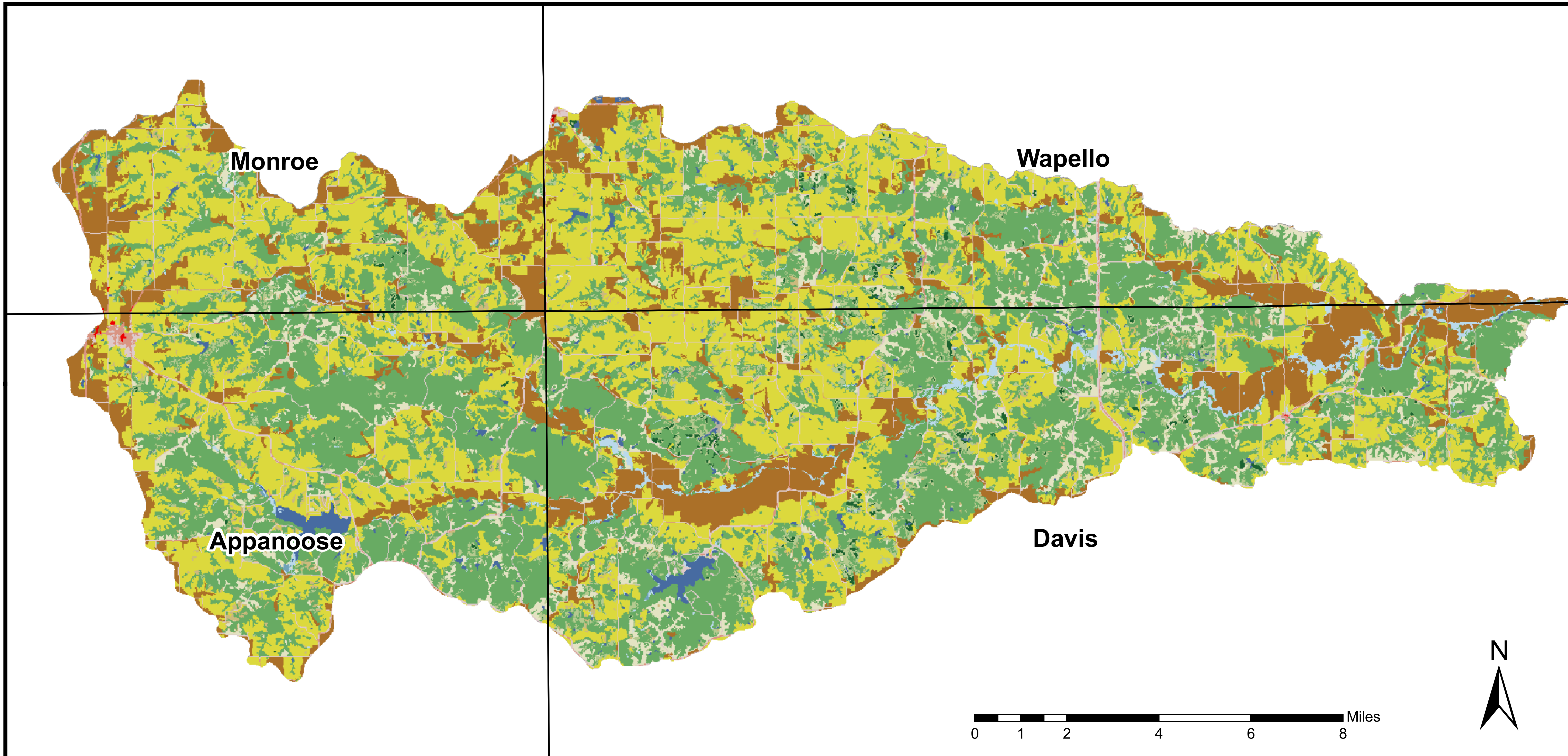
Watershed Slope
High
Low
Counties

Date: 04/25/2014

By: Jingyun Sun

Data Sources:
Extracted using LiDAR DEM Data (1 m), IDNR.

Figure A-2



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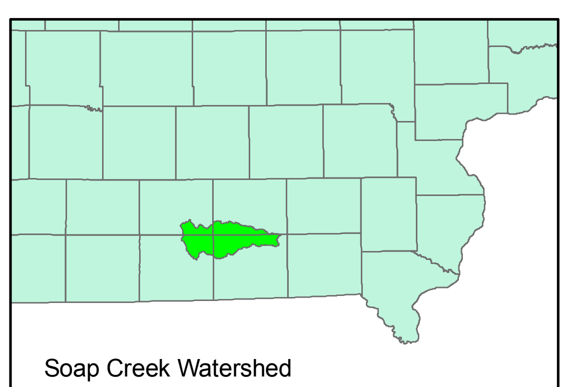
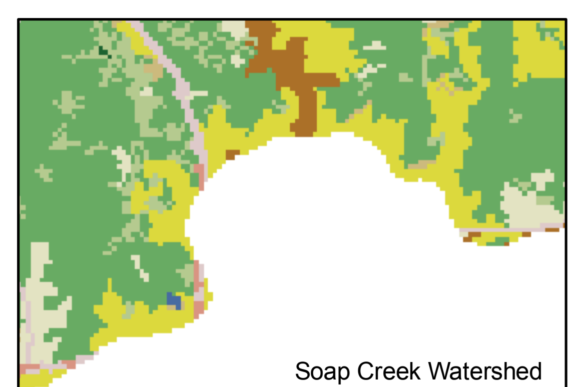




