IIHR Report
No. 501

September, 2016

Iowa Watersheds Project
Phase II Report

South Chequest Creek Watershed

Project Evaluation

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

Sponsored by:
Chequest Creek Advisory Committee

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

Iowa Watersheds Project Phase II: South Chequest Creek Watershed Evaluation of Project Performance

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Acknowledgements

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

Chequest Creek Advisory Committee
Davis County Soil and Water Conservation District
Iowa Department of Natural Resources
Natural Resources Conservation Service (NRCS)
Soap Creek Watershed Board

Cover photograph. Flood Mitigation Structure, Davis County. Photograph by Iowa Flood Center.

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1. Introduction

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

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

In Phase I of the project, the Iowa Flood Center conducted a hydrologic assessment of the Chequest Creek Watershed (IFC, 2014). The assessment characterized the water cycle of Chequest Creek using historical observations on the adjacent Fox River, as well as investigated trends observed for Chequest Creek within the broader context of historic changes in land use and weather patterns. Researchers developed a hydrologic model of Chequest Creek using the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) to identify areas in the watershed with high runoff potential. They also ran simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed. For scenario development, researchers focused on understanding the impacts of: (1) increasing infiltration in the watershed; and (2) implementing a system of distributed storage projects (ponds) across the landscape.

Researchers are adding modeling results and scenario simulations from the Phase I hydrologic assessments to the Iowa Watershed Decision Support System (IoWaDSS) as part of an IFC project funded by the U.S. Army Corps of Engineers Institute for Water Resources. The system aims to assemble data, tools, and models in one place to: (1) inform watershed stakeholders of the current status and forecasts in Iowa watersheds; (2) support the assessment of alternative strategies for sustainable watershed resources; (3) provide real-time, integrated data, and simulation models from multiple disciplines; and (4) facilitate collaboration and the sharing of resources and model results across agencies and communities. A video tutorial of the IoWaDSS is available at https://www.youtube.com/watch?v=-yIikldRrXA. Modeling results for the Soap Creek and Turkey River watersheds are now available online (http://iowawatersheds.org/dev/dss_alpha/). Results for the Upper Cedar River Watershed may be added to the IoWaDSS in the future.

In Phase II of the project, researchers identified a smaller catchment (known as a HUC12 subwatershed) for development and construction of flood mitigation projects. In collaboration with the Chequest Creek Advisory Committee, researchers selected the South Chequest Creek Watershed (Figure 1.1), where IFC researchers had evaluated the flood mitigation performance of proposed projects through monitoring and detailed hydrologic modeling. The team developed small-scale hydrologic simulations for the South Chequest Creek Watershed using more highly detailed representations of the watershed and flood mitigation strategies than those that were used in Phase I. This report describes the assessment results for Phase II of the South Chequest Creek Watershed Project.

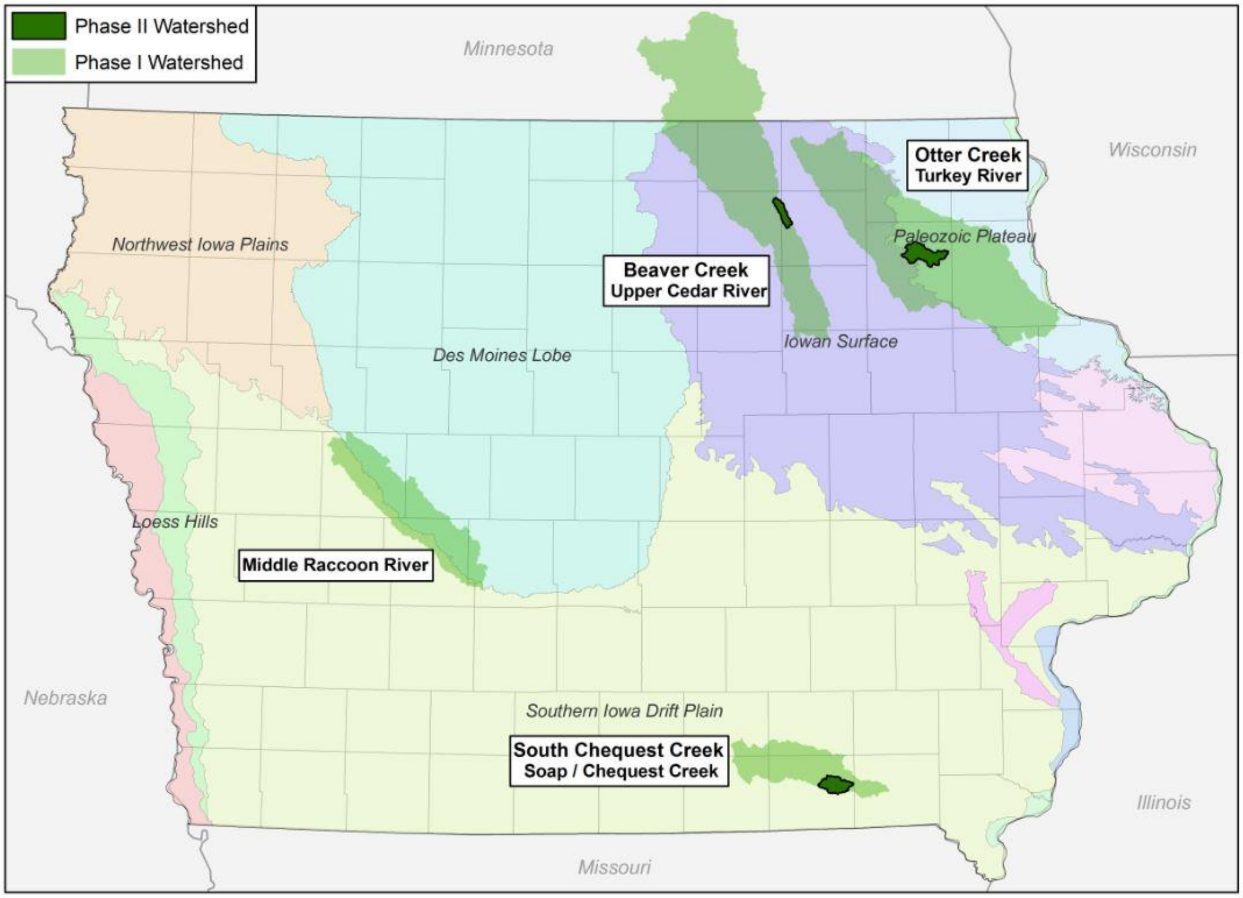


Figure 1.1. Iowa Watersheds Project, Phase I and Phase II selected watersheds.

2. Conditions in the South Chequest Creek Watershed

This chapter provides an overview of current South Chequest Creek Watershed conditions, including hydrology, geology and soils, topography, and land use.

a. Hydrology

The South Chequest Creek Watershed in Southeast Iowa has a drainage area of approximately 31.2 square miles (mi^2) and is a subwatershed of the larger Chequest Creek Watershed, as defined by the boundary of 10-digit Hydrologic Unit Code (HUC10) 0710000912. The Chequest Creek Watershed has a drainage area of approximately 124 square miles and is a subwatershed within the Lower Des Moines River Watershed identified by the eight-digit Hydrologic Unit Code (HUC8) 0710009.

The Chequest Creek HUC10 watershed can be described as narrow, only about 7.5 miles at its widest. Chequest Creek has two headwater branches (North and South) that flow west to east. Figure 2.1 highlights the location of the South Chequest HUC12 watershed within the Chequest Creek HUC10 watershed. The two branches come together in eastern Davis County and continue eastward, discharging into the Des Moines River approximately four miles upstream of Keosauqua.

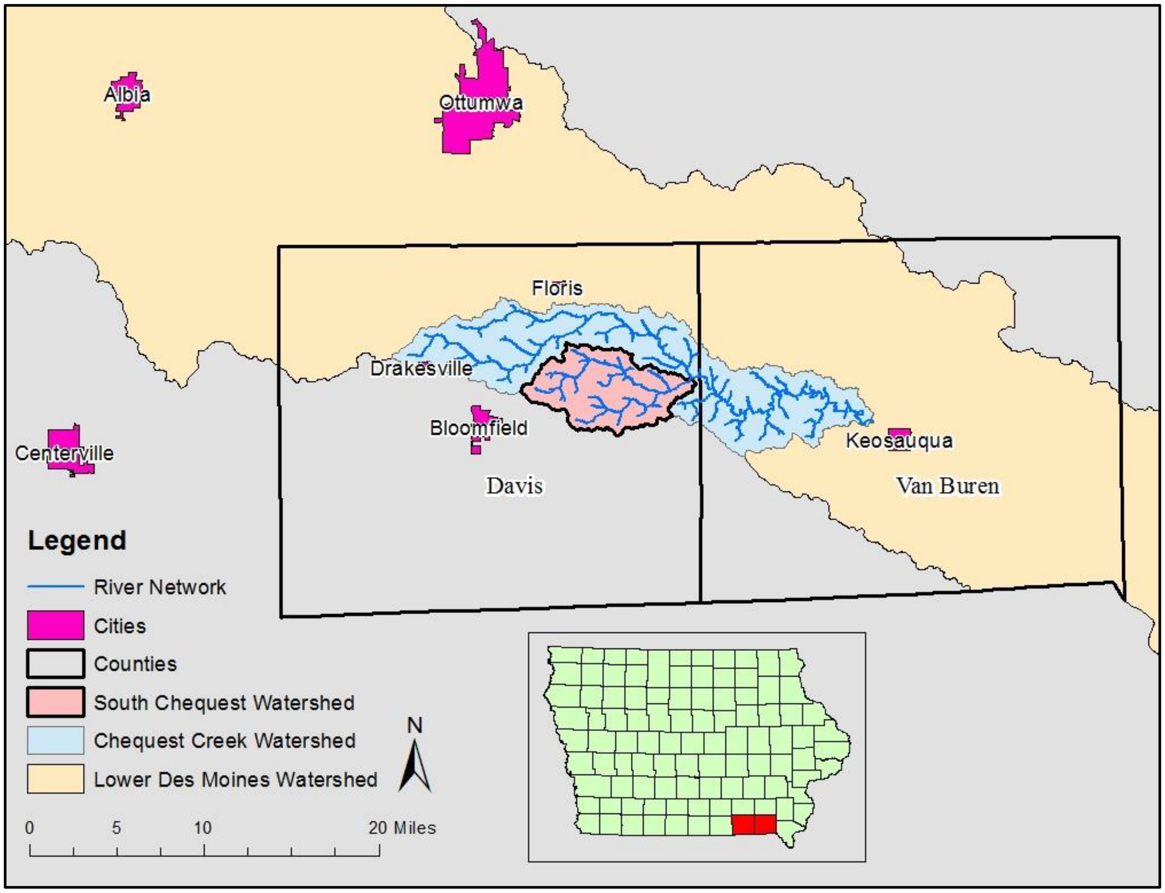


Figure 2.1. The South Chequest Creek Watershed drains 31.2 square miles.

Average annual precipitation for this region of Southeast Iowa is roughly 39 inches (PRISM Climate Group, 2016, 1981–2010 normal precipitation), with about 80% of the annual precipitation falling between April and September. During this period, thunderstorms capable of producing torrential rain are possible, with the peak frequency of intense storms occurring in June. However, South Chequest Creek is surface-flow dominated, and whenever heavy rainfall occurs during the year, large river flows can occur.

b. Geology and Soils

The entire Chequest Creek Watershed is located within the Southern Iowa Drift Plain (see Figure 2.2). Glacial deposits left by ice sheets extending south into Missouri over half a million years ago dominate this region. The deposits were carved by deepening episodes of stream erosion, and only a horizon line of hill summits mark the once-continuous glacial plain. Numerous rills, creeks, and rivers branch across the landscape, shaping the old glacial deposits into steeply rolling hills and valleys. A mantle of loess drapes the uplands and upper hill slopes (Iowa Geological & Water Survey, The Iowa Department of Natural Resources, 2013).

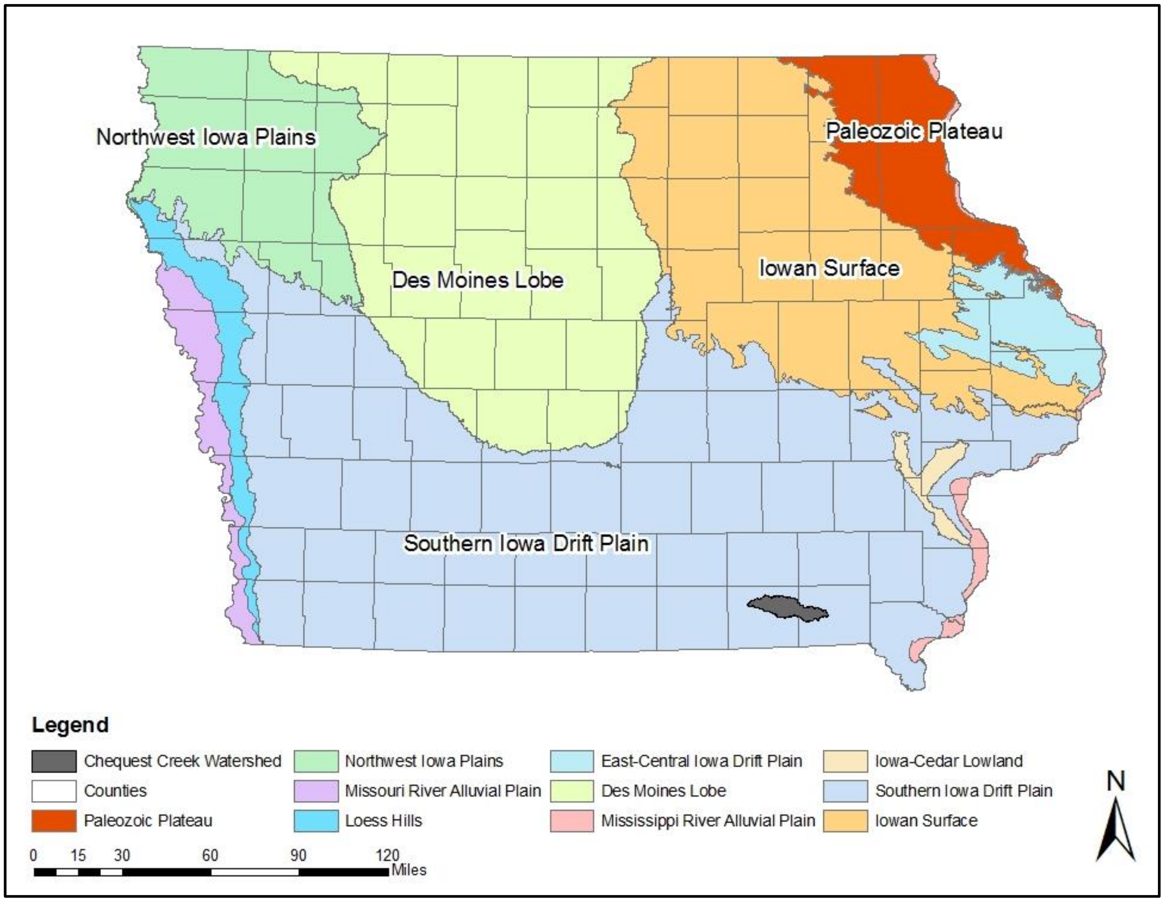


Figure 2.2. Landform Regions of Iowa. Chequest Creek Watershed shown in Southeast Iowa.

The Natural Resources Conservation Service (NRCS) classifies soils into four Hydrologic Soil Groups (HSG) based on the soil's runoff potential. The four HSGs are A, B, C, and D, where A-type soils have the lowest runoff potential and D-type have the highest. In addition, there are dual code soil classes – A/D, B/D, and C/D – assigned to certain wet soils. In the case of these soil groups, even though the soil properties may be favorable to allow infiltration (water passing from the surface into the ground), a shallow groundwater table (within 24 inches of the surface) typically prevents much water from doing so. For example, a B/D soil will have the runoff potential of a B-type soil if the shallow water table were to be drained away, but the higher runoff potential of a D-type soil if it is not. Complete descriptions of the Hydrologic Soil Groups can be found in *USDA-NRCS National Engineering Handbook*, Part 630 – Hydrology, Chapter 7 (Natural Resource Conservation Service, 2004a).

The Southern Iowa Drift Plain in Southeast Iowa consists of Grundy, Haig, and Arispe soils on the headland ridges, with slopes generally 9% or less. These soils typically contain 42–48% clay in the subsoil. Many of the side slopes that are steeper than 9% developed in glacial till. These soils classify as primarily HSG C and D type soils, resulting in areas that range from moderate to high runoff potential. Figure 2.3 shows the soil distribution of the South Chequest Creek Watershed per digital soils data (SSURGO) available from the USDA-NRCS Web Soil Survey (WSS).

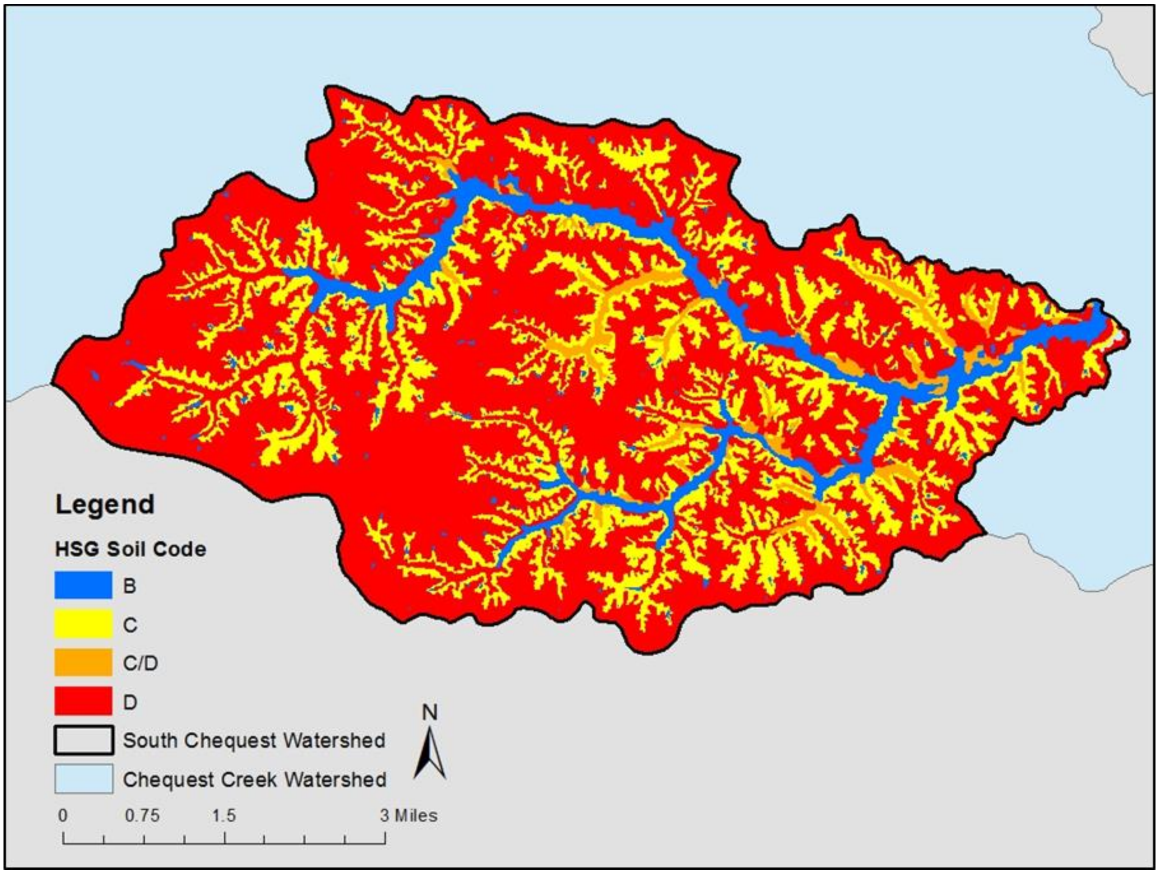


Figure 2.3. Distribution of Hydrologic Soil Groups in the South Chequest Creek Watershed. Hydrologic Soil Groups reflect the degree of runoff potential a particular soil has, with A-type representing the lowest runoff potential and D-type representing the highest runoff potential.

The map illustrates the dominance of D-type soils in the headland areas and exposed C-type soils in the eroded rills of the watershed. This distribution of soils is the primary reason South Chequest

Creek is surface-flow dominated, as the infiltration rates and capacities of these soils are quite low. Table 2.1 shows the approximate percentages by area of each soil type for the Southern Iowa Drift Plain in the South Chequest Creek Watershed. Figure 2.4 shows the soil texture classification of the soils found within the watershed.

Table 2.1. Approximate Hydrologic Soil Group percentages by area of the South Chequest Creek Watershed.

Hydrologic Soil Group	***Runoff Potential***	***Percent of Watershed Area***
A	Low	0%
A/D		0%
B	Moderately Low	6.8%
B/D		0%
C	Moderately High	23.4%
C/D		3.1%
D	High	66.7%

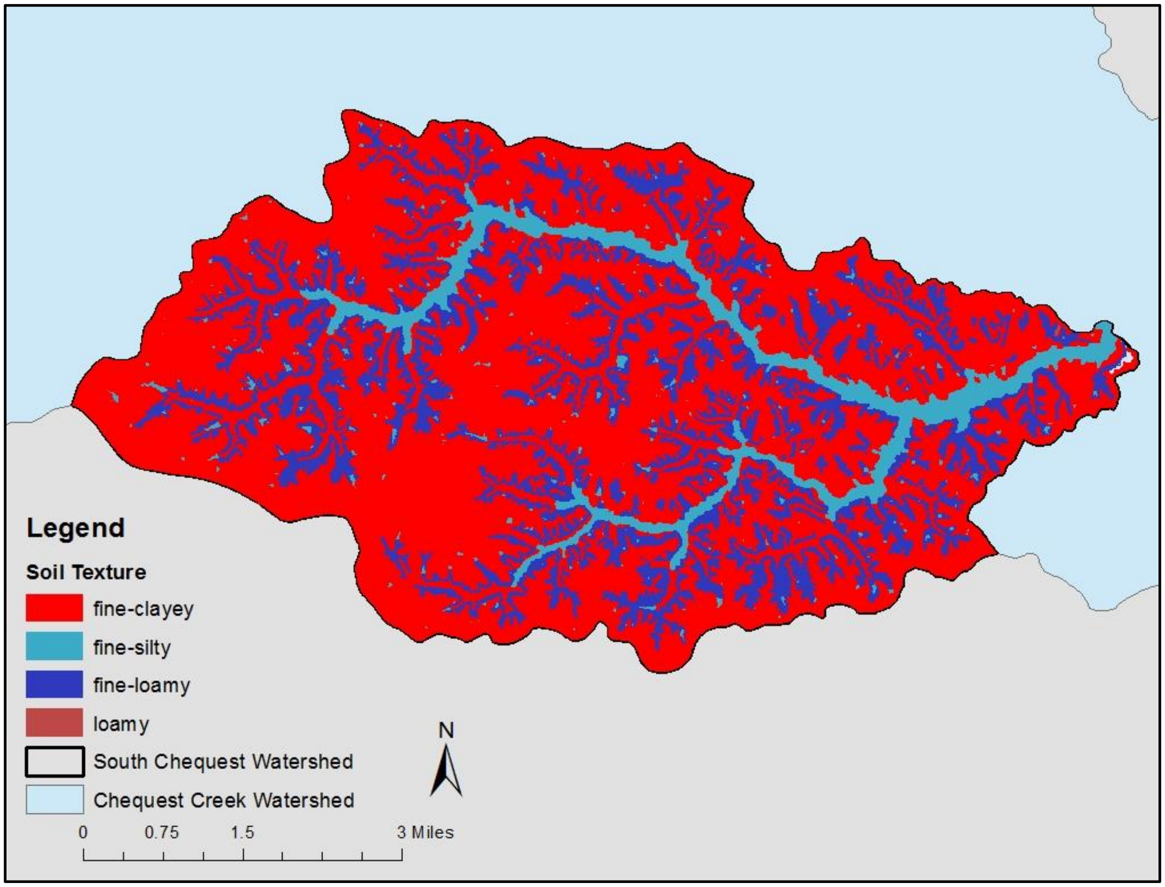


Figure 2.4. Soil texture within the South Chequest Creek Watershed.

c. Topography

The topography (Figure 2.5) of the South Chequest Creek Watershed reflects its geologic past. Elevations range from approximately 858 feet above sea level in the uppermost part of the watershed to 675 feet at the outlet. The terrain, along with the underlying soils, make the area well suited for water impoundments, and many ponds have been successfully constructed across the landscape.

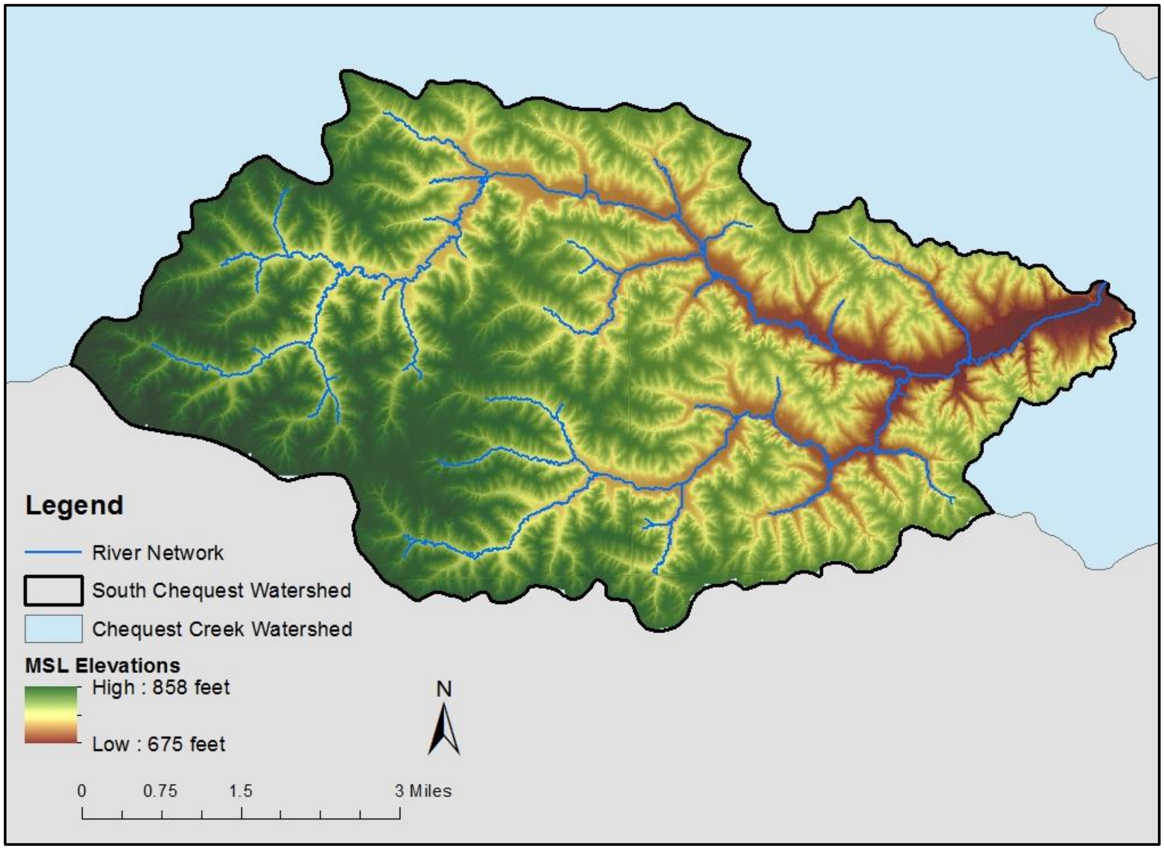


Figure 2.5. Topography of the South Chequest Creek Watershed.

Figure 2.6 depicts the land surface slope in the South Chequest Creek Watershed. As previously mentioned, the headland ridge areas generally have slopes of 9% or less, whereas steeper slopes are evident in the eroded rills.

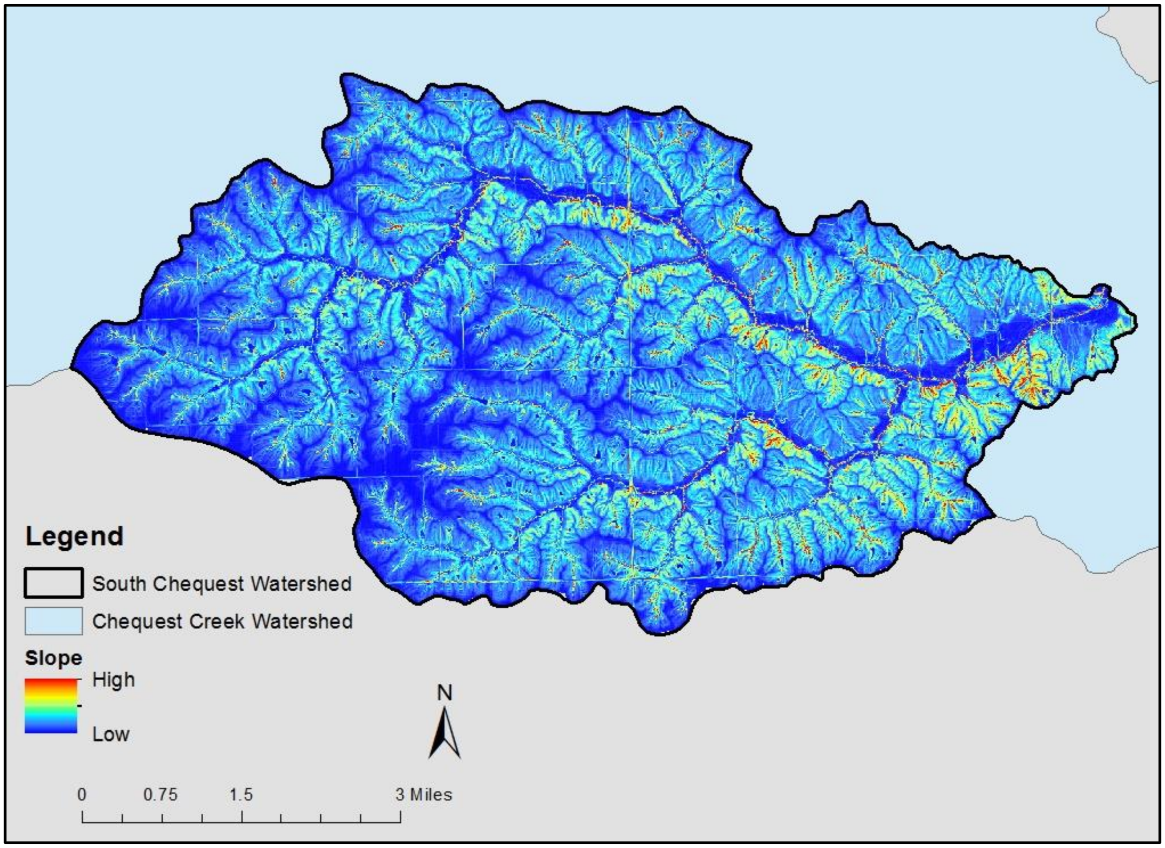


Figure 2.6. Land surface slopes within the South Chequest Creek Watershed.

d. Land Use

Land use in the South Chequest Creek Watershed is heavily agricultural. However, unlike much of the rest of the state of Iowa where row crop production is the predominant agricultural land use, approximately 52% of the watershed acreage is in grass/hay/pasture, and row crop production is only approximately 18%. The watershed consists of about 26% forested lands; the remaining acreage consists of 3% developed land and 1% open water and/or wetlands, per the 2009 High Resolution Land Cover Data (HRLC) Set. In excess of 90% of the land in the watershed is privately owned.

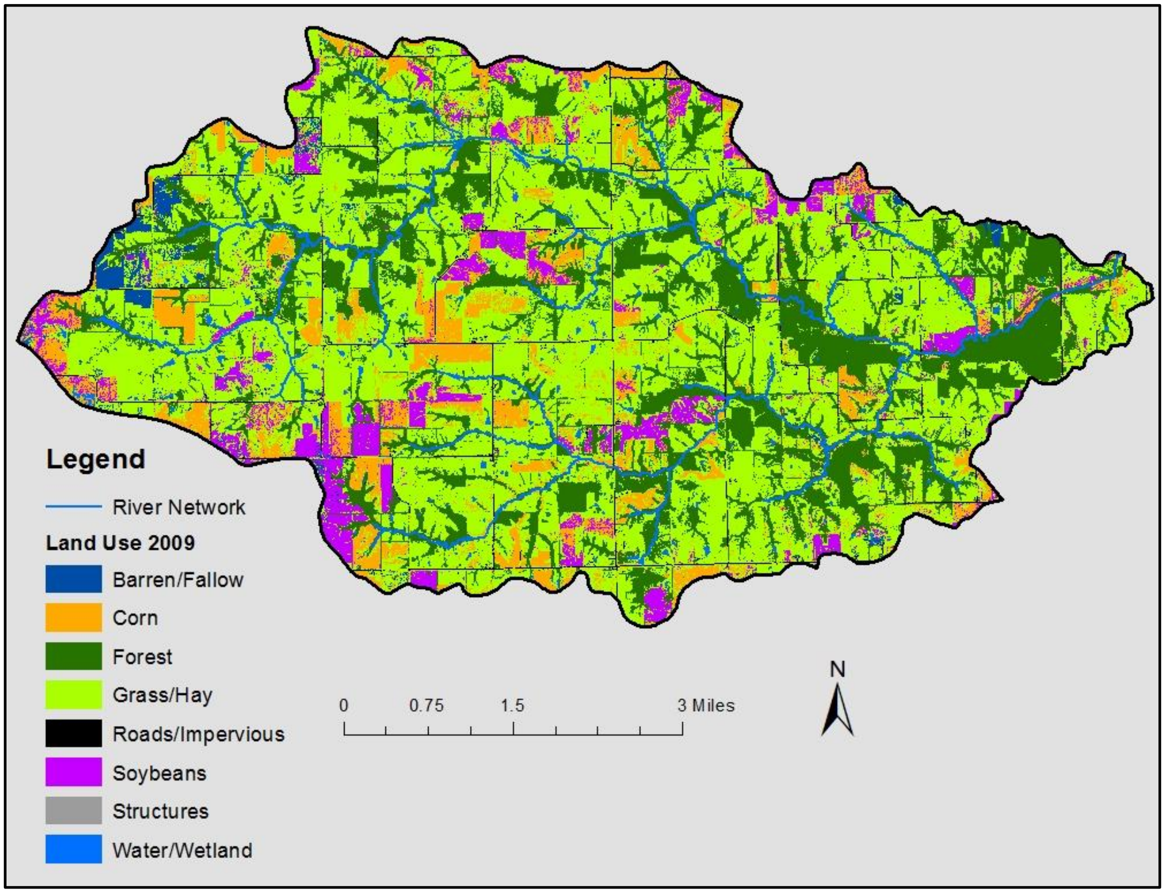


Figure 2.7. Land use composition in the South Chequest Creek Watershed per the 2009 HRLC.

