Hydrologic Modeling of the English River Watershed

by

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# Contents

1 Introduction  

2 English River Watershed Hydrology  
   2.1 Hydrology of the English River  
      2.1.1 Statewide Precipitation  
      2.1.2 The Water Cycle of the English River  
      2.1.3 Monthly Water Cycle  
      2.1.4 Flood Climatology  
   2.2 Hydrological Alterations in Iowa Watersheds  
      2.2.1 Hydrological Alterations from Agricultural-Related Land Use Changes  
      2.2.2 Hydrological Alterations Induced by Climate Change  
      2.2.3 Hydrological Alterations Induced by Urban Development  
      2.2.4 Detecting Streamflow Changes in Iowa’s Rivers  
   2.3 Summary of Iowa’s Flood Hydrology  

3 HSPF Modeling of the English River  
   3.1 Historical Weather and Streamflow  
   3.2 River Reach Delineation  
   3.3 Land Segment Definition  
   3.4 Calibration and Validation  
      3.4.1 Monthly Water Cycle  
      3.4.2 Annual Runoff  
      3.4.3 Annual Maximum Peak Discharge  

4 Watershed Analysis and Scenarios  
   4.1 Flood Characteristics of the English River Watershed
Chapter 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 locally to tackle local challenges with a unified watershed approach.

This hydrologic assessment of the English River watershed is carried out by the Iowa Flood Center, located at IIHR–Hydroscience & Engineering on the University of Iowa campus, for the English River Watershed Management Authority. The assessment is meant to provide local leaders, landowners and residents in the English River watershed an understanding of the hydrology – or movement of water – within the watershed, and the potential of various hypothetical flood mitigation strategies.

The assessment begins by characterizing the water cycle of the English River using historical observations of precipitation and streamflow. We also investigate trends observed for the English River, within the broader context of trends that have been observed in Iowa watershed related to changes in land use and weather patterns. This analysis of observations provides a baseline for assessing model predictions of river characteristics.

A hydrologic model of the English River watershed, using the Hydrological Simulation Program-FORTRAN (HSPF), was developed to make long-term continuous hourly simulations of flows throughout the watershed for a 64-year period. The model was calibrated using observations for the most recent 20-year period, and validated using the remaining 44-year
period. The English River HSPF model’s predictive ability was assessed by comparing the simulated water cycle with historical observations.

The English River HSPF model was then used to examine the flood characteristics of the watershed, and run simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed. Areas in the watershed with high runoff or high flood potential were identified, and the severity and extent of simulated flooding for extreme flood years was examined. Focus for the scenario development was placed on understanding the impacts of increasing infiltration in the watershed and implementing a system of storage projects (ponds) across the landscape.

The focused hydrologic assessment provides watershed residents and local leaders an additional source of information and should be used in tandem with additional reports and watershed plans working to enhance the social, economic, and environmental sustainability and resiliency of the English River watershed.
Chapter 2

English River Watershed Hydrology

This chapter illustrates facts about the water cycle and flood hydrology of the English River watershed based on historical observations. The historical records for precipitation and streamflow are examined to describe how much precipitation falls, how that water moves through the landscape, when storms typically produce river flooding.

2.1 Hydrology of the English River

The English River drains 655 square miles (mi$^2$) of the Southern Iowa Drift Plain. Precipitation measurements are available from one station within the watershed (at North English), and at seven others in close proximity outside the watershed. Streamflow measurements are available at the long record U.S. Geological Survey (USGS) stream-gage at Kalona (USGS 05455500 English River at Kalona, IA).

2.1.1 Statewide Precipitation

Iowa’s climate is marked by a smooth transition of annual precipitation from the southeast to the northwest (see Figure 2.1). The average annual precipitation reaches 40 inches in the southeast corner, and drops to 26 inches in the northwest corner. Over the English River watershed, the mean annual precipitation is 36.5 inches.
Figure 2.1: Average annual precipitation for Iowa. Precipitation estimates are based on the 30-year annual average (1981-2010) for precipitation gauge sites. Interpolation between gauge sites to an 800 m grid was done by the PRISM (parameter-elevation relationships on independent slopes model) method. (Data source: http://www.prism.oregonstate.edu/)
2.1.2 The Water Cycle of the English River

Of the precipitation that falls across the English River watershed, the water either evaporates into the atmosphere, or drains into streams and rivers. Table 2.1 shows the partitioning of precipitation among these components.

Table 2.1: Annual water cycle for the English River watershed. The components are shown as a depth (in inches) and as a percentage of average annual precipitation (100% of the water).

<table>
<thead>
<tr>
<th>Component</th>
<th>Depth (in)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>36.5</td>
<td>100</td>
</tr>
<tr>
<td>Evaporation</td>
<td>25.3</td>
<td>69.3</td>
</tr>
<tr>
<td>Surface Flow</td>
<td>5.0</td>
<td>13.7</td>
</tr>
<tr>
<td>Baseflow</td>
<td>6.2</td>
<td>17.0</td>
</tr>
</tbody>
</table>

Evaporation: In the English River (as in other Iowa watersheds), the majority of water leaves by evaporation — either directly from lakes and streams, or by transpiration from crops and vegetation. Evaporation accounts for about 69% of precipitation.

Surface Flow: The precipitation that drains into streams and rivers can take two different paths. During rainy periods, some water quickly drains across the land surface, and causes streams and rivers to rise in the hours and days following the storm. This portion of the flow is often called surface flow, even though some of the water may soak into the ground and discharge later (e.g., a tile drainage system). In the English River, surface flow accounts for about 14% of precipitation.

Baseflow: The rest of the water that drains into streams and rivers takes a longer, slower path; first it infiltrates into the ground, percolates down to the groundwater, and then slowly moves towards a stream. The groundwater eventually reaches the stream, maintaining flows in a river even during extended dry periods. This portion of the flow is often called baseflow. In the English River, baseflow accounts for about 17% of precipitation.
A watershed’s geology and soils helps determine the partitioning of precipitation runoff into surface flow and baseflow. In the English River, more water reaches the river as baseflow; the ratio of baseflow to surface is 1.24.

### 2.1.3 Monthly Water Cycle

The English River has a cycle of average monthly precipitation and streamflow that is typical of Iowa watersheds (see Figure 2.2). Precipitation is at its lowest in winter months; still, the precipitation is often in the form of snow, and can accumulate within the watershed until it melts. Spring is marked by an increase in precipitation, the melting of any accumulated winter snow, and low evaporation before the growing season begins; these factors combine to produce high springtime streamflows.

![English River at Kalona](image.png)

Figure 2.2: Monthly water cycle for the English River watershed. The plots show the average monthly precipitation (in inches) and the average monthly streamflow (in inches). The average monthly estimates for precipitation and streamflow are based on the same 30-year period (1983-2012).
The watershed has a first peak in its average monthly streamflow in early spring (March), as snow accumulation and melt is more pronounced; a secondary peak occurs in late spring/early summer (June). As crops and vegetation evaporate more and more water as we enter the summer months, moisture in the soil is depleted and the average monthly streamflow decreases (even though average monthly rainfall amounts are relatively high).

2.1.4 Flood Climatology

Figure 2.3 shows the annual maximum peak discharges (or the largest streamflow observed each year) and the calendar day of occurrence for the English River. Only those peaks greater than the average annual maximum are shown. The average annual maximum — also known as the mean annual flood — is a common threshold for “flooding”; the size of a river’s channel is often closely related to the mean annual flood. Hence, the results shown in Figure 2.3 are a proxy for the flood events that have occurred over the historical record. Note that in the 75 years of record, flood events occurred in 25 years (or 33% of the years).

The flood flows on the English River have a distinct seasonal pattern. The majority of floods occur between late-February and August. This period defines the “flood season” for most Iowa streams. Only 2 (out of 25) floods occurred outside this season in the English River at Kalona. Some events occur in late-winter and early-spring; these maximums may be associated with snow melt, rain on snow events, or heavy spring rains when soils are often near saturation. Still, the largest annual maximums tend to occur in the summer season, when the heaviest rainstorms occur. Note that 14 (out of 25) floods occurred in the 3-month period between May and July.

2.2 Hydrological Alterations in Iowa Watersheds

Although the hydrologic conditions presented for the English River watershed illustrate the historical water cycle, the watershed itself is not static; historical changes have occurred that have altered the water cycle. In this section, we review the hydrological alterations typical of Iowa watersheds,
Figure 2.3: Annual maximum peak discharges and the calendar day of occurrence for the English River at Kalona (USGS 05455500). The plots show all annual maximums greater than the mean annual flood (horizontal line). The annual peaks are for the period of record from 1940 to 2014.
and look for evidence of these alterations in long-term streamflow records of the English River.

2.2.1 Hydrological Alterations from Agricultural-Related Land Use Changes

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

Still, other transformations associated with an agricultural landscape have also impacted runoff potential. Wetland drainage and stream channelization (e.g., straightening, deepening, and relocation) have led to reductions of upland and in-stream storage, and acceleration of streamflow velocities (Jones and Schilling, 2011; Knox, 2001). Large-scale development of tile drainage has modified the drainage system, affecting runoff timing and groundwater storage capacity (Winsor, 1975; Thompson, 2002; Urban and Rhoads, 2003; Burkart, 2010; Schottler et al., 2014). In contrast, the introduction of conservation practices in the second half of the 20th century should reduce runoff. The Conservation Reserve Program (CRP) originally began in the 1950s. Many programs were established in the 1970s to remove lands from agricultural production and establish native or alternative permanent vegetative cover; in an effort to reduce erosion and gulley formation, practices such as terraces, conservation tillages, and contour cropping were also encouraged. The Farm Bill of 1985 was the first act that officially established the CRP as we know it today, followed by expanded activities through the Bills of 1990, 1996, 2002, and 2008. Hence, the timeline of agriculture-driven land use change is marked by continual evolution in practices.
2.2.2 Hydrological Alterations Induced by Climate Change

Over periods ranging from decades to millions of years, Iowa has seen significant changes to its climate. Studies show that since the 1970s, Iowa and the Midwest have seen increases in annual and seasonal precipitation totals, and changes in the frequency of intense rain events and the seasonality of timing of precipitation (Takle, 2010). Large increases in runoff and flood magnitudes in the north central U.S. (including Iowa) have prompted scientific inquiries to unequivocally attribute these changes to driving factors (Ryberg et al., 2014). Although recent agricultural land use changes, such as the transition from perennial vegetation to seasonal crops, is an important driver (Zhang and Schilling, 2006a,b; Schilling et al., 2008, 2010), other investigations show that climate-related drivers may be an equal or more significant contributor to recent hydrologic trends (Ryberg et al., 2014; Frans et al., 2013).

2.2.3 Hydrological Alterations Induced by Urban Development

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

2.2.4 Detecting Streamflow Changes in Iowa’s Rivers

Hydrologic alterations in Iowa watersheds have been tested through the analysis of changes in the long-term flow at the stream-gaging sites. The identification of statistically significant shifts in the flow time series were
made using the approach developed by Villarini et al. (2011). Figure 2.4 shows the results of the analysis for annual average discharge and the annual maximum peak discharge for the English River at Kalona. Although it is clear that the largest annual discharges and the largest peak discharges have occurred in more recent decades, the analysis does not indicate any statistical significant changes (or trends) over the 75 year period of record.

In contrast, other watershed in Iowa do have statistically significant changes in annual discharge occurring sometime between 1968 and 1978. Streamflow since the 1970s is slightly higher than before, and its year-to-year variability has increased. For peak charges, many Iowa watersheds also have statistically significant increases in high flows and greater variability in the last 40 years; however, some others do not (like the English River). Still, the general tendencies observed in Iowa streams for increased flow amounts and greater variability in recent decades are also apparent in the English River flow record. The evidence suggests that Iowa (and elsewhere in the Midwest) has experienced long-term changes in the nature of streamflow (around 1970). The reasons for these changes is still the subject of intense on-going research (Mora et al., 2013; Frans et al., 2013; Schottler et al., 2014; Wu et al., 2013). Still, Iowans have all seen the impacts of increased and more highly variable flows; the widespread flooding in 1993 and 2008 mark two visible examples.

2.3 Summary of Iowa’s Flood Hydrology

Hydrologic assessment begins by looking at the historical conditions within a watershed, and moves on to predicting their flooding characteristics. Ultimately, for watersheds to reduce flood hazards, large- and small-scale mitigation projects directed towards damage reduction can be proposed and implemented. In many instances, projects aim to change the hydrologic response of the watershed, e.g., by storing water temporarily in ponds, enhancing infiltration and reducing runoff, etc. Such changes have (and are designed to have) significant local water cycle effects; cumulatively, the effects of many projects throughout the watershed can also have impacts further downstream. Still, it is important to recognize that all Iowa watersheds are undergoing alterations — changes in land use, conservation practices, increases in urban development, and changes in weather patterns with a changing climate. Therefore, a watershed-focused strat-
Figure 2.4: English River at Kalona (USGS 05455500) time series of: (a) annual average discharge (in cfs) and (b) annual maximum peak discharge (cfs). Results are shown for the period of record from 1940 to 2014. Although the trend lines show an increase in flows over time, the trends observed are not large enough to be considered statistically significant.
egy, which considers local interventions and their impacts on the basin as a whole, within the historical context of a changing water cycle, is needed for sound water resources planning.
Chapter 3

HSPF Modeling of the English River

This chapter summarizes the development of a computer simulation model for the English River watershed. The modeling was performed using the Environmental Protection Agency (EPA) Hydrological Simulation Program–FORTRAN (HSPF) Version 12.2 (Bicknell et al., 2005). HSPF is designed to make long-term continuous simulations of hydrologic (rainfall-runoff) and water quality (e.g., nutrient) processes of a watershed. The model has been used for water quantity and quality simulation for large and small watersheds across Iowa (Donigian et al., 1983a, 1984) and the United States; for instance, the Chesapeake Bay Watershed HSPF model has been used for many years in a community effort to study water management and restoration options for inflows to the threatened Chesapeake Bay. The remaining sections describe the model representation of the English River watershed, the calibration of the model parameters using historical streamflow observations, and the validation of the model predictions.