Soap Creek Watershed
Land Cover

Legend

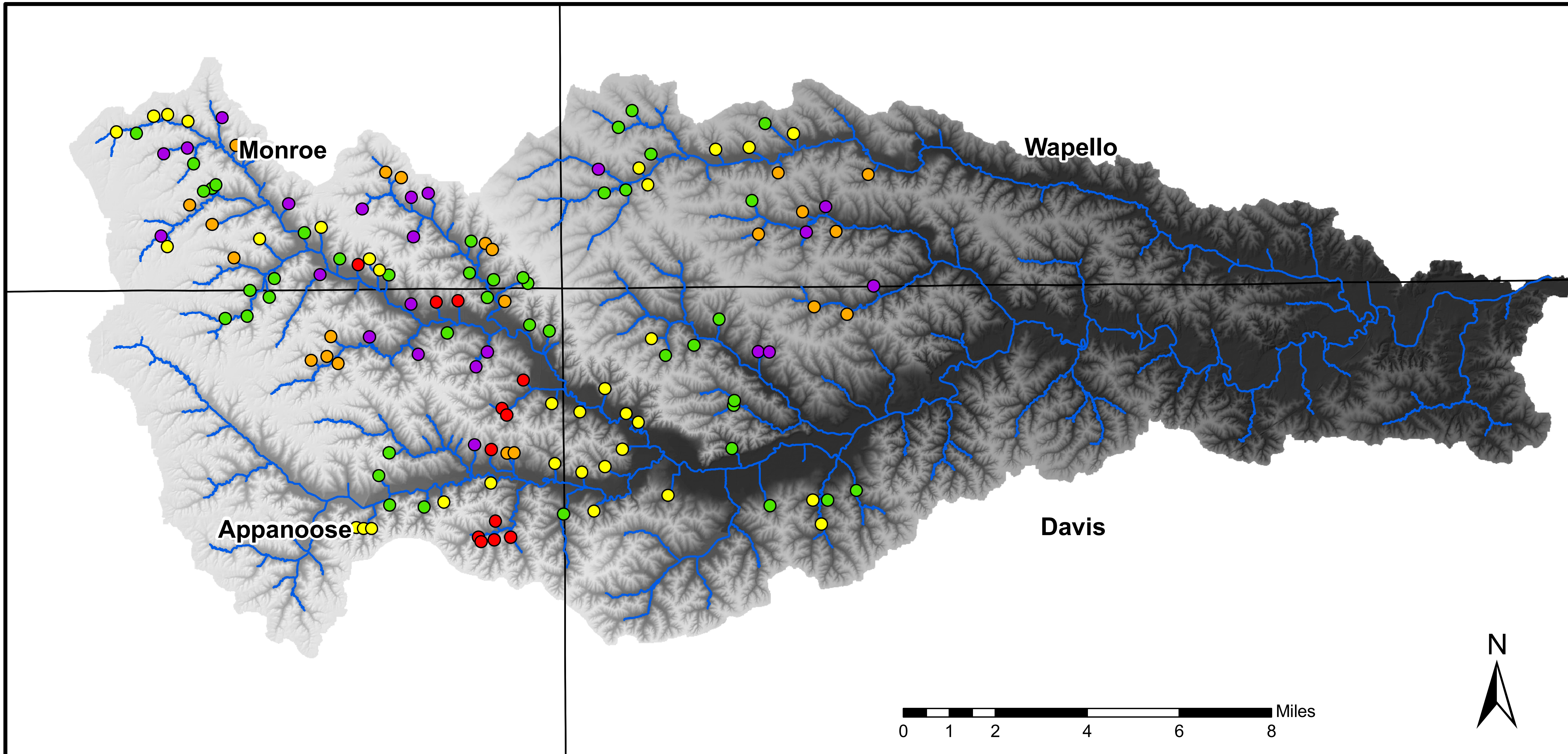
Land Cover Type
- Barren Land (Rock/Sand/Clay)
- Cultivated Crops
- Deciduous Forest
- Developed, High Intensity
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, Open Space
- Emergent Herbaceous Wetlands
- Evergreen Forest
- Grassland/Herbaceous
- Mixed Forest
- Open Water
- Pasture/Hay
- Shrub/Scrub
- Woody Wetlands

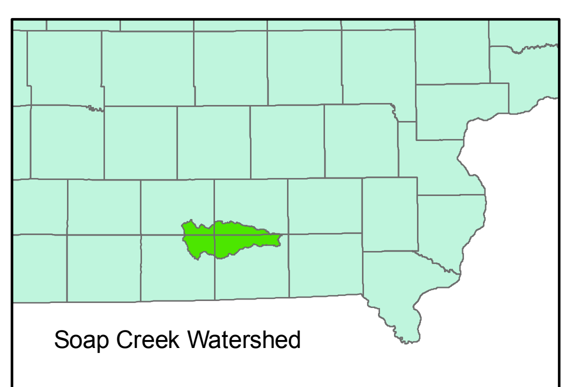
Date: 04/25/2014

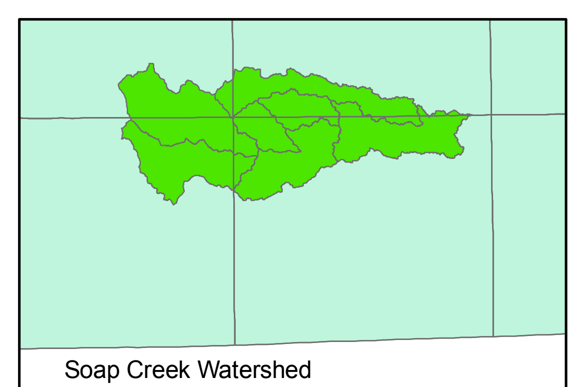
By: Jingyun Sun

Data Sources:
National Land Cover Database 2006, MRLC

Figure A-3







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Soap Creek Watershed
Complete Structures as of 2013

