Hydrologic Assessment of the Turkey River Watershed

July 2014

Iowa Flood Center | IIHR—Hydroscience & Engineering
The University of Iowa
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Cover photograph. Otter Creek, Fayette County. Photograph by Iowa Flood Center.

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Introduction

Heavy rains and subsequent flooding during the summer of 2008 brought economic, social, and environmental impacts to many individuals and communities in watersheds across the state of Iowa. In the response and recovery, a handful of Watershed Management Authorities –bodies consisting of representatives from municipalities, counties, and soil and water conservation 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 Turkey River 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 Turkey River and compares local conditions to those in three other watersheds – the Middle Raccoon River, the Upper Cedar River and Soap/Chequest Creeks.

A hydrologic model of the Turkey River Watershed, using HEC-HMS, was used to identify areas in the watershed with high runoff potential and run simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed. Focus for the scenario development was placed on understanding the impacts of (1) increasing infiltration in the watershed and (2) implementing a system of distributed storage projects (ponds) across the landscape.

The focused hydrologic assessment provides watershed residents and local leaders an additional source of information and should be used in tandem with additional reports and watershed plans working to enhance the social, economic, and environmental sustainability and resiliency of the Turkey River 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 Turkey River Watershed, as well as that for the three other Iowa watersheds that are part of the Iowa Watersheds Project (see Figure 1.1).

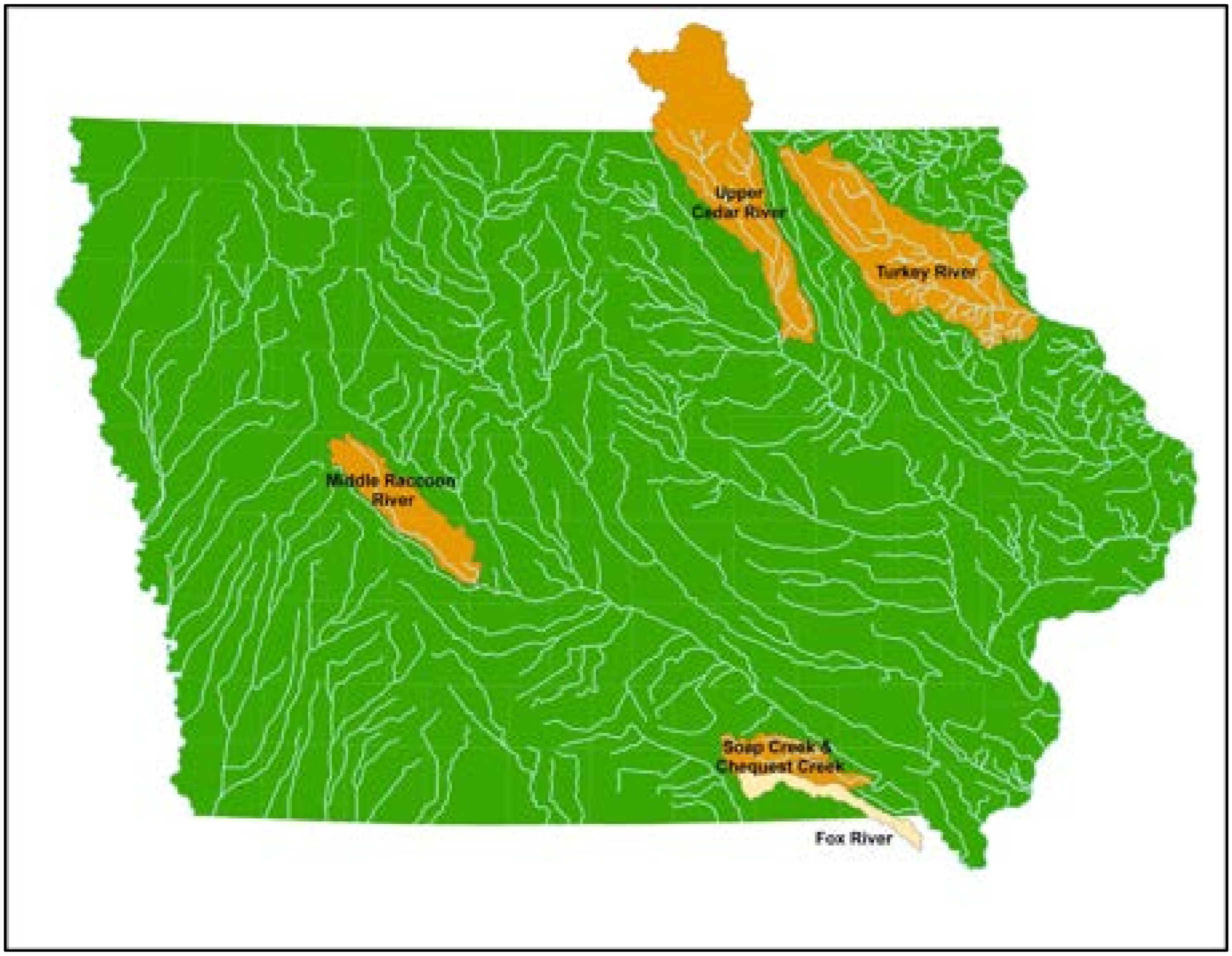

Figure 1.1. Iowa Watersheds Project study areas.

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 1661 mi^2 — mostly from the Iowan Surface landform. The Middle Raccoon River drains 375 mi^2 (USGS 05483450 Middle Raccoon River near Bayard), and is located in the west-central part of the state. The upper part of the basin is located in flat terrain of the Des Moines Lobe, while the lower part is located within the Southern Iowa Drift Plain. Soap and Chequest Creeks in the southern part of the state are located in the Southern Iowa Drift Plain. 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.

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

i. Statewide Precipitation

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

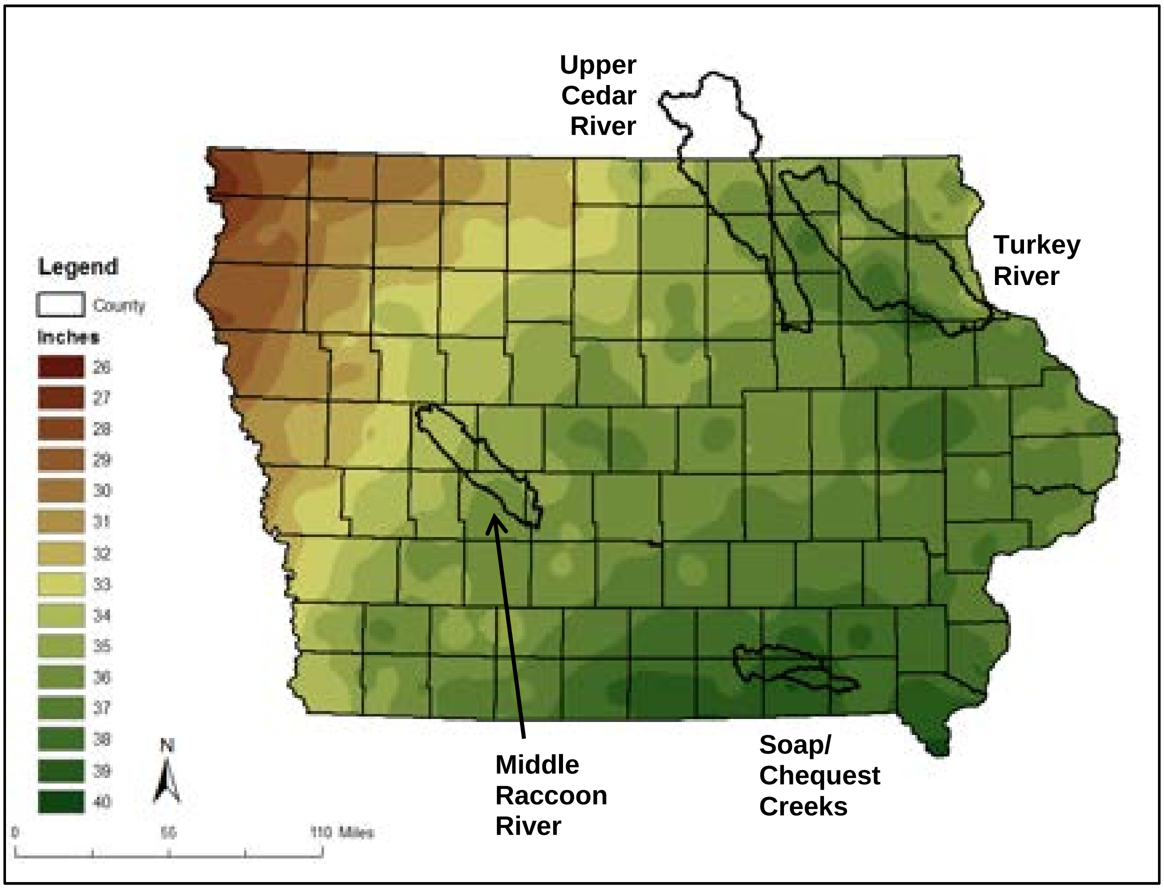

Figure 1.2. Average annual precipitation for Iowa. Precipitation estimates are based on the 30-year annual average (1981-2010) for precipitation gauge sites. Interpolation between gauge sites to an 800 m grid was done by the PRISM (parameter-elevation relationships on independent slopes model) method.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

ii. The Water Cycle in Iowa

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

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

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

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

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

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

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

[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.

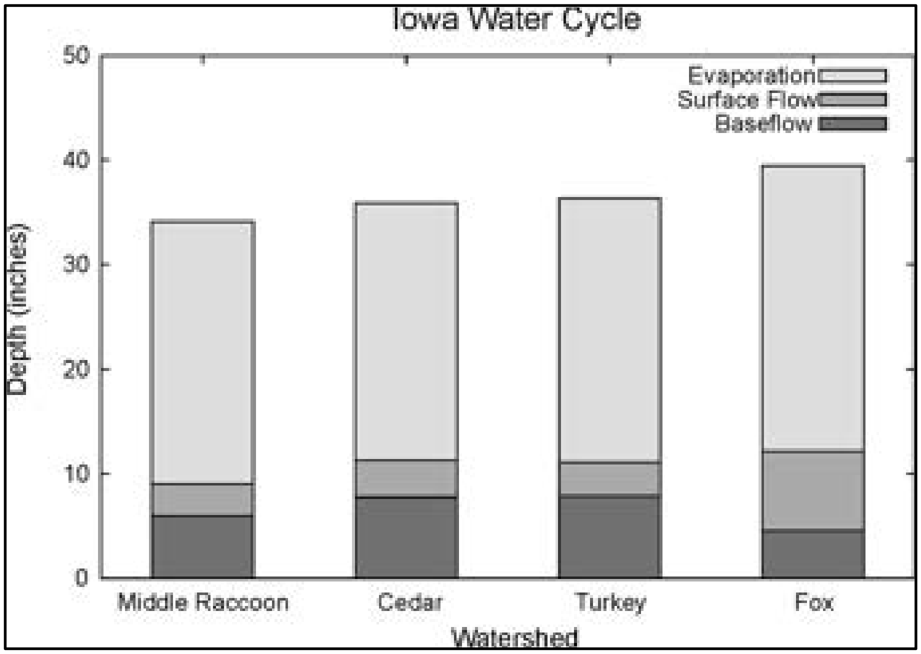

Figure 1.3. Iowa water cycle for four watersheds. The chart shows the partitioning of the average annual precipitation depth (in inches) into evaporation, surface flow, and baseflow components.[2]

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

iii. Monthly Water Cycle

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

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

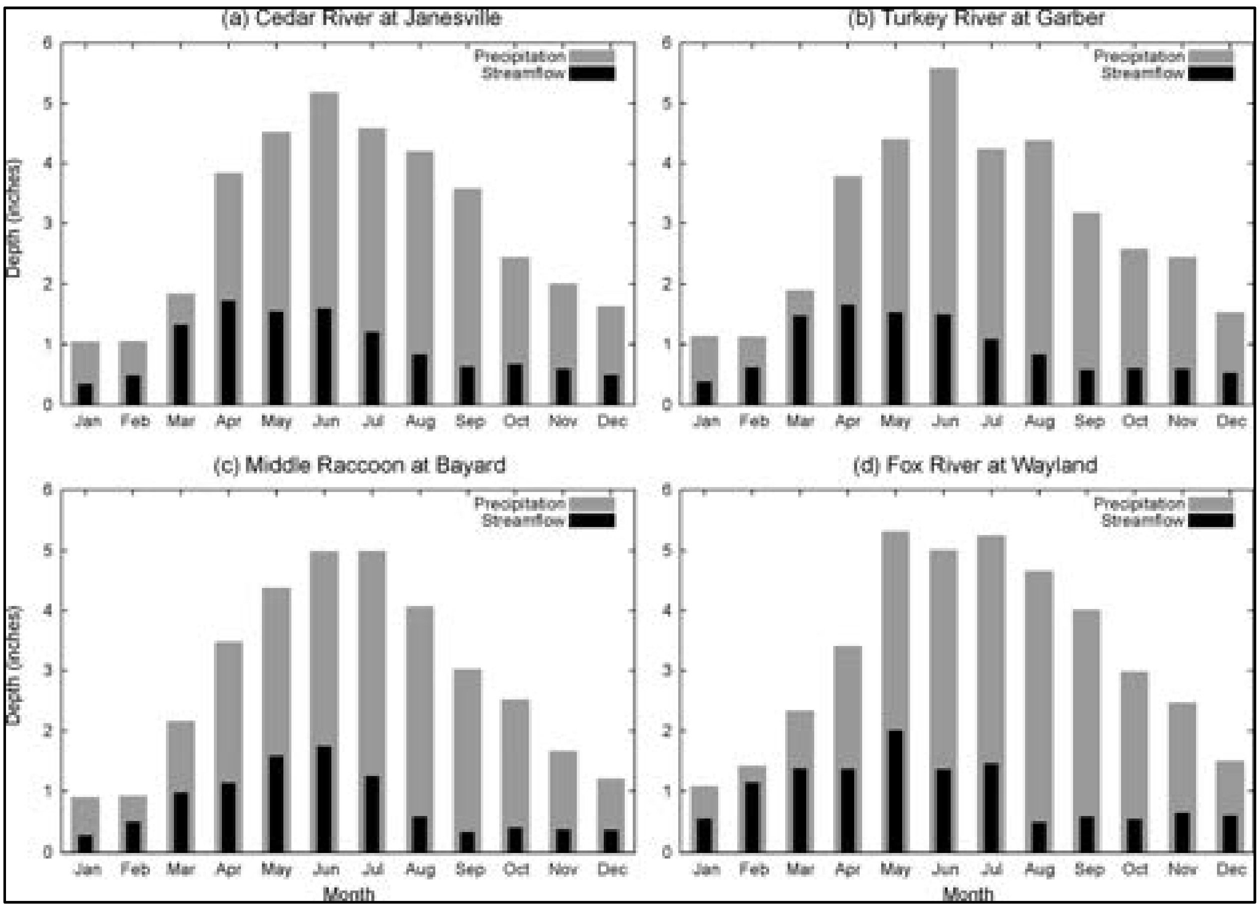

Figure 1.4. Monthly water cycle for four Iowa watersheds. The plots show the average monthly precipitation (in inches) and the average monthly streamflow (in inches). The average monthly estimates for precipitation and streamflow are based on the same 30-year period (1981-2010).

iv. Flood Climatology

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

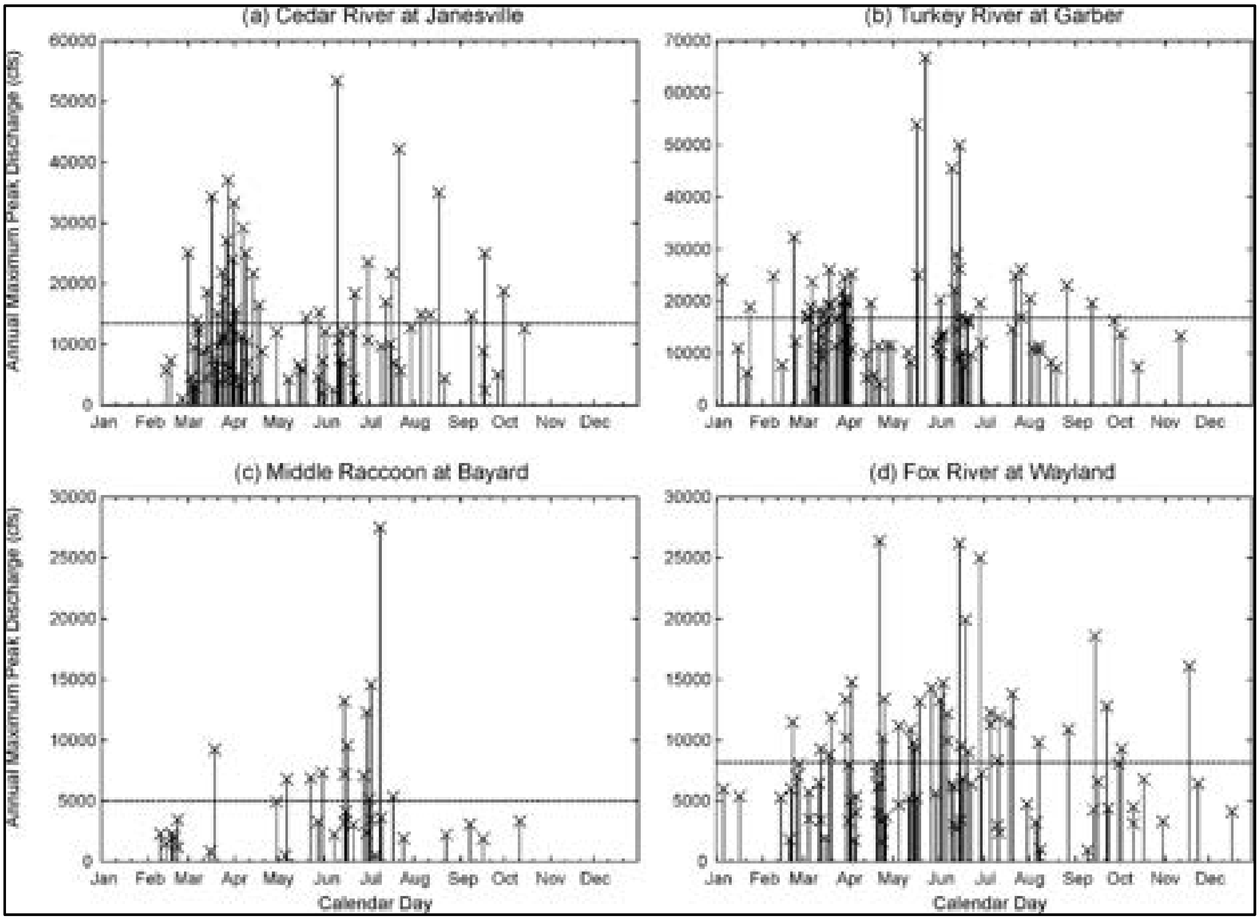

Figure 1.5. Annual maximum peak discharges and the calendar day of occurrence for four Iowa watersheds. The plots show all annual maximums for the period of record at four USGS stream-gage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and (d) Fox River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

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

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

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

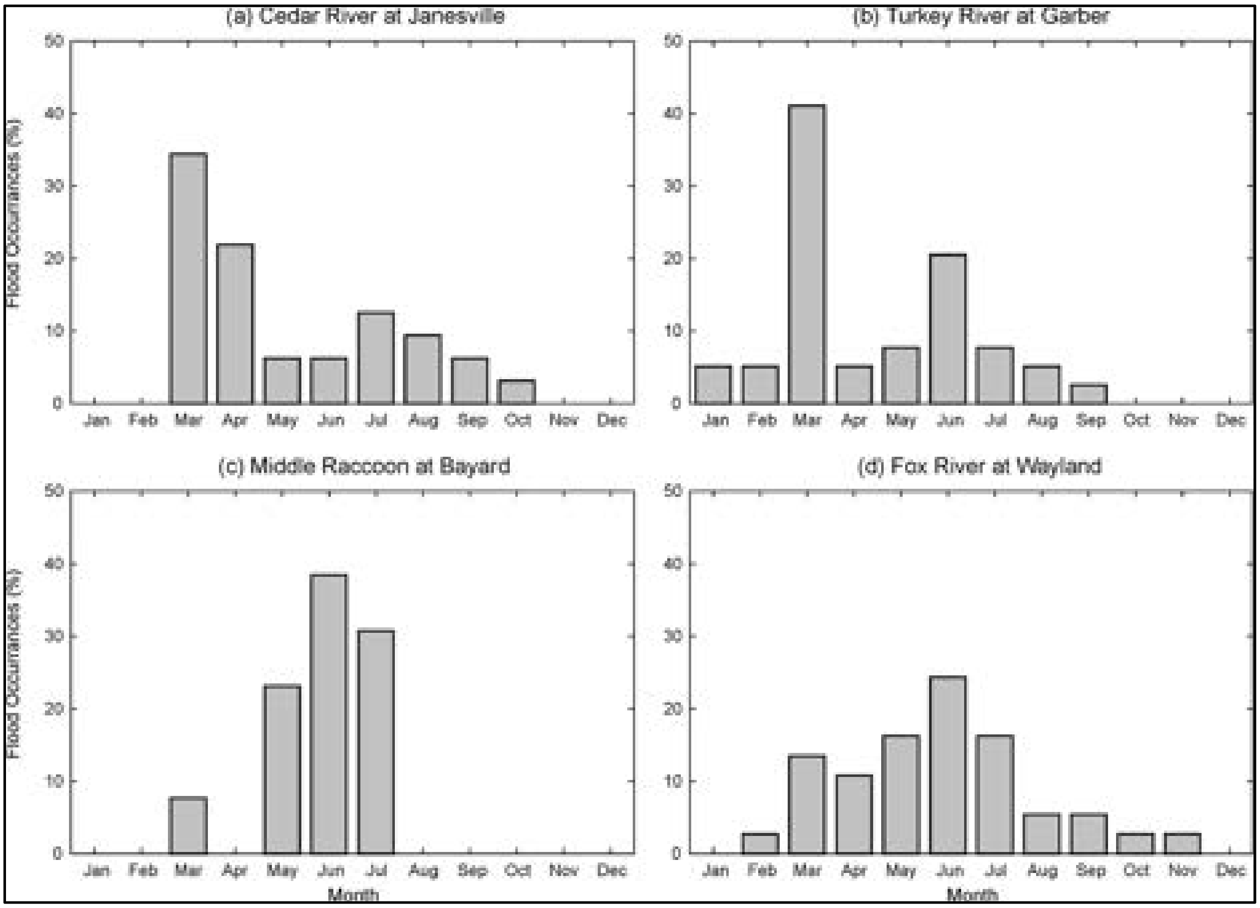

Figure 1.6. Flood occurrence frequency by month for four Iowa watersheds. The plots show the percent of peak annual discharges for a given month that exceed the mean annual flood at four USGS stream-gage sites: (a) Cedar River at Janesville, (b) Turkey River at Garber, (c) Middle Raccoon at Bayard, and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

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

b. Hydrological Alterations in Iowa and the Iowa Watersheds Project Study Areas

Although the hydrologic conditions presented for the Iowa Watersheds Project study areas illustrate the historical water cycle, the watersheds themselves are not static; historical changes have occurred that have altered the water cycle. In this section, we discuss the 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 stream-gage record for the Middle Raccoon River at Bayard does not begin until 1980, so analysis results are shown for the downstream stream-gage for the Raccoon River at Van Meter, where the record spans 96 years.

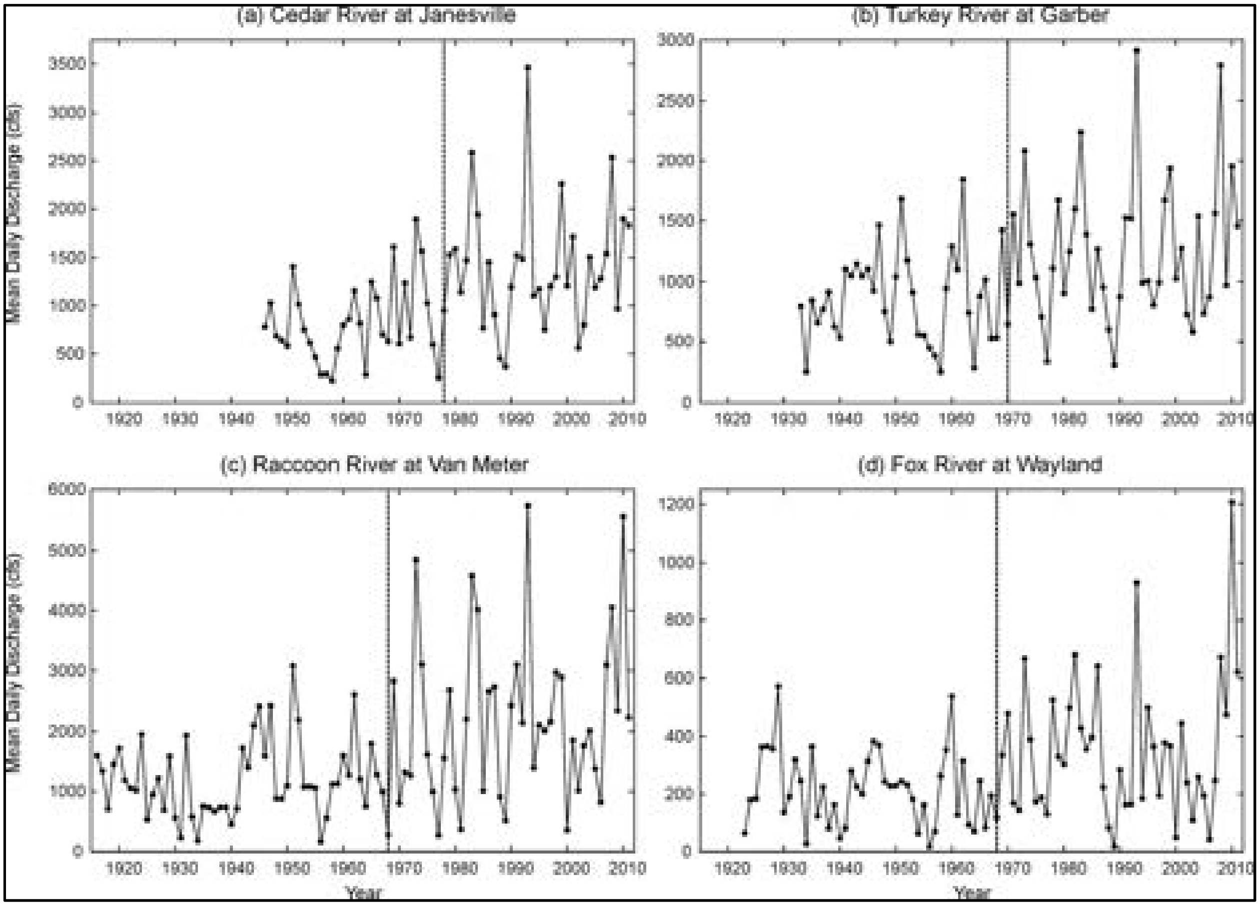

Figure 1.7. Time series of mean daily discharge for the period of record. An analysis was carried out to detect changes in the statistical characteristics of mean daily discharge; the vertical dashed lines indicate the location of any identified change point.

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

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

c. Summary of Iowa's Flood Hydrology

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

2. Conditions in the Turkey River Watershed

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

a. Hydrology

The Turkey River Watershed as defined by the boundary of eight-digit Hydrologic Unit Code (HUC8) 07060004 is located in Northeast Iowa and encompasses approximately 1693 square miles (mi^2). This watershed boundary falls within eight counties and actually includes two substantial rivers, the Turkey and Volga Rivers. The Turkey River and its tributaries are generally located in the northern portion of the watershed and flow northwest to southeast with the outlet discharging to the Mississippi River approximately six miles south of Guttenberg, Iowa. The Volga River (drainage area approximately 406 square miles) is located in the southwestern one-quarter of this defined watershed boundary, discharging into the Turkey River near Elkport, Iowa.

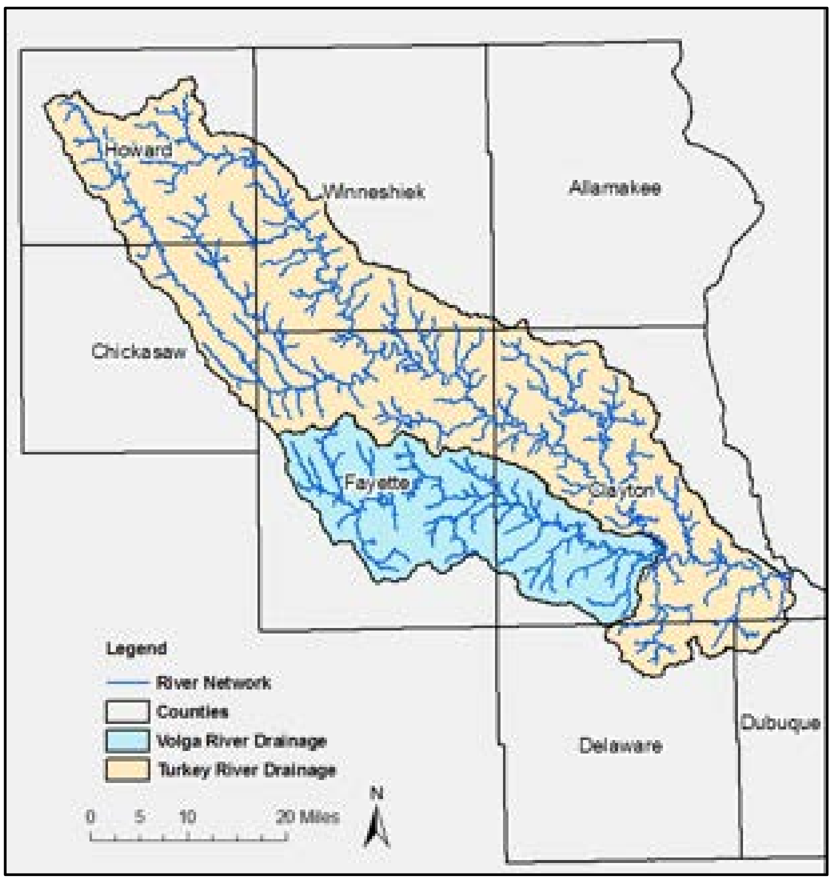

Figure 2.1. The Turkey River Watershed (HUC8 07060004), drains 1693 mi^2. The Volga River is a major tributary in the SW portion of the watershed.

Average annual precipitation for this region of Northeast Iowa is roughly 36 inches (PRISM, 1981-2010), with about 70% of the annual precipitation falling as rain during the months of April - September. During this period, thunderstorms capable of producing torrential rains are possible with the peak frequency of such storms occurring in June. Northeast Iowa has experienced increased variability in annual precipitation since 1975, along with a general increase in the amount of spring rainfall (U.S. Department of Agriculture - Iowa State University, 2011).

b. Geology and Soils

The Turkey River Watershed is located within two identified landform regions, the Iowan Surface and Paleozoic Plateau, each of which has a unique influence on the rainfall-runoff characterization of the watershed. The Iowan Surface of Northeast Iowa is dominated by gently rolling terrain created during the last period of intense glacial cold, 21,000 to 16,000 years ago. Hilly landscapes succumbed to vigorous episodes of weathering and leveling as materials were loosened and moved (Iowa Geological & Water Survey, Iowa Department of Natural Resources, 2013).

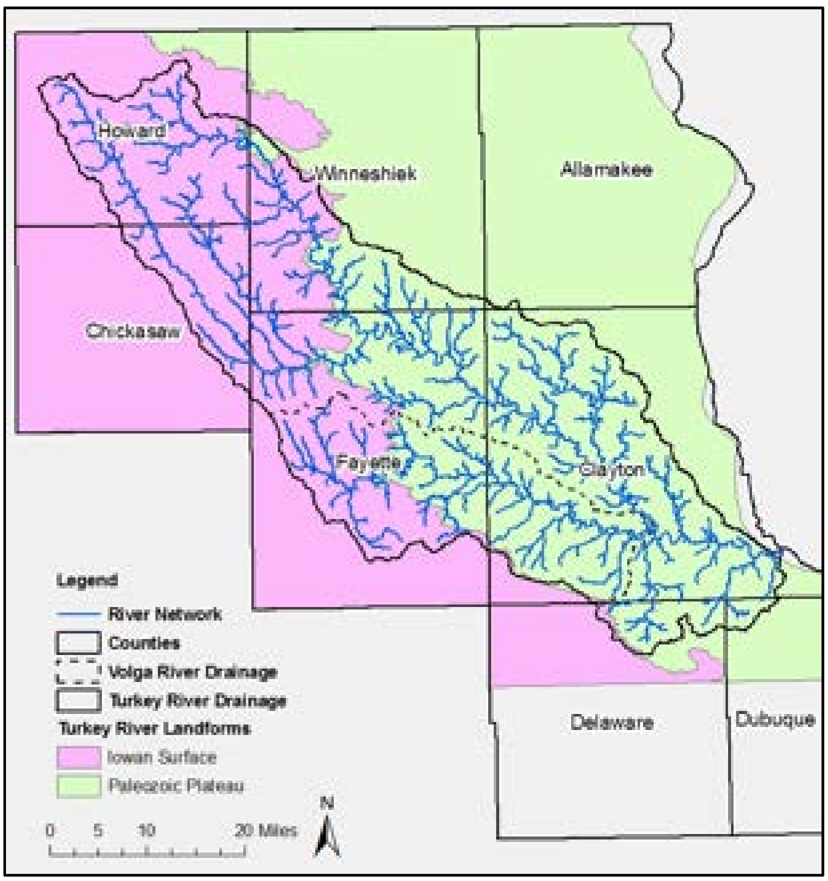

Figure 2.2. Defined Landform Regions of the Turkey River Watershed.

In contrast, the Paleozoic Plateau is characterized by narrow valleys deeply carved into sedimentary rock. The rock layers vary in resistance to erosion, producing bluffs, waterfalls, and rapids. Shallow limestone coupled with the dissolving action of groundwater yields numerous caves, springs, and sinkholes (Iowa Geological & Water Survey, Iowa Department of Natural Resources, 2013). The locations of over 10,300 sinkholes have been mapped in the Turkey River Watershed by Iowa Department of Natural Resources (IDNR) and are shown in the following figure.

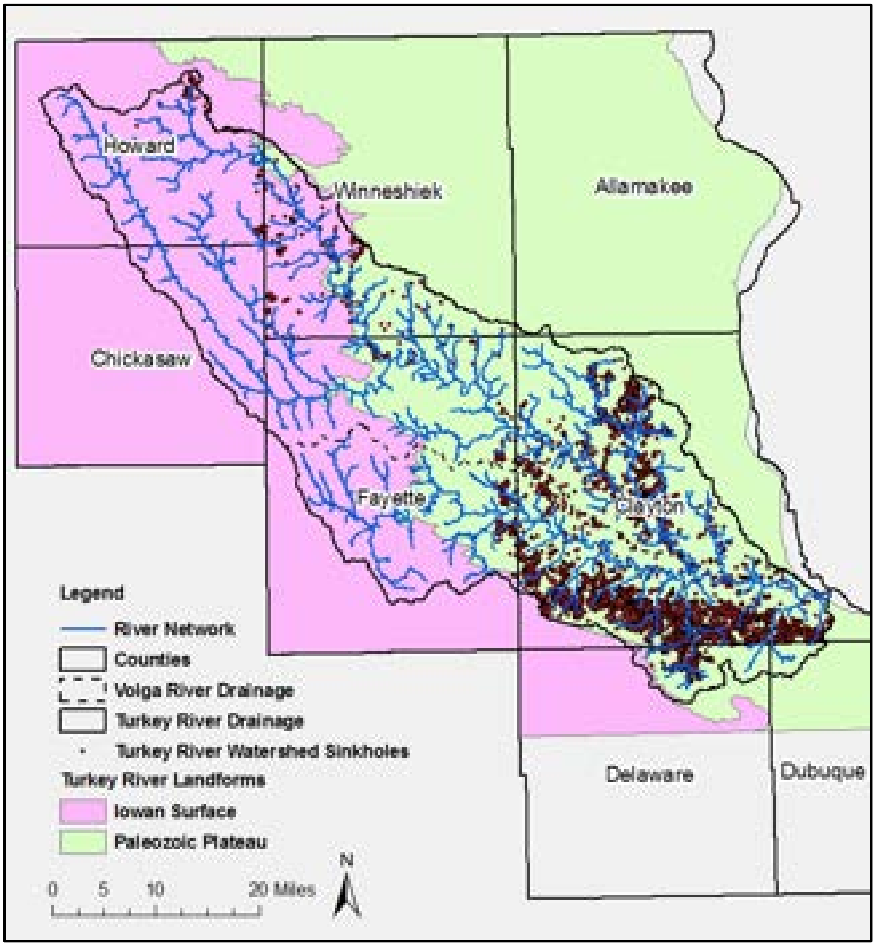

Figure 2.3. Location of Sinkholes as Mapped by Iowa Department of Natural Resources.

Soils are classified into four Hydrologic Soil Groups (HSG) by the Natural Resources Conservation Service (NRCS) based on the soil's runoff potential. The four HSG's are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, there are dual code soil classes A/D, B/D, and C/D that are assigned to certain wet soils. In the case of these soil groups, even though the soil properties may be favorable to allow infiltration (water passing from the surface into the ground), a shallow groundwater table (within 24 inches of the surface) typically prevents much from doing so. For example a B/D soil will have the runoff potential of a B-type soil if the shallow water table were to be drained away, but the higher runoff potential of a D-type soil if it is not. Complete descriptions of the Hydrologic Soil Groups can be found in USDA-NRCS National Engineering Handbook, Part 630 – Hydrology, Chapter 7.