3. Data Collection

The Chequest Creek Watershed has historically had a limited data collection network. As part of Phase II work on the Iowa Watersheds Project, the Iowa Flood Center and IIHR—Hydroscience & Engineering installed instruments within the South Chequest Creek Watershed to monitor hydrologic variables and water quality. This chapter describes the Phase II data collection effort in the South Chequest Creek Watershed.

a. Water and Water-quality Measurement Locations

Beginning in the spring of 2014, researchers installed sensors in the South Chequest Creek Watershed. The Iowa Flood Center (IFC) deployed sensors to monitor several hydrologic variables, such as stream stage and rainfall/soil moisture; IIHR—Hydroscience & Engineering (IIHR) led the water-quality monitoring effort. The instrumentation includes three rain gauge and soil moisture (RGSM) platforms, one stream-stage sensor, and one water-quality sensor. Figure 3.1 shows the sensor sites; Table 3.1 shows the sensor station names and periods of record.

Rain Gauge and Soil Moisture Platforms

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

Stream-stage Sensor

The stream-stage sensor is mounted on the bridge crossing South Chequest Creek at Yak Boulevard. The sensor acoustically measures the distance to the water surface. Researchers surveyed the elevation of the face of the sensor, allowing the IFC to calculate the water surface elevation (WSE) from each distance observation. A measurement of the bed elevation at the time of installation enables the estimation of water depth; however, observations have revealed periodic episodes of scour and aggradation of sand and pebble bed material at this site. Thus, the depth based on WSEs is not consistent across the period of record.

Water-quality Sensor

The IIHR water-quality station is currently collocated with the stream-stage sensor (see Figure 3.1). The sensor platform consists of a Hach Nitratax SC Nitrate Sensor, an FTS DTS-12 Turbidity Sensor, and an Ott-Hydromet Hydrolab DS5X Sonde. Researchers configured the Hydrolab multiprobe sensors to measure water temperature, specific conductance, chlorophyll a, pH, and dissolved oxygen.

Each monitoring system described above consists of an IIHR developed datalogger, battery, solar panel, GPS antenna, and a cellular modem. The system transmits the collected data to computer servers at the University of Iowa on a 15-minute schedule.

Hydrologic and water-quality data collected by the sensors presented in Figure 3.1 is publicly available on the internet. The Iowa Flood Center's Iowa Flood Information System (IFIS) online tool provides real-time information on watersheds, precipitation, and stream levels for more than 1,000 Iowa communities. Interested persons can access the data collected from the rain gauge/soil moisture platforms and the stream sensor deployed in the South Chequest Creek Watershed at http://ifis.iowafloodcenter.org/ifis/app/.

IIHRs Iowa Water-Quality Information System (Iowa WQIS) online tool is built on the same user-friendly Google Maps platform as the IFIS platform developed by the IFC. The Iowa WQIS integrates data gathered by IIHR and the United States Geological Survey (USGS) and allows users to track water-quality conditions in real-time. Users can access water-quality data for South Chequest Creek from the site at http://iwqis.iowawis.org/app/.

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

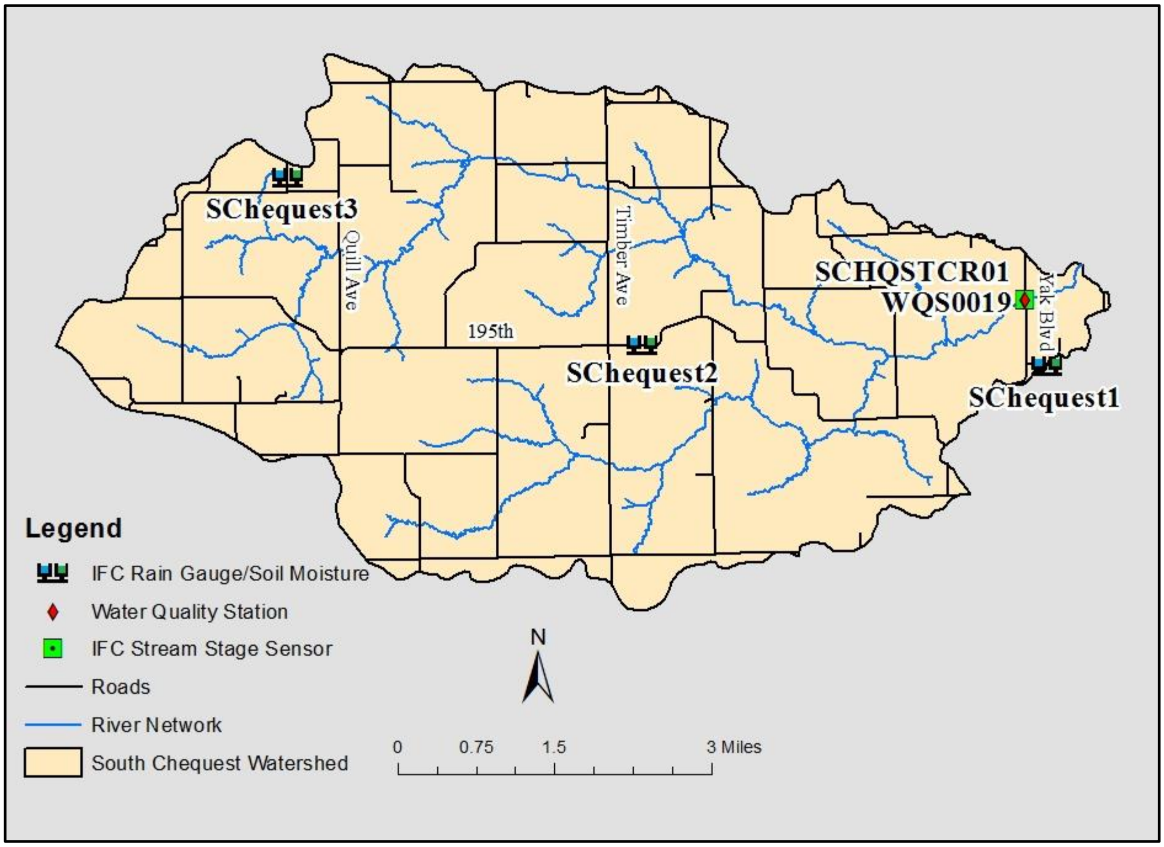


Figure 3.1. Water and water-quality monitoring stations in the South Chequest Creek Watershed.

Table 3.1. Stream-stage Sensor, Water-quality Station, and Precipitation Gauges in the South Chequest Creek Watershed.

Gauge Type	***Location***	***Period of Record***
IFC Stream Sensor (stage) SCHQSTCR01	South Chequest Creek 1, Yak Blvd, Davis County	May 2014 – present
Water-quality Station WQS0019	Co-located at South Chequest Creek 1, Yak Blvd, Davis County	April 2014 – present
IFC Rain Gauge/Soil Moisture/Soil Temperature SChequest3	Near intersection 180th St. and Quill Ave., Davis County	May 2014 – present
IFC Rain Gauge/Soil Moisture/Soil Temperature SChequest2	Near intersection 195th St. and Timber Ave., Davis County	May 2014 – present
IFC Rain Gauge/Soil Moisture/Soil Temperature SChequest1	Near intersection 198th St. and Yak Blvd., Davis County	May 2014 – present

b. Stream-stage Measurements

Since the installation of the Iowa Flood Center stream-stage and rain gauge/soil moisture sensors in spring 2014, the system has recorded continuous observations of hydrologic conditions at the stations. Figure 3.2 shows stream-stage and precipitation observations for the 2014 measurement season. The figure shows the average hourly precipitation rate (in inches per hour) for the three rain gauge platforms, and the 15-minute stream-stage observations (in feet above sea level) at SCHQSTCR01. As can be seen, the watershed responds quickly when it rains; the stream stage increases rapidly with heavy rainfall rates and then recedes shortly after the rainfall ends.

In 2014, heavy rainfall was observed in June, July, August, and September. After normal spring rains in the watershed, the ground was fairly wet. When the heavy rainfall of June 7 occurred, it produced the annual maximum stage (water surface elevation). The summer of 2014 was fairly dry; however, whenever thunderstorms occurred, the stream responded by showing some rise. Larger rain events returned in late August and again in early September. Despite the rainfall total, September's event was similar to that of June 7. With drier watershed conditions, the stream response was not as drastic.

After storm-generated runoff passes, the stage returns to lower levels, where streamflow is the result of groundwater inflow to the stream (known as baseflow). In general, baseflow levels are slightly higher in the spring when there is more soil moisture in the ground. Baseflow decreases throughout the summer and fall as soil moisture is depleted and groundwater levels drop. As previously mentioned, infiltration in the South Chequest watershed is quite low and, at times, the creek nearly becomes a dry bed. Note that baseflow measurements appear to oscillate daily; this artifact is most likely related to the acoustic sensors, which are affected by daily temperature variations, and not a real oscillation in water levels.

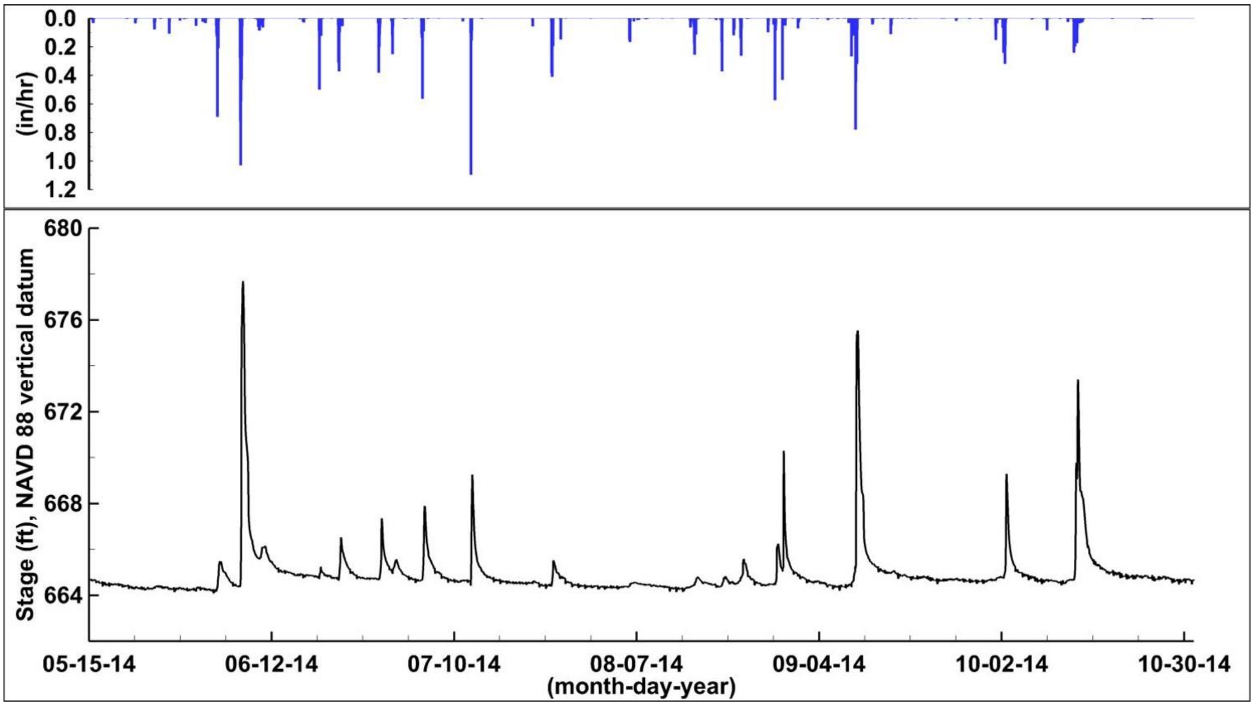


Figure 3.2. Stream-stage hydrograph and precipitation measurements for the 2014 season. The stream-stage elevation (in feet above sea level) is shown for the IFC sensor (SCHQSTCR01). Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

Figure 3.3 shows the nine-day period of June 5–14, 2014, which includes the highest stream stage that occurred in 2014. The average rainfall total from the three rain gauge platforms in the watershed was 3.7" during this event. However, the western part of the watershed saw higher rainfall totals and the eastern part logged lower totals. As can be seen in the plot, stream stage rose quickly as rainfall rates were quite high when the storm reached the watershed. As the rain ended, the stream receded and streamflow was soon again a result of groundwater flow only. The baseflow stage is observed to be higher than before the storm, suggesting that a portion of rainfall had infiltrated and recharged baseflows.

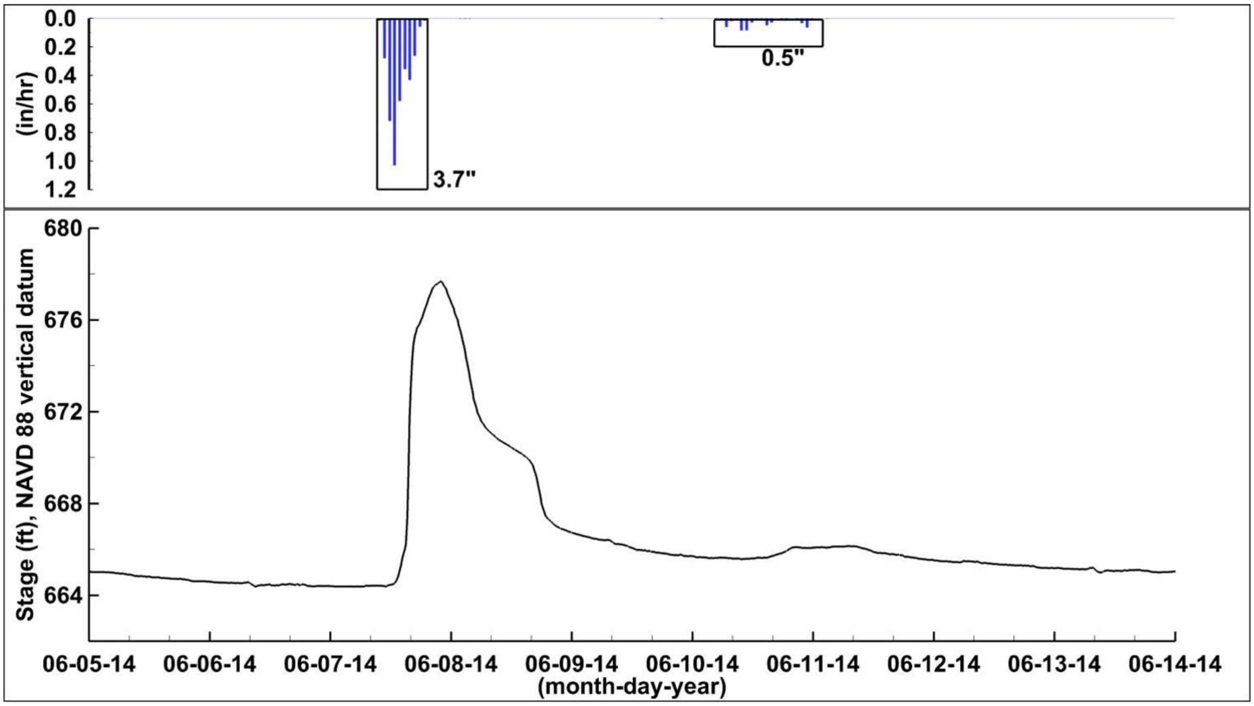


Figure 3.3. Stream-stage hydrograph and precipitation measurements for a nine-day period in June 2014. The stream-stage elevation (in feet above sea level) is shown for the IFC sensor (SCHQSTCR01). Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

c. Soil Moisture Measurements

Figure 3.4 shows soil moisture and precipitation observations for the 2014 measurement season. The figure shows the soil moisture (in percent) at 2-, 4-, 8-, and 20-inches depths. The observations plotted are the average soil moisture at these depths at the three soil moisture platforms (see Figure 3.1). The precipitation is the average hourly precipitation rate for the three rain gauge platforms. Clearly, the soil moisture reacts differently at the different depths. Near to the surface at a 2-inch depth, soil moisture content varies the most; it goes from near saturation (100%) to dry conditions (as low as 30%) many times over the season in response to rainfall. The variation at the 4-inch depth is similar, but not as extreme as at 2 inches; the variation is even less at the 8-inch depth. Down at a 20-inch depth, the soil moisture varies much more slowly and over a much narrower range.

Note that at depths from 2 to 8 inches, soil moisture increases rapidly when sufficient infiltration of rainfall occurs. Afterwards, the soil dries more quickly near the surface (2-inch depth); the drying is delayed at the 4-inch depth and even more so at the 8-inch depth. This occurs through a combination of evapotranspiration and percolation. The water nearest to the surface is most readily available for evaporation and transpiration (by plants). The water that does not evaporate percolates downward through the soils. The soils in the South Chequest watershed have low infiltration rates, keeping the soil moisture at greater depths higher for longer. At the 20-inch depth, the soil moisture only increases rapidly during storms when the entire profile is near saturation. Starting in mid-July, the soil moisture at this depth slowly decreases through August, even though some rainstorms significantly increase soil moisture near the surface. Higher September and October rains (when transpiration from plants is less than during the summer) reverse this trend, and soil moisture at 20 inches slowly increases. The depletion of soil moisture at this level (and lower) in the summer growing season helps explain why baseflow (stream inflow from saturated groundwater) typically decreases through the summer months.

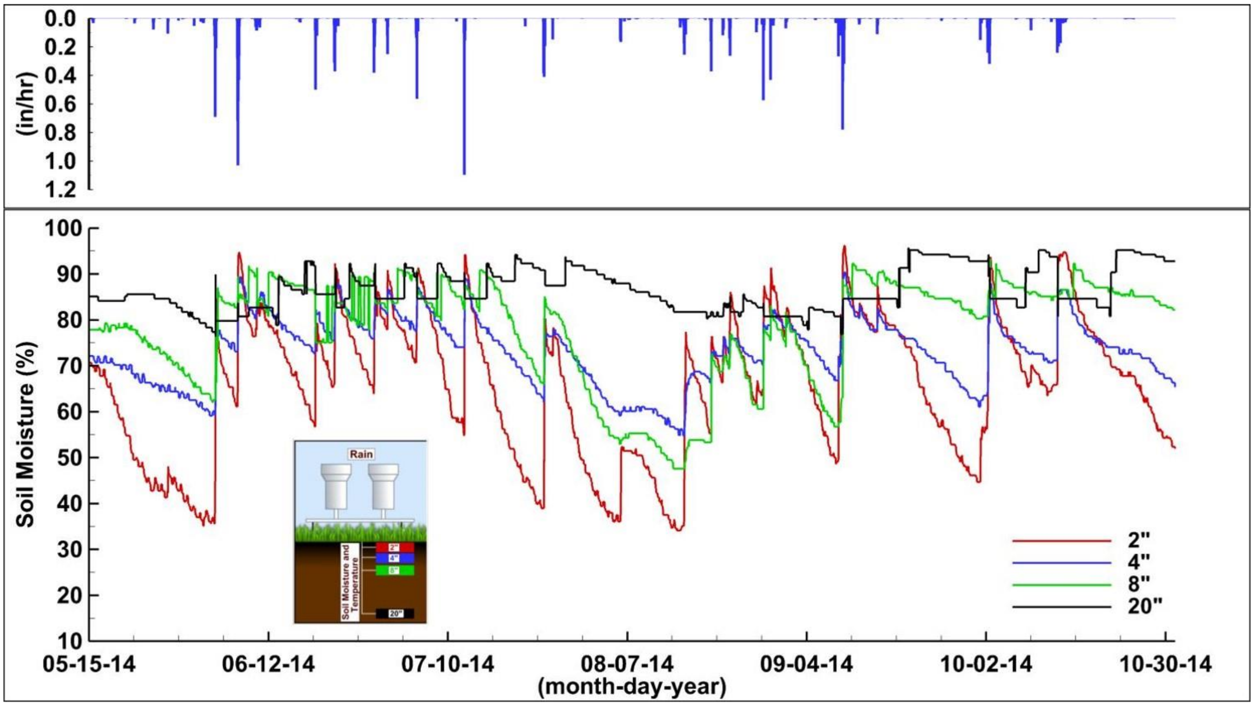


Figure 3.4. Soil moisture and precipitation measurements for the 2014 season. Soil moisture is reported at 2-, 4-, 8-, and 20-inch depths from the surface. The soil moisture values are the average from the three rain gauge/soil measurement platforms in the South Chequest Creek Watershed. Soil moisture is reported as a percentage; saturated conditions correspond to a soil moisture of 100%. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

Figure 3.5 shows a nine-day period in June 2014 (same nine-day period as shown in Figure 3.3) that includes approximately 3.7 inches of rain. Before the heavy rain period on June 7, the soils were drying at the 2- and 4-inch depths and constant at the 8- and 20-inch levels. When the heaviest rainfall occurred, the soil moisture increased rapidly at the 2-inch depth, going from about 50% to near saturation (100%). The soil moisture at the 4-inch depth increased slightly slower and by a lesser amount, nonetheless reaching 90% fairly quickly. At both the 8-inch and 20-inch depths, there was no significant increase in soil moisture. However, the soils were already quite wet. Within a few hours of the precipitation's onset, a majority of rainfall was being converted to runoff, as the soil's properties limited infiltration. Hence, when quantifying the landscape's response to rainfall (the partitioning of rainfall into infiltration and surface runoff), the soil moisture near the surface and through the entire profile is important to understand.

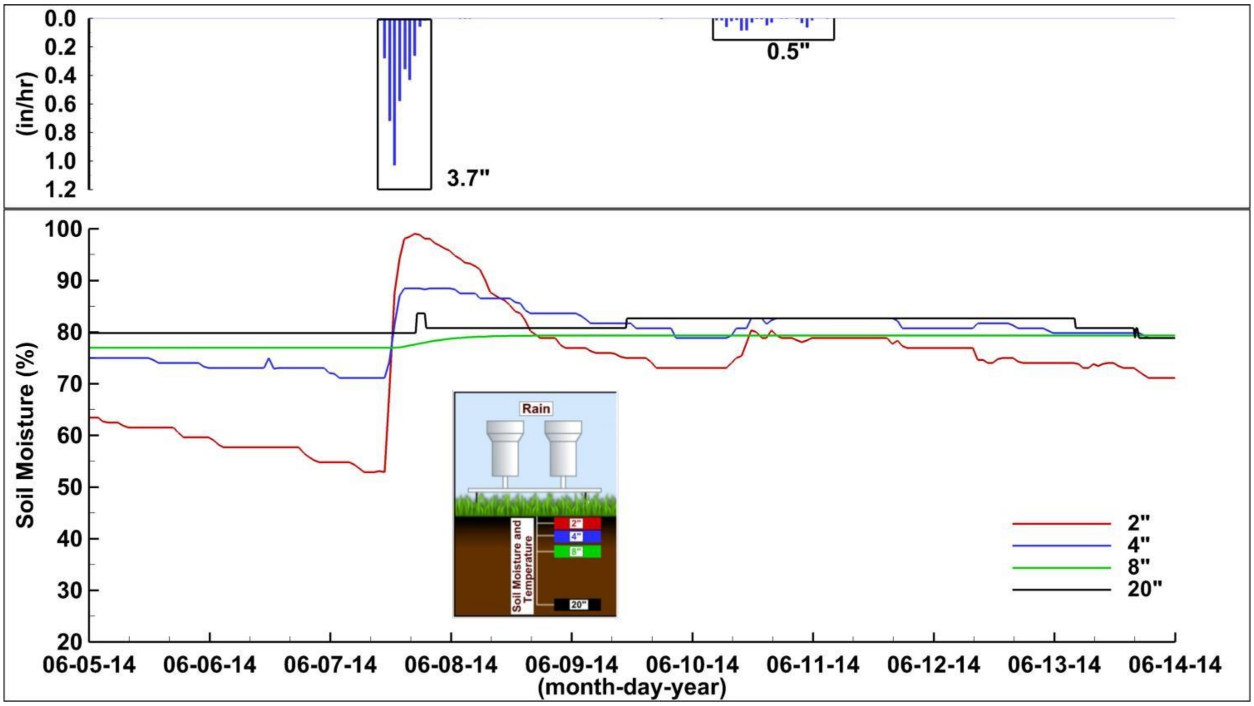


Figure 3.5. Soil moisture and precipitation measurements for the same nine-day period in June 2014 shown in Figure 3.3. Soil moisture is reported at 2-, 4-, 8-, and 20-inch depths from the surface. The soil moisture values are the average from the three rain gauge/soil measurement platforms in the South Chequest Creek Watershed. Soil moisture is reported as a percentage; saturated conditions correspond to a soil moisture of 100%. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

d. Soil Temperature Measurements

Figure 3.6 shows soil temperature and precipitation observations for the 2014 measurement season. The figure shows the soil temperature (in °F) at 2-, 4-, 8-, and 20-inches depths; the observations are the average temperature at these depths at the three soil moisture platforms (see Figure 3.1). The precipitation is the average hourly precipitation rate for the three rain gauge platforms. The variations in temperature are what one would expect; the largest diurnal range in temperature occurs nearest to the surface (at the 2-inch depth), where the ground heats during the day and cools rapidly at night. A smaller diurnal range is seen at lower depths. At the lowest depth (20-inch), daily fluctuations are very minor. Overall, the soil warms from April to mid-September and from mid-September to November, the soil cools. Note that the temperature at the lowest depth (20-inch) often lags behind the other stations, both during the warm-up in spring and summer and the cool-down in fall.

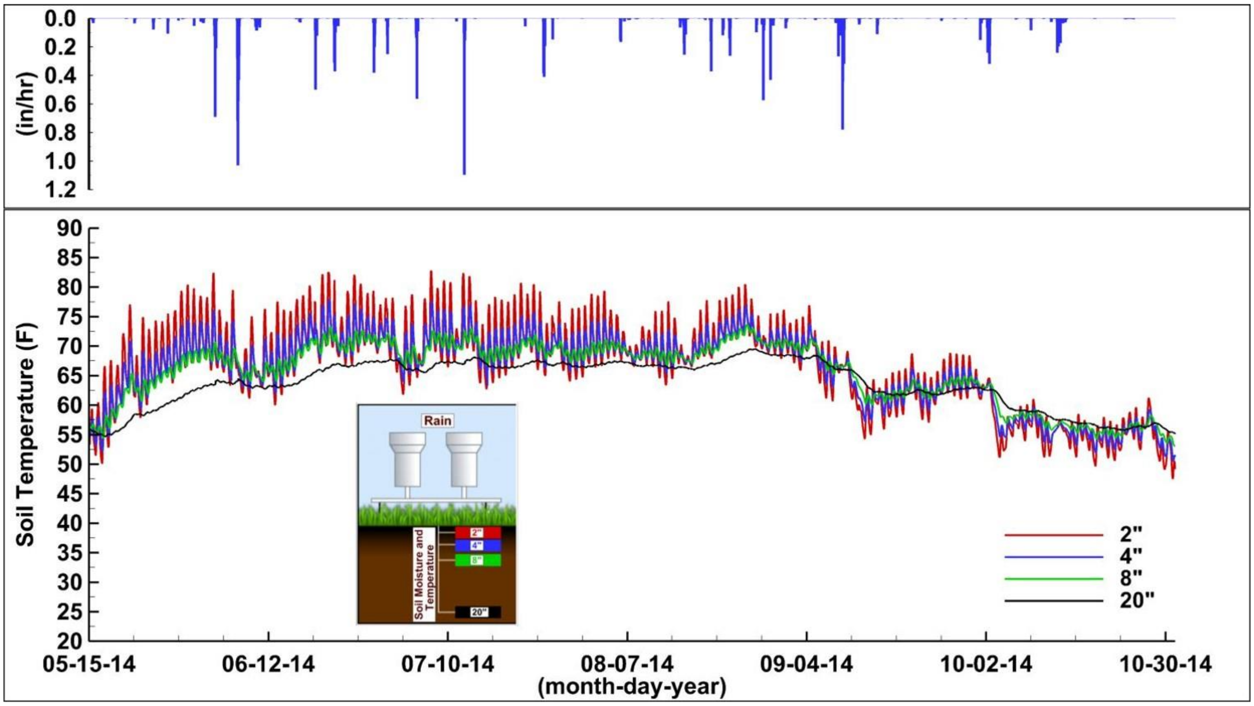


Figure 3.6. Soil temperature and precipitation measurements for the 2014 season. Soil temperature (in °F) is reported at 2-, 4-, 8-, and 20-inch depths from the surface. The soil temperature values are the average from the three rain gauge/soil measurement platforms in the South Chequest Creek Watershed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

Many of these features are seen more clearly during the nine-day period in June 2014 previously discussed (shown in Figure 3.7). The soil temperature is higher and has a larger daily range at the 2-inch depth (nearest to the surface). The temperature gets progressively lower and has a smaller daily range in temperature as one moves down to the 4-, 8-, and 20-inch depths. The effects of the rainy periods on soil temperature is also clearly seen. On days with significant rain, the daily range of soil temperature tends to be lower than on no-rain days. Rainy days often have less sunshine to warm the soils. Furthermore, after it rains, the soil is heated less because more incoming solar radiation is used in evaporate soil moisture. These two factors explain why rainy days tend to have a lower daily range in temperatures.

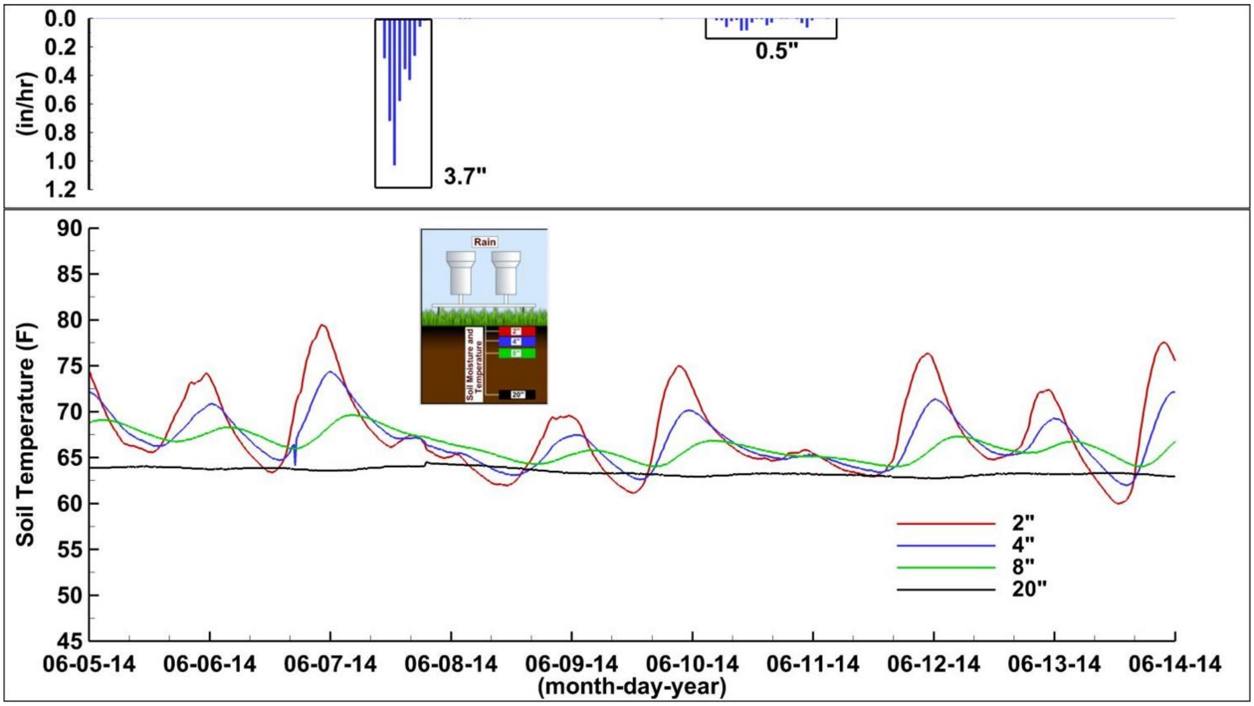


Figure 3.7. Soil moisture and precipitation measurements for the same nine-day period in June 2014 that is shown in Figures 3.3 and 3.5. Soil temperature (in °F) is reported at 2-, 4-, 8-, and 20-inch depths from the surface. The soil temperature values are the average from the three rain gauge/soil measurement platforms in the South Chequest Creek Watershed. Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

e. Water-quality Measurements

Figure 3.8 shows nitrate concentrations, stream stage, and precipitation observations for the 2015 measurement season. The figure shows the nitrate concentrations (Nitrate-N in mg/L) at the IIHR water-quality station (WQS0019), which is currently co-located with the IFC stream-stage sensor (SCHQSTCR01) near the confluence of the north and south branches of Chequest Creek (see Figure 3.1). The precipitation shown is again the average hourly precipitation rate for the three rain gauge platforms in the watershed. Nitrate concentrations are quite low in the South Chequest Creek Watershed compared to much of the rest of the state of Iowa. This is a factor of at least two things: the amount of available nitrogen in the soils and the extent of the areas devoted to agricultural activities with associated fertilizer application. From April 1 – June 23, 2015, the sensor recorded increased levels of nitrate corresponding to rainfall events in the watershed, as expected. There is a period of no data beginning on June 23, when a large thunderstorm produced sudden runoff and a large amount of sediment that actually buried the sensor. Over the next month, a series of repeating thunderstorms moved through the watershed, keeping the streamflow high enough that sensor maintenance was not possible. The sensor was re-established in August 2015, and data is available for all but this five-week period.