3.1 Historical Weather and Streamflow

Historical weather information is the main time series input driving an HSPF watershed simulation. Historical observations of streamflow play an important role in estimating model parameters (called model calibration) and assessing the predictive ability of the model (called model validation). This section describes the historical weather and streamflow observations
used with the English River HSPF model.

Table 3.1 shows the eight weather stations near the English River watershed used for the long-term simulations. Hourly precipitation and temperature time series are produced at each of these locations. Four of the stations collect hourly precipitation data (Grinnell 3 SW, Iowa City, North English, and Washington); the other four collect daily precipitation data. Therefore, daily precipitation was disaggregated into hourly time steps using the precipitation pattern at the hourly stations (including nearby hourly stations not used in the simulation). All the stations except two (Montezuma 1 W and North English) collect minimum and maximum air temperature data; for one other (Brooklyn) the daily temperature record is only about 19 years long. At stations with missing temperature records, the daily minimum and maximum temperature data was interpolated using observations at other stations (including nearby air temperature stations not used in the simulation). Hourly temperature time series are then generated from daily records of maximum and minimum temperature using a fixed daily cycle. At all the stations, there are gaps in the record (observations are missing or incomplete). All the gaps in the record were filled by interpolation of data from nearby stations.

Table 3.1: Weather stations near the English River watershed.

<table>
<thead>
<tr>
<th>Station</th>
<th>COOP ID</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Area(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brooklyn</td>
<td>130933</td>
<td>41.739</td>
<td>92.440</td>
<td>10.7</td>
</tr>
<tr>
<td>Grinnell 3 SW</td>
<td>133473</td>
<td>41.720</td>
<td>92.748</td>
<td>3.4</td>
</tr>
<tr>
<td>Iowa City</td>
<td>134101</td>
<td>41.609</td>
<td>91.505</td>
<td>7.7</td>
</tr>
<tr>
<td>Montezuma 1 W</td>
<td>135650</td>
<td>41.583</td>
<td>92.549</td>
<td>19.3</td>
</tr>
<tr>
<td>North English</td>
<td>136076</td>
<td>41.517</td>
<td>92.059</td>
<td>40.1</td>
</tr>
<tr>
<td>Sigourney</td>
<td>137678</td>
<td>41.332</td>
<td>92.197</td>
<td>2.0</td>
</tr>
<tr>
<td>Washington</td>
<td>138688</td>
<td>41.282</td>
<td>91.707</td>
<td>6.7</td>
</tr>
<tr>
<td>Williamsburg</td>
<td>139067</td>
<td>41.640</td>
<td>91.978</td>
<td>10.1</td>
</tr>
</tbody>
</table>

Figure 3.1 shows the location of the eight weather stations. Also shown is a set of polygons, which delineates the area that is closest to each of the eight stations. For the simulations, a station’s hourly precipitation and temperature record is used as the time series input for all the area that is closest to the station. Note that only one of the weather station (North
English) is located within the English River watershed; 40.1% of the watershed drainage area is closest to this station. The remaining stations each represent between 2.0% (Sigourney) to 19.3% (Montezuma 1 W) of watershed area (see also Table 3.1).

Figure 3.1: Location of the eight weather stations used in the English River HSPF model. The area that is closest to each station is indicated by the polygons; the station provides the precipitation and air temperature inputs used for these indicated areas.

HSPF also requires time series inputs on cloud cover, wind speed, and dew point temperature. These data are used primarily in the cold season to predict snowfall and snow accumulation and melt. Cloud cover, wind speed, and dew point temperature are measured at only a few (airport) stations in Iowa. The closest stations are at the Iowa City and Washington Airports, but the records are only available since about 1995. From 1973 to 1995, the records for the Cedar Rapids and Ottumwa Airports are used instead. Prior to 1973, the Des Moines and Moline Airport stations are the closest sites with available data. For each period, the average observation at the two sites are used as the input for the English River watershed.
Even though none of these sites is located within the watershed, cloud cover, wind speed, and dew point temperature vary relatively smoothly in space, so averaging of the two-station data is appropriate.

Finally, HSPF requires time series inputs on potential evapotranspiration and solar radiation. These variables are rarely measured directly. However, methods based on weather inputs can provide reliable estimates for hydrologic modeling. Using time series on air temperature, dew point temperature, and cloud cover, daily time series of potential evapotranspiration and solar radiation were estimated using a Penman approach (Shuttleworth, 1993). Potential evapotranspiration is the more critical variable; it along with precipitation predicts the overall water balance and storage of water in the subsurface (soils) for the simulation. Solar radiation is used only to predict snow melt during the cold season. Still, this approach provides consistent estimates of the two (related) variables for both uses of the data. Hourly time series are then generated from the daily values using a fixed daily cycle.

3.2 River Reach Delineation

Figure 3.2 shows the subdivision of the English River watershed into 103 subbasin areas. These areas define the drainage areas to a portion of the river network of streams (shown as the blue lines in Figure 3.2). Within HSPF, these areas are known as river reaches; runoff from the surrounding drainage area, as well as flow from upstream river reaches, is combined to predict the resulting flow at the river reach outlet using an HSPF RCHRES operation. Hence, the outlet of the river reaches are locations where model predictions are made. For the English River HSPF model, the average river reach drainage area is 6.1 square miles.

For each river reach segment, HSPF RCHRES requires river channel hydraulic information to determine how quickly water moves through the reach. This information is summarized by the storage-discharge relationship. For a given amount of water (stored within the channel of the river reach), the discharge at the outlet is determined from the relationship. For locations with a stream-gage, this information is straightforward to estimate. A stream-gage provides direct measurements of the discharge and the channel cross-section flow area; by multiplying the area by the HSPF river reach length, the reach storage can also be obtained. Unfortu-
Figure 3.2: Subdivision of the English River watershed into HSPF RCHRES river reaches. The English River network of streams is indicated by the blue lines. The black lines outline the drainage area of the river reaches. The location of the USGS English River at Kalona stream-gage is indicated by the green triangle. Note that HSPF RCHRES river reaches are subbasin areas, and the runoff from these areas is combined with flows from upstream river reaches to make predictions at the outlet of the reach.
nately, there are only two sites within the English River watershed with suitable stream-gage measurements — the English River at Kalona (USGS 05455500, 574 mi²) and the South English River Tributary near Barnes City (USGS 05455280, 2.51 mi²). A standard approach for estimating channel reach information uses a scaling relationship between channel reach dimensions and drainage area. Using a relationship fitted to measurements from the two available English River sites, and supplemented with nearby measurements for streams of intermediate sizes from Old Man’s Creek near Parnell (USGS 05455050, 81.2 mi²) and Rapid Creek near Iowa City (USGS 05454000, 25.3 mi²), the channel reach dimensions were estimated for all 103 HSPF RCHRES segments. Combining the dimensions with the reach lengths, and using estimates of the hydraulic roughness of the channel and floodplain area, a storage-discharge relationship was estimated for all the segments for the English River HSPF model.

3.3 Land Segment Definition

HSPF uses land segments to represent the hydrologic and water quality response at different locations. Pervious land segments (PLSs) represent the response from most areas; impervious land segments (ILSs) represent the response from roads and urban areas where water cannot infiltrate into the ground.

Land segments are not meant to represent the hydrology of any one specific point in the watershed; instead, they represent the average response from locations with similar characteristics (soils and land use) given the input weather time series. Therefore, land segments are defined by identifying areas with similar characteristics. Figure 3.3 shows the land use map for the English River watershed, created by the Iowa Soybean Association (ISA) for 2013 conditions. The land area is partitioned into seven distinct groups: corn (32.12%), soybeans (26.10%), grass/pasturelands (28.74%), forest (6.21%), wetlands (1.44%), barren land (<0.01%), and urban (5.37%). All the groups except urban and wetlands are represented by a unique pervious land segment. Urban and wetland areas are represented by both a pervious land segment, and an impervious land segment. Based on this classification, there are nine different land segment types.

Note that a further subdivision of land segments is accomplished in the English River HSPF model based on the weather inputs. For example, the
Figure 3.3: Land use classification for the English River watershed used to define HSPF land segments. The land use information was compiled by the Iowa Soybean Association for 2013 conditions.
areas closest to the Grinnell 3 W station are simulated with the weather inputs for that station, the areas closest to the North English are simulated with the weather inputs for that station, and so on. Hence, for any given land use classification (e.g., soybeans), there are eight different HSPF pervious land segments (one associated with each weather station). Table 3.2 shows the percentage of area for the five dominant land uses for each of the eight weather stations.

Table 3.2: Watershed area (in %) by land use classification for each of the eight weather stations.

<table>
<thead>
<tr>
<th>Station</th>
<th>Corn</th>
<th>Soybeans</th>
<th>Grass</th>
<th>Urban</th>
<th>Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brooklyn</td>
<td>30.6</td>
<td>25.7</td>
<td>34.7</td>
<td>4.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Grinnell 3 SW</td>
<td>47.4</td>
<td>30.7</td>
<td>12.2</td>
<td>7.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Iowa City</td>
<td>25.3</td>
<td>16.9</td>
<td>36.6</td>
<td>7.7</td>
<td>8.7</td>
</tr>
<tr>
<td>Montezuma 1 W</td>
<td>38.1</td>
<td>33.6</td>
<td>20.9</td>
<td>5.3</td>
<td>1.9</td>
</tr>
<tr>
<td>North English</td>
<td>29.0</td>
<td>24.2</td>
<td>31.6</td>
<td>5.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Sigourney</td>
<td>41.8</td>
<td>22.1</td>
<td>26.7</td>
<td>4.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Washington</td>
<td>30.0</td>
<td>24.0</td>
<td>25.4</td>
<td>6.5</td>
<td>12.4</td>
</tr>
<tr>
<td>Williamsburg</td>
<td>34.4</td>
<td>27.7</td>
<td>28.1</td>
<td>4.7</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Even though HSPF uses a different model land segment operation to represent the same land segment type for different weather stations, the HSPF model parameters are almost identical for a land segment type. That is, soybean land segments all share similar model parameter values, corn land segments all share similar parameter values, and so on. The only parameter values that are different is the land surface slope (SLSUR). For this parameter, all the areas designated with the same land segment type for a given weather station were sampled to estimate the average land surface slope. That is, all soybean areas for the Grinnell 3 W station were used to estimate SLSUR for that land segment, all soybean areas for the North English station were used to estimate SLSUR for that land segment, and so on for each land segment type and station. This approach was used to account for variations in topography across the watershed.
3.4 Calibration and Validation

Model calibration was carried out for a 20-year period (water years 1993 to 2012). We chose to use the last portion of the historical record for calibration, since it should be more representative of current land use conditions. The HSPF model was used to simulate runoff and flows on an hourly time step for the calibration period; simulated flows were then compared with observed flows at the USGS stream-gage for the English River at Kalona (USGS 05455500). Model parameters were then changed so that the simulation better matched the observations.

Two model calibration approaches were used. First, a systematic manual approach was used make model parameter adjustments. We first diagnosed the mismatch between simulated and observed flows, and adjusted model parameters that control processes that were not well represented. After improving the overall water balance and seasonal flow prediction with the manual approach, the adjusted parameters were used as a starting point for an automated approach. The automated approach minimizes two error measures (objective functions) using the Shuffled Complex Evolution (SCE-UA) method (Duan et al., 1992). One objective function — the root mean squared error (RMSE) — measures the errors in the simulation of high flows. The second objective function — the relative squared error (RSE) — measures the errors in the simulation of low flows. Using this multi-objective calibration approach finds model parameters that better balance the simulation of both high and low flows (Vrugt et al., 2003).

Figure 3.4 shows the daily time series for the 20-year calibration period. Results are shown for the simulation with the final model parameters. In general, the model does a good job simulating flows for the English River using weather inputs and its simplified representation of the rainfall-runoff process. Of course, there are periods when the simulation matches the observation quite closely, and others when it does not.

Given the inherent limitations of hydrologic modeling, some degree of mismatch with model simulations is to be expected. Still, one measure of the quality of the model is its ability predict the components of the water cycle as observed from measurements. Another measure is the ability of the model to predict flows for a periods that was not used for model calibration (often referred to as a “validation” period). In the following sections, we compare the simulation with observations for different components of the water cycle.
Figure 3.4: Observed and simulated daily flow time series for the English River at Kalona (USGS 05455500) for the calibration water years from 1993 to 2012.
3.4.1 Monthly Water Cycle

The English River has a pronounced seasonal cycle in runoff (see Figure 3.5). For the calibration period (panel a), the simulated monthly water cycle matches observations quite closely. The largest discrepancy occurs for the months of May and June, when the simulation underestimates the observed monthly average flow. From the daily time series for the calibration period (see again Figure 3.4), the wet May and June periods in recent years (2008 to 2011) appear to be largely responsible for the mismatch. Overall, the simulated water runoff underestimates observed runoff by only 3.7%.

For the period of record (panel b), which also includes the 44-year validation period not included as part of model calibration, the simulated monthly water cycle still matches observations well. However, the simulation consistently overestimates the observed monthly average flow in most months; the largest discrepancies occur during the warm season months (May through September). Overall, both the observed and simulated monthly average flows are lower over the 64-year period of record (panel b) and then the shorter 20-year calibration period. For the period of record, the simulated water runoff overestimates observed runoff by 14.4%. Note that the land use conditions assumed are fixed for the simulation for the entire period of record; this assumption may account (in part) for the over-estimation for the period of record, while the flows for the calibration period are slightly under-estimated.