Pond Constructed Before

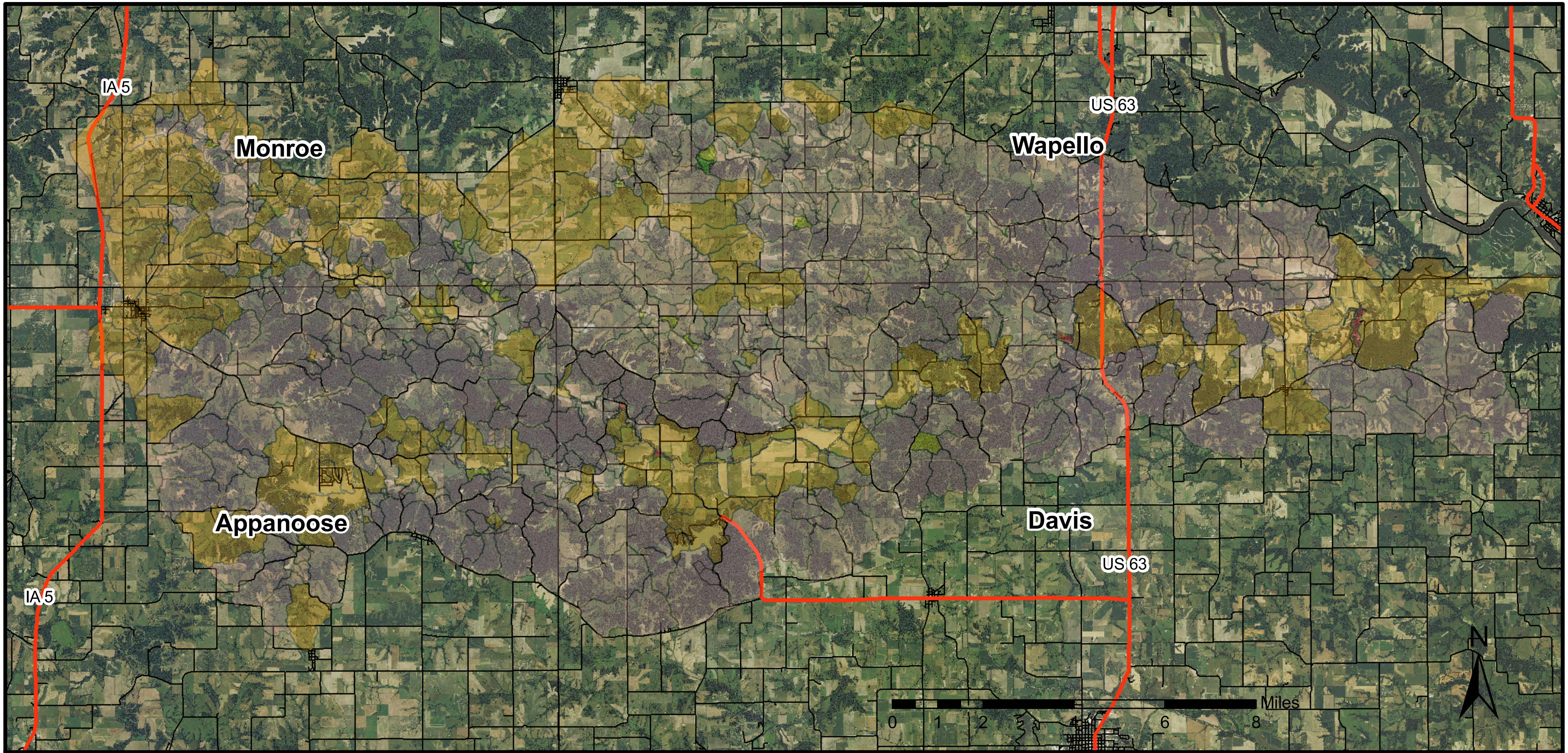
- 1993
- 1999
- 2005
- 2008
- 2013
- River Network

Date: 04/25/2014

By: Jingyun Sun

Data Sources:
Reservoirs,Iowa Department of Natural Resource's Office of Dam Safety in Des Moines,Iowa and Regional NRCS officies.