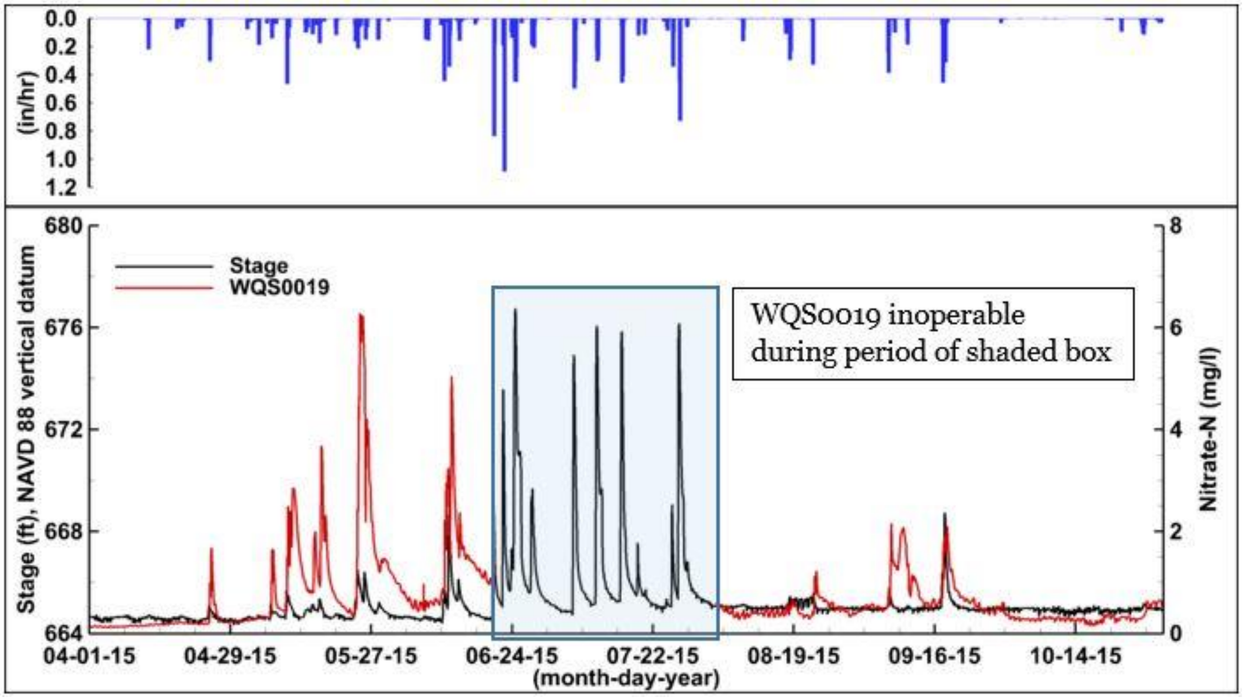


Figure 3.8. Nitrate concentrations, stream-stage, and precipitation measurements for the 2015 season. The nitrate concentrations (Nitrate-N in mg/L) are shown for the IIHR Water-quality Station (WQS0019). The stream-stage elevation (in feet above sea level) is shown for the IFC sensor (SCHQSTCR01). Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

Figure 3.9 shows a seven-day period in June 2015 just prior to the sensor being buried. The figure illustrates at a finer scale how nitrate concentrations in the stream respond to rainfall in the watershed. During the heavy rainfall periods, nitrate concentrations actually decrease at the sensor. The decrease occurs during the rising limb of the stream-stage hydrograph as the influx of runoff water dilutes the concentration, but the concentration rapidly rebounds to higher levels afterwards. After the storm ends, runoff from groundwater sources (baseflow) continues, but at a higher rate than before the storm. The increased baseflow leaches and transports more of the nitrate stored in the soils, resulting in the higher nitrate concentration after the storm.

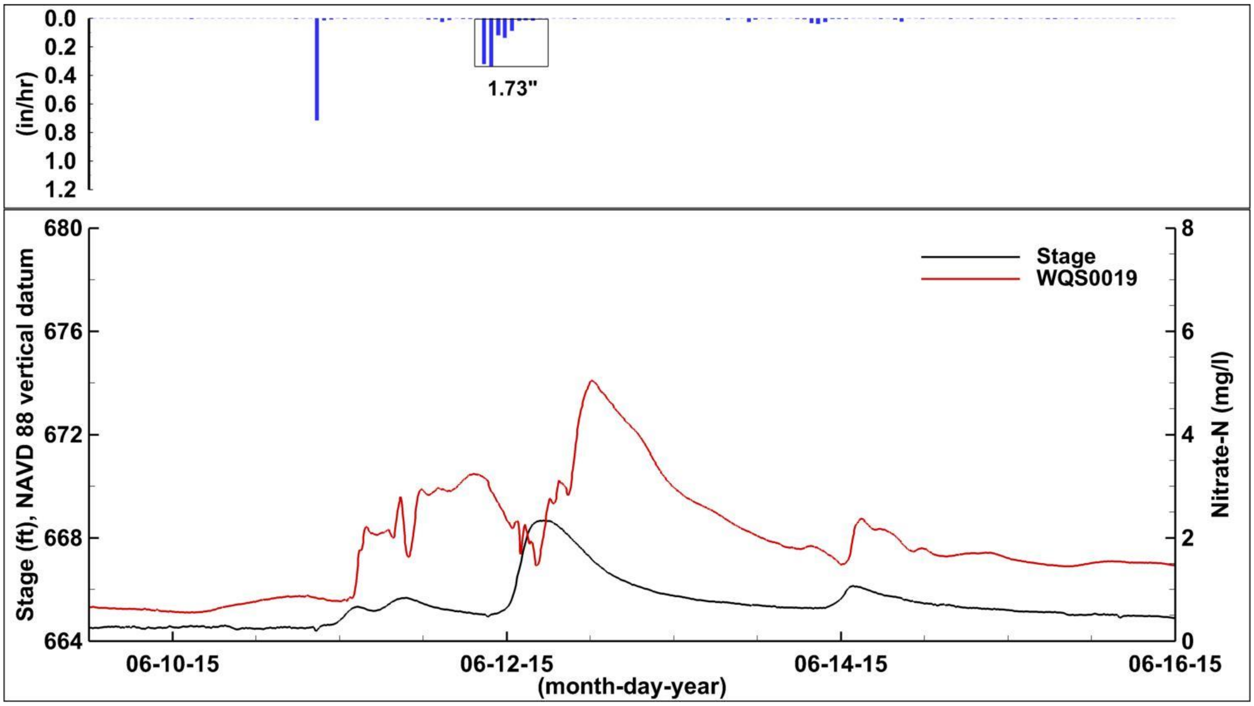


Figure 3.9. Nitrate concentrations, discharge, and precipitation measurements for the same nine-day period in June 2014 shown in Figures 3.3, 3.5, and 3.7. The figure shows nitrate concentrations (Nitrate-N in mg/L) for the IIHR Water-quality Station (WQS0019). The stream-stage elevation (in feet above sea level) is shown for the IFC sensor (SCHQSTCR01). Precipitation (in inches per hour) is the average of the measurements at the three rain gauge platforms.

In the 12 months since the June 2015 event that resulted in the water-quality sensors being buried, the stream has scoured and moved areas of the large sand deposit; subsequent storms have also deposited new sediment, causing the main channel to continuously shift location. The continued shifting has buried a second group of water-quality sensors, and a third nitrate sensor positioned in the spring of 2016 sensor has often been left unsubmerged – thus, not collecting data. This sensor is currently under consideration for relocation to another site in the lower part of the Chequest Creek (HUC10) watershed that may facilitate more reliable water-quality data collection.

f. Monitoring Summary

Beginning in 2014, the Iowa Flood Center and IIHR started intensive monitoring of water and water quality in the South Chequest Creek Watershed. Instrumentation placed in the watershed now measures precipitation, stream stage, soil moisture, soil temperature, and water quality. This data collection effort guides our work to develop detailed hydrologic models that mimic observed watershed processes. Researchers will also use the network of instruments to monitor changes in the watershed as project activities are implemented. The data collected by these instruments are available to the public on a near real-time basis. Please refer to the beginning of Chapter 3 to review how you may access these data.

4. Project Inventory

To meet the primary goal of the Iowa Watersheds Project, researchers allocated a total of $1,050,000 to the South Chequest Creek Watershed to plan, implement, and construct watershed improvement projects to reduce flood damage. In addition to these flood mitigation projects, state and federal cost share programs funded other conservation best management practices (BMPs) to help protect watershed resources. Project locations were selected based on volunteer landowner interest and a ranking system developed by the Chequest Creek Advisory Board.

The projects built in the South Chequest Creek Watershed are intended to serve as demonstration projects so other landowners can visit to better understand what the projects consist of as the Chequest Creek Advisory Board and the Davis County Soil and Water Conservation District seek to implement practices in other locations across the entire Chequest Creek Watershed. This chapter describes the Iowa Watersheds Project Phase II projects built in the South Chequest Creek Watershed.

a. Iowa Watersheds Project Phase II Flood Mitigation Projects

Many ponds in Iowa have been constructed to provide flood storage. Figure 4.1 illustrates a schematic of a typical flood storage pond. An earthen embankment constructed across the stream creates the pond. The pond usually holds some water all the time (called permanent pond storage). However, if the water level rises high enough, an outlet passes water safely through the embankment. This outlet is called the principal spillway. Typically, this principal spillway consists of a pipe passing through the embankment and discharging water back to the stream downstream of the embankment. As the water level rises during a flood, more water is temporarily stored in the pond. Eventually, the water level reaches the auxiliary spillway elevation. The auxiliary spillway releases water rapidly so the flow does not damage or overtop the earthen embankment. The volume of water stored between the principal spillway elevation and the auxiliary spillway elevation is called the flood storage.

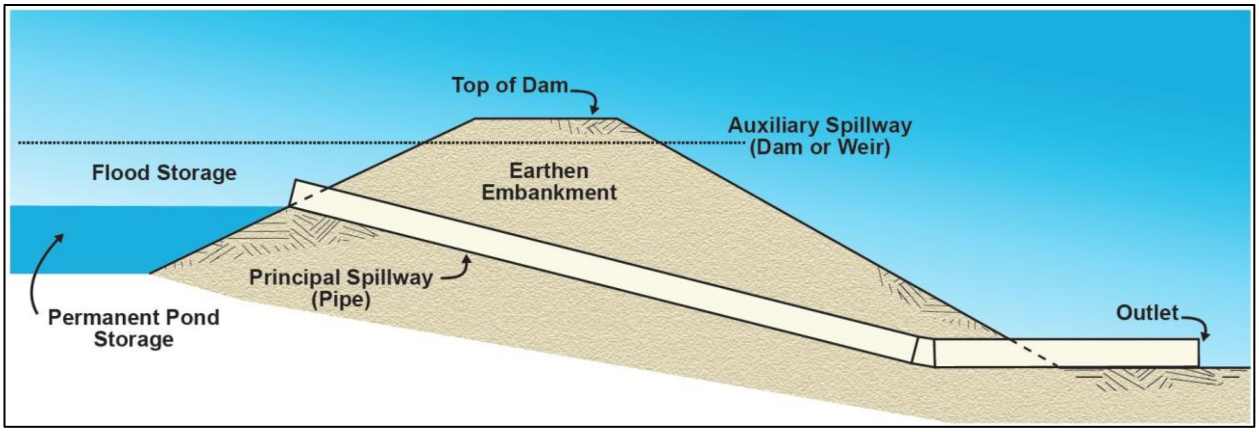


Figure 4.1. Schematic of pond constructed to provide flood storage.

As a part of Iowa Watersheds Project Phase II in the South Chequest Creek Watershed, landowners constructed 22 ponds, providing 334.4 acre-feet of flood storage. Additional storage is provided as the water level rises higher than the elevation of the auxiliary spillway up to the top of the dam. The storage from the principal spillway elevation to the top of dam is often called total storage. The 22 ponds in South Chequest provide potential total storage of nearly 547 acre-feet.

A private consulting engineering firm completed the project designs, with the exception of one project designed by the Davis County NRCS staff. All were built to NRCS Practice Codes No. 410 (NRCS 1985), No. 378 (NRCS 2011), and Iowa Department of Natural Resources (IDNR) Technical Bulletin No. 16 (IDNR 1990). Researchers numbered the project locations from 1 to 22 for IFC tracking purposes (shown in Figure 4.2). Table 4.1 provides the IFC pond ID #, the property owner, and the name given as the pond identifier on the design documentation.

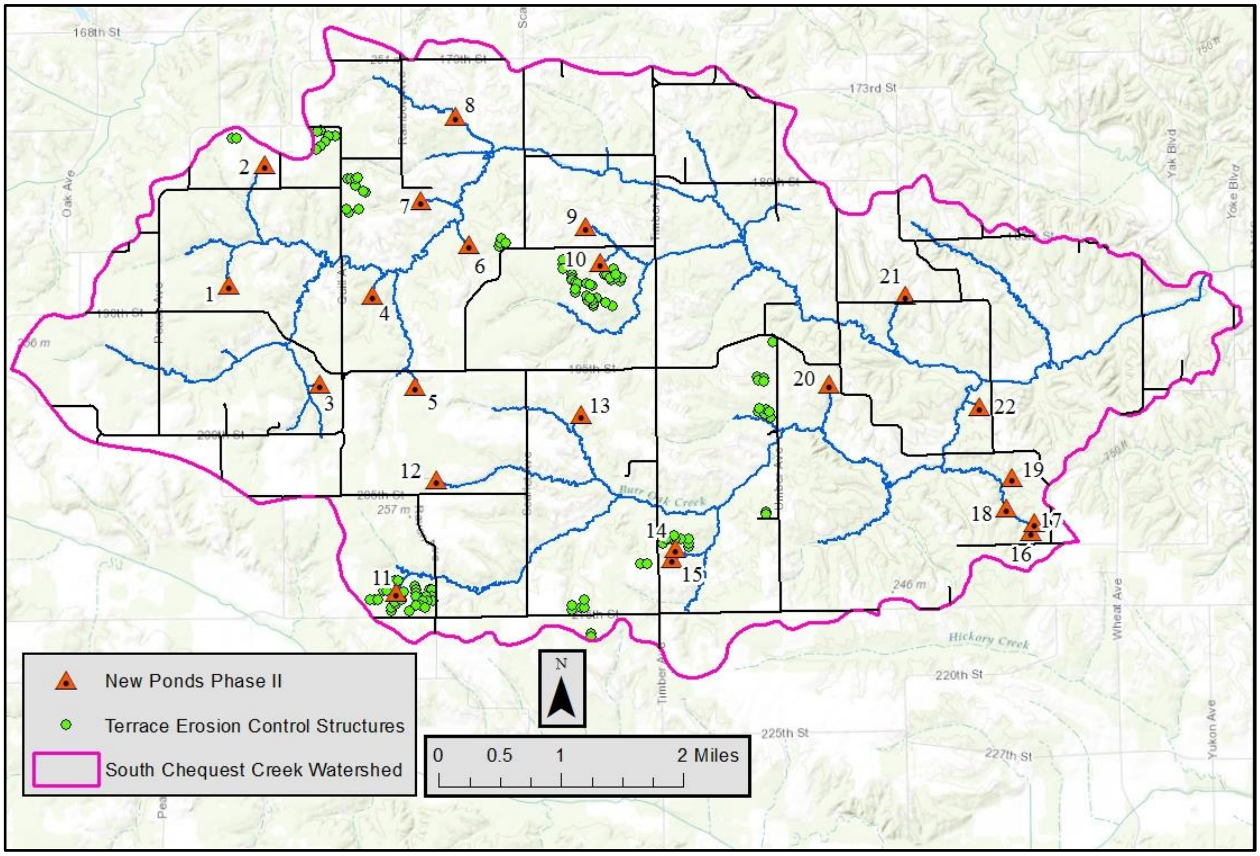


Figure 4.2. Iowa Watersheds Project Phase II project locations in the South Chequest Creek Watershed.

Table 4.1. Iowa Watersheds Project Phase II flood mitigation projects in the South Chequest Creek Watershed.

Pond ID #	***Property Owner***	***Design Documentation ID***
1	Wortman	Wortman
2	Davis	Davis
3	Campbell	Campbell
4	J. Utt	J. Utt North
5	J. Utt	J. Utt South
6	G. Utt	G. Utt
7	Eaton	Eaton
8	Smith	Smith
9	Christensen	Christensen
10	Padget	Padget
11	Birchmier	Birchmier
12	Mincks	Mincks
13	Lough	Lough
14	Bergen	Bergen North
15	Bergen	Bergen South
16	Rodgers	Rodgers
17	McClure Trust	McClure Trust - East
18	McClure Trust	McClure Trust - West
19	Anderson	Anderson
20	L. Utt	L. Utt
21	Ridgeway	Ridgeway
22	Kitzman	Kitzman

Figure 4.3 shows the earthen embankment of one of the Iowa Watersheds Project flood mitigation structures in the South Chequest Creek Watershed after construction has been completed, the area has been reseeded, and the pond has been filling (taken 4/12/2016).

Figure 4.3. Earthen embankment of one of the Iowa Watersheds Project ponds constructed to provide flood storage.

b. Erosion Control Structures

In Southeast Iowa, erosion of soil is quite common. Flood mitigation ponds constructed in the neighboring Soap Creek Watershed have experienced higher than anticipated sedimentation rates. As the sediment settles out of the runoff and remains in the pond, the flood and total storage capacity diminishes. As a part of Phase II project construction, 106 terrace water and sediment control basins and 10 diversion dams were also built. A terrace water and sediment control basin is an earth embankment or a combination ridge and channel constructed across the slope of minor watercourses to form a sediment trap and water detention basin with a stable outlet. This practice may be applied as part of a resource management system for one or more of the following purposes: to reduce watercourse and gully erosion, to trap sediment, and/or to reduce and manage local onsite and downstream runoff (NRCS Code No. 638). Figure 4.2 shows the locations of the terrace water and sediment control structures.

c. Hydraulics of Flood Mitigation (Pond) Projects

Pond projects can reduce flood damage by storing water during high runoff periods. That is, storage ponds hold floodwaters temporarily and release water at a lower rate. Therefore, the peak flood discharge downstream of a storage pond is lowered. The effectiveness of any one storage pond depends on its size (storage volume) and how quickly water is released. Ponds are engineered to efficiently use their available storage for large floods (typically in the 10- to 50-year return period range). Figure 4.4 shows two hydrographs for one of the Phase II pond locations.

The larger magnitude hydrograph is the inflow to the pond (or what would pass downstream if the pond wasn't there), and the smaller magnitude hydrograph shows what is coming out of the pond. The solid black line would be exceeded in magnitude by the outflow hydrograph if the auxiliary spillway was activated during this storm event. However, the auxiliary spillway was not activated and the pond stored a significant volume of water while only discharging out the principal spillway during the event.

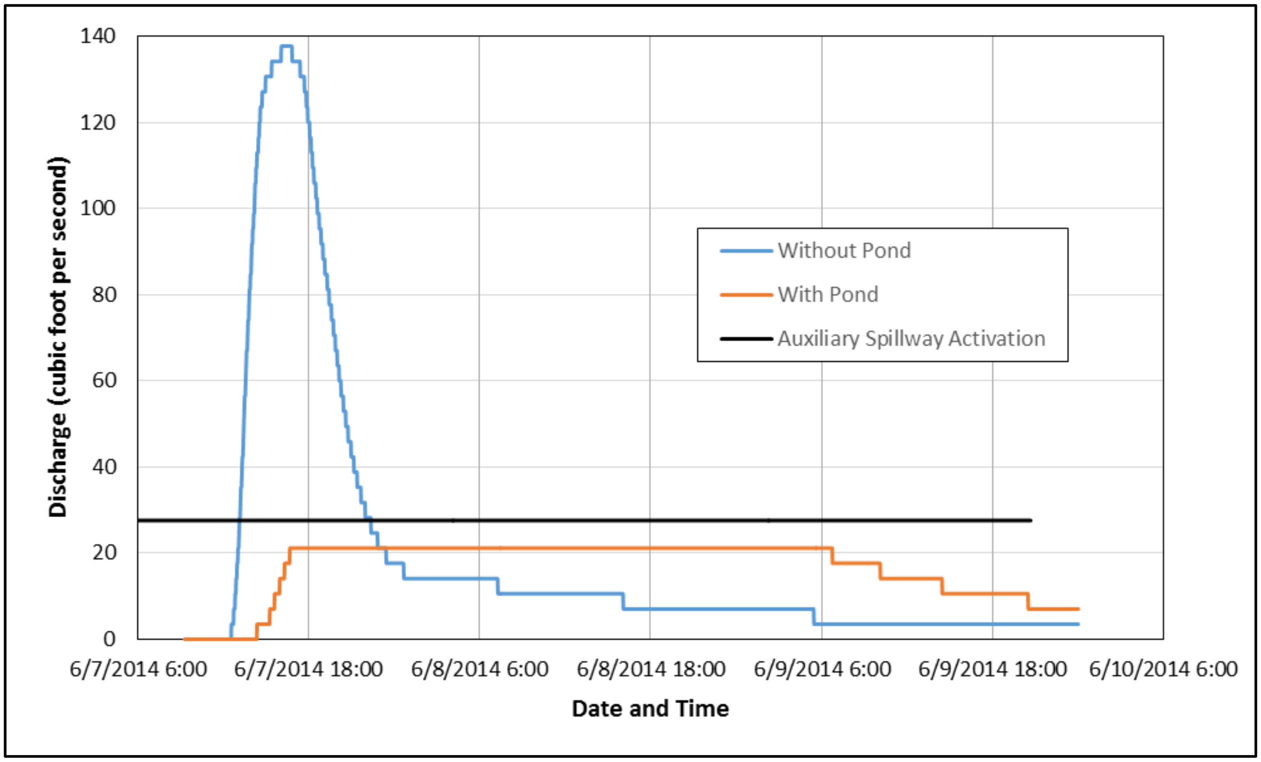


Figure 4.4. Inflow and outflow hydrographs for one of the Iowa Watersheds Project Phase II pond projects.

To determine the pond volume and outflow characteristics of the 22 Iowa Watersheds Project ponds, researchers obtained design documentation was obtained from the design engineer and/or Davis County Soil & Water Conservation District field office staff. This included the project plans, which describe how the project was built, as well as hydrologic design information used to select the principal and auxiliary spillway outflow structures. The consulting engineer determined each pond's stage (elevation)-storage relationship as part of the predesign topographic analysis; this was included in a table in the design plans. For hydrologic modeling purposes, the pond's stage-discharge table is needed to route rainfall runoff through the pond at the appropriate magnitude throughout the duration of the simulation. Iowa Flood Center engineers determined the stage-discharge relationship for each project based on the final design specifications for the principal spillway (pipe) size and slope, and the width and retardance class of the auxiliary spillway. Discharge in the event of dam overtopping was estimated based on design documentation from similar ponds designed for Soap Creek and the same values were used for all 22 Phase II projects in the South Chequest Creek Watershed. Figure 4.5 shows an example of a stage-storage relationship of one of the ponds and the developed stage-discharge relationship for the same pond. Appendix A includes stage-storage tables provided by the consulting engineer and stage-storage-discharge tables as used for hydrologic modeling for each of the 22 Phase II projects.

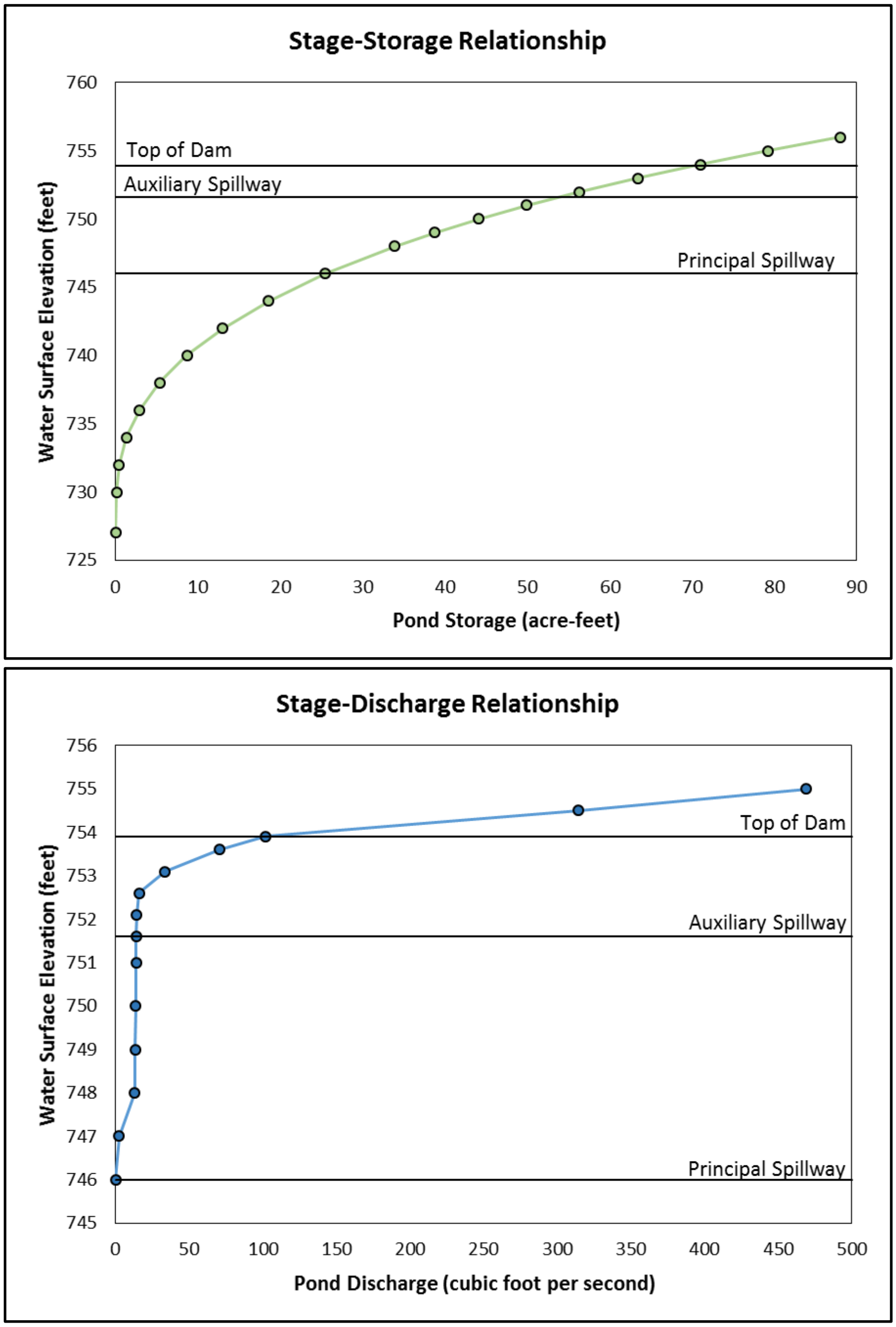


Figure 4.5. Pond hydraulic relationships for one of the Iowa Watersheds Project Phase II flood mitigation projects: (top) Stage (Elevation) – Storage relationship; and (bottom) Stage – Discharge relationship. The elevations of the principal spillway, the auxiliary spillway, and the top of dam are indicated.

d. Project Summary

The projects constructed through the Iowa Watersheds Project provide multiple benefits both on- and off-site. Landowners enjoy the farm ponds on their property for their aesthetic beauty, recreation potential, and the wildlife they attract. In addition, landowners can use the ponds to water livestock and control erosion. Landowner input and Davis County NRCS staff guidance determined the placement of the ponds so that the structure(s) fits the overall working plan the landowner has for the ground. The flood mitigation projects create water storage on the landscape that reduces downstream flooding, protecting both people and infrastructure. The pond structures are able to provide significant savings in federal, state, and local road and bridge maintenance costs by managing runoff to reduce and mitigate structural and nonstructural flood damage.

Figure 4.6. Iowa Watersheds Project Phase II projects: (top) flood mitigation pond and (bottom) terrace water and sediment control structure.

5. Detailed Predictions of Hydrologic Alterations

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

a. Physically-based Simulations

Researchers selected the numerical model HydroGeoSphere (HGS) to investigate the detailed aspects of integrated watershed response to flood mitigation practices. HGS takes into account all of the key components of the hydrologic cycle (see Figure 5.1), applying the most physically realistic representation of water movement.

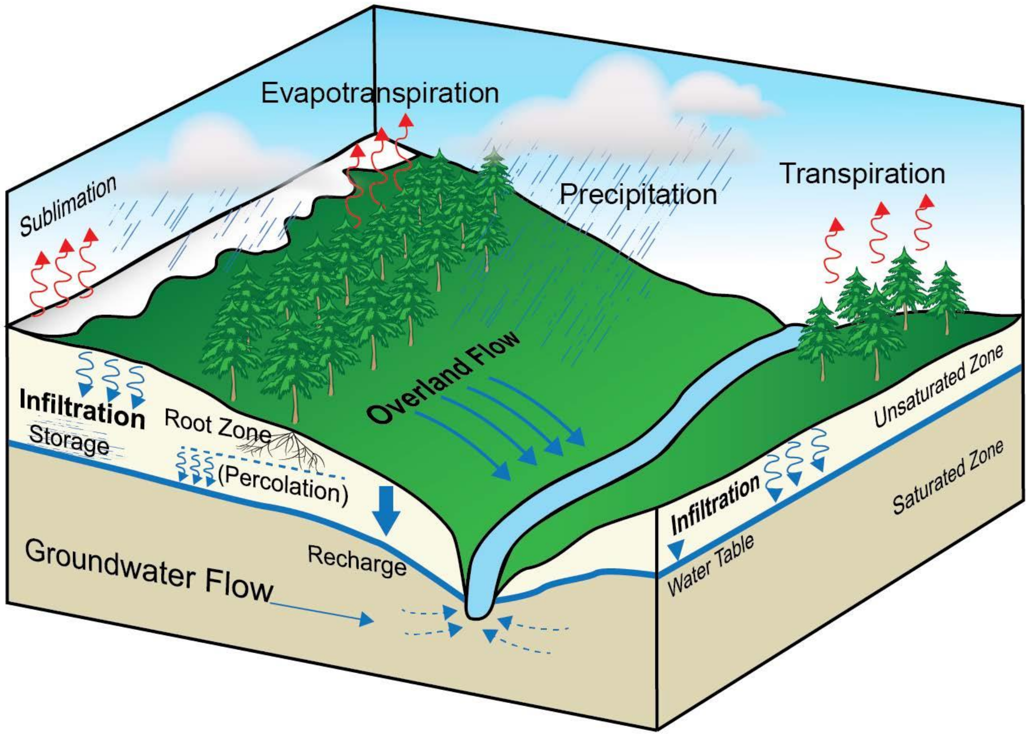


Figure 5.1. The numerical model HydroGeoSphere simulates the hydrologic processes.

Within the model domain, rainfall is partitioned between overland surface flow, evaporation, transpiration, and infiltration, enabling discharge through the surface or subsurface into downstream water bodies or aquifer flows (Brunner and Simmons, 2011). The software can implement wells, tile drains, subsurface fractures, and channelized flow. Rainfall is applied to the surface of the domain. Interception, evaporation, and transpiration are modeled using the Kristensen and Jensen approach (Brunner and Simmons, 2011), where evapotranspiration is a function of soil water availability and vegetation growth characteristics. HGS quantified and illustrated the micro- and macro-scale effects of each project on the water balance and overall fluxes.