3.4.2 Annual Runoff

Annual runoff from the English River watershed varies significantly from year to year (see Figure 3.6). Basin-average runoff depths range from about 1 inch in the driest year (1954), to over 40 inches in the wettest year (1993). For a perfect simulation, the simulated and observed runoff values would all be the same, and plotted values would all fall along the one-to-one line (shown on Figure 3.6 for reference). For the calibration period, the simulated and observed annual runoff follows the one-to-one closely; low-runoff years tend to be simulated with slightly more runoff than observed, and high-runoff years tend to be simulated with slightly less runoff than observed. However, there is no significant overall bias in the predictions. For the validation period, the majority of years have
Figure 3.5: Observed and simulated average monthly runoff depth (in inches) for the English River watershed. Results are shown for (a) the calibration period from 1993 to 2012, and (b) the period of record from 1949 to 2012.
simulated runoff slightly higher than observed. In part this occurs because there are fewer very wet years; the largest observed runoff depth during the validation period is 21.3 inches (1974). Still, it is clear that the model parameters calibrated with observed flows for more recent years (1993 to 2012) have a tendency to overpredict flows for the earlier years (1949 to 1992). Again, changes in land use conditions — and their resulting increases in runoff — may explain the mismatch in simulation for the validation period (where fixed parameters are assumed for the entire simulation period).

![English River at Kalona](image)

**Figure 3.6:** Simulated versus observed annual flow depth (in inches) for the English River at Kalona. Results are shown for the calibration period from 1993 to 2012 (green circles) and the validation period from 1949 to 2012 (purple triangles).

To test this hypothesis, trends in the simulated and observed annual flow time series were evaluated. As noted in Chapter 2, observed annual runoff tends to increase over time (see blue line). Although there is no
statistically significant trend, runoff in more recent decades was higher than runoff in earlier decades. In contrast, the simulated annual runoff shows almost no increase over time (see red line). The English River HSPF model can only capture trends due to weather, which appear to be insignificant. That is because the HSPF model parameters for the watershed are fixed; they do not change over time to represent changes in agricultural practices (e.g., additions of tile drainage, buffer strips, conservation practices). Therefore, its hydrologic response does not change through time. Instead, the parameters best represent the conditions of the model calibration period (1992-2012). The results therefore suggest that the increasing observed annual runoff is related to changes in the hydrologic response due to land use change within the watershed; changes in weather patterns have had little overall affect on annual runoff.

Figure 3.7: Annual runoff time series for simulated and observed flows for the English River at Kalona (USGS 05455500). The trend lines for the simulated and observed time series were evaluated with linear regression.
3.4.3 Annual Maximum Peak Discharge

The English River HSPF model makes hourly flow predictions, and can be used to assess flood characteristics throughout the watershed. Figure 3.8 shows the model’s ability to predict the flood characteristics at the Kalona stream-gage for the calibration and validation periods. Here, the simulated and observed annual maximum peak discharge are compared. Although there is some mismatch between individual simulated and observed peaks for the calibration, there is no systematic under- or over-prediction of flood peaks; the plotted data are scattered about the one-to-one line. Even for the validation period, which contains 44 additional flood events not included in the calibration period, the model shows no tendency for under- or over-prediction of flood peaks. There is slightly greater variability, but the values scatter around the one-to-one line.

![Simulated versus observed annual maximum peak discharges for the English River at Kalona (USGS 05455500). Results are shown for the calibration period from 1993 to 2012 (green circles) and the validation period from 1949 to 2012 (purple triangles).](image)

Figure 3.8: Simulated versus observed annual maximum peak discharges for the English River at Kalona (USGS 05455500). Results are shown for the calibration period from 1993 to 2012 (green circles) and the validation period from 1949 to 2012 (purple triangles).
Even though the model predictions of one flood may be too low, and another may be too high, what is most important for flood assessment is that the model can reproduce the statistical characteristics of flood peaks over the historical record. Figure 3.9 shows a flood frequency analysis of simulated and observed annual maximum peak discharge for Kalona. For the 64-year simulation period, the annual maximum peak discharges are ranked from smallest to largest, and then plotted versus a sample estimate of their exceedance probability. Note that to estimate flood magnitudes for large events (e.g., the 100-year flood, which has a 1% exceedance probability), engineers typically fit a mathematical model (known as a probability distribution) to these sample data. As the plot illustrates, the sample probability distributions for simulated and observed flows match quite well. Therefore, we can conclude that the English River HSPF model provides a reliable basis for assessing flood characteristics.

Figure 3.9: Flood frequency analysis of annual maximum peak discharges for simulated and observed flows for the English River at Kalona (USGS 05455500). The annual maximums are for the entire for water years 1949 to 2012 (the entire simulation period).
Chapter 4

Watershed Analysis and Scenarios

The calibrated English River HSPF model was used to assess hydrologic conditions throughout the watershed. First, we used long-term simulations to identify areas in the watershed with high runoff and high flood potential. We then examined severity and extent of simulated flooding throughout the watershed for the most extreme flood years in the simulated record. We also ran simulations to help understand the potential impact of alternative flood mitigation strategies in the watershed. For the scenario simulations, we focused on understanding the impacts of increasing infiltration in the watershed, and implementing a system of storage projects (ponds) across the landscape.

4.1 Flood Characteristics of the English River Watershed

Identifying areas of the watershed with higher runoff is the first step in selecting mitigation project sites. High runoff areas offer the greatest opportunity for retaining more water from large rainstorms on the landscape and reducing downstream flood peaks. High flood areas are locations where upstream runoff combines to elevate flood magnitudes, and are locations where the impacts of upstream mitigation projects should be evaluated.
4.1.1 High Runoff Areas

The English River HSPF model produces estimates of runoff for each of its 103 subbasin areas; evaluating the runoff depths from the 64-year simulation can be used to identify high runoff areas. Overall, the simulated average annual runoff depth for the entire English River watershed is 11.3 inches. Some subbasins have higher runoff; others have lower runoff. Runoff depths for individual subbasins range from a low of 8.6 inches to a high of 12.1 inches.

Another way to represent runoff is with the runoff coefficient. The runoff coefficient is the fraction of precipitation that becomes runoff. Figure 4.1 maps the average annual runoff coefficient from the 64-year simulation across the English River watershed. The runoff ranges from as low as 24% of precipitation, to as high as 36% of precipitation. Areas in the basin with high runoff are primarily located in the western portion of the watershed, in upland tributaries of the upper English River, Deep River, and the upper and middle South English River in Poweshiek, Iowa, and Keokuk Counties. These areas closely correspond to the following hydrologic units defined by the U.S. Geological Survey (known as HUC-12 subwatersheds): English River-Dugout Creek, Upper English River, English River-Jordan Creek, Deep River, Upper South English River, and theUnnamed Creek-South English River. Another area with relatively high runoff is located in eastern portion of the watershed, in Deer Creek and Birch Creek tributaries of Johnson and Iowa Counties. These areas closely correspond to the Dear Creek-English River HUC-12 subwatershed, and a portion of the English River-Birch Creek subwatershed.

In the areas with high runoff, agricultural land use dominates (as it does for the entire watershed in general), but there is less forest and grassland areas than in other locations. From a hydrologic perspective, implementing projects that can reduce runoff from the high runoff areas should be a priority. Conservation farming practices, the use of cover crops, and targeted land use changes can all promote additional infiltration and reduce runoff. Delaying the movement of excess runoff can also reduce the flood impacts of high runoff locally and downstream. Small flood mitigation ponds are commonly implemented to store water temporarily and release it downstream at lower rates.

Still, high runoff is but one factor in selecting locations for potential projects. Alone, it has limitations. For example, some of the highest runoff
Figure 4.1: Average annual runoff coefficient in the English River watershed. The average annual runoff coefficient is the fraction of precipitation that becomes runoff (report here as a percentage). The runoff coefficient is computed for the HSPF RCHRES subbasins from the 64-year simulation.
areas have very flat terrain. Flat terrain would make the siting of flood mitigation ponds more challenging. Of course, there are many factors to consider in site selection. Landowner willingness to participate is essential. Also, existing conservation practices may be in place, or areas such as timber that should not be disturbed. Stakeholder knowledge of places with repetitive loss of crops or roads/road structures is also valuable in selecting locations.

4.1.2 High Flood Locations

The English River HSPF model also produces estimates of the flows at the outlet of each of the subbasins. This is done by combining the runoff from upstream areas, and routing the flow through the stream network. Evaluating the largest peak discharges each year from the 64-year simulation can be used to identify locations where the average flood magnitudes are relatively high. This approach integrates the effect of high runoff from upstream areas, and the influence of the stream network as water moves downstream during a high flow event, to show downstream areas most impacted by high runoff.

At subbasin outlets, the largest peak discharge in each of the 64 water years simulated was determined; the long-term sample average is known as the mean annual flood. For a river basin, the mean annual flood tends to increase with drainage area; smaller drainage areas tend to have a smaller mean annual flood than larger drainage areas. By creating a mathematical model describing the relationship between the mean annual flood and drainage area for the English River watershed, we can see which locations have much a higher mean annual flood than predicted by the relationship. For this analysis, we excluded the 38 headwater reaches (those with no inflows from upstream areas), since the mean annual flood estimates at these outlets are less reliable (i.e., more heavily influenced by precipitation station differences in rainrates for a few large storm events), and do not reflect the routing effects through the stream network. Figure 4.2 shows the results of this analysis. Based on the difference between the sample mean annual flood and that predicted by the mathematical model for the outlet’s upstream drainage area, we classified the annual flood at each location. The top third are classified as locations with a high annual flood, the middle third (closest to the mathematical model prediction) as
locations with a medium annual flood, and the bottom third as locations
with a low annual flood.

Figure 4.2: The relationship between the mean annual flood and drainage
area in the English River watershed. The mean annual flood computed for
the HSPF RCHRES subbasin outlets from the 64-year simulations is plotted
against the total upstream drainage area at the outlet; headwater sub-
basins are excluded from this analysis. A power-law mathematical model
was fit to the sample data (solid black line). Comparing the distance of
the sample mean annual flood from that predicted by the mathematical
model (line), the top third is classified as a high annual flood (red), the
middle third is classified as a medium annual flood (yellow), and the bot-
tom third is classified as a low annual flood (green).

Figure 4.3 maps the location of high, medium, and low annual floods at
their subbasin outlet for the English River watershed. Although some high
annual flood areas are the same as high runoff areas, some high runoff ar-
 eas are classified a low annual flood areas. For example, in the western-
most portion of the English River (near US Highway 63), we see a transi-
tion from higher to lower annual floods for connected reaches, and lower
annual floods continuing downstream. Although many of these subbasin areas produce higher runoff (see Figure 4.1), the upstream drainage area has a long and narrow (elongated) shape. The long time it takes for water to move through this channel, with relatively small additional drainage area contributing flow, results in lower mean annual floods than those of similar-sized drainage areas (with shorter channels and less elongated shapes). A similar affect is seen for Deep River, immediately to the south of the Upper English River section. At a larger scale, this effect is seen for the Lower South English River. Although its uppermost areas are high runoff areas, and the Middle South English contains medium runoff areas, the Lower South English River has low annual floods (down to its confluence with the English River main stem). Again, it takes longer for water to flow down this long narrow tributary, which helps to reduce the flood magnitudes downstream. Other examples occur throughout the watershed.

In contrast, many high flood locations tend to be situated just downstream of the confluence of two tributaries of similar size. One example in the downstream portion of the river is the confluence of the (North) English and South English Rivers. Although this portion of the basin has lower runoff areas (see Figure 4.1), two large tributaries combine at this point. The timing of the arrival of tributary flows is such that their combination can result in higher annual flows. Higher annual floods continue downstream for some distance. Another example of a confluence creating high annual flood magnitudes is just downstream of the junction of the Middle English River with Gritter Creek (near North English). Most of the other high flood locations are seen in the western portion of the watershed, and are directly associated with areas of high runoff. The high flood areas in the uppermost reach of the English River west of US Highway 63, in the Deep River tributary, and the upper reaches of the South English River, are examples.

From a hydrologic perspective, high annual flood locations should be a focus in flood mitigation planning. High flood locations are where upstream runoff combines to elevate flood magnitudes. The impacts of upstream mitigation projects should be assessed at these locations. For instance, projects in high runoff areas aimed at increasing infiltration into the soil and reducing runoff from the landscape should reduce peak flows downstream. But these measures can also change the timing of flows. High flood locations, which tend to be situated downstream of river con-
Figure 4.3: Mean annual flood anomalies for locations in the English River watershed. The mean annual flood computed for the HSPF RCHRES sub-basin outlets from the 64-year simulations is compared against a mathematical relation of mean annual flood and drainage area for the entire basin; headwater subbasins are excluded from this analysis. Locations with higher mean annual floods are shown in red.
fluences, are sensitive to the arrival of upstream flows. If peak flows on
the two tributaries arrive at same time, the combination increases peak
flows downstream. However, if the peak flows arrive at different times,
the peak from one tributary can pass downstream as the peak from the
second tributary arrives, decreasing the peak flows downstream. Given
the complex interaction of the timing of tributary flows, and their depen-
dance on where and when it rains within the watershed, high flood areas
make good locations for assessing the overall impact of upstream mitiga-
tion project.

4.1.3 Intensity and Extent of Extreme Floods

Our examination of high flood areas summarizes the average flood char-
acteristics over the 64-year simulation period. However, using the simu-
lated peak discharges at the subbasins outlets, we can also examine what
individual extreme floods are like in the watershed.

To identify extreme floods, peak discharge is an insufficient measure.
Peak discharges for large drainage areas are usually much larger than for
small drainage areas, even in cases when a flood is “more severe” at small
drainage locations. Hence, we will use a flood severity index to characterize
annual maximum peak discharge at all locations. Our flood severity in-
dex is simply the ratio of the peak discharge to the mean annual flood at a
location. Since the mean annual flood is a rough measure of the bankfull
discharge, a flood severity of 1 or greater is an indicator of a flood. By
determining the flood severity index for the annual maximum peak dis-
charge at all sites for each year, we can rank the outcomes to identify years
with extreme flooding. Table 4.1 shows the ranking of the top five years.

Based on the average flood severity index across all locations, 1993 is
clearly the top flood year. The average index value is 3.50; on average,
the peak discharge was three and half times the mean annual flood across
the watershed. Figure 4.4 maps out the flood severity index for subbasins
for 1993. What is unique about 1993 is the widespread extent of flooding;
every subbasin was simulated to have experienced sufficient flow to pro-
duce flooding. Although the intensity varies with location, it is high and
much more uniform across the watershed than for any other flood year.