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

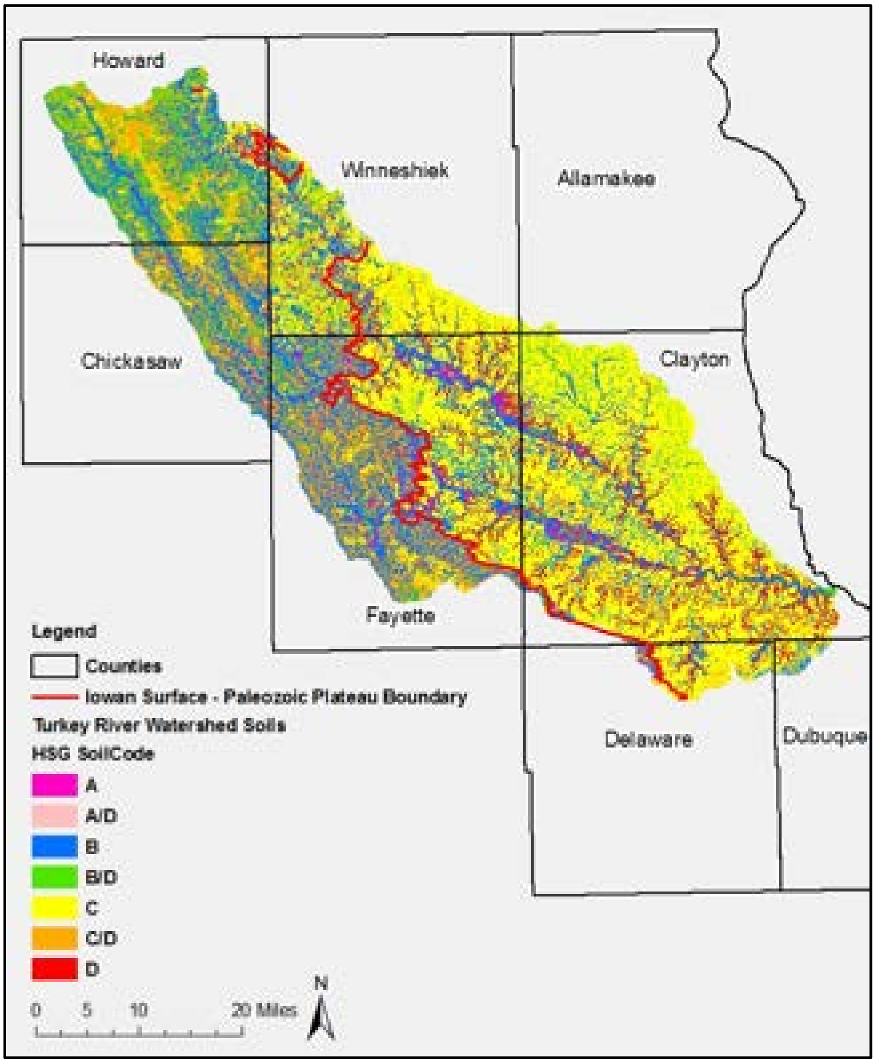

Figure 2.4. Distribution of Hydrologic Soil Groups in the Turkey River Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with Type A representing the lowest runoff potential and Type D representing the highest runoff potential.

Viewing the soil distribution at this map scale is difficult, but the map does illustrate how much soils vary in space and the noticeable difference in soil types of the Iowan Surface compared to those of the Paleozoic Plateau. Higher detailed soil distribution maps are included in Appendix A. Table 2.1 shows the approximate percentages by area of each soil type for the Iowan Surface and the Paleozoic Plateau.

Table 2.1. Approximate Hydrologic Soil Group Percentages by Area of the Turkey River Watershed.

Hydrologic Soil Group	*Iowan Surface Approximate %*	*Paleozoic Plateau Approximate %*
A	3.9	2.0
A/D	0.1	0
B	33.1	17.6
B/D	16.4	4.4
C	14.3	62.9
C/D	30.6	2.0
D	1.6	11.1

c. Topography

The topography of the Turkey River Watershed reflects its geologic past. The northwest or upper part of the watershed, located in Howard and Chickasaw Counties, as well as the western portions of Winneshiek and Fayette Counties, drains the low-relief, rolling terrain of the Iowan Surface. Streams of this area are well defined but with relatively low slopes.

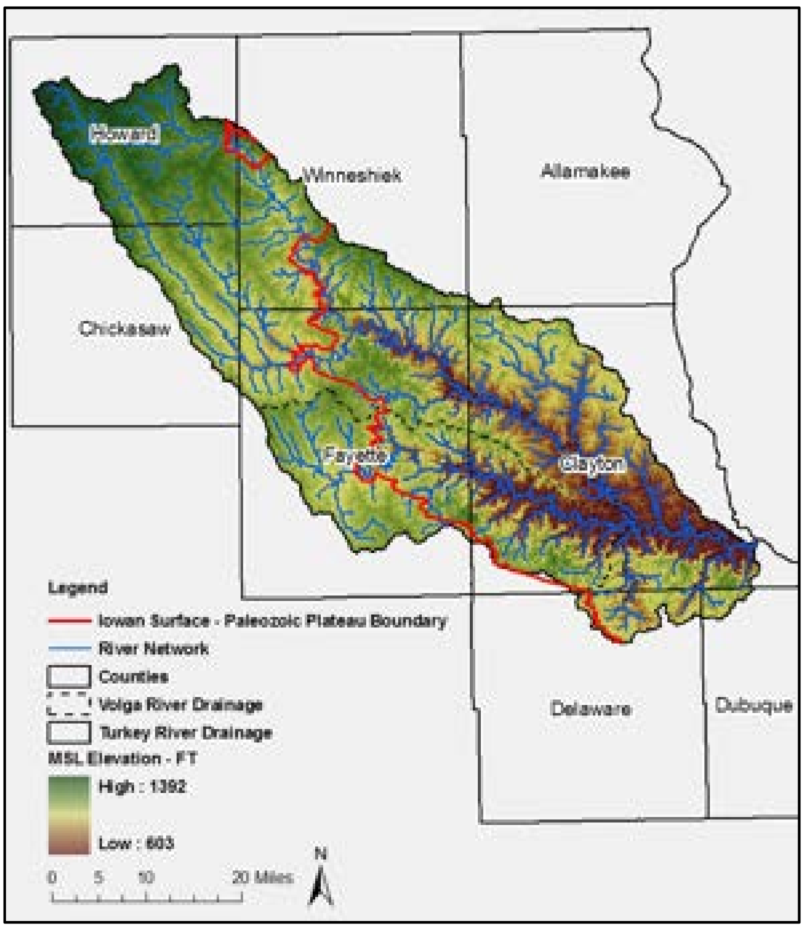

Figure 2.5. Topography of the Turkey River Watershed.

As the streams of the watershed continue southeasterly through Winneshiek and Fayette Counties, they cross the boundary between the Iowan Surface and the Paleozoic Plateau. The bedrock dominated topography of the Paleozoic Plateau is characterized by flatter upland regions with integrated drainages of deeply carved valleys and steep sloping streambeds. Elevations range from approximately 1392 feet above sea level in the uppermost part of the watershed to 603 feet at the Mississippi River outlet.

d. Land Use

Land use in the Turkey River Watershed is predominantly agricultural, dominated by cultivated crops (corn/soy beans) at approximately 56% of the acreage, followed by grass/hay/pasture at approximately 25%. The remaining acreage in the watershed is about 16% forest (primarily deciduous forest), 2% developed land, and 1% open water and/or wetlands, per the 2006 National Land Cover Data (NLCD) Set. Approximately 91% of the land within the watershed is privately owned.

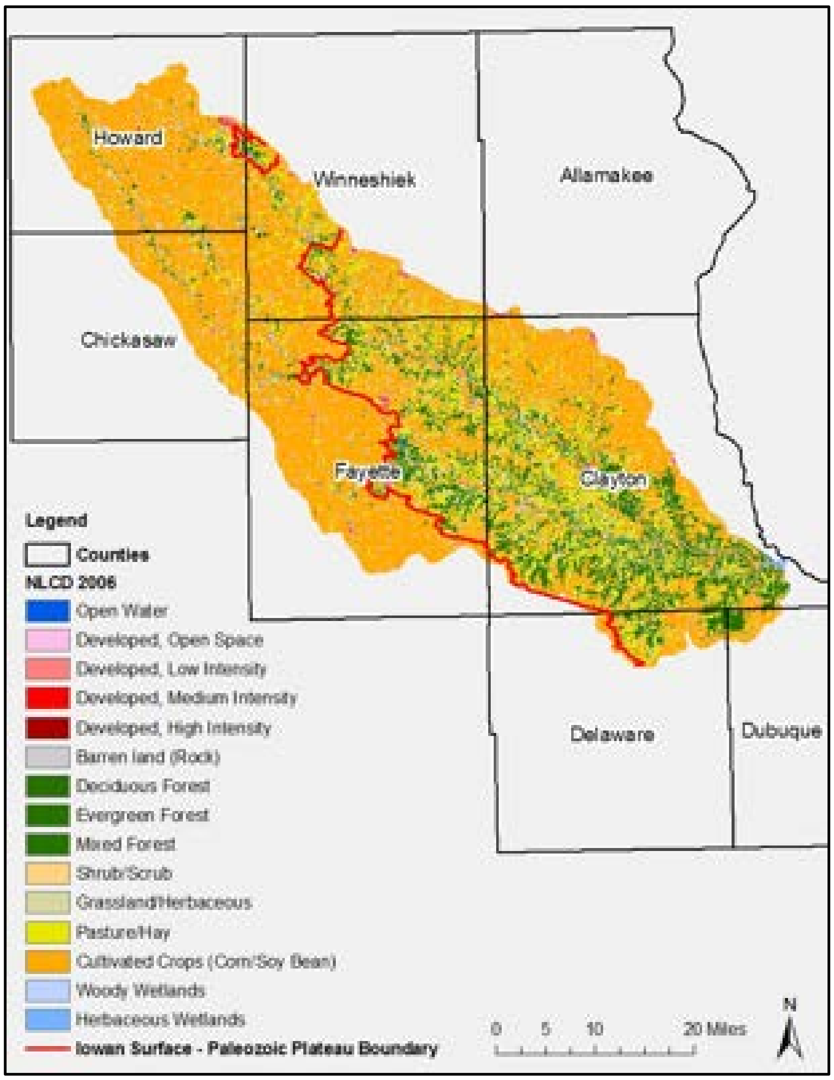

Figure 2.6. Land use composition in the Turkey River Watershed per the 2006 NLCD. Cultivated Crops shown in orange.

e. Instrumentation/Data Records

The Turkey River Watershed has instrumentation installed to collect and record stream stage, discharge, and precipitation measurements. There are six United States Geological Survey (USGS) operated stage & discharge gages and eleven Iowa Flood Center (IFC) stream stage sensors located within the watershed. There are four National Oceanic and Atmospheric Administration (NOAA) 15-minute/hourly precipitation gages within or near the watershed and an additional nine NOAA-partnered daily-measuring precipitation gages within or near the watershed. The operational period of record varies amongst each of these gages. The following figure and tables detail the instrumentation and its period of record.

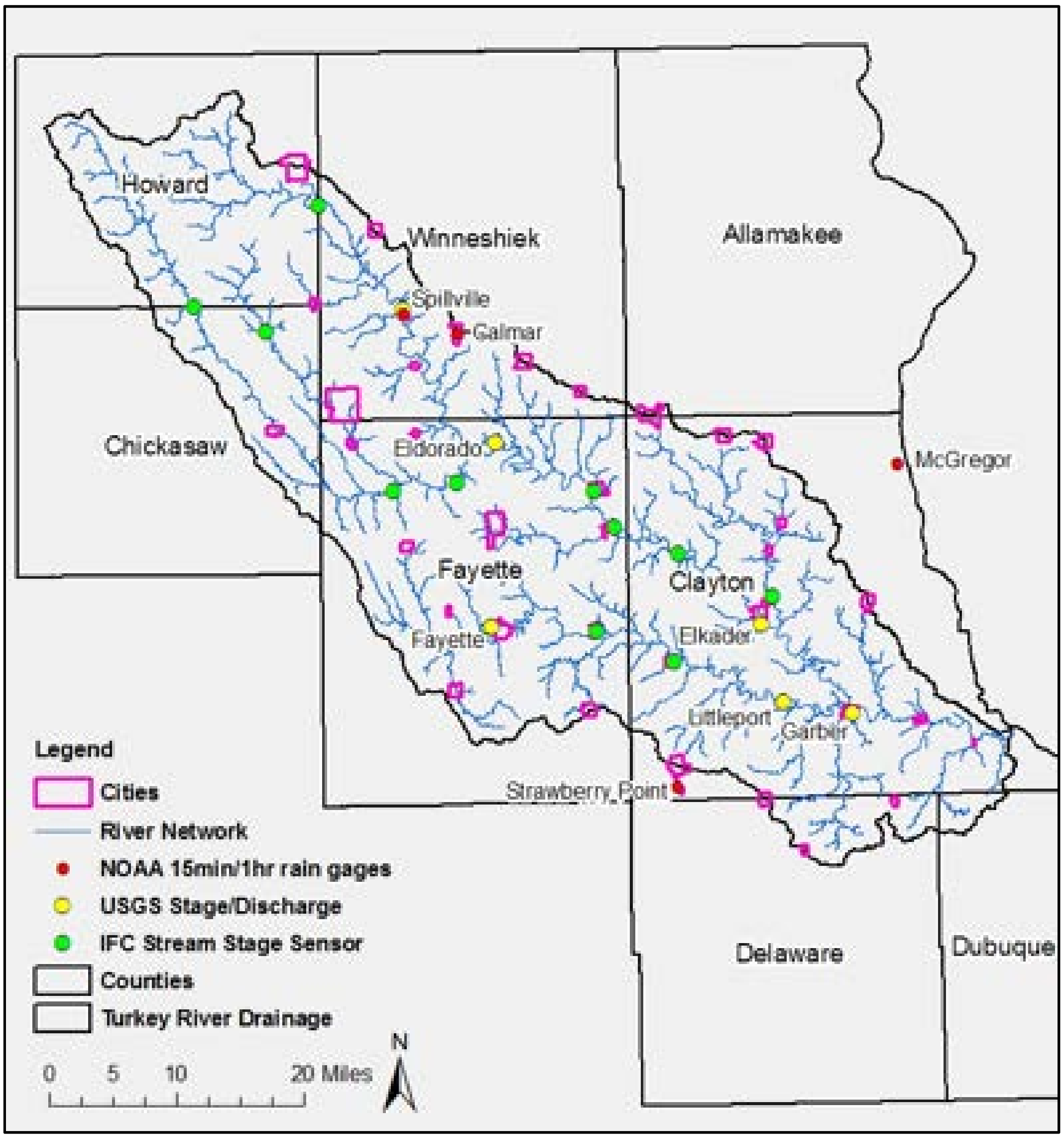

Figure 2.7. Hydrologic and meteorologic instrumentation in the Turkey River Watershed. Stage/discharge gages (17) are shown in yellow or green while NOAA 15 minute/hourly precipitation gages (4) are shown in red.

Table 2.2. Stage/Discharge Gages and Precipitation Gages in the Turkey River Watershed.

Gage Type	*Location*	*Period of Record*
USGS Stage/Discharge	Turkey River at Spillville, IA, 05411600	1956 – 1973 1977 – 1991 2010 – present
USGS Stage/Discharge	Turkey River near Eldorado, IA, 05411850	2000 – present
USGS Stage/Discharge	Turkey River above French Hollow Creek at Elkader, IA, 05412020	2001 – present
USGS (stage, discharge) –	Turkey River at Garber, IA, 05412500	1913 – 1916 1919 – 1927 1929 – 1930 1932 – present
USGS (stage, discharge) –	Volga River at Fayette, IA, 05412340	2010 – present
USGS (stage, discharge) –	Volga River at Littleport, IA, 05412400	1999 – present
IFC Stream Sensor (stage)	Crane Creek, 100th St., County B16, Howard/Chickasaw Co. Line	2011 – present
IFC Stream Sensor (stage)	Crane Creek, Spruce Rd., Fayette County	2011 – present
IFC Stream Sensor (stage)	Little Turkey River, 120th St., County B22, Chickasaw County	2011 – present
IFC Stream Sensor (stage)	Little Turkey River, Nature Rd., County B44, Fayette County	2011 – present
IFC Stream Sensor (stage)	Turkey River, 345th St., County Line Rd, Howard/Winneshiek Co. Line	2010 – present
IFC Stream Sensor (stage)	Turkey River, Clermont, IA, Hwy 18, Mill St., Fayette County	2011 – present
IFC Stream Sensor (stage)	Otter Creek, Elgin, IA, Mill St., Fayette County	2011 – present
IFC Stream Sensor (stage)	Turkey River, Cable Ave., Clayton County	2010 – present
IFC Stream Sensor (stage)	Roberts Creek, Hwy 13, Clayton County	2011 – present
IFC Stream Sensor (stage)	Volga River, Wadena, IA, South Mill St., County W51, Fayette, County	2011 – present
IFC Stream Sensor (stage)	Volga River, Volga, IA, Domino Rd., County C2W, Clayton County	2011 – present
NOAA 15min/1hr Precip	Spillville, IA	1983 – 2007
NOAA 15min/1hr Precip	Calmar, IA	2009 – present
NOAA 15min/1hr Precip	McGregor, IA	1983 – present
NOAA 15min/1hr Precip	Strawberry Point, IA	1983 – present
NOAA-partnered Daily Precip	Clermont, IA	2010 – 2012
NOAA-partnered Daily Precip	Cresco, IA	1893 – present
NOAA-partnered Daily Precip	Decorah, IA	1893 – present
NOAA-partnered Daily Precip	Elkader, IA	1893 – present
NOAA-partnered Daily Precip	Fayette, IA	1892 – present
NOAA-partnered Daily Precip	Postville, IA	1893 – present
NOAA-partnered Daily Precip	Waucoma, IA	1954 – present
NOAA-partnered Daily Precip	Waukon, IA	1934 – 2013
NOAA-partnered Daily Precip	West Union, IA	2002 – 2013

f. Floods of Record

Four large floods have been recorded at the USGS Turkey River gaging station at Garber, Iowa since 1991. These four flood peaks, June 15, 1991 - 49,900 cubic feet per second (cfs); May 17, 1999 - 53,900 cfs; May 23, 2004 – 66,700 cfs; and June 10, 2008 – 45,500 cfs are the four largest discharges observed during the continuous operation of this gage since 1932. The fifth largest peak discharge since 1932 at this gage was 29,000 cfs on June 13, 1947.

The 1991 and 2008 floods both exceeded the peak discharge of the 2004 flood at the Turkey River above French Hollow Creek at Elkader gaging station (38,300 and 40,500 vs. 33,300 cfs respectively). The 1999 flood exceeded the peak discharge of the 2004 flood at the Volga River at Littleport gaging station (30,000 vs. 21,000 cfs respectively) (Eash, 2004). However, the timing of the flood peaks on the two rivers in 2004 came together at just the right time along with inflow from Roberts and Elk Creeks to produce the monumental peak discharge of 66,700 cfs at the Turkey River at Garber gage.

Table 2.3. Discharges from Four Flooding Events in the Turkey River Watershed since 1991.

	USGS Gage Peak Discharge (cfs)			
Date	*TR-Eldorado*	*TR-Elkader*	*VR-Littleport*	*TR-Garber*
June 15, 1991	17,600 [1]	38,300 [1]	13,500 [1]	49, 900
May 17, 1999	N/A	N/A	30,000 [1]	53,900
May 23, 2004	19,700	33,300	21,000	66,700
June 8-10, 2008	50,100 (June 9)	40,500 (June 10)	18,900 (June 8)	45,500 (June 10)

[1]*Historic Peaks, documented by USGS*

The flood stage established by the National Weather Service at which minor flooding begins to occur along the river for the location of the Turkey River above French Hollow Creek at Elkader gaging station is 12 feet. In the 2004 flooding event, the river stage was greater than 12 feet for three days, May 22-25 with a peak flood stage of 25.6 feet on May 23, 2004; 13.6 feet above minor flood stage. Likewise, the flood stage for the Turkey River at Garber gaging station for which minor flooding begins to occur in the small communities of Garber, Osterdock, and Millville is 17 feet, which was exceeded for four days, May 22-26. The peak flood stage, also on May 23, 2004 at this gage, was 32.8 feet, exceeding minor flood stage at this site by 15.8 feet. The dike meant to protect the community of Elkport, another community along the lower Turkey River near Garber, failed at about 11:30 a.m. on May 23rd and in just a couple hours the entire community was flooded and most of the houses in Elkport were under 8 feet of water, leaving the entire community a loss (Eash, 2004).

The flooding that occurred in June 2008 was set up by a wet fall of 2007, followed by abundant snowfall over the winter of 2007-2008, and then a wet spring of 2008. Precipitation from December 2007 through May 2008 was the second wettest on record from 1895-2008. Most notably, the precipitation totals in Eastern Iowa and Southwest Wisconsin was characterized by the USGS as extremely wet conditions (Buchmiller and Eash, 2010). By June of 2008, the soil was at a point so wet that it could accept very little water from infiltration when more heavy rain storms tracked over the Turkey River Watershed. Rainfall was significant beginning June 7 through June 9 with an excess of 3 inches of rain falling across the entire Turkey River Watershed, however 6 to 7 inches fell in the upper northwest quarter of the watershed (Howard and Winneshiek Counties). The runoff and subsequent flooding was just as significant. In this event, the peak flood stage at the Turkey River above French Hollow Creek gaging station reached 27.77 feet, more than 2 feet higher than it had just been in 2004. The flooding downstream of Elkader had the potential to greatly exceed that of 2004, fortunately unlike the flooding of 2004, timing of the rainfall distribution and the subsequent flood peaks of the Volga and Turkey Rivers were offset by two days when they passed the gaging station at Garber. Yet, a peak discharge was recorded on June 10 as 45,500 cfs with a flood stage of 29.13 feet, still exceeding minor flood stage by 12 feet.

3. Turkey River Hydrologic Model Development

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

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 Turkey River Watershed or larger). Figure 3.1 reviews the water cycle and major hydrologic processes that occur in a watershed.

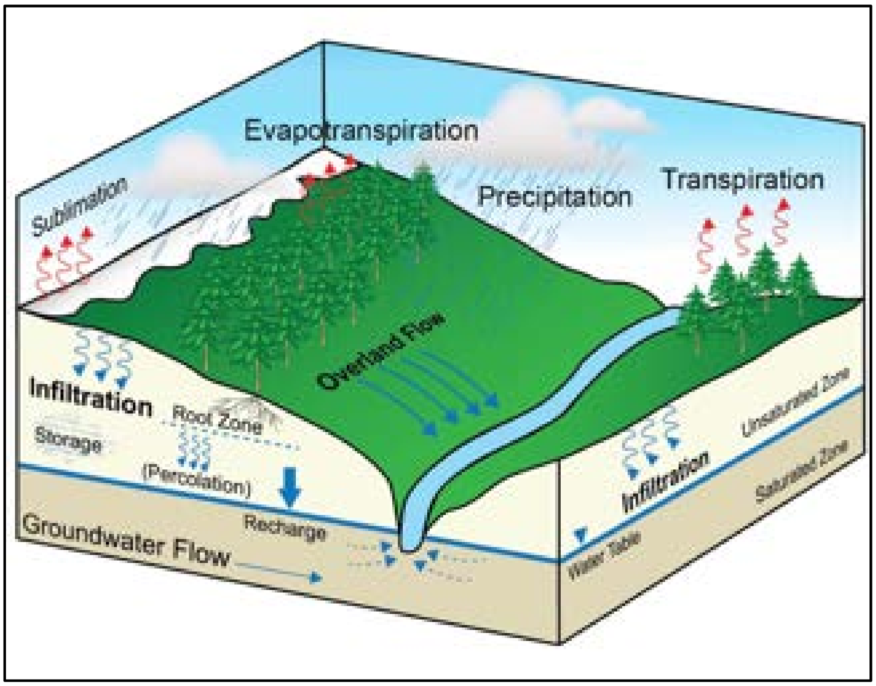

Figure 3.1. Hydrologic processes that occur in a watershed. Phase I modeling only considered the precipitation, infiltration, and overland components of the water cycle.

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

The Turkey River Watershed as modeled and detailed herein is approximately 1693 square miles. For modeling, the watershed was divided into 710 smaller units, called subbasins in HMS, with an average area of about 2.4 square miles, but as large as 7.6 square miles. The subbasin delineation of the Turkey River Watershed implemented into HMS is shown in Figure 3.2.

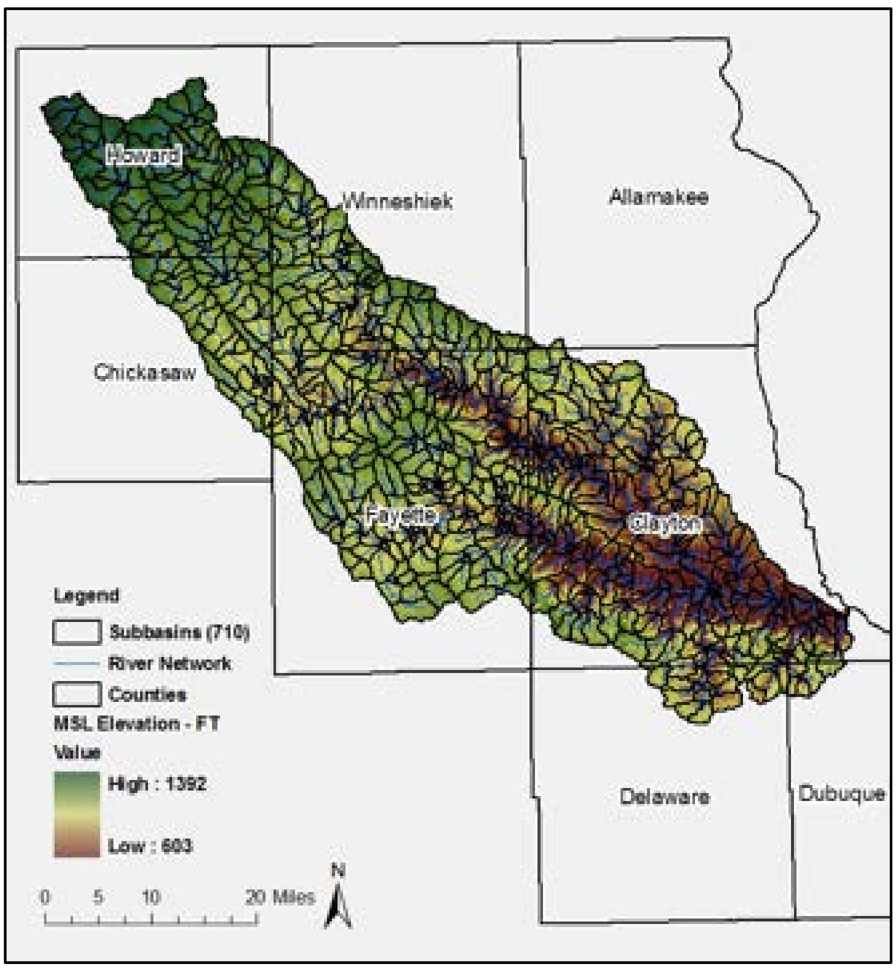

Figure 3.2. HMS model development of the Turkey River Watershed. The watershed was divided into 710 subbasins for modeling.

ESRI ArcGIS and Arc Hydro tools were used for terrain preprocessing, creating flow direction and flow accumulation grids, defining the stream network, and delineation of the subbasins. The stream network was defined to begin when the upstream drainage area was 1.5 square miles 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 USGS gage location, as well as the discharge point of two incorporated structures (Volga Lake and Lake Meyer; refer to Chapter 3.a.i.). In HMS, the averaging previously described for lumped parameter models is performed within the boundary of each subbasin and then each subbasin is assigned a single value for the parameter being developed.

i. Incorporated Structures

Two reservoirs, Volga Lake and Lake Meyer, (shown in the following figure) were incorporated into the HMS model. Volga Lake is a 138-acre lake located in Fayette County, south of West Union, Iowa. Lake Meyer is a 38-acre lake in Winneshiek County, west of Calmar, Iowa. Stage-storage-discharge relationships were obtained for each lake from Iowa Department of Natural Resources' Office of Dam Safety in Des Moines, Iowa. The stage-storage-discharge rating curves used in the Turkey River Watershed HMS model are available in Appendix B. No existing farm ponds or other possible water storage structures were included in the HMS model.

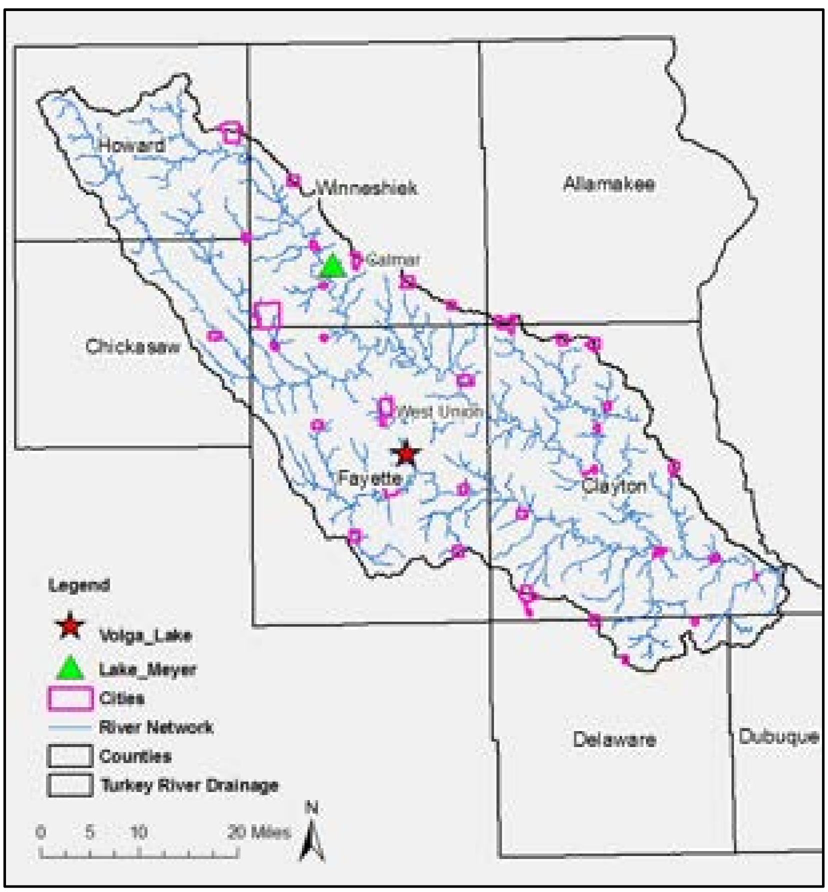

Figure 3.3. Location Map Showing Volga Lake and Lake Meyer.

ii. Development of Model Inputs and Parameters

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

Rainfall (Meteorological Model)

Stage IV radar rainfall estimates (NCEP/EMC 4KM Gridded Data (GRIB) Stage IV Data) were used as the precipitation input for simulation of actual rainfall events known to have occurred within the watershed. The Stage IV data set is produced by the National Center for Environmental Prediction (NCEP) by taking radar rainfall estimates produced by the 12 National Weather Service (NWS) River Forecast Centers across the Continental United States and combining them into a nationwide 4 km x 4 km (2.5 mile x 2.5 mile) gridded hourly precipitation estimate data set. These data are available from January 1, 2002 – Current.

Figure 3.4, developed using HEC-GridUtil 2.0, shows an example of the Stage IV radar rainfall estimates of cumulative rainfall during a one hour period (May 21, 2004, 5 a.m. to 6 a.m.) in the Turkey River Watershed. This figure helps demonstrate the gridded nature of the radar rainfall estimate data, as well as the distributed nature of rainfall in time and space during large storm events.

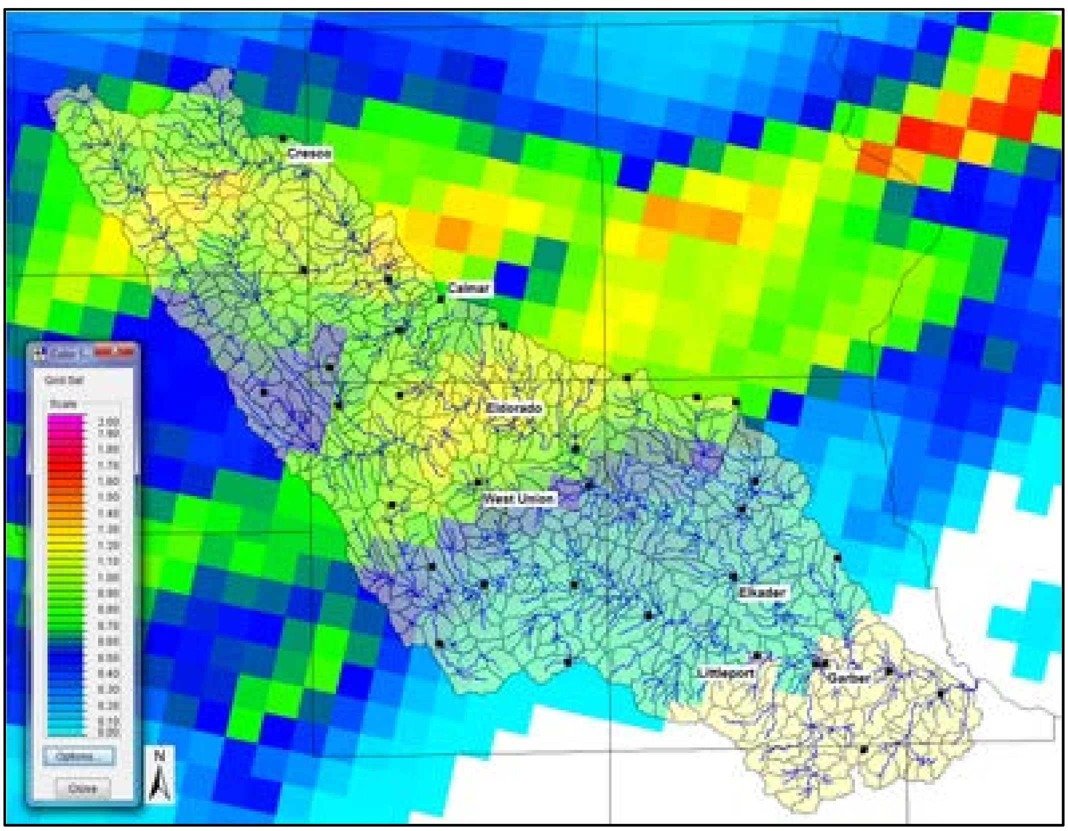

Figure 3.4. Example of the Stage IV radar rainfall product used as the precipitation input in the Turkey River Watershed HMS model. The Stage IV product provides hourly cumulative rainfall estimates for each 4 km x 4 km grid cell. The scale shown refers to the depth of rainfall (in inches) estimated for a one hour period.

Use of radar rainfall estimates provides increased accuracy of the spatial and time distribution of precipitation over the watershed and Stage IV estimates provide a level of manual quality control (QC) performed by the NWS that incorporates available rain gage measurements into the rainfall estimates. Actual storms using Stage IV data were the basis for model calibration and validation. The storm events used in model calibration and validation are discussed in Chapter 3.b and Chapter 3.c.

Hypothetical storms were developed for comparative analyses such as potential runoff generation, increased infiltration capacity, or increased distributed storage within the watershed. These hypothetical storms apply a uniform depth of rainfall across the entire watershed with the same timing everywhere. Soil Conservation Service (SCS) Type-II distribution, 24-hour storms were used for all hypothetical storms. Point precipitation values (rainfall depths) for 2-, 5-, 10-, 25-, 50-, and 100-year average recurrence interval, 24-hour storms were derived using the online version of National Oceanic and Atmospheric Administration (NOAA) Atlas 14 – Point Precipitation Frequency Estimates (NOAA, 2013). Point estimates were obtained for several locations throughout the Turkey River Watershed, in which the variation of these estimates were within approximately 0.2", thus the average resulted in a reasonable value to use watershed-wide for each average recurrence interval.

Studies have been performed on the spatial distribution characteristics of heavy rainstorms in the Midwestern United States (Huff and Angel, 1992). Point precipitation frequency estimates are generally only applicable for drainage areas up to 10 square miles before the assumption of being uniformly distributed is no longer valid, thus for drainage areas between 10 and 400 square miles, relations have been established between point precipitation estimates and an areal mean precipitation approximation. Adjustment factors based on storm duration and drainage area can be found in Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992). Guidance from NOAA regarding adjusting point estimates to areal mean estimates: We don't recommend extrapolation of the curves much beyond the limits [400 square miles]. The basic assumption behind areal reduction factors is that there is dependence between the point and areal values. The correlation between point estimates reduces as they get farther apart until the values become independent and so the dependence relation between a point and an area breaks down as well (NOAA FAQ, 2013).

For the comparative analyses that were performed in this modeling effort, an extrapolation was performed to get an areal reduction factor beyond 400 square miles. It is agreed that this depth of rainfall would not fall uniformly across a watershed this large, however to have reasonable rainfall depth estimates with a general relationship to the average recurrence interval 24-hour storms in the Turkey River Watershed, the point rainfall estimates were reduced by a factor of 0.88. Table 3.1 shows the point precipitation estimates obtained from NOAA Atlas 14 and the areal reduced precipitation values used for hypothetical storms in this hydrologic assessment.

Table 3.1. Summary of NOAA point precipitation frequency estimates and areal reduced values for the 2, 5, 10, 25, 50, and 100 year, 24 hour design storms. The areal reduced values were used for the hypothetical analyses in HMS.

Hypothetical Storm	*NOAA Point Precipitation (in)*	*Areal Reduced Precipitation (in)*
2 year - 24 hour	3.02	2.66
5 year - 24 hour	3.74	3.29
10 year - 24 hour	4.43	3.90
25 year - 24 hour	5.50	4.84
50 year - 24 hour	6.42	5.67
100 year - 24 hour	7.43	6.54

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

Watershed (Basin Model)

Elevation data was obtained from the National Elevation Dataset (NED). The four blocks (n43w092, n43w093, n44w092, and n44w093) of 10-meter resolution digital elevation models (DEM's) covering the extent of the Turkey River Watershed were downloaded, were clipped to the needed extents using ESRI ArcGIS, then the mosaic tool on the HEC-GeoDozer toolbar was used to join them into a seamless DEM. NED data are distributed in geographic coordinates in units of decimal degrees, in conformance with the North American Datum of 1983 (NAD 83). All elevation values are in meters and are referenced to the North American Vertical Datum of 1988 (NAVD 88).

Soil Conservation Service (SCS) Curve Number methodology was used to determine the rainfall-runoff partitioning for the Turkey River Watershed HMS modeling. Curve Number (CN) values range from 30-100 and 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.

However, rainfall-runoff partitioning for an area is also dependent on the antecedent soil moisture conditions (how wet the soil is) (AMC) at the time rain falls on the land surface. The wetter the soil is, less water is able to infiltrate and more water is then converted to runoff. Therefore, when using SCS Curve Number methods to determine runoff volumes, determination of antecedent soil moisture content and classification into the antecedent moisture classes AMC I, AMC II, and AMC III, representing dry, average, and wet conditions, is an essential matter for the application of the SCS Curve Number (Silveira et al., 2000) and Curve Numbers may need adjustment to accurately simulate runoff for dryer or wetter than normal conditions.

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

Additionally, there were instances of soils from the SSURGO data without a soil type assigned. Based on the location of most of these soil areas falling in the Paleozoic Plateau region of the watershed, they were assumed to be rock outcrops. In conversation with Calvin Wolter, Iowa Geologic Survey Geologist and GIS Analyst, it was confirmed these were areas of rock or likely only a thin layer of soil over rock and therefore no soil attributes had been assigned. It was recommended to assign as D-type soils for establishing runoff potential for these areas.

The Curve Numbers used for each land use/soil type combination for the Turkey River HMS model is shown below.

Table 3.2. Curve Number assignment in the Turkey River Watershed based on land use and soil type. Area-weighted averaging was used to calculate a single Curve Number for each subbasin.