In direct comparison to the Hydrologic Assessment of the Chequest Creek Watershed, HGS is a mathematical, physically-based, distributed, coupled, surface-subsurface hydrologic model. We will briefly discuss each of these items. The fact that HGS is a mathematical model implies that the different hydrologic processes are represented by mathematical expressions based on the fundamentals of fluid mechanics or based in physics. HGS is a distributed parameter model, meaning that physical characteristics of the watershed, such as land use and soil type, are spatially variable representative of each location. HGS is a coupled model, meaning the different hydrologic processes are solved jointly rather than independently. In reality, surface and subsurface processes are dependent on one another and their governing equations should be solved simultaneously. Finally, HGS is a surface-subsurface hydrologic model, meaning it is applicable to most every hydrologic simulation.

b. Mesh Generation

The objectives of this study required investigation of surface and near surface water flow processes. Researchers created a two-dimensional representation of the land surface by automatically generating variably sized triangular elements. For this study, the model produced a mesh from the watershed boundary, stream centerlines, roadways, and hydraulic structure locations. The watershed boundary was identified as the local topographic high, draining all internal areas to a single outlet location. This boundary acts as the lateral edge of both the surface and subsurface domains. During heavy rainfall events, elevated roadways act as topographic divides, forcing rainfall into nearby drainage ditches and then into stream channels. HGS extracts elevation information from element edges. By allocating element edges along topographic features, the elevation at that location is enforced. Researchers deemed roadways and stream centerlines topographically significant features and included them as mesh generation boundaries. They delineated stream centerlines and incorporated them to ensure continuous flow to the catchment outlet, maintaining travel times and realistically capturing surface-subsurface interactions (Li et al., 2008). To increase efficiency of numerical simulations, researchers coarsened the mesh elements to 600 feet across mildly sloped areas, and refined them to 80 feet near streams and constructed projects. Figure 5.2 shows topographic features and an example of the mesh generated for one location within the watershed. The final two-dimensional surface grid for the entire South Chequest Creek Watershed contained 28,241 triangular elements.

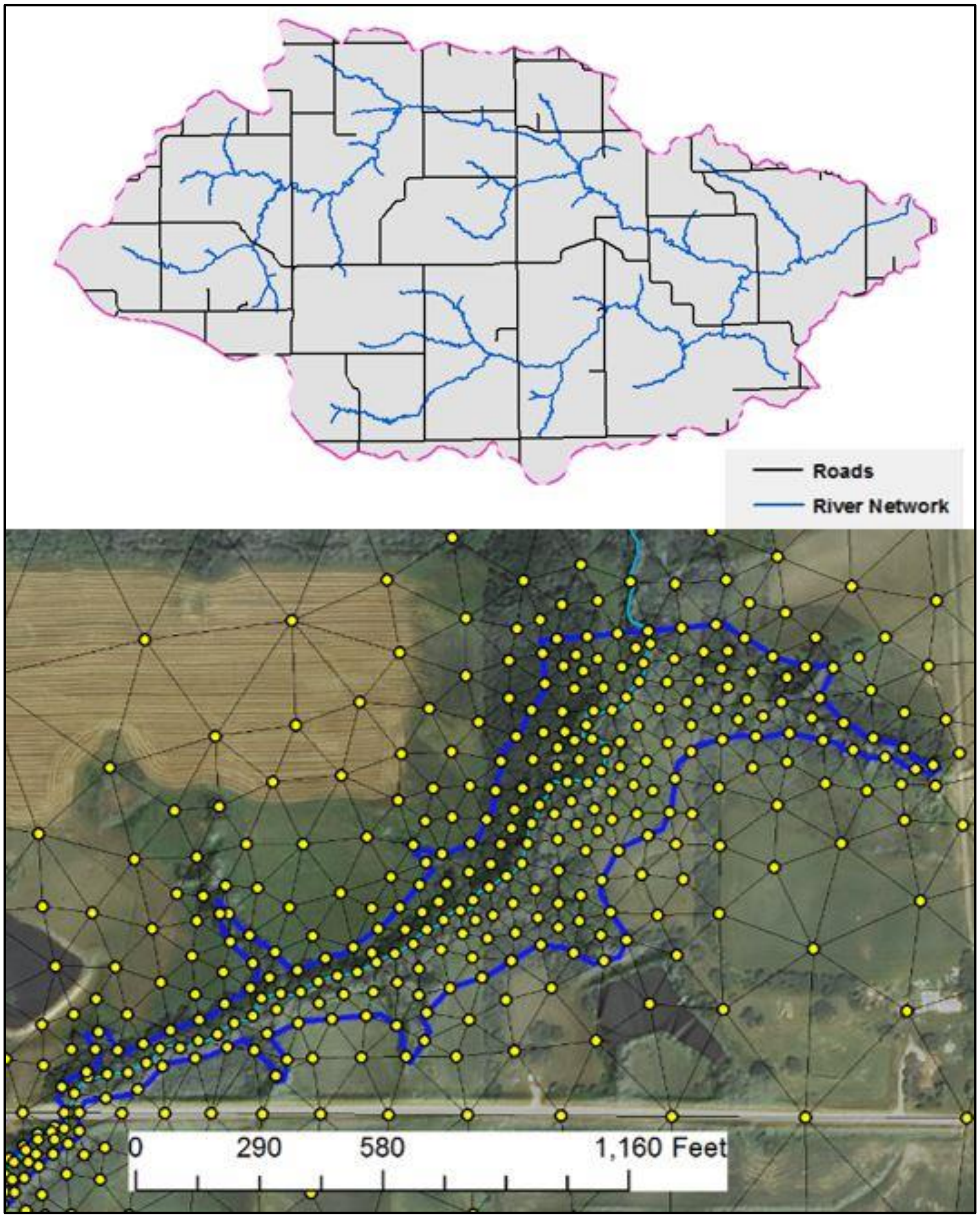


Figure 5.2. South Chequest Creek Watershed surface domain grid generation: (top) boundaries for mesh generation, (bottom) example location of the completed 2-D finite element grid.

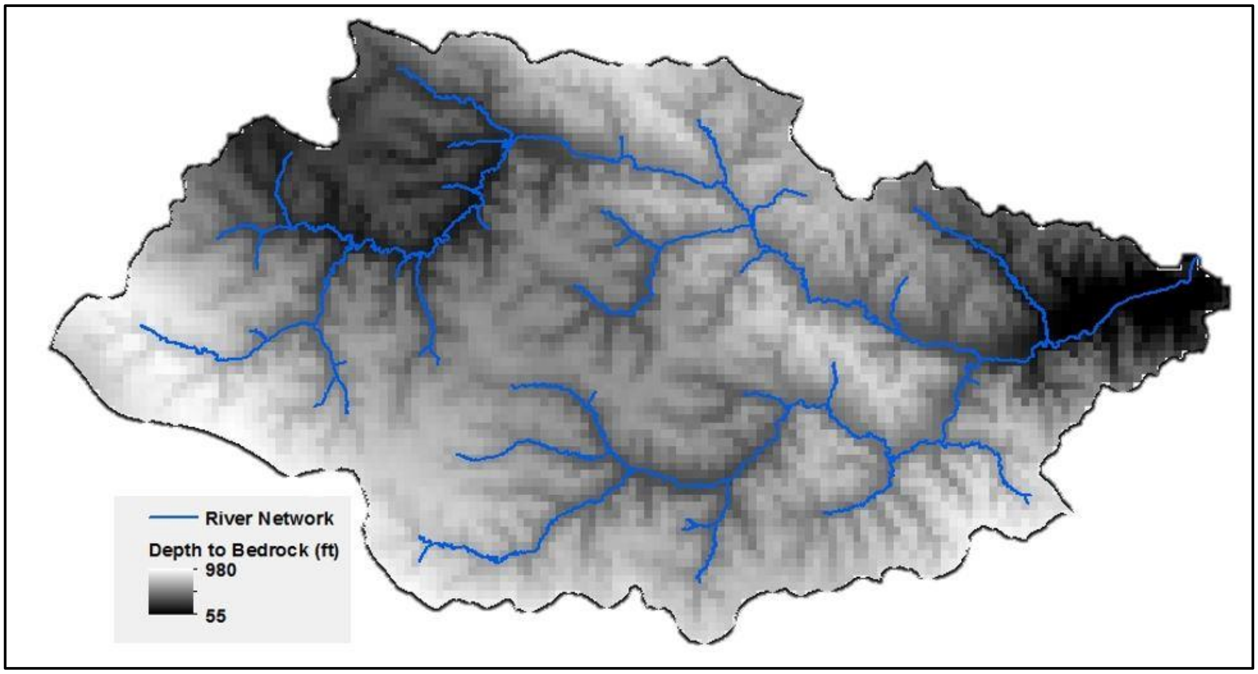


Figure 5.3. Estimated depth to bedrock as defined by the Iowa Geologic Survey (2010) in the South Chequest Creek Watershed.

Researchers projected the completed two-dimensional surface mesh downward to the estimated bedrock depth (Witzke et al., 2010) to form three-dimensional subsurface elements. They divided the subsurface was divided into two zones, from the surface down three feet, and from a three-foot depth to the bedrock. They spaced 10 elements vertically through the top three feet of soil, such that the depths of the IFC soil moisture sensors were explicitly included (2 in., 4 in., 8 in., and 20 in.). The remaining element depths varied in increasing thickness from two feet to six feet near the impermeable layer (Figure 5.3). The increased number of numerical elements near the surface allowed for a more accurate representation of the interactions between the surface and subsurface domains.

Figure 5.4 illustrates superimposing the surface mesh onto the terrain topography to create a three dimensional mesh and then the subsurface is added to create the final computational mesh used in HGS. The product of mesh generation results in a 227,368 element three-dimensional modeling domain.

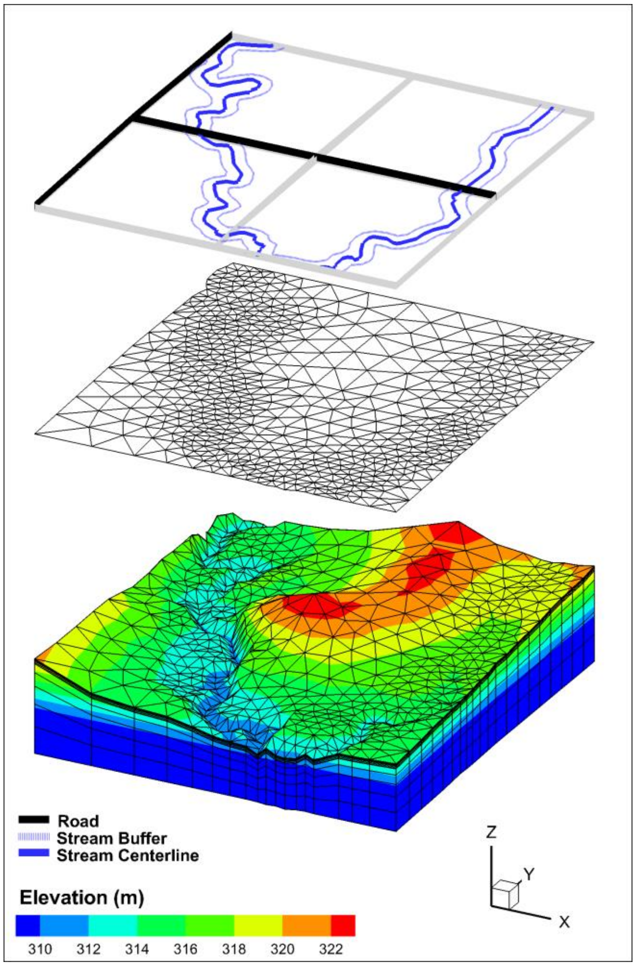


Figure 5.4. Generation of 2-D and 3-D mesh: (top) conceptual mesh generation through incorporation of important boundaries; (middle) a 2-D mesh; and (bottom) 2-D mesh projected downwards to create a 3-D tetrahedral mesh. Vertical axis at 10:1 ratio.

c. Attributing the Model

Publically available land use, soil type, and well log data was used to spatially describe surface and subsurface classifications.

i. Surface

Each triangular surface element was assigned spatially variable land use, and topographic information, relating the location to overland roughness, evapotranspiration properties, and land surface slopes, respectively.

Spatially variable land use classifications were obtained from the National Land Cover Database 2009 (Fry, et al., 2011). Land classifications were simplified into five classifications, agriculture, grassland, forest, developed, and water and assigned to the appropriate elemental area (Fig. 2.7). The five surface land use classifications related surface elements to overland flow resistance parameters and vegetation properties. The parameters used to calculate the actual evapotranspiration (Kristensen and Jensen, 1975), were described thoroughly by Li et al. (2008).

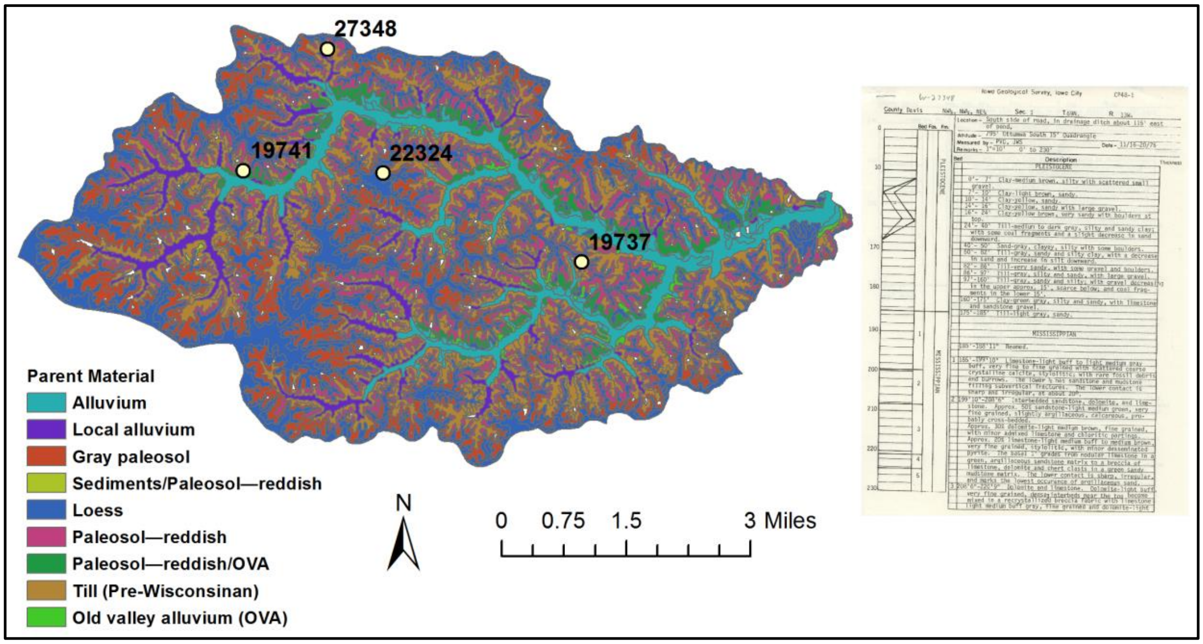
The landscape topography was described utilizing Light Detection and Ranging (LiDAR) datasets, which were aggregated for the entire state of Iowa between 2007 and 2010 (Iowa Geological and Water Survey, 2010). One meter resolution Digital Elevation Models (DEM) of bare ground surface data was derived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

ii. Subsurface

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

The Soil Survey Geographic (SSURGO) database (Soil Survey Staff, 2014) (Fig. 2.4), was used to describe the top three feet of the subsurface. The flow properties were allocated based on soil texture classification, and assigned the mean textural properties.

The remaining deeper geology below the top three feet of soil was described by historical well logs at 4 sites across the watershed and surrounding area (IGS, 2015) (Fig. 5.5). Information available was used to produce an aggregated representation of geologic properties. The deeper subsurface was represented by the above described homogeneous representation of hydraulic properties from three feet deep to the estimated depth to bedrock (Fig. 5.3).



W-27348 Iowa Geological Survey, Iowa City CP48-1

County Davis NW¼, NW¼, NE¼ Sec 1 T69N. R 13W.

Location - South side of road, in drainage ditch about 115' east of pond.

Altitude - 795' Ottumwa South 15' Quadrangle

Measured by - PVC, JWS Date - 11/16-20/75

Remarks - 1"=10' 0' to 230'

Bed	Description	Thickness
	PLEISTOCENE	
	0'- 7' Clay-medium brown, silty with scattered small gravel.	
	7'- 10' Clay-light brown, sandy.	
	10'- 14' Clay-yellow, sandy.	
	14'- 16' Clay-yellow, sandy with large gravel.	
	16'- 24' Clay-yellow brown, very sandy with boulders at top.	
	24'- 40' Till-medium to dark gray, silty and sandy clay; with some coal fragments and a slight decrease in sand downward.	
	40'- 50' Sand-gray, clayey, silty with some boulders.	
	50'- 82' Till-gray, sandy and silty clay, with a decrease in sand and increase in silt downward.	
	82'- 86' Till-very sandy, with some gravel and boulders.	
	86'- 97' Till-gray, silty and sandy, with large gravel.	
	97'-160' Till-gray, sandy and silty; with gravel decreasing in the upper approx. 15', scarce below; and coal fragments in the lower 15'.	
	160'-175' Clay-green gray, silty and sandy, with limestone and sandstone gravel.	
	175'-185' Till-light gray, sandy.	
	MISSISSIPPIAN	
	185'-185'11" Reamed.	
1	185'-199'10" Limestone-light buff to light medium gray buff, very fine to fine grained with scattered coarse crystalline calcite, stylolitic, with rare fossil debris and burrows. The lower ½ has sandstone and mudstone filling subvertical fractures. The lower contact is sharp and irregular, at about 20°.	
2	199'10"-208'6" Interbedded sandstone, dolomite, and limestone. Approx. 50% sandstone-light medium brown, very fine grained, slightly argillaceous, calcareous, probably cross-bedded. Approx. 30% dolomite-light medium brown, fine grained, with minor admixed limestone and chloritic partings. Approx. 20% limestone-light medium buff to medium brown, very fine grained, stylolitic, with minor dessiminated pyrite. The basal 1' grades from nodular limestone in a green, argillaceous sandstone matrix to a breccia of limestone, dolomite and chert clasts in a green sandy mudstone matrix. The lower contact is sharp, irregular, and marks the lowest occurance of argillaceous sand.	
3	208'6"-220'9" Dolomite and limestone. Dolomite-light buff, very fine grained, dense; interbeds near the top become mixed in a recrystallized breccia fabric with limestone-light medium buff gray, fine grained and dolomite-light	

Figure 5.5. Geologic well log locations (4) within the South Chequest Creek Watershed. Driller's log for the well 27348.

d. Meteorological Input for Hydrologic Simulation

Researchers applied measured meteorological data for 2014 from the South Chequest Creek Watershed for the annual simulation. This section describes the exact alterations to the raw data for input into numerical simulations.

Precipitation was measured at three locations at 15-minute increments (Fig. 3.1). Researchers aggregated the raw data to the hourly time step. This produced a uniformly distributed rainfall at hourly time steps from May 15, 2014, to Nov. 9, 2014. Researchers further altered the precipitation input time series by incorporating solid form snow storage when temperatures dropped below freezing (32° F). They aggregated PRISM daily average temperature data (PRISM, 2016) for 2014 at the centroid of the South Chequest Creek Watershed. When temperatures were below freezing, snow was assumed to accumulate on the land and stored until temperatures rose above freezing. The degree day method per NRCS (2004) standards allowed for temperature to be used as an index for a wide range of energy fluxes affecting the melting process. A difference of temperature to a base temperature (freezing) allows daily melt depths to be calculated until the storage of snow has been depleted. For modeling purposes, researchers completed this analysis prior to simulation, and input the daily melt flux as a rainfall rate into the domain. This process shifts the introduction of frozen precipitation into the early spring months, saturating near surface soils and causing higher runoff potential.

Researchers based daily potential evapotranspiration (PET) on the Penman-Monteith approach, downloaded from the Iowa State AgClimate station at Chariton, Iowa (Iowa State University, 2015). A gap in PET data from April 21, 2014, to July 17, 2014, required supplemental PET data. Using time series on air temperature, dew point temperature, and cloud cover from Charles City, Iowa, modelers estimated daily PET using a Penman approach (Shuttleworth, 1993).

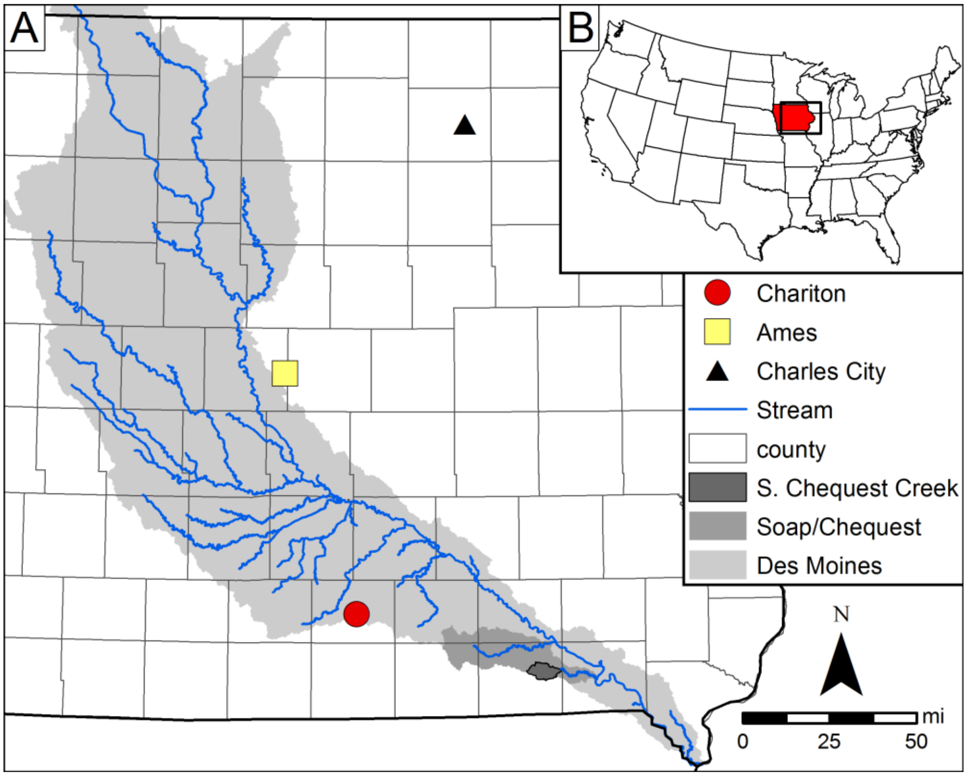


Figure 5.6 Data collection sites in Iowa. Ames SCAN – long-term water content (yellow); Charles City - supplemental meteorological data for PET calculation (black); and Chariton – PET data (red).

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

Studies showed that SCAN soil water content data varies with depth and time. Researchers noted that shallower soils have increased soil moisture variability, with lower median soil moisture values. As measurement depth increased, median soil moisture increased, and variability decreased. The highest median soil water values and lowest variability occurred in the months of March, April, and May, due to spring snowmelt and rainfall. June, July, and August showed the highest variability and lowest median moisture values due to high ET. Temporal trends held true at each depth.

e. Calibration

Researchers adjusted model parameters so that simulated results match known annual ratios between components of the hydrologic cycle as closely as possible. They used the following target ratios: discharge to precipitation (Q/P); evapotranspiration to precipitation (ET/P); evaporation to evapotranspiration (E/ET); transpiration to evapotranspiration (T/ET); and baseflow to discharge (Qb/Q). Table 5.1 presents the targets for the ratios. When evaluating the existing literature for these ratios, researchers gave preference to studies performed in Iowa or in agriculturally dominated landscapes of the Midwest, but in some cases they used ratios from other locations.

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

Calibrated water balance components generally matched the calibration targets adequately. Q/P was 45%, with ET/P representing the remaining 55%, approximately 15% higher and lower than the respective ratios. This indicates that the watershed over this period tended toward a “wet” condition. This was a reasonable result, as 2014 was wetter than normal (higher precipitation). An iterative cycle of a wet year pushes the model into a wet equilibrium. E/ET (41%) and T/ET (59%) allocated more water toward the evaporation component than the calibration targets. This is representative of a wet watershed condition. Evaporation is not limited near saturation, but transpiration is. Furthermore, evaporation acts over the top 8 in. of soil, with transpiration over the top 3 feet. With a wet condition, more water is closer to the surface and available to evaporation. Baseflow accounted for approximately 48% of the total outflow, close to the calibration target range. The partitioning of water balance components over the iteratively run wet year responds in a logical pattern tending toward a wetter condition.

Researchers used the IFC South Chequest stream-stage sensor to evaluate the hydrologic model. They converted stream-stage readings to discharge using a rating curve developed by IFC engineers for this site. They selected a series of events occurring in June 2014 as an example time period to evaluate. Rainfall events produced peaks in the measured time series, with the event occurring on June 7 producing the maximum stage reading for 2014. Figure 5.8 shows the rainfall input, an average of the three IFC rain gauge platforms in the watershed, along with hydrographs showing the estimated discharge via the rating curve and the HGS simulated discharge.

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

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

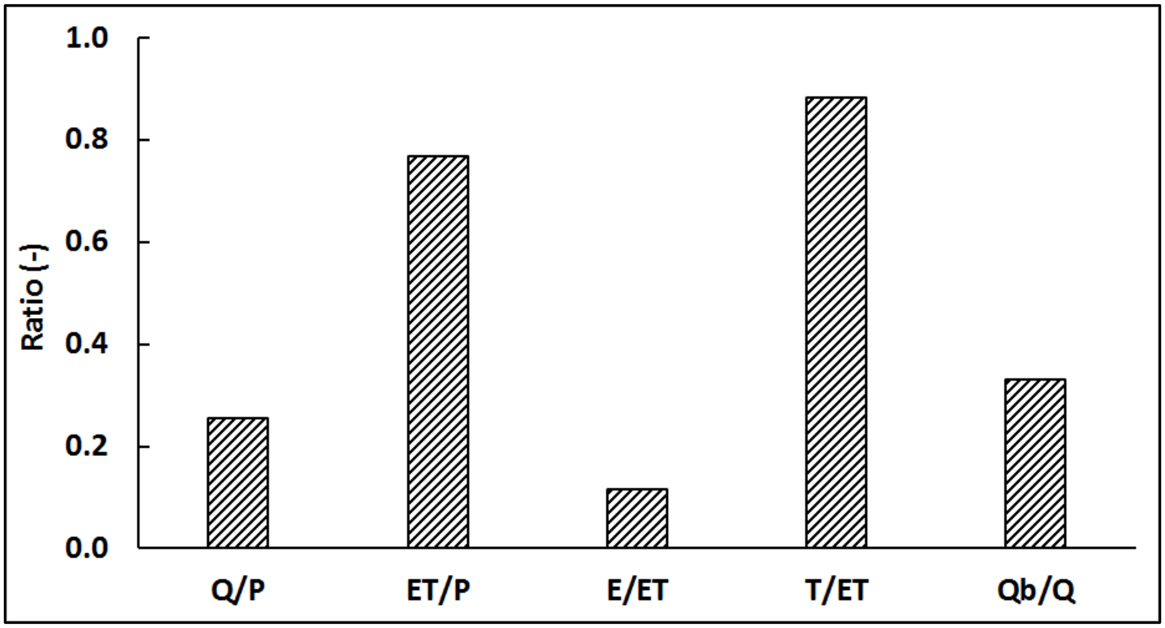


Figure 5.7. Calibration. Estimated annual ratios of hydrologic components obtained with the final set of parameters (fourth year).

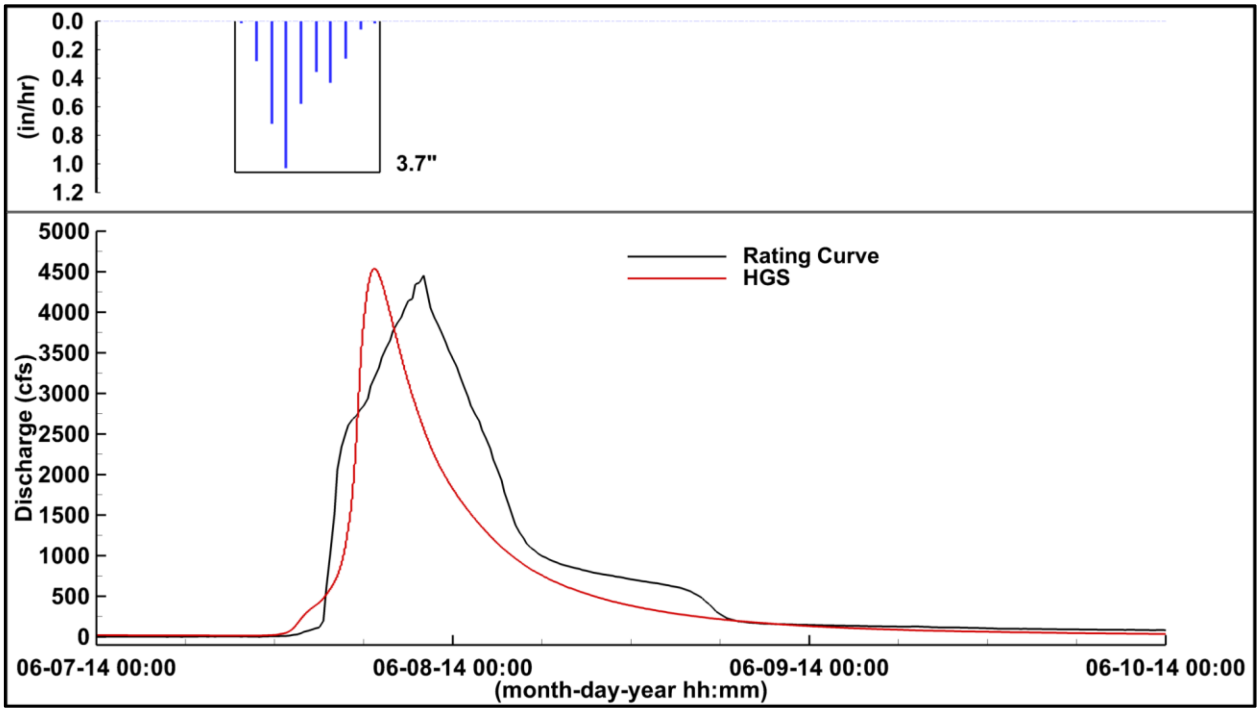


Figure 5.8. Calibration. Comparison between discharge values simulated (HGS) and estimated with a rating curve developed to convert stream stage measured at SCHQSTCR01 (Fig. 3.1) to discharge. Precipitation is the average of the measurements of the three rain gauge platforms.

Differences in the estimated discharge from the observed stage readings and the calibration results can be attributed to model complexities, representation of the rainfall, and calibration time period. Although rainfall data was collected locally, refining the space and time distributions of rainfall can greatly impact a watershed response. Overall, the calibration results successfully depict the expected variation from the calibration targets, and represent overall watershed processes well.

f. Localized Impact of Projects

Researchers used HGS to analyze the impact of adding pond #8 (see Table 4.1) to the watershed, providing a comprehensive numerical depiction of water dynamics in the general area of the pond. This section continues as follows: description of project incorporation into the HGS model, and testing of the selected project under high and low potential peak flow reduction scenarios.

i. Project Inclusion (Mesh and Elevation)

The IFC incorporated Pond #8 into the mesh through two components: the structural embankment centerline and the estimated inundation limits of the auxiliary spillway elevation (Fig. 5.9). Researchers assigned elevation of the top of dam and the auxiliary spillway per design documentation. They refined the mesh in proximity to the detention structure, ensuring the appropriate representation of inflow, storage, and inundation.

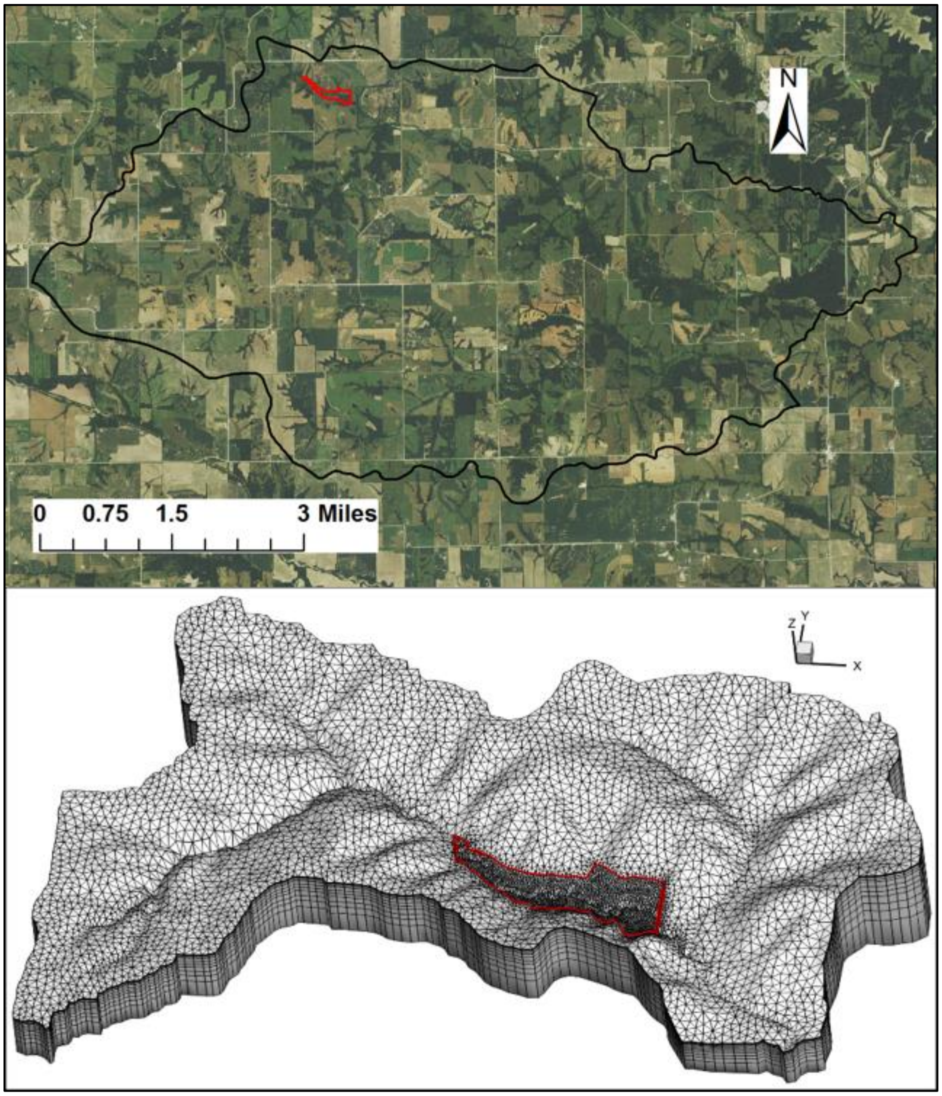


Figure. 5.9 Example of project incorporation into the numerical mesh through embankment centerline and estimated maximum inundation extent (red line). *Note the additional refinement of the numerical mesh near the project embankment and estimated inundation area.

ii. Watershed Response with Incorporated Flood Mitigation Project

Researchers analyzed the new flood mitigation project for a range of antecedent wetness conditions and pre-event project storage conditions for a given design storm precipitation event. Antecedent soil wetness refers to how wet the soil is prior to precipitation. The wetter the soil, the greater the basin's peak flow response will be. Pre-event storage refers to the amount of water contained in the flood mitigation detention structure prior to a precipitation event. An "empty" pond (holding no water) would provide the greatest amount of potential storage. However, the ponds are designed to hold a permanent pool of water. In general, once the pond has filled the first time, the pond will stop discharging after a storm event passes once the water surface elevation reaches the invert elevation of the principal spillway. This is considered the normal pool elevation. Additional reduction of the water elevation is possible as water evaporates. However, modelers can perform a conservative assessment by starting simulations with the pond considered “full.” In other words, the water surface elevation of the pond is set at the normal pool elevation. This section describes the watershed response to a given precipitation depth under differing antecedent soil moisture and pre-event project storage conditions.