The remaining top five flood years all have much lower average index
values, ranging from 2.35 to 2.58 (or about two and half times of the mean
Table 4.1: Ranking of the top simulated flood years in the English River watershed based on a flood severity index. The index is the ratio of annual maximum peak discharge (for the year) and the mean annual flood. The flood years are ranked below based on the average index at all 103 subbasin outlets. Also shown is the maximum and minimum index values at locations within the watershed.

<table>
<thead>
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<th>Rank</th>
<th>Water Year</th>
<th>Average</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>1993</td>
<td>3.50</td>
<td>3.99</td>
<td>1.57</td>
</tr>
<tr>
<td>2</td>
<td>1965</td>
<td>2.58</td>
<td>5.50</td>
<td>0.83</td>
</tr>
<tr>
<td>3</td>
<td>2010</td>
<td>2.50</td>
<td>4.41</td>
<td>0.80</td>
</tr>
<tr>
<td>4</td>
<td>1982</td>
<td>2.39</td>
<td>6.14</td>
<td>0.98</td>
</tr>
<tr>
<td>5</td>
<td>1950</td>
<td>2.35</td>
<td>4.31</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Figure 4.4: Flooding intensity and extent for the 1993 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity.
annual flood, on average). However, all these years are simulated to have experienced more intense flooding at some location within the watershed, as indicated by their maximum index values in Table 4.1. Figure 4.5 maps out the flood severity index for subbasins for 1965. The most intense flooding was simulated to have occurred on the Middle English, Gritter Creek, Smith Creek (upstream of Wellman), and a few other isolated subbasins. Flooding continued at downstream locations, but its intensity was much less. Compared to 1993, it is clear that the extent of flooding was much more localized in 1965; for vast portions of the South English River, Deep River, and upstream portions of the North English River, no flooding was simulated (i.e., the peak discharge was less than the mean annual flood).

Figure 4.5: Flooding intensity and extent for the 1965 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.

Maps of the flood severity index for the remaining top floods — 2010, 1982, and 1950 — are shown in Figures 4.6-4.8. Flooding extent was widespread in 2010, but no flooding was simulated for some tributaries in the
eastern portion of the watershed. High flood intensities were simulated for Deep River, upper portions of the South English River, the Middle English River, and Smith Creek. The flood intensity was low over much of the North English River, and along the mainstem of the English River. The simulated flooding in 1982 is notable for its localized high intensity in the Deer Creek and Birch Creek tributaries. The simulated flooding in 1950 also was most intense in the Deer Creek and Birch Creek tributaries, but its intensity is less severe and the flood extent across the watershed is greater.

Figure 4.6: Flooding intensity and extent for the 2010 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.

The examination of extreme flooding from the 64-year English River HSPF model simulations provides a better understanding of the nature of extreme floods in the watershed. Some are quite localized in extent, and impact just a few tributaries severely. Other are associated with more widespread flooding, although the intensity may be less severe. From a
Figure 4.7: Flooding intensity and extent for the 1982 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.
Figure 4.8: Flooding intensity and extent for the 1950 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.
flood mitigation planning perspective, it is important to recognize how different individual flood extremes can be. Often in engineering design of flood mitigation measures, a design storm with uniform rainfall across the basin is used to predict flows. One advantage of using a continuous simulation model (like HSPF) for planning is that the performance of flood mitigation measures over a range of potential flood conditions can be simulated and evaluated. In the remaining sections of this chapter, we use this approach to evaluate different hypothetical watershed scenarios.

4.2 Reducing High Runoff with Increased Infiltration

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

In this section, we examine two different alternatives with runoff reduced by increased infiltration. One simulates the hydrology of the tall-grass prairie landscape that existed before the advent of row crop agriculture. The other simulates the impacts of implementation of agricultural best management practices on all croplands. Both are hypothetical examples; they are meant to illustrate the potential effects on flood reduction. The examples are also not project proposals; they would neither be recommended or practically feasible. Still, the hypothetical examples do provide valuable benchmarks on the limits of flood reduction that are physically possible with runoff reduction.
4.2.1 Tall-Grass Prairie in Row Crop Areas Scenario

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

HSPF was used to simulate the hydrology a native tall-grass prairie landscape for the English River watershed. In this example, all current cropland was replaced with native tall-grass prairie with its much higher infiltration characteristics; all other land uses (including urban) are unchanged. Obviously, converting all croplands to this pre-settlement condition is not a viable watershed plan. Still, this scenario is an important benchmark to compare with any watershed improvement project considered.

To simulate a native tall-grass prairie with the English River HSPF model, the calibrated model parameters for row crops were adjusted to reflect the tall-grass prairie condition. Specifically, existing corn and soybean land segments, which account for 58% of the watershed area, were redefined as tall-grass prairie. Using the guidance outlined by Donigian et al. (1983a), we then adjusted several model parameters. Table A.1 summarizes the parameter adjustments. Note that the resulting parameters are just an approximation of prairie conditions, using our best judgment based on experience with the HSPF model. The resulting simulations should also be considered an approximation, and are not as reliable as the calibrated HSPF model is for current (baseline) conditions.

**Effect on Simulated Runoff**

Following the assignment of HSPF parameters for tall-grass prairie land segments, the model was run for the 64-year simulation period. As expected, replacing row crops with tall-grass prairie has a significant effect on the simulated watershed hydrology. The average annual runoff depth for the prairie scenario (8.3 inches) is 3.0 inches less than that for the base-
line (current conditions) simulation (11.3 inches), a reduction in runoff by 27%. Figure 4.9 compares the simulated monthly water cycle for the baseline and the prairie scenario for the English River at Kalona. The runoff is lower for the prairie scenario for all months. The decrease in runoff for the prairie scenario is largest at the beginning of the year, and continues into the early summer. Later in the summer and fall, the decrease is less.

Figure 4.9: Simulated average monthly runoff depth (in inches) for the English River at Kalona for the baseline simulation and prairie scenario. The baseline is the calibrated HSPF model representing current conditions; the prairie scenario replaces row crops with tall-grass prairie. Results are shown for 64-year simulation period (from 1949 to 2012).

Figure 4.10 shows the change in the average annual runoff depth of the prairie scenario from that for the baseline (current condition) simulations. The reduction in runoff ranges from 7.3% to a maximum of 38.0%. As one would expect, subbasin areas that currently have the highest percentage of row crops — some with as much as 80% row crops or more — also have the largest reductions when replaced by tall-grass prairie. Indeed, subbasins with large reductions are now low runoff areas for the tall-grass prairie

48
scenario, with average annual runoff depths of 7 inches or less; subbasins with small reductions are now high runoff areas, with average depths of 10 inches or more.

Figure 4.10: Change (in %) of the average runoff depth in the English River watershed for the prairie scenarios. The change is based on the average annual runoff depth from the prairie scenario and the baseline (current conditions) simulation for each subbasin from the 64-year simulation.

**Effect on Simulated Floods**

Figure 4.11 shows six locations in the watershed that were selected as points of reference (index points) for comparing simulated floods for watershed scenarios to current conditions. All six locations were identified as high flood locations (see Figure 4.3). Four locations are small to mid-sized drainages in Deep River, the upper North English, the South English, and the Middle English. The remaining locations are downstream, on the English River downstream of the confluence of the North and South English, and at the USGS stream-gage for the English River at Kalona.
Figure 4.11: Location of the six locations in high flood areas selected as index points.
Figure 4.12 shows the flood frequency analysis for the prairie scenario and the baseline simulation (current conditions). Annual maximum peak discharges for the six index locations are shown. For the 64-year simulation period, the annual maximum peak discharges are ranked from smallest to largest, and then plotted versus a sample estimate of their exceedance probability. At all locations, the prairie scenario has much lower simulated peak discharges. One measure of the change is the peak reduction effect — the percentage reduction in the scenario peak discharge relative to that for the baseline simulation. The peak reduction effect was computed for each of the 64 ranked events. For the smaller drainages — the Deep River, upper North English, and South English locations — the peak reduction effect for the prairie scenario is higher; the average peak reduction is between 72 and 77%. For the other three drainages — the Middle English, English River confluence, and English River at Kalona — the peak reduction effect is lower; the average peak reduction is between 56 and 60%. The higher peak reduction effect for the three smaller drainages is relatively consistent for all events. However, for the three larger drainages, the peak reduction effect is diminished for the largest ranked events. For the Middle English, the peak reduction is 45% for the largest flood event (compared to the 60% average). For the English River confluence, the peak reduction is 38% for the largest two flood events (compared to the 57% average). At Kalona, the peak reduction is 39% for the largest two floods (compared to the 56% average). Table 4.2 summarizes the average peak reduction, and the peak reduction for 2-, 10-, and 25-year return period peak discharge levels.

The diminished peak reduction seen for the largest events for the larger drainage areas is related to the nature of floods at different scales. For smaller drainages, floods are caused by local high rainfall intensities; for larger drainages, floods are caused by widespread high rainfall accumulations. For the largest events, rainfall accumulations upstream are so large that the storage in the soils is overwhelmed (even in a prairie landscape). Hence, one might anticipate that major floods — on the order of a 100- or 500-year return period — the peak reduction effect may be even more diminished for larger drainages.

To better understand how the prairie scenario changes simulated flood peaks, Figure 4.13 maps the average peak reduction effect at subbasin outlet throughout the watershed. Clearly, the peak reduction effect is large everywhere, ranging from 30-40% in certain headwater subbasins, to around
Figure 4.12: Sample probability distribution of annual maximum peak discharges for the baseline simulation and the prairie scenario.
Table 4.2: Peak reduction effect for the prairie scenario (relative to the baseline simulation). The average reduction is shown (in %) for the 64 annual maximum events. Also shown are the reductions (in %) for the 2-, 10-, and 25-year return period events.

<table>
<thead>
<tr>
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<tr>
<td></td>
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<tr>
<td>English River at Kalona</td>
<td>56</td>
</tr>
</tbody>
</table>

55% along the lower mainstem of the English River, to as high as 85% for subbasins that currently have a high row crop percentage (and are replaced with prairie for this simulation). The largest peak reductions occur in headwater subbasins; the peak reduction effect tends to slowly diminish as one moves downstream.

4.2.2 Agricultural Management Practices Scenario

Over the past few decades, in an effort to reduce soil erosion and nutrient loads that impair river and lakes, farmers in Iowa have begun implementing agricultural best management practices (or BMPs). Examples of commonly used vegetative and tillage practices include contour farming, filter strips, conservation tillage, and cover crops. Examples of common structural practices include terraces, grassed waterways, and streambank protection. Although agricultural best management practices are often aimed at improving downstream water quality, many practices do so by enhancing infiltration of water into the soil. In addition, these practices can also improve soil quality, further increasing the soil’s ability to absorb and hold water.

As an example, the use of a cover crop is a practice that involves the planting of vegetation after the harvest of either corn or soybean. The planting “covers” the ground through winter until the next growing sea-
Figure 4.13: Average peak discharge reduction (in %) for locations in the English River watershed for the prairie scenario. The annual maximum peak discharge for the subbasin outlets from the 64-year simulations are compared for the prairie scenario and the baseline simulation. The average peak reduction effect was computed from the 64 ranked annual events.
son begins. The cover crop can be killed off in the spring by rolling it or grazing it with livestock; afterwards, row crops can be planted directly into the remaining cover crop residue. Cover crops provide a variety of benefits, including improved soil quality and fertility, increased organic matter content, increase infiltration and percolation, reduced soil compaction, and reduced erosion and soil loss. One source suggests that for every one percent increase in soil organic matter (e.g., from 2 to 3%), the soil can retain an additional 17,000 to 25,000 gallons of water per acre (Archuleta, 2014). Examples of cover crops include clovers, annual and cereal ryegrasses, winter wheat, and oilseed radish (Mutch, 2010).

To better understand the cumulative effect that these practices can have on the water cycle and flood characteristics, HSPF was used to simulate the hydrology of the English River watershed assuming widespread implementation of best management practices on croplands. In this example, all current cropland was assumed to have appropriate agricultural management practices implemented; the improvement in infiltration capacity and soil storage associated with such practices is assumed to occur on all croplands. Clearly, this hypothetical agricultural management practices scenario would be very difficult to implement on a watershed-scale. Still, the scenario does provide another benchmark for comparison.

To simulate the agricultural management practices scenario with the English River HSPF model, the calibrated model parameters for row crops were adjusted to a ideal runoff conditions. Specifically, we adjusted several model parameters for corn and soybean land segments (which account for 58% of the watershed area), to reflect the best agricultural conditions reported by Donigian et al. (1983a) for row crops. Table B.1 summarizes the parameter adjustments.

### Effect on Simulated Runoff

The English River HSPF model was run for the 64-year simulation period for the agricultural management practices scenario. As expected, improving the runoff condition of agricultural lands reduces simulated runoff from the watershed. The average annual runoff depth for the agricultural management scenario (10.8 inches) is 0.5 inches less (or 4.8%) than for the baseline (current conditions) simulation (11.3 inches). Figure 4.14 compares the simulated monthly water cycle for the baseline and the agricultural management scenario for the English River at Kalona. The runoff
is lower for the agricultural management scenario for all months. As with the prairie scenarios, the decrease in runoff for the agricultural management scenario is largest at the beginning of the year, and continues into the early summer. Later in the summer and fall, the decrease is less.

Figure 4.14: Simulated average monthly runoff depth (in inches) for the English River at Kalona for the baseline simulation and agricultural management practices scenario. The baseline is the calibrated HSPF model representing current conditions; the agricultural management scenario assumes row crops have optimal runoff characteristics. Results are shown for 64-year simulation period (from 1949 to 2012).