Figure A-4



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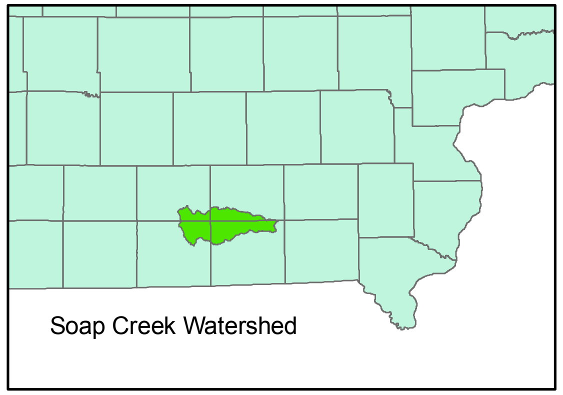
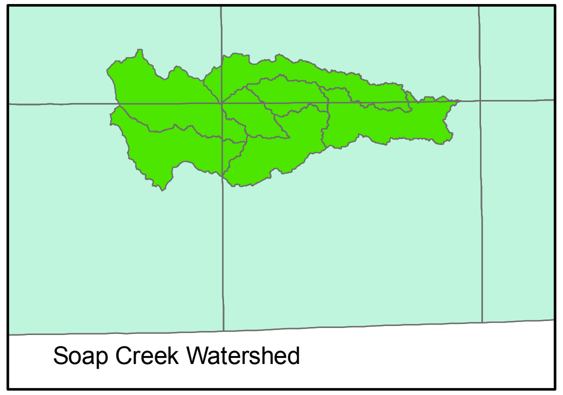




Soap Creek Watershed
Potential Runoff Assessment

Legend

Percent of Rainfall Converted to Runoff

Subbasin

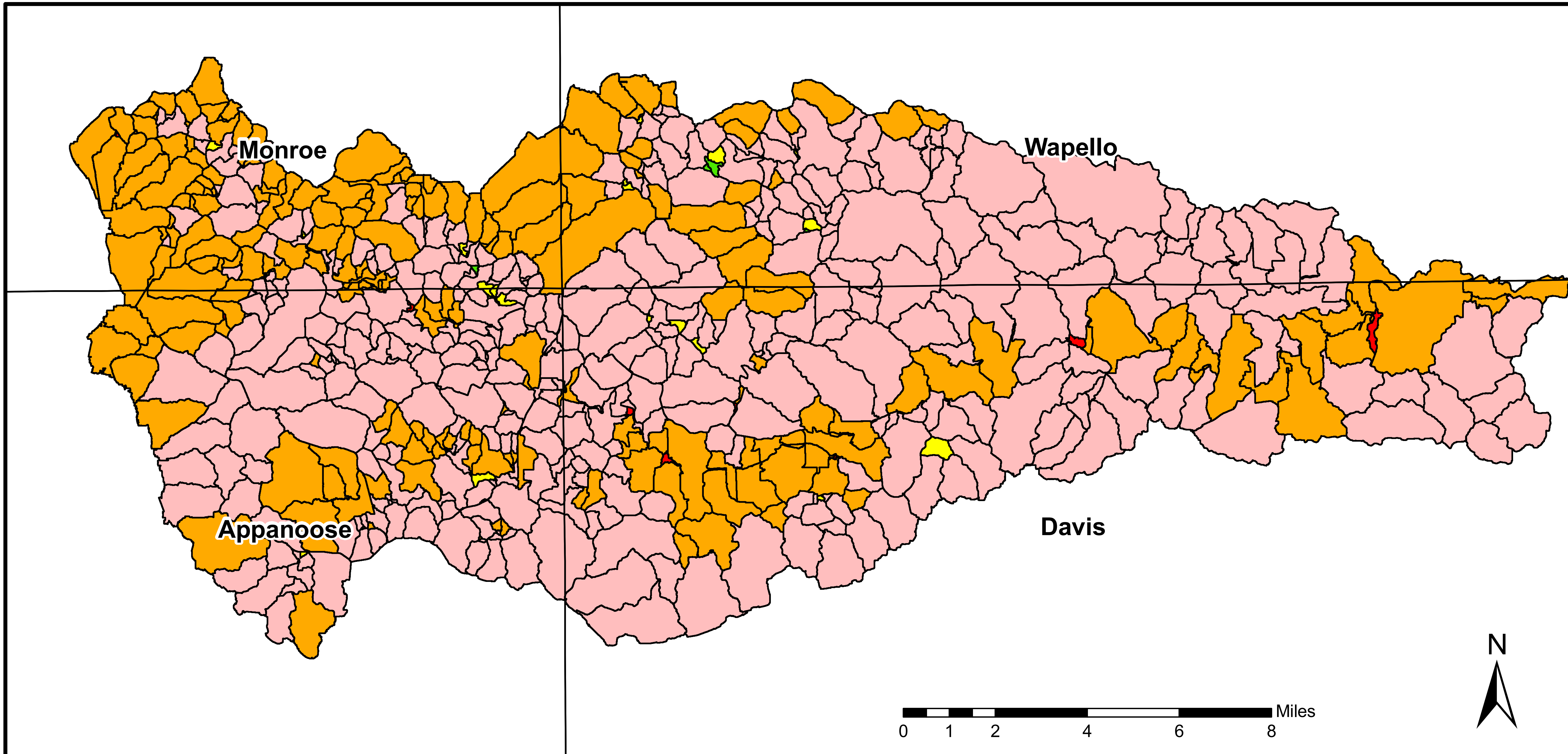
- 38 - 40 Lower
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80 Higher
- Highway
- Iowa_roads