Synthetic Precipitation

The IFC developed a hypothetical design storm for comparative analyses of pond #8. The hypothetical storm applies a uniform depth of rainfall across the entire model domain with the same timing everywhere. They used an SCS Type-II distribution, 24-hour storm. They derived the point precipitation values (rainfall depths) for the 50-year average recurrence interval (6.3 in.), 24-hour design storm using the online version of NOAA Atlas 14 – Point Precipitation Frequency Estimates (Perica et al., 2013).

Antecedent Soil Moisture

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

Researchers normalized, ranked, and plotted the hourly soil moisture data with measured soil porosity at each depth (Fig. 5.10) (NRCS 2004; NRCS 2015). They extracted the 98% and 50% exceedance probability soil moisture contents at each measurement depth, representing very wet (98%) and normal soil wetness (50%) conditions. They defined soil moisture initial conditions in the top three feet of the model subsurface to match, on average, the profiles presented in Figure 5.10. Near stream channels, the soil was assumed to have a saturation value of 1.0 for the profile depth.

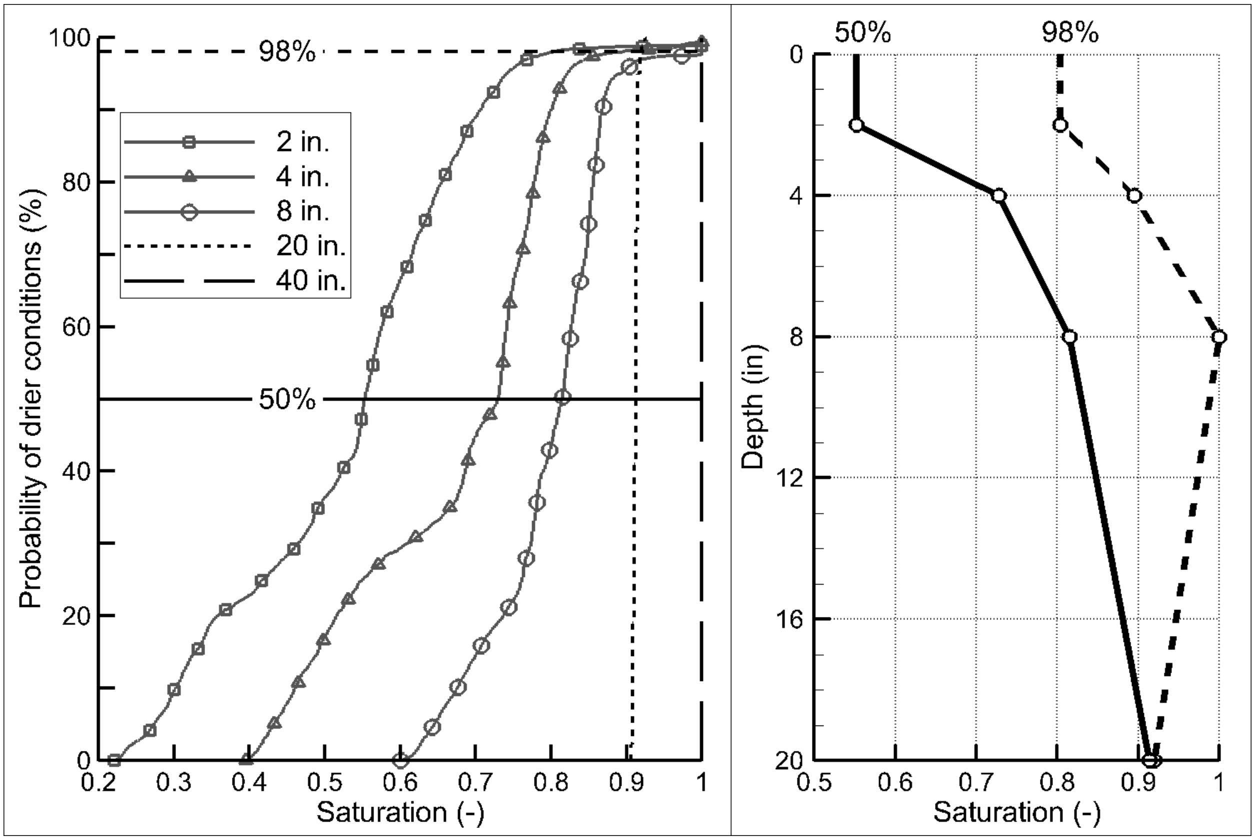


Figure. 5.10 (Left) Ranked saturation values at five measured depths. Horizontal lines represent the initial conditions for event simulation. (Right) Soil water initialization saturation over the first 20 in. The 40-in. initialization state was equal to 1.0 for all chosen exceedance probabilities. Circles indicate soil measurement location; lines indicate linearly interpolated HGS input values.

Pond Initial Storage Condition

Peak flow alterations from flood control structures have previously been noted as dependent upon the initial storage. Researchers chose three project conditions to adequately encompass the detention basin's initial conditions: no pond, "empty" pond, and "full" pond. These conditions represent a control (no projects), a maximum peak flow reduction potential (empty projects), and a conservative peak flow reduction potential (full projects). Modelers initialized empty project scenarios without surface water stored behind the structures; they initialized full project simulations with water up to the normal pool elevation.

Pond Influence Analysis

Researchers performed an analysis to quantify the impact of the project. They selected the 50-year average recurrence interval rainfall event for comparison of the basin response under heavy rainfall for pre- and post-project construction. They isolated the local area containing the project (Figure 5.9), representing the location of maximum project influence, for further analysis. Hydrographs shown were extracted from the outlet of the model domain, not directly at the outlet of the pond.

The modelers selected soil moisture antecedent conditions from the 10-year aggregation described above to represent a normal wetness condition (50%) and a high wetness condition (98%). This range encompasses a reasonable range of flood-producing soil moisture conditions. They simulated three event initial conditions: (1) They assigned the normal wetness condition with no pre-event water stored behind the structure. This is unlikely, as it would take an excessive period of high temperatures and no precipitation to empty this project; however, this situation would provide the maximum storage capacity available, representing an upper bound on flood mitigation potential; (2) The normal wetness condition with a normal pool initial storage condition. This represents the most likely circumstances; and (3) Modelers assigned the high wetness condition along with a normal pool initial storage condition. This condition represents a lower bound for peak flow reduction, as the soil has little holding capacity for this incoming heavy rainfall. In simulations of the project, it should be noted that water was allowed to flow downstream only by passing through the auxiliary spillway once the stored water reached that elevation, and the effect of the principal spillway (24" pipe) was neglected.

Figure 5.11 describes the peak discharge response from initial normal wetness conditions, with and without the flood detention structure. Without the flood detention structure, the peak flow was approximately 772 cfs, while maximum discharge for the empty project simulation was close to 444 cfs. The no-project simulation hydrograph displays a single peaked response, as flows from both stream segments shown combine to make a unified peak at the outlet. The "empty" pond simulation hydrograph also shows a single peak, with a reduction in peak discharge as the storage capacity if the pond were empty would hold all the runoff from the stream segment coming into the pond. In contrast, the predicted hydrograph for the simulation with an initial "full" pond shows two peaks (Fig. 5.11, blue line). Runoff from the area downstream of the project generated the first one, and the second peak is related to water flowing into the pond and then over the project's auxiliary spillway and arriving at the outlet later. The maximum peak flow reduction (no-project vs. "empty" project) under initial normal wetness conditions is approximately 43% at the outlet of the model domain. Under the "full" pond scenario, the reduction is essentially the same at about 43% when considering peak discharge reduction, as the pond still slowed the release of water from the stream segment coming into the pond, such that the peak from the downstream stream segment had already passed the outlet. The overall volume of water being passed through the outlet and downstream is more, as the volume required to "fill" the pond is not remaining in the pond.

As expected, under high soil wetness initial conditions, peak discharge is higher than it is under normal wetness conditions (Fig. 5.11 and Fig. 5.12). This is a result of limited capacity of the soil to store water, and most rainfall is converted into runoff. Comparison of the results presented in Figures 5.11 and 5.12 shows that under high soil wetness, peak flows are approximately 18% and 29% larger for the no-project and full-project simulations, respectively. Peak discharge reduction for the "full" pond scenario with high initial wetness conditions is approximately 33%. Model predictions show that the auxiliary spillway is activated faster with the high soil wetness initial condition. This explains why the blue line in Figure 5.12 shows a shorter falling limb after the first peak than that in Figure 5.11.

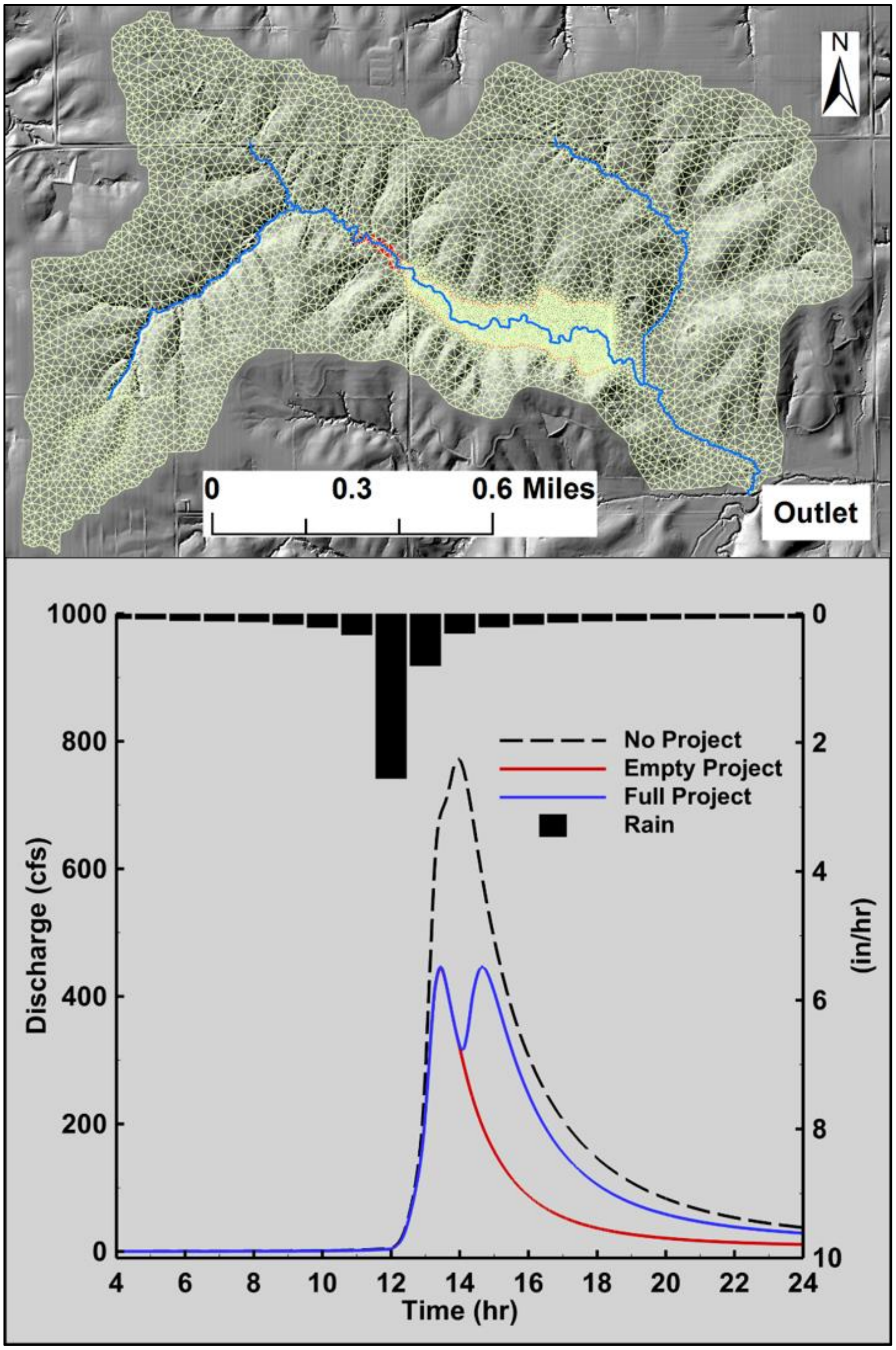


Figure. 5.11 Hydrographs at the outlet of the model domain. Fifty-year design storm under normal wetness initial condition.

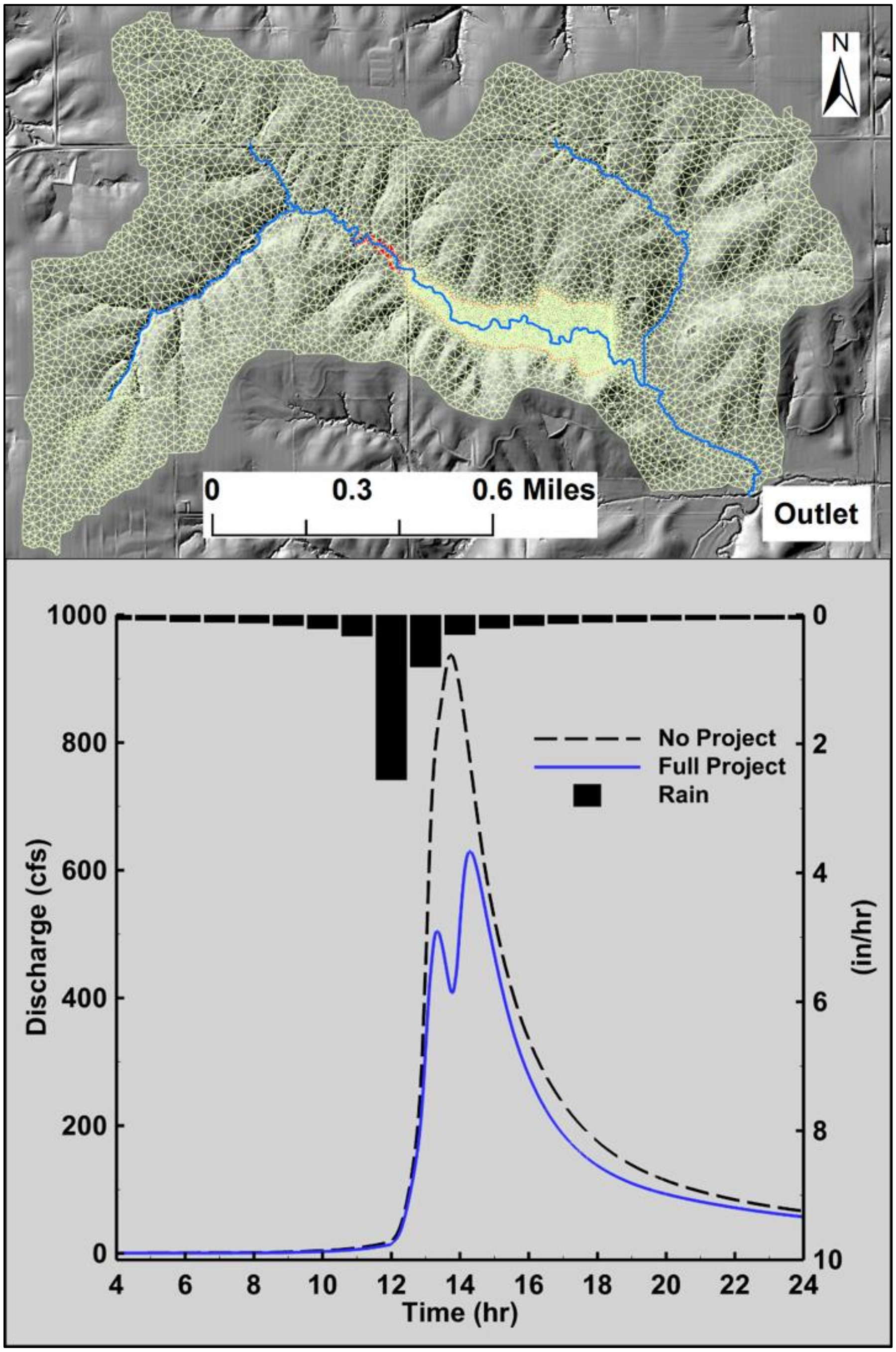


Figure. 5.12 Hydrographs at the outlet of the model domain. Fifty-year design storm under high wetness initial condition.

g. June 2008 Flooding

As documented in the Hydrologic Assessment of the Chequest Creek Watershed (IIHR, 2014), in June 2008, much of the state experienced flooding conditions. A cooler and wetter than average fall in 2007, followed by abundant snowfall over the winter of 2007–08 and a wet spring in 2008 preceded the 2008 flooding. By the time the thunderstorms that occurred in June arrived, the soil across much of the state was so wet that very little of the rainfall infiltrated into the ground, causing flooding after almost any rain event. One storm in early June in the adjacent Fox River Watershed was characterized by a basin wide average rainfall depth of approximately 3.93 inches in about 11 hours, producing a peak discharge of 8870 cfs at the USGS stream gauging station at Bloomfield, Iowa (on June 3).

Precipitation was slightly less within the South Chequest Watershed. Radar precipitation estimates show an average rainfall accumulation of about 2.8 inches over an 11-hour period on June 3, 2008. As the South Chequest Creek Watershed had no streamflow gauging instruments in 2008, this simulation is performed to estimate the watershed discharges during this exceptionally wet period.

June 2008 Rainfall

Researchers performed a HydroGeoSphere (HGS) simulation for June 2008 in the South Chequest Watershed to estimate the discharge of this past flood event. Wet conditions were present before the storm; the API was 0.80 inches, corresponding to the 0.81 percentile. Modelers initialized the simulation with output from the recursive 2014 simulation (fourth year) for June 7, as it is assumed that this provided a good representation of the initial wetness conditions in the watershed on June 1, 2008.

For the June 2008 simulation, researchers used Stage IV radar-rainfall estimates as the precipitation input (Figs. 5.13, 5.14, & 5.15). The National Center for Environmental Prediction (NCEP) produces the Stage IV dataset by taking Stage III radar-rainfall estimates from the 12 National Weather Service (NWS) River Forecast Centers across the continental United States and combining them into a nationwide 4 km x 4 km (2.5 mile x 2.5 mile) gridded hourly precipitation estimate dataset. Stage IV radar-rainfall estimates are available from January 2002–present.

The use of radar-rainfall estimates provides increased accuracy with regard to the spatial and temporal distribution of precipitation over the watershed. Stage IV estimates provide a level of manual quality control performed by the NWS that incorporates available rain gauge measurements into the rainfall estimates.

Figure 5.13 shows an example of the Stage IV radar-rainfall product. The cumulative rainfall estimated for each grid cell during an 11-hour period is shown (June 3, 2008, 00:00 am–11:00 am). 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. The entire Chequest Creek Watershed is shown, with the South Chequest Creek Watershed shaded in gray.

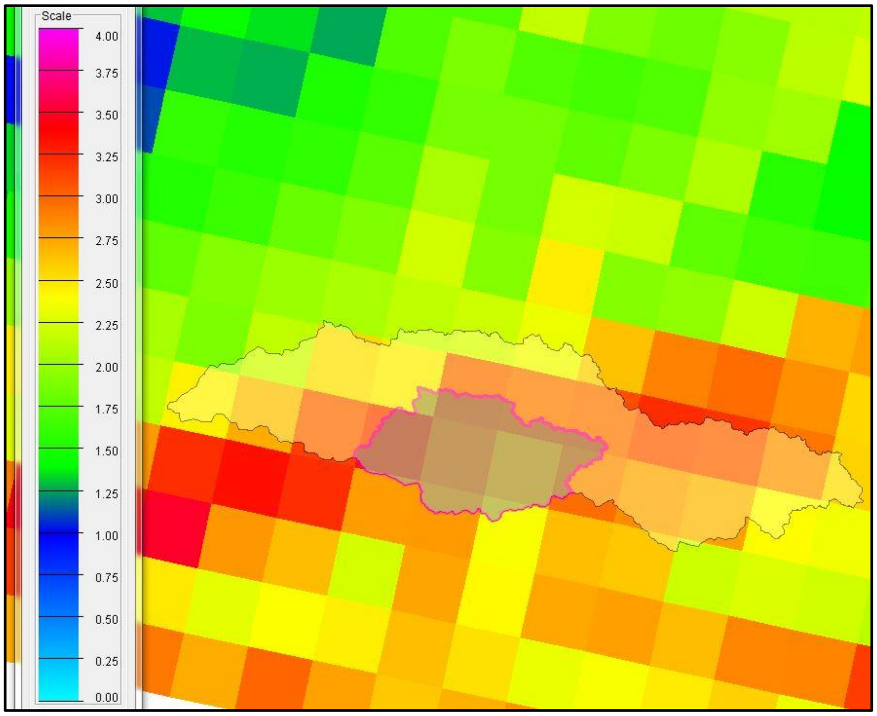


Figure. 5.13 NEXRAD Stage IV radar cumulative rainfall estimate for an 11-hour period on June 3, 2008.

Researchers resampled the 4 km-resolution gridded rainfall product to a raster dataset with approximately a 2 km-resolution. They then smoothed it such that computation elements within HGS would only have a single rainfall input value (no computation cell crosses a rainfall grid boundary) to ensure numerical stability. Figure 5.14 shows the cumulative rainfall distribution of the converted dataset for the same 11-hour period.

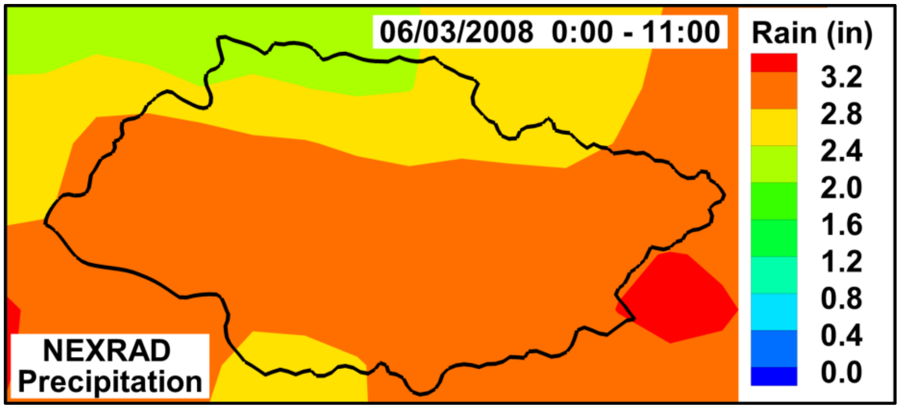


Figure. 5.14 NEXRAD Stage IV radar cumulative rainfall estimate after being resampled to a 2 km resolution raster dataset and smoothed for use in HydroGeoSphere.

Watershed Response

Heavy precipitation on the morning of June 3, 2008, induced a simulated peak flow rate of 5,909 cfs at the watershed outlet. The intensity and depths of rainfall across the watershed forced streams to rapidly rise. The middle panel in Figure 5.15 shows the predicted varying surface depth response to rainfall, on June 3, 2008, at 9:00 am NEXRAD Stage IV precipitation data estimates indicate about 9.3 inches of rain fell in the South Chequest watershed in June 2008. HGS simulations predict that approximately 68% of that precipitation was transformed into streamflow.

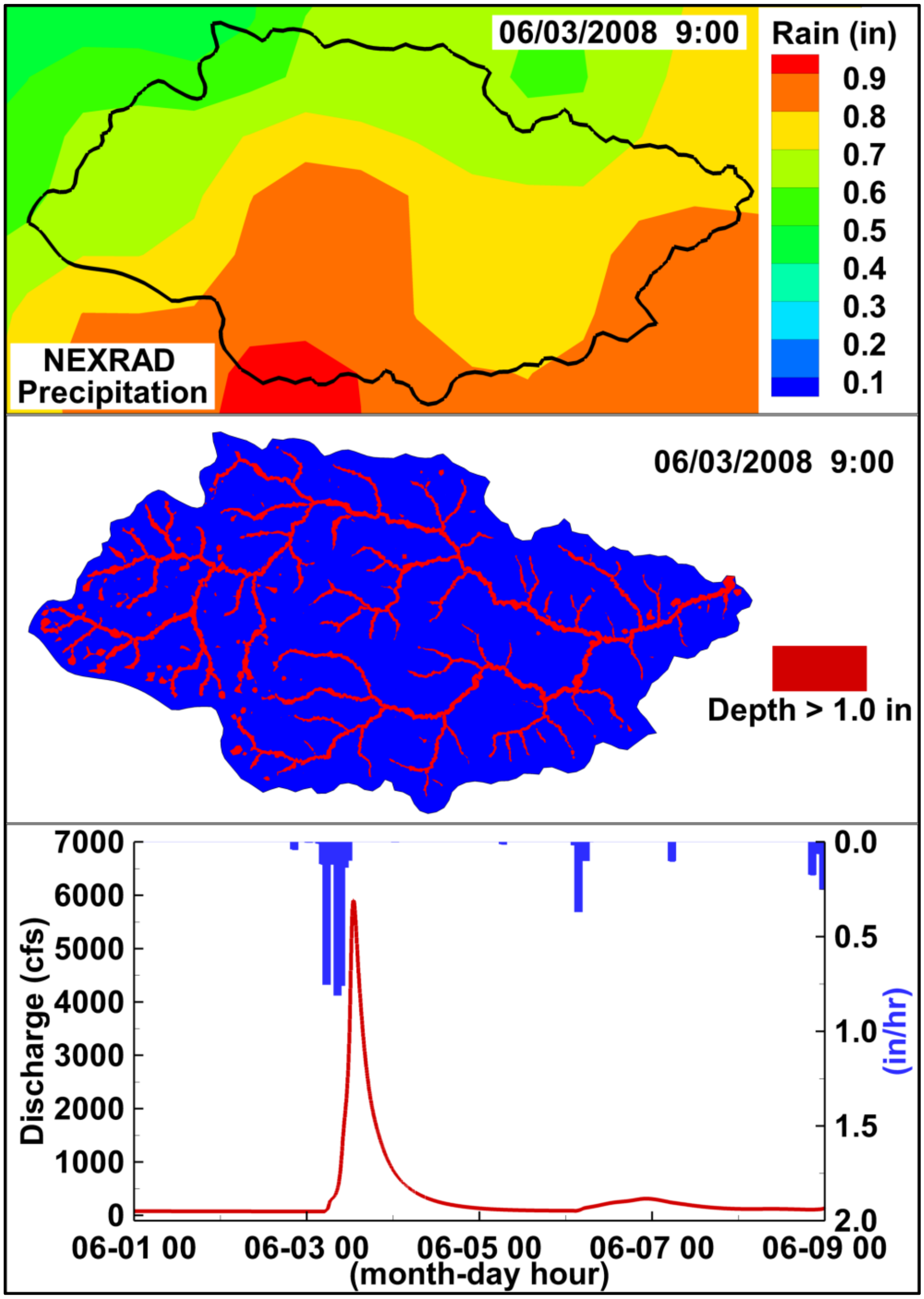


Figure. 5.15 South Chequest Creek Watershed response to NEXRAD Stage IV radar-rainfall for the June 3, 2008, flood event. Top: Rainfall on June 3 at 9:00 am; Middle: Stream inundation extent; Bottom: Resulting outflow hydrograph at South Chequest Creek Watershed outlet.

h. Summary and Conclusions

This chapter described the simulated results of the flood conditions that may have occurred in the watershed during June 2008. The chapter also gave a detailed look at the local project influence of one of the Iowa Watersheds Project Phase II flood mitigation structures during a synthetic heavy rainfall event under a range of soil and project storage initial conditions. The results indicated that for the modelled area (Figure 5.11 and 5.12) and under the best case scenario. the Smith project (see Table 4.1) could locally provide a 43% maximum peak flow reduction, decreasing to 33% under extremely wet initial conditions.

Physically-based coupled surface-subsurface modeling offers many capabilities important to investigations of flood mitigation strategies. Physics-based modeling offers a fundamental approach to fluid movement though the surface and subsurface domains, where surface and subsurface domains are parameterized by known measurable quantities. The model physically represents baseflow through subsurface-surface exchange. Furthermore, these incorporations allow for long-term simulations to be performed, and antecedent moisture and pre-event storage can be investigated in a realistic manner. Projects could be incorporated into the model through altered elevations mimicking the construction of the flood mitigation project. Inundation extents are dynamically formed and can be evaluated continuously.

The drawback to this style of modeling is the extensive time required to set up and calibrate the model. Simulation run times often exceed three days for a year of simulation time, reducing the model’s capability to handle long-term datasets within a reasonable timeframe. Chapter 6 will investigate the flow reduction potential at each pond location, as well as the additive flow reduction of all the projects at the larger basin scale.

Another style of modeling can better complete the task of evaluating the performance of each of the Phase II flood mitigation structure during different rainfall events, as well as the cumulative influence of the projects on flood discharges at downstream locations. The next chapter describes a simplified approach to incorporate realistic fluid dynamics without comprehensively solving the fundamental equations of fluid mechanics. This approach allowed for reduced computational time, more hypothetical and historical simulations, and a comprehensive view of peak flow reduction within the watershed.

6. Simulation of Flood Control Project Performance

The Iowa Flood Center used the U.S. Army Corps of Engineers' Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), a mathematical lumped-parameter hydrologic model, to evaluate Chequest Creek Watershed's response to different rainfall scenarios in the Iowa Watersheds Project Phase I. Model development and calibration is detailed extensively in the Phase I Hydrologic Assessment of the Chequest Creek Watershed (IFC, 2014). Modelers updated and enhanced the HMS model to contain only elements from the South Chequest Creek Watershed and to include the flood mitigation projects from the Iowa Watersheds Project Phase II. In addition, installation of the Iowa Flood Center's stream-stage sensor made further validation of the modeling system's calibration possible.

a. Model Configuration

The South Chequest Creek Watershed as modeled using HEC-HMS is approximately 31.2 square miles. For modelling purposes, researchers divided the watershed into 126 smaller units, called sub-basins in HMS, with an average of about 0.25 square miles, but as large as 1.05 square miles. They directly transferred watershed parameters from the calibrated parameters developed in the Phase I modeling effort.

Researchers included five existing NRCS designed ponds (within the South Chequest Creek Watershed) in the Phase I HEC-HMS model. These were carried forward to remain in the Phase II HEC-HMS model. Researchers compiled the Stage-Storage-Discharge relationships of these ponds based on the best information available. Appendix C of this report provides this information. Please refer to Chapter 4 for description of the new Phase II flood mitigation ponds. The Stage-Storage-Discharge relationships of the new ponds can be referenced from Appendix A. Figure 6.1 shows the sub-basin configuration, along with the locations of Phase II flood mitigation projects and the existing NRCS designed ponds.