2006 NLCD Code	*Description*	*HSG A*	*HSG B*	*HSG C*	*HSG D*
11	Open Water	100	100	100	100
21	Developed, Open Space	49	69	79	84
22	Developed, Low Intensity	57	72	81	86
23	Developed, Medium Intensity	81	88	91	93
24	Developed, High Intensity	89	92	94	95
31	Bare Rock/Sand/Clay	98	98	98	98
41	Deciduous Forest	32	58	72	79
42	Evergreen Forest	32	58	72	79
43	Mixed Forest	32	58	72	79
52	Shrub/Scrub	32	58	72	79
71	Grassland/Herbaceous	49	69	79	84
81	Pasture/Hay	49	69	79	84
82	Row Crops	67	78	85	89
90	Woody Wetlands	100	100	100	100
95	Emergent Herbaceous Wetlands	100	100	100	100

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

Runoff Hydrographs

Using the SCS Curve Number methodology for rainfall-runoff partitioning accounts for precipitation losses related to initial abstraction, which is an initial amount of rainfall that falls before any runoff begins (interception on plants, wetting of the soil, etc.) and the amount of precipitation that is estimated to infiltrate into the ground during the simulation. The remaining precipitation is considered excess precipitation and is converted to runoff. Evaporation and transpiration (evapotranspiration) was neglected in the Turkey River Watershed modeling as the focus is to simulate short duration, large rain events when evapotranspiration is considered to be a minimal component of the water balance. Seasonal antecedent rainfall tables from NRCS technical references were used as guidelines for estimating Curve Number adjustments (if necessary) for antecedent moisture conditions.

The SCS Dimensionless Unit Hydrograph method was used to convert excess precipitation to a runoff hydrograph for each subbasin. This method required the development of a parameter called basin lag time, which describes the time difference between the center of mass of the excess precipitation and the peak of the runoff hydrograph. 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 composite Curve Number. ESRI ArcGIS tools were used for terrain analysis to identify subbasin slopes and the longest flowpaths.

The following graphic illustrates the SCS methodologies as applied for runoff volume estimation and conversion of the excess precipitation into a runoff hydrograph.

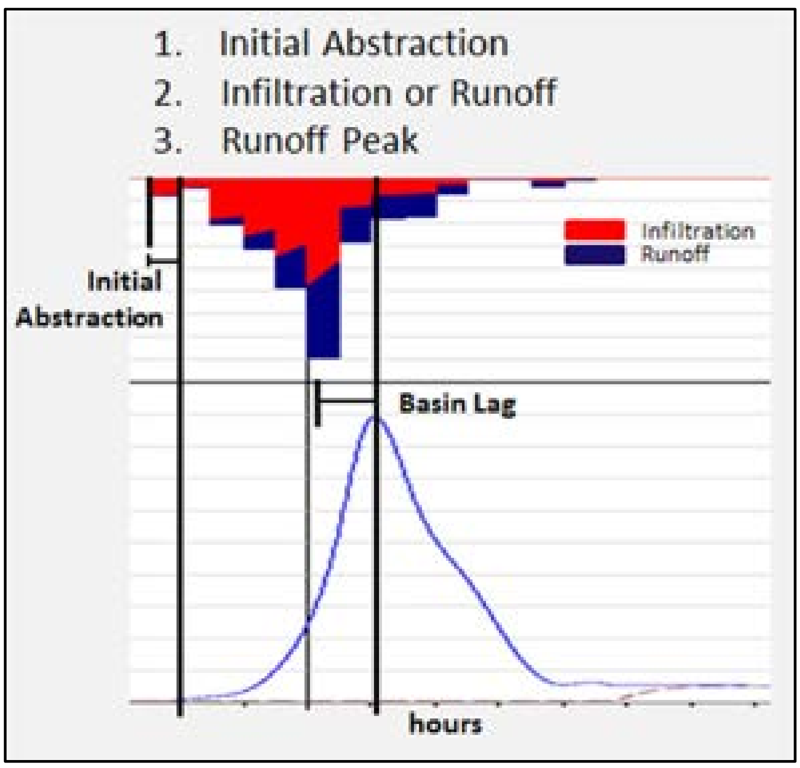

Figure 3.5. Subbasin runoff hydrograph conceptual model. This figure shows how rainfall is partitioned into runoff using the SCS Curve Number methodology and converted to a runoff hydrograph.

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

The USGS stage/discharge gages for the Turkey River at Eldorado, Elkader, and Garber were used for the Turkey River and the gaging station at Littleport was used for the Volga River 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. A single initial baseflow condition was determined to best describe the Turkey River and its tributaries and a separate initial baseflow condition was developed for the Volga River. These unique initial conditions were applied to the appropriate corresponding subbasins within the HMS interface for each actual storm event simulation.

Baseflow initial conditions prior to performing simulations using hypothetical storms cannot be identified using the USGS gages. It can be assumed though, that there is a fraction of the overall streamflow coming from each subbasin; just the actual value of the discharge is unknown. For the purposes of the hydrologic assessments being made using the HMS model developed for the Turkey River Watershed, each hypothetical storm event was simulated using the same baseflow initial conditions as was used for the May 21-23, 2004 actual storm event (0.8 cfs/mi^2 for the Turkey River and 1.1 cfs/mi^2 for the Volga River). Similar, slightly lower baseflow conditions were observed before a storm event that occurred June 2-4, 2002 and it should be noted that with the exceptionally wet conditions present in the spring of 2008, baseflow conditions prior to the June 7-9 storm event were considerably higher.

Parameters Assigned in HEC-HMS: Flood Wave Routing

Conveyance of runoff through the river network, or flood wave routing was accomplished using the Muskingum routing method. Three inputs are required to use the Muskingum routing method in HMS, the flood wave travel time in a reach (K), a weighting factor that describes storage within the reach as the flood wave passes through (X), and the ratio to peak, which describes at what discharge baseflow is once again the dominant source of streamflow after direct runoff ends.

The allowable range for the X parameter is between 0 and 0.5. Generally, X ranges between a value of 0.1 and 0.3 for natural streams, with the value of 0.2 frequently used in engineering practice and was used in this modeling analysis. Great accuracy in determining X may not be necessary because the results are relatively insensitive to the value of this parameter (Chow/Maidment/Mays, 1988). The flood wave travel time, K, is much more important and can be estimated by dividing the reach length by a reasonable travel velocity (1-5 feet per second, in general) as a starting point, but is generally best obtained by adjustment in the model calibration process using measured discharge records if available. Ratio to peak can also be first estimated, but generally is best obtained by adjustment in the model calibration process as well.

b. Calibration

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

The Turkey River Watershed HMS model was calibrated to the storm event occurring May 21-23, 2004. This storm, characterized by intense thunderstorms tracking over Northeast Iowa, produced severe flooding throughout the southern half of the Turkey River Watershed and a peak flow of 66,700 cubic feet per second (cfs) at the USGS gage on the Turkey River at Garber, IA. Stage IV radar rainfall estimates and USGS discharge records for the Turkey River at Eldorado, Elkader, and Garber, as well as the Volga River at Littleport were used in the model calibration efforts. Hydrographs for each of these locations for measured and simulated discharges are provided in Appendix C.

The following figure, developed using HEC-GridUtil 2.0, shows the Stage IV cumulative rainfall estimates (inches) for the Turkey River Watershed beginning at midnight May 21 and ending at 6:00 p.m. on May 23, 2004.

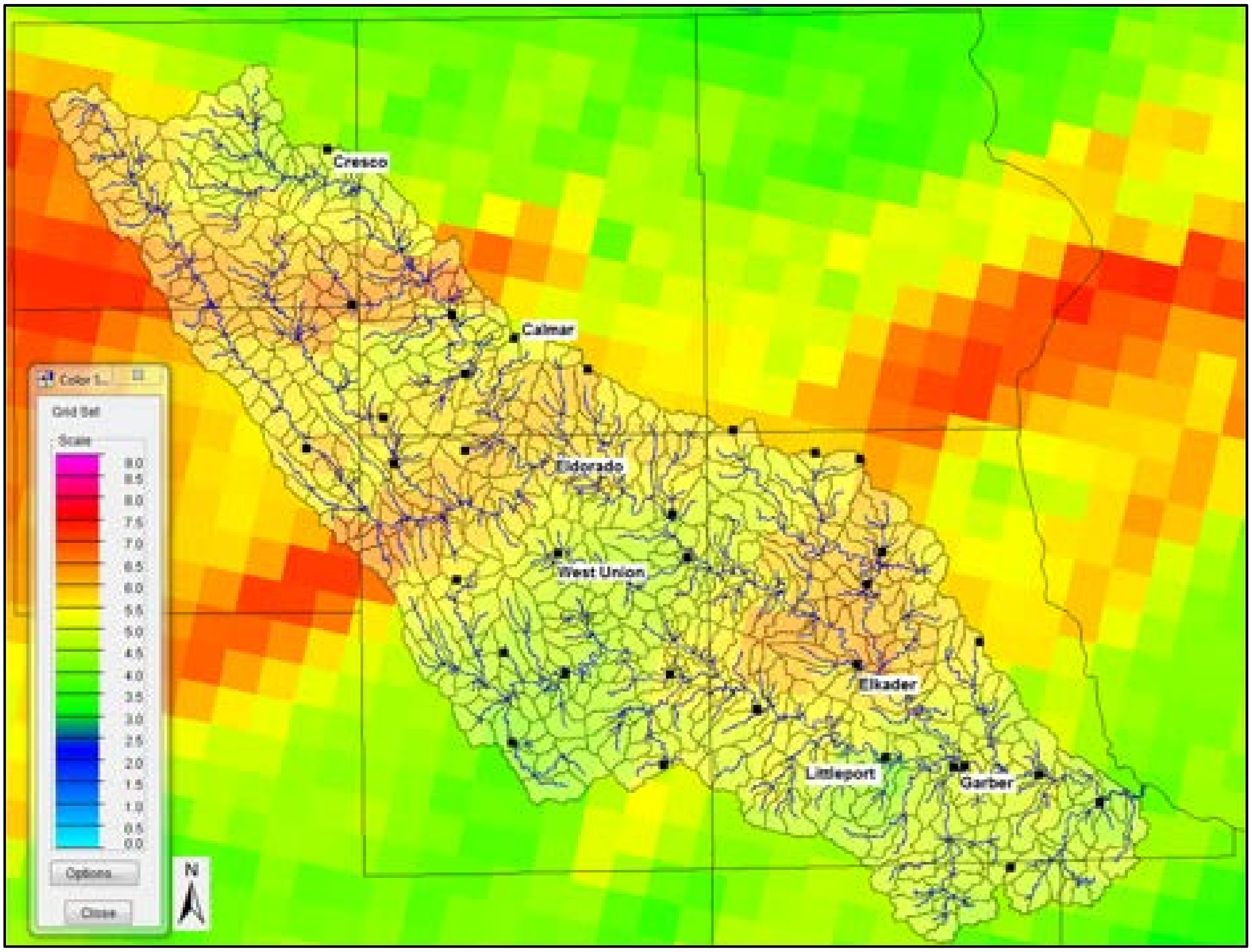

Figure 3.6. Cumulative Rainfall (inches) for May 21-23, 2004 in the Turkey River Watershed.

c. Validation

For model validation, the intent is to use the model parameters developed during calibration to simulate other events and evaluate how well the model is able to replicate observed stream flows. Storms producing the highest runoff were of most interest, however with the availability of Stage IV radar rainfall estimates beginning in January 2002, the flooding events of June 1991 and May 1999, which measured discharges of 49,900 and 53,900 cubic feet per second (cfs) at the USGS Garber gage were not simulated for model validation.

The storm event of June 7-9, 2008, which caused significant flooding in the Turkey River Watershed (45,500 cfs at the Garber gaging station) and a smaller event resulting from a storm that occurred June 2-4, 2002 (13,800 cfs at the Garber gaging station) were used for validation. Antecedent rainfall was analyzed using the radar rainfall estimates and the NOAA and NOAA-partnered rain gages prior to each of these events to determine the antecedent moisture conditions. Baseflow conditions were established using the USGS gage discharge data and adjusted in the HMS model so the initial streamflow conditions matched the observed data as well as possible at the time the simulation was to start. Overall, the model parameters developed using the May 2004 flooding event produced acceptable results on the simulations of both the large flooding event of June 2008 and the smaller event of June 2002.

For the simulation of the June 7-9, 2008 event, no adjustment was necessary to the Curve Numbers established during the calibration process, however, the wet conditions across the entire Turkey River Watershed leading up to the June 7-9, 2008 event resulted in very little initial abstraction of rainfall from this storm, resulting in rising rivers almost immediately upon the beginning of additional rain.

The June 2-4, 2002 event occurred with slightly wetter antecedent moisture conditions as compared to prior to the 2004 event. Again, no adjustment was needed for the Curve Numbers, but initial abstraction was reduced to reflect wetted conditions from approximately 1-2" of rain that fell within the watershed May 29th. While the rainfall of June 2-4 was intense at times, the volume of rain was much less than what fell in May 2004 or June 2008 and produced much smaller discharges. It is noted that the ratio of the baseflow compared to the peak discharge as a result of runoff was much larger and this adjustment was needed to accurately describe the baseflow conditions.

Additional detailed information regarding model calibration and validation including the hydrographs of simulated results compared to measured discharges and the parameter values used in each simulation is available in Appendix C.

4. Analysis of Watershed Scenarios

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

a. High Runoff Potential Areas

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

In the HMS model of the Turkey River Watershed, the runoff potential for each subbasin is defined by the SCS Curve Number (CN). The CN assigned to a subbasin depends on its land use and the underlying soils. The fraction of rainfall that is converted to runoff — also known as the runoff coefficient — is a convenient way to illustrate runoff potential. Areas with higher runoff coefficients have higher runoff potential. To evaluate the runoff coefficient, the runoff from each subbasin area is simulated with the HMS model for the same rainstorm; we chose a rainstorm applied uniformly across the watershed with a total accumulation of 4.84 inches in 24 hours (25-year average recurrence interval).

Figure 4.1 shows the runoff coefficient as a percentage (from 0% for no runoff to 100% when all rainfall is converted to runoff) at the HEC-HMS subbasin scale. Since the subbasin areas shown were defined for numerical modeling purposes, the results were aggregated to more commonly used subbasin areas — namely, hydrologic units defined by the U.S. Geological Survey (USGS). The smallest hydrologic units, known as HUC 12 watersheds, are shown in Figure 4.2 with area-weighted average runoff coefficients determined for each of the 53 HUC 12 watersheds in the Turkey River Watershed.

Areas in the Turkey River Watershed with the highest runoff potential are primarily located in Howard County in the headwater areas of the Turkey River and of Crane Creek, and in Clayton County in the Roberts Creek area. Runoff coefficients mostly exceed 50% in these areas. Agricultural land use dominates these areas (and the entire watershed in general), however this is not the sole reason they might produce higher runoff. In the case of Howard County, these areas have moderately to poorly drained soils, which are characteristic of much of the Iowan Surface geographic landform and the Roberts Creek area in Clayton County is located in the Paleozoic Plateau (Clayton County) landform region and has shallow soils overlying deep layers of limestone bedrock. From a hydrologic perspective, flood mitigation projects that can reduce runoff from these high runoff areas would be a priority.

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

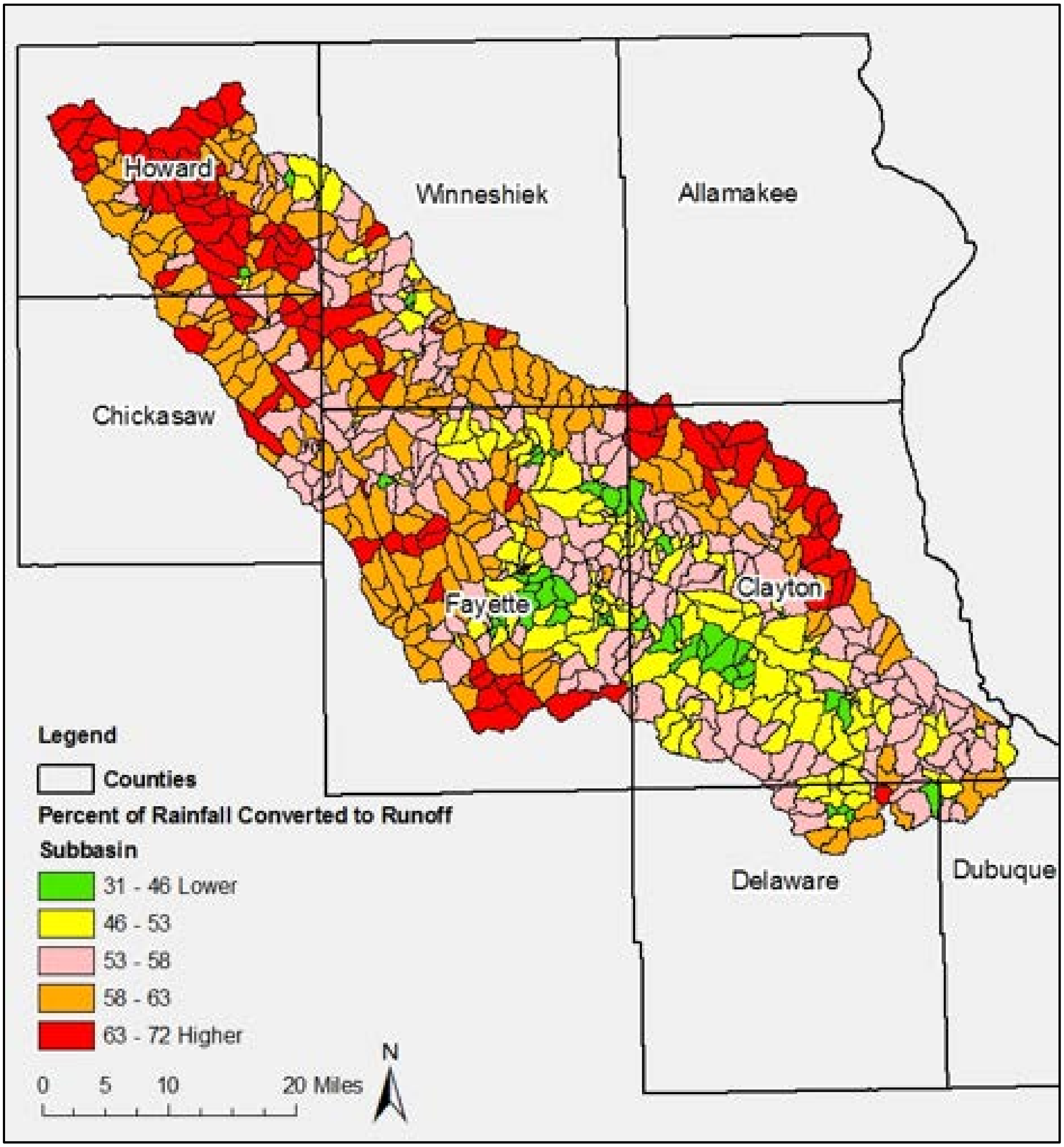

Figure 4.1. Runoff potential analysis for the Turkey River Watershed. This figure shows the runoff coefficient for each subbasin for the 25 year – 24 hour storm (4.84 inches of rain). Higher runoff coefficients are shown in red.

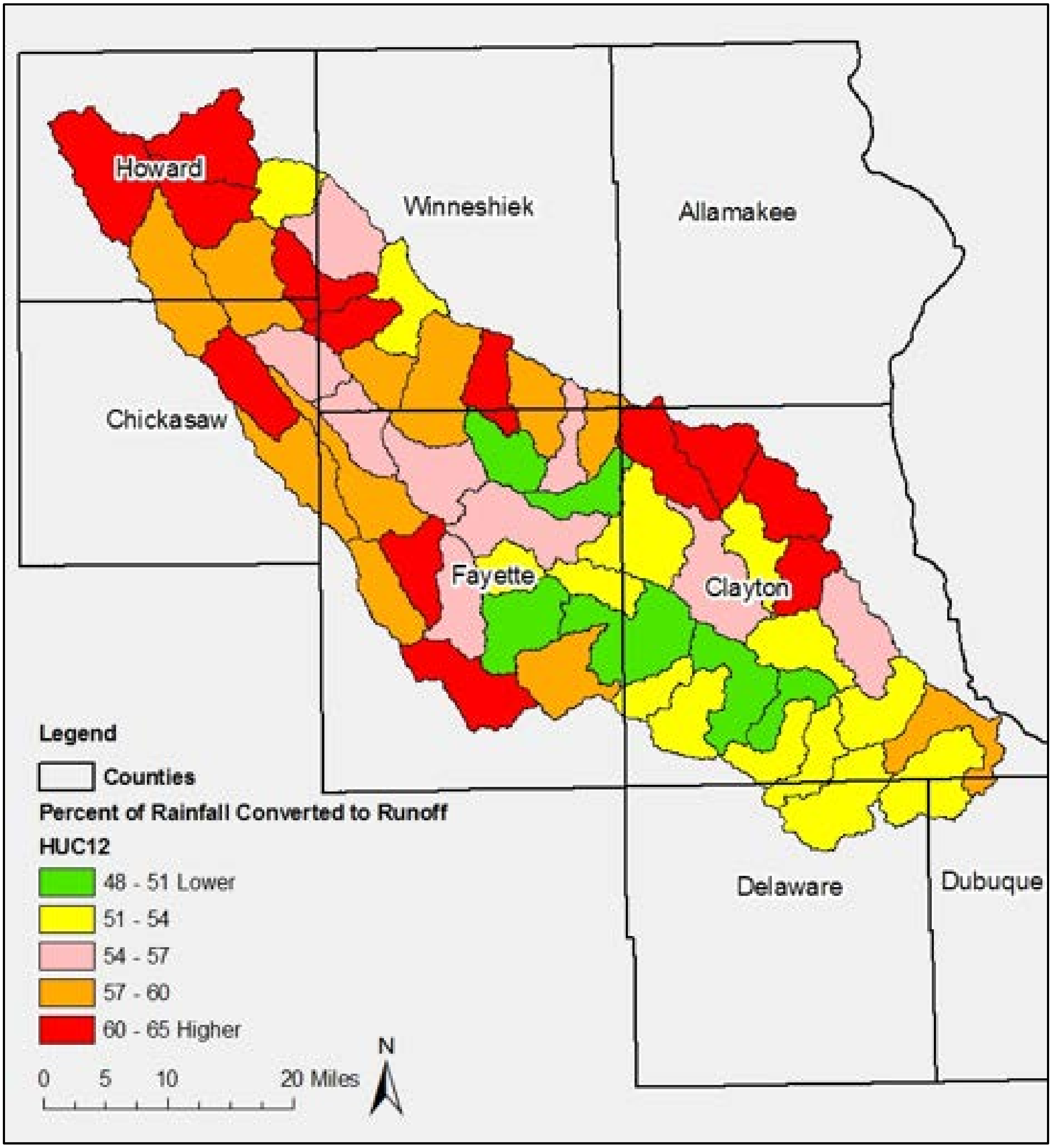

Figure 4.2. Runoff potential analysis for the Turkey River Watershed. This figure shows the aggregated runoff coefficient calculated for each HUC 12 watershed for the 25 year – 24 hour storm (4.84 inches of rain). Higher runoff coefficients are shown in red.

b. Analysis of Flood Mitigation Strategies

Two potential strategies to lessen the flooding effects of runoff coming from areas identified as having high-runoff potential are 1) increasing the amount of infiltration that occurs during larger precipitation events and/or 2) construct a system of storage locations throughout the watershed (distributed storage).

Changes in a watershed that result in a particular area having greater infiltration will reduce the volume of water that leaves that drainage area during the storm event and in the short-term (few days) afterwards. The increased water that passes from the surface into the ground may later evaporate or it will travel through the soil, either seeping deeper into the groundwater stores or travel beneath the surface towards a stream. The rate of travel of the water in this path beneath the surface is much slower than if it were running across the surface. While much of this water may eventually make it to a stream, it will be at a much later time than if it were surface runoff and is what keeps rivers running during longer periods without rain.

A system providing distributed storage on the other hand, in general, does not change the volume of water that runs off the landscape. Instead, storage ponds (Figure 4.3) hold floodwater temporarily, and release it at a lower rate. Therefore, the peak flood discharge downstream of the storage pond is lowered. The effectiveness of any one storage pond depends on its size (storage volume) and how quickly water is released. By adjusting the size and the pond outlets, storage ponds can be engineered to efficiently utilize their available storage for large floods.

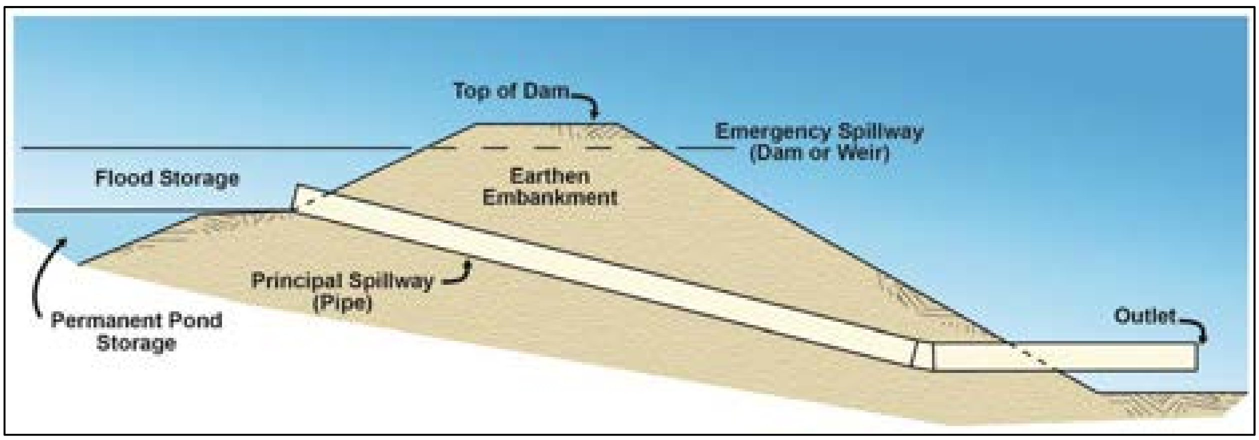

Figure 4.3. Schematic of a pond constructed to provide flood storage.

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

i. Mitigating the Effects of High Runoff with Increased Infiltration

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

An analysis could be performed proposing a scenario where all current land uses are converted back to native tall-grass prairie with its much higher infiltration characteristics within the Turkey River Watershed. The likelihood of obtaining pre-settlement conditions of all tall-grass prairies along with what is currently forest is unlikely. However, to highlight the significance of what a moderate change in increasing infiltration can have within a watershed, a smaller drainage area watershed can be used for demonstration. A hypothetical storm of 5.67 inches of rain over a 24-hour period (50-year average recurrence interval) has been applied to the Otter Creek Watershed (approximately 47 sq. mi.) in Fayette County, in which an increased infiltration analysis is performed.

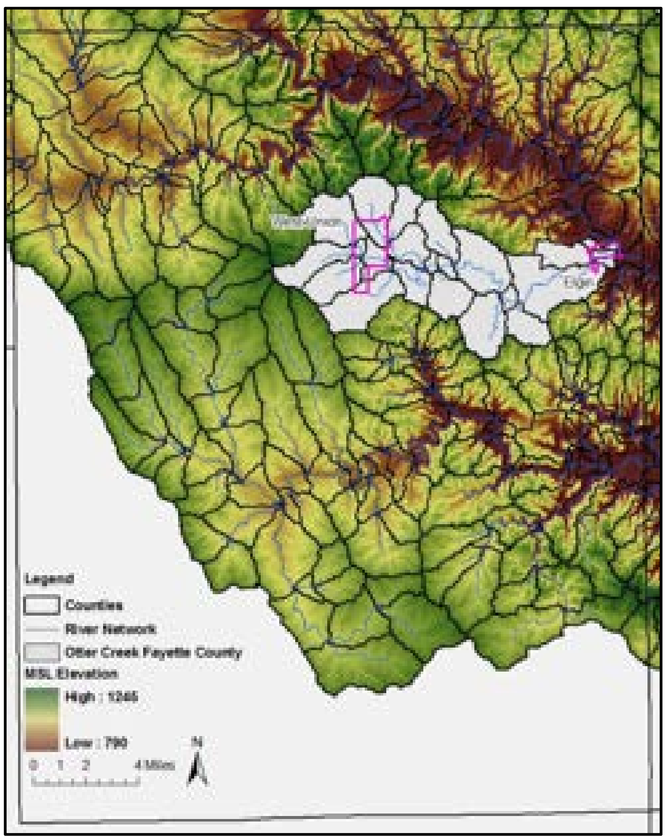

Figure 4.4. Otter Creek Watershed located in Fayette County.

For this analysis, the HEC-HMS model was run with the parameters determined during the calibration process for the May 2004 storm event and again with a hypothetical 15% increase in precipitation loss from infiltration. This increase in infiltration during the storm period resulted in approximately ½ inch more of the total rainfall to be infiltrated into the ground instead of converted to runoff. Otter Creek at the downstream bridge at Elgin (just upstream of the confluence with the Turkey River) experiences a 24.4% reduction in peak discharge. When comparing the current conditions vs. increased infiltration hydrographs, there is a noticeable difference in total volume of water passed during the period of the simulation shown. The following figure shows Otter Creek's response at Elgin to a 15% increase in infiltration in all subbasins that are upstream of this point.

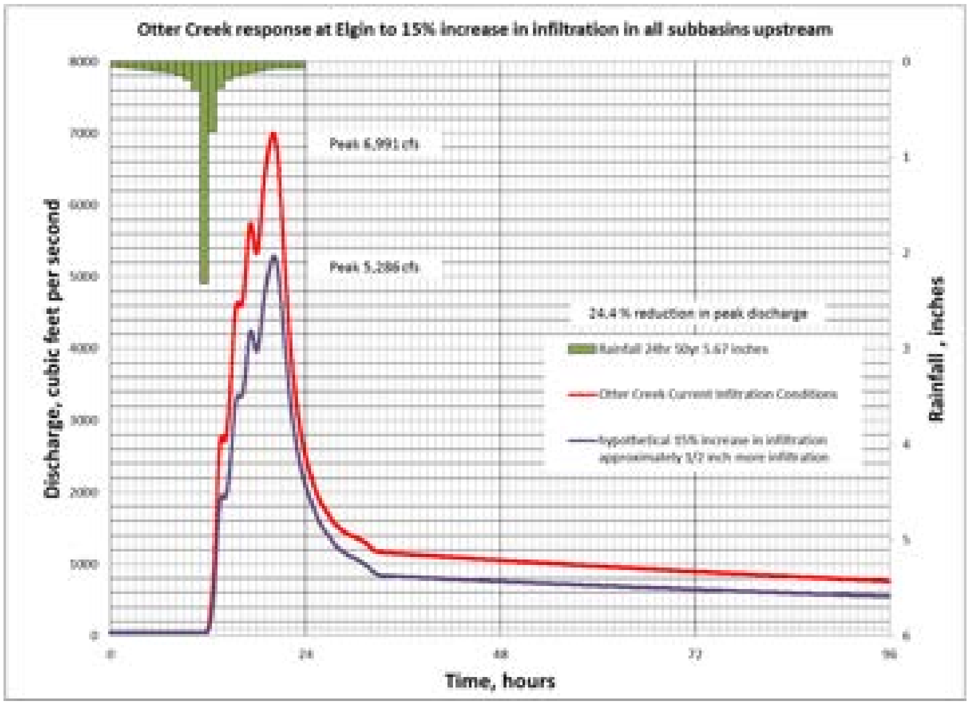

Figure 4.5. Hydrograph comparison for Otter Creek at Elgin with current conditions and the hypothetical increased infiltration scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

ii. Mitigating the Effects of High Runoff with Distributed Storage

The hypothetical distributed storage analysis performed using the Turkey River HMS model was based on information developed from the Soap Creek Watershed (another of the Iowa Watersheds Projects study areas) as well as input from NRCS staff working within the Turkey River Watershed.

The Soap Creek Watershed Board was formed in the 1980's as a result of the watershed's landowners coming together wanting to do something to reduce flood damage and erosion within their watershed. They adopted a plan that included identifying the locations of 154 distributed storage structures (mainly ponds) that could be built within the watershed. As of 2014, 132 of these structures have been built.

Soap Creek Watershed drains approximately 250 square miles, equaling an average density of 1 built pond for every 1.9 square miles of drainage area. Further analysis of the Soap Creek structures shows that most of these structures are constructed in the headwater areas of the watershed, which allows for smaller structures, rather than having large, high-hazard class structures on the main rivers. When looking at the ponds in each HUC12 within the Soap Creek Watershed (see Figure 4.6), pond density ranged from 1 pond per 0.8 square miles in Upper Soap Creek to 1 pond per 5.4 square miles in Middle Soap Creek. The western portion of South

Soap Creek has no constructed ponds in the draining area to Lake Sundown and in Middle Soap Creek there are no constructed ponds in the draining area to Lake Wapello. The average pond density in the headwater areas where the majority of the ponds have been constructed is approximately 1 pond per 1.4 square miles.

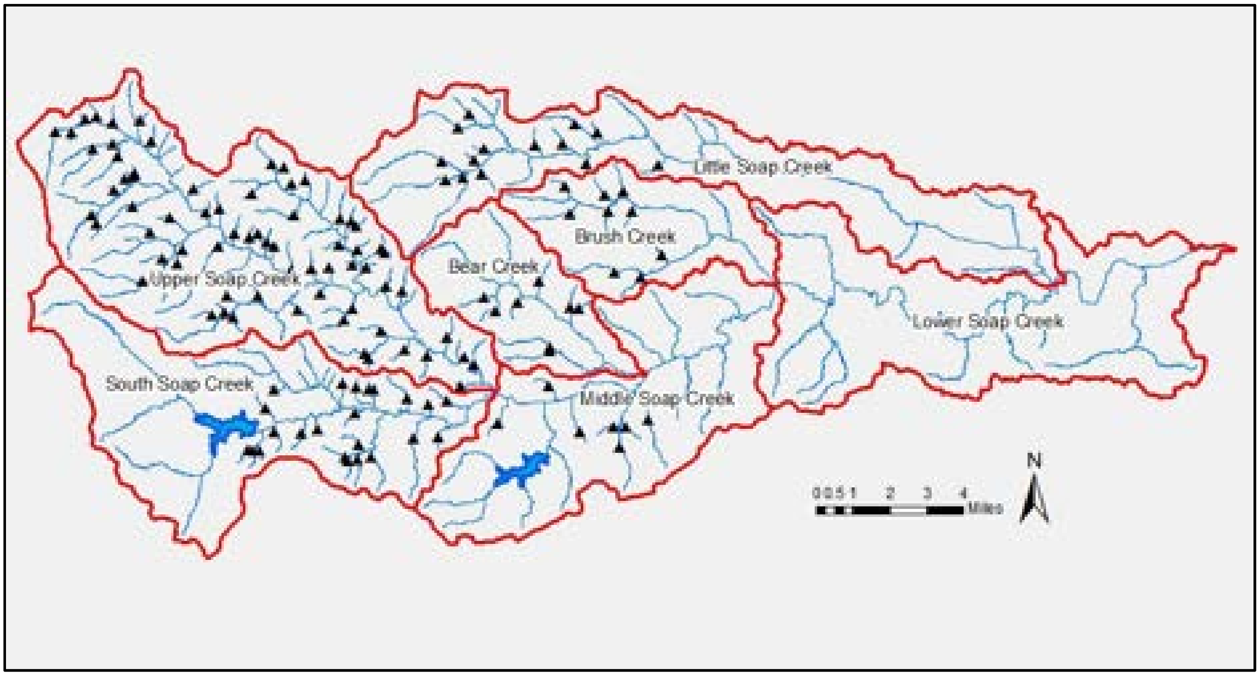

Figure 4.6. Pond placement of constructed ponds in Soap Creek. 132 ponds have been constructed between 1992 and 2014.

For the Turkey River hypothetical distributed storage simulation, it was decided to place pond structures only in headwater subbasins of the HMS model at a density of 1 pond for every 2 square miles of drainage area. For example, if the subbasin was roughly 6 square miles, 3 ponds were incorporated into the simulation for that subbasin. There are some subbasins that have been identified to have ponds that were less than 2 square miles; these subbasins still were assigned to have 1 pond. See Figure 4.7 for the subbasins (colored beige) identified to have pond flood storage incorporated into the simulation. The number label within these subbasins reflects the number of ponds to be considered within that subbasin. A larger, higher detailed map is provided in Appendix A (Figure A-17).

There certainly are opportunities to design and construct ponds at locations in subbasins that have not been identified in this analysis, as well as some identified may not work for ponds. Some limestone areas are especially difficult or hazardous for use as pond sites. There may be crevices, sinks, caverns or channels in the limestone below the soil that are not visible from the surface. A thorough site investigation shall be performed if shallow limestone bedrock is suspected. One of the best guides to the suitability of a site in such areas is the degree of success experienced with any other farm ponds in the immediate vicinity (NRCS-EFH-11, 1980). Extra caution should be placed in geologic investigation for pond design in the Turkey River Watershed, especially those areas of Winneshiek (SE), Fayette (East 1/2), and Clayton (All) Counties in the Paleozoic Plateau landform region.

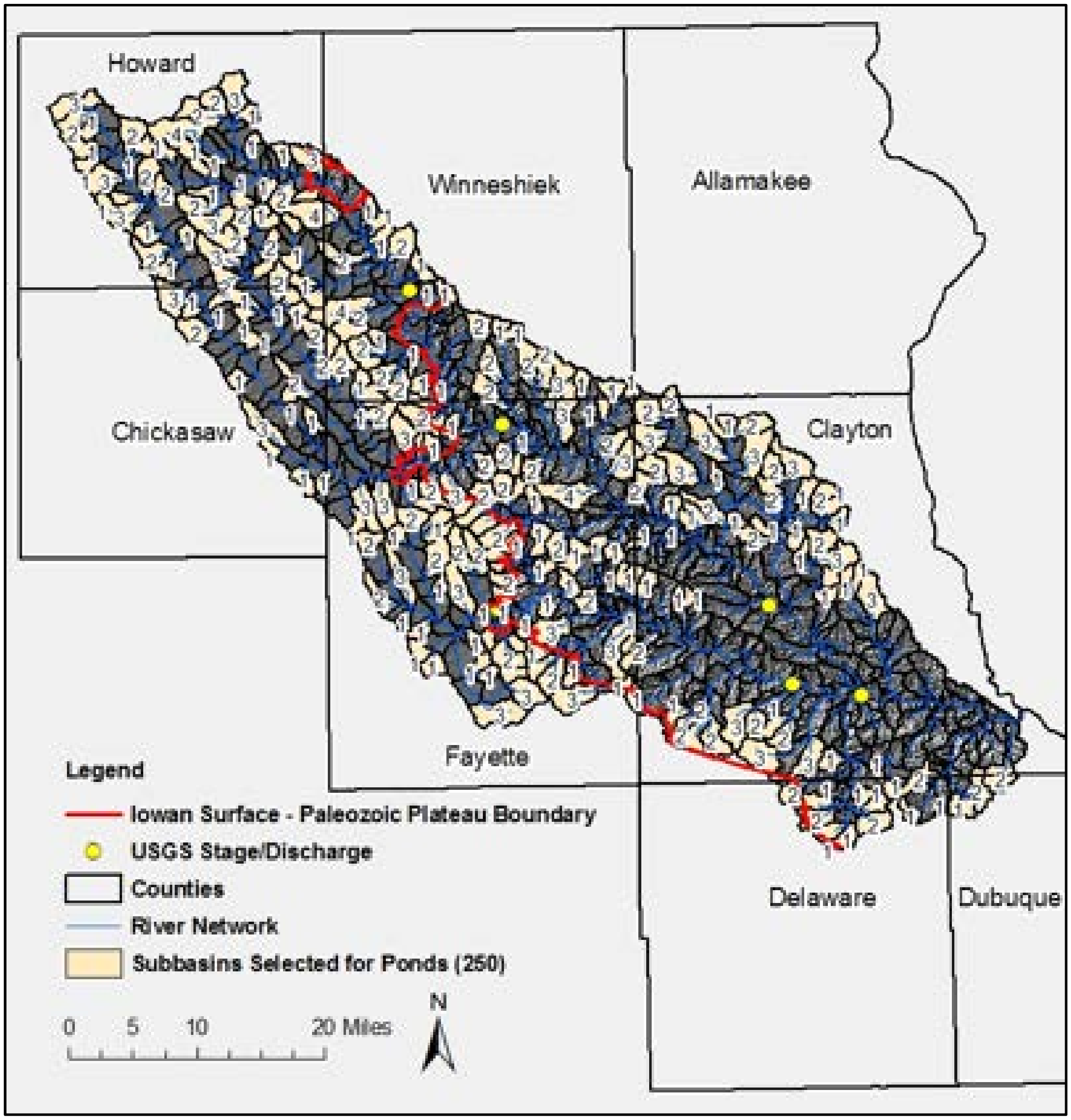

Figure 4.7. Headwater subbasins identified to have pond structures incorporated into the hypothetical distributed storage simulation.