Date: 04/25/2014

By: Jingyun Sun

Data Sources:
2013 Aerial Photography,
Iowa Geographic Map Server

Figure A-5



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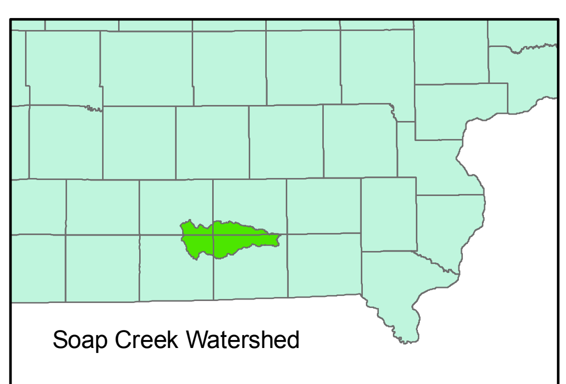

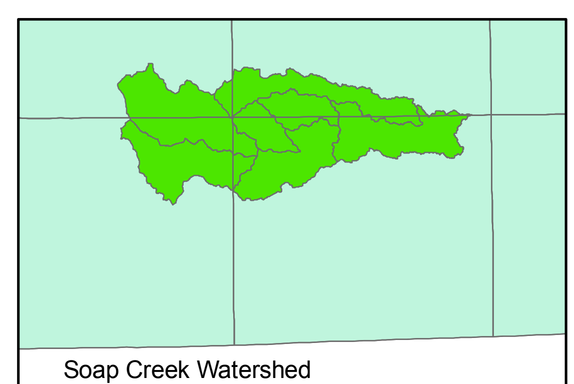

Soap Creek Watershed

Potential Runoff Assessment

Legend

Percent of Rainfall Converted to Runoff

Subbasin

- 38 - 40 Lower
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80 Higher

Date: 04/25/2014

By: Jingyun Sun

Data Sources:
Derived using SCS Curve Number Methodology

Figure A-6

Appendix B – Incorporated Structures

Table B. 1. Structural data of 132 constructed ponds in Soap Creek

Project	*Drainage Area (mi²)*	*Storage (ac-ft)*
26-127	0.531	85.74
26-32	0.146	15.51
26-33	0.077	8.18
26-34	0.469	67.68
26-36	0.525	79.30
26-37A	0.541	53.07
26-37B	0.198	17.88
26-38	0.471	84.40
26-39	0.412	62.83
26-44	0.488	188.94
26-49	0.360	54.88
26-51B	0.761	122.45
26-51C	1.147	198.35
26-52	0.377	64.05
26-53	0.193	16.76
26-55	1.784	769.24
26-58	0.427	70.91
26-63	1.853	307.43
26-64	0.237	28.97
26-65	1.942	308.81
26-66	0.235	23.60
26-67	0.219	30.07
26-68	0.328	40.35
26-71	0.375	54.13
26-73	0.102	10.65
26-74	0.344	48.58
4-109	0.245	34.97
4-110	0.780	118.68
4-111	0.273	35.85
4-112	0.371	51.63
4-113	0.764	122.23

Project	*Drainage Area (mi²)*	*Storage (ac-ft)*
4-114	0.194	30.90
4-31	1.831	319.25
4-35	0.464	66.39
4-36	0.230	31.47
4-37	0.121	16.14
4-38A	0.427	64.48
4-39	0.313	47.46
4-40A	0.298	46.13
4-40B	0.225	30.09
4-40C	0.156	17.41
4-44	0.250	40.13
4-48	0.100	10.62
4-53	0.098	9.04
4-54	0.144	14.70
4-55	0.098	9.11
4-55X	0.053	9.29
4-56	0.413	63.86
4-57A	0.216	126.11
4-57B	0.861	32.56
4-58	0.349	49.23
4-73	0.312	38.82
4-74	0.116	14.73
4-77	0.402	60.07
4-78	0.113	18.65
4-79	0.346	52.24
4-81	0.420	64.10
4-84	0.384	35.59
4-86	0.399	55.90
4-87	0.238	32.00
4-88	0.069	7.28
4-89	0.165	16.89
4-90A	0.500	78.74
4-90B	0.105	11.16
4-91	0.121	16.87

Project	*Drainage Area (mi²)*	*Storage (ac-ft)*
4-92	0.134	15.22
4-93	0.273	36.85
4-94	0.271	41.20
4-98	1.063	341.21
4-99	0.441	72.00
68-114A	0.138	17.51
68-114C	0.186	35.26
68-29	0.099	8.50
68-31	0.218	33.73
68-32	0.441	69.16
68-33A	1.293	295.22
68-33B	0.241	40.84
68-35	0.449	66.75
68-36	0.301	41.61
68-42	0.217	32.87
68-44	0.111	20.80
68-47	0.248	40.42
68-49	0.187	25.94
68-50	0.136	26.64
68-53	0.133	14.99
68-54	1.501	269.30
68-56	0.804	148.19
68-58A	0.100	9.58
68-58B	0.093	11.26
68-58C	0.070	6.37
68-58D	0.124	14.39
68-60	0.113	12.94
68-61	0.332	50.74
68-62	0.211	26.85
68-63	0.204	31.25
68-64A	0.189	24.01
68-64B	0.029	4.55
68-65	0.046	4.77
68-66	1.087	298.89