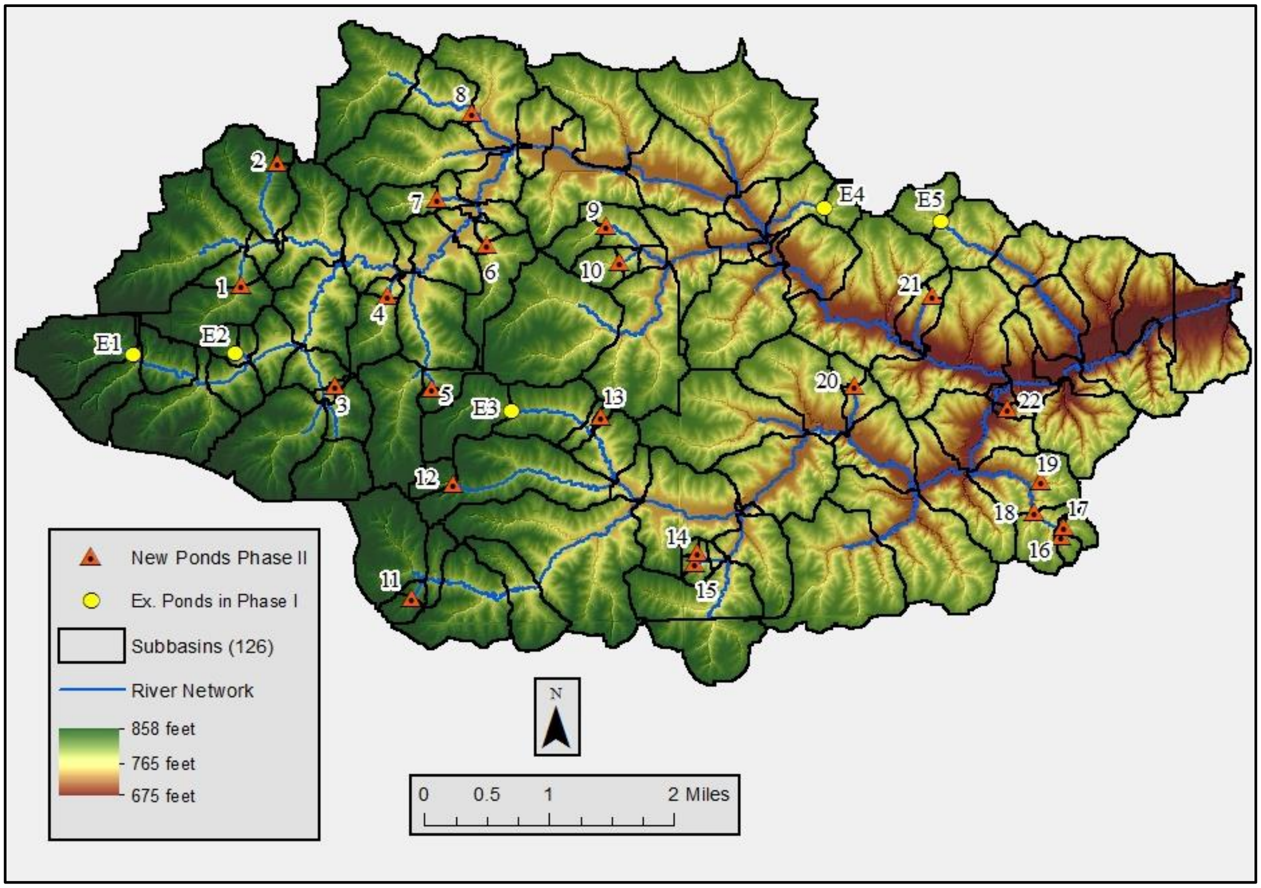


Figure 6.1. HMS model development of the South Chequest Creek Watershed. Researchers divided the watershed was divided into 126 sub-basins for modeling.

b. Rainfall Inputs

Modelers used Stage IV radar-rainfall estimates as the precipitation input for all simulations of actual (historical) rainfall events that occurred within the watershed. The National Center for Environmental Prediction (NCEP) produced the Stage IV data by taking Stage III radar-rainfall estimates produced by the 12 National Weather Service (NWS) River Forecast Centers across the continental United States and combining them into a nationwide 4 km x 4 km (2.5 mile x 2.5 mile) gridded hourly precipitation estimate dataset. These data are available from January 2002 – present. The use of radar-rainfall estimates provides increased accuracy of the spatial and temporal distribution of precipitation over the watershed. Stage IV estimates provide a level of manual quality control performed by the NWS that incorporates available rain gauge measurements into the rainfall estimates. Actual storms using Stage IV data were the basis for model calibration and validation in the Phase I Hydrologic Assessment. Figure 6.2 shows the gridded cumulative rainfall estimates for the storm occurring June 7, 2014, in the South Chequest Creek Watershed. The entire Chequest Creek Watershed is shown, with South Chequest Creek Watershed shaded in gray.

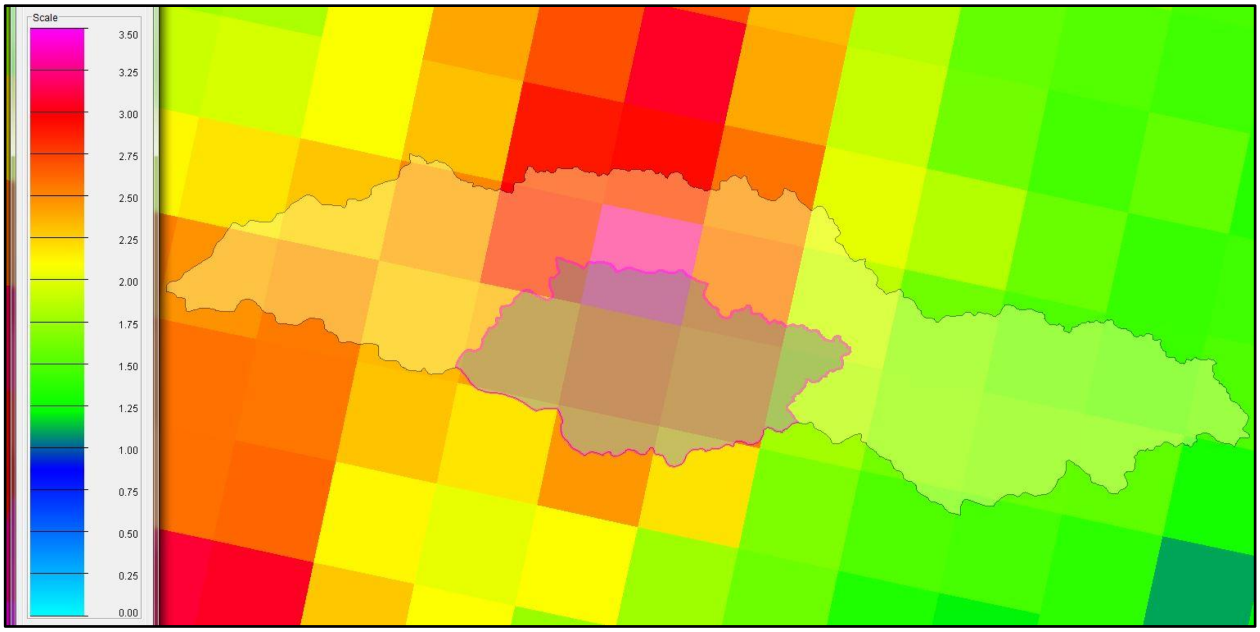


Figure 6.2. Demonstration of the gridded Stage IV radar-rainfall product used as the precipitation input for historical storms in the South Chequest Creek HMS model. The Stage IV product provides hourly rainfall estimates for each 4 km x 4 km grid cell. The scale shown refers to the total depth of rainfall (in inches) estimated for a nine hour period (June 7, 2014, 10 am to 7 pm).

Hypothetical storms were developed for comparative analyses such as project performance based on known rainfall amounts. 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. Precipitation values (rainfall depths) for 10-, 25-, 50-, and 100-year average recurrence interval, 24-hour storms were derived using the online version of NOAA Atlas 14 – Point Precipitation Frequency Estimates (NOAA, 2013). The 24-hour rainfall depths used are 4.4 inches, 5.4 inches, 6.3 inches, and 7.2 inches respectively. The peak discharge reduction at the South Chequest stream-stage sensor after adding the Phase II flood mitigation projects is also presented for these storms, however the likelihood of getting uniform rainfall (in time and space) across the watershed is pretty unlikely.

c. South Chequest Model Validation

With the addition of the IFC South Chequest stream-stage sensor, IFC engineers used the stage (elevation) readings from the sensor along with discharge measurements and HEC-RAS, a one-dimensional hydraulic model to develop a rating curve used to convert stage measurements to discharge estimates. Use of radar-rainfall estimates for the event shown on June 7, 2014 were used to further validate the hydrologic model beyond what was done in the Phase I Hydrologic Assessment.

Rainfall started in the western end of the watershed at approximately 10 am. The storm moved from west to east, with rainfall occurring across the entire watershed by 11 am. The heaviest rainfall occurred between 11 am and 1 pm. Figure 6.3 shows the observed stream-stage readings at the IFC stream-stage sensor in the upper hydrograph. The initial stream-stage response was observed at about 11:30 am. This is assumed to be rainfall near the sensor site. A rapid rise is observed to begin at about 12:45 pm, coinciding with the heaviest rainfall in the watershed. Peak stream stage was observed at 10 pm, and then the stream receded over the next 18–20 hours.

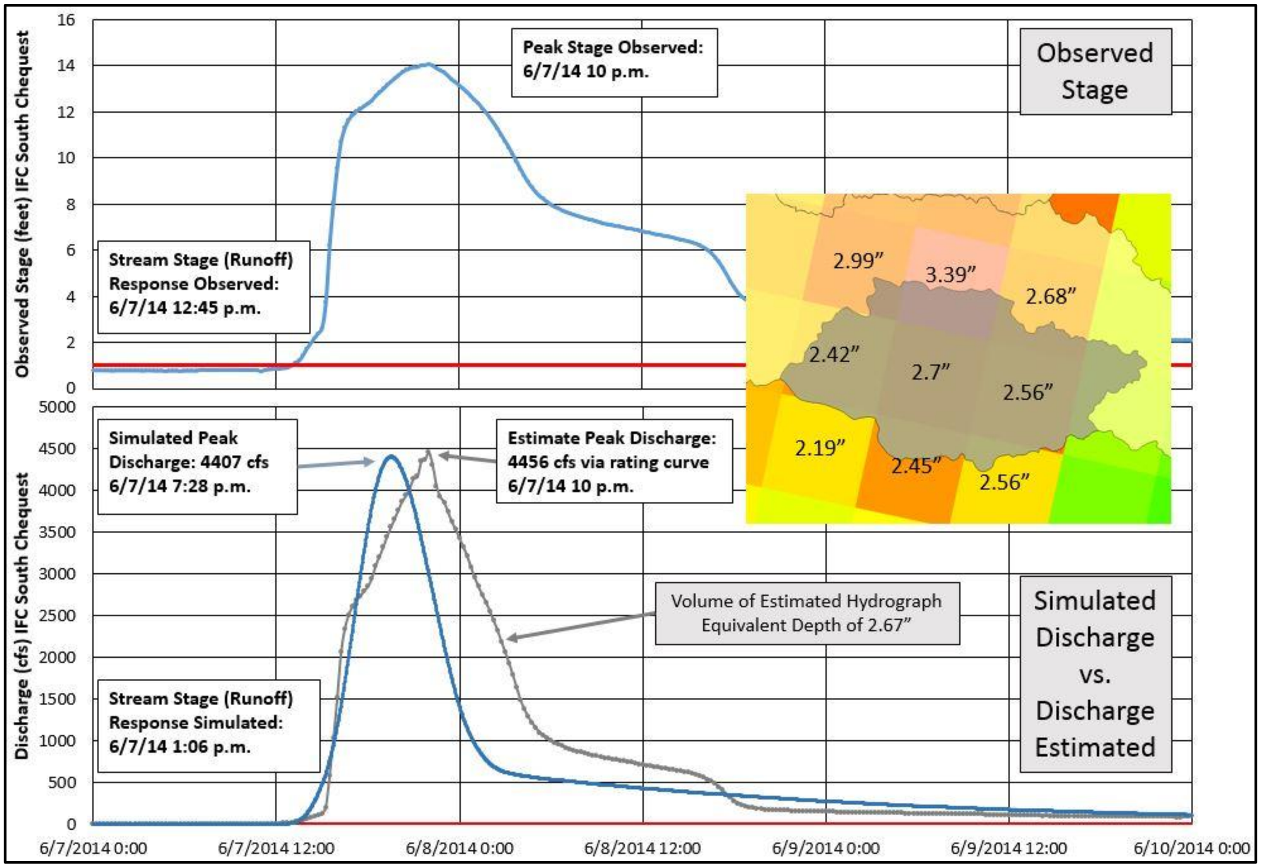


Figure 6.3. Stream response to rainfall at the IFC South Chequest stream-stage sensor on June 7, 2014. Top hydrograph shows the observed stage. Bottom hydrographs show the estimated discharge (gray, dotted line) using a rating curve developed for the sensor site and the HMS simulated discharge (blue, solid line).

The rapid stream response coinciding with the beginning of the heavy rainfall indicates that very little of the rainfall was considered as initial abstraction — that fraction of rainfall that generally falls before runoff is observed. In most instances, some rainfall goes to wetting the surface soil, filling surface depressions, and plant interception. Based on soil moisture measurements provided by the IFC rain gauge and soil moisture platforms and looking at previous rainfall in the watershed leading up to this June 7, 2014, rainfall event, researchers determined that the watershed was already in an above average anteceded soil moisture condition. The only adjustments to the HEC-HMS model parameters to produce the simulated hydrograph shown above was to make this adjustment to reflect the above average soil moisture. The estimated discharges obtained from the rating curve are trusted and assumed to be a reasonable estimate of discharge. This event helps validate the rating curve as well. For example, in Figure 6.3, if we look at the hydrograph for the estimated discharge based on the rating curve (gray, dotted line) and compute the volume of water passed during this event, we find that an equivalent depth of rain across the watershed area to reach this volume would be 2.67 inches. In looking at the cumulative rainfall distribution from radar estimates for the event, we see the average rainfall across the basin is 2.77 inches, with higher rainfall totals in the north central part of the watershed and less elsewhere. Generally in hydrologic analysis, we would not expect to see all the rainfall pass through the system as streamflow this quickly. But with above average soil moisture in the watershed, the value indicates a reasonable approximation for discharge using the rating curve.

Chapter 5 discussed how the physically-based hydrologic model HydroGeoSphere also simulated this event. A comparison of the results from the complex, fully-coupled model to those from the South Chequest HEC-HMS model shows that the two modeling platforms simulate the discharge from this event with similar results.

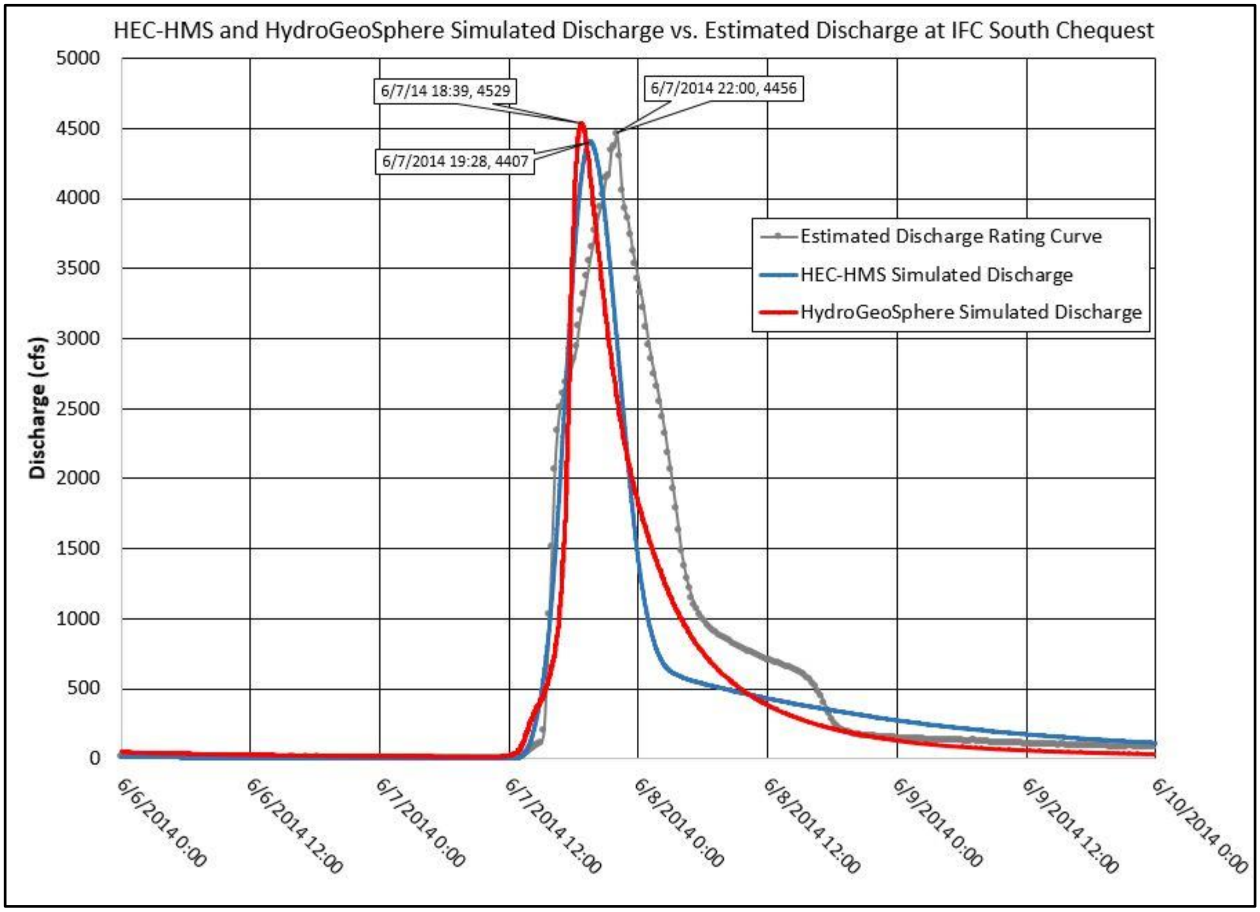


Figure 6.4. Stream response at the IFC South Chequest stream-stage sensor to rainfall occurring June 7, 2014. The hydrographs show the estimated discharge (gray, dotted line) using a rating curve developed for the sensor site and the HEC-HMS simulated discharge (blue, solid line) and HydroGeoSphere simulated discharge (red, solid line).

This validation exercise provides further confidence in the HEC-HMS model for the South Chequest Watershed and its use to evaluate the performance of the Iowa Watersheds Project Phase II flood mitigation structures.

d. Evaluation of the Flood Mitigation Projects

The updated HEC-HMS model created for the South Chequest Creek Watershed is a useful tool to rapidly assess the performance of the flood mitigation projects (ponds) constructed in the watershed as a part of the Iowa Watersheds Project Phase II. It is also a powerful tool to assess future potential flood reduction through creation of a hypothetical analysis in which additional ponds can be distributed across the watershed to analyze the potential additional reduction to peak flood discharges beyond what is experienced with the newly constructed Phase II projects.

Pond Performance with Hypothetical Rainfall

In general, ponds like the flood mitigation projects in South Chequest Creek Watershed are typically designed to have the auxiliary spillway able to safely pass the runoff generated by a 50-year average recurrence interval design storm without having the water surface in the pond get near the top of the dam. This section will discuss the evaluation of the 50-year rainfall (6.3 inches) of an SCS Type-II 24-hour storm in detail. Appendix D of this report will include similar results from the other return period storms.

The addition of flood mitigation ponds to the HEC-HMS model reduced peak flood discharges across the watershed. At the outlets of sub-basins in which the ponds have been included, the peak discharge reductions ranged from 66.7 to 93.8%. On a local scale, these ponds have had a significant impact to the discharges observed immediately downstream of each project. As you move further downstream from the project site, more direct runoff occurs from areas that are not routed through a pond, and the stream discharge increases. As you get to the IFC South Chequest Creek stream-stage sensor near the confluence with the north branch of Chequest Creek, the reduction in peak discharge as a result of the 22 flood mitigation ponds in the watershed is 9.3%.

Figure 6.5 shows the simulated hydrographs at the South Chequest stream-stage sensor for a 50-year rainfall, with and without the new flood mitigation ponds. The figure also shows another plot in the upper right corner illustrating the peak discharge reductions for all return period design storm rainfalls analyzed. As the rainfall depths increase, the peak flood discharge reduction increases up to the 50-year event, as the flood storage provided by the flood mitigation projects is maximized. The 100-year event realizes essentially the same percent reduction in peak discharge as the 50-year event.

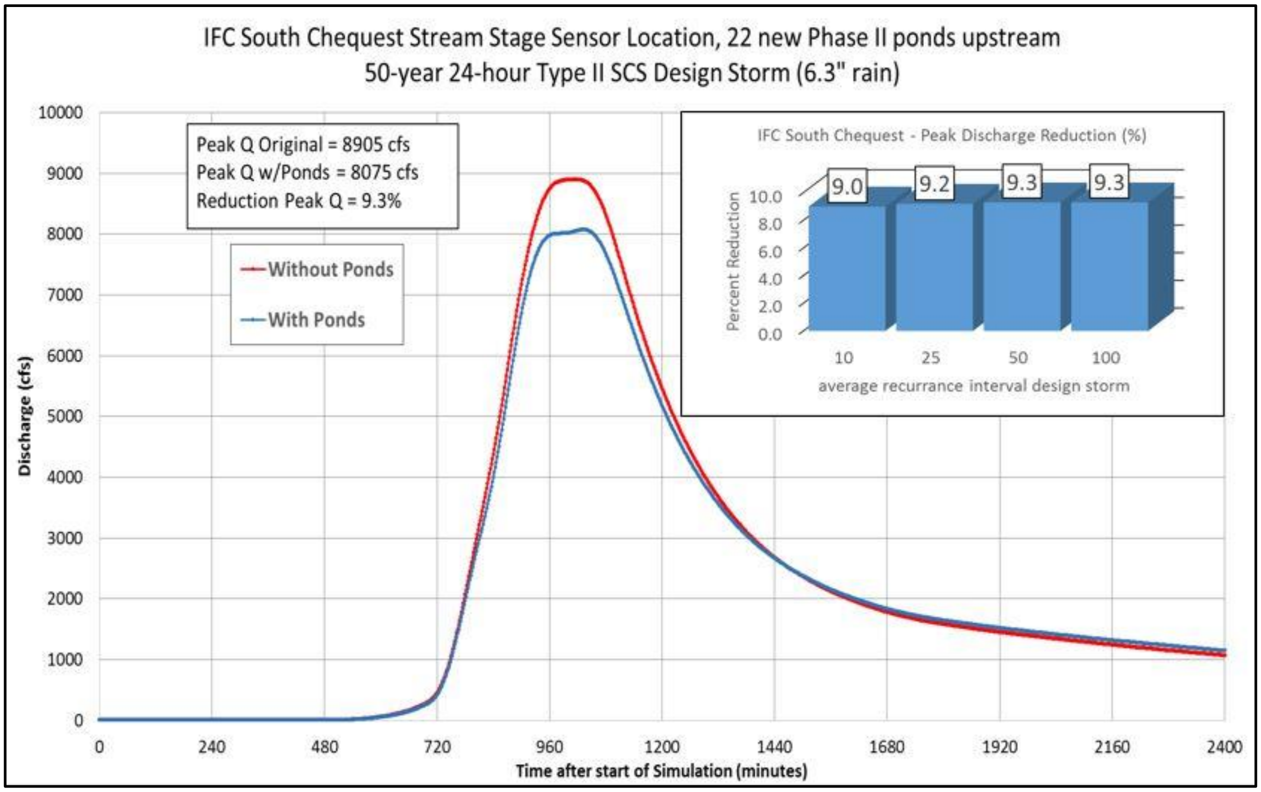


Figure 6.5. Simulated hydrographs at the IFC South Chequest stream-stage sensor to the 50-year average recurrence interval design storm (6.3" of rain) for the without and with new ponds scenarios.

For the 50-year event, all but three ponds had flow coming from the auxiliary spillway. In other words, an event of this magnitude would use almost all the potential flood storage in the watershed. For most ponds, the depth of flow in the auxiliary spillway ranged from 0.5 to 1.3 feet deep. This is precisely what one would expect based on the design standards. However, we can look at the potential total storage in the watershed (the storage from the principal spillway to the top of dam of each structure) and see that an event of this size uses approximately 68% of the potential total storage available. Table 6.1 summarizes the performance of the 22 projects with the 50-year 24-hour rainfall (6.3 inches).

All auxiliary spillways activated during the 100-year event, as expected. No dams overtopped with this event, thus the designed auxiliary spillways provided adequate relief for the volume of runoff coming into the ponds; 79% of the potential total storage was used.

Table 6.1. Pond performance of the Iowa Watersheds Project Phase II flood mitigation projects in the South Chequest Creek Watershed. The table shows performance for the 50-year, 24-hour design storm (6.3 inches of rain).

Pond ID #	***Auxiliary Spillway (A.S.) Elevation (ft)***	***Max. Water Surface Elevation (ft)***	***A.S. Activated***	***Flood Storage Used (%)***	***Total Storage Used (%)***	***Peak Discharge Reduction (%)***
1	802.8	802.16	No	86.7	60.2	82.3
2	827.4	828.08	Yes	100	52.3	88.9
3	813.0	813.32	Yes	100	35.2	66.7
4	776.5	776.90	Yes	100	67.1	84.8
5	809.0	809.71	Yes	100	69.9	92.4
6	767.8	769.03	Yes	100	85.8	82.9
7	775.4	776.25	Yes	100	76.4	92.5
8	761.2	761.15	No	99.9	64.9	81.4
9	781.6	781.82	Yes	100	65.0	82.6
10	773.2	774.28	Yes	100	82.7	90.3
11	821.6	822.63	Yes	100	78.8	89.4
12	826.3	827.10	Yes	100	70.2	80.0
13	805.7	806.10	Yes	100	46.7	80.0
14	792.5	792.65	Yes	100	32.5	91.8
15	793.4	792.98	No	66.1	24.9	80.0
16	778.8	779.53	Yes	100	71.8	92.8
17	776.5	777.56	Yes	100	69.5	82.3
18	751.6	752.95	Yes	100	82.9	83.3
19	750.3	751.31	Yes	100	62.9	80.0
20	766.2	767.06	Yes	100	65.8	93.8
21	765.0	765.75	Yes	100	57.2	90.0
22	719.0	719.49	Yes	100	48.5	87.5

Pond Performance with Radar-rainfall

The Iowa Watersheds Project Phase II flood mitigation structures can also be analyzed using past rainfall events. This provides perspective as to what level of peak discharge reduction might be achieved when rainfall is not uniform in space and time. The non-uniformity of rainfall leads to the percent reduction in peak discharges dependent on the location, rainfall amount, rainfall intensity, and timing of the rain storm. This section details the June 7, 2014, event.

For this rain event, none of the ponds would have reached their auxiliary spillway. Thus, any discharge from the pond structures would have flowed through the principal spillway only. Because water levels did not reach the auxiliary spillway at the structures, this event would have only used approximately 56% of the available flood storage provided; only approximately 34% of the potential total storage was used. Figure 6.6 shows the simulated hydrographs at the South Chequest stream-stage sensor for the without and with new flood mitigation ponds as well as the June 7, 2014, rainfall if the ponds had been constructed in the watershed by then. Using the IFC-developed rating curve to convert stage to discharge, we can invert that and convert simulated discharges to stage. The flood mitigation structures provided flood reduction to reduce the water surface elevation by approximately 0.4 feet at the location of the IFC stream-stage sensor. Table 6.2 summarizes the performance of the 22 projects with the June 7, 2014, rainfall.

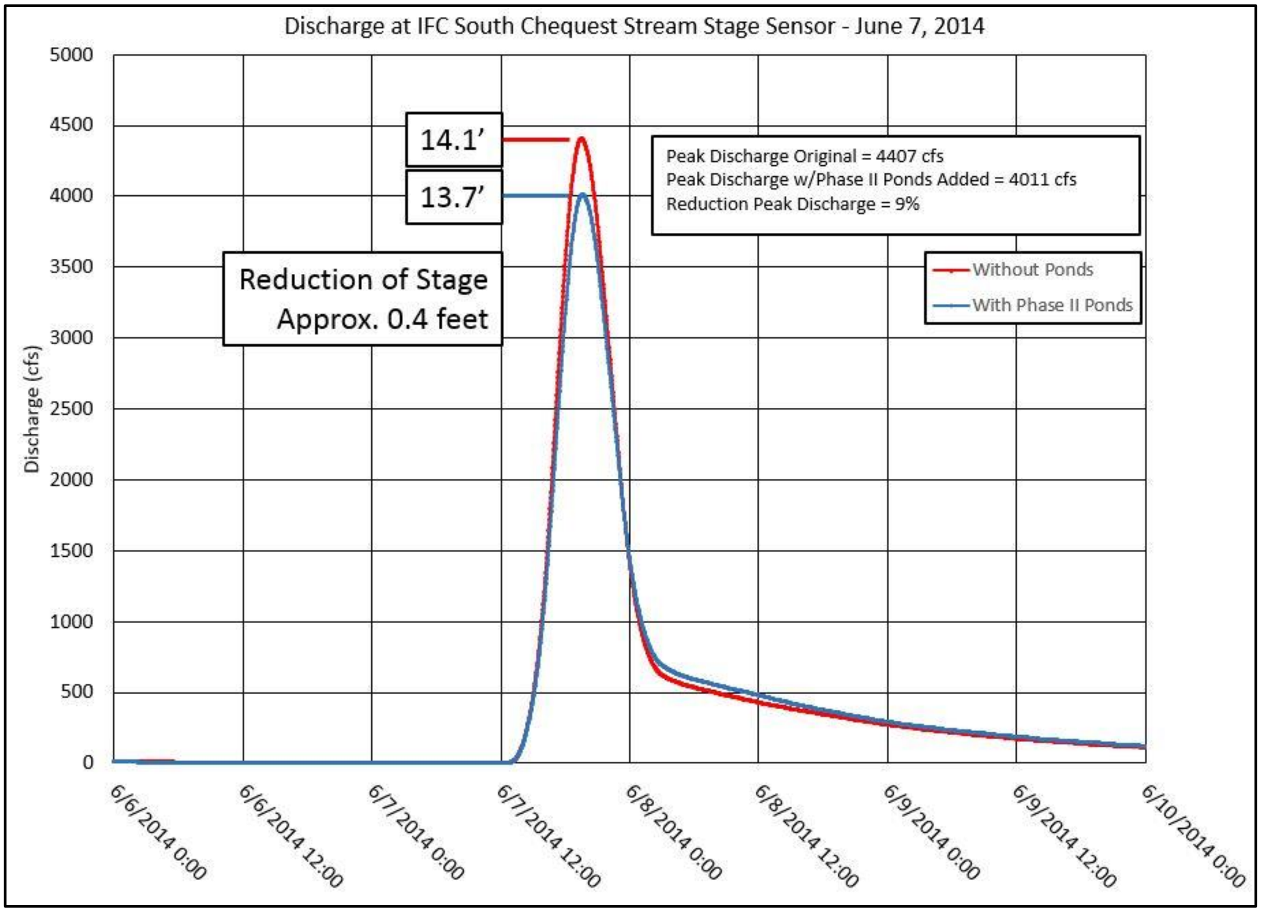


Figure 6.6. Simulated hydrographs at the IFC South Chequest stream-stage sensor to the June 7, 2014. rain event for the without and with new ponds scenarios.

Table 6.2. Pond performance of the Iowa Watersheds Project Phase II flood mitigation projects in the South Chequest Creek Watershed. Performance shown is for the June 7, 2014, rainfall event if the ponds had been constructed in the watershed by then.

Pond ID #	***Auxiliary Spillway (A.S.) Elevation (ft)***	***Max. Water Surface Elevation (ft)***	***A.S. Activated***	***Flood Storage Used (%)***	***Total Storage Used (%)***	***Peak Discharge Reduction (%)***
1	802.8	800.52	No	53.3	37.6	65.2
2	827.4	827.10	No	83.6	30.5	67.6
3	813.0	812.66	No	69.8	20.9	68.6
4	776.5	775.26	No	66.6	41.0	76.9
5	809.0	808.07	No	59.1	31.1	66.7
6	767.8	766.07	No	60.2	39.1	71.4
7	775.4	773.62	No	61.6	40.0	80.0
8	761.2	759.19	No	53.2	35.2	57.1
9	781.6	780.18	No	38.9	29.7	48.6
10	773.2	771.33	No	61.1	38.8	85.7
11	821.6	820.54	No	66.3	36.8	75.0
12	826.3	825.13	No	55.6	29.9	66.7
13	805.7	805.12	No	55.9	16.0	68.6
14	792.5	791.67	No	30.8	9.5	77.1
15	793.4	792.32	No	22.6	8.3	64.3
16	778.8	775.92	No	23.0	12.5	48.6
17	776.5	775.26	No	41.8	19.8	69.6
18	751.6	747.70	No	26.3	16.6	50.0
19	750.3	749.02	No	44.4	18.0	77.4
20	766.2	765.09	No	44.5	19.0	80.4
21	765.0	764.76	No	68.4	20.4	84.5
22	719.0	718.50	No	46.3	14.2	60.0

e. Additional Hypothetical Ponds to Further Increase Peak Flood Reduction

We can apply the HEC-HMS model to assess possible further peak flood discharge reduction by adding additional hypothetical structures in the watershed. This type of effort does take some generalization and assumptions, however. Construction of any future flood mitigation structures, such as the Iowa Watersheds Project Phase II projects, will depend on landowner willingness; this may dictate the placement more than maximization of flood reduction. Also, the local site survey will determine the stage-storage relationship for each structure; this cannot be anticipated in advance.

For this analysis, researchers developed a "typical" pond based on one similar to the average stage-storage relationship of the ponds constructed in the watershed as part of Phase II of the Iowa Watersheds Project. Researchers assigned the pond a 12-inch pipe as the principal spillway; it has a 10-foot wide, retardance Class B auxiliary spillway. Appendix B of this report provides the stage-storage-discharge relationships of the "typical" pond.