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

The stage-discharge relationship was then determined from pipe flow calculations based on the elevation of stored water over the pipe spillway up until the activation of the emergency spillway. Then a combined outflow of pipe flow and flow through the emergency spillway was used. Discharge of the emergency spillway was determined using NRCS Technical References assuming "C-Type" retardance on the spillway, which it was determined in conversation with NRCS area engineers that is what most ponds are designed with. As mentioned, if a subbasin was identified to have multiple ponds incorporated into the simulation, the values for storage and discharge of the typical pond were multiplied by the number of ponds for each respective elevation. The typical pond stage-storage-discharge table is shown below and can be found in Appendix B, along with the stage-storage-discharge tables for the multiples of 2, 3, and 4 ponds.

Table 4.1. Stage-Storage-Discharge relationship of Typical Pond developed for use in the Turkey River Hypothetical Distributed Storage Simulation based on 0.125 – 1.5 Square Mile Drainage Areas.

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	3.1	2.2	0	2.2
2	8.9	11.1	0	11.1
3	15.8	11.5	0	11.5
4	22.8	11.9	0	11.9
5 *Emergency Spillway*	30.9	12.3	0	12.3
5.5	35.2	12.5	14.0	26.5
6	40.2	12.6	40.0	52.6
6.5	44.5	12.8	80.0	92.8
7 *Top of Dam*	50.0	13.0	140.0	153
7.5	54.6	13.2	448.1	461.3
8	59.4	13.4	609.1	622.5
9	71.5	13.8	1099.7	1113.5

It is assumed that the runoff from the entire drainage area of a subbasin identified to have a pond would not be able to be routed through a pond. For this simulation, the drainage area of the subbasin was divided in half, with ½ the drainage area remaining uncontrolled and the other ½ being routed through the typical pond (or aggregated value for multiple ponds). The location of each actual pond would be determined by landowner willingness to allow the pond to be constructed and applicable topography, and these locations cannot be predicted at this time. Rather, the influence from the pond was placed at the midpoint of the longest flowpath of the subbasin and the outflow was then routed through a channel to the outlet using the same routing method and parameters as the 2004 calibrated model. Each ½ of the split subbasin were assigned identical SCS Curve Numbers and initial abstraction values (same values as for the original, un-split subbasin). The Basin Lag for the ½ of the drainage area that was to be controlled by the pond was recalculated using ½ the length of the longest flowpath.

On a subbasin scale, the altered model configuration was compared to the original configuration at several locations to verify the change in model construction was giving reasonable results. Also, the volume difference between the hydrograph of the original (no ponds) condition and the split configuration with pond(s) was analyzed to ensure that any volumetric difference observed is what could actually be stored within the applied pond. The two hydrographs, one with current conditions and the second with hypothetical ponds added are shown for a subbasin (W6100) in Figure 4.8 for the 24-hour period during which the rainfall is applied (again 5.67", the 50-year average recurrence interval).

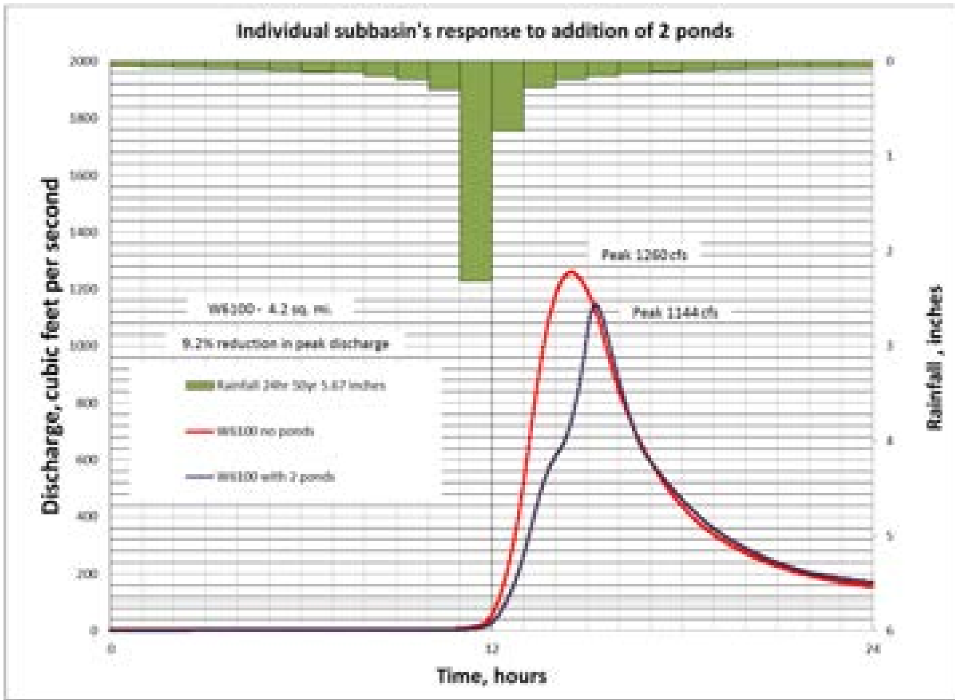

Figure 4.8. Hydrographs for a subbasin (W6100) for with and without ponds conditions. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

The volume difference observed between the two hydrographs from hours 11 to 14 is what is being stored as the pond (2 times the typical pond) fills. With this amount of rainfall, the available flood storage is filled rather quickly and the emergency spillway is activated at about hour 13, just over an hour after the heaviest pulse of rain. The dam is overtopped about an hour later. After hour 17, the discharge is higher for the subbasin configuration with ponds as compared to the no ponds scenario and remains so for the next several days of the simulation. This is because the pond continues to store water and is letting it out at the controlled rate rather than the quicker response displayed in the without the ponds hydrograph.

Several locations (Otter Creek at Elgin, Turkey River at Spillville, the outlet of Crane Creek at the Little Turkey River, Turkey River at Eldorado, Turkey River at Elkader, Turkey River at Garber, the Turkey River outlet at the Mississippi River, Volga River at Fayette, and the Volga River at Littleport) were analyzed to evaluate the influence this hypothetical pond distribution could have on flood hydrographs (See Table 4.2). As expected, as you move further downstream in the watershed, which increases the amount of uncontrolled contributing drainage area, the percent of reduction of the peak discharge decreases. However, this simulation applied 5.67 inches of rainfall in 24 hours over the entire watershed at the same time. This rainfall scenario is highly unlikely as the drainage area increases, especially above 400 square miles. Yet, even when applying rainfall volumes at a pretty extreme rate, reduction in peak discharge was observed at all locations.

To reflect on past major flooding events and compare the discharges from applying this rainfall, the Turkey River at Elkader without ponds peaked at 44,374 cfs, whereas actual floods of record at this location were 40,500 cfs in 2008 and 33,300 cfs in 2004. The addition of the ponds in the hypothetical distributed storage scenario reduced the peak flow at Elkader to 42,669 cfs, a 3.8% reduction in discharge which equates to an estimated 0.5 foot decrease in peak water surface elevation. Likewise, the Volga River at Littleport without ponds peaked at 25,681 cfs vs. record flood peaks of 18,900 cfs in 2008 and 21,000 cfs in 2004. With the ponds added, the peak discharge was reduced to 23,990; a 6.6% reduction in discharge with an estimated 0.5 foot decrease in peak water surface elevation. The Turkey River at Garber without ponds peaked at 57,195 cfs without ponds, which is greater than the flood peaks of 1991, 1999, and 2008 (49,900 cfs, 53,900 cfs, and 45,500 cfs respectively), however less than the 66,700 cfs experienced in May 2004. Adding ponds reduced the flood peak to 56,288 cfs, a 1.7% reduction. Lastly, the at the outlet at the Mississippi River, adding ponds reduced the peak discharge from 60,490 cfs to 59,390 cfs, a 1.7% reduction.

Table 4.2. Percent reduction in peak discharge by location from current conditions to the hypothetical ponds scenario.

Location	*Drainage Area (sq. mi.)*	*# Subbasins upstream with ponds*	*# of ponds*	*Peak discharge no ponds (cfs)*	*Peak discharge with ponds (cfs)*	*Percent reduction in peak discharge*
Otter Creek at Elgin	47	10	14	6,991	5,162	26.2
Turkey River at Spillville	177	33	55	19,915	16,624	16.5
Crane Creek at Little Turkey River	209	31	52	14,664	13,538	7.7
Turkey River at Eldorado	641	105	171	38,544	36,278	5.9
Turkey River at Elkader	903	153	253	44,374	42,669	3.8
Turkey River at Garber	1545	241	388	57,195	56,228	1.7
Turkey River Outlet at Mississippi	1693	250	402	60,490	59,390	1.7
Volga River at Fayette	130	24	38	22,168	20,159	9.1
Volga River at Littleport	348	58	88	25,681	23,990	6.6

Upon completing the hypothetical distributed storage simulation, we can again look closer at the smaller drainage area of Otter Creek in Fayette County. There were 10 subbasins in the Otter Creek Watershed (47 sq. mi.) that were selected for ponds with a total of 14 ponds controlling approximately 14.2 square miles of the drainage area (See Figure 4.9).

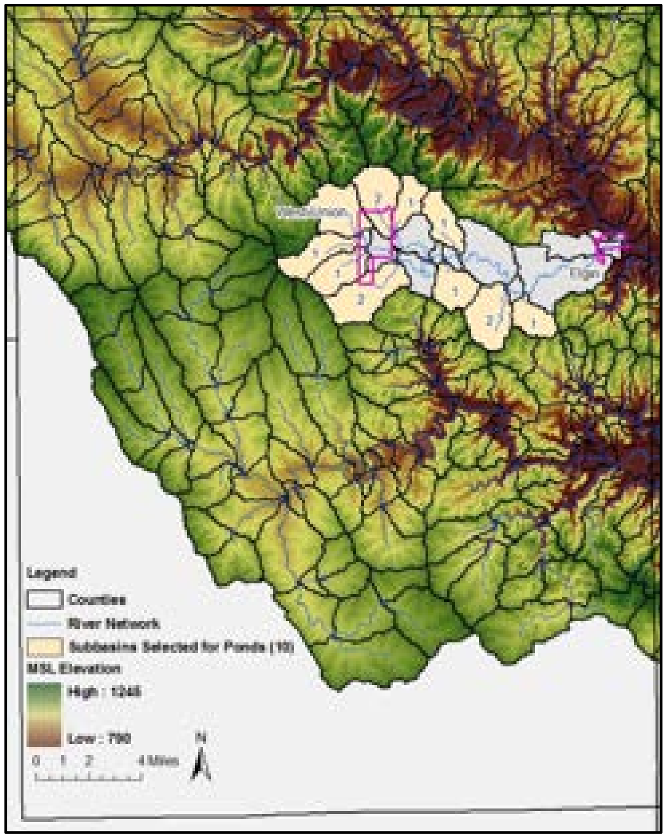

Figure 4.9. Subbasins selected for hypothetical ponds within the Otter Creek Watershed in Fayette County.

The hydrographs from a current conditions (no ponds) simulation and a simulation with ponds at 1 pond per 2 square miles are shown for Otter Creek at Elgin (Figure 4.10). The peak discharge when adding hypothetical "typical" ponds was reduced by 26.2 percent.

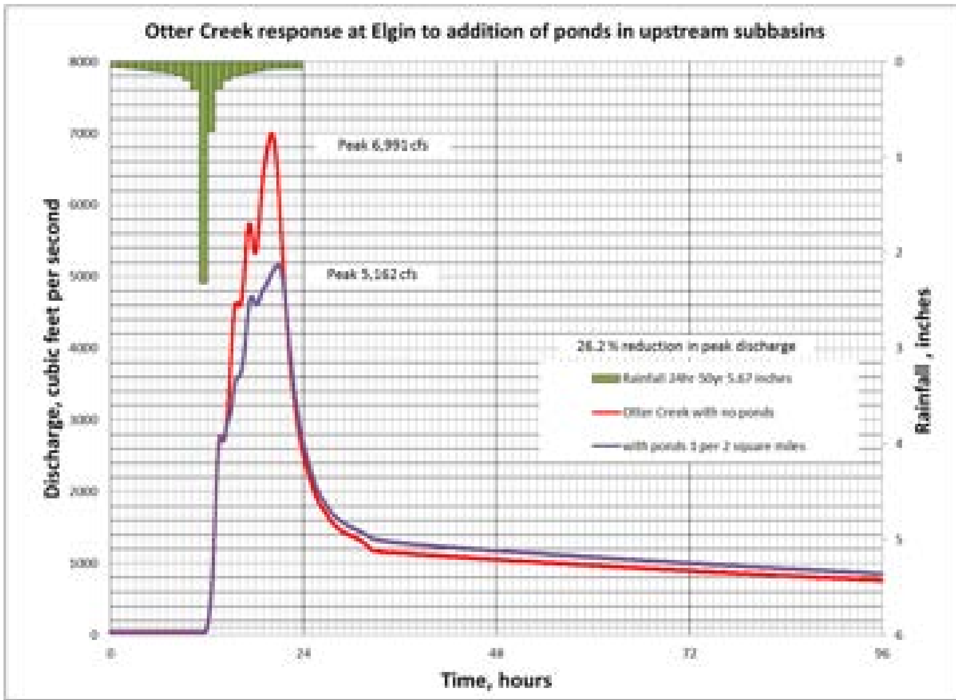

Figure 4.10. Hydrograph comparison for Otter Creek at Elgin with current conditions and the hypothetical ponds scenario when using the "typical" pond stage-storage-discharge relationship. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

In the following figures, Figure 4.11 shows the simulated with and without ponds hydrographs for the Turkey River at Elkader with a 3.8% reduction in peak discharge. Figure 4.12 shows the hydrographs for the Volga River at Littleport (6.6% reduction), Figure 4.13 shows the Turkey River at Garber (1.7% reduction) and Figure 4.14 shows the hydrographs at the outlet at the Mississippi River (1.7% reduction). The time of the peak of the Turkey River at Elkader is at approximately hour 50 and this peak continues downstream and reaches Garber at roughly hour 56, whereas the Volga River at Littleport peaks at approximately hour 41 and passes Garber around hour 46; 10 hours before the peak flood wave coming down the Turkey River. Again, this demonstrates the significance of rainfall distribution and timing. Had the two flood waves reached Garber at the same time (as they did in 2004); the simulated discharge would have likely exceeded the 66,700 cfs observed at the USGS gage on May 23, 2004.

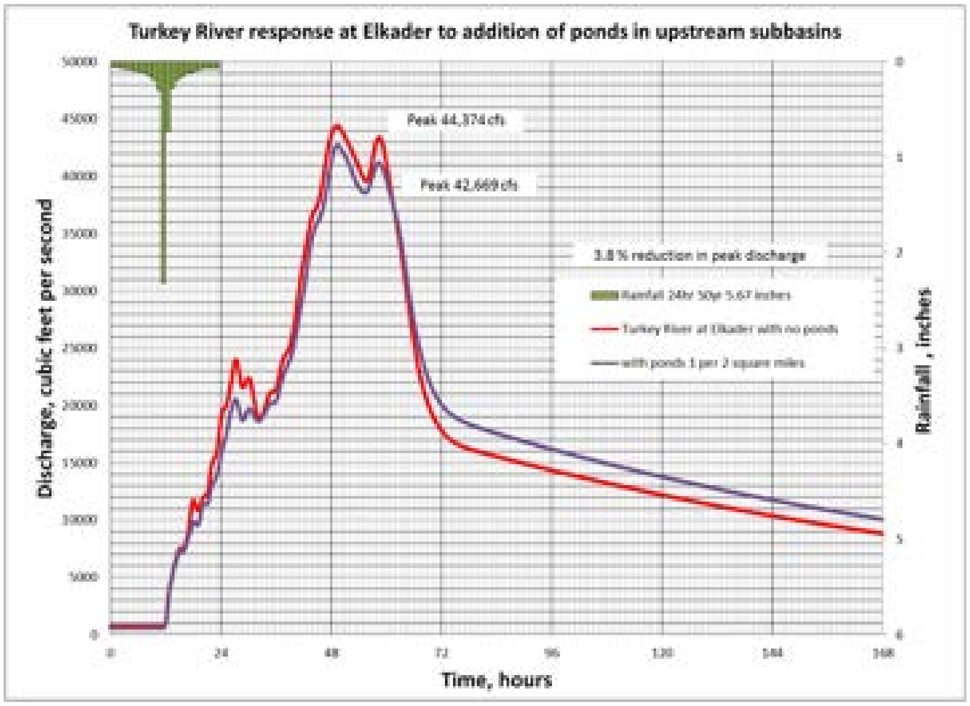

Figure 4.11. Hydrograph comparison for Turkey River at Elkader with current conditions and the hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

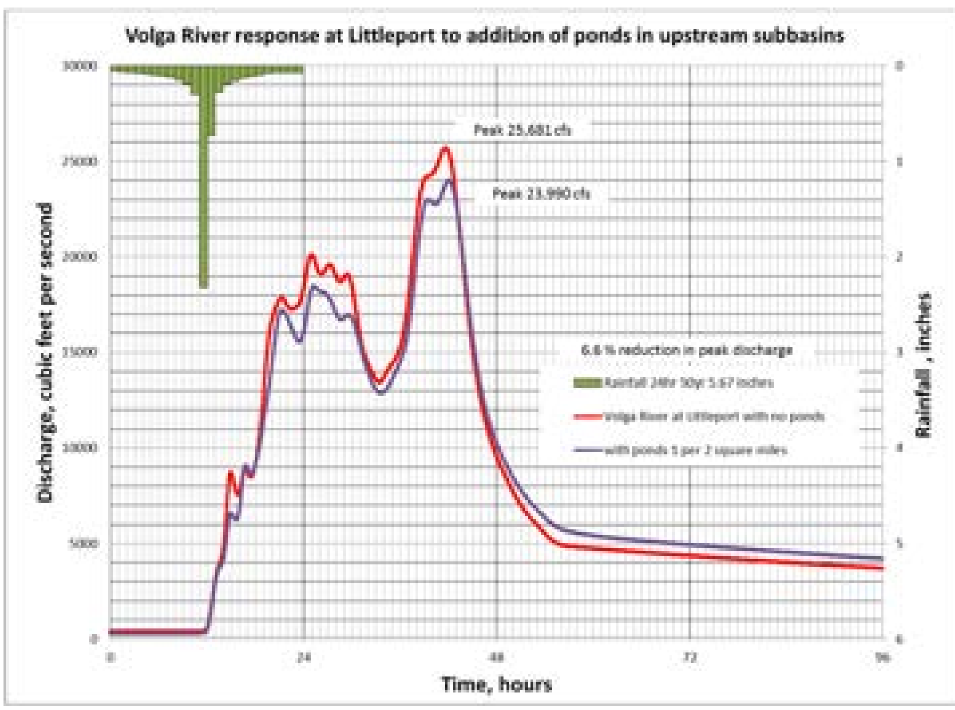

Figure 4.12. Hydrograph comparison for Volga River at Littleport with current conditions and the hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

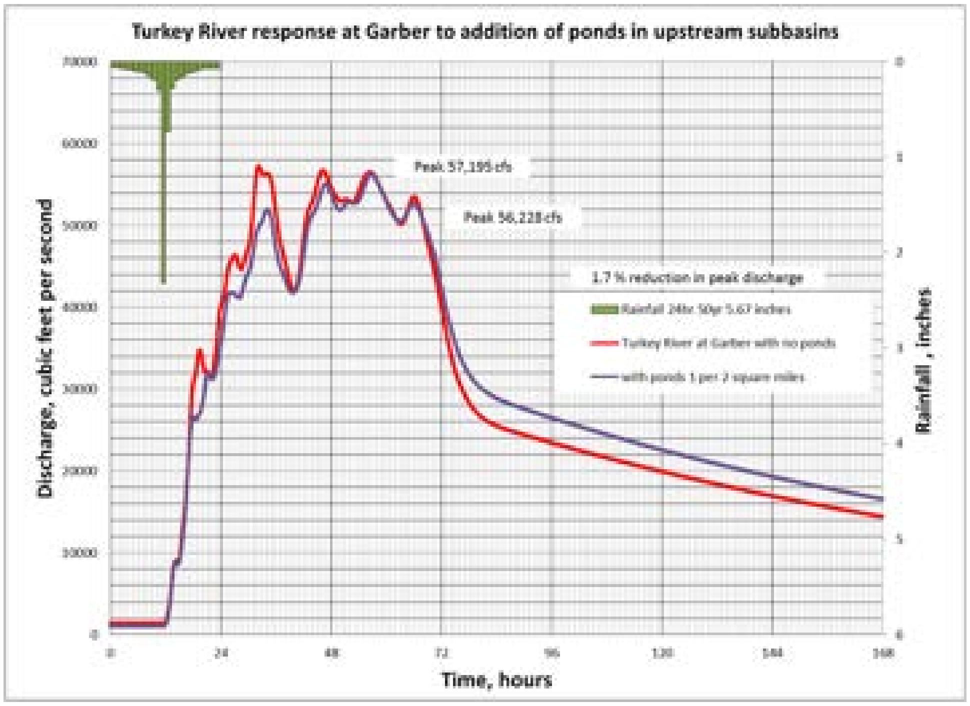

Figure 4.13. Hydrograph comparison for Turkey River at Garber with current conditions and the hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

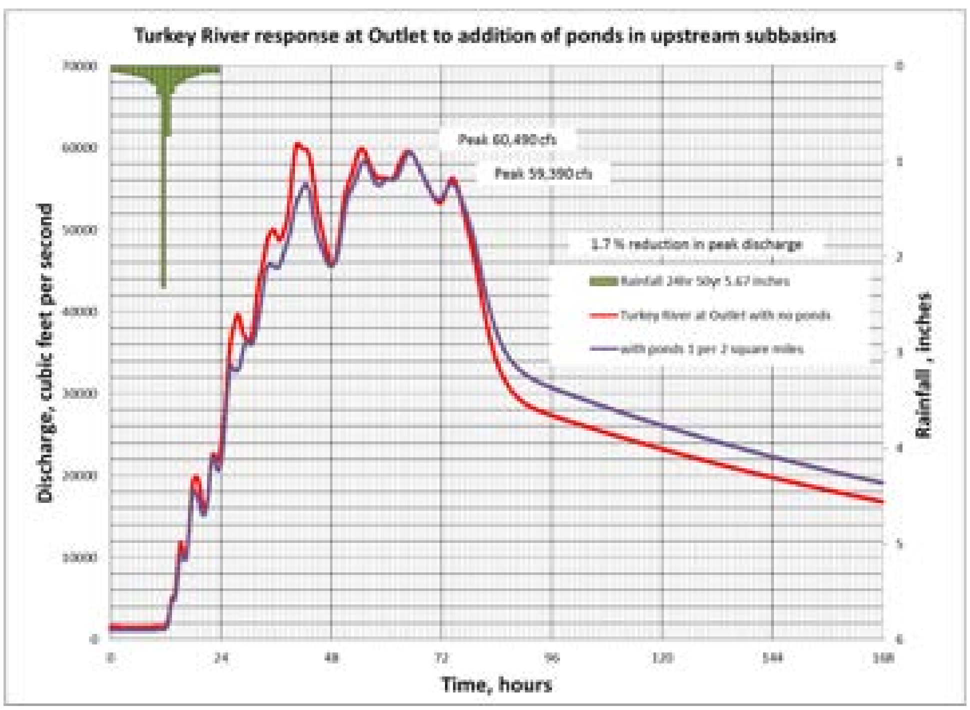

Figure 4.14. Hydrograph comparison for Turkey River at outlet at Mississippi River with current conditions and the hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

If the hypothetical pond distributed throughout the Turkey River Watershed could replicate the stage-storage relationship developed based only on larger Soap Creek ponds, those with drainage areas of 0.5 – 1.5 square miles (320 – 960 acres), the flood storage provided in each pond could be increased by approximately 36 percent. This would likely increase the permanent storage surface area of the ponds to approximately 4 – 5 acres. The stage-storage-discharge relationship is shown in Table 4.3.

Table 4.3. Stage-Storage-Discharge relationship of Typical Pond developed for use in the Turkey River Hypothetical Distributed Storage Simulation based on 0.5 – 1.5 Square Mile Drainage Areas.

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

The following table, Table 4.4, shows the same reference points as Table 4.2, however with the potential influence of 402 of the larger hypothetical ponds distributed in place of the smaller "typical" pond.

Table 4.4. Percent reduction in peak discharge by location from current conditions to the larger hypothetical ponds scenario.

Location	*Drainage Area (sq. mi.)*	*# Subbasins upstream with ponds*	*# of ponds*	*Peak discharge no ponds (cfs)*	*Peak discharge with ponds (cfs)*	*Percent reduction in peak discharge*
Otter Creek at Elgin	47	10	14	6,991	4,604	34.1
Turkey River at Spillville	177	33	55	19,915	15,462	22.3
Crane Creek at Little Turkey River	209	31	52	14,664	12,150	17.0
Turkey River at Eldorado	641	105	171	38,544	34,173	11.0
Turkey River at Elkader	903	153	253	44,374	40,681	8.3
Turkey River at Garber	1545	241	388	57,195	54,483	4.7
Turkey River Outlet at Mississippi	1693	250	402	60,490	57,679	4.6
Volga River at Fayette	130	24	38	22,168	17,923	19.1
Volga River at Littleport	348	58	88	25,681	22,440	12.6

The hydrographs from a current conditions (no ponds) simulation and a simulation with larger hypothetical ponds at 1 pond per 2 square miles are shown for Otter Creek at Elgin (Figure 4.15). The peak discharge when adding the larger hypothetical ponds was reduced by 34.1 percent.

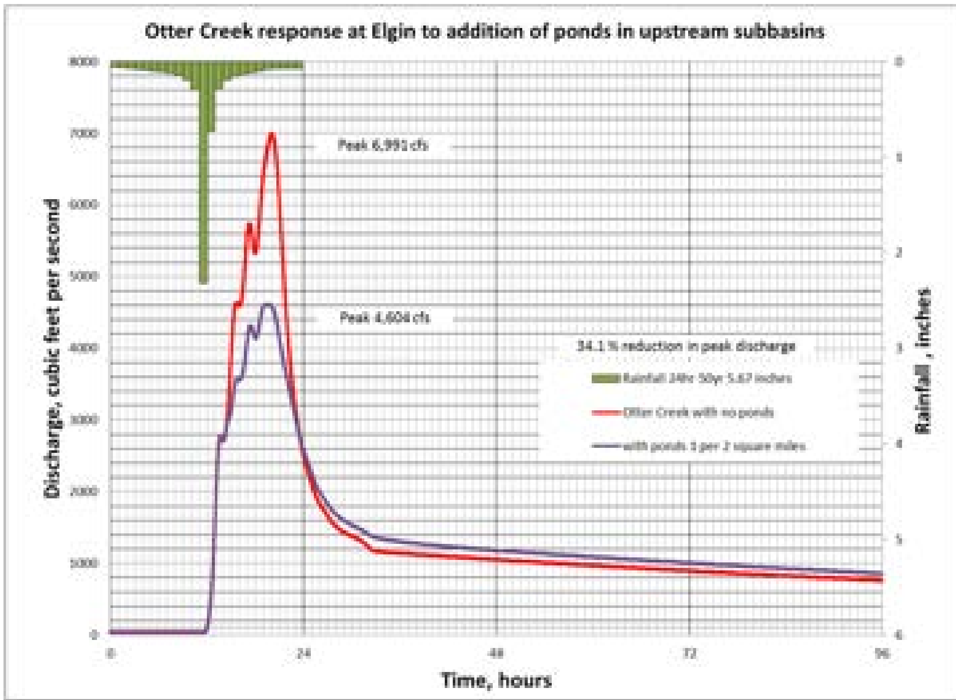

Figure 4.15. Hydrograph comparison for Otter Creek at Elgin with current conditions and the larger hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

In the following figures, Figure 4.16 shows the simulated with and without ponds hydrographs for the Turkey River at Elkader with an 8.3% reduction in peak discharge. Figure 4.17 shows the hydrographs for the Volga River at Littleport (12.6% reduction), Figure 4.18 shows the Turkey River at Garber (4.7% reduction) and Figure 4.19 shows the hydrographs at the outlet at the Mississippi River (4.6% reduction). All reductions in Figures 4.15 – 4.19 are for the larger hypothetical ponds.

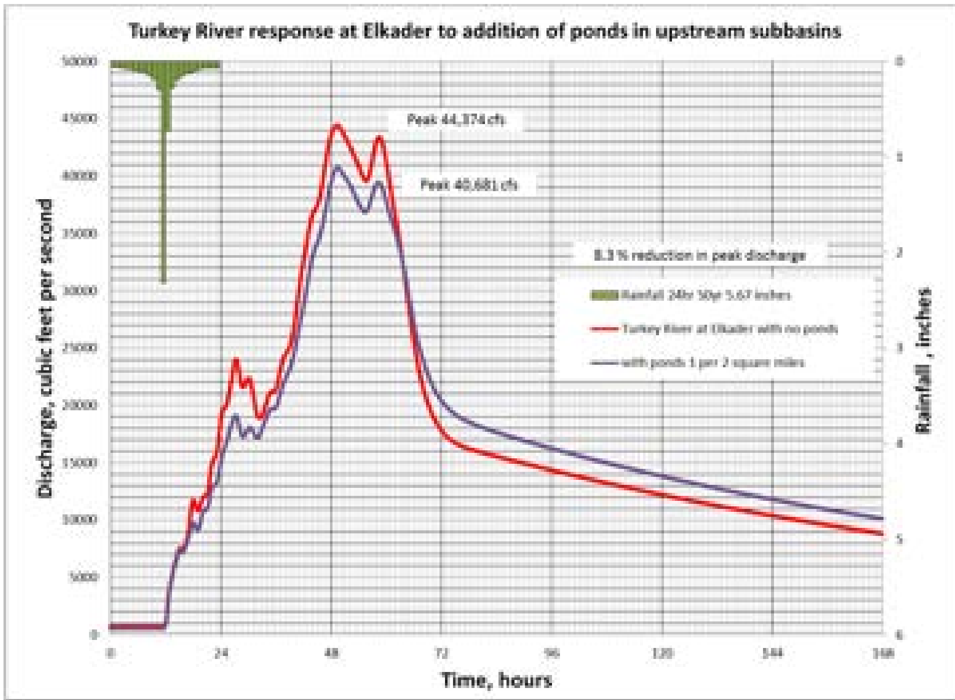

Figure 4.16. Hydrograph comparison for Turkey River at Elkader with current conditions and the larger hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

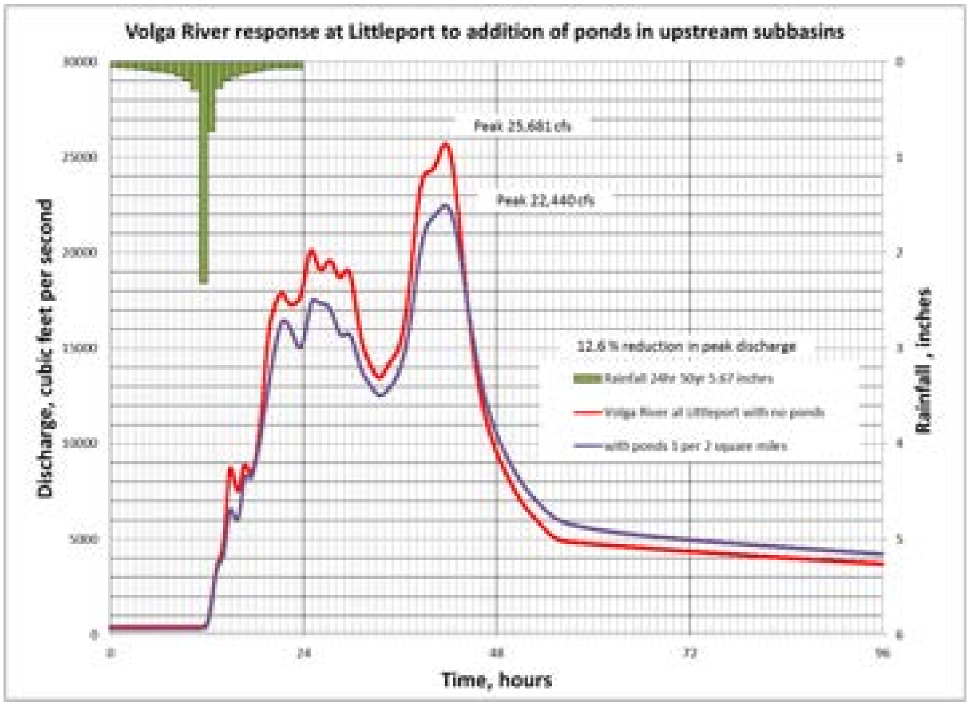

Figure 4.17. Hydrograph comparison for Volga River at Littleport with current conditions and the larger hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

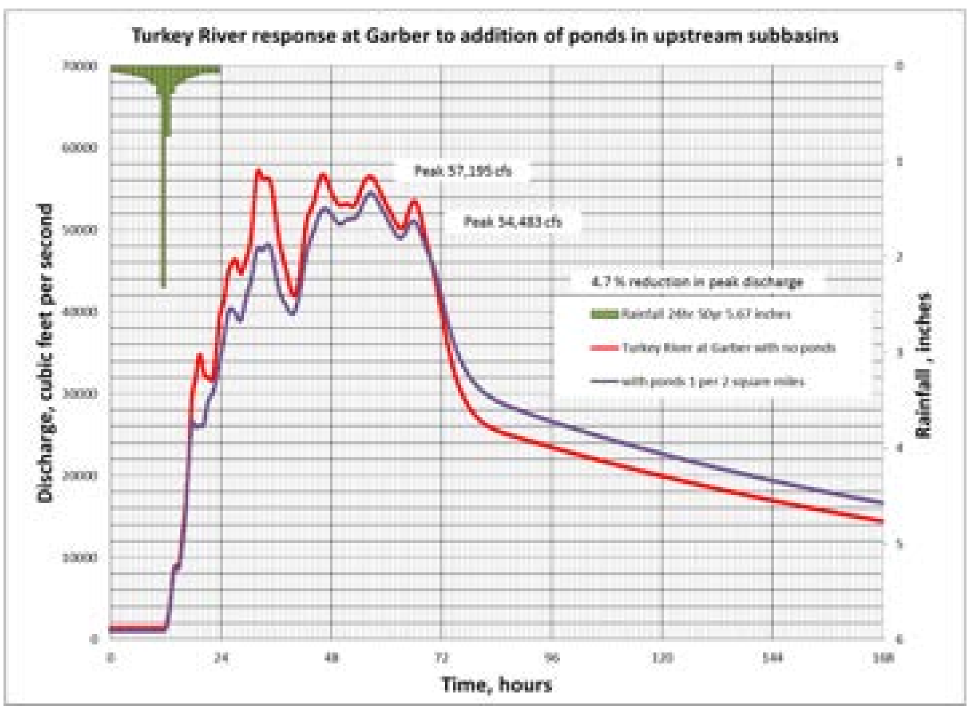

Figure 4.18. Hydrograph comparison for Turkey River at Garber with current conditions and the larger hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

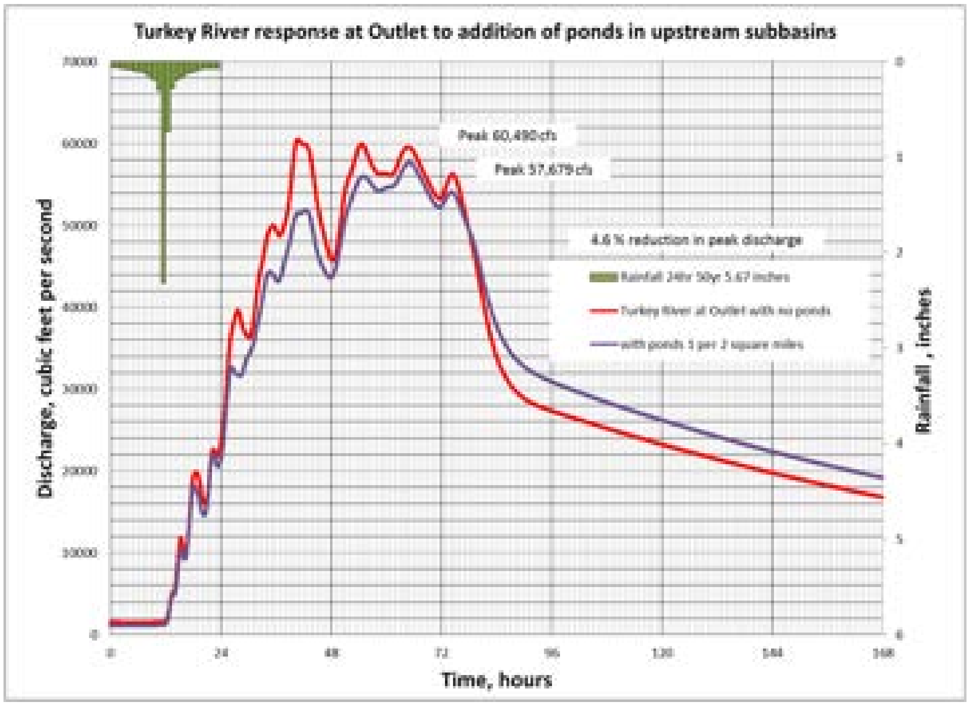

Figure 4.19. Hydrograph comparison for Turkey River at outlet at Mississippi River with current conditions and the larger hypothetical ponds scenario. Results shown are for the 50 year – 24 hour storm (5.67 inches of rain in 24 hours).