Figure 4.15 shows the change in the average annual runoff depth of the agricultural management scenario from that for the baseline (current condition) simulations. Although the pattern of runoff reduction resembles that for the prairie scenarios (see Figure 4.10), the magnitude of reduction is much less. For the agricultural management scenario, the reduction ranges for 1.3% to a maximum of 7.1%. Subbasin areas with the highest percentage of row crops have the largest reductions when agricultural runoff conditions are improved with best management practices.
Figure 4.15: Change (in %) of the average runoff depth in the English River watershed for the agricultural management practices scenario. The change is based on the average annual runoff depth from the agricultural management scenario and the baseline (current conditions) simulation for each subbasin from the 64-year simulation.
Effect on Simulated Floods

Figure 4.16 shows the flood frequency analysis of simulated current conditions (baseline) and agricultural management scenario. Annual maximum peak discharges for the six index locations are shown. At all locations, the agricultural management scenario has has significantly lower simulated peak discharges. As in the prairie scenario, the average peak reduction effect for the smaller drainages — the Deep River, upper North English, and South English locations — is greater than in the other locations; the average peak reduction is between 24 and 26%. For the other three drainages — the Middle English, English River confluence, and English River at Kalona — the peak reduction effect is less; the average peak reduction is between 17 and 20%. However, unlike the prairie scenario, the peak reduction effect diminishes for the largest ranked events at all locations. For example, at Kalona, the peak reduction is 5.6% for the largest flood (compared to the 17% average). Table 4.3 summarizes the average peak reduction, and the peak reduction for 2-, 10-, and 25-year return period peak discharge levels.

Table 4.3: Peak reduction effect for the agricultural management scenario (relative to the baseline simulation). The average reduction is shown (in %) for the 64 annual maximum events. Also shown are the reductions (in %) for the 2-, 10-, and 25-year return period events.

<table>
<thead>
<tr>
<th>Location</th>
<th>Average</th>
<th>2-year</th>
<th>10-year</th>
<th>25-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep River</td>
<td>26</td>
<td>27</td>
<td>19</td>
<td>11</td>
</tr>
<tr>
<td>Upper North English</td>
<td>26</td>
<td>28</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>South English</td>
<td>24</td>
<td>19</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>Middle English</td>
<td>20</td>
<td>23</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>English River confluence</td>
<td>17</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>English River at Kalona</td>
<td>17</td>
<td>18</td>
<td>14</td>
<td>13</td>
</tr>
</tbody>
</table>

The diminished peak reduction seen at all locations is related to the depletion of the additional available soil storage for the agricultural management scenario. Improved runoff conditions would allow the soil to infiltrate and storage additional water, resulting in the peak reduction for
Figure 4.16: Sample probability distribution of annual maximum peak discharges for the baseline simulation and the agricultural management scenario.
this scenario. However, compared to the prairie scenario, the additional soil storage is limited. For the largest events, this storage is depleted, resulting in a smaller peak reduction effect for large flood. In contrast, the prairie scenario has more additional storage, and a diminished (but still quite large) peak reduction only occurs for large drainages.

To better understand how the agricultural management scenario changes simulated flood peaks, Figure 4.17 maps the average peak reduction effect at subbasin outlet throughout the watershed. Again, the pattern of peak reduction resembles that for the prairie scenarios (see Figure 4.13), but the magnitude of reduction is much less. The highest reductions are around 32% in subbasins with high row crop percentages, and diminishes downstream to around 16% along the lower mainstem of the English River. The lowest reductions (about 11 to 12%) occur in headwater subbasins with minimal row crop percentages.

4.3 Mitigating the Effects of High Runoff with Flood Storage

Another way to mitigate the effects of high runoff is with flood storage. The most common type of flood storage is a pond. In agricultural areas, ponds usually hold some water all the time. However, ponds also have the ability to store extra water during high runoff periods. This so-called flood storage can be used to reduce flood peak discharges.

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

A system of ponds located throughout a watershed could be an effective strategy for reducing flood peaks at many stream locations. As an example, in the 1980s, landowners in southern Iowa came together to form the Soap Creek Watershed Board. Their motivation was to reduce flood damage and soil loss within the Soap Creek Watershed. They adopted
Figure 4.17: Average peak discharge reduction (in %) for locations in the English River watershed for the agricultural management practices scenario. The annual maximum peak discharge for the subbasin outlets from the 64-year simulations are compared for the agricultural management scenario and the baseline simulation. The average peak reduction effect was computed from the 64 ranked annual events.
a plan that included identifying the locations for 154 distributed storage structures (mainly ponds) that could be built within the watershed. As of 2015, 132 of these structures have been built.

In this section, we use the HSPF model to simulate the effect of pond storage on flood peaks. For this hypothetical example, many ponds are distributed in tributary areas throughout the English River watershed. Because an actual storage pond design requires detailed site-specific information, we instead use a prototype pond design that mimics the hydrologic impacts of flood storage. Therefore, this example is not a proposed plan for siting a system of storage ponds; we have not determined whether suitable sites are available in the simulated locations. Still, this hypothetical example does provide a quantitative benchmark on the effectiveness of distributed flood storage and the flood reduction benefits that are physically possible.

4.3.1 Prototype Storage Pond Design

Many ponds in Iowa have been constructed to provide flood storage. A pond schematic is illustrated in Figure 4.18. The pond is created by constructing an earthen embankment across the stream. A typical pond 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. As the water level rises during a flood, more water is stored temporarily in the pond. Eventually, the water level reaches the emergency spillway. The emergency spillway is constructed as a means to release water rapidly so the flow does not damage or overtop the earthen embankment. The volume between the principal spillway elevation and emergency spillway elevation is called the flood storage.

Prototype Pond Outlet and Emergency Spillway

Using information from ponds constructed in Soap Creek and NRCS technical references on pond design, a prototype pond outlet and emergency spillway were defined for the simulation experiments. A 12-inch pipe outlet was assumed for the principal spillway. A 20-foot wide overflow opening was assumed for the emergency spillway. The top of the dam was set two feet above the emergency spillway.
The elevation difference between the principal and emergency spillways was varied; simulations were done with elevation differences of 3, 5, and 7 feet. As the elevation difference increases, the available flood storage increases exponentially. Therefore, simulations for ponds with a 7 foot elevation difference have much more flood storage than those with a 3 foot difference. The amount of water released downstream by the pond depends on the water depth. The discharge from the principal spillway was determined using pipe flow hydraulic calculations. Once the water depth reaches the emergency spillway, releases also include contributions from the emergency spillway. Discharge of the emergency spillway was determined using NRCS technical references assuming “C-Type” retardance on the spillway, which was determined to be a reasonable design assumption (based on discussions with regional NRCS engineers).

Prototype Pond Shape

Although pond design specifications and built ponds in Iowa provide a reasonable prototype for a pond outlet, the amount of water stored behind an earth embankment requires local knowledge of the topography behind the embankment. However, to represent a large number of ponds in our simulations, the effort to compute a precise relationship between pond stage (water level) and water storage for each would be enormous. The effort is also unwise, unless good sites for pond structures are selected in the first place (for each and every pond). As a compromise, we utilized the prototype pond shape developed in a recent study by the Iowa Flood
In the Iowa Flood Center (2014) study, potential pond sites in the Upper Cedar River watershed were selected for topographic analysis; a total of seven sites in headwater basins were selected. Each site was where there was sufficient topographic relief to support the construction of the pond. The water volume impounded behind the dam was computed as a function of water depth. The result — the storage volume in the pond for different water levels — is known as a stage-storage relationship. Since the stage-storage relationship differs at each site, an average fit to the relationships for all seven was used as the prototype pond shape. The results were compared to similar projects constructed in the Soap Creek watershed to validate the approach. Since the topography of the English River watershed is similar to that in the Upper Cedar, the same prototype pond shape was used here for all simulated pond locations.

Prototype Pond Hydraulics

The pond shape defines the stage-volume relationship as the water level changes in the pond. In contrast, the pond outlet defines the stage-discharge relationship for the pond. This information is combined to define the prototype storage-discharge hydraulic relationship needed for pond simulations. In all, three different prototype ponds are used. For the small pond, the emergency spillway elevation is set to 3 feet above the primary spillway; this results in a flood storage capacity of 10.9 acre-feet. For the medium-sized pond, the emergency spillway elevation is set to 5 feet above the primary spillway; this results in a flood storage capacity of 26.8 acre-feet. For the large pond, the emergency spillway elevation is set to 7 feet above the primary spillway; this results in a flood storage capacity of 48.2 acre-feet.

4.3.2 Siting of Hypothetical Ponds in the English River Watershed

To examine the hypothetical impact that flood storage would have on the flood hydrology of the English River watershed, we placed prototype ponds throughout the headwater subbasins. In the Soap Creek Watershed, where flood storage is already used extensively, the average pond density
is 1 built pond for every 1.9 mi$^2$ of drainage area. Therefore, for the flood storage simulations for the English River watershed, we decided to place pond structures in headwater subbasins at a density of 1 pond for every 2 mi$^2$ of drainage area.

The 38 headwater subbasins in the English River watershed range in size from 3.3 to 10.4 mi$^2$. Hence, all the subbasins contain more than one pond. For example, if a subbasin drainage area was 6 mi$^2$, it would have 3 ponds. Furthermore, not all the area within a subbasin will drain to a pond; some water would flow into the stream below the ponds and not be temporarily stored. To handle these conditions in the HSPF model, we first assumed that half the subbasin area drains through a pond, and half does not. Next, for areas that drain through a pond, we assumed that the water passes through only one pond (and not from one to the next and so on). This step is most efficiently accomplished in the model by creating a single aggregate pond. That is, if there were 3 ponds in a subbasin, it has the same aggregate effect of a single pond that has three times the storage and three times the outflow. So from an HSPF modeling standpoint, the half of the subbasin that drains through a pond can more simply be routed through a single aggregated pond. In this way, the effects of the pond storage can be estimated, without having to specify the exact physical locations of any pond.

For the 38 headwater subbasins, a total of 124 prototype ponds were simulated. All the subbasins contained between 2 and 5 ponds. Figure 4.19 shows the 38 headwater subbasins, and the number of ponds assigned to each. In HSPF, the 124 prototype ponds were represented by 38 aggregated ponds, one for each of the 38 headwater subbasins. Overall, the ponds control flows from a total area of 123.5 mi$^2$; in other words, 19% of the watershed area drains through the simulated prototype ponds.

The pond characteristics upstream of the seven index locations are characterized in Table 4.4. Although 19% of the entire watershed drains through the prototype ponds, this percentage varies for the index locations. The percentages are lower in the lower parts of the watershed — the Middle English (16.7%), the English River confluence (17.5%), and the English River at Kalona (18.8%). The percentages are higher in the upper parts of the watershed; the South English has the highest percentage of area that drains through ponds (33.5%).

Table 4.5 summarizes the flood storage available for the three pond scenarios. For small ponds, the total flood storage is 1352 acre-feet; this
Figure 4.19: Headwater subbasins selected for distributed flood storage analysis and number of prototype ponds assigned to each subbasin. Each headwater subbasin contained two to five ponds, resulting in 124 prototype ponds that were aggregated into 38 ponds, one for each headwater subbasin.
Table 4.4: Summary of pond characteristics at index locations for simulated prototype ponds. The upstream drainage area, the number of ponds, and the drainage area upstream of the ponds is indicated by index location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Drainage Area (mi²)</th>
<th>Ponds Upstream (#)</th>
<th>Area Upstream From Ponds (mi²)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep River</td>
<td>24.7</td>
<td>7</td>
<td>4.8</td>
<td>19.4</td>
</tr>
<tr>
<td>Upper North English</td>
<td>26.7</td>
<td>6</td>
<td>6.6</td>
<td>24.6</td>
</tr>
<tr>
<td>South English</td>
<td>52.4</td>
<td>18</td>
<td>17.5</td>
<td>33.5</td>
</tr>
<tr>
<td>Middle English</td>
<td>70.4</td>
<td>11</td>
<td>11.8</td>
<td>16.7</td>
</tr>
<tr>
<td>English River Confluence</td>
<td>472.0</td>
<td>83</td>
<td>82.4</td>
<td>17.5</td>
</tr>
<tr>
<td>English River at Kalona</td>
<td>595.0</td>
<td>114</td>
<td>111.8</td>
<td>18.8</td>
</tr>
</tbody>
</table>

amount of water placed over the upstream drainage area controlled by ponds would have a water depth of 0.21 inches. Hence, the ponds can temporarily store roughly 0.21 inches of runoff from a storm event. For medium-sized ponds, the total flood storage is 3311 acre-feet; this is equivalent to roughly 0.50 inches of runoff. For large ponds, the total storage is 5977 acre-feet; this is equivalent to roughly 0.91 inches.

Table 4.5: Summary of the flood storage available for the small, medium, and large pond scenarios.

<table>
<thead>
<tr>
<th>Pond Scenario</th>
<th>Total Pond Storage (ac-ft)</th>
<th>Equivalent Storage Depth (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>1352</td>
<td>0.21</td>
</tr>
<tr>
<td>Medium</td>
<td>3311</td>
<td>0.50</td>
</tr>
<tr>
<td>Large</td>
<td>5977</td>
<td>0.91</td>
</tr>
</tbody>
</table>
4.3.3 Storage Pond Simulations

The English River HSPF model was run for the 64-year simulation period for the three flood storage pond scenarios. Unlike the tall grass prairie or the agricultural BMP scenarios, the storage ponds do not alter the amount of runoff that is generated from the landscape; instead, the ponds temporarily store the runoff in the ponds and release water downstream at a lower rate. Therefore, we only examine the effect of the ponds on the simulated flood magnitudes.

Figure 4.20 shows the flood frequency analysis of simulated current conditions (baseline) and large storage pond scenario (7 foot emergency spillway elevation). In this scenario, each pond provides 48.2 acre-feet of flood storage, resulting in a total of 5977 acre-feet of flood storage for the entire watershed. Annual maximum peak discharges for the six index locations are shown. At all locations, the large pond scenario has lower simulated peak discharges. The average peak reduction effect is largest for the Upper North English (11.8%) and South English locations (13.2%); these locations also have the largest percentage of upstream area draining through the ponds (see again Table 4.4). The average peak reduction effect is less at the other locations, ranging from 2.9 to 6.5%. Unlike the tall grass prairie and agricultural management scenarios, the peak reduction effect tends to be greatest for larger simulated flood events. For example, at Kalona, the peak reduction is 10.3% for the largest flood (compared to the 2.9% average).