Project	*Drainage Area (mi²)*	*Storage (ac-ft)*
68-68	0.062	12.33
68-69B	0.198	22.66
68-70	0.099	15.55
68-71A	0.737	141.48
68-72	0.087	18.85
68-74	0.367	67.00
68-76A	0.183	26.88
68-76B	0.201	29.29
68-77	0.251	35.32
68-78	0.213	27.21
68-80	1.905	303.77
68-88	0.784	79.29
68-89	0.538	79.29
90-102	0.390	42.90
90-112	1.208	262.85
90-113	0.433	74.36
90-70	0.178	22.30
90-73	0.434	117.59
90-74	0.337	39.30
90-75	0.840	115.19
90-79B	1.363	260.11
90-79C	0.327	35.68
90-83	2.570	462.81
90-84	2.537	503.57
90-85	2.342	485.99
90-86	0.125	16.62
90-87	0.275	40.55
90-88	0.192	22.92
90-91	0.312	54.46
90-92	0.250	32.47
90-94	0.077	8.85
90-95	0.508	74.73
90-97	0.178	19.67

Appendix C – Soap Creek and Fox River Comparison

Table C. 1. Soil type comparison between the Soap Creek and Fox River Watersheds.

Soil Type	*Soap Creek Area (%)*	*Fox River Area (%)*
A	~0	~0
A/D	~0	~0
B	8.9	5.4
B/D	0.3	0.1
C	32.7	21.8
C/D	10.0	8.5
D	48.1	64.2

Table C. 2. Land use comparison between the Soap Creek and Fox River Watersheds.

Land Use Description	*Soap Creek Area (%)*	*Fox River Area (%)*
Open Water	1.1	0.6
Developed, Open Space	3.3	4.5
Developed, Low Intensity	0.6	1.9
Developed, Medium Intensity	~0	0.2
Developed, High Intensity	~0	~0
Barren Land (Rock/Sand/Clay)	~0	~0
Deciduous Forest	34.9	10.3
Evergreen Forest	0.4	0.2
Mixed Forest	3.6	1.2
Shrub/Scrub	1.5	1.2
Grassland/Herbaceous	4.6	0.9
Pasture/Hay	34.7	50.6
Cultivated Crops	13.9	27.2
Woody Wetlands	1.3	1.2
Emergent Herbaceous Wetlands	0.1	0.1

Table C. 3. Watershed slope comparison between the Soap Creek and Fox River Watersheds.

	Soap Creek	*Fox River*
Range	0% - 167.7%	0% - 160.8%

Appendix D – Calibration and Validation Hydrographs

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 was increased by 4.8% to reflect these wet conditions and the model did a reasonable job simulation this particular storm as the simulated peak is only 5.6% overestimated, and 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 (cumulated precipitation excess per cumulated precipitation) was 0.61.

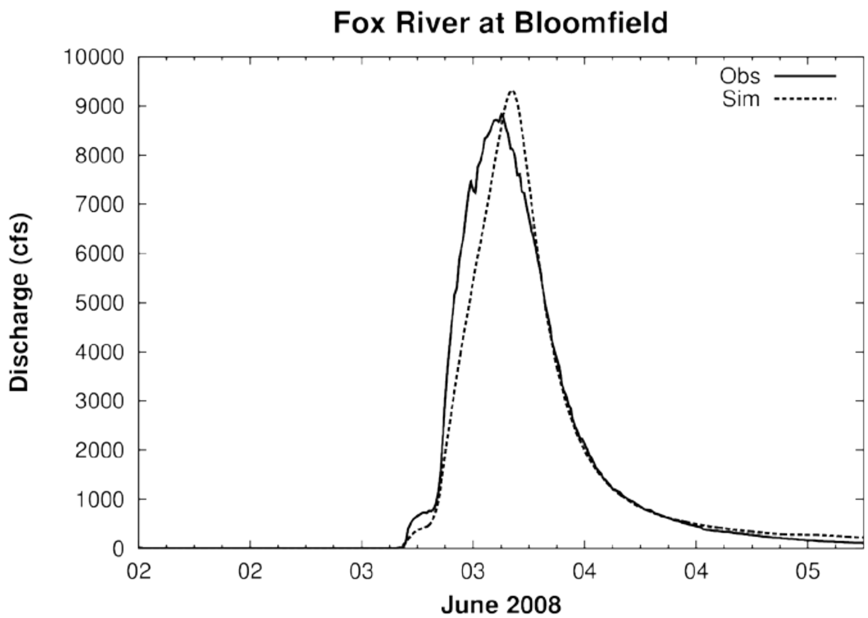

Figure D. 1. Observed and simulated hydrographs at Bloomfield. Run for the June 2008 rainfall event with post calibration parameters.

The July 2009 storm was characterized by a basin wide average Stage IV radar rainfall depth of 2.00 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.