One can ask how might the hypothetical distributed storage scheme effect flood peaks from actual storm events. The answer is that the percent of reduction realized in peak discharge at any given location is going to depend on the rainfall amount, rainfall intensity, location of rainfall, and timing of the rain during the storm event. The radar rainfall estimates from May 21-23, 2004 were applied to the with and without ponds scenarios to assess the hypothetical distributed storage's performance for this event. The results presented in Table 4.5 are from using the "typical" pond developed using Soap Creek ponds with drainage areas of 0.125 – 1.5 square miles (80 – 960 acres). The stage-storage-discharge relationship for this "typical" pond is shown in Table 4.1. Then the stage-storage-discharge relationship of the larger hypothetical pond (Table 4.3) is substituted to identify the effect of distributing the larger flood storage capacity ponds throughout the watershed (Table 4.6). Figures 4.20 - 4.24 display the simulation hydrographs for Otter Creek at Elgin, Turkey River at Elkader, Volga River at Littleport, Turkey River at Garber, and the Turkey River at the outlet showing the current conditions (no ponds) along with reductions in peak discharge for both the typical ponds and the larger hypothetical ponds scenarios when distributed in headwater subbasins upstream of the point of interest.

Table 4.5. Percent reduction in peak discharge by location with current conditions and the hypothetical distributed storage scenario. Results shown are from using the May 21-23, 2004 radar rainfall estimates and the "typical" pond stage-storage-discharge relationship.

Location	*Drainage Area (sq. mi.)*	*# Subbasins upstream with ponds*	*# of ponds*	*Peak discharge no ponds (cfs)*	*Peak discharge with ponds (cfs)*	*Percent reduction in peak discharge*
Otter Creek at Elgin	47	10	14	2,839	2,037	28.2
Turkey River at Spillville	177	33	55	7,758	6,885	11.3
Crane Creek at Little Turkey River	209	31	52	8,993	7,909	12.1
Turkey River at Eldorado	641	105	171	24,113	23,000	4.6
Turkey River at Elkader	903	153	253	33,848	31,715	6.3
Turkey River at Garber	1545	241	388	64,384	61,747	4.1
Turkey River Outlet at Mississippi	1693	250	402	65,927	63,389	3.8
Volga River at Fayette	130	24	38	7,835	6,518	16.8
Volga River at Littleport	348	58	88	21,483	20,321	5.4

Table 4.6. Percent reduction in peak discharge by location with current conditions and the hypothetical distributed storage scenario. Results shown are from using the May 21-23, 2004 radar rainfall estimates and the larger hypothetical pond stage-storage-discharge relationship.

Location	*Drainage Area (sq. mi.)*	*# Subbasins upstream with ponds*	*# of ponds*	*Peak discharge no ponds (cfs)*	*Peak discharge with ponds (cfs)*	*Percent reduction in peak discharge*
Otter Creek at Elgin	47	10	14	2,839	2,019	28.9
Turkey River at Spillville	177	33	55	7,758	6,441	17.0
Crane Creek at Little Turkey River	209	31	52	8,993	7,274	19.1
Turkey River at Eldorado	641	105	171	24,113	21,444	11.1
Turkey River at Elkader	903	153	253	33,848	29,745	12.1
Turkey River at Garber	1545	241	388	64,384	58,240	9.5
Turkey River Outlet at Mississippi	1693	250	402	65,927	59,932	9.1
Volga River at Fayette	130	24	38	7,835	6,147	21.5
Volga River at Littleport	348	58	88	21,483	19,138	10.9

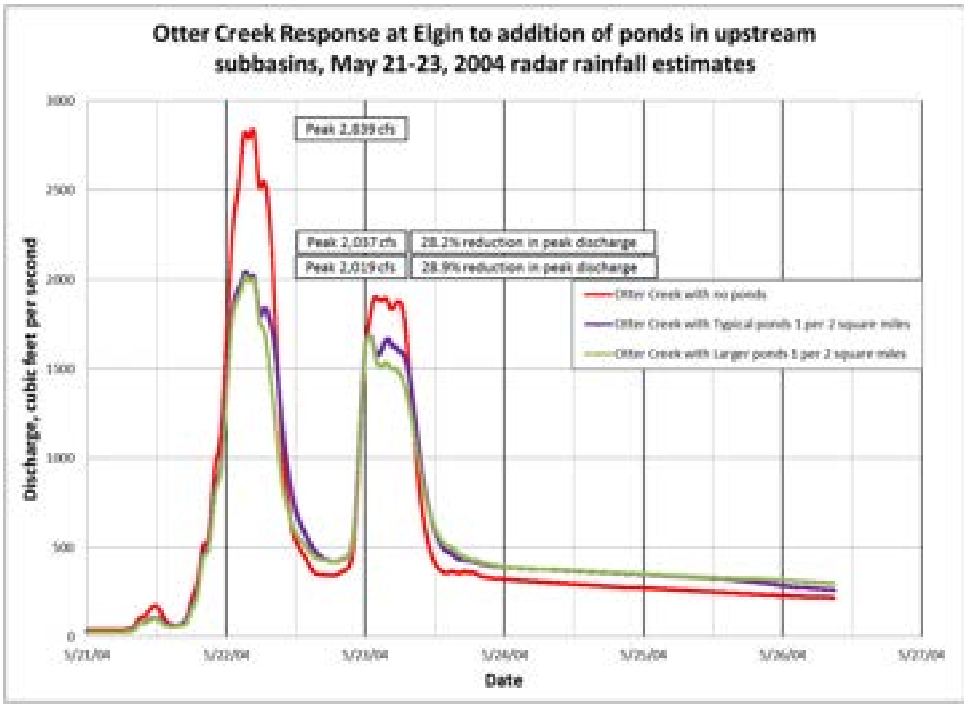

Figure 4.20. Hydrograph comparison for Otter Creek at Elgin with current conditions along with the typical and larger hypothetical ponds scenarios. Results shown are from using the May 21-23, 2004 radar rainfall estimates.

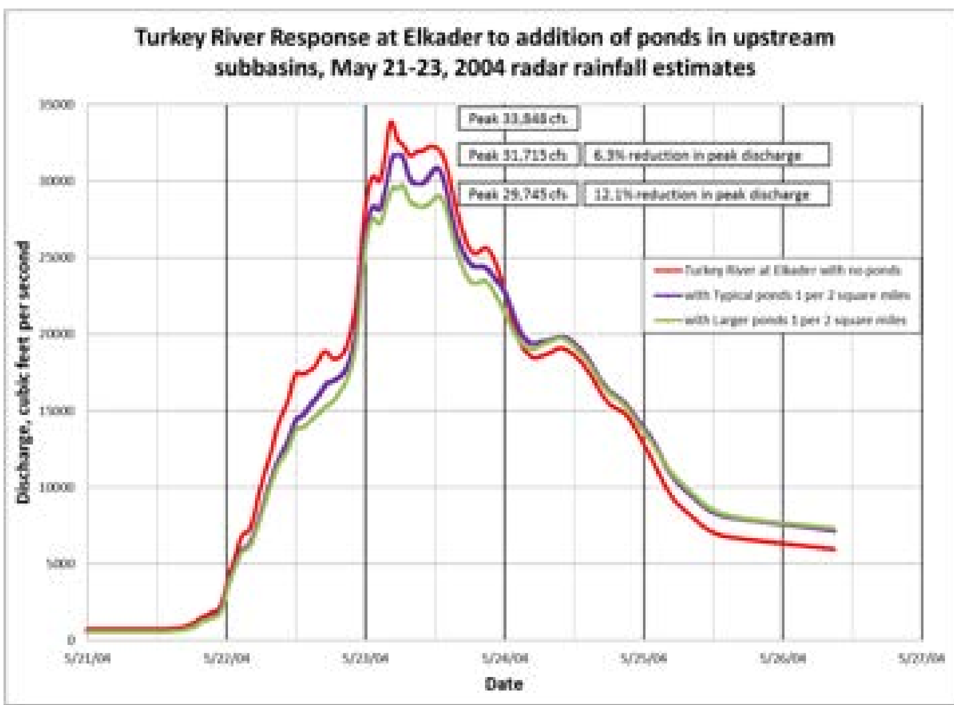

Figure 4.21. Hydrograph comparison for Turkey River at Elkader with current conditions along with the typical and larger hypothetical ponds scenarios. Results shown are from using the May 21-23, 2004 radar rainfall estimates.

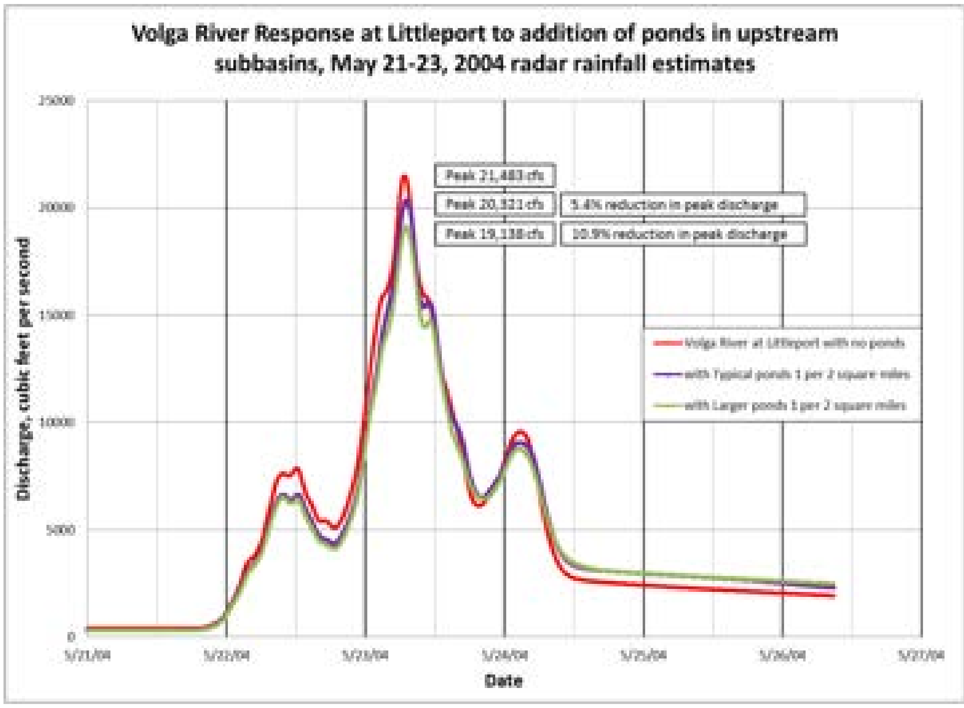

Figure 4.22. Hydrograph comparison for Volga River at Littleport with current conditions along with the typical and larger hypothetical ponds scenarios. Results shown are from using the May 21-23, 2004 radar rainfall estimates.

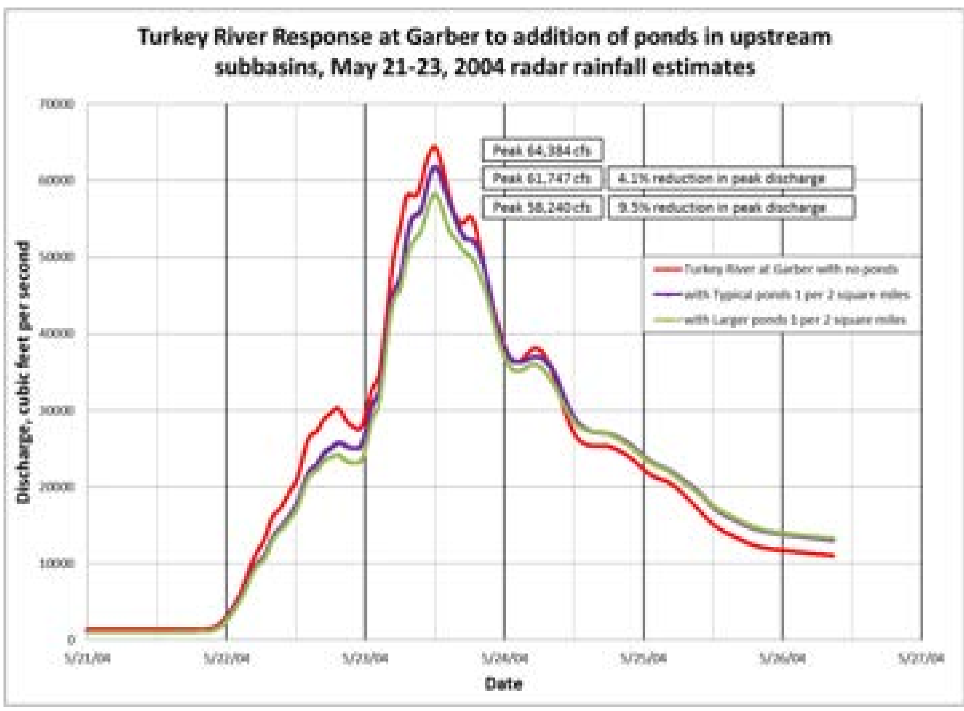

Figure 4.23. Hydrograph comparison for Turkey River at Garber with current conditions along with the typical and larger hypothetical ponds scenarios. Results shown are from using the May 21-23, 2004 radar rainfall estimates.

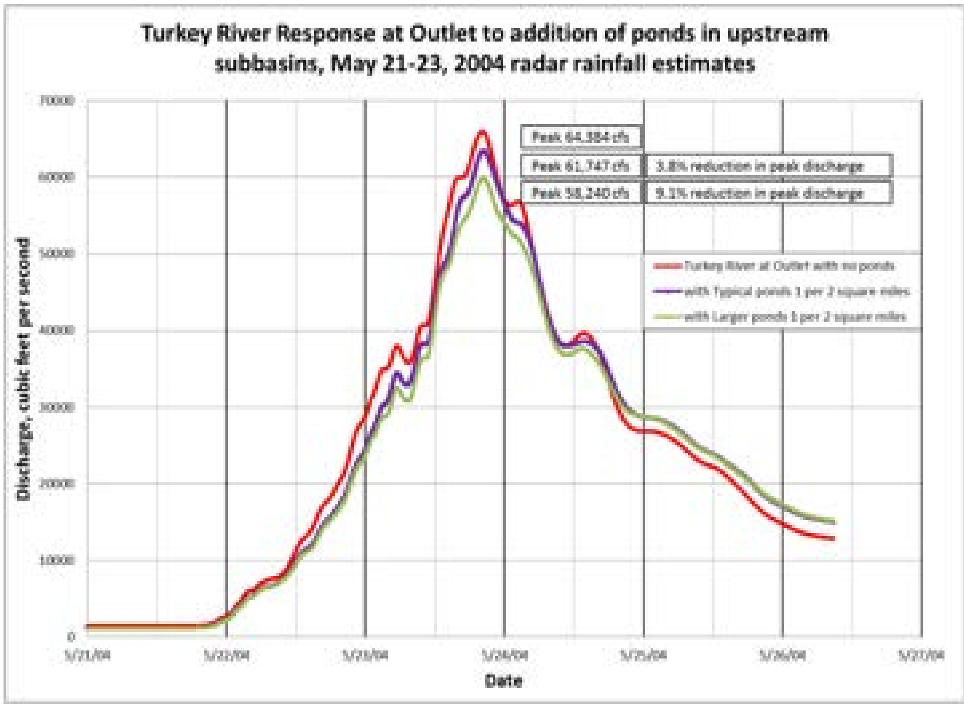

Figure 4.24. Hydrograph comparison for Turkey River at outlet at Mississippi River with current conditions along with the typical and larger hypothetical ponds scenarios. Results shown are from using the May 21-23, 2004 radar rainfall estimates.

When the "typical" pond stage-storage-discharge relationship is used in the distributed storage simulation, there is an estimated reduction in peak discharge at all of the points of interest investigated. There was a significant increase in the percentage of reduction in peak discharge when switching to the larger pond stage-storage-discharge relationship at all locations except for Otter Creek at Elgin. However, there is an estimated 28.2% reduction with the "typical" ponds distributed in Otter Creek, which is significant reduction in itself. With the larger ponds added to Otter Creek, the percent reduction increased only slightly to 28.9%. The peak discharge at Elgin, which occurred on May 22nd, was driven by rainfall that fell in the overnight hours of May 21 into early May 22 in the lower ½ of the Otter Creek Watershed, which is just upstream of Elgin in the area with lesser pond control for this simulation. The rainfall timing within the Otter Creek Watershed for this overnight event was very close to having the same timing at all locations in the watershed. Consequently, the peak outflow passed Elgin roughly the same time the emergency spillways activated on the ponds upstream of West Union. Thus, if we evaluated Otter Creek at West Union for this rainfall event, we estimate a 30.5% reduction in peak discharge with the "typical" ponds and a 45.8% reduction for the larger ponds. This difference in discharge is observed in the hydrographs of the two hypothetical pond scenarios as the flow travels downstream, however it is not realized at Elgin until approximately 7 hours after the river peaked from the rainfall in the downstream portion of the watershed.

5. Summary and Conclusions

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

a. Turkey River Water Cycle and Watershed Conditions

The water cycle of the Turkey River Watershed was examined using historical precipitation and streamflow records. The average annual precipitation for the Turkey River Watershed is 36.3 inches. Of this precipitation amount, 69.4% (25.2 inches) evaporates back into the atmosphere and the remaining 30.6% (11.1 inches) runs off the landscape into the streams and rivers. The majority of the runoff amount is baseflow (70.7% or 7.85 inches), and the rest is surface flow (29.3% or 3.25 inches). Average monthly streamflow peaks in April, and decreases slowly through the summer growing season. In most years, the largest discharge observed during the year occurs in March or April, associated with snow melt, rain on snow events, or heavy spring rains. However, the largest floods on record tend to occur in the summer season (e.g., 2004, 2008) when the heaviest rainfall can occur.

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

The Turkey River Watershed is located within two identified landform regions, the Iowan Surface and Paleozoic Plateau, each of which has a unique influence on the rainfall-runoff characterization of the watershed. The Iowan Surface of Northeast Iowa is dominated by gently rolling terrain with well-defined streams but with relatively low slopes, whereas the Paleozoic Plateau is characterized by narrow valleys deeply carved into sedimentary rock. The rock layers vary in resistance to erosion, producing bluffs, waterfalls, and rapids. Shallow limestone coupled with the dissolving action of groundwater yields numerous caves, springs, and sinkholes (Iowa Geological & Water Survey, Iowa Department of Natural Resources, 2013. Storms in recent decades produced record flood levels at stream-gages in June 1991, May 1999, May 2004, and June 2008.

b. Turkey River Hydrologic Model

The U.S. Army Corp of Engineers' (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was used to develop a flood prediction model for the Turkey River Watershed. First, the watershed was divided into 710 smaller units, called subbasins, with an average area of about 2.4 mi^2. For model calibration and validation with actual (historical) rainfall events, radar rainfall estimates were used as the precipitation input for simulation. For the analysis of watershed scenarios, 24-hour duration design storms (an NRCS Type-II distribution) with rainfall accumulations equal to the 25- and 50-year return period basin-average depths were used as the precipitation input.

The NRCS Curve Number (CN) methodology was used to determine the rainfall-runoff partitioning in the Turkey River 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. The SCS Dimensionless Unit Hydrograph method was used to convert excess precipitation into a direct runoff hydrograph for each subbasin. Baseflow was determined from USGS discharge gaging stations for each simulation during model calibration and validation when simulating actual (historical) rainfall events. The initial baseflow condition from the May 2004 storm used for calibration was used for design storm based simulations. Conveyance of runoff through the river network, or flood wave routing, was executed using the Muskingum routing method.

c. Watershed Scenarios for the Turkey River

To better understand the flood hydrology of the Turkey River Watershed, and to evaluate potential flood mitigation strategies, the HEC-HMS model of the watershed was used in several ways. We first assessed the runoff potential throughout the basin. 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).

To quantify the potential effects of flood mitigation strategies, the HEC-HMS model was used to simulate river flows throughout the Turkey River Watershed. Two strategies are considered — increasing infiltration and storing floodwaters temporarily in ponds throughout the watershed to reduce downstream discharges. The effects of these strategies were simulated for significant design flood events — those resulting from a 50-year average recurrence interval 24-hour design rainfall. This event corresponds to rainfall of 5.67 inches in 24 hours over the entire Turkey River Watershed. The results for these strategies were compared to simulations of flows for the existing watershed condition. Although each scenario simulated is hypothetical and simplified, the results provide valuable insights on the relative performance of each strategy for flood mitigation planning.

i. Increased Infiltration in the Watershed

An analysis could be performed proposing a scenario where all current land uses across the entire Turkey River Watershed (1,693 square miles) are converted back to native tall-grass prairie with its much higher infiltration characteristics. The likelihood of successfully reestablishing pre-settlement conditions of all tall-grass prairies along with what is currently forest is unlikely and economically not viable. However, to highlight the significance of what a moderate change in increasing infiltration can have within a watershed, a smaller drainage area watershed – Otter Creek in Fayette County (approximately 47 sq. miles) was used for demonstration. From the simulation results, enhancing infiltration, such that just an additional ½ inch of rainfall passing into the ground, has a significant impact on runoff and the resulting peak streamflow. The peak discharge in Otter Creek at the bridge just upstream of the confluence with the Turkey River at Elgin decreased by approximately 24.5% in the hypothetical ½ inch increased infiltration simulation.

ii. Increased Storage on the Landscape

In some ways, using ponds to temporarily store floodwaters is an attempt to replace the loss of water that was stored in the soils in the pre-agricultural landscape. In the distributed pond analysis, a "typical" pond stage-storage-discharge relationship was developed and evaluated when applying a 50-year average recurrence interval 24-hour design rainfall. In addition to the "typical" pond, a larger hypothetical pond was proposed and evaluated with the same rainfall.

If we first look at Otter Creek in Fayette County when adding "typical" ponds to headwater subbasins of this watershed, the peak discharge in Otter Creek at the bridge just upstream of the confluence with the Turkey River at Elgin decreased by approximately 26%. As a flood mitigation strategy, ponds are generally very effective in reducing flood peaks immediately downstream of their headwater sites. Further downstream, floodwaters originating from locations throughout the watershed arrive at vastly different times; some areas are controlled by ponds, others are not. The result is that the storage effect from controlled areas 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. Yet, even when applying rainfall at a pretty extreme rate across the entire Turkey River Watershed, distributed storage through a series of ponds in the headwater areas were still able to reduce flood peaks. With the larger ponds, the percent decrease in peak discharge increased substantially, in which the peak discharge in Otter Creek at Elgin was decreased by approximately 34%.

It is reasonable for one to ask how might the hypothetical distributed storage scheme effect flood peaks from actual storm events. The answer is that the percent of reduction realized in peak discharge at any given location is going to depend on the rainfall amount, rainfall intensity, location of rainfall, and timing of the rain during the storm event. The radar rainfall estimates from May 21-23, 2004 were applied to the pond scenarios to assess the hypothetical distributed storage's performance for this event. When using the May 2004 rainfall, all points of interest investigated realized reductions in peak discharge, with all locations except Otter Creek at Elgin realizing significant increases in reduction with the larger ponds. Peak discharge was reduced for Otter Creek at Elgin by approximately 28% with the "typical" pond and about 29% with the larger ponds. The slight increase in reduction is a result of rainfall location and timing within the Otter Creek Watershed influencing the realized reduction, not related to available flood storage provided from all 14 incorporated ponds in the Otter Creek Watershed.

d. Concluding Remarks

Figure 5.1 summarizes the relative effectiveness of each flood mitigation strategy considered for reducing peak discharges in the Otter Creek Watershed (47 sq. mi.) in Fayette County, showing the relative impact of each strategy for both the 50-year, 24-hour design storm (5.67 inches of rain in 24 hours) and the May 2004 flood simulation using radar rainfall estimates.

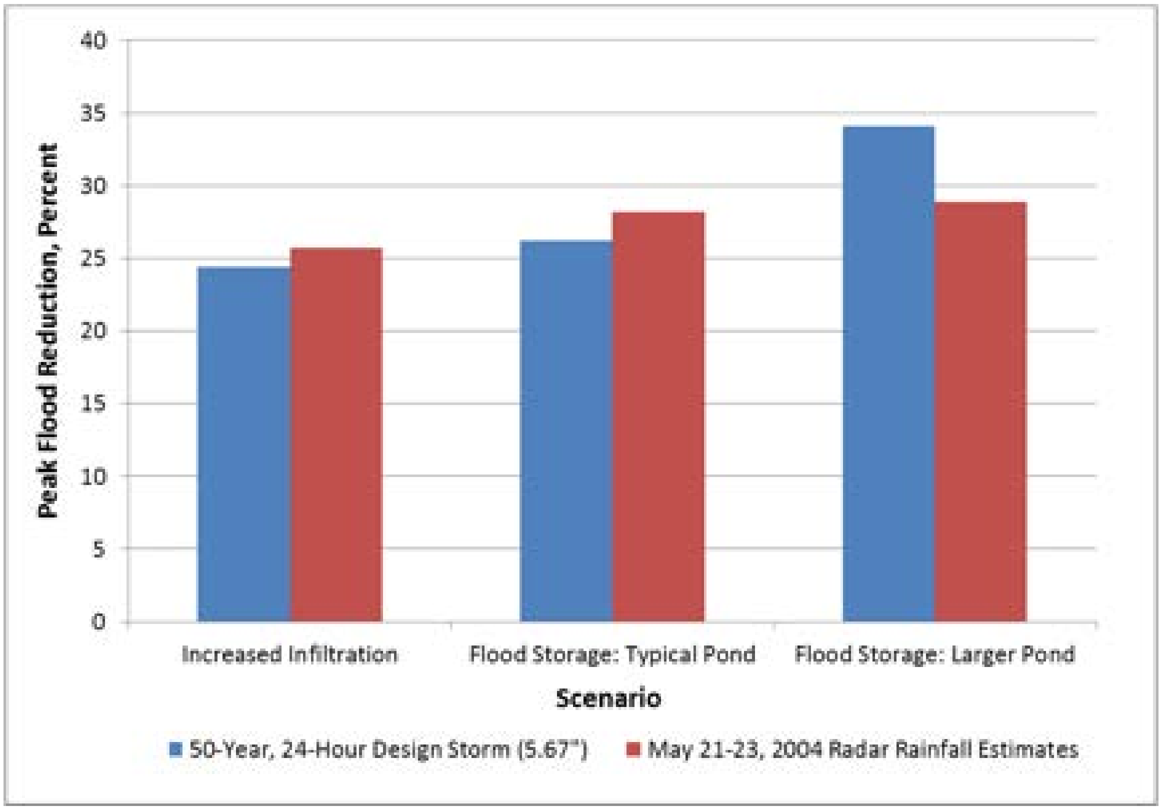

Figure 5.1. Comparison of the relative impact of the flood mitigation scenarios for reducing peak discharges on Otter Creek at Elgin, Iowa.

Mitigating flooding impacts through distributed storage is probably more attainable in the Turkey River Watershed; however a combined approach of ponds and conservation practices intending to increase infiltration would most desired. Figures 5.2 and 5.3 summarize the reductions in peak discharge at points of interest through the watershed. Results are for the "typical" pond and larger hypothetical pond stage-storage-discharge relationships and once again are displayed for both the 50-year, 24-hour design storm (5.67 inches of rain in 24 hours) and the May 2004 flood simulation using radar rainfall estimates.

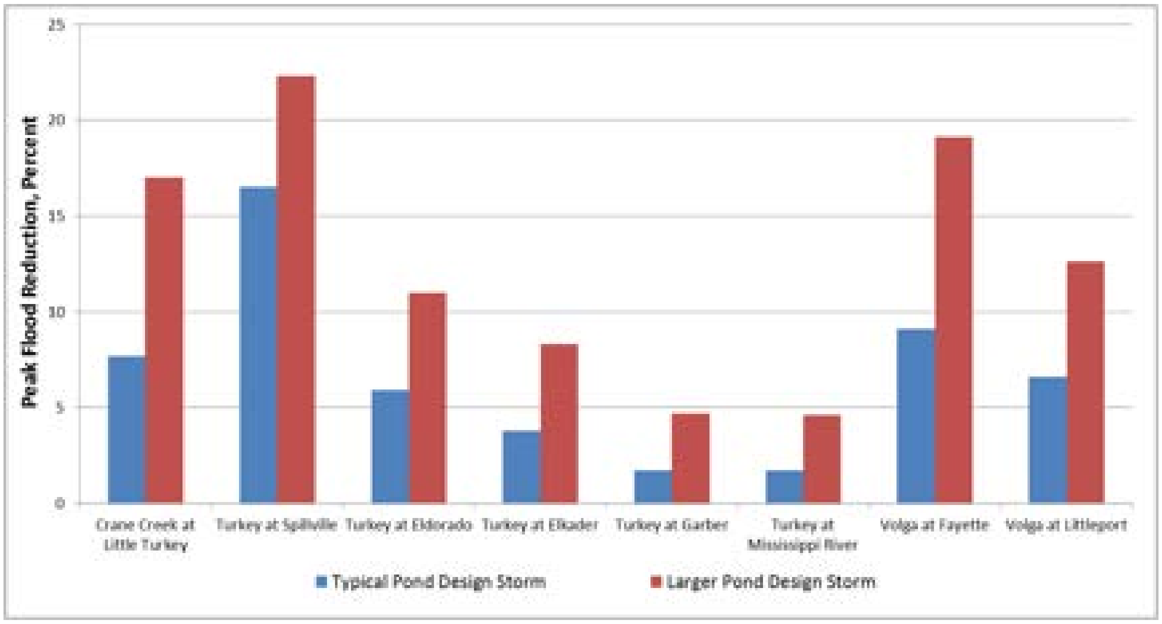

Figure 5.2. Comparison of the relative impact of the distributed storage scenarios for reducing peak discharges in the Turkey River Watershed. Results are using 50-Year, 24-Hour Design Storm (5.67”).

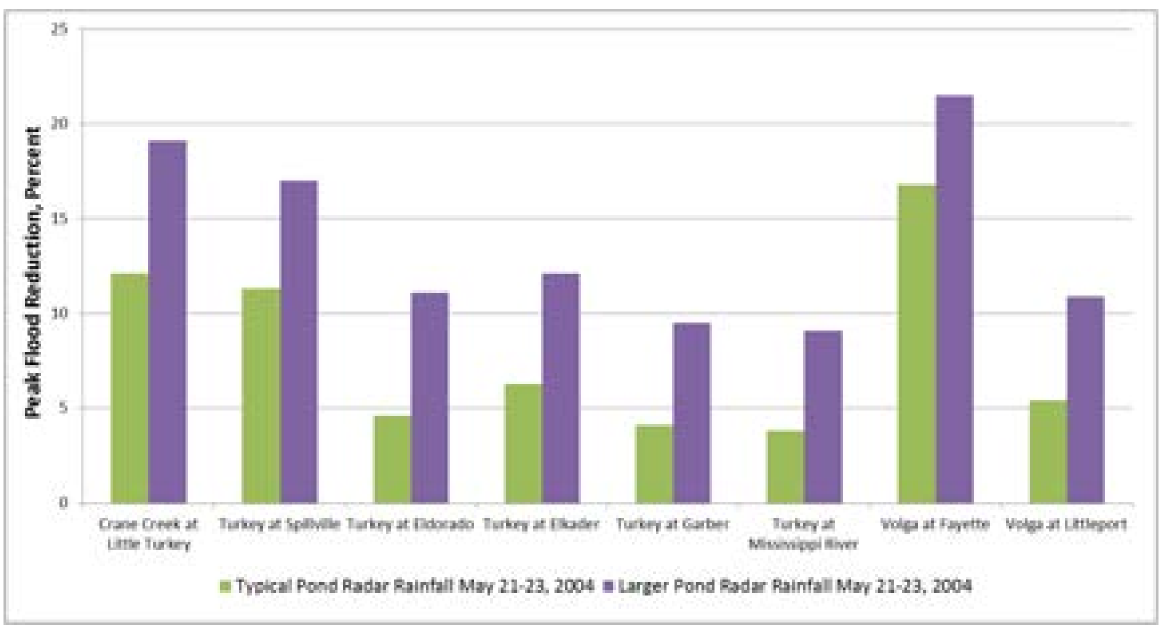

Figure 5.3. Comparison of the relative impact of the distributed storage scenarios for reducing peak discharges in the Turkey River Watershed. Results are using May 21-23 radar rainfall estimates.

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

Appendix A – Maps

Iowa Flood Center

IIHR Hydroscience & Engineering

The University of Iowa
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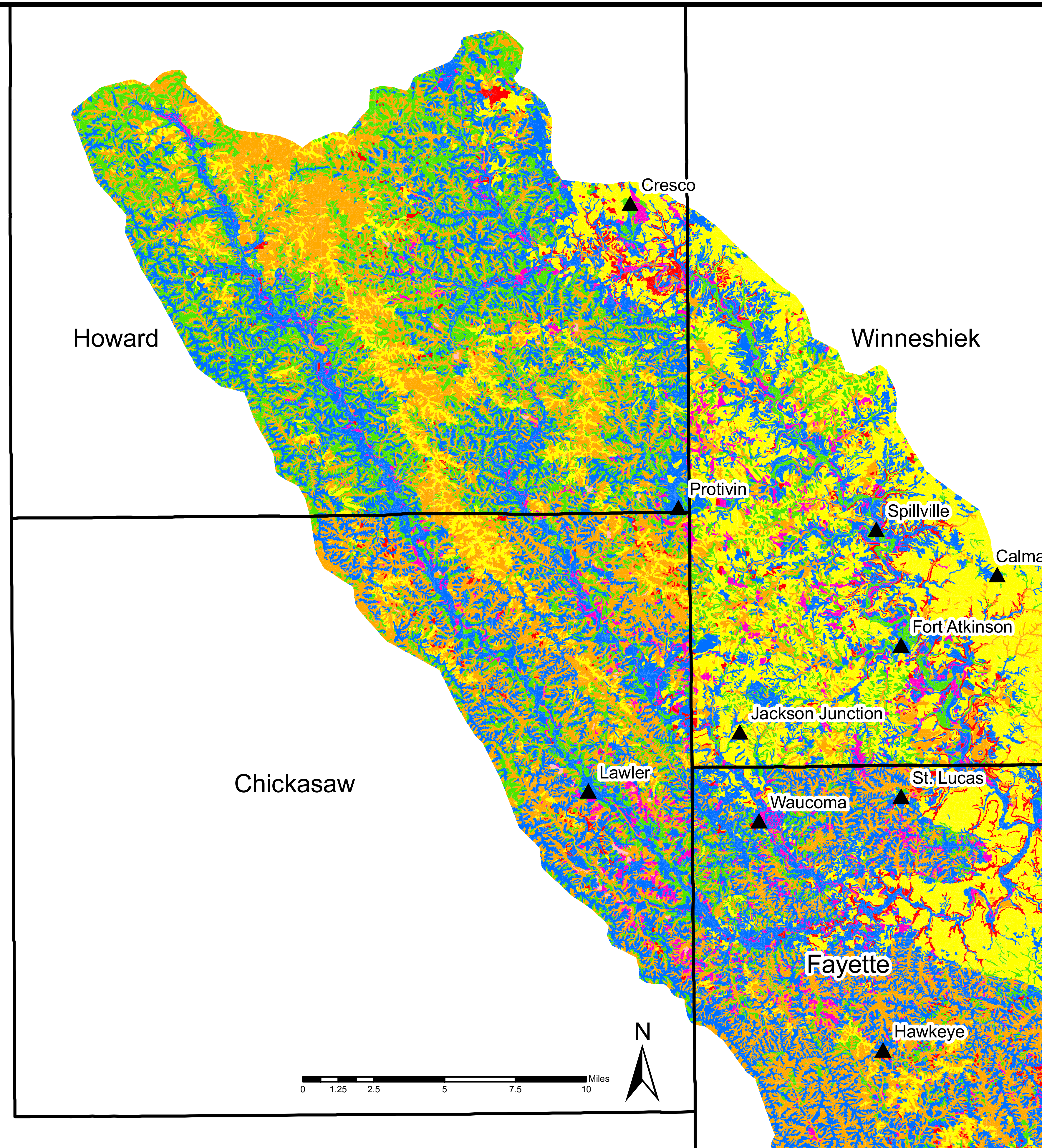
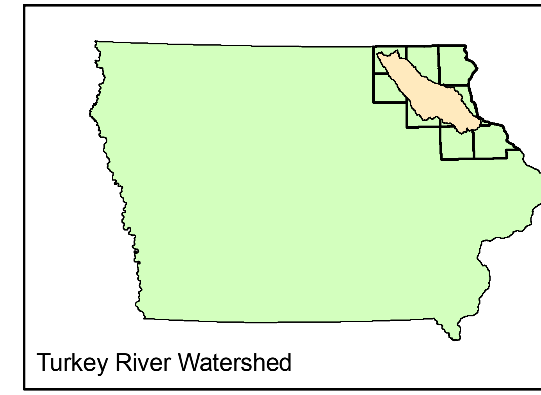
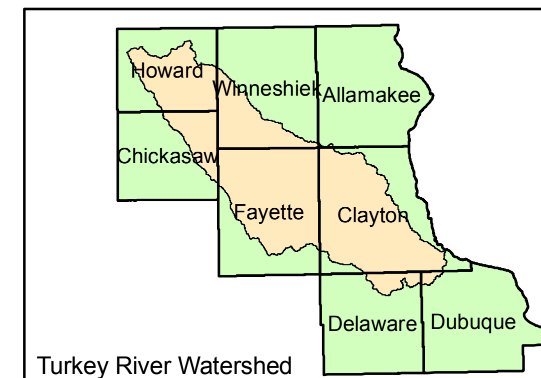
Iowa City, Iowa 52246







Turkey River Watershed

Howard and Chickasaw County Soils

Legend

- Cities
- Counties
- A
- A/D
- B
- B/D
- C
- C/D
- D

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Natural Resource Conservation Service (NRCS)
Web Soil Survey