By design, ponds store a greater volume of water as flows increase; after the water level raises above the emergency spillway elevation, the flood storage volume is exhausted and the peak reduction diminishes. Therefore, the flood storage is most effective in reducing peak discharges for a targeted range of flows.

This effects explains the results in Table 4.6 for the three flood storage pond scenarios. The table summarizes the average peak reduction at the six locations. Note that at all locations, the largest average peak reduction occurs with the medium-sized pond scenario. In other words, for medium-sized ponds, the available flood storage is most effectively used over the range of commonly-occurring flood flows. It is not surprising medium-sized ponds are more effective than smaller ponds, because smaller ponds will exhaust their storage capability more quickly. However, the large pond scenario has more storage available, but a lower av-
Figure 4.20: Sample probability distribution of annual maximum peak discharges for the baseline simulation and the large flood storage pond scenario.
verage peak reduction than for medium-sized ponds. This occurs because large ponds do not utilize their storage as much as medium-sized ponds for common flood events. Instead, they are more effective for rarer large flood events.

This effect is more clearly seen by looking at the peak reduction for the 2-, 10-, and 25-year return period peak discharge levels (also shown on Table 4.6). For the large pond scenario, the largest peak reduction occurs at the 10-year or 25-year return period level; at nearly all locations, the largest peak reduction is also greater than the average peak reduction for all 64 events (the Deep River location is the lone exception). This occurs because the larger ponds are utilizing their storage for rarer large flood events. In contrast, the medium pond scenario, the largest peak reduction occurs mostly at the 2-year return period level (the two smaller drainages, Deep Creek and Upper North English, are exceptions). For the small pond scenario, the largest peak reduction occurs at the 2-year return period level at all locations.

To better understand how the flood storage scenarios change simulated flood peaks, Figure 4.21 maps the average peak reduction effect at sub-basin outlet throughout the watershed for the large ponds. Notice that some outlets have very high peak reductions, approaching almost 44%; such levels are similar or exceed the largest peak reductions observed for the prairie scenario (see Figure 4.13) or the agricultural management scenario (see Figure 4.17). However, these high peak-reduction locations are only observed for the headwater subbasins, where are the 124 storage ponds were located. Indeed, flood storage is most effective immediately downstream of a pond. As one moves downstream from a pond, the peak reduction effect diminishes rapidly. For subbasins immediately downstream of headwater subbasins, the peak reduction effect often drops to half (or less) than that observed upstream. The effect continues to diminish downstream of large tributaries and the main stem, reaching the lowest peak reduction of 2.4% at the downstream outlet where the English River empties in the Iowa River.

4.4 Summary

The calibrated HSPF model was used examine flooding characteristics in the English River. Based on the results from a 64-year simulation, areas
Table 4.6: Peak reduction effect for the three flood storage pond scenario (relative to the baseline simulation). The average reduction is shown (in %) for the 64 annual maximum events. Also shown are the reductions (in %) for the 2-, 10-, and 25-year return period events. The reductions are evaluated at the six index locations.

<table>
<thead>
<tr>
<th>Pond Size</th>
<th>Return Period</th>
<th>Average</th>
<th>2-year</th>
<th>10-year</th>
<th>25-year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deep River (24.7 mi²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td>3.8</td>
<td>2.6</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>4.3</td>
<td>2.7</td>
<td>2.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Large</td>
<td></td>
<td>4.2</td>
<td>2.8</td>
<td>2.5</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Upper North English (26.7 mi²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td>8.7</td>
<td>7.1</td>
<td>6.9</td>
<td>6.7</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>12.3</td>
<td>12.3</td>
<td>14.2</td>
<td>10.5</td>
</tr>
<tr>
<td>Large</td>
<td></td>
<td>11.8</td>
<td>9.6</td>
<td>19.3</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>South English (52.4 mi²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td>9.1</td>
<td>13.0</td>
<td>8.1</td>
<td>5.4</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>15.2</td>
<td>24.0</td>
<td>19.0</td>
<td>10.1</td>
</tr>
<tr>
<td>Large</td>
<td></td>
<td>13.2</td>
<td>14.6</td>
<td>26.6</td>
<td>21.7</td>
</tr>
<tr>
<td></td>
<td>Middle English (70.4 mi²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td>5.4</td>
<td>6.4</td>
<td>2.4</td>
<td>4.3</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>7.3</td>
<td>8.8</td>
<td>3.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Large</td>
<td></td>
<td>6.5</td>
<td>7.3</td>
<td>4.4</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>English River confluence (472 mi²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td>3.0</td>
<td>5.1</td>
<td>2.9</td>
<td>2.6</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>6.2</td>
<td>11.7</td>
<td>6.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Large</td>
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<td>4.2</td>
<td>6.7</td>
<td>8.1</td>
<td>7.3</td>
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<tr>
<td></td>
<td>English River at Kalona (595 mi²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td>2.3</td>
<td>2.9</td>
<td>2.4</td>
<td>1.9</td>
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<tr>
<td>Medium</td>
<td></td>
<td>5.0</td>
<td>7.8</td>
<td>5.7</td>
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<tr>
<td>Large</td>
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<td>2.9</td>
<td>2.4</td>
<td>5.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Figure 4.21: Average peak discharge reduction (in %) for locations in the English River watershed for the large flood storage pond scenario. The annual maximum peak discharge for the subbasin outlets from the 64-year simulations are compared for the large pond scenario and the baseline simulation. The average peak reduction effect was computed from the 64 ranked annual events.
within the watershed with high runoff were identified. Implementing projects that can reduce runoff from these high runoff areas should be a priority. The results were also used to identify locations in the stream network with unusually high flood levels. Some high flood locations are located directly downstream of high runoff areas; however, many others tend to be situated just downstream of the confluence of two tributaries of similar size. High flood areas make good locations for assessing the overall impact of upstream mitigation project.

Several hypothetical flood reduction scenarios were explored. One scenario examined the flood hydrology of the tall-grass prairie landscape that existed in the watershed before today’s current agricultural landscape. A second scenario examined impacts of using agricultural best management practices throughout the watershed to produce the best possible runoff conditions on farmlands. Both of these two scenarios reduce flood magnitudes by infiltrating more water into the soils. The remaining scenarios examined the use of flood storage to store excess runoff temporarily, thereby reducing downstream flood peak discharges. Storage was added to the English River watershed with 124 prototype ponds.

Figure 4.22 summarizes the relative effectiveness of each watershed scenario in reducing peak discharges from the current conditions for the 25-year return period discharge, used here as a measure of a significant flood event. Results are shown at six index locations. Clearly, the tall-grass prairie scenario has the greatest flood peak reduction — the reduction is much greater than any other scenario. These results are an indication of the dramatic effect that historical changes to the landscape have had on Iowa’s water cycle and flood hydrology. The agricultural management scenario ranks second in its effectiveness. Though much smaller than for the prairie scenario, the peak reduction effect is still significant, ranging from about 10 to 16%; the reductions are larger than those for the flood storage scenarios at most index locations. At one index location, the large pond flood storage scenario has a slightly higher peak reduction. But at the others it is less than for the agricultural management scenario. Whereas the assumed land use changes with agricultural management occur throughout the watershed, flood storage only reduces peaks downstream of ponds. The portion of upstream area that drains through the ponds can vary, resulting in a more variable peak reduction with flood storage. Not surprisingly, the effectiveness of the flood storage pond scenarios depends on the pond size. The large ponds are the most effective
(ranging from a 3 to 21% peak reduction), and the small ponds are the least effective (ranging from a 2 to 7% peak reduction).

Figure 4.22: Reduction (in %) for the 25-year return period peak discharge for locations in the English River watershed for different watershed scenarios. The annual maximum peak discharge for the subbasin outlets from the 64-year simulations are compared for the scenarios and the baseline simulation. The 25-year return period peak discharge was computed based on the ranked annual events.
Chapter 5

Water Quality Simulation

This chapter describes a preliminary investigation on the use of the English River HSPF model for water quality simulation. In particular, the model was used to simulate the nitrogen cycle for the watershed. Nitrogen (N) is an important nutrient for plant growth. Fertilizer is often used in agricultural settings to add nutrients needed for crop growth. However, when it rains, some the nitrogen leaches from the soil and is transported with the moving water, most commonly in the form of nitrate (NO$_3$). There are other sources of nitrogen in rivers and streams. Livestock wastes contain nitrogen. Likewise, sewage waste and septic tank leaching can also add nitrogen to the stream. And of course, earth’s atmosphere is 78% nitrogen, so wet deposition (precipitation) and dry deposition add nitrogen to the land surface. Reducing the nutrients that enter Iowa’s rivers and are transported downstream — where the excess nutrients contribute to algal growth and the depletion of oxygen in the Gulf of Mexico — is the aim of the Iowa Nutrient Reduction Strategy (Iowa Department of Agriculture et al., 2014).

Calibrating and verifying HSPF for water quality simulation is very challenging. Fortunately, HSPF models for nutrient simulation have already been developed for nearby Iowa streams. Also, there has been some limited sampling of water quality variables on the English River since 1998 (about once a month). And recently, the Iowa Soybean Association carried out synoptic sampling of water quality at twenty sites in the watershed in 2014 (Iowa Soybean Association, 2014). For this analysis, we added the water quality components developed from previous Iowa HSPF studies directly into the English River HSPF model. We then compared the simu-
lated nitrogen loads to the observational record, to assess whether results are reasonable. Finally, we used long-term simulations over the 64-year historical period to evaluate spatial variations in nitrogen loads within the English River, and to see if they are qualitatively consistent with the results of synoptic sampling.

5.1 Previous Iowa HSPF Water Quality Studies

Donigian et al. (1983b) report on a water quality study using HSPF for Four Mile Creek in Iowa. The watershed drains about 19.5 square miles, and its outlet is near Traer, Iowa. The creek empties into Wolf Creek, a tributary of the Cedar River. This study was commissioned by the Environmental Protection Agency (EPA), and represents the first attempt at water quality simulation using HSPF that combines agricultural runoff and in-stream transport and transformations.

Imhoff et al. (1983) expanded on this work in a simulation study using HSPF for the larger Iowa River basin. The study area included the drainage area above Coralville Reservoir, or about 2795 square miles. As in our application of HSPF to the English River watershed, the Iowa River study defined land segments based on land use characteristics and weather inputs. The land area was partitioned into three groups — corn, soybeans, and other; for the English River model, we defined seven groups. A further subdivision was accomplished based on weather inputs — three meteorologic zones were defined with different weather station inputs; for the smaller English River watershed, we defined eight zones, each corresponding to a different precipitation station. Runoff from the land segments was routed into 13 river reach segments, compared to the 103 reach segments we used in the English River model. The higher resolution of the English River HSPF model simply reflects technological advances in recent decades; there is greater availability and access to data, and greater computing power available to support more detailed simulations.

The Iowa River basin study considered pollutants from both point and nonpoint sources. Points sources include municipal sewage systems, industrial plants, and animal feeding operations. Nonpoint sources include agricultural farmlands. Imhoff et al. (1983) focused on simulation of sediment, nutrients, and pesticides; only nonpoint sources of pollutants were simulated, as they represent the bulk of the influent to the river. However,
they note that point source loadings can be a significant contributor during low flow periods, but found that the simulation provides reasonable results given the predominance of nonpoint sources.

To establish nutrient parameters for simulation of the Iowa River basin, Imhoff et al. (1983) transferred the calibrated parameters from the Four Mile Creek study by Donigian et al. (1983b). In that Four Mile Creek study, runoff from small field sites and soil core data for corn, soybean, and pasture were used to calibrate nutrient parameters. The resulting parameters were then used for the entire Four Mile Creek watershed, and assessed using nutrient observations at the watershed outlet.

5.2 English River HSPF Water Quality Model

For our preliminary investigation on the use of HSPF for water quality simulation, we added the water quality components developed in the Iowa River basin study (Imhoff et al., 1983) directly into the English River HSPF model. Although components were added for sediment, pesticides, and nutrients — as these were simulated in the Iowa River study — only the results for the nutrient simulation are examined in this report. In the following sections, we describe the HSPF model setup for the nutrient simulation.

5.2.1 Chemical Loadings

As in the Iowa River study, the only source of chemical loadings to the English River simulated were from agricultural farmlands. Point sources like effluent from municipal sewage systems or animal feeding operations were ignored.

On farmlands, nitrogen fertilizer application is a nutrient source. According to the 2013 land use information collected by Iowa Soybean Association, about 60% of area in the English River watershed is agricultural land use. Corn covers about 32% and soybeans covers about 26% of total area of English River watershed. Imhoff et al. (1983) report that nitrogen fertilizer application to soybeans in Iowa is a small fraction (0.3 to 0.6%) of that applied to corn; therefore, for simulation purposes, nitrogen fertilizer was applied only to corn land segments. Using recent data on nitrogen fertilizer application for Iowa from the U.S. Department of Agriculture
(USDA) Economic Research Service (ERS), and the relative portion of corn and soybean areas in the English River watershed, we find that application to soybeans is about 1.2% of that applied to corn (based on available data from 1964 to 2010). Therefore, we have utilized that same approach adopted by Imhoff et al. (1983), and only simulate fertilizer application to corn land segments.

In the Iowa River study, a constant annual nitrogen fertilizer application of 140 kilograms per hectare (kg/ha) was assumed for corn land segments; 132 kg/ha comes from direct fertilizer application, and 8 kg/ha accounts for atmospheric deposition (from rain). Imhoff et al. (1983) arrive at the direct fertilizer application value using available state-wide USDA data for a four-year period in the 1970s; applications vary by year (for various reasons), but the 140 kg/ha represents a weighted-average. Using a longer record of USDA data for Iowa, we find the longer-term averages are consistent with those from the Iowa River study; the application average for available data for 1964 to 2010 are slightly lower, but the average for a more recent 20-year period is slightly higher (1983 to 2002, the last 20-year period with complete data). Therefore, we find the application rate from the Iowa River study to be reasonable, and utilize it for the English River HSPF water quality model.