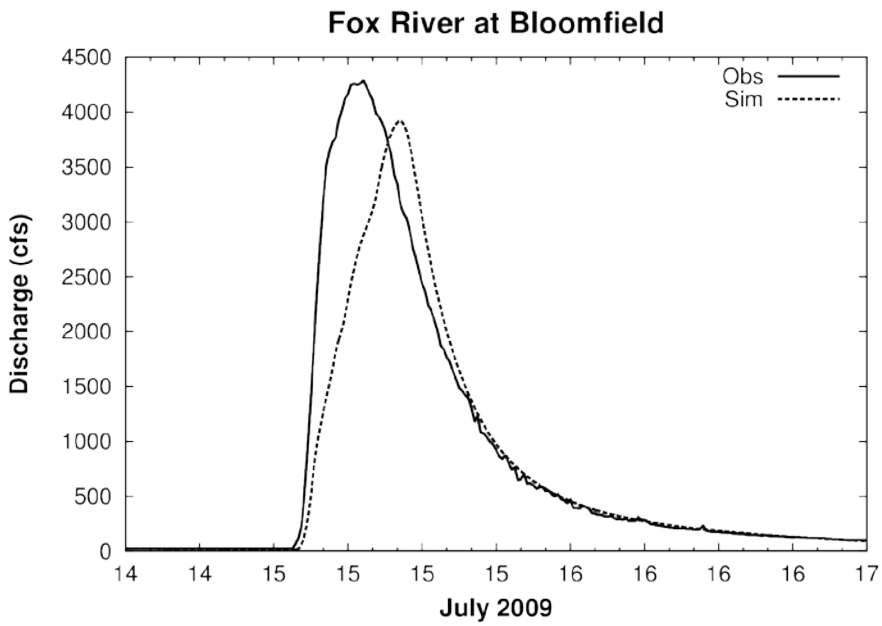

Figure D. 2. Observed and simulated hydrographs at Bloomfield. Run for the July 2009 rainfall event with post calibration parameters.

The August 2009 storm was characterized by a basin wide average Stage IV radar 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.

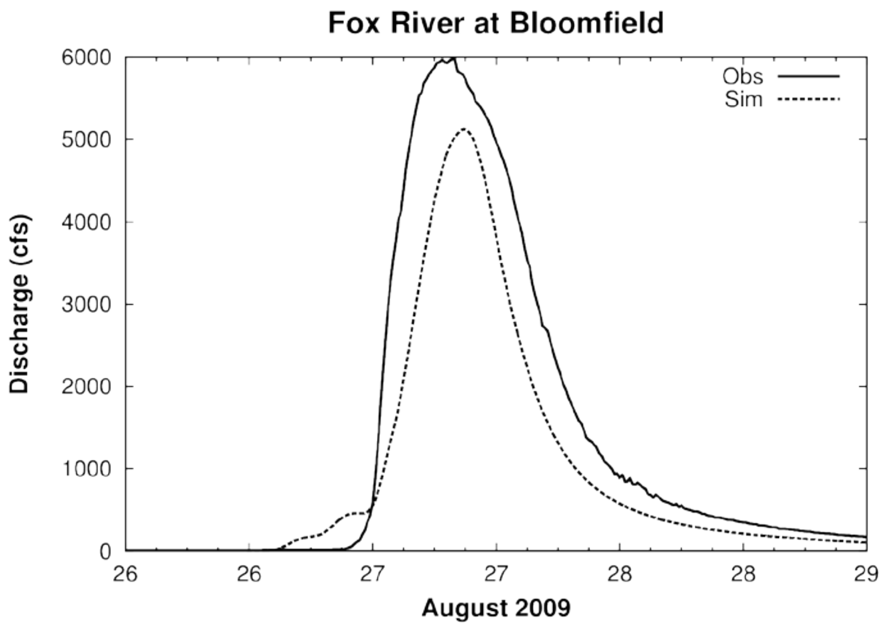

Figure D. 3. Observed and simulated hydrographs at Bloomfield. Run for the August 2009 rainfall event with post calibration parameters.

The May 2013 storm was characterized by a basin wide average Stage IV radar 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, the API was 2.14 inches (corresponding to the 0.97 quantile). CNs in the HMS model were increased to reflect wetter conditions by 6.96%. 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.

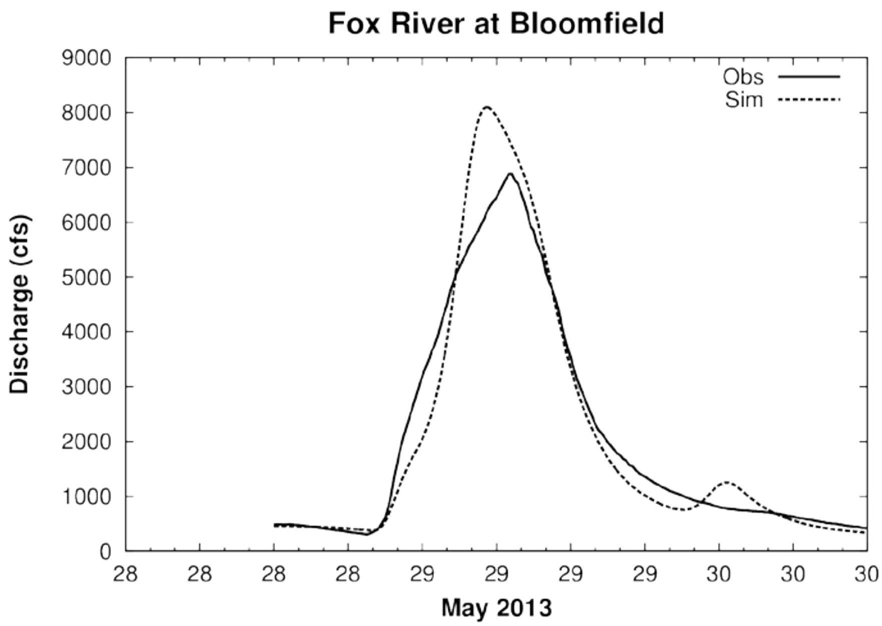

Figure D. 4. Observed and simulated hydrographs at Bloomfield. Run for the May 2013 rainfall event with post calibration parameters.