Figure A-1

The University of Iowa
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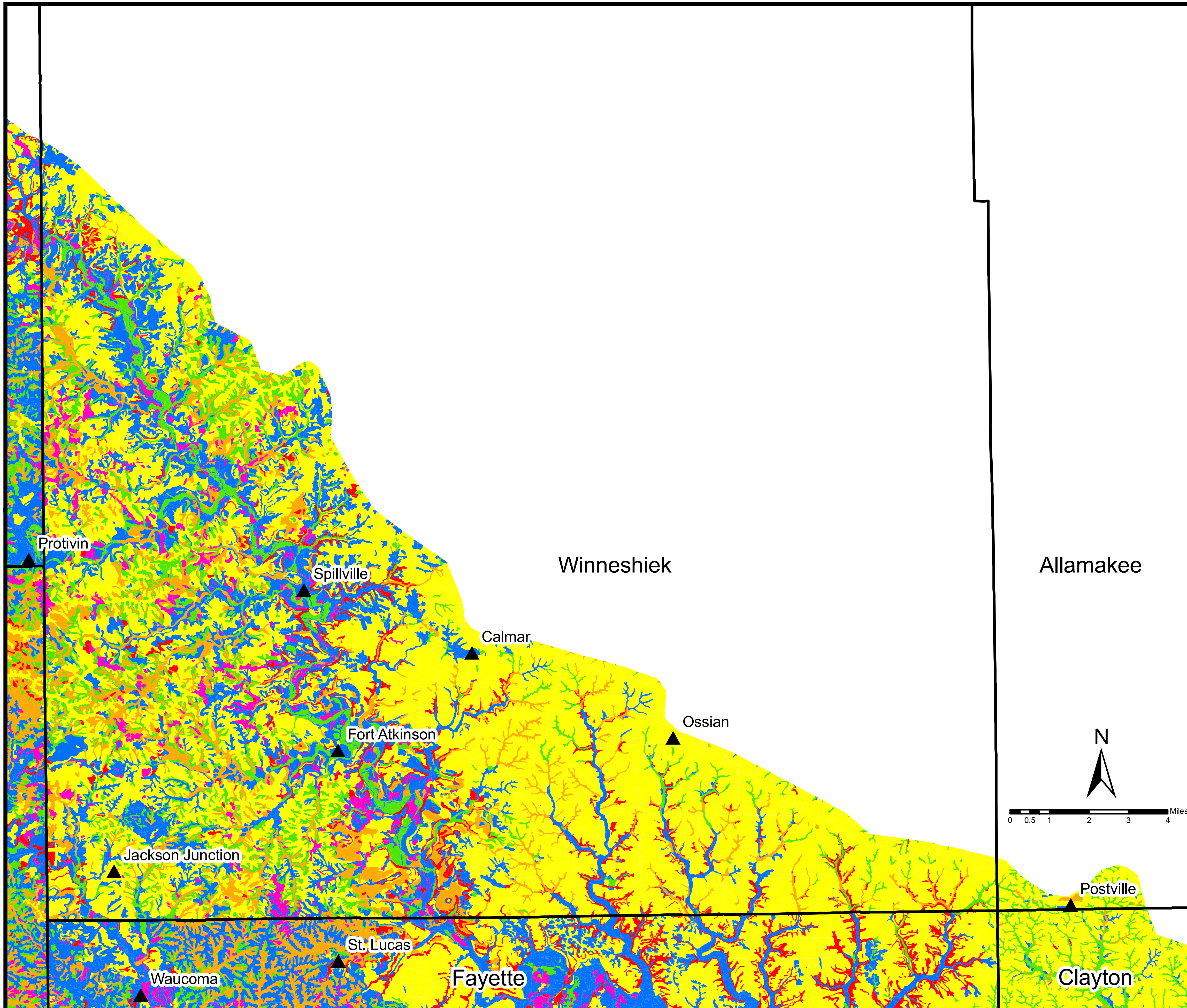
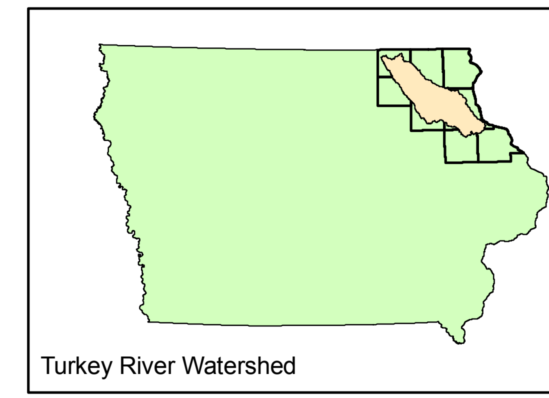
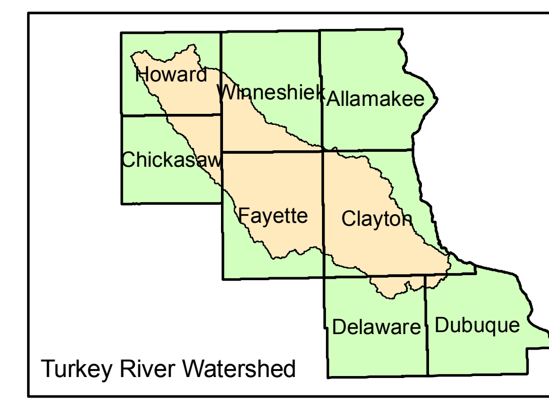
Iowa City, Iowa 52246







Turkey River Watershed
Winneshiek and Allamakee County Soils

Legend

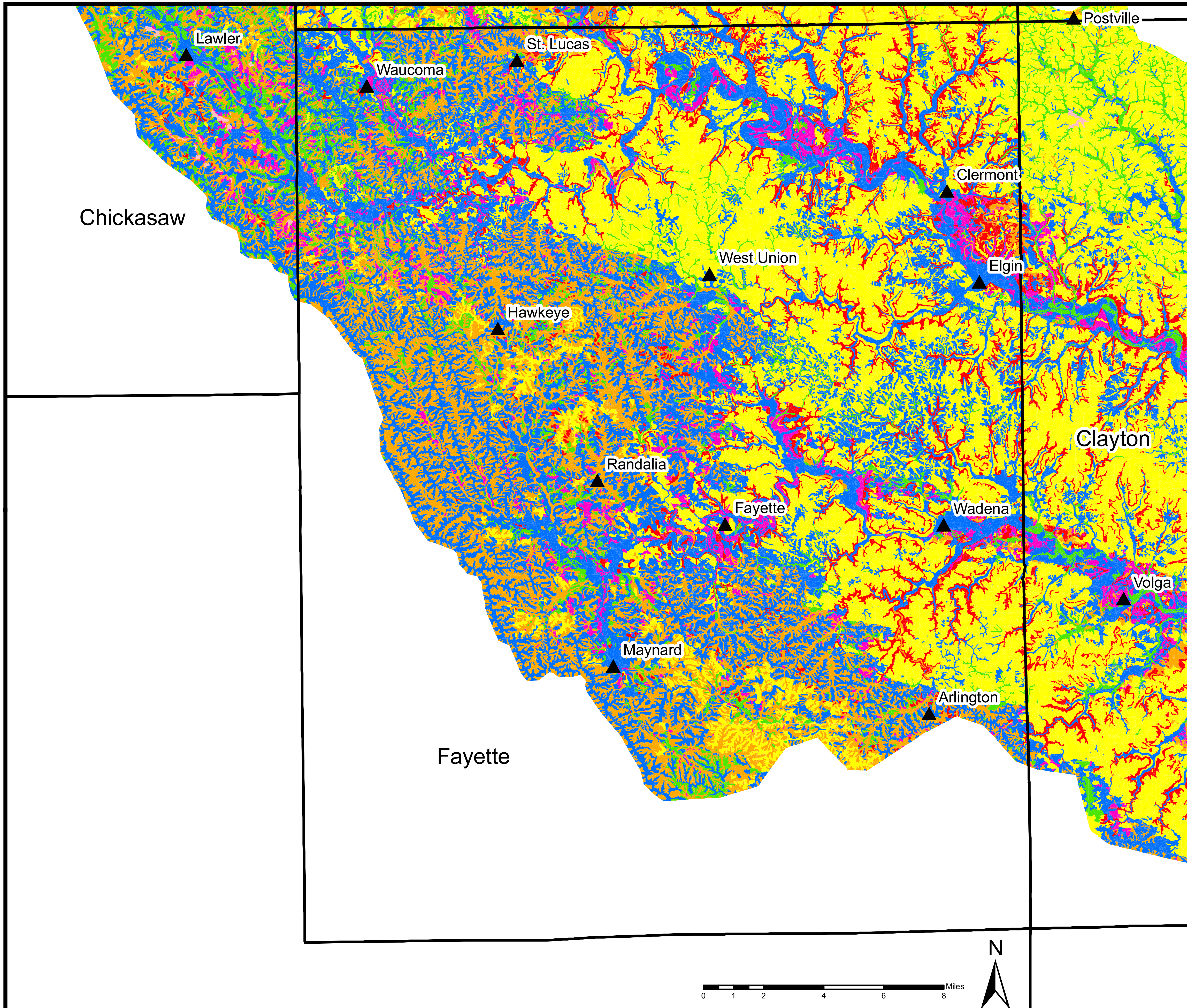
- ▲ Cities
- Counties
- A
- A/D
- B
- B/D
- C
- C/D
- D

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Natural Resource Conservation Service (NRCS)
Web Soil Survey

Figure A-2



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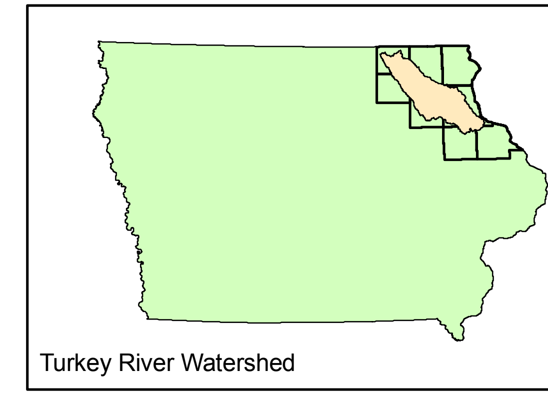
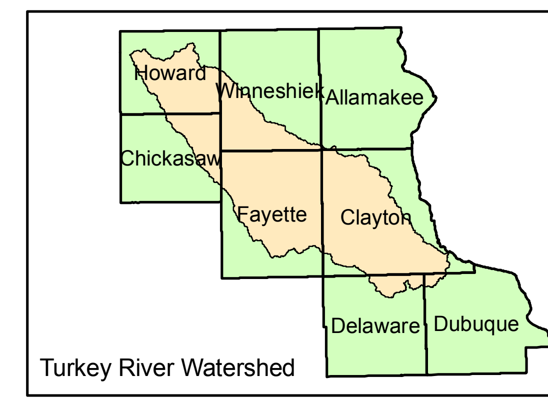




Turkey River Watershed
Fayette County Soils

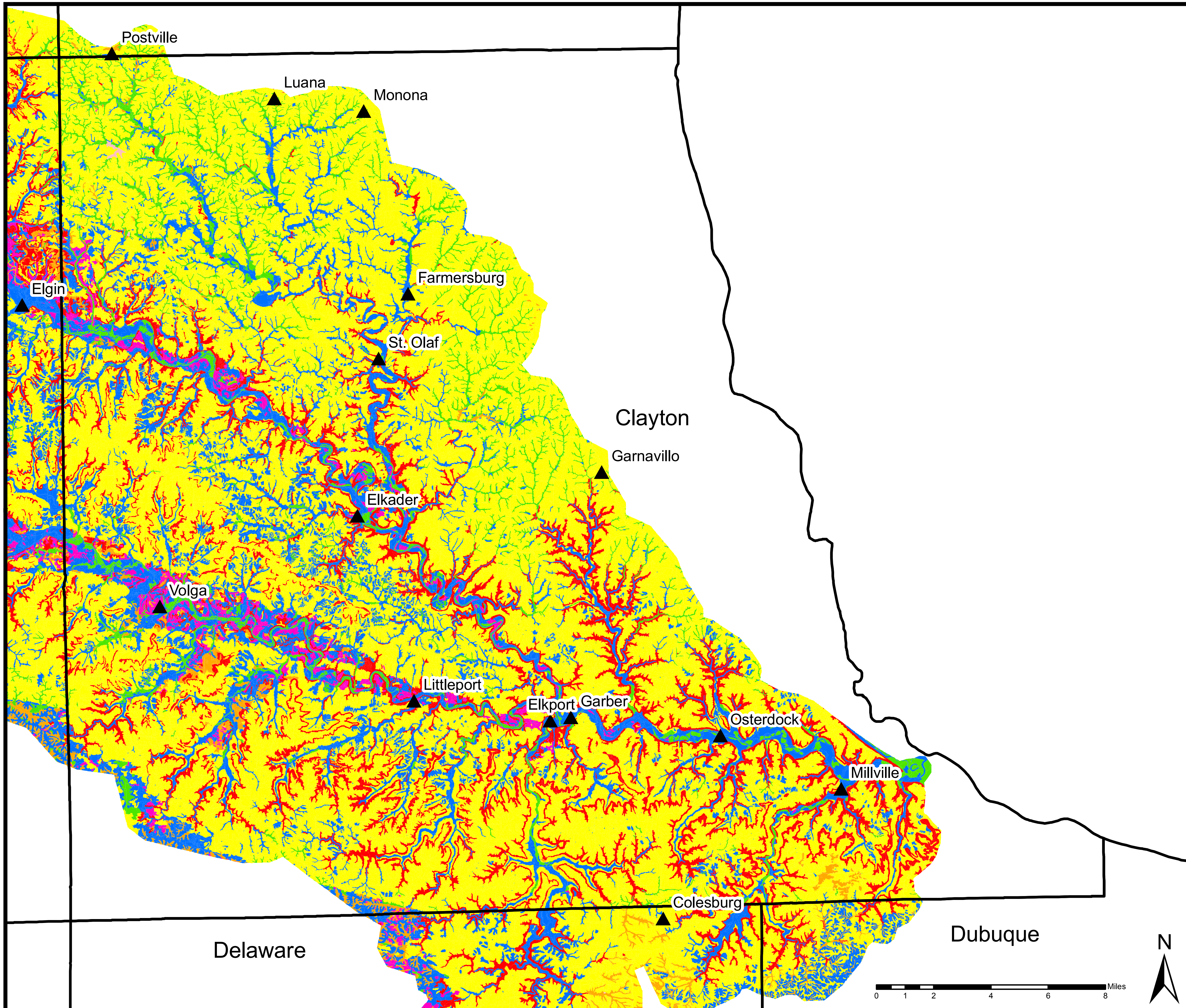
Legend
- Cities
- Counties
- A
- A/D
- B
- B/D
- C
- C/D
- D

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Natural Resource Conservation Service (NRCS)
Web Soil Survey

Figure A-3



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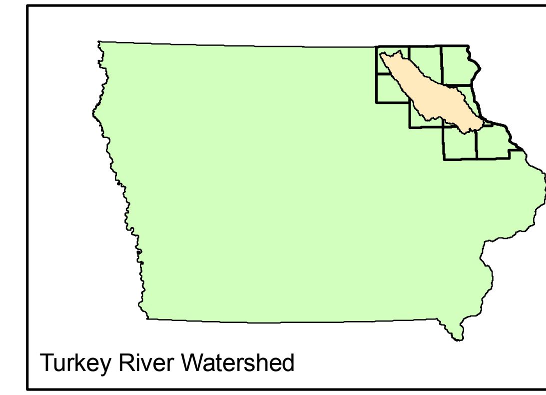
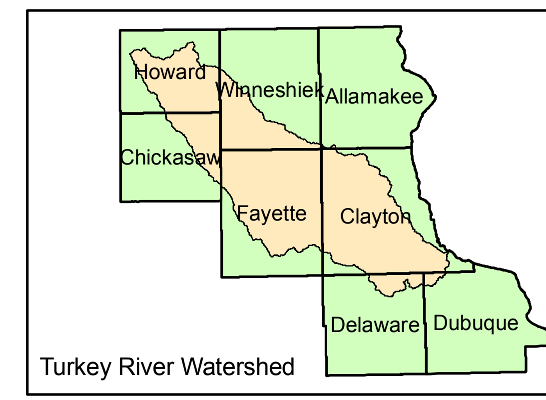




Turkey River Watershed

Clayton County Soils

Legend

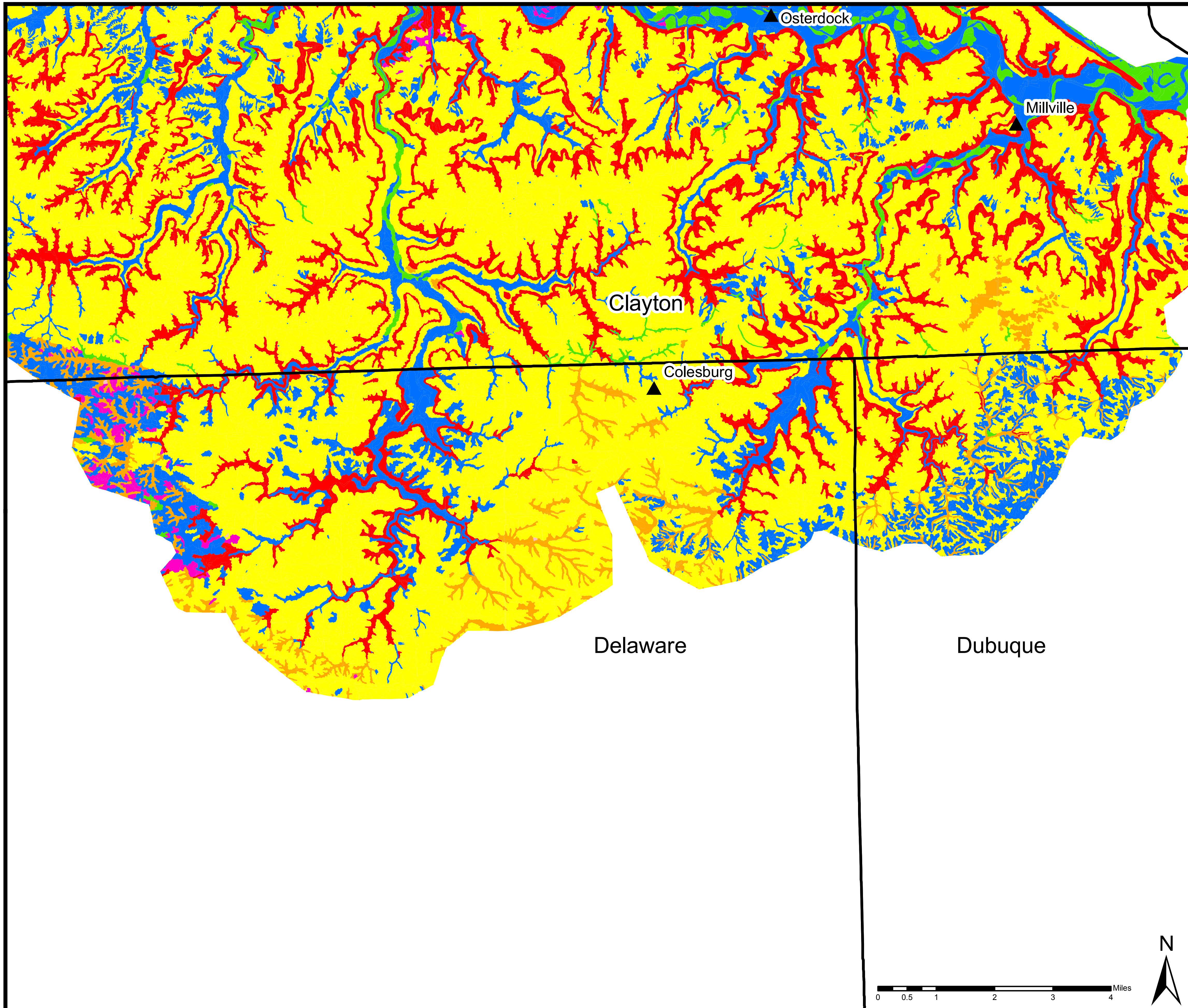
- Cities
- Counties
- A
- A/D
- B
- B/D
- C
- C/D
- D

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Natural Resource Conservation Service (NRCS)
Web Soil Survey

Figure A-4



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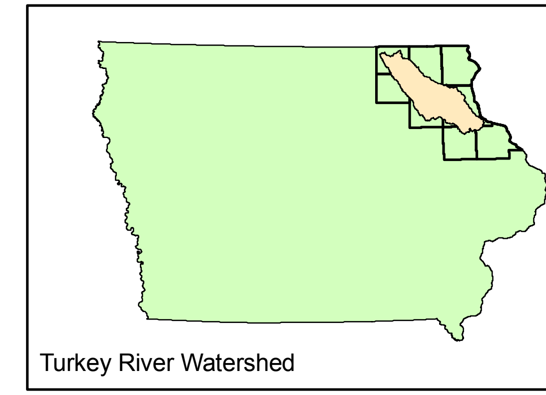
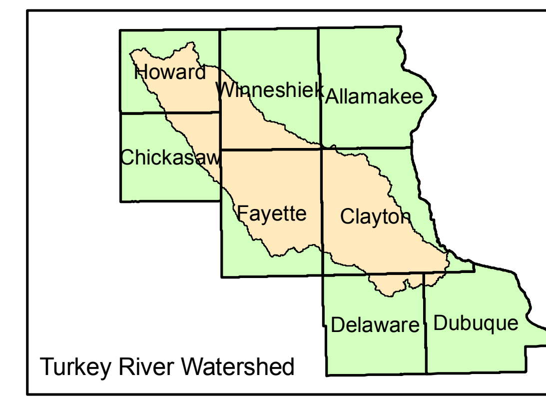




Turkey River Watershed

Delaware and Dubuque County Soils

Legend

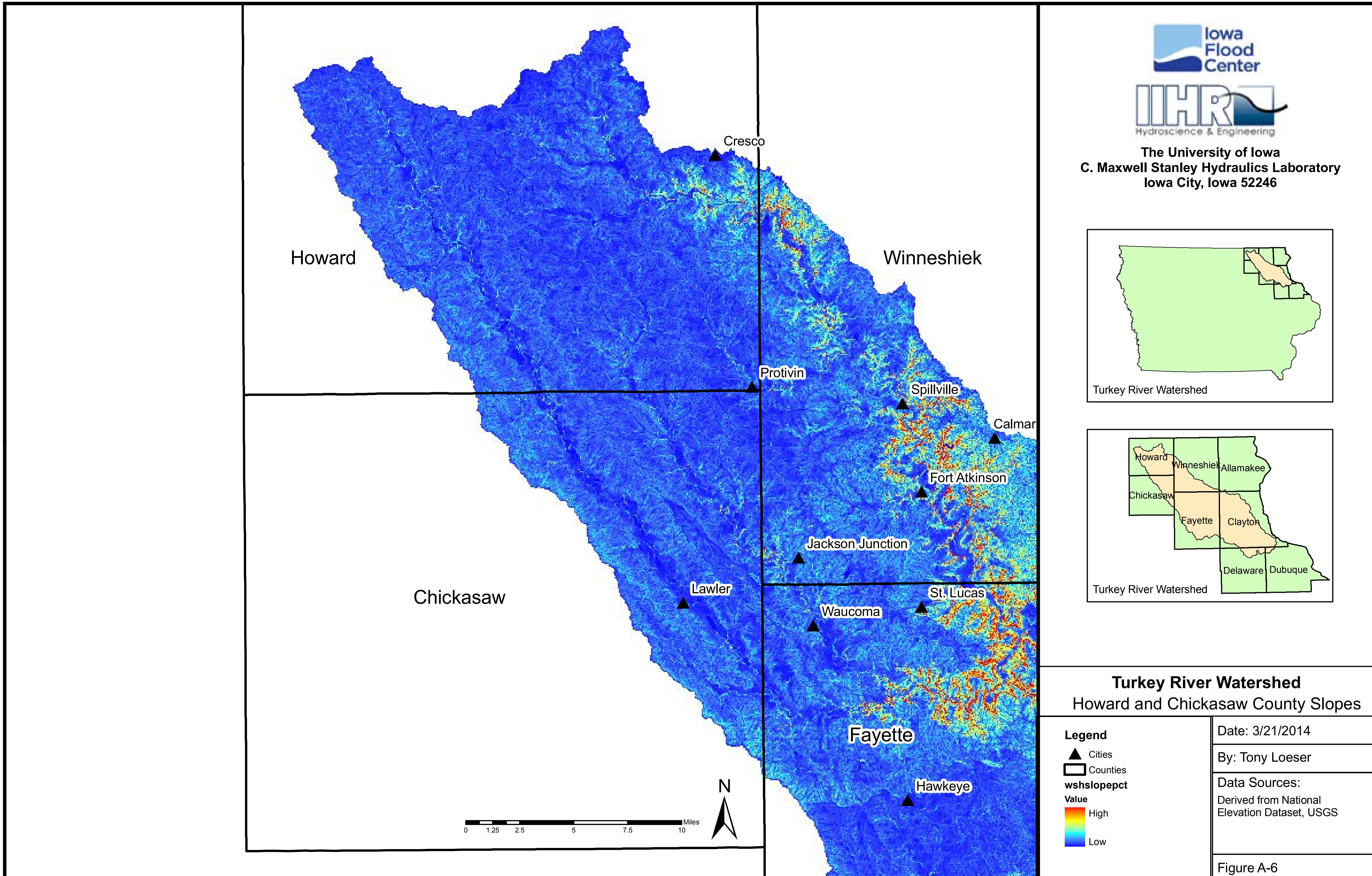
- Cities
- Counties
- A
- A/D
- B
- B/D
- C
- C/D
- D

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Natural Resource Conservation Service (NRCS)
Web Soil Survey

Figure A-5



Howard
Chickasaw
Winneshiek
Fayette
Cresco
Protivin
Spillville
Calmar
Fort Atkinson
Jackson Junction
Lawler
St. Lucas
Waucoma
Hawkeye
N
0 1.25 2.5 5 7.5 10 Miles
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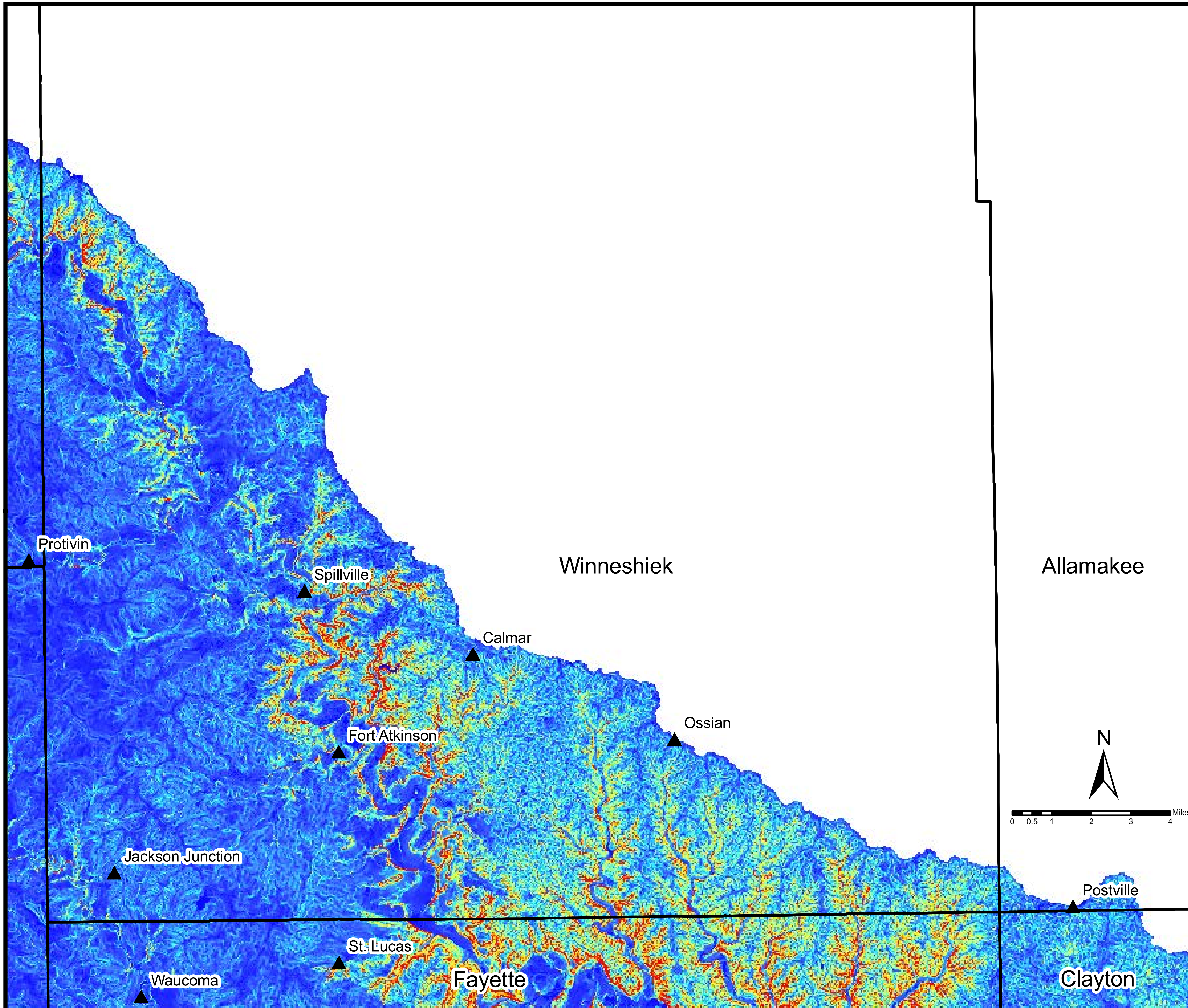
Iowa City, Iowa 52246
Turkey River Watershed
Howard
Winneshiek
Allamakee
Chickasaw
Fayette
Clayton
Delaware
Dubuque
Turkey River Watershed
Turkey River Watershed
Howard and Chickasaw County Slopes
Legend
Cities
Counties
wshslopepct
Value
High
Low
Date: 3/21/2014
By: Tony Loeser
Data Sources:
Derived from National Elevation Dataset, USGS
Figure A-6



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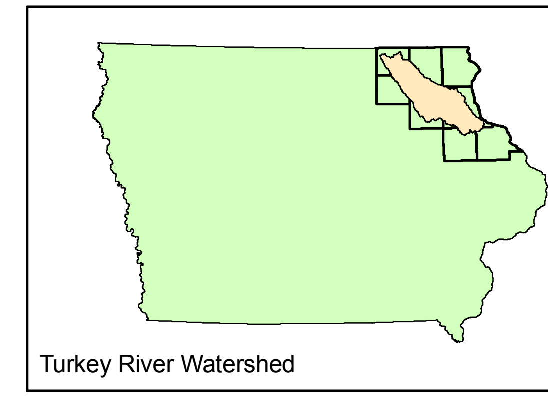
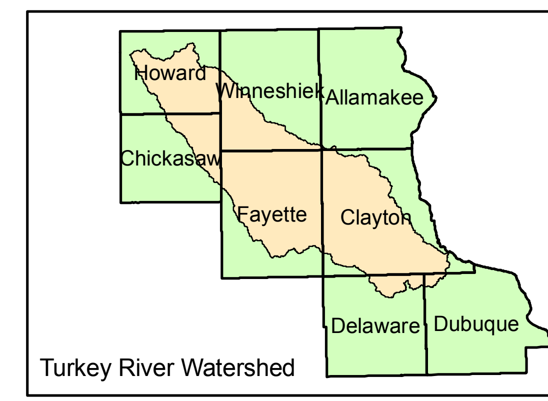




Turkey River Watershed
Winneshiek and Allamakee County Slopes

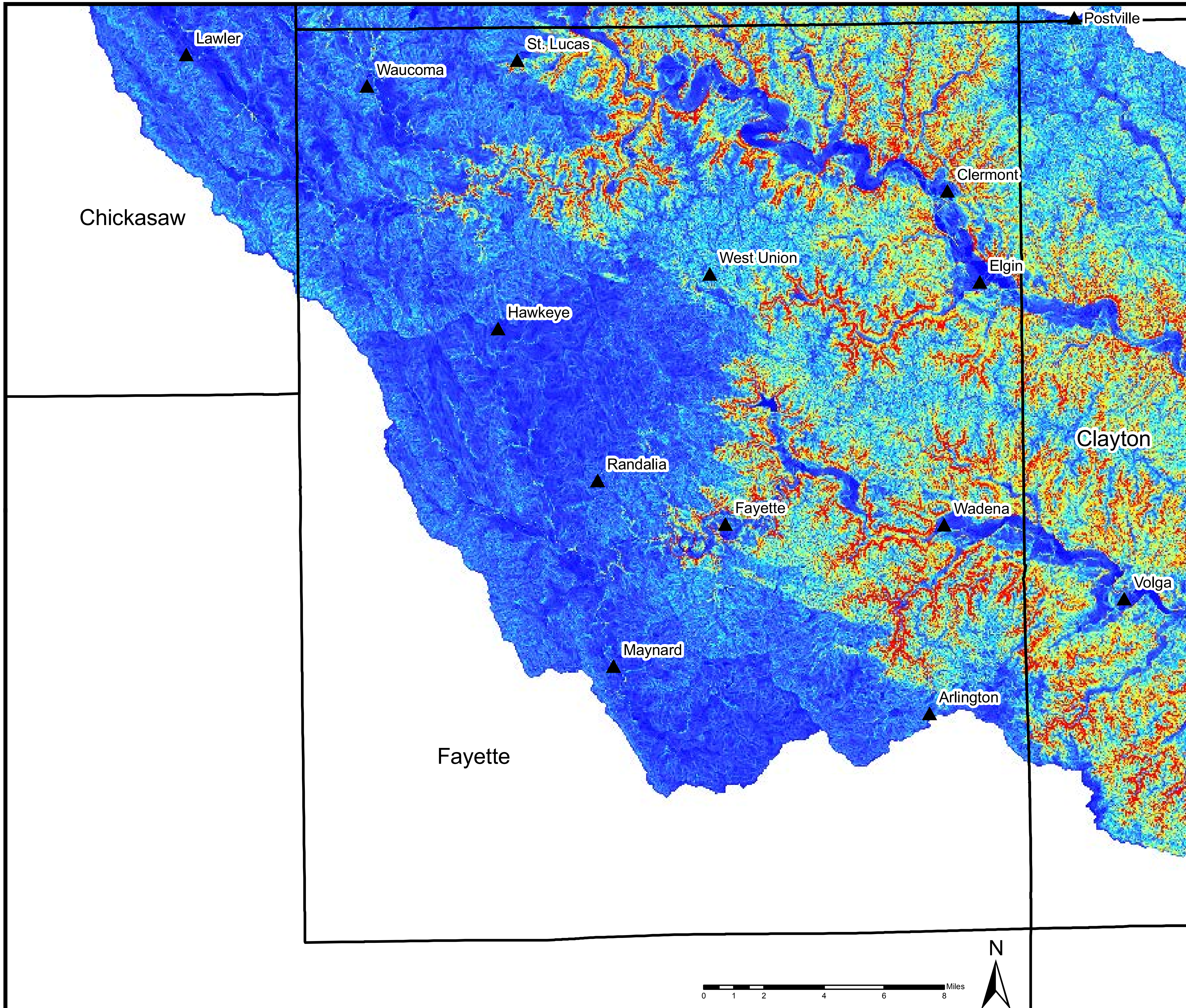
Legend
Cities
Counties
wshslopepct
Value
High
Low

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Derived from National Elevation Dataset, USGS

Figure A-7



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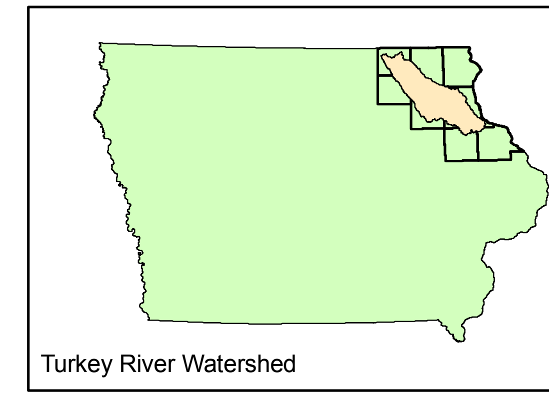
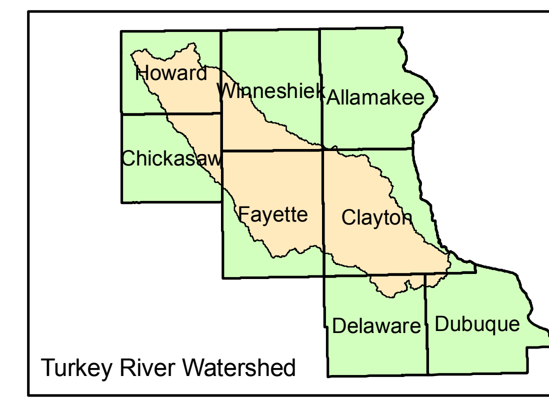




Turkey River Watershed

Fayette County Slopes

Legend

Cities

Counties

wshslopepct

Value

High

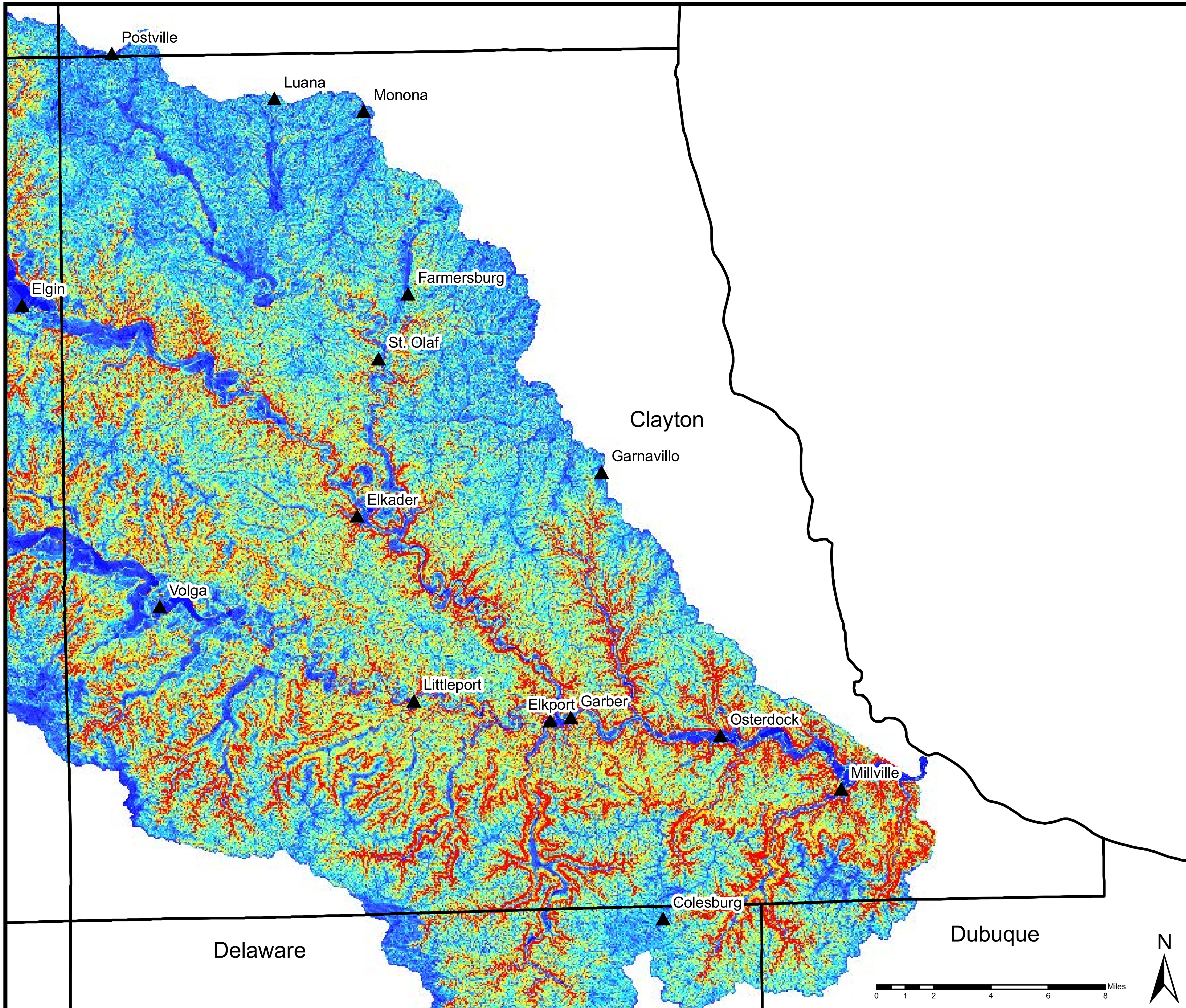
Low

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Derived from National Elevation Dataset, USGS