As for timing and application of nitrogen fertilizer, we used the same target dates and amounts as those in the Iowa River study, which are summarized in Table 5.1. The total fertilizer application of 140 kg/ha was divided into three separate applications, which includes 20% application in fall, 50% application in spring, and 30% application in summer. Because fertilizer application methods can vary with tillage method, the location in the soil profile where the nitrogen is added vary by application. Following the Iowa River study, we assumed that fall fertilizer application stores 100% of the nitrogen on the surface, the spring application stores 20% on the surface and 80% in the upper layer, and the summer application stores 40% on the surface and 60% in the upper layer. Note that although the target date for application remained constant throughout the 64-year simulation, fertilizer application is weather dependent. Therefore, an adjustment to the application date was made to the actual dates each year to prevent application from occurring on rainy days (using the Special Actions Block of HSPF).
Table 5.1: Timing of nitrogen fertilizer application in corn land use for the English River watershed simulation.

<table>
<thead>
<tr>
<th>Season</th>
<th>Target Date</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Target Amount (kg/ha)</td>
</tr>
<tr>
<td>Fall</td>
<td>7-Nov</td>
<td>28</td>
</tr>
<tr>
<td>Spring</td>
<td>25-Apr</td>
<td>70</td>
</tr>
<tr>
<td>Summer</td>
<td>20-Jun</td>
<td>42</td>
</tr>
</tbody>
</table>

5.2.2 Nutrient Simulation

HSPF simulates the chemical and biological transformation and transport of nitrogen on the land surface. Some of the processes simulated include plant uptake of nitrate and ammonium, mineralization of organic nitrogen, biological denitrification of nitrate and nitrite to atmospheric nitrogen, biological nitrification of ammonium to nitrite and nitrate, and adsorption/desorption of ammonium and organic nitrogen. Plant uptake of nitrogen was varied monthly to approximate plant growth. To represent the contribution of nitrogen from plant roots, stubble and residues, organic nitrogen stores in the soil were reset to their initial values at the end of the growing season. Nutrient parameters for the land surface simulation were derived from the Iowa River study (Imhoff et al., 1983). Key model parameters are summarized in Appendix C.

For nitrogen leaving the land surface associated with runoff of water and sediment, HSPF simulates its chemical and biological transformation and transport in river reaches. Nitrification, denitrification, and ammonia volatilization were also considered for the instream simulation. The nitrification algorithm of HSPF also requires the simulation of dissolved oxygen content because nitrification requires minimum dissolved oxygen.

5.3 Nutrient Simulation Validation

Model validation was carried out for a 14-year period (water years 1999 to 2012) when nitrate (N\textsubscript{3}-N) and nitrite (N\textsubscript{2}-N) observations are avail-
able. A water quality monitoring station is located on the English River at Riverside; the site is monitored by the Iowa Department of Natural Resources (INDR), and the data are available from their STORET database (Station ID 10920001). Instantaneous measurements of nitrate (N$_3$-N) and nitrite (N$_2$-N) are collected at this site. Typically, about one measurement is made each month; however, there are some periods in 2000 and 2001 when measurements are made more frequently (daily or weekly).

The English River HSPF model with water quality enhancements was used to simulate flows and nitrogen transport on an hourly time step for the validation period; simulated nitrogen concentrations were then compared with the available observations. The simulated total nitrogen from nitrate (N$_3$-N) and nitrite (N$_2$-N) corresponding to the same hour as the observation was selected for comparison. Figure 5.1 shows the results.

In general, the simulated total nitrogen concentration in the river is much more variable than the observations. The simulated concentration spikes early in the growing season above the observations, then drops slightly below the observations for the remainder of the year. In contrast, the observed concentrations are more consistent during the growing season. In part, the spiking in the simulation is related to the simulated application of fertilizer. In the model, the application target dates and the application amounts are the same each and every year, and at each and every location. Therefore, the first significant rainfall after application results in significant washoff of nutrients from the land surface to receiving streams. Another factor may be that fixation of nitrogen to the soils is under-predicted by the model, which contributes to the larger simulated washoff after fertilizer applications. It is worth noting that the validation simulation plots for the Iowa River basin also show a similar tendency.

Overall, the simulated average total nitrogen concentration (8.0 mg/L) is higher than the observed average (5.9 mg/L). Also, more nitrogen is retained on the land surface after fertilizer application, and more slowly leaches into streams, than is simulated. Still, given the large errors typical of water quality simulation, and that no adjustment of model parameters was attempted to improve the fit, the results are quite reasonable; an over-prediction of nitrogen concentration by about 36% is not uncommon in water quality simulation (especially when compared to a sparse sample of observations). Hence, the simulation results will be used to examine relative variations in nutrient loads throughout the basin; seasonal variations in loads are expected to be less reliable, and will not be explored.
Figure 5.1: Time series of simulated and observed total nitrogen concentration for the English River at Riverside (Iowa Department of Natural Resources, Station ID: 10920001).
5.4 Spatial Variations in Nutrient Loads

The English River HSPF water quality model produces estimates of nutrient loads for each of its 103 subbasin areas; evaluating the loads from the 64-year simulation can be used to examine expected variations in water quality throughout the watershed. Figure 5.2 shows 64-year average nitrate (NO$_3$-N) load for each of the 103 subbasins. For comparison, the total mass of nitrate outflow was divided by the total volume of water outflow from the reach from the 64-year simulation, and reported as a concentration (in mg/L); this is often referred to as the flow-weighted concentration, as it would be different from the average concentration at a site (also known as the time-weighted concentration). As can be seen, the nitrate load varies significantly throughout the basin, ranging from about 1 to 8 mg/L. Locations with the highest loads are associated with reaches that have the highest percentages of agricultural land. As runoff moves downstream and mixes with water from tributary flows, the average load tends to decrease. At the outlet, the average load is about 5 mg/L.

A similar analysis of the nitrite (NO$_2$-N) load is shown in Figure 5.3. The nitrite loads are much lower than for nitrate, ranging from about 0.015 to 0.6 mg/L. Nitrite is a much less stable form of nitrogen; it is quickly converted to a more stable form (nitrate) or is volatilized back into the atmosphere. Unlike nitrate, the nitrite load increases in the downstream direction; the highest loads are located on the main stem near the outlet.

In 2014, the Iowa Soybean Association (ISA) performed water quality sampling at sites throughout the English River watershed (see Figure 5.4). The synoptic sampling was carried out on a day in the spring (28 April), the summer (17 July), and the fall (21 October). Both nitrate (NO$_3$-N) and nitrite (NO$_2$-N) were among the variables sampled. The results of the sampling are reported in Iowa Soybean Association (2014). By design, synoptic sampling provides an instantaneous snapshot of water quality, and an indication of the spatial variation in water quality throughout the basin. By comparing the instantaneous concentrations with the long-term simulated loads, we can assess whether the model predictions of high (or low) loads are consistent with sampled locations with high (or low) concentrations.

Figure 5.5 compares the instantaneous nitrate concentrations with the long-term model-simulated load at the Iowa Soybean Association sampling sites. As can be seen in the plots, there is a strong correlation be-
Figure 5.2: Average nitrate (NO$_3$-N) load for locations in the English River watershed. The total load is computed for the HSPF RCHRES subbasin outlets from the 64-year simulation. The load is divided by the total flow volume and reported as a flow-weighted concentration (in mg/L).
Figure 5.3: Average nitrite (NO$_2$-N) load for locations in the English River watershed. The total load is computed for the HSPF RCHRES subbasin outlets from the 64-year simulation. The load is divided by the total flow volume and reported as a flow-weighted concentration (in mg/L).
Figure 5.4: Sampling sites for the Iowa Soybean Association’s 2014 water quality snapshot.
 tween the instantaneous nitrate concentrations and the simulated loads. Locations where the sampled nitrate concentration is relatively high tend to be where the model predicts the long-term average nitrate load is relatively high, and vice versa. The correlation coefficient is 0.64 in Spring, 0.86 in Summer, 0.67 in Fall (a coefficient of 1 indicates a perfect positive relation, whereas a coefficient near 0 suggests there is no relation). These results suggest that the HSPF model adequately captures the land-use driven spatial variations in nitrogen in the watershed.

Still, there are some locations where the observations are inconsistent with the model predictions; at these locations, observed nitrate concentrations are anomalously high compared to the overall relationship. The results for these sites are plotted as red squares, to distinguish them from the remaining sites (green circles). Looking first at Figure 5.5(b) for the summer (17 July), the observed nitrate concentrations for site 2 (Camp Creek), site 4 (Deer Creek), and site 5 (Lime Creek) appear unusually high; indeed, if these sites were removed, the correlation would increase from 0.86 to 0.98. Looking at Figure 5.5(c) for the fall (21 October), these sites again have unusually high nitrate concentrations; if removed the fall correlation would increase from 0.67 to 0.90. However, looking at Figure 5.5(a) for the spring (28 April), only site 2 (Camp Creek) has an unusually high nitrate concentration; although there is more scatter in the observations, sites 4 (Deer Creek) and 5 (Lime Creek) are consistent with the other observations in Spring 2014.

The comparison between instantaneous nitrite concentrations and the long-term model-simulated load are less conclusive. During the fall (21 October) sampling, nitrite was below the detection limit at all but one site. During the summer (17 July) sampling, nitrite was again near the detection limit, so site-to-site variations were small. During the spring (28 April), nitrite concentrations are higher and there is greater site-to-site variation; Figure 5.6 shows a plot of the results. There is only a weak correlation between the instantaneous nitrite concentrations and the simulated loads; the correlation coefficient is 0.25. Again, some sites have anomalously high nitrite concentrations. Sites 2 (Camp Creek), 4 (Deer Creek), and 5 (Lime Creek) are shown with red squares; as was the case for nitrates in summer and fall, these sites tend to have higher nitrite concentrations during spring sampling. If removed the spring correlation would increase from 0.25 to 0.47. However, two other sites also have elevated nitrite concentrations — Site 20 (English River-Dugout Creek) and Site 19 (Upper English
Figure 5.5: Nitrate water quality snapshot for 2014 and HSPF-simulated nitrate load for the English River watershed. The plot compares instantaneous snapshot concentrations with the long-term model-simulated load. The snapshot sampling was performed by the Iowa Soybean Association.
River), two sequential sampling sites in the Upper English River tributary.

Figure 5.6: Nitrite water quality snapshot for Spring 2014 (28 April) and HSPF-simulated nitrate load for the English River watershed. The plot compares instantaneous snapshot concentrations with the long-term model-simulated load. The snapshot sampling was performed by the Iowa Soybean Association.

5.5 Summary

A preliminary investigation was made on the use of the English River HSPF model for nutrient simulation. For this analysis, we added the water quality components developed from previous Iowa HSPF studies directly into the English River HSPF model. HSPF was then used to simulate nutrient transformations and transport on the land surface and river reaches. Water quality model simulations were run to produce estimates of nutrient loads for each of its 103 subbasin areas for a 64-year simulation period.
The results of the simulation were compared to observations of total nitrogen made at a sampling site near outlet (Riverside) from 1999 to 2012. The observations are limited — instantaneous measurements made about once per month. As a result, they are unable to capture the rapid variations in nitrogen concentrations associated with storm events. Overall, the simulated concentrations are in the same range as the observations. The simulated concentrations tend to spike after spring and summer applications, and drop to low level afterwards. In contrast, the observed concentrations are more consistent throughout the year. During this period, the averaged simulated concentration is 38% higher than the observed average. Given the large mismatches typical of water quality simulations, these results are quite reasonable.

Additional model calibration could be utilized to try to improve the simulation results. There are several avenues worth exploring. One would be to reassess the fertilizer application assumptions used. For example, the timing and partitioning of the nitrogen fertilizer on the surface and upper soil layer was based on the Iowa River basin study in 1983 (Imhoff et al., 1983). Agricultural practices have changed over the years, and applications now may be more efficient in storing nitrogen in the soils (reducing spikes during storms). Indeed, the simulated amount of nitrogen stored within soils may need to be increased, so that more nitrogen leaches to the stream throughout the year (as observed).

To examine the spatial variations in nitrogen loads through the watershed, maps of the 64-year average load for nitrate (NO$_3$-N) and nitrite (NO$_2$-N) were produced. Not surprisingly, simulated nitrate loads are higher in subbasins with a higher percentage of agricultural land uses. As the water moves downstream through the river network, the simulated nitrate loads tend to decrease. In contrast, nitrite — a less stable form on nitrogen — is present at much lower levels, and nitrite loads tend to increase moving downstream through the river network.

The predicted spatial variations in nitrogen loads were qualitatively assessed by comparison with the water quality snapshots performed by the Iowa Soybean Association in 2014 (Iowa Soybean Association, 2014). More specifically, we compared concentrations measured at twenty sites, with the long-term average loads simulated by the English River HSPF water quality model, on the three sampling dates in 2014. Obviously, one does expect that the instantaneous measurements made throughout the basin on a single day will match the long-term averages. However, we found
that where the model predicts that the average load is relatively high, the snapshot concentrations tend to be relatively high, and vice versa. For nitrate the correlations were strong on all three sampling dates; for nitrite the concentrations were above detection levels only in the spring, and the correlation with predicted loads was much weaker. Overall, the comparison suggests that the HSPF model adequately captures the land-use driven spatial variations in nitrogen in the watershed.

Still, there are some sampling locations where the observed concentrations were higher than expected based on the overall relation. These anomalies suggest that some nutrient sources upstream of these locations are not accounted for in the English River HSPF water quality model. Nitrogen fertilizer applications are clearly the dominate source of nitrogen in agricultural landscapes; as was the case in other Iowa HSPF studies, other sources of nitrogen were not simulated. In particular, point sources from municipal sewage system and animal feeding operations were not incorporated into the model. Typically, municipalities treat wastewater to reduce nitrate concentrations in their effluent discharges to the river. Since wastewater discharges are usually small compared to the discharge in the river, the additional load is small and diluted by the river’s flow. However, during periods with low river flows, or in small tributaries where municipal discharges account for a larger percentage of the river flow, neglecting municipal point sources of nitrogen would underestimate concentrations. Additionally, Iowa Department of Natural Resources data show that there may be as many as twenty animal feedlots and confinement operations within the English River watershed. Operations are less numerous than other parts of Iowa, and the size of the operations are smaller. A few operations are located in the three tributaries with usually high snapshot concentrations; many others are not. These nitrogen sources are also not simulated, and their loads are not well known.