Validation Storm Events

The April 2010 validation storm was characterized by a basin wide average Stage IV radar rainfall depth of 1.69 inches and a peak discharge of 5,219cfs at Bloomfield. Wetter than normal conditions were present before the storm, 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, 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.

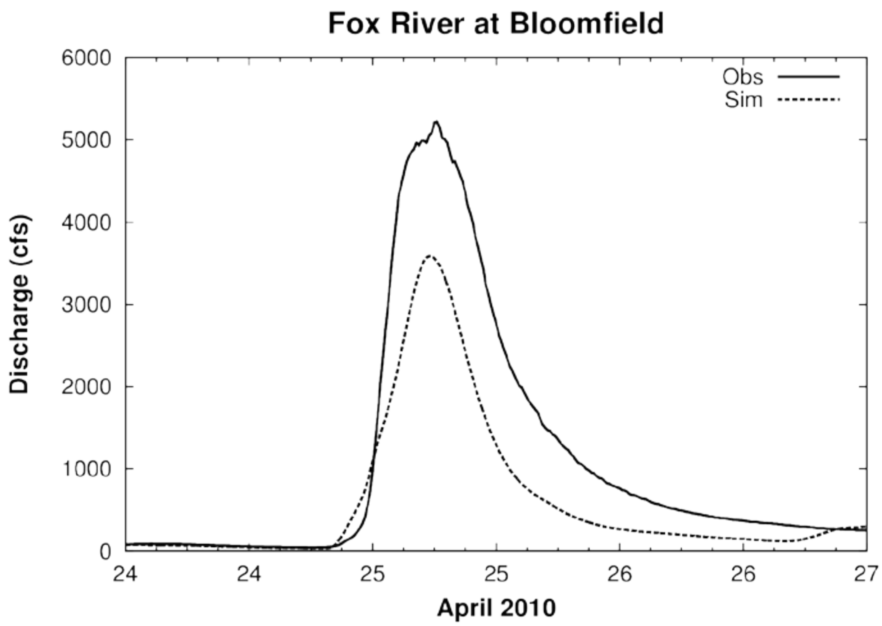

Figure D. 5. Observed and simulated hydrographs at Bloomfield. Validation for the April 2010 rainfall event, run with post calibration parameters.

Figure D.6. depicts the simulated and observed hydrographs generated by the Aril 2013 validation storm. The April 2013 storm was characterized by a basin wide average Stage IV radar 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.

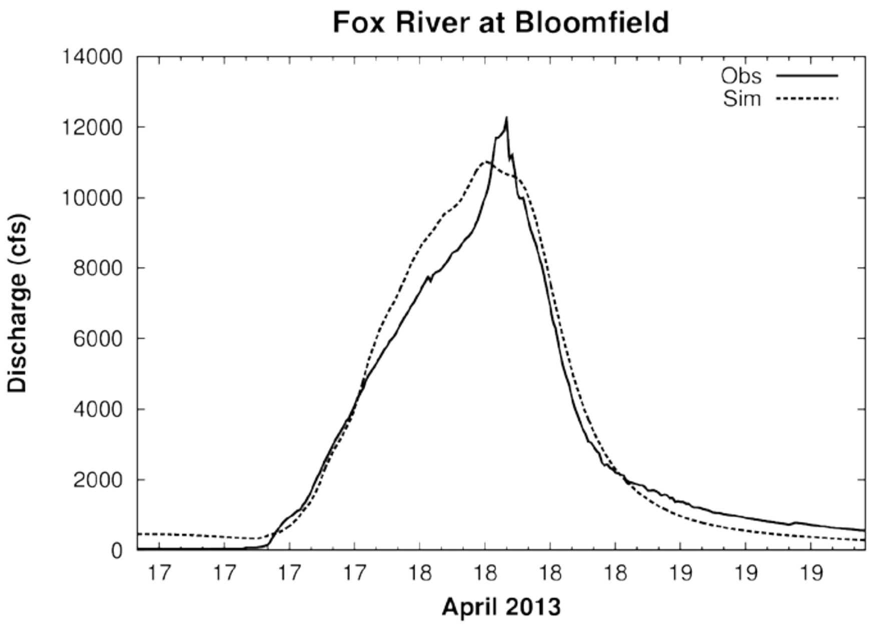

Figure D.6. Observed and simulated hydrographs at Bloomfield; validation for the April 2013 rainfall event, run with post calibration parameters.

Table D. 1. The initial and calibrated parameters for the Fox Watershed and Parameters for the Soap Creek Watershed.

Parameters	*Initial Value (Fox River Watershed)*	*Calibrated Value (Fox River Watershed)*	*Transferred Value (Soap Creek Watershed)*
Ratio to peak	0.10	0.06	0.06
Recession Constant	0.90	0.25	0.25
Muskingum K	Based on velocity of 0.7 m/s	Based on velocity of 1.3 m/s	Based on velocity of 1.7 m/s
Curve Number	Initial curve number generated from GIS	Values vary based on antecedent moisture condition	2.67 % decrease overall
Storage Coefficient	2 times the time of concentration	3 times the time of concentration	3 times the time of concentration

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