Figure A-8



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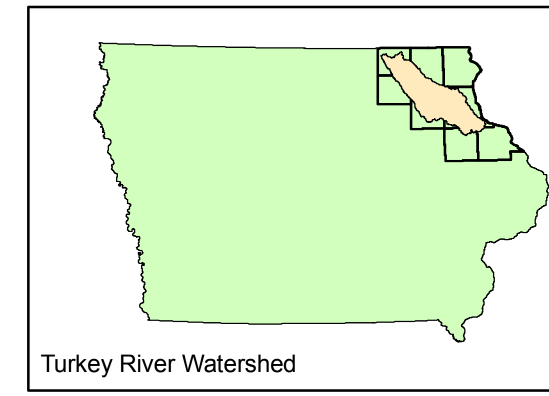
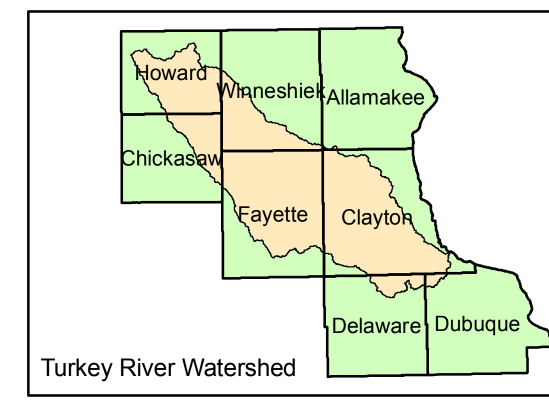




Turkey River Watershed
Clayton County Slopes

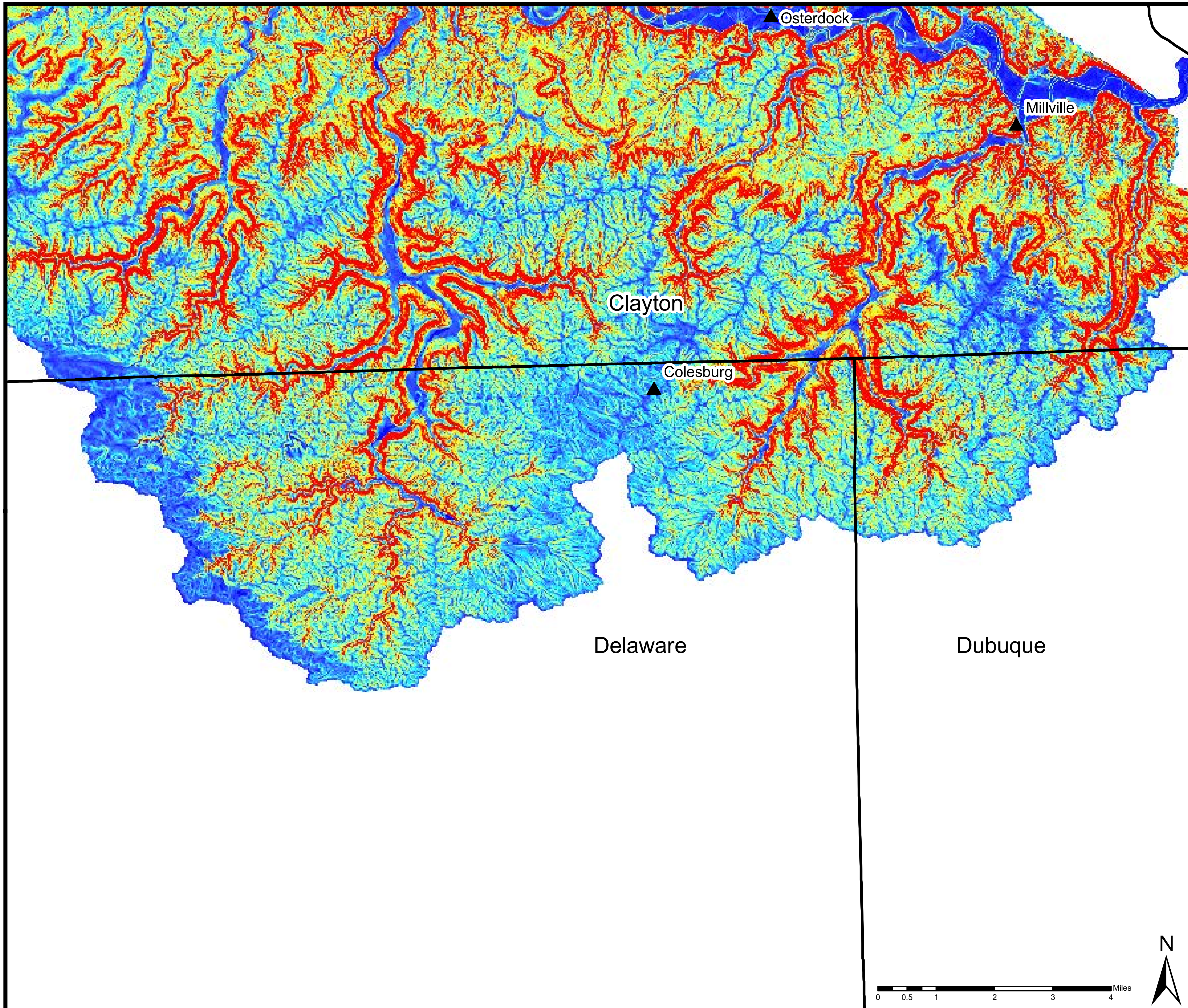
Legend
Cities
Counties
wshslopepct
Value
High
Low

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Derived from National Elevation Dataset, USGS

Figure A-9



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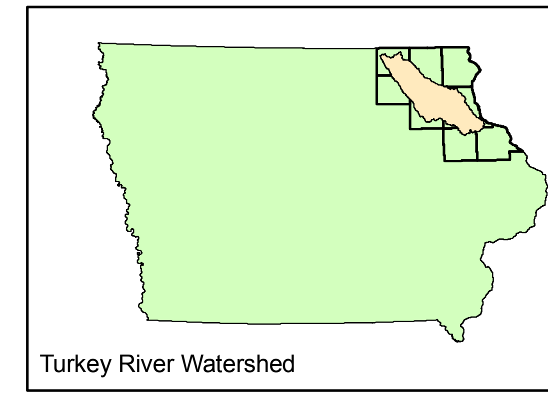
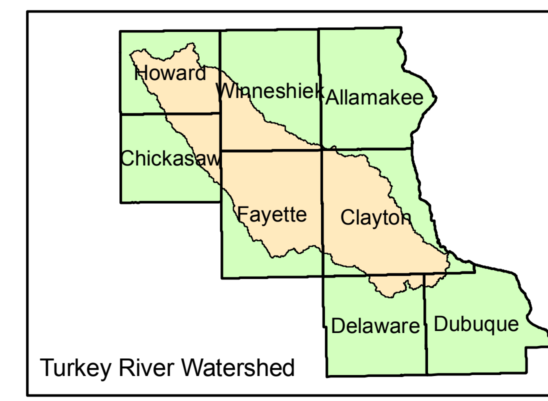




Turkey River Watershed

Delaware and Dubuque County Slopes

Legend

Cities

Counties

wshslopepct

Value

High

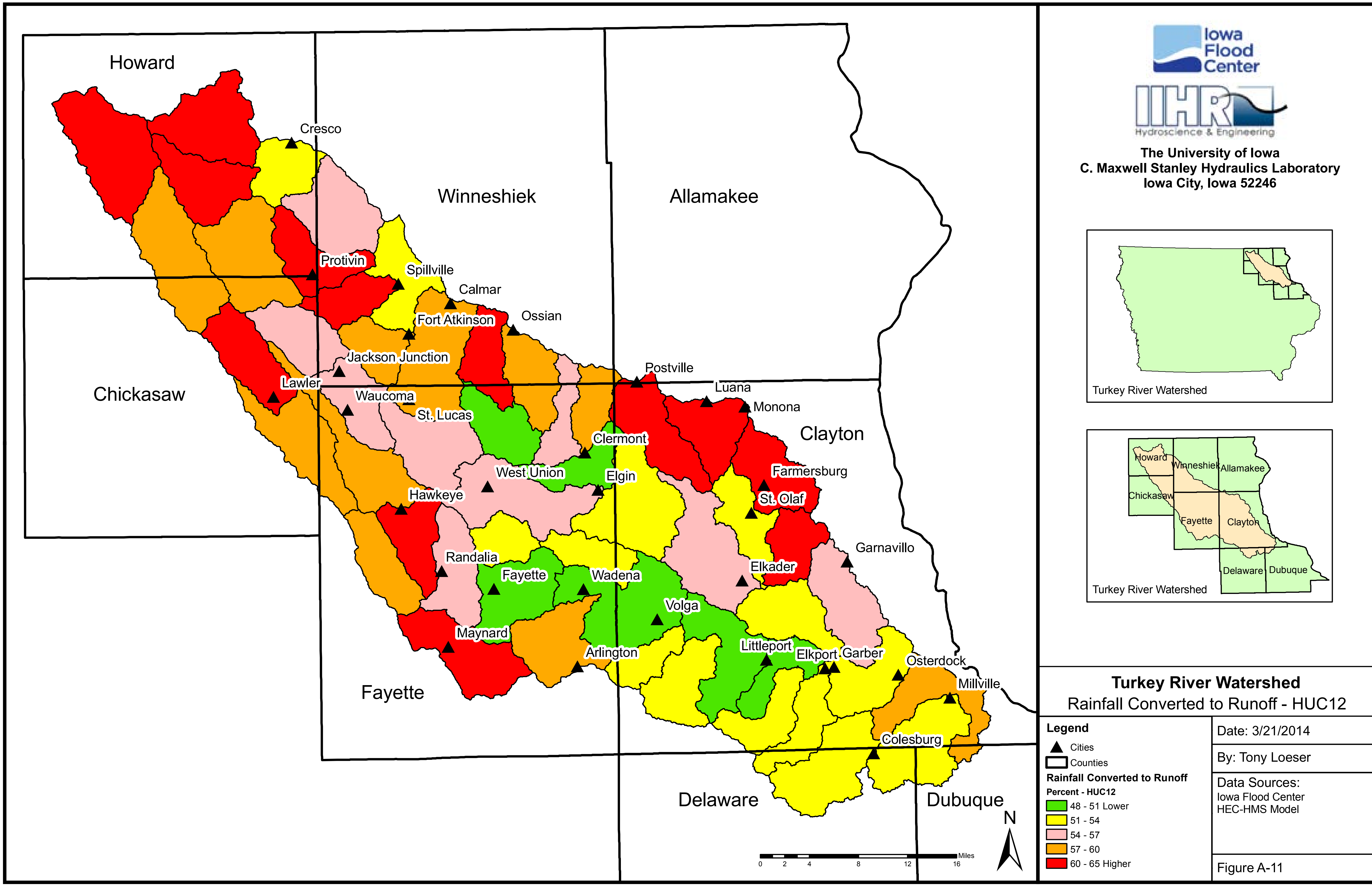
Low

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Derived from National Elevation Dataset, USGS

Figure A-10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Dubuque
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Spillville
Calmar
Fort Atkinson
Ossian
Jackson Junction
Lawler
Waucoma
St. Lucas
Postville
Luana
Monona
Clermont
West Union
Elgin
Hawkeye
Farmersburg
St. Olaf
Garnavillo
Elkader
Randalia
Fayette
Wadena
Volga
Maynard
Arlington
Littleport
Elkport
Garber
Osterdock
Millville
Colesburg
N
0 2 4 8 12 16 Miles
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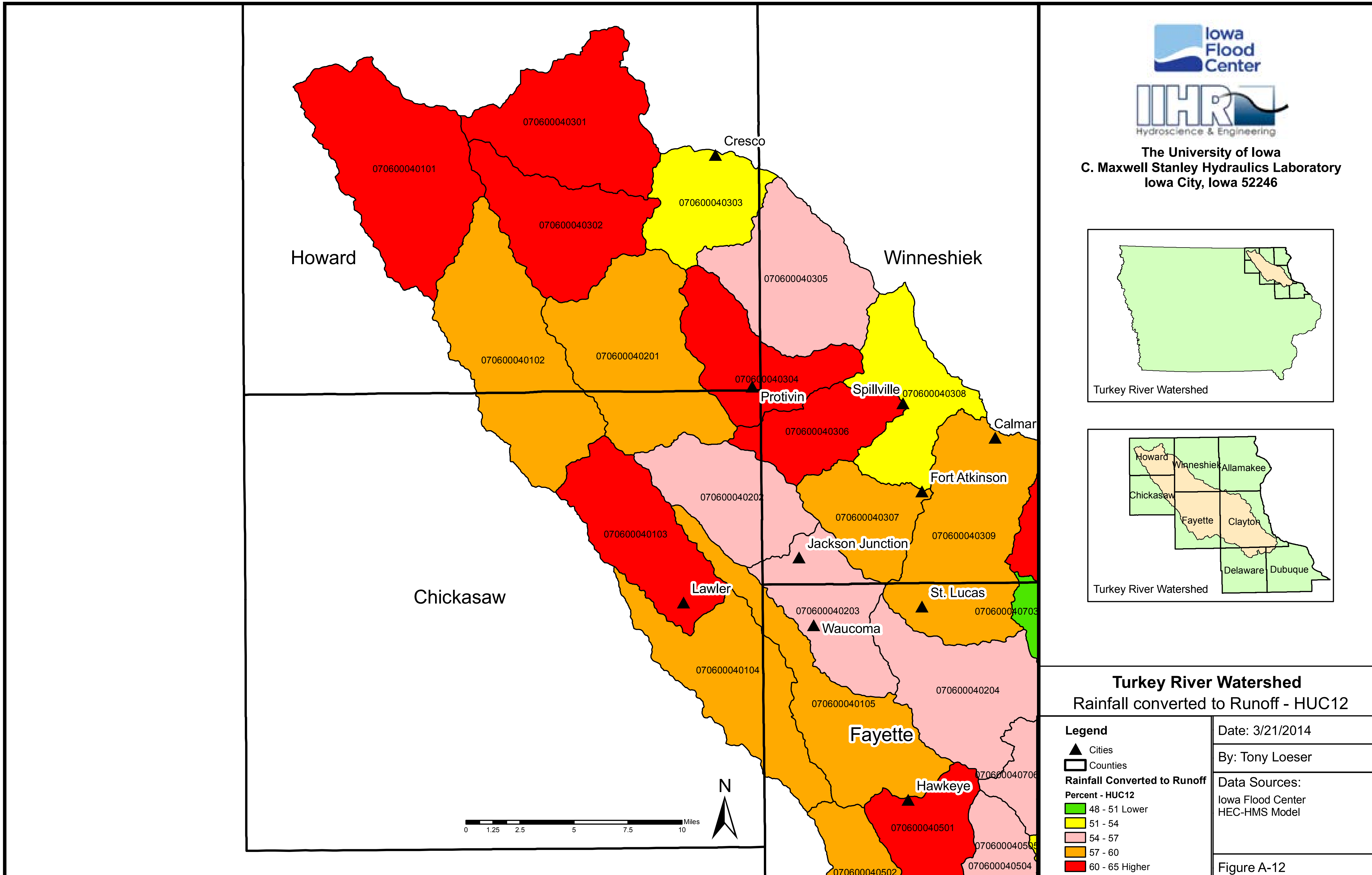
Turkey River Watershed
Howard
Winneshiek
Allamakee
Chickasaw
Fayette
Clayton
Delaware
Dubuque
Turkey River Watershed
Turkey River Watershed
Rainfall Converted to Runoff - HUC12
Legend
Cities
Counties
Rainfall Converted to Runoff
Percent - HUC12
48 - 51 Lower
51 - 54
54 - 57
57 - 60
60 - 65 Higher
Date: 3/21/2014
By: Tony Loeser
Data Sources:
Iowa Flood Center
HEC-HMS Model
Figure A-11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Turkey River Watershed
Howard
Winneshiek
Allamakee
Chickasaw
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Turkey River Watershed
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Protivin
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Calmar
Fort Atkinson
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Lawler
St. Lucas
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070600040502
070600040504
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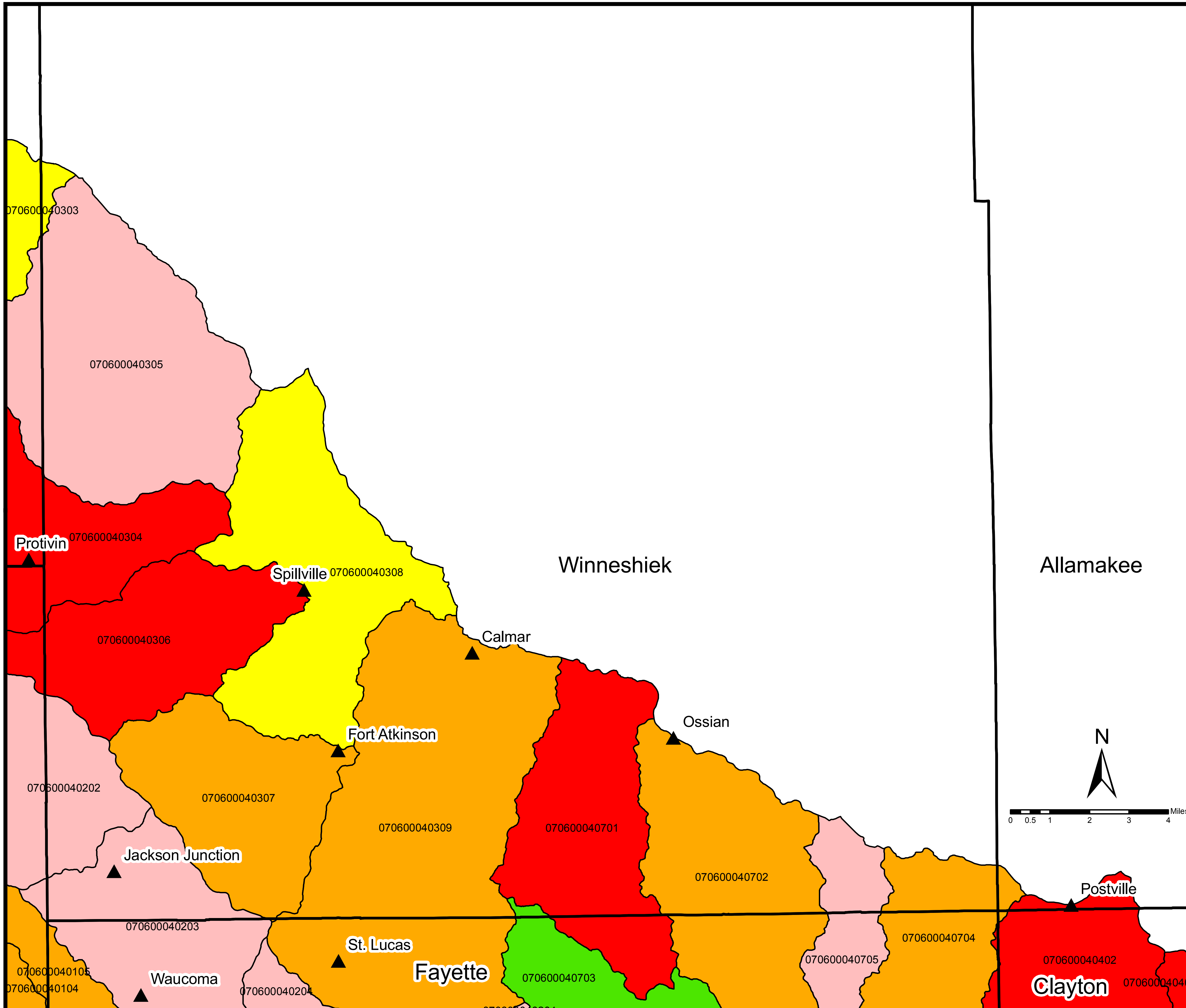
0 1.25 2.5 5 7.5 10 Miles
Turkey River Watershed
Rainfall converted to Runoff - HUC12
Legend
Cities
Counties
Rainfall Converted to Runoff
Percent - HUC12
48 - 51 Lower
51 - 54
54 - 57
57 - 60
60 - 65 Higher
Date: 3/21/2014
By: Tony Loeser
Data Sources:
Iowa Flood Center
HEC-HMS Model
Figure A-12



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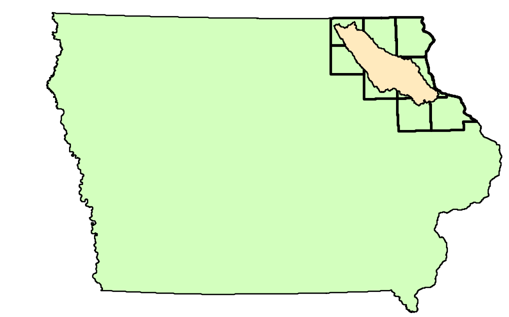
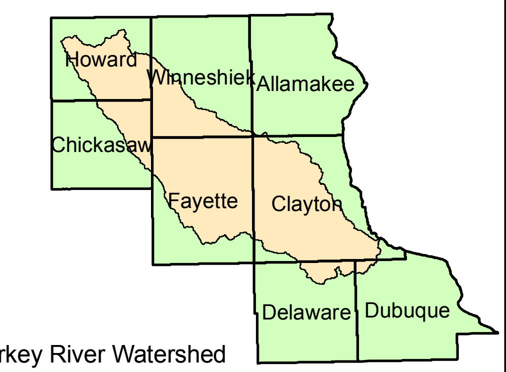

Turkey River Watershed



Turkey River Watershed

Turkey River Watershed
Rainfall converted to Runoff - HUC12

Legend

- Cities
- Counties

Rainfall Converted to Runoff
Percent - HUC12

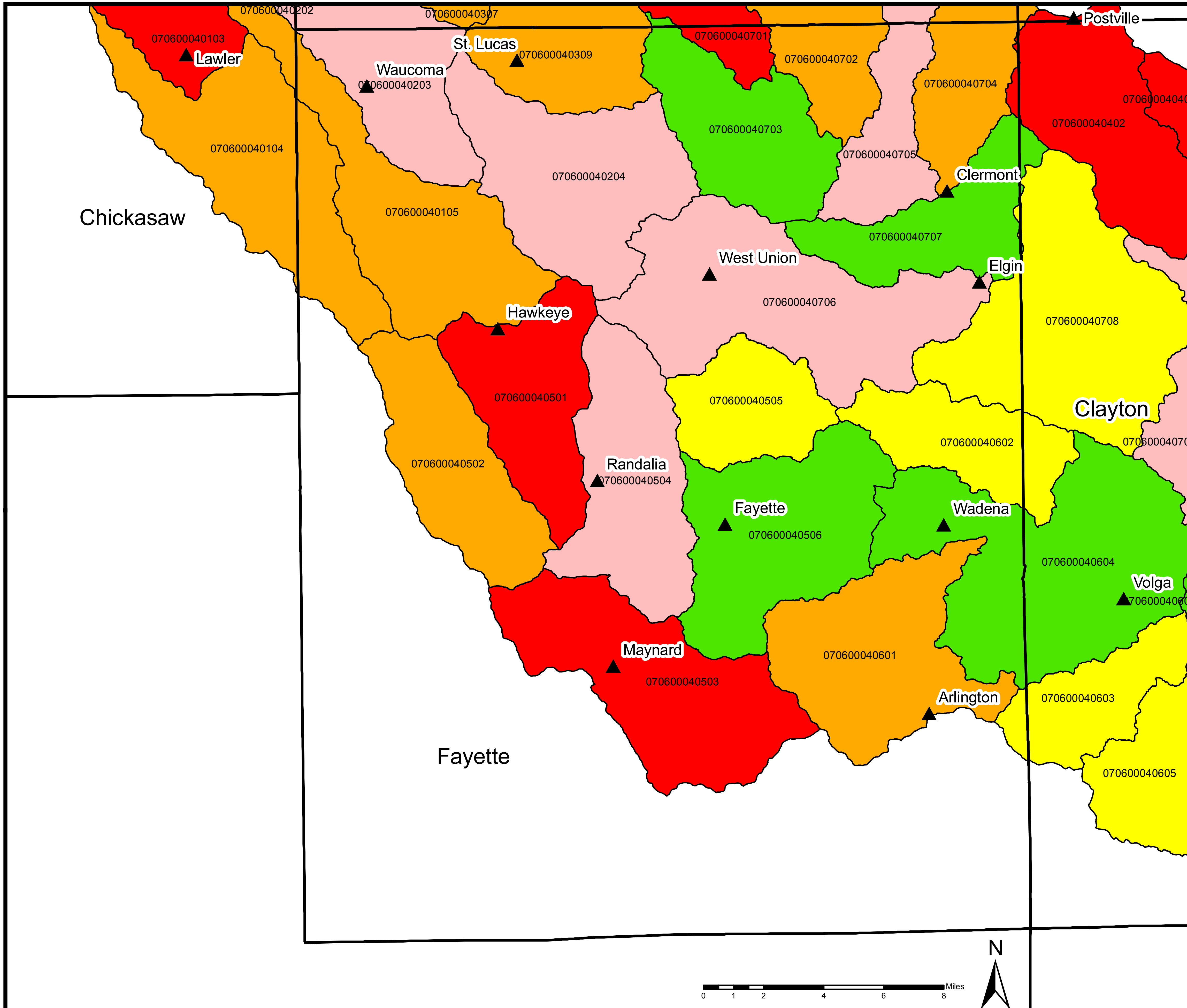
- 48 - 51 Lower
- 51 - 54
- 54 - 57
- 57 - 60
- 60 - 65 Higher

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Iowa Flood Center
HEC-HMS Model

Figure A-13



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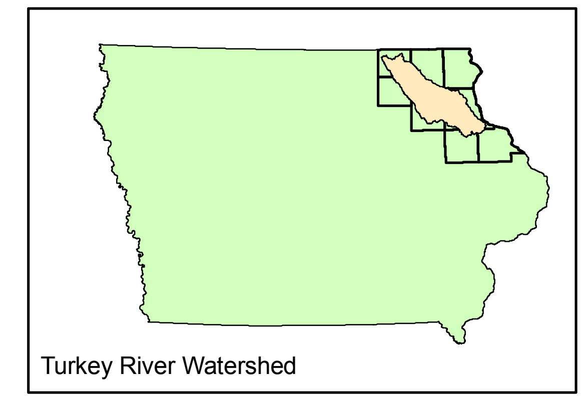
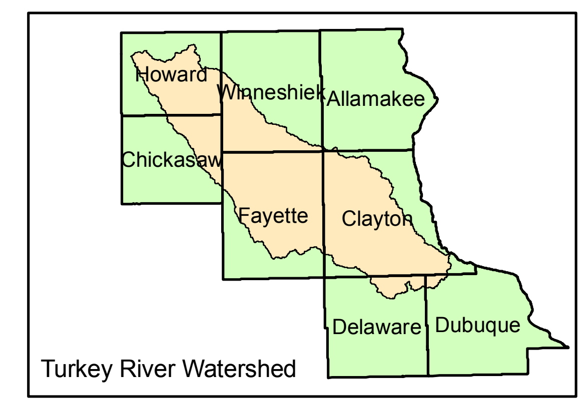




Turkey River Watershed
Rainfall converted to Runoff - HUC12

Legend

- ▲ Cities
- ☐ Counties

Rainfall Converted to Runoff
Percent HUC12

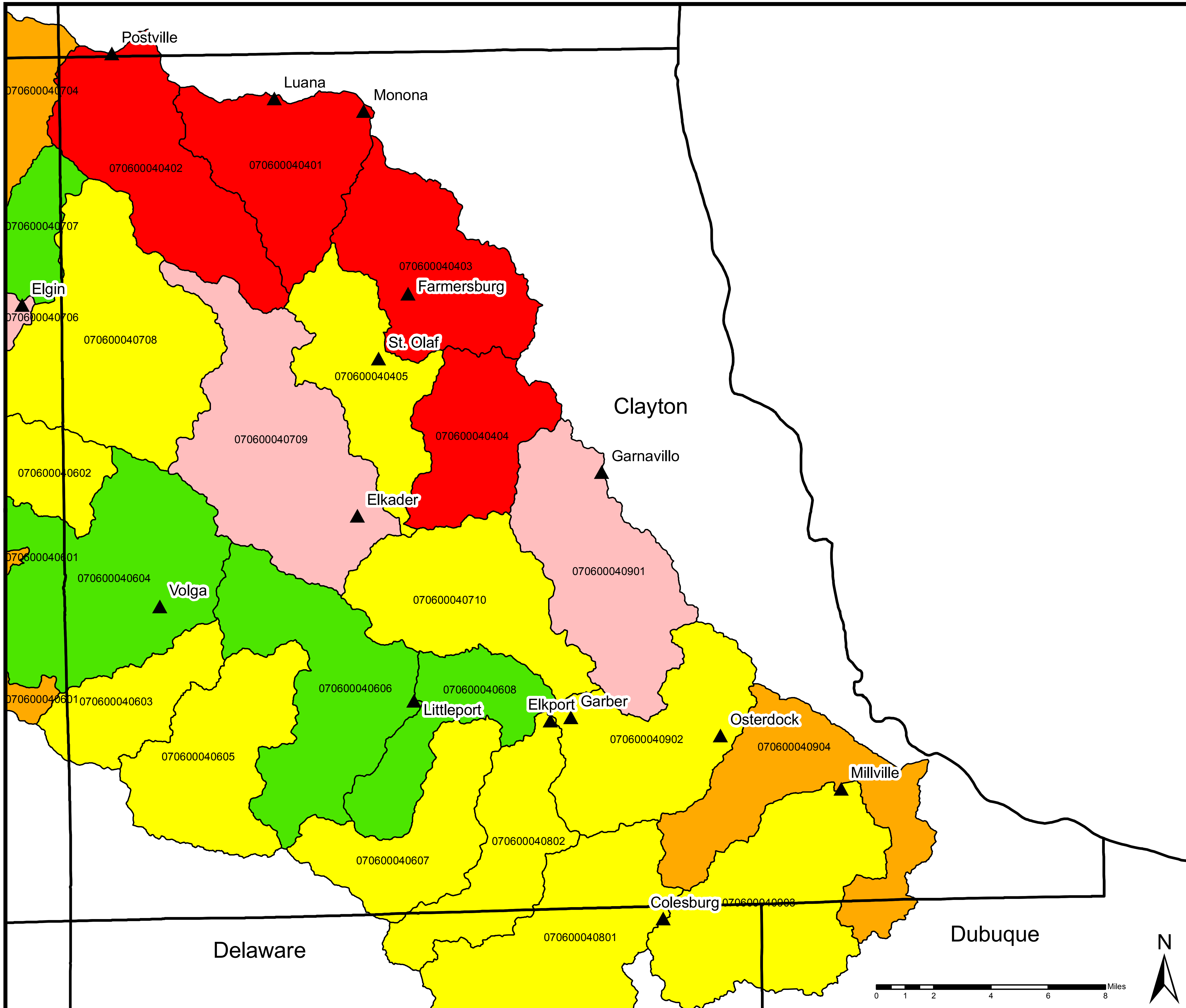
- 48 - 51 Lower
- 51 - 54
- 54 - 57
- 57 - 60
- 60 - 65 Higher

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Iowa Flood Center
HEC-HMS Model

Figure A-14



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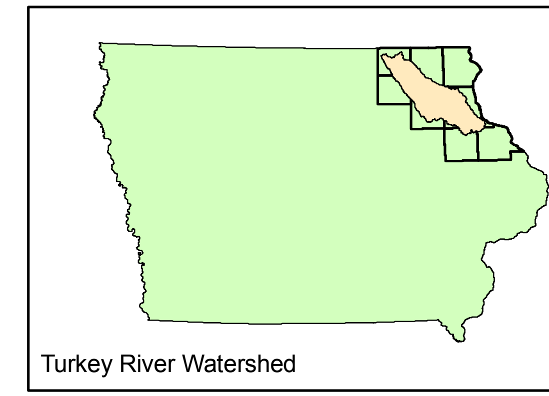
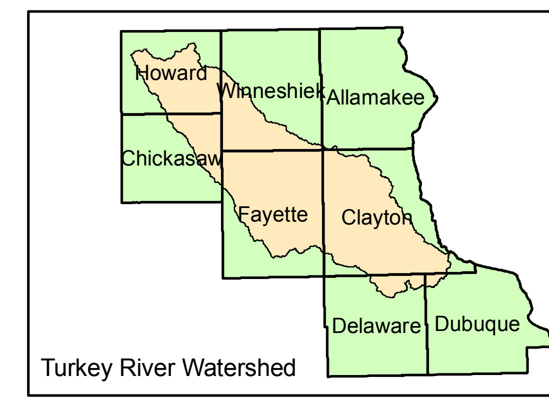




Turkey River Watershed
Rainfall converted to Runoff - HUC12

Legend
- Cities
- Counties

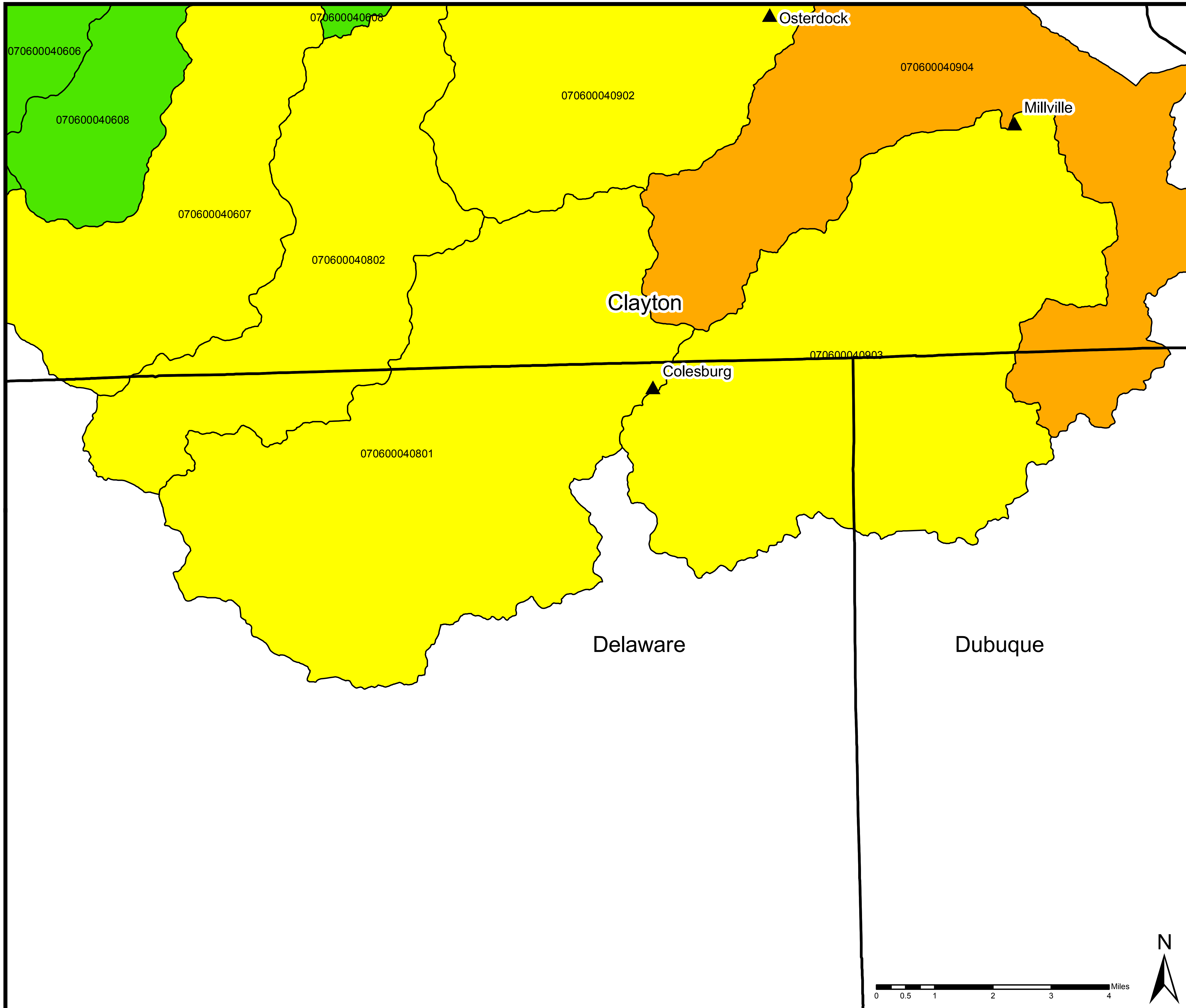
Rainfall Converted to Runoff
Percent - HUC12
- 48 - 51 Lower
- 51 - 54
- 54 - 57
- 57 - 60
- 60 - 65 Higher

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Iowa Flood Center
HEC-HMS Model

Figure A-15



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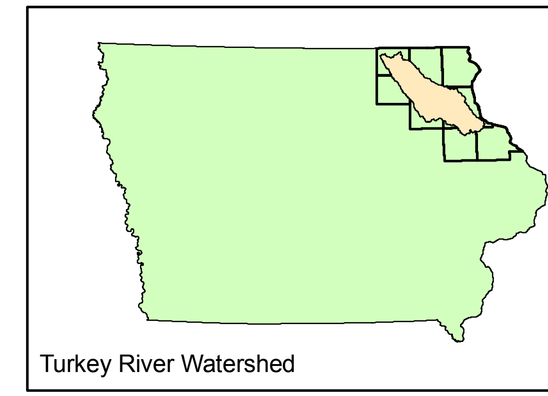
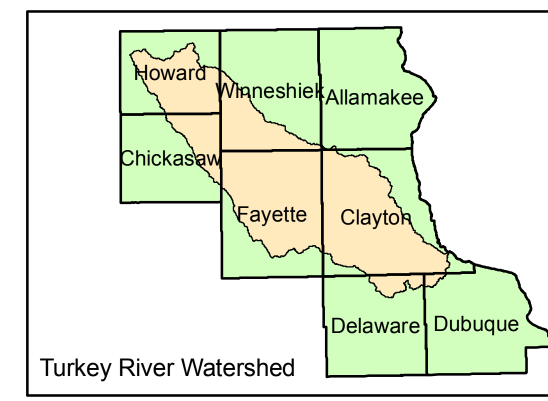