The influence of the ponds has been placed at the approximate center of headwater sub-basins (of the South Chequest Creek HEC-HMS model) without other flood mitigation projects. Opportunities certainly do exist to design and construct ponds in sub-basins not identified in this analysis; likewise, some identified here may not work for ponds. This analysis is meant to provide a glimpse of the potential impact of adding additional structures to the distributed storage system in the watershed. In Figure 6.7, modelers selected the sub-basins highlighted in pink for the addition of hypothetical ponds to assess potential future additional flood reduction. They selected some sub-basins for more than one flood mitigation structure, based on their size. The number shown in the sub-basin is the number of "typical" ponds considered in the analysis.

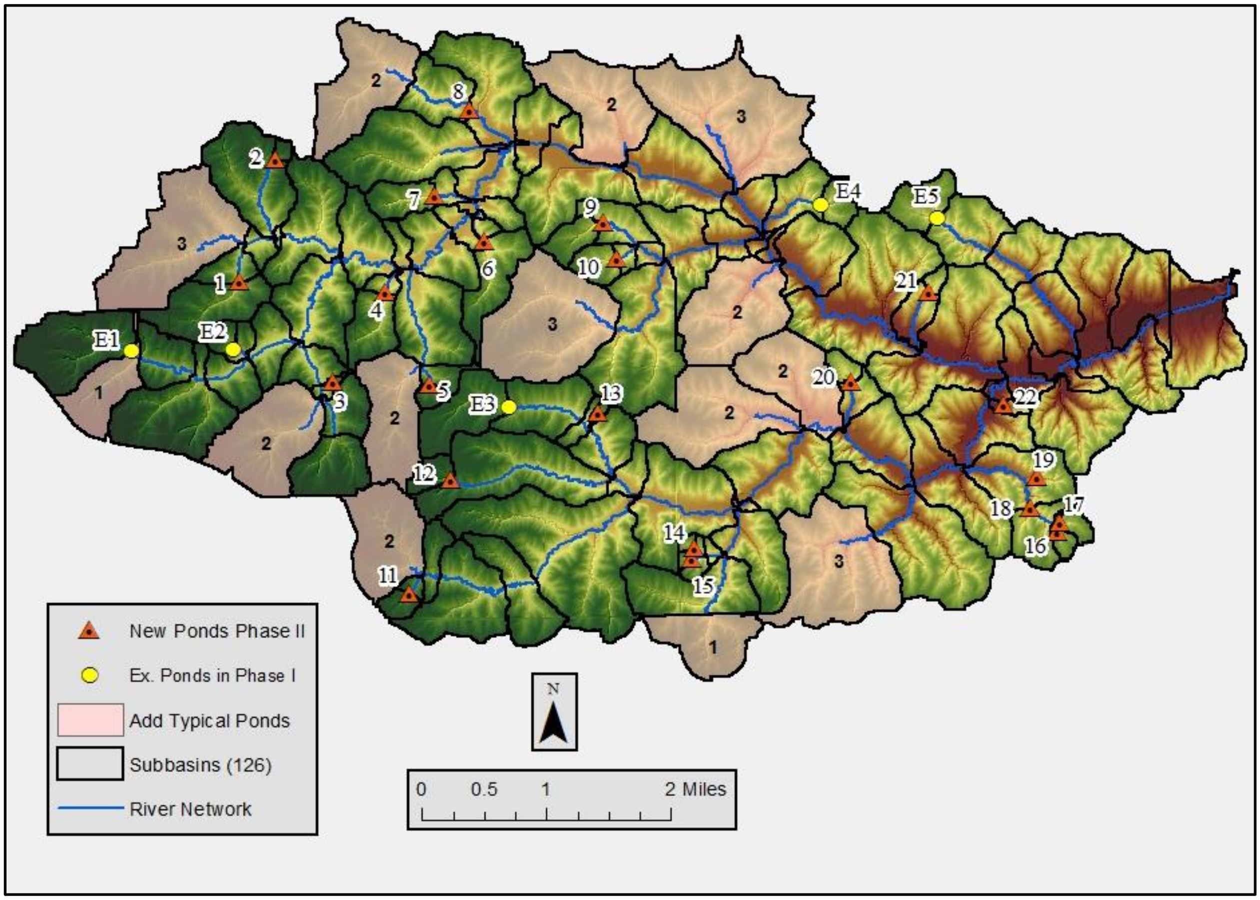


Figure 6.7. Sub-basins selected to for the addition of hypothetical ponds to assess potential future flood reduction beyond what was achieved by the Iowa Watersheds Project Phase II flood mitigation structures.

Figure 6.8 shows the result of adding 30 additional "typical" ponds to the watershed, which would be quite a large investment. However, additional flood reduction potential is achievable in the South Chequest Watershed. In this scenario, an additional 8.5% reduction in the peak flood discharge was simulated, bringing the total reduction from the June 7, 2014, event to 17.5% and a reduction in water surface elevation of approximately 1 foot. It should be noted, again, that actual flood reduction potential will be based on placement of the flood mitigation structures, how much storage is available at the location, and the rainfall characteristics.

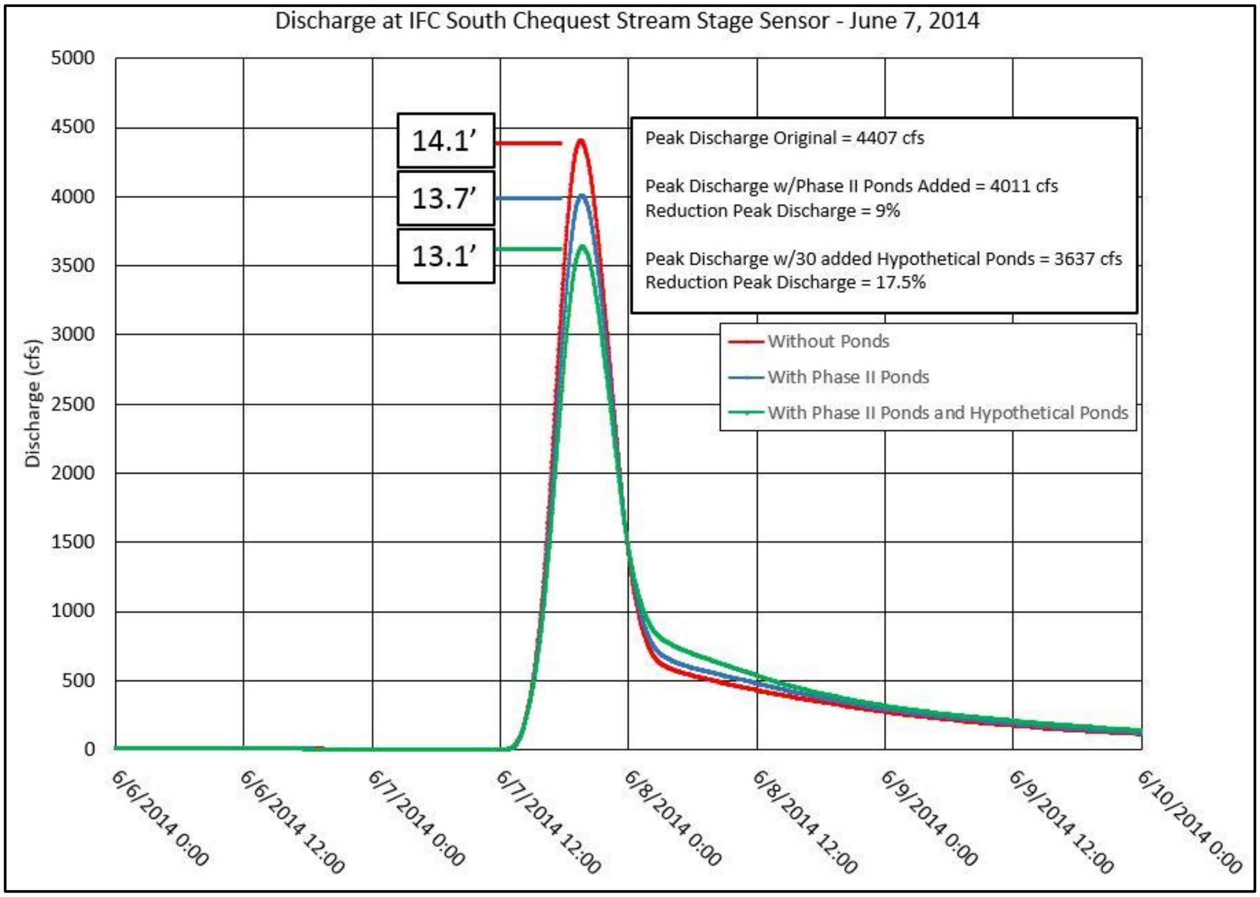


Figure 6.8. Simulated hydrographs at the IFC South Chequest stream-stage sensor to the June 7, 2014, rain event for the without and with new Phase II ponds scenarios, plus an additional hydrograph showing the addition of 30 more hypothetical “typical” ponds.

f. Summary

The historical hydrology of the native tall-grass prairie is well documented, and evidence suggests that the prairie could handle up to six inches of rain without significant runoff. This was a result of the deep, loosely-packed, organically-rich soils and the deep root systems of the prairie plants that allowed a high volume of the rainfall to infiltrate into the ground. Southeast Iowa is known to have higher-clay content, lower-infiltration soils that drive much of the runoff processes in the South Chequest Creek Watershed; however, a portion of this area was once home to tall-grass prairie. The root structure and increased organic material in the soil in a prairie landscape would have provided slightly better infiltration rates and a capacity to hold more water than what can be found in the watershed today. The Iowa Watersheds Project is not suggesting that agricultural lands should revert back to tall-grass prairie; rather, the intent is to identify and evaluate strategies to reduce peak flood discharges through a suite of conservation practices, while working in harmony with agriculture.

Using ponds to temporarily store floodwaters could be considered an attempt to replace the loss of water that was once stored in the soils in the pre-agricultural landscape. The completed projects in the South Chequest Creek Watershed build resiliency in the agricultural landscape and have been embraced by the land owners that participated in the project. The projects constructed provide multiple benefits both on- and off-site. Landowners enjoy the farm ponds on their property for their aesthetic beauty, recreational uses, and the wildlife they attract. In addition, landowners can use the ponds to water livestock and control erosion on their land. The South Chequest Creek Watershed projects serve as demonstration projects for other landowners to help them understand what the projects consist of, as the Chequest Creek Advisory Board and the Davis County Soil and Water Conservation District look to implement the practices in other locations across the entire Chequest Creek Watershed.

Researchers used the HEC-HMS model developed for the South Chequest Creek Watershed to simulate runoff scenarios and evaluate the performance of the flood mitigation projects. Peak discharge reductions at the projects ranged from 66.7–93.8%. On a local scale, these ponds have had a significant impact to the discharges observed immediately downstream of the pond site. As you move further downstream from the project site, more direct runoff occurs from areas that are not routed through a pond, and the stream discharge increases. As you get to the IFC South Chequest Creek stream-stage sensor near the confluence with the north branch of Chequest Creek, the reduction in peak discharge as a result of the 22 flood mitigation ponds in the watershed ranges 8–9.5%, lowering the depth of water found in the floodplain. Thus, researchers have found that the pond structures can provide significant savings in federal, state, and local road and bridge maintenance costs by managing runoff to reduce and mitigate structural and nonstructural flood damage.

7. Summary and Conclusions

The Iowa Flood Center (IFC), a unit of the University of Iowa's IIHR—Hydroscience & Engineering (IIHR) , has collaborated with the Chequest Creek Advisory Board and the Davis County Soil and Water Conservation District in Phase II of the Iowa Watersheds Project. Phase II involved the development and construction of flood mitigation projects within the South Chequest Creek Watershed, a subwatershed of Chequest Creek. In this report, IFC researchers evaluated the flood mitigation performance of proposed projects through monitoring and detailed hydrologic modeling. The team developed small-scale hydrologic simulations for the South Chequest Creek Watershed using a more detailed representation of the watershed and flood mitigation strategies than what was used in the Phase I study of the entire Chequest Creek Watershed.

a. Monitoring Stations and Data Collection

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

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

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

b. Constructed Projects

In 2014, researchers allocated $1,050,000 to the South Chequest Creek Watershed to plan, design, and construct 22 farm ponds to reduce flood damage. The projects reduce flooding by increasing the storage capacity on the landscape and also improve water quality through nutrient processing. The ponds also provide tertiary benefits to landowners, such as improving the accessibility of their land, decreasing erosion, providing a source of water for livestock, and creating an area for recreation and personal enjoyment. Lastly, they add aesthetic beauty to the land and create abundant habitat for wildlife. The constructed projects act as demonstration sites to promote the adoption of additional best management practices (BMPs) and serve as locations for education and outreach opportunities.

Volunteer landowners received 75% cost share assistance on constructed projects. The project designs follow Natural Resource Conservation Service (NRCS) specifications and guidelines, and the projects come with a 20-year maintenance agreement. With guidance from the staff at the Davis County Soil and Water Conservation District in Bloomfield, Iowa, and consultation with the Iowa Flood Center, the projects were sited on the landscape at the landowner's discretion.

c. Evaluation of Project Performance

Researchers evaluated the performance of the constructed projects using two hydrologic models. The South Chequest Creek HydroGeoSphere (HGS) model is a high-resolution physics-based model that continuously simulates water storage and movement within the watershed at nearly 30,000 grid elements. It can track the movement of water flowing over the land surface and in the subsurface (soils). The model can simulate flows through each of the projects for hypothetical design storm rainfall, and can use radar-rainfall estimates to analyze actual past rainfall events.

Since such a detailed model can take several days of computer time to simulate a year's worth of conditions, researchers also used a simpler model to evaluate project performance during a shorter specified time window when a rainfall event occurs. The modeler specifies initial conditions within the watershed before simulating an event. Again with the simpler model, hypothetical design storm rainfall and radar-rainfall estimates of actual events can be used to assess project performance. Researchers used the U.S. Army Corps of Engineers' Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) for the South Chequest Creek Watershed. The HEC-HMS model breaks the watershed into 126 smaller units called sub-basins, in which variables such as land use, soil type, slope, etc. are averaged to a single value for the area and used to estimate runoff from that sub-basin. The simulated runoff is then routed through the watershed via a system of interconnected stream networks.

Both hydrologic models demonstrate the effectiveness of the flood mitigation projects in reducing downstream flood peaks. Just downstream of the projects themselves, peak discharge reduction for design or historical events is significant, even for large flood events. Peak discharge reductions at the projects ranged from 66.7–93.8%. As one moves downstream from the projects, the peak reduction effect diminishes. However, even at the outlet of the watershed, the 22 flood mitigation projects in the watershed were able to reduce peak discharges by 8–9.5%, which will reduce the depth of out of bank water across the floodplain. Simulations of the addition of more "hypothetical" ponds beyond the 22 that were included in the Iowa Watersheds Project Phase II illustrate how additional investments in flood mitigation could enhance flood peak reduction in the lower watershed.

d. Concluding Comments

The watershed demonstration projects are an essential first step toward long-term recovery and improved flood resiliency in Iowa. The hydrologic assessment, watershed planning, and project evaluation will guide future decision making to expand project implementation to other Chequest Creek sub-watersheds. This work will also serve as leverage for the Chequest Creek Advisory Committee and Davis County Soil and Water Conservation District to seek additional funding for continued work toward their long-term goals.

In January 2016, the U.S. Department of Housing and Urban Development (HUD) awarded $96.9 million to Iowa for a statewide watershed improvement program, the Iowa Watershed Approach (IWA). The IWA will address issues associated with the devastating and dangerous floods Iowa communities experience year after year. The foundation of the IWA was built on the framework and success of the Iowa Watersheds Project, which served as a significant source of leverage for the state of Iowa to receive another round of HUD funding for a new five-year project.

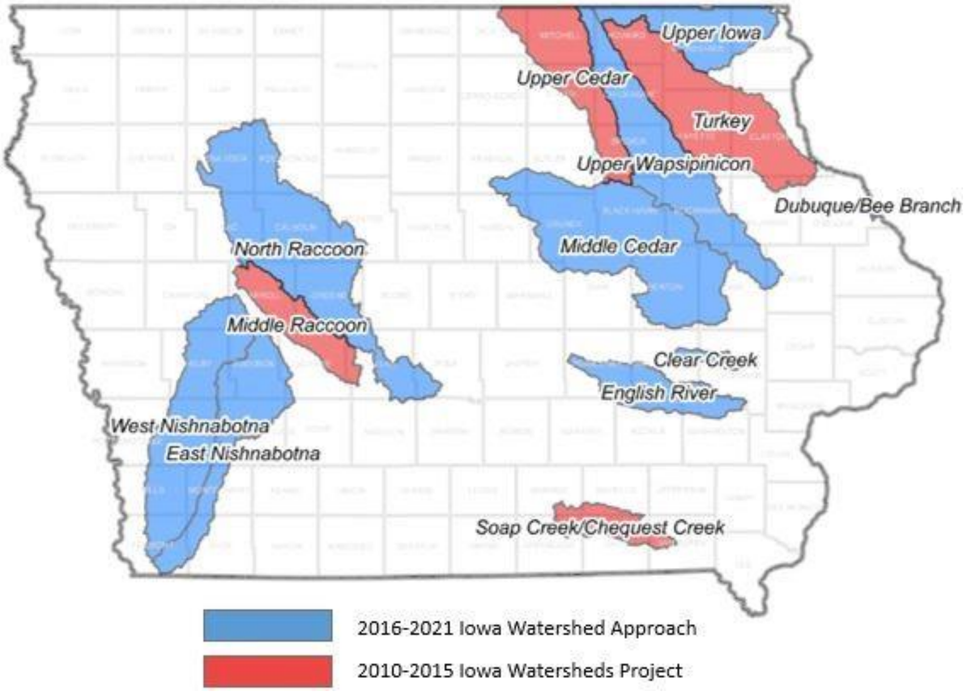


Figure 7.1. Location of watersheds selected for the Iowa Watersheds Project and the Iowa Watershed Approach.

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

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

Appendix A – Iowa Watersheds Project Phase II Pond Stage-Storage-Discharge Relationships

Project: **Wortman Pond** **Pond ID #1**
Drainage Area: 211 acres (0.33 square miles)
Description: The principal spillway is a 16" smooth steel pipe (SSP), invert elevation of 796.5 feet MSL. The auxiliary spillway is 12 feet wide, retardance class B, with 30-foot control length, crest elevation at 802.8 feet MSL. Top of dam at 804.8 feet MSL.
Hydraulic Design: Davis County NRCS

Wortman Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	779.5	0	0	
4.5	784.0	0.06	0.14	
8.5	788.0	0.78	1.82	
12.5	792.0	2.56	8.50	
16.5	796.0	5.06	23.74	principal spillway: 796.5
20.5	800.0	8.23	50.32	auxiliary spillway: 802.8
24.5	804.0	11.79	90.36	top of dam: 804.8
25.5	805.0	13.74	102.62	

Wortman Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	779.5	0	0	
16.5	796.0	23.74	0	
17	796.5	27.06	0	principal spillway
18	797.5	33.71	2.65	
18.5	798.0	37.03	5.29	
19	798.5	40.35	24.76	
20	799.5	47.0	25.97	
20.5	800.0	50.32	26.28	
21	800.5	55.33	26.5	
22	801.5	65.34	27.2	
23	802.5	75.35	27.87	
23.3	802.8	78.35	28.06	auxiliary spillway
23.8	803.3	83.35	28.43	
24.3	803.8	88.36	31.07	
24.8	804.3	94.04	52.09	
25.3	804.8	100.17	93.1	top of dam
25.8	805.3	106.30	303.1	
26.3	805.8	109.97	430.4	

Project: **Davis Pond** **Pond ID #2**
Drainage Area: 15 acres (0.023 square miles)
Description: The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 826.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 827.4 feet MSL. Top of dam at 829.4 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Davis Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	804.0	0	0	
2	806.0	0.03	0.03	
4	808.0	0.06	0.12	
6	810.0	0.09	0.27	
8	812.0	0.13	0.49	
10	814.0	0.18	0.80	
12	816.0	0.24	1.22	
14	818.0	0.34	1.80	
16	820.0	0.52	2.66	
18	822.0	0.80	3.98	
20	824.0	1.20	5.98	
22	826.0	1.60	8.78	principal spillway: 826.0
24	828.0	2.10	12.48	auxiliary spillway: 827.4
26	830.0	2.70	17.28	top of dam: 829.4
28	832.0	3.40	23.38	
30	834.0	4.40	31.18	

Davis Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	804.0	0	0	
21.5	825.5	8.08	0	
22	826.0	8.78	0	principal spillway
18	827.0	10.63	2.82	
18.5	827.4	11.37	2.84	auxiliary spillway
19	827.9	12.30	2.95	
20	828.0	12.48	3.29	
20.5	828.4	13.44	4.64	
21	828.9	14.64	21.91	
22	829.4	15.84	58.86	top of dam
23	829.9	17.04	314.1	
23.3	830.4	18.50	469.1	

Project: **Campbell Pond** **Pond ID #3**
Drainage Area: 4 acres (0.006 square miles)
Description: The principal spillway is a 6" diameter pipe riser with 1" holes, invert elevation of 812.0 feet MSL, top of riser at 814.0 MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 813.0 feet MSL. Top of dam at 815.0 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Campbell Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	799.0	0.01	0	
1	800.0	0.02	0.01	
2	801.0	0.04	0.04	
3	802.0	0.06	0.09	
4	803.0	0.08	0.16	
5	804.0	0.11	0.25	
6	805.0	0.14	0.38	
7	806.0	0.17	0.54	
8	807.0	0.21	0.73	
9	808.0	0.25	0.96	
10	809.0	0.30	1.24	
11	810.0	0.36	1.56	
12	811.0	0.42	1.95	
13	812.0	0.48	2.40	principal spillway: 812.0
14	813.0	0.53	2.91	auxiliary spillway: 813.0
15	814.0	0.60	3.47	top of riser: 814.0
16	815.0	0.66	4.10	top of dam: 815.0
17	816.0	0.73	4.79	
18	817.0	0.91	5.61	

Campbell Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	799.0	0	0	
12.5	811.5	2.18	0	
13	812.0	2.40	0	principal spillway
14	813.0	2.91	2.2	auxiliary spillway
14.5	813.5	3.19	2.95	
15	814.0	3.47	4.64	top of riser
15.5	814.5	3.79	21.91	
16	815.0	4.10	58.86	top of dam
16.5	815.5	4.45	314.1	
17	816.0	4.79	469.1	

Project:	**J. Utt North Pond Pond ID #4**
Drainage Area:	128 acres (0.20 square miles)
Description:	The principal spillway is a 12" smooth steel pipe (SSP), invert elevation of 772.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 776.5 feet MSL. Top of dam at 778.6 feet MSL.
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa

J. Utt North Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	762.0	0	0	
2	764.0	0.25	0.25	
4	766.0	0.78	1.28	
6	768.0	1.59	3.65	
8	770.0	2.73	7.97	
10	772.0	3.90	14.60	principal spillway: 772.0
12	774.0	5.21	23.71	
14	776.0	6.53	35.45	auxiliary spillway: 776.5
16	778.0	7.96	49.94	top of dam: 778.6
18	780.0	9.31	67.21	

J. Utt North Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	762.0	0	0	
9.5	771.5	12.94	0	
10	772.0	14.60	0	principal spillway
11	773.0	19.16	2.2	
12	774.0	23.71	11.1	
13	775.0	29.58	11.5	
14	776.0	35.45	12.0	
14.5	776.5	39.04	12.1	auxiliary spillway
15	777.0	42.70	12.2	
15.5	777.5	46.32	14.1	
16	778.0	49.94	31.53	
16.6	778.6	55.12	68.62	top of dam
17	779.0	58.58	303.1	
17.5	779.5	62.9	430.4	

Project:	**J. Utt South Pond Pond ID #5**
Drainage Area:	26 acres (0.04 square miles)
Description:	The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 806.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 809.0 feet MSL. Top of dam at 811.0 feet MSL.
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa

J. Utt South Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	790.0	0	0	
2	792.0	0.02	0.02	
4	794.0	0.05	0.09	
6	796.0	0.11	0.25	
8	798.0	0.22	0.58	
10	800.0	0.37	1.17	
12	802.0	0.57	2.11	
14	804.0	0.84	3.52	
16	806.0	1.20	5.52	principal spillway: 806.0
18	808.0	1.60	8.32	auxiliary spillway: 809.0
20	810.0	2.00	11.92	top of dam: 811.0
22	812.0	2.50	16.42	

J. Utt South Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	790.0	0	0	
15.5	805.5	5.02	0	
16	806.0	5.52	0	principal spillway
17	807.0	6.92	2.82	
18	808.0	8.32	2.84	
19	809.0	10.12	2.87	auxiliary spillway
19.5	809.5	11.02	2.95	
20	810.0	11.92	4.64	
20.5	810.5	13.05	21.91	
21	811.0	14.17	58.86	top of dam
21.5	811.5	15.3	314.1	
22	812.0	16.42	469.1	

Project:	**G. Utt Pond** **Pond ID #6**
Drainage Area:	166 acres (0.26 square miles)
Description:	The principal spillway is a 12" smooth steel pipe (SSP), invert elevation of 762.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 767.8 feet MSL. Top of dam at 769.9 feet MSL.
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa

G. Utt Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	749.0	0	0	
1	750.0	0.01	0.01	
3	752.0	0.05	0.07	
5	754.0	0.25	0.37	
7	756.0	0.66	1.28	
9	758.0	1.06	3.00	
11	760.0	1.73	5.79	
13	762.0	3.29	10.81	principal spillway: 762.0
15	764.0	4.50	18.60	
17	766.0	5.69	28.79	
19	768.0	7.38	41.86	auxiliary spillway: 767.8
21	770.0	8.91	58.15	top of dam: 769.9
23	772.0	10.43	77.49	

G. Utt Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	749.0	0	0	
12.5	761.5	9.56	0	
13	762.0	10.81	0	principal spillway
14	763.0	14.71	2.2	
15	764.0	18.60	12.85	
16	765.0	23.70	13.2	
17	766.0	28.79	13.5	
18	767.0	35.33	13.85	
18.8	767.8	40.55	14.12	auxiliary spillway
19.3	768.3	44.31	14.32	
19.8	768.8	48.38	16.14	
20.3	769.3	52.45	33.53	
20.9	769.9	56.52	70.52	top of dam
21.3	770.3	61.05	314.1	
21.8	770.8	65.89	469.1	

Project: **Eaton Pond** **Pond ID #7**
Drainage Area: 90 acres (0.14 square miles)
Description: The principal spillway is an 8" smooth steel pipe (SSP), invert elevation of 770.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 775.4 feet MSL. Top of dam at 777.4 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Eaton Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	758.0	0	0	
2	760.0	0.11	0.11	
4	762.0	0.37	0.59	
6	764.0	0.70	1.66	
8	766.0	1.10	3.46	
10	768.0	1.80	6.36	
12	770.0	2.60	10.76	principal spillway: 770.0
14	772.0	3.40	16.76	
16	774.0	4.30	24.46	auxiliary spillway: 775.4
18	776.0	5.30	34.06	
20	778.0	6.30	45.66	top of dam: 777.4
22	780.0	7.40	59.36	
24	782.0	8.60	75.36	
26	784.0	9.90	93.86	
28	786.0	11.20	114.96	
30	788.0	12.60	138.76	

Eaton Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	758.0	0	0	
11.5	769.5	9.66	0	
12	770.0	10.76	0	principal spillway
13	771.0	13.76	4.67	
14	772.0	16.76	5.12	
15	773.0	20.61	5.23	
16	774.0	24.46	5.35	
17	775.0	29.26	5.48	
17.4	775.4	31.18	5.52	auxiliary spillway
18	776.0	34.06	5.63	
18.5	776.5	36.96	8.65	
19	777.0	39.86	30.95	

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Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
19.4	777.4	42.18	61.6	top of dam
20	778.0	45.66	314.1	
20.5	778.5	49.09	469.1	

Eaton Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project: **Smith Pond** **Pond ID #8**
Drainage Area: 480 acres (0.75 square miles)
Description: The principal spillway is a 24" smooth steel pipe (SSP), invert elevation of 756.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 761.2 feet MSL. Top of dam at 763.2 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Smith Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	738.0	0	0	
2	740.0	0.07	0.07	
4	742.0	0.12	0.26	
6	744.0	0.25	0.62	
8	746.0	1.74	2.69	
10	748.0	3.34	7.71	
12	750.0	5.15	16.31	
14	752.0	7.42	28.77	
16	754.0	10.22	46.41	
17	755.0	12.04	57.54	
18	756.0	14.11	70.61	principal spillway: 756.0
19	757.0	15.70	85.52	
20	758.0	17.67	102.20	
21	759.0	19.73	120.90	
22	760.0	21.76	141.64	
23	761.0	23.81	164.43	auxiliary spillway: 761.2
24	762.0	26.22	189.44	
25	763.0	28.50	216.80	top of dam: 763.2
26	764.0	30.91	246.51	
27	765.0	33.25	278.58	

Smith Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	738.0	0	0	
17.5	755.5	64.08	0	
18	756.0	70.61	0	principal spillway
18.5	756.5	78.07	1.3	
19	757.0	85.52	3.67	
19.5	757.5	93.86	8.18	
20	758.0	102.2	12.17	
20.5	758.5	111.55	27.81	

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Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
20.75	758.75	116.23	46.58	
20.85	758.85	118.10	53.33	
21	759.0	120.9	62.96	
22	760.0	141.64	65.59	
23	761.0	164.43	67.27	
23.2	761.2	169.43	67.61	auxiliary spillway
23.7	761.7	181.94	68.47	
24.2	762.2	194.91	70.98	
24.7	762.7	208.59	89.06	
25.2	763.2	222.74	126.79	top of dam
25.7	763.7	237.6	314.1	
26.2	764.2	252.92	469.1	

Smith Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project:	**Christensen Pond Pond ID #9**
Drainage Area:	70 acres (0.11 square miles)
Description:	The principal spillway is a 12" smooth steel pipe (SSP), invert elevation of 778.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 781.6 feet MSL. Top of dam at 783.7 feet MSL.
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa

Christensen Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	756.0	0	0	
2	758.0	0.02	0.02	
4	760.0	0.06	0.10	
6	762.0	0.19	0.35	
8	764.0	0.33	0.87	
10	766.0	0.49	1.69	
12	768.0	0.68	2.86	
14	770.0	0.89	4.43	
16	772.0	1.20	6.52	
18	774.0	1.60	9.32	
20	776.0	2.0	12.92	
22	778.0	2.70	17.62	principal spillway: 778.0
24	780.0	3.50	23.82	
26	782.0	4.50	31.82	auxiliary spillway: 781.6
28	784.0	5.60	41.92	top of dam: 783.7
30	786.0	7.11	54.63	

Christensen Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	756.0	0	0	
21.5	777.5	16.45	0	
22	778.0	17.62	0	principal spillway
23	779.0	20.72	2.2	
24	780.0	23.82	12.85	
25	781.0	26.92	13.2	
25.6	781.6	30.22	13.4	auxiliary spillway
26.1	782.1	32.33	13.58	
26.6	782.6	34.85	15.42	
27.1	783.1	37.38	32.82	
27.7	783.7	39.4	69.82	top of dam
28.2	784.2	43.19	303.1	
28.7	784.7	46.37	430.4	

Project: **Padget Pond** **Pond ID #10**
Drainage Area: 64 acres (0.10 square miles)
Description: The principal spillway is an 8" smooth steel pipe (SSP), invert elevation of 768.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 773.2 feet MSL. Top of dam at 775.3 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Padget Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	755.0	0	0	
2	757.0	0.08	0.08	
4	759.0	0.23	0.39	
6	761.0	0.56	1.18	
8	763.0	0.95	2.69	
10	765.0	1.30	4.94	
12	767.0	1.70	7.94	principal spillway: 768.0
14	769.0	2.10	11.74	
16	771.0	2.50	16.34	
18	773.0	3.20	22.04	auxiliary spillway: 773.2
20	775.0	3.80	29.04	top of dam: 775.3
22	777.0	4.10	36.94	
24	779.0	5.20	46.24	
26	781.0	6.10	57.54	
28	783.0	7.20	70.84	
30	785.0	8.40	86.44	

Padget Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	755.0	0	0	
12.5	767.5	8.89	0	
13	768.0	9.84	0	principal spillway
14	769.0	11.74	4.67	
15	770.0	14.04	5.12	
16	771.0	16.34	5.23	
17	772.0	19.19	5.35	
18	773.0	22.04	5.48	
18.2	773.2	22.74	5.50	auxiliary spillway
18.7	773.7	24.49	5.57	
19.2	774.2	26.24	7.31	
19.7	774.7	27.99	24.61	continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
20	775.0	29.04	48.28	
20.3	775.3	30.23	71.95	top of dam
21	776.0	32.99	314.1	
21.5	776.5	34.97	469.1	

Padget Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project:	**Birchmier Pond Pond ID #11**
Drainage Area:	38 acres (0.06 square miles)
Description:	The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 818.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 821.6 feet MSL. Top of dam at 823.6 feet MSL.
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa

Birchmier Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	802.0	0	0	
2	804.0	0.01	0.01	
4	806.0	0.02	0.03	
6	808.0	0.07	0.12	
8	810.0	0.16	0.35	
10	812.0	0.29	0.80	
12	814.0	0.59	1.68	
14	816.0	0.88	3.16	
16	818.0	1.30	5.30	principal spillway: 818.0
18	820.0	1.80	8.50	
20	822.0	2.40	12.70	auxiliary spillway: 821.6
22	824.0	3.10	18.20	top of dam: 823.6
24	826.0	4.10	25.40	
26	828.0	5.30	34.80	
28	830.0	7.10	47.20	
30	832.0	9.0	63.30	

Birchmier Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	802.0	0	0	
15.5	817.5	4.77	0	
16	818.0	5.30	0	principal spillway
17	819.0	6.90	2.82	
18	820.0	8.50	2.84	
19	821.0	10.60	2.87	
19.6	821.6	11.86	2.93	auxiliary spillway
20.1	822.1	12.98	2.97	
20.6	822.6	14.35	4.67	
21.1	823.1	15.73	21.97	
21.6	823.6	17.1	58.92	top of dam
22.1	824.1	18.56	314.1	
22.6	824.6	20.36	469.1	

Project: **Mincks Pond** **Pond ID #12**
Drainage Area: 51 acres (0.08 square miles)
Description: The principal spillway is a 12" smooth steel pipe (SSP), invert elevation of 823.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 826.3 feet MSL. Top of dam at 828.4 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Mincks Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	804.0	0	0	
2	806.0	0.002	0.002	
4	808.0	0.004	0.01	
6	810.0	0.03	0.04	
8	812.0	0.17	0.24	
10	814.0	0.33	0.74	
12	816.0	0.58	1.65	
14	818.0	0.89	3.12	
16	820.0	1.21	5.22	
18	822.0	1.61	8.04	principal spillway: 823.0
20	824.0	2.14	11.79	
22	826.0	2.80	16.73	auxiliary spillway: 826.3
24	828.0	3.68	23.21	top of dam: 828.4
26	830.0	4.79	31.68	
28	832.0	6.27	42.74	
30	834.0	8.70	57.71	

Mincks Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	804.0	0	0	
18.5	822.5	8.98	0	
19	823.0	9.92	0	principal spillway
20	824.0	11.79	2.2	
21	825.0	14.26	12.86	
22	826.0	16.73	13.2	
22.3	826.3	17.70	13.3	auxiliary spillway
22.8	826.8	19.32	13.49	
23.3	827.3	20.94	15.32	
23.8	827.8	22.56	32.73	
24.4	828.4	24.98	69.78	top of dam
24.8	828.8	26.60	314.1	
25.3	829.3	28.72	469.1	

Project: **Lough Pond** **Pond ID #13**

Drainage Area: 6 acres (0.009 square miles)

Description: The principal spillway is a 6" diameter pipe riser with 1" holes, invert elevation of 804.7 feet MSL, top of riser at 806.7 MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 805.7 feet MSL. Top of dam at 807.7 feet MSL.

Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Lough Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	783.0	0.00	0	
3	786.0	0.01	0.02	
5	788.0	0.02	0.05	
7	790.0	0.04	0.11	
9	792.0	0.05	0.20	
11	794.0	0.07	0.33	
13	796.0	0.10	0.50	
15	798.0	0.14	0.73	
17	800.0	0.20	1.06	
18	801.0	0.23	1.28	
19	802.0	0.28	1.54	
20	803.0	0.34	1.85	
21	804.0	0.41	2.23	
22	805.0	0.49	2.68	principal spillway: 804.7
23	806.0	0.59	3.23	auxiliary spillway: 805.7
24	807.0	0.69	3.86	top of riser: 806.7
25	808.0	0.81	4.61	top of dam: 807.7
26	809.0	0.93	5.48	
27	810.0	1.11	6.50	

Lough Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	783.0	0	0	
21.2	804.2	2.32	0	
21.7	804.7	2.55	0	principal spillway
22.7	805.7	3.07	2.2	auxiliary spillway
23.2	806.2	3.36	2.95	
23.7	806.7	3.67	4.64	top of riser
24.2	807.2	4.01	21.91	
24.7	807.7	4.39	58.86	top of dam
25	808.0	4.61	314.1	
26	809.0	5.48	469.1	

Project: **Bergen North Pond Pond ID #14**
Drainage Area: 11 acres (0.017 square miles)
Description: The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 791.5 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 792.5 feet MSL. Top of dam at 794.5 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Bergen North Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	768.0	0	0	
2	770.0	0.01	0.01	
4	772.0	0.02	0.04	
6	774.0	0.04	0.10	
8	776.0	0.07	0.21	
10	778.0	0.17	0.45	
12	780.0	0.36	0.98	
14	782.0	0.61	1.95	
16	784.0	0.98	3.54	
18	786.0	1.41	5.93	
20	788.0	1.85	9.19	
22	790.0	2.37	13.41	principal spillway: 791.5
24	792.0	2.95	18.73	auxiliary spillway: 792.5
26	794.0	3.55	25.23	top of dam: 794.5
28	796.0	4.28	33.06	
30	798.0	4.70	42.04	

Bergen North Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	768.0	0	0	
23	791.0	16.07	0	
23.5	791.5	17.40	0	principal spillway
24	792.0	18.73	1.1	
24.5	792.5	20.36	2.2	auxiliary spillway
25	793.0	21.98	2.95	
25.5	793.5	23.61	4.64	
26	794.0	25.23	21.91	
26.5	794.5	27.19	58.86	top of dam
27	795.0	29.15	314.1	
27.5	795.5	31.11	469.1	

Project: **Bergen South Pond Pond ID #15**
Drainage Area: 8 acres (0.012 square miles)
Description: The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 792.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 793.4 feet MSL. Top of dam at 795.4 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Bergen South Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	768.0	0	0	
2	770.0	0.01	0.01	
4	772.0	0.01	0.02	
6	774.0	0.02	0.05	
8	776.0	0.06	0.13	
10	778.0	0.11	0.29	
12	780.0	0.16	0.57	
13	781.0	0.20	0.75	
14	782.0	0.24	0.96	
15	783.0	0.29	1.22	
16	784.0	0.36	1.55	
17	785.0	0.45	1.95	
18	786.0	0.59	2.46	
19	787.0	0.75	3.13	
20	788.0	0.89	3.95	
21	789.0	1.03	4.91	
22	790.0	1.16	6.00	
23	791.0	1.31	7.24	
24	792.0	1.46	8.67	principal spillway: 792.0
25	793.0	1.63	10.17	auxiliary spillway: 793.4
26	794.0	1.79	11.87	
27	795.0	1.95	13.74	top of dam: 795.4
28	796.0	2.13	15.78	
29	797.0	2.32	18.01	

Bergen South Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	768.0	0	0	
	791.5	6.62	0	
	792.0	8.67	0	principal spillway
	792.5	9.42	1.1	
	793.0	10.17	2.2	continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
	793.4	10.85	2.84	auxiliary spillway
	793.9	11.70	2.95	
	794.4	12.62	4.64	
	794.9	13.55	21.91	
	795.4	14.56	58.86	top of dam
	795.9	15.58	314.1	
	796.4	16.67	469.1	

Bergen South Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project:	**Rodgers Pond** **Pond ID #16**
Drainage Area:	22 acres (0.035 square miles)
Description:	The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 775.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 778.8 feet MSL. Top of dam at 781.0 feet MSL.
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa

Rodgers Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	749.0	0	0	
4	753.0	0.04	0.06	
7	756.0	0.07	0.22	
10	759.0	0.11	0.50	
13	762.0	0.19	0.94	
16	765.0	0.29	1.65	
19	768.0	0.40	2.68	
20	769.0	0.44	3.10	
21	770.0	0.49	3.57	
22	771.0	0.56	4.09	
23	772.0	0.65	4.70	
24	773.0	0.75	5.39	
25	774.0	0.87	6.20	
26	775.0	0.98	7.13	principal spillway: 775.0
27	776.0	1.10	8.17	
28	777.0	1.23	9.33	
29	778.0	1.39	10.65	auxiliary spillway: 778.8
30	779.0	1.56	12.00	
31	780.0	1.74	13.77	
32	781.0	1.94	15.61	top of dam: 781.0
33	782.0	2.16	17.65	
34	783.0	2.38	19.92	
35	784.0	2.59	22.41	

Rodgers Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	749.0	0	0	
25.5	774.5	6.67	0	
26	775.0	7.13	0	principal spillway
26.5	775.5	7.65	1.1	
27	776.0	8.17	2.2	
28	777.0	9.33	2.87	

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
29.8	778.8	11.73	2.96	auxiliary spillway
30.3	779.3	12.53	3.0	
30.8	779.8	13.42	4.72	
31	780.0	13.77	8.80	
31.3	780.3	14.32	21.99	
31.8	780.8	15.24	58.91	
32	781.0	15.61	78.78	top of dam
32.5	781.5	16.63	314.1	
33	782.0	17.65	469.1	

Rodgers Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project:	**McClure Trust East Pond**	**Pond ID #17**
Drainage Area:	32 acres (0.05 square miles)	
Description:	The principal spillway is a 10" smooth steel pipe (SSP), invert elevation of 774.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 776.5 feet MSL. Top of dam at 778.7 feet MSL.	
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa	

McClure Trust East Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	746.0	0	0	
2	748.0	0.02	0.02	
6	752.0	0.05	0.13	
10	756.0	0.14	0.49	
14	760.0	0.29	1.34	
16	762.0	0.38	2.01	
18	764.0	0.47	2.86	
20	766.0	0.58	3.90	
22	768.0	0.72	5.18	
24	770.0	0.94	6.82	
25	771.0	1.07	7.83	
26	772.0	1.21	8.96	
27	773.0	1.37	10.25	
28	774.0	1.52	11.73	principal spillway: 774.0
29	775.0	1.69	13.30	
30	776.0	1.86	15.08	auxiliary spillway: 776.5
31	777.0	2.07	17.04	
32	778.0	2.26	19.20	top of dam: 778.7
33	779.0	2.46	21.57	
34	780.0	2.66	24.13	

McClure Trust East Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	746.0	0	0	
27.5	773.5	10.99	0	
28	774.0	11.73	0	principal spillway
29	775.0	13.30	1.78	
30	776.0	15.08	8.55	
30.5	776.5	16.06	8.7	auxiliary spillway
31	777.0	17.04	8.82	
31.5	777.5	18.12	10.59	continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
32	778.0	19.20	27.93	
32.5	778.5	20.39	64.92	
32.7	778.7	20.86	84.88	top of dam
33	779.0	21.57	314.1	
33.5	779.5	22.85	469.1	

McClure Trust East Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project: **McClure Trust West Pond** **Pond ID #18**

Drainage Area: 173 acres (0.27 square miles) **
** McClure Trust West Pond has McClure Trust East (#17) and Rodgers (#16) Pond upstream

Description: The principal spillway is a 12” smooth steel pipe (SSP), invert elevation of 746.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 751.6 feet MSL. Top of dam at 753.9 feet MSL.

Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

McClure Trust West Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	727.0	0	0	
3	730.0	0.09	0.12	
5	732.0	0.26	0.45	
7	734.0	0.59	1.30	
9	736.0	1.02	2.92	
11	738.0	1.44	5.38	
13	740.0	1.90	8.71	
15	742.0	2.45	13.04	
17	744.0	3.10	18.58	
19	746.0	3.82	25.48	principal spillway: 746.0
21	748.0	4.62	33.93	
22	749.0	5.07	38.77	
23	750.0	5.57	44.08	
24	751.0	6.13	49.93	auxiliary spillway: 751.6
25	752.0	6.72	56.36	
26	753.0	7.33	63.38	top of dam: 753.9
27	754.0	7.91	71.00	
28	755.0	8.47	79.19	
29	756.0	9.03	87.94	
30	757.0	9.59	97.25	
31	758.0	10.58	107.34	
32	759.0	11.62	118.43	

McClure Trust West Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	727.0	0	0	
18.5	745.5	23.76	0	
19	746.0	25.48	0	principal spillway
20	747.0	29.71	2.2	

continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
21	748.0	33.93	12.85	
22	749.0	38.77	13.2	
23	750.0	44.08	13.5	
24	751.0	49.93	13.85	
24.6	751.6	53.79	14.06	auxiliary spillway
25.1	752.1	57.06	14.24	
25.6	752.6	60.57	16.07	
26.1	753.1	64.14	33.47	
26.6	753.6	67.95	70.51	
26.9	753.9	70.24	101.89	top of dam
27	754.0	71.0	200.0	
27.5	754.5	75.5	314.14	
28	755.0	79.19	469.1	

McClure Trust West Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project:	**Andersen Pond** **Pond ID #19**
Drainage Area:	40 acres (0.06 square miles)
Description:	The principal spillway is a 10" smooth steel pipe (SSP), invert elevation of 748.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 750.3 feet MSL. Top of dam at 752.5 feet MSL.
Hydraulic Design:	French-Reneker-Associates. Inc., Fairfield, Iowa

Andersen Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	729.0	0	0	
3	732.0	0.12	0.20	
5	734.0	0.23	0.55	
7	736.0	0.35	1.13	
9	738.0	0.46	1.94	
10	739.0	0.52	2.43	
11	740.0	0.58	2.98	
12	741.0	0.66	3.60	
13	742.0	0.76	4.31	
14	743.0	0.89	5.13	
15	744.0	1.03	6.09	
16	745.0	1.18	7.20	
17	746.0	1.32	8.45	
18	747.0	1.47	9.84	
19	748.0	1.64	11.41	principal spillway: 748.0
20	749.0	1.81	13.13	
21	750.0	2.00	15.03	auxiliary spillway: 750.3
22	751.0	2.19	17.12	
23	752.0	2.38	19.41	top of dam: 752.5
24	753.0	2.60	21.89	

Andersen Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	729.0	0	0	
18.5	747.5	10.63	0	
19	748.0	11.41	0	principal spillway
20	749.0	13.13	1.6	
21	750.0	15.03	8.55	
21.3	750.3	15.66	8.65	auxiliary spillway
21.8	750.8	16.70	8.76	
22.3	751.3	17.81	10.58	continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
22.8	751.8	18.95	27.9	
23.3	752.3	19.91	65.0	
23.5	752.5	20.65	84.9	top of dam
24	753.0	21.89	303.1	
24.5	753.5	23.63	430.4	

Andersen Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project: **L. Utt Pond** **Pond ID #20**

Drainage Area: 32 acres (0.05 square miles)

Description: The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 764.2 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 766.2 feet MSL. Top of dam at 768.3 feet MSL.

Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

L. Utt Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	745.0	0	0	
2	747.0	0.01	0.01	
4	749.0	0.03	0.04	
5	750.0	0.04	0.08	
6	751.0	0.06	0.13	
7	752.0	0.08	0.20	
8	753.0	0.12	0.30	
9	754.0	0.24	0.48	
10	755.0	0.40	0.80	
11	756.0	0.58	1.30	
12	757.0	0.79	1.98	
13	758.0	0.99	2.87	
14	759.0	1.22	3.98	
15	760.0	1.47	5.32	
16	761.0	1.73	6.92	
17	762.0	2.07	8.82	
18	763.0	2.35	11.03	
19	764.0	2.65	13.53	principal spillway: 764.5
20	765.0	3.03	16.37	
21	766.0	3.45	19.61	auxiliary spillway: 766.2
22	767.0	3.91	23.29	
23	768.0	4.34	27.42	top of dam: 768.3
24	769.0	4.78	31.98	
25	770.0	5.26	37.00	

L. Utt Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	745.0	0	0	
19	764.0	13.53	0	
19.2	764.2	14.10	0	principal spillway
19.7	764.7	15.56	1.1	continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
20.2	765.2	17.02	2.2	
21.2	766.2	20.35	2.95	auxiliary spillway
21.7	766.7	22.19	3.0	
22.2	767.2	24.12	4.73	
22.7	767.7	26.18	22.13	
23.3	768.3	28.79	69.37	top of dam
23.8	768.8	31.07	314.1	
24.3	769.3	33.49	469.1	

L. Utt Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project: **Ridgeway Pond** **Pond ID #21**
Drainage Area: 19 acres (0.03 square miles)
Description: The principal spillway is a 6" smooth steel pipe (SSP), invert elevation of 764.0 feet MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 765.0 feet MSL. Top of dam at 767.0 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Ridgeway Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	731.0	0	0	
3	734.0	0.03	0.04	
6	737.0	0.06	0.16	
9	740.0	0.10	0.40	
12	743.0	0.15	0.78	
15	746.0	0.21	1.31	
18	749.0	0.27	2.02	
20	751.0	0.33	2.61	
23	754.0	0.50	3.82	
24	755.0	0.60	4.37	
25	756.0	0.70	5.02	
26	757.0	0.81	5.77	
27	758.0	0.94	6.65	
28	759.0	1.09	7.66	
29	760.0	1.25	8.83	
30	761.0	1.43	10.17	
31	762.0	1.61	11.69	
32	763.0	1.79	13.40	principal spillway: 764.0
33	764.0	2.00	15.34	
34	765.0	2.22	17.45	auxiliary spillway: 765.0
35	766.0	2.46	19.74	
36	767.0	2.73	22.39	top of dam: 767.0
37	768.0	3.01	25.20	
38	769.0	3.30	28.35	

Ridgeway Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	745.0	0	0	
18.5	763.5	14.37	0	
19	764.0	15.34	0	principal spillway
19.5	764.5	16.40	1.1	

continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
20	765.0	17.45	2.2	auxiliary spillway
20.5	765.5	18.6	2.95	
21	766.0	19.74	4.64	
21.5	766.5	21.07	21.91	
22	767.0	22.39	58.86	top of dam
22.5	767.5	23.8	314.1	
23	768.0	25.2	469.1	

Ridgeway Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Project: **Kitzman Pond** **Pond ID #22**
Drainage Area: 13 acres (0.02 square miles)
Description: The principal spillway is a 6" diameter pipe riser with 1" holes, invert elevation of 718.0 feet MSL, top of riser at 720.0 MSL. The auxiliary spillway is 10 feet wide, retardance class B, with 30 foot control length, crest elevation at 719.0 feet MSL. Top of dam at 721.0 feet MSL.
Hydraulic Design: French-Reneker-Associates. Inc., Fairfield, Iowa

Kitzman Pond: Elevation (Stage) – Pool Area – Storage relationships from design documentation.

Stage (feet)	Elevation (feet)	Pool Area (acres)	Accumulated Storage (acre-feet)	
0	700.0	0.00	0	
1	701.0	0.00	0.00	
2	702.0	0.01	0.01	
3	703.0	0.02	0.02	
4	704.0	0.07	0.07	
5	705.0	0.13	0.17	
6	706.0	0.20	0.33	
7	707.0	0.29	0.58	
8	708.0	0.39	0.92	
9	709.0	0.51	1.37	
10	710.0	0.61	1.92	
11	711.0	0.71	2.58	
12	712.0	0.83	3.36	
13	713.0	0.95	4.25	principal spillway: 718.0
14	714.0	1.07	5.26	auxiliary spillway: 719.0
15	715.0	1.20	6.40	top of riser: 720.0
16	716.0	1.33	7.66	top of dam: 721.0
17	717.0	1.46	9.05	
18	718.0	1.59	10.58	
19	719.0	1.73	12.24	
20	720.0	1.88	14.05	
21	721.0	2.05	16.01	
22	722.0	2.22	18.16	
23	723.0	2.35	20.45	

Kitzman Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models.

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
0	700.0	0	0	
17.5	717.5	9.82	0	
18	718.0	10.58	0	principal spillway
19	719.0	12.24	2.2	auxiliary spillway
19.5	719.5	13.15	2.95	continued on next page

Stage (feet)	Elevation (feet)	Accumulated Storage (acre-feet)	Discharge (cfs)	
20	720.0	14.05	4.64	top of riser
20.5	720.5	15.03	21.91	
21	721.0	16.01	58.86	top of dam
21.5	721.5	17.09	314.1	
22	722.0	18.16	469.1	

Kitzman Pond: Elevation (Stage) – Storage – Discharge relationships developed by IFC for hydrologic models – Continued from previous page.

Appendix B – Iowa Watersheds Project Phase II "Typical" Pond Stage-Storage-Discharge Relationships

Project:	**Phase II Typical Pond**
Drainage Area:	N/A
Description:	Conceptual pond based upon the average stage-storage relationships of the ponds built in the Iowa Watersheds Project Phase II. Used for hypothetical analysis of adding additional ponds in the watershed. See Chapter 6 Section e. for application and analysis of hypothetical ponds. The principal spillway is assumed to be a 12" smooth steel pipe (SSP), invert elevation of 0.0 feet based on local on-site datum. The auxiliary spillway is 10 feet wide, retardance class C, crest elevation at 3.6 feet. Top of dam at 5.7 feet.
Hydraulic Design:	Conceptual design by IFC engineers
Typical Pond:	Elevation (Stage) – Discharge relationships from design documentation.

Stage (feet)	Elevation (feet)	Discharge (cfs)	Accumulated Storage (acre-feet)	
0	0.0	0	0.0	principal spillway: 0.0
1	1.0	2.2	3.10	
2	2.0	11.1	6.20	
3	3.0	11.51	10.20	
3.6	3.6	11.7	12.60	auxiliary spillway: 3.6
4	4.0	22.0	14.20	
4.6	4.6	45.3	17.23	
5.1	5.1	73.22	19.76	
5.7	5.7	106.32	22.79	top of dam: 5.7
6	6.0	224.36	24.30	
6.2	6.2	303.1	25.57	
6.7	6.7	430.4	28.75	

Appendix C - Existing Ponds Iowa Watersheds Project Phase I Stage-Storage-Discharge Relationships

Project:	**Existing Bert Pond** **Pond ID #E1**
Drainage Area:	285 acres (0.44 square miles)
Description:	Existing NRCS designed pond located in South Chequest watershed at time of Phase I modeling. Constructed in 1976. Design documentation not available from Davis County NRCS office in Bloomfield, IA. Design specifications obtained via request, sent April 29, 2013 by Lee White, NRCS Des Moines, IA. Discharge determined by Iowa Flood Center. The principal spillway is an 18" corrugated metal pipe (CMP), invert elevation estimate of 813.8 feet based on LiDAR dataset. The auxiliary spillway is 20 feet wide, crest elevation estimate of 820.8 feet based on LiDAR dataset. Top of dam elevation estimate of 821.8 feet based on LiDAR dataset.
Hydraulic Design:	U.S. Dept. of Agriculture – Soil Conservation Service (SCS)
Wuthrich Pond:	Elevation (Stage) – Discharge relationships from design documentation.

Stage (feet)	Elevation (feet)	Discharge (cfs)	Accumulated Storage (acre-feet)	
0	813.8	0	26.0	principal spillway: 813.8
7	820.8	24	98.0	auxiliary spillway: 820.8
7.5	821.3	48.45	105.82	
8	821.8	92.33	114.0	top of dam: 821.8
8.5	822.3	149.86	122.52	

Project: **Existing Wuthrich Pond** **Pond ID #E2**
Drainage Area: 34 acres (0.05 square miles)

Description: Existing NRCS designed pond located in South Chequest watershed at time of Phase I modeling. Constructed in 1996. Design documentation obtained from Davis County NRCS office in Bloomfield, IA.

The principal spillway is a 6" smooth steel pipe (SSP) with hood inlet, invert elevation of 110.0 feet based on local on-site datum. The auxiliary spillway is 10 feet wide, retardance class C, with 30 foot control length, crest elevation at 111.3 feet. Top of dam at 113.4 feet.

Hydraulic Design: U.S. Dept. of Agriculture – Soil Conservation Service (SCS)

Wuthrich Pond: Elevation (Stage) – Discharge relationships from design documentation.

Stage (feet)	Elevation (feet)	Discharge (cfs)	Accumulated Storage (acre-feet)	
0	110.0	0		principal spillway: 110.0
1	111.0	2.82		auxiliary spillway: 111.3
1.5	111.5	11.21		
2	112.0	21.97		
2.5	112.5	61.02		
3	113.0	119.03		top of dam: 113.4
3.5	113.5	202.0		
4	114.0	314.14		
4.5	114.5	469.09		
5	115.0	671.27		
6	116.0	1072.34		

Project: **Existing G. Utt Pond** **Pond ID #E3**

Drainage Area: 34 acres (0.05 square miles)

Description: Existing NRCS designed pond located in South Chequest watershed at time of Phase I modeling. Constructed in 2002. Design documentation obtained from Davis County NRCS office in Bloomfield, IA.

The principal spillway is a 12" smooth steel pipe (SSP) with hood inlet, invert elevation of 95.0 feet based on local on-site datum. The auxiliary spillway is 20 feet wide, retardance class C, crest elevation at 99.9 feet. Top of dam at 102.0 feet.

Hydraulic Design: U.S. Dept. of Agriculture – Soil Conservation Service (SCS)

G. Utt Pond: Elevation (Stage) – Discharge relationships from design documentation.

Stage (feet)	Elevation (feet)	Discharge (cfs)	Accumulated Storage (acre-feet)	
0	95.0	0	23.70	principal spillway: 95.0
1	96.0	2.2	27.18	
2	97.0	13.21	31.65	
3	98.0	13.58	36.58	
4	99.0	13.95	41.99	
4.9	99.9	14.27	47.90	auxiliary spillway: 99.9
6	101.0	46.97	54.38	
6.5	101.5	110.69	57.86	
7	102.0	194.44	61.20	top of dam: 102.0
7.5	102.5	303.13	65.08	
8	103.0	430.44	68.81	
8.5	103.5	610.83	72.80	

Project: **Existing Yahnke Pond** **Pond ID #E4**
Drainage Area: 50 acres (0.08 square miles)

Description: Existing NRCS designed pond located in South Chequest watershed at time of Phase I modeling. Constructed in 1970. Design documentation not available from Davis County NRCS office in Bloomfield, IA. Design specifications obtained via request, sent April 29, 2013 by Lee White, NRCS Des Moines, IA. Discharge determined by Iowa Flood Center.

The principal spillway is a 12" corrugated metal pipe (CMP), invert elevation estimate of 765.2 feet based on LiDAR dataset. The auxiliary spillway is 22 feet wide, crest elevation estimate of 771.1 feet based on LiDAR dataset. Top of dam elevation estimate of 772.6 feet based on LiDAR dataset.

Hydraulic Design: U.S. Dept. of Agriculture – Soil Conservation Service (SCS)

Yahnke Pond: Elevation (Stage) – Discharge relationships from design documentation.

Stage (feet)	Elevation (feet)	Discharge (cfs)	Accumulated Storage (acre-feet)	
0	765.2	0	22.0	principal spillway: 765.2
1	766.2	2.2	24.30	
2	767.2	13.21	26.60	
3	768.2	13.58	28.90	
4	769.2	13.95	31.20	
5	770.2	14.3	33.50	
5.9	771.1	14.65	35.57	auxiliary spillway: 771.1
6.4	771.6	40.6	36.91	
6.9	772.1	87.95	38.4	
7.4	772.6	149.21	40.0	top of dam: 772.6

Project: **Existing Ware Pond** **Pond ID #E5**

Drainage Area: 107 acres (0.17 square miles)

Description: Existing NRCS designed pond located in South Chequest watershed at time of Phase I modeling. Constructed in 2000. Design documentation obtained from Davis County NRCS office in Bloomfield, IA.

The principal spillway is a 10" smooth steel pipe (SSP) with hood inlet, invert elevation of 90.0 feet based on local on-site datum. The auxiliary spillway is 10 feet wide, retardance class C, crest elevation at 95.9 feet. Top of dam at 98.0 feet.

Hydraulic Design: U.S. Dept. of Agriculture – Soil Conservation Service (SCS)

G. Utt Pond: Elevation (Stage) – Discharge relationships from design documentation.

Stage (feet)	Elevation (feet)	Discharge (cfs)	Accumulated Storage (acre-feet)	
0	90.0	0	12.56	principal spillway: 95.0
1	91.0	1.78	13.78	
2	92.0	7.5	15.95	
3	93.0	7.7	18.48	
4	94.0	7.89	21.36	
5	95.0	8.08	24.56	
5.9	95.9	8.25	27.73	auxiliary spillway: 95.9
6	96.0	9.85	28.08	
6.4	96.4	16.87	29.62	
6.9	96.9	27.83	31.55	
7	97.0	32.79	31.93	
7.4	97.4	65.11	33.60	
7.9	97.9	127.56	35.69	
8	98.0	161.47	36.70	top of dam: 98.0
9	99.0	314.14	40.63	

Appendix D – Iowa Watersheds Project Phase II Pond Performance Tables, 10-, 25-, and 100-year Average Recurrence Interval Design Storm Rainfall

Table D.1. Pond performance of the Iowa Watersheds Project Phase II flood mitigation projects in the South Chequest Creek Watershed. Performance shown is for the 10-year, 24-hour design storm (4.4 inches of rain).

Pond ID #	*Auxiliary Spillway (A.S.) Elevation (ft)*	*Max. Water Surface Elevation (ft)*	*A.S. Activated*	*Flood Storage Used (%)*	*Total Storage Used (%)*	*Peak Discharge Reduction (%)*
1	802.8	799.87	No	42.7	30.1	74.1
2	827.4	827.10	No	77.3	28.2	83.3
3	813.0	812.66	No	69.8	20.9	78.9
4	776.5	774.61	No	55.6	34.3	84.2
5	809.0	808.07	No	64.5	34.0	87.5
6	767.8	766.40	No	71.6	46.6	83.3
7	775.4	773.29	No	53.6	34.8	93.3
8	761.2	759.19	No	53.7	34.9	70.0
9	781.6	780.18	No	43.8	33.4	71.4
10	773.2	772.31	No	80.4	51.1	89.5
11	821.6	821.85	Yes	100	57.5	91.7
12	826.3	825.46	No	69.9	37.6	66.7
13	805.7	805.45	No	86.3	24.8	83.0
14	792.5	791.99	No	60.0	18.5	93.8
15	793.4	792.65	No	37.4	13.8	89.6
16	778.8	777.56	No	65.3	35.4	87.5
17	776.5	775.91	No	81.1	38.5	80.0
18	751.6	750.0	No	66.9	42.3	83.3
19	750.3	750.0	No	82.6	33.5	81.8
20	766.2	766.08	No	84.5	36.1	88.9
21	765.0	765.09	Yes	100	33.1	83.3
22	719.0	718.83	No	85.4	26.1	80.0

Table D.2. Pond performance of the Iowa Watersheds Project Phase II flood mitigation projects in the South Chequest Creek Watershed. Performance shown is for the 25-year, 24-hour design storm (5.4 inches of rain).

Pond ID #	***Auxiliary Spillway (A.S.) Elevation (ft)***	***Max. Water Surface Elevation (ft)***	***A.S. Activated***	***Flood Storage Used (%)***	***Total Storage Used (%)***	***Peak Discharge Reduction (%)***
1	802.8	800.85	No	65.0	45.8	78.4
2	827.4	827.43	Yes	100	38.5	87.5
3	813.0	812.99	No	99.9	30.5	66.7
4	776.5	775.92	No	85.5	52.6	88.5
5	809.0	809.06	Yes	100	57.6	90.9
6	767.8	768.05	Yes	100	70.0	87.9
7	775.4	774.93	No	87.8	57.0	90.9
8	761.2	760.17	No	76.8	49.9	77.1
9	781.6	781.17	No	65.3	49.8	78.9
10	773.2	773.40	Yes	100	77.5	92.3
11	821.6	822.51	Yes	100	76.7	93.8
12	826.3	826.44	Yes	100	54.7	75.0
13	805.7	806.0	Yes	100	37.9	75.0
14	792.5	792.32	No	83.8	25.9	93.9
15	793.4	792.65	No	52.3	19.3	92.2
16	778.8	779.20	Yes	100	59.4	90.9
17	776.5	776.90	Yes	100	55.3	71.4
18	751.6	751.97	Yes	100	70.4	87.9
19	750.3	750.65	Yes	100	50.5	87.5
20	766.2	766.73	Yes	100	54.2	92.3
21	765.0	765.42	Yes	100	46.9	88.9
22	719.0	719.16	Yes	100	38.1	85.7

Table D.3. Pond performance of the Iowa Watersheds Project Phase II flood mitigation projects in the South Chequest Creek Watershed. Performance shown is for the 100-year, 24-hour design storm (7.2 inches of rain).

Pond ID #	***Auxiliary Spillway (A.S.) Elevation (ft)***	***Max. Water Surface Elevation (ft)***	***A.S. Activated***	***Flood Storage Used (%)***	***Total Storage Used (%)***	***Peak Discharge Reduction (%)***
1	802.8	803.15	Yes	100	74.0	82.3
2	827.4	828.18	Yes	100	60.4	88.9
3	813.0	813.42	Yes	100	44.8	66.7
4	776.5	777.56	Yes	100	78.2	84.8
5	809.0	810.04	Yes	100	74.7	92.4
6	767.8	769.36	Yes	100	93.6	82.9
7	775.4	776.57	Yes	100	84.4	92.5
8	761.2	762.14	Yes	100	82.1	83.7
9	781.6	782.48	Yes	100	79.9	82.6
10	773.2	774.60	Yes	100	87.4	90.3
11	821.6	822.83	Yes	100	84.3	78.3
12	826.3	827.43	Yes	100	81.2	80.0
13	805.7	806.43	Yes	100	55.4	80.0
14	792.5	792.75	Yes	100	39.8	92.6
15	793.4	793.31	No	82.1	30.4	80.0
16	778.8	779.86	Yes	100	74.7	92.8
17	776.5	777.89	Yes	100	76.6	82.3
18	751.6	753.05	Yes	100	86.5	83.3
19	750.3	751.64	Yes	100	69.8	80.0
20	766.2	767.39	Yes	100	70.2	93.8
21	765.0	766.07	Yes	100	65.3	90.0
22	719.0	719.82	Yes	100	57.5	87.5

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