Turkey River Watershed



Turkey River Watershed

Turkey River Watershed

Rainfall converted to Runoff - HUC12

Legend

Cities

Counties

Rainfall Converted to Runoff

Percent - HUC12

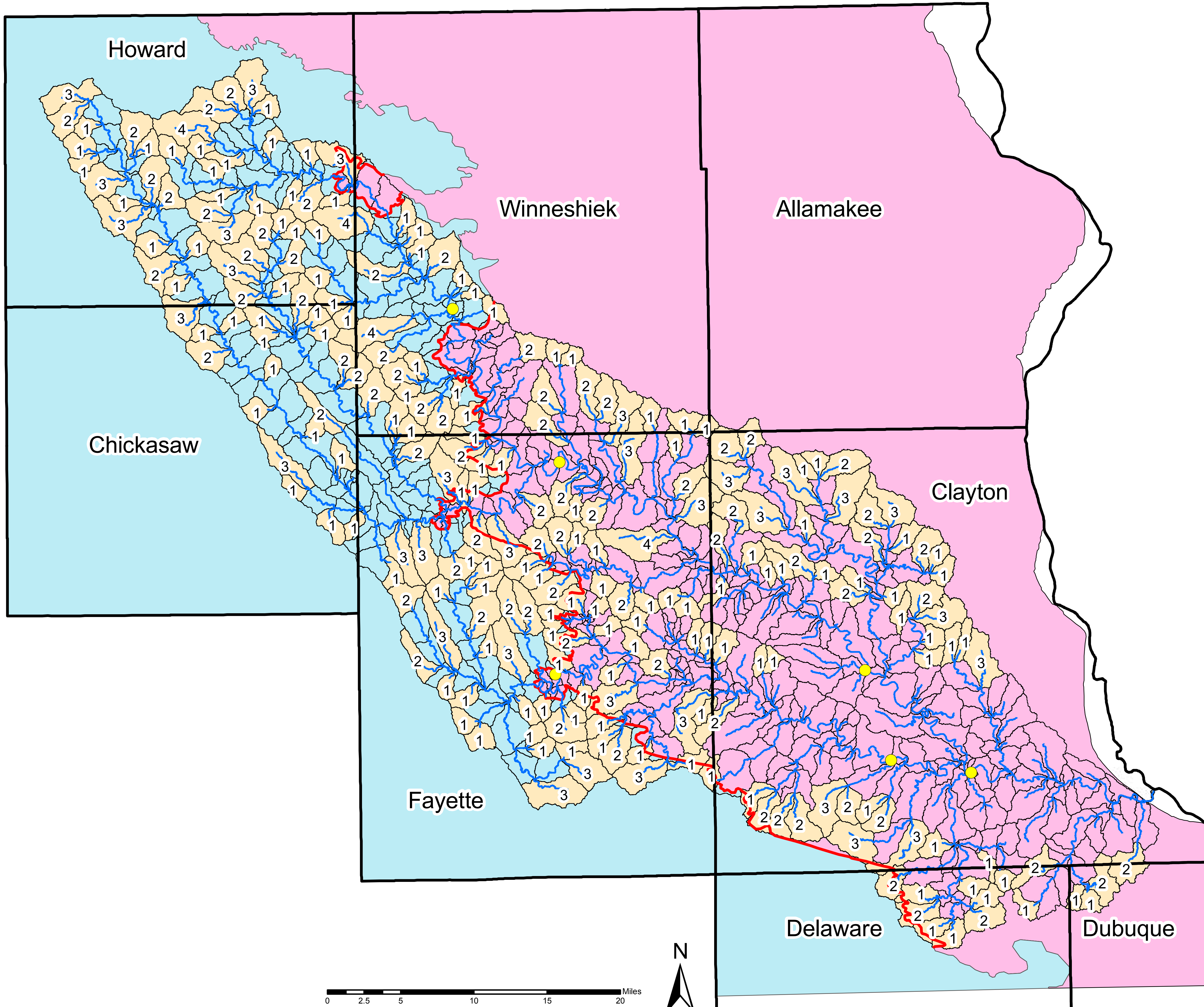
- 48 - 51 Lower
- 51 - 54
- 54 - 57
- 57 - 60
- 60 - 65 Higher

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Iowa Flood Center
HEC-HMS Model

Figure A-16



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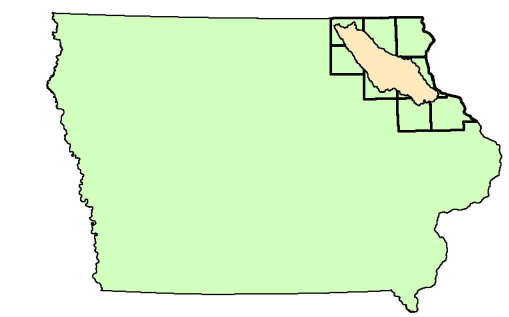
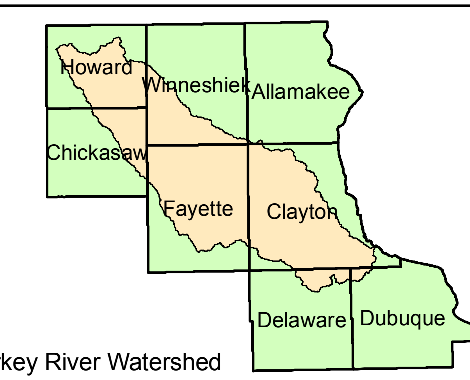


Turkey River Watershed



Turkey River Watershed

Turkey River Watershed

Hypothetical Distributed Storage with Ponds

Legend

- USGS Stage/Discharge
- Counties
- Landform Boundary
- Pond Analysis Subbasins (250)
- Subbasin (710)
- IowanSurface
- PaleozoicPlateau

Date: 3/21/2014

By: Tony Loeser

Data Sources:
Iowa Flood Center
HEC-HMS Model

Figure A-17

Appendix B – Incorporated Structures

Table B.1. Volga Lake Stage-Storage-Discharge Table

Elevation [1] (ft)	*Stage (ft)*	*Storage (ac-ft)*	*Discharge (cfs)*	*Notes*
998.105	0	1670	0	Normal pool level
999.105	1		121	
1000.105	2	1958	343	
1001.105	3		629	
1002.105	4		969	
1003.105	5		1,354	Emergency spillway
1004.105	6		2,060	
1005.105	7		2,846	
1006.105	8		3,845	
1007.105	9		5,020	
1008.105	10		6,330	
1009.105	11		7,780	
1010.105	12	3808	9,345	Top of dam

[1] Elevation given in design documentation converted from NGVD 29 to NAVD 88 using VERTCON.

Initial conditions assumed at normal pool level, initial storage in reservoir set to 1670 ac-ft.

Table B.2. Lake Meyer Stage-Storage-Discharge Table

Elevation[1] (ft)	*Stage (ft)*	*Storage (ac-ft)*	*Discharge (cfs)*	*Notes*
1107.05		0	75	Continuous discharge through pipe
1138.05	0	564	79	Normal pool level
1140.05	2	642.7	80	
1142.05	4		81	Emergency spillway
1143.05	5		140	
1144.05	6		290	
1145.05	7		510	
1146.05	8		790	
1147.05	9		1110	
1148.05	10	1029.5	1500	Top of dam, storage interpolated
1150.05	12	1126.2		No discharge provided beyond top of dam, but storage was

[1] Elevation given in design documentation converted from NGVD 29 to NAVD 88 using VERTCON.

Initial conditions assumed at normal pool level, initial storage in reservoir set to 564 ac-ft.

Table B.3. Typical Pond Stage-Storage-Discharge Table

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	3.1	2.2	0	2.2
2	8.9	11.1	0	11.1
3	15.8	11.5	0	11.5
4	22.8	11.9	0	11.9
5 *Emergency Spillway*	30.9	12.3	0	12.3
5.5	35.2	12.5	14.0	26.5
6	40.2	12.6	40.0	52.6
6.5	44.5	12.8	80.0	92.8
7 *Top of Dam*	50.0	13.0	140.0	153.0
7.5	54.6	13.2	448.1	461.3
8	59.4	13.4	609.1	622.5
9	71.5	13.6	1099.7	1115.3

Table B.4. Multiples of Typical Pond Stage-Storage-Discharge Tables: *2 Ponds*

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	6.2	4.4	0	4.4
2	17.8	22.2	0	22.2
3	31.6	23.0	0	23.0
4	45.6	23.8	0	23.8
5 *Emergency Spillway*	61.8	24.6	0	24.6
5.5	70.4	25.0	28.0	53.0
6	80.4	25.2	80.0	105.2
6.5	89.0	25.6	160.0	185.6
7 *Top of Dam*	100.0	26.0	280.0	306.0
7.5	109.2	26.4	896.2	922.6
8	118.8	26.8	1218.2	1245.0
9	143.0	27.2	2199.4	2226.6

Table B.5. Multiples of Typical Pond Stage-Storage-Discharge Tables: *3 Ponds*

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	9.3	6.6	0	6.6
2	26.7	33.3	0	33.3
3	47.4	34.5	0	34.5
4	68.4	35.7	0	35.7
5 *Emergency Spillway*	92.7	36.9	0	36.9
5.5	105.6	37.4	42.0	79.4
6	120.6	37.8	120.0	157.8
6.5	133.5	38.4	240.0	278.4
7 *Top of Dam*	150.0	39.0	420.0	459.0
7.5	163.8	39.6	1344.3	1383.9
8	178.2	40.2	1827.3	1867.5
9	214.5	40.8	3299.1	3339.9

Table B.6. Multiples of Typical Pond Stage-Storage-Discharge Tables: *4 Ponds*

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	12.4	8.8	0	8.8
2	35.6	44.4	0	44.4
3	63.2	46.0	0	46.0
4	91.2	47.6	0	47.6
5 *Emergency Spillway*	123.6	49.2	0	49.2
5.5	140.8	49.8	56.0	105.8
6	160.8	50.4	160.0	210.4
6.5	178.0	51.2	320.0	371.2
7 *Top of Dam*	200.0	52.0	560.0	612.0
7.5	218.4	52.8	1792.4	1845.2
8	237.6	53.6	2436.4	2490.0
9	286.0	54.4	4398.8	4453.2

Table B.7. Larger Hypothetical Pond Stage-Storage-Discharge Table

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	6.1	2.2	0	2.2
2	14.9	11.1	0	11.1
3	25.2	11.5	0	11.5
4	36.4	11.9	0	11.9
5 *Emergency Spillway*	48.6	12.3	0	12.3
5.5	55.6	12.5	14.0	26.5
6	62.9	12.6	40.0	52.6
6.5	70.3	12.8	80.0	92.8
7 *Top of Dam*	77.7	13.0	140.0	153.0
7.5	85.4	13.2	448.1	461.3
8	93.1	13.4	609.1	622.5
9	101.8	13.6	1099.7	1113.3

Table B.8. Multiples of Larger Pond Stage-Storage-Discharge Tables: 2 Ponds

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	12.2	4.4	0	4.4
2	29.8	22.2	0	22.2
3	50.4	23.0	0	23.0
4	72.8	23.8	0	23.8
5 *Emergency Spillway*	97.2	24.6	0	24.6
5.5	111.2	25.0	28.0	53.0
6	125.8	25.2	80.0	105.2
6.5	140.6	25.6	160.0	185.6
7 *Top of Dam*	155.4	26.0	280.0	306.0
7.5	170.8	26.4	896.2	922.6
8	186.2	26.8	1218.2	1245.0
9	203.5	27.2	2199.4	2226.6

Table B.9. Multiples of Larger Pond Stage-Storage-Discharge Tables: 3 Ponds

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	18.3	6.6	0	6.6
2	44.7	33.3	0	33.3
3	75.6	34.5	0	34.5
4	109.2	35.7	0	35.7
5 *Emergency Spillway*	145.8	36.9	0	36.9
5.5	166.8	37.4	42.0	79.4
6	188.7	37.8	120.0	157.8
6.5	210.9	38.4	240.0	278.4
7 *Top of Dam*	233.1	39.0	420.0	459.0
7.5	256.2	39.6	1344.3	1383.9
8	279.3	40.2	1827.3	1867.5
9	305.4	40.8	3299.1	3339.9

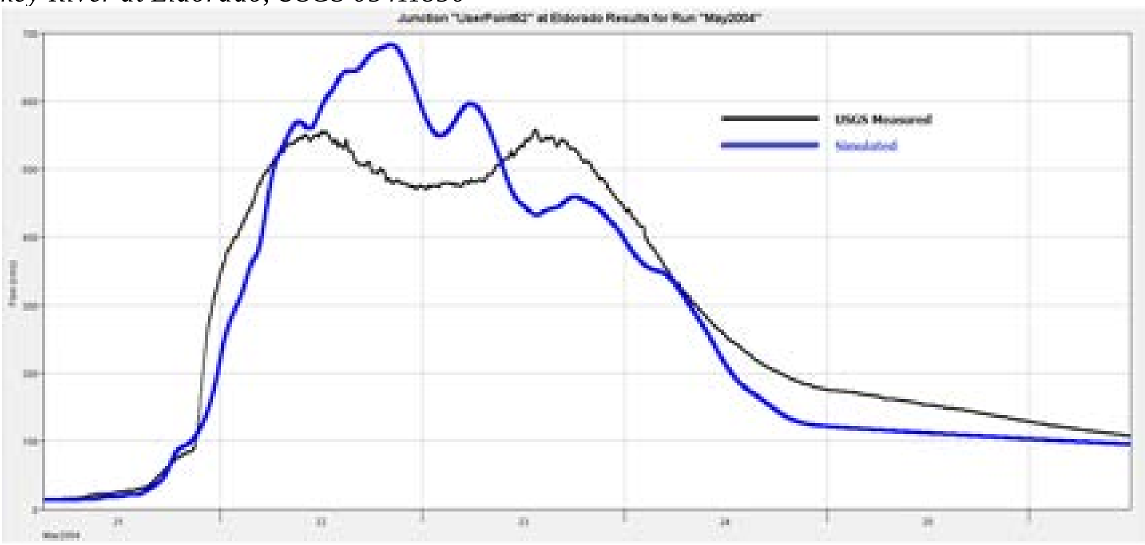
Table B.10. Multiples of Larger Pond Stage-Storage-Discharge Tables: 4 Ponds

Stage above Pipe (ft)	*Storage (ac-ft)*	*Outflow Pipe (cfs)*	*Outflow Emergency Spillway (cfs)*	*Total Outflow (cfs)*
0	0	0	0	0
1	24.4	8.8	0	8.8
2	59.6	44.4	0	44.4
3	100.8	46.0	0	46.0
4	145.6	47.6	0	47.6
5 *Emergency Spillway*	194.4	49.2	0	49.2
5.5	55.6	49.8	56.0	105.8
6	251.6	50.4	160.0	210.4
6.5	70.3	51.2	320.0	371.2
7 Top of Dam	310.8	52.0	560.0	612.0
7.5	85.4	52.8	1792.4	1845.2
8	372.4	53.6	2436.4	2490.0
9	407.2	54.4	4398.8	4453.2

Appendix C – Calibration and Validation Hydrographs

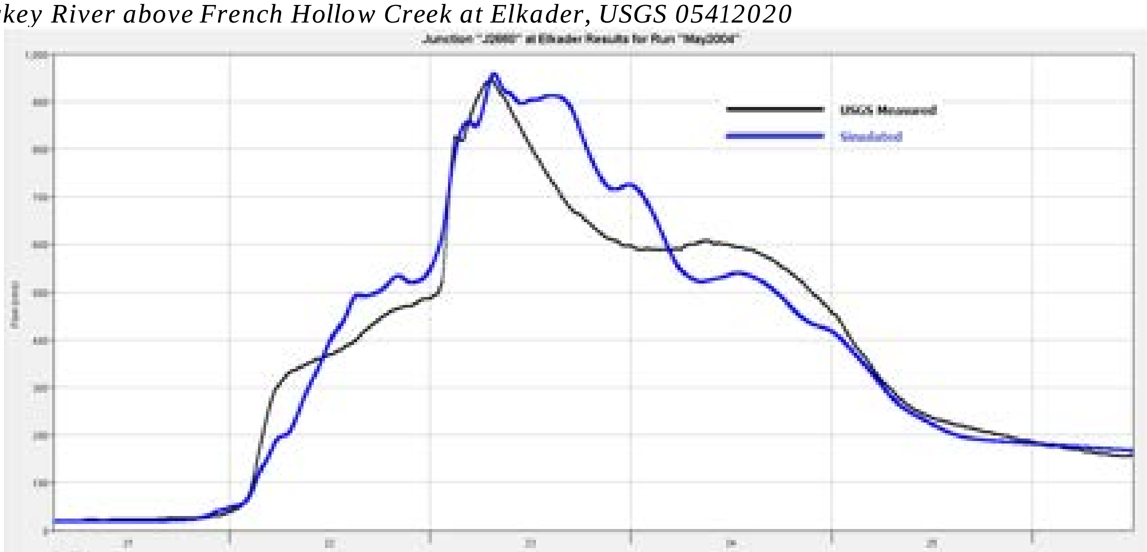
Figure C.1. Calibration Storm Event - May 21-26, 2004

Turkey River at Eldorado, USGS 05411850



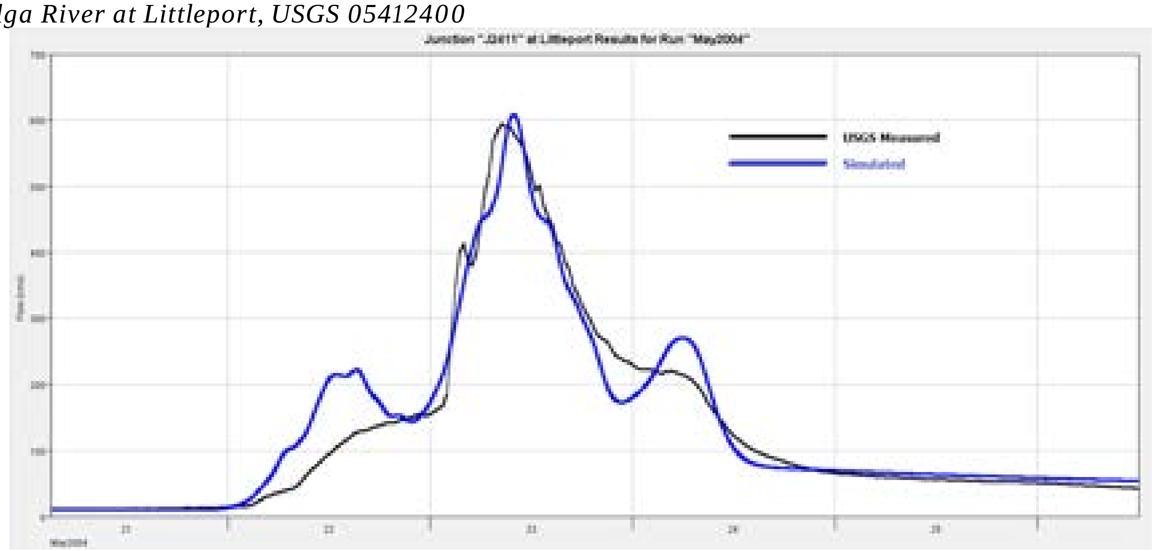
	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	682.9	22 May 2004, 2018	76.8
Observed	557.9	23 May 2004, 1330	80.0

Turkey River above French Hollow Creek at Elkader, USGS 05412020



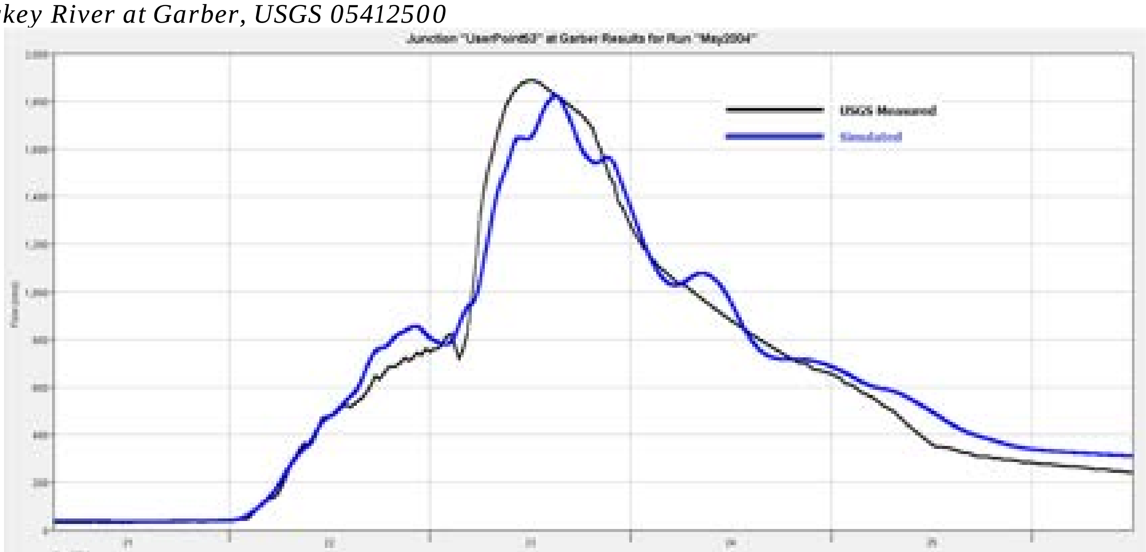
	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	943.1	23 May 2004, 0700	74.3
Observed	958.6	23 May 2004, 0738	75.9

Volga River at Littleport, USGS 05412400



	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	608.4	23 May 2004, 0954	67.8
Observed	594.7	23 May 2004, 0830	64.6

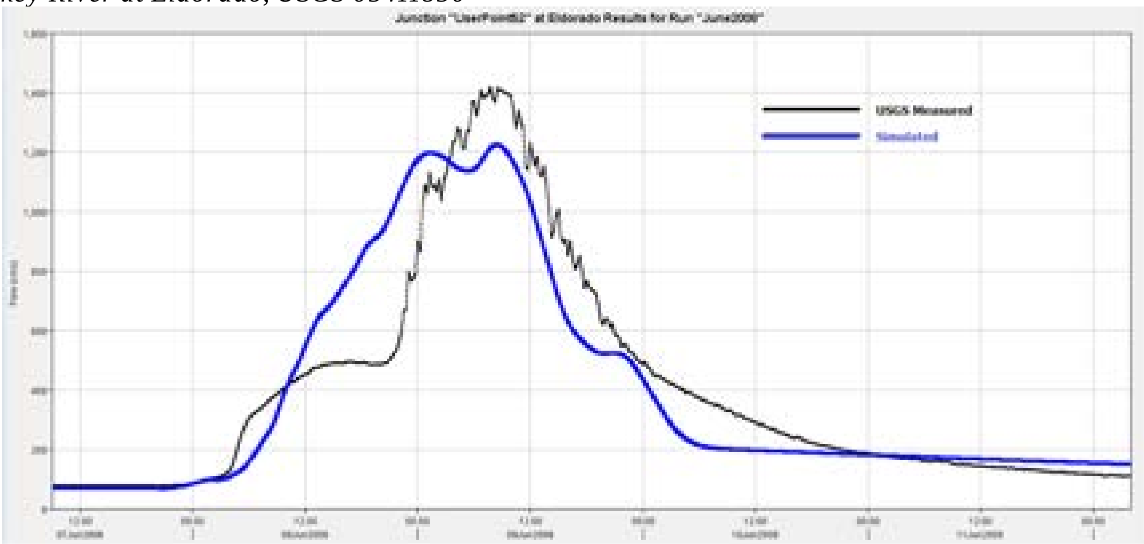
Turkey River at Garber, USGS 05412500



	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	1823.4	23 May 2004, 1502	74.6
Observed	1889.0	23 May 2004, 1200	72.5

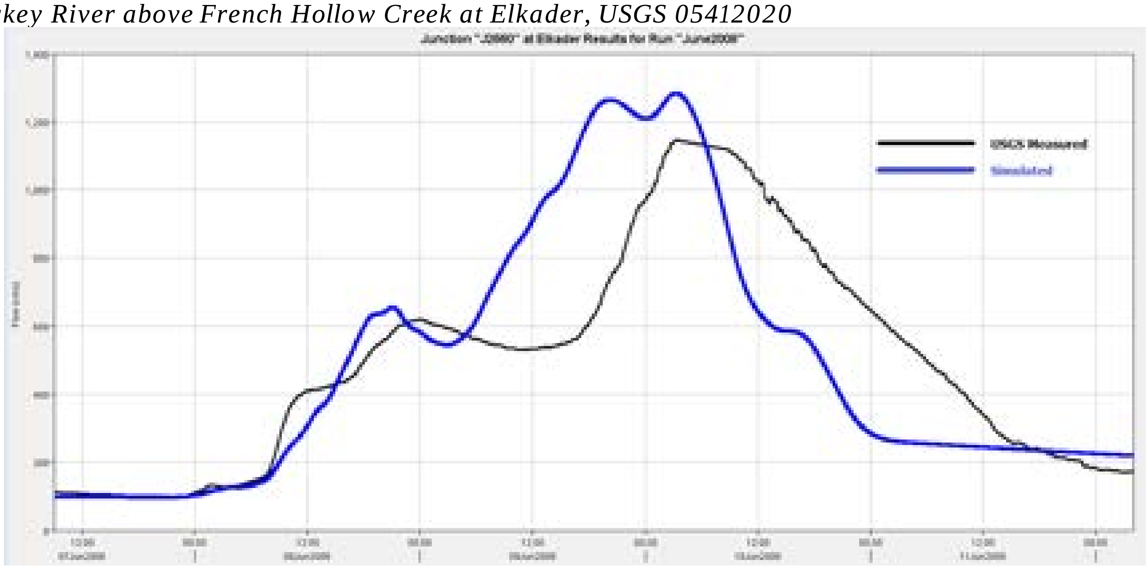
Figure C.2. Validation Storm Events - June 7-11, 2008

Turkey River at Eldorado, USGS 05411850



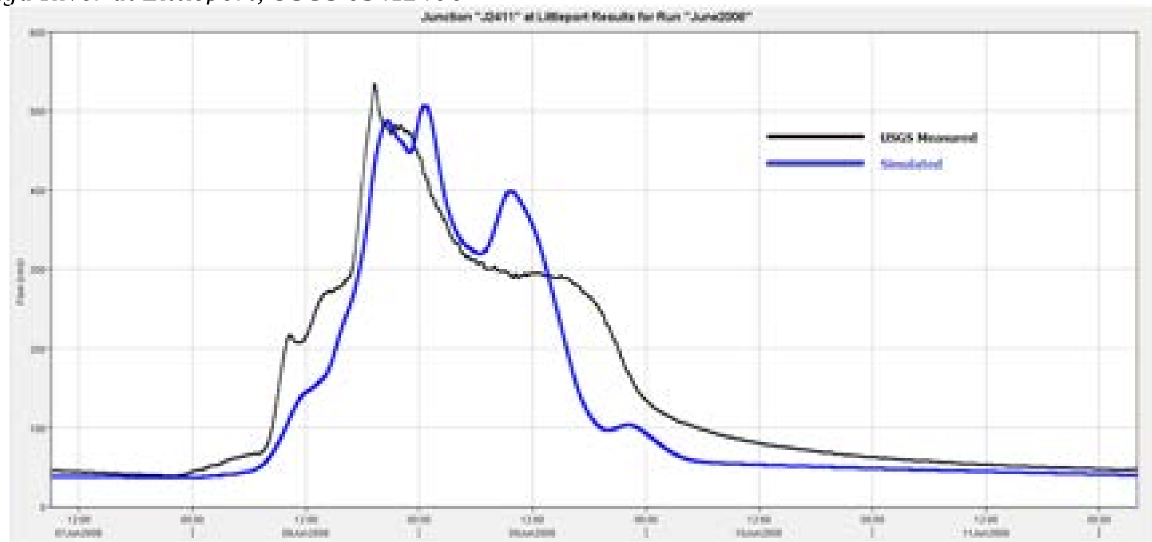
	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	1223.9	9 June 2008, 0826	98.1
Observed	1417.0	9 June 2008, 0744	100.2

Turkey River above French Hollow Creek at Elkader, USGS 05412020



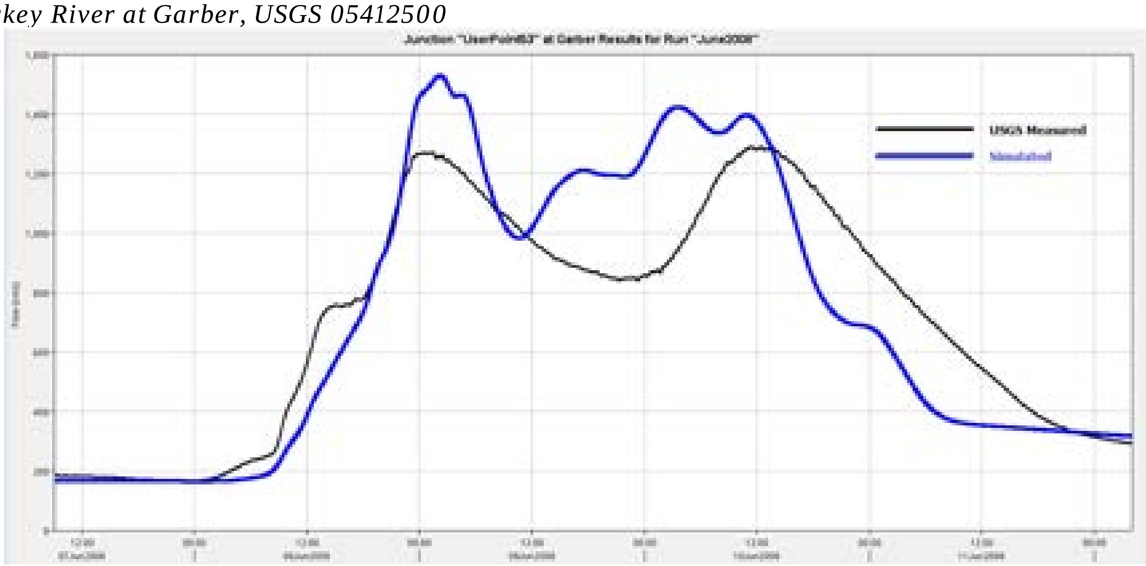
	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	1284.4	10 June 2008, 0316	87.0
Observed	1146.8	10 June 2008, 0316	87.8

Volga River at Littleport, USGS 05412400



	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	506.8	9 June 2008, 0038	55.1
Observed	534.4	8 June 2008, 1916	64.1

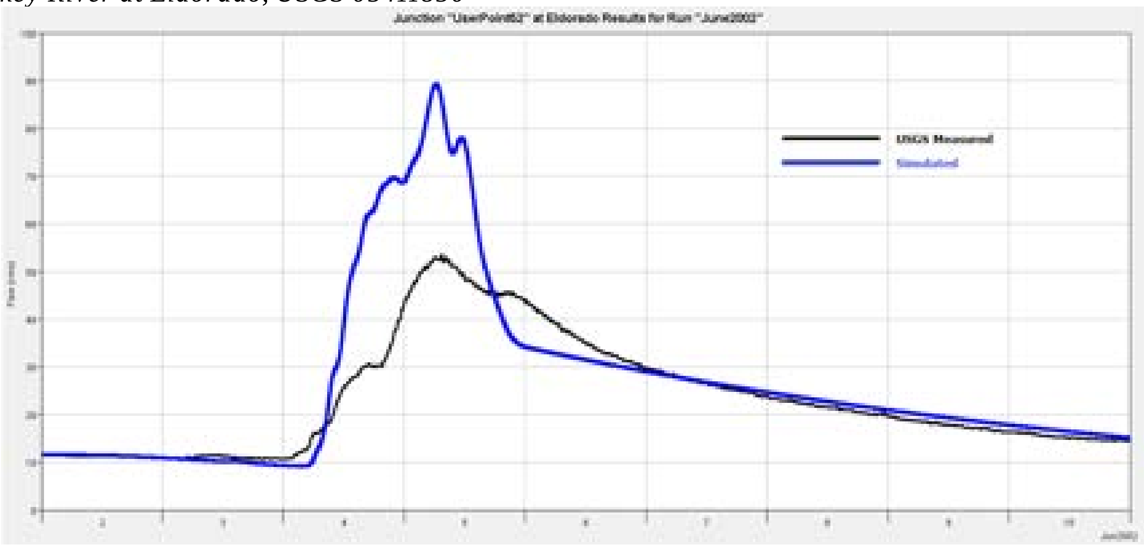
Turkey River at Garber, USGS 05412500



	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	1528.0	9 June 2008, 0212	73.9
Observed	1288.4	10 June 2008, 1130	73.3

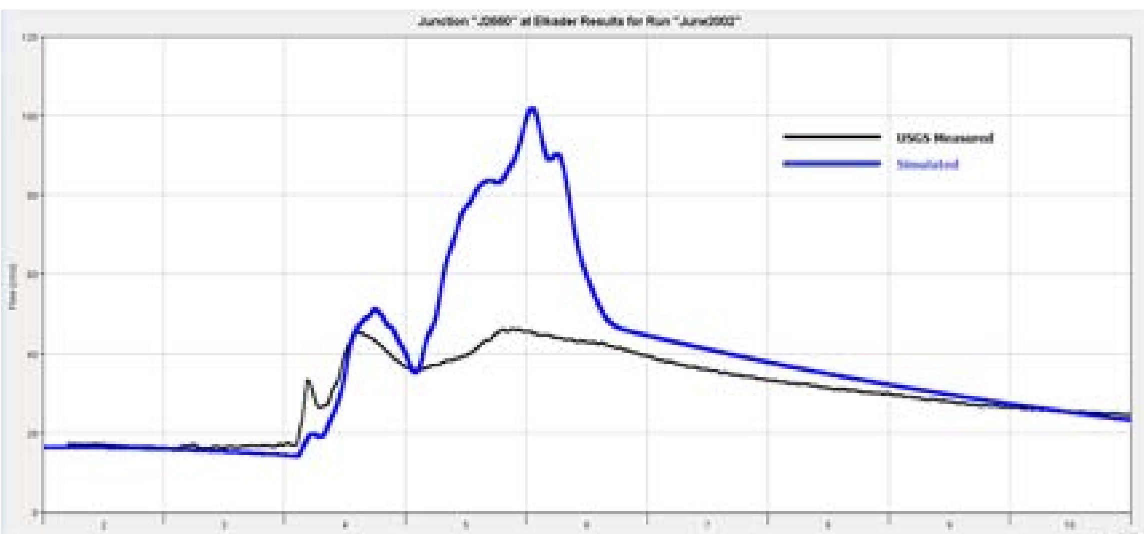
Figure C.3. Validation Storm Events - June 2-10, 2002

Turkey River at Eldorado, USGS 05411850



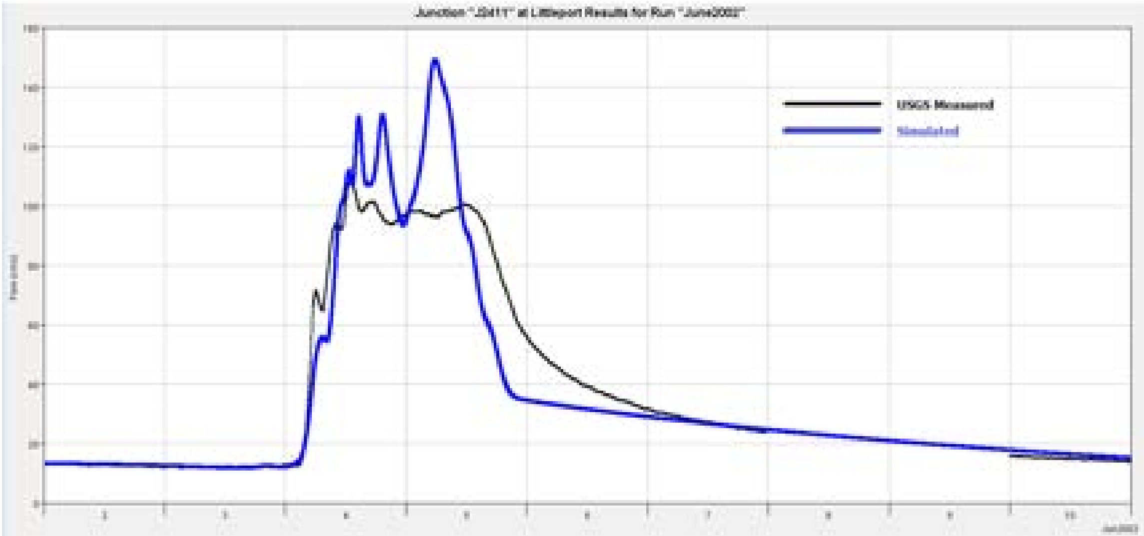
	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	89.3	5 June 2002, 0630	12.5
Observed	53.5	5 June 2002, 0730	10.8

Turkey River above French Hollow Creek at Elkader, USGS 05412020



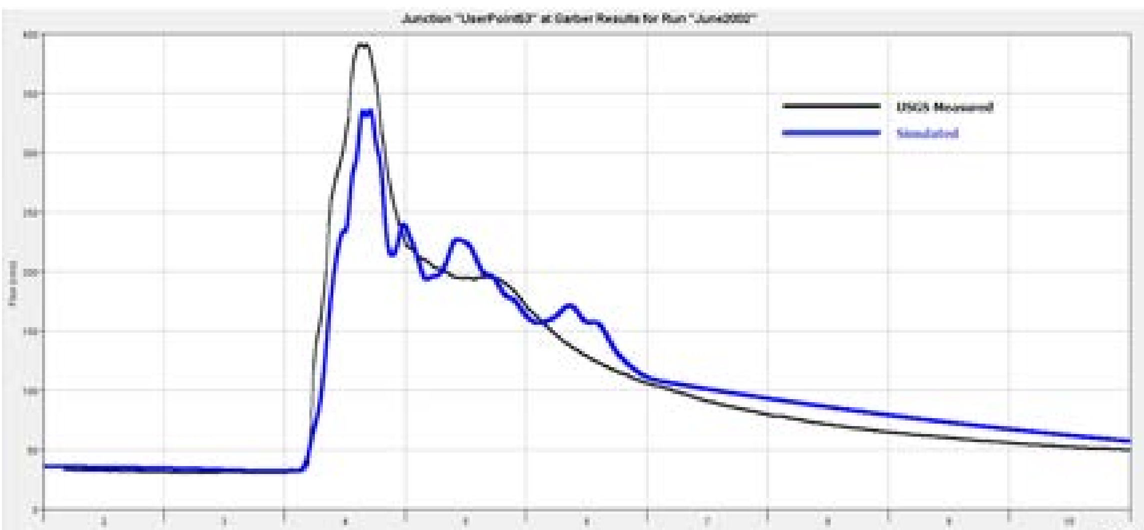
	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	101.9	6 June 2002, 0108	12.2
Observed	46.2	5 June 2002, 1930	9.9

Volga River at Littleport, USGS 05412400



	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	149.1	5 June 2002, 0542	28.3
Observed	107.9	4 June 2002, 1300	24.8

Turkey River at Garber, USGS 05412500



	Peak Discharge (cms)	*Time of Peak*	*Total Volume (mm)*
Simulated	335.3	4 June 2002, 1702	19.9
Observed	390.8	4 June 2002, 1446	19.2

Appendix D – References

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