Overall, the water quality simulation results illustrate the benefits of using both models and measurements to understand watershed processes. Model predictions provide a valuable context for interpreting measurements. Given the HSPF model simplifications, it is very encouraging to see that it could take available information on land use and weather conditions and accurately predict locations where expected nitrogen loads and concentrations are relatively high (or low). But the mismatches between the model and the synoptic water quality sampling are also informative; they tell us that some nutrient sources are not being accounted for, and
are having a significant effect on concentrations. These subbasins should be subject of further investigation to determine what is going on. Further synoptic sampling would also be a valuable tool in understanding what additions are needed in the model to better simulate nitrogen throughout the watershed.
Chapter 6

Summary and Recommendations

This hydrologic assessment of the English River watershed was carried out by the Iowa Flood Center, located at IIHR–Hydroscience & Engineering on the University of Iowa campus, for the English River Watershed Management Authority. The assessment is meant to provide local leaders, landowners and watershed residents in the English River watershed an understanding of the hydrology – or movement of water – within the watershed, and the potential of various hypothetical flood mitigation strategies.

6.1 English River Water Cycle

The water cycle of the English River watershed was examined using historical precipitation and streamflow records. The average annual precipitation for the English River watershed is 36.5 inches. Of this precipitation amount, 69% (25.3 inches) evaporates back into the atmosphere and the remaining 31% (11.2 inches) runs off the landscape into the streams and river. The majority of the runoff amount is baseflow (55% or 6.2 inches), and the rest is surface flow (45% or 5.0 inches). Average monthly streamflow peaks in June, and decreases slowly through the summer growing season. In some years, the largest discharge observed during the year occurs in March or April, associated with snow melt, rain on snow events, or heavy spring rains. However, the majority of years the largest discharge is observed between May and August, when the heaviest rainfall can occur. It is also during this season when the largest floods on record have
occurred on the English River (e.g., 1993).

The water cycle has changed due to land use and climate changes. The largest change occurred in the late 1800s when the landscape was transformed from low-runoff prairie and forest to higher-runoff farmland. Since the 1970s, Iowa has seen increases in precipitation, changes in timing of precipitation, and changes in the frequency of intense rain events. Streamflow records in Iowa suggest that average flows, low flows, and perhaps high flows have all increased and become more variable since the late 1960s or 1970s; however, the relative contributions of land use and climate changes are difficult to sort out. The English River streamflow record also shows increases in flow in recent decades; but the magnitude of this trend is smaller than seen in other Iowa streams and not statistically significant.

6.2 English River HSPF Model

A computer simulation model of the English River watershed was developed using the Environmental Protection Agency (EPA) Hydrological Simulation Program–FORTRAN (HSPF). The model can make long-term continuous simulations of hydrologic (rainfall-runoff) and water quality (e.g., nutrient) processes of the watershed. First, eight weather stations in and near the English River were selected, and hourly precipitation and air temperature time series inputs were developed for a 64-year period (water years 1949 to 2012) from historical records. Other weather time series were obtained from airport weather stations in Iowa. The watershed area was then subdivided into 103 river reaches, where runoff from the surrounding drainage area, as well as flow from upstream river reaches, was combined to predict the resulting flow at their outlet. The average area of the river reach is 6.1 square miles. The watershed area was also subdivided by land use into one of seven groups: corn, soybeans, grass/pasturelands, forest, wetlands, barren land, and urban. Hydrologic and water quality processes for different land uses were simulated using pervious and impervious model land segments.

HSPF model parameters were estimated using a model calibration process. Model calibration adjusts an initial set of model parameters so that simulated discharge matches observed discharge at a gaging station more closely. The English River HSPF model was calibrated using observed
daily discharges for a 20-year period, from water years 1993 to 2012. The last portion of the historical record was used for calibration, since it should be more representative of current land use conditions. The calibration process first involved both manual adjustments of parameters, and then a multi-objective automated approach, which attempts to find parameters that perform well for the simulation of both high and low flows.

After calibration of model parameters, model validation assessed the predictive capability of the model to simulate discharge for other periods (not used in calibration). The remaining 42-year simulation period, from water years 1949 to 1992, was used for model validation. Comparisons of simulated and observed flows were made for the monthly water cycle, annual flows, and annual maximum peak discharges, using a fixed set of model parameters for the entire simulation. Overall, the model predicts the annual cycle of monthly average flows quite well (Figure 3.5); it slightly underestimates the total runoff volume for the calibration period (by 3.7%), but overestimates the volume for the entire simulation period (by 14.4%). For annual flows, the model tends to overestimate annual flows for dry and average years, but underestimate flows for the wettest years, which mostly occurred in recent decades (during the calibration period) (Figure 3.6). Still, for the largest peak discharges, the model does not show any pronounced tendency (or over- or underestimation) (Figure 3.8). As a result, the statistical characteristics of simulated and observed peak discharge match quite well (Figure 3.9). These comparisons show that the calibrated English River HSPF model has predictive ability, and can reliably represent and water cycle and flood characteristics of the watershed.

6.3 Flood Characteristics

The calibrated English River HPSF model was first used to identify areas within the watershed with high runoff. Based on the average annual runoff coefficient — the fraction of precipitation that becomes runoff — from the 64-year simulation, subbasin areas with higher runoff were mapped (Figure 4.1). Most areas with higher runoff are located in the western portion of the watershed, in upland tributaries of the upper English River, Deep River, and the upper and middle South English River in Poweshiek, Iowa, and Keokuk Counties. Other areas with higher runoff are located in the eastern portion of the watershed, in Deer Creek and
Birch Creek tributaries of Johnson and Iowa Counties. In these high runoff areas, agriculture land use dominates (as it does for the entire watershed in general), but there is less forest and grassland areas than in other locations. Implementing projects that can reduce runoff from the high runoff areas should be a priority.

The English River HSPF model was also used to identify locations within the watershed where the flood magnitudes are relatively high. This analysis integrates the effect of runoff from upstream areas, and the influence of the stream network as water moves downstream, to show downstream areas most impacted by high runoff. Based on the overall relationship better the mean annual flood and upstream drainage area, subbasin outlets with high floods were mapped (Figure 4.3). Many high flood areas tend to be located just downstream of the confluence of two tributaries of similar size. When two tributaries come together, the timing of flow arrival and the combination of flows often results in higher annual floods. Locations of higher floods include downstream of the English and South English River confluence (starting near the English River Wildlife Area), and downstream of the English River and Gritter Creek confluence (near North English). Other high flood areas in the western portion of the watershed are associated with drainage from the high runoff areas. High flood areas should be a focus in mitigation planning; they make good locations for assessing the overall impact of upstream mitigation projects.

Finally, the English River HSPF model was used to examine the severity and extent of simulated flooding throughout the watershed over the 64-year simulation period. The top flood years were identified based on a flood severity index (evaluated at all subbasin outlets). The top flood year is 1993, and is unique for its widespread extent of intense flooding; every subbasin was simulated to have experienced sufficient flow to produce flooding. In all the other top flood years, some portion of the watershed had no flooding. Some years are notable for their high intensity but localized flood extent (1965 and 1982); other were more widespread and less intense locally (1950 and 2010). One advantage of using a continuous simulation model like HSPF is that it can represent the nature of flooding that occurs in the watershed, and can evaluate the performance of flood mitigation measures over a range of potential flood conditions.
6.4 Hypothetical Watershed Scenarios

The calibrated English River HPSF model was next used to explore several hypothetical watershed scenarios. One scenario examined the flood hydrology of the tall-grass prairie landscape that existed in the watershed before today’s current agricultural landscape. A second scenario examined impacts of using agricultural best management practices throughout the watershed to produce the best possible runoff conditions on farmlands. The remaining scenarios examined the use of flood storage to store excess runoff temporarily, and thereby reducing the flood peak discharge for the event. It is important to note that we evaluated the hydrologic effectiveness of these watershed scenarios for flood mitigation, and not their effectiveness in other ways. For instance, while certain strategies are more effective from a hydrologic point of view, they may not be more effective economically. As part of the flood mitigation planning process, factors such as the cost and benefits of alternatives, landowner willingness to participate, and more should be considered in addition to the hydrology.

6.4.1 Tall-Grass Prairie Scenario

From the simulation results, the conversion of native tall-grass prairie to agriculture land use has resulted in a significant reduction in the infiltration capacity of the landscape and more runoff. The model predicts that the average runoff would be 27% less with a tall-grass prairie landscape. The effect on flood events is even larger. At the 25-year return period — a flood level that has a 4% chance of being exceeded in any given year — the model predicts that the peak discharge would be between 58 to 79% less than current conditions (Table 4.2). Obviously, converting today’s agricultural landscape back to tall-grass prairie is not a practical or economically desirable strategy. Still, from a hydrologic point of view, targeted projects that enhance infiltration by land-use change could be an effective part of a watershed’s flood mitigation efforts. Infiltrating more water is effective because potential floodwaters are instead stored within the landscape.
6.4.2 Agricultural Management Scenario

Even without changes to land use, agricultural best management practices can be implemented that increase the infiltration of rain water. Examples of commonly used vegetative and tillage practices include contour farming, filter strips, conservation tillage, and cover crops. Examples of common structural practices include terraces, grassed waterways, and streambank protection. Such practices cannot replicate the infiltration conditions of a tall-grass prairie landscape; still, the impacts can be significant. The model predicts that the average runoff would be 5% less than current conditions, assuming that appropriate best management practices are implemented across the watershed (resulting in the best agricultural runoff conditions). Peak discharges for the 25-year return period flood are predicted to be between 10 to 16% less (Table 4.3). Given the widespread agricultural land use in the English River watershed, and the growing interest in the use of agricultural management practices as a part of Iowa’s nutrient reduction strategy, implementation of such practices could play an important role as a watershed-wide flood mitigation strategy.

6.4.3 Flood Storage Scenario

In some ways, using ponds to temporarily store floodwaters is an attempt to replace the loss of water that was stored in soils (in the pre-agricultural landscape). In the hypothetical scenarios involving pond storage, between 1352 acre-feet and 5977 acre-feet of storage was added to the English River watershed with 124 prototype ponds. For the upstream areas that have runoff that drains through the ponds, this is equivalent to an added storage depth between 0.2 inches (using small ponds) and 0.9 inches (for large ponds) of runoff. However, for the English River watershed as a whole (not just the area with ponds), the added storage depth ranges from 0.04 to 0.17 inches. Compared to the extra water that was stored by infiltration in the previous two scenario simulations, the amount of storage replaced by ponds is much smaller. Still, peak discharges for the 25-year return period flood are reduced by as much as 40% just downstream of the ponds. However, further downstream the peak reduction effect is less. At Kalona, the peak is about 5% less with large ponds, and 2% less with small ponds (Table 4.6). Still, compared to the other scenarios, the flood storage scenario is one that is more realistically achievable. As a flood mitigation
strategy, ponds are very effective in reducing flood peaks immediately downstream of their headwater sites. Further downstream, floodwaters originating from locations throughout the watershed arrive at vastly different times; some areas have ponds, others do not. The result is that the storage effect from ponded areas is spread out in time, instead of being concentrated at the time of highest flows. Hence, as one moves further downstream in the watershed, the flood peak reduction of storage ponds slowly diminishes.

6.5 Water Quality Simulation

A preliminary investigation was made on the use of the English River HSPF model for nutrient simulation. For this analysis, we added the water quality components developed from previous Iowa HSPF studies directly into the English River HSPF model. HSPF was then used to simulate nutrient transformations and transport on the land surface and river reaches. Water quality model simulations were run to produce estimates of nutrient loads for each of its 103 subbasin areas for a 64-year simulation period. Comparing the results to available instantaneous concentration measurements at Riverside, the simulated concentrations are in the same range as the observations; however, the average simulated concentration is 38% higher than observed. This mismatch is not unreasonable, as no attempt to calibrate (or tune) the model to improve simulation results was performed.

The English River HSPF water quality model was used to predict the 64-year average simulated nitrogen load at each of the watershed subbasin outlets. Simulated nitrate loads are higher in subbasins with a higher percentage of agricultural land uses (Figure 5.2). In contrast, nitrate loads are much lower, and tend to increase moving downstream through the river network. Comparing the average loads to snapshot water quality samples gathered at twenty sites by the Iowa Soybean Association in 2014 (Iowa Soybean Association, 2014), the snapshot nitrate concentration tends to be relatively high where the model predicts that average loads are high, and vice versa. This outcome suggests that the HSPF model adequately captures the land-use driven spatial variations in nitrogen in the watershed. Still, there are some sampling locations where the observed concentrations were higher than expected based on the overall relation. These anomalies
suggest that some nutrient sources upstream of these locations are not accounted for in the English River HSPF water quality model. As such, the model predictions provide a valuable context for understanding the interpreting the snapshot field measurements. Further snapshot sampling would also be a valuable tool in understanding what nitrogen sources are missing from the model simulation, and their amount.

6.6 Recommendations

The hydrologic assessment of the English River watershed provides a better understanding of the water cycle and flood characteristics of the river, of areas where runoff is higher, of locations where higher flooding can occur, and the potential impacts of alternative watershed practices to deal with runoff and flooding. As work to develop and implement runoff and flood mitigation projects moves forward, we recommend that a watershed-focused strategy, which considers local interventions and their impacts on the basin as a whole, is needed for sound water resources planning. Other recommendations for English River watershed management are as follows.

Avoid development and re-development within flood-prone areas: Development of land for roads, buildings, and infrastructure involves choices. Communities and government entities — especially those in areas like the English River watershed, where rural land uses dominate — have many more choices than those in extensively developed urban landscapes (e.g., highly populated areas of the eastern United States). Choosing to locate new development outside of flood-prone areas avoids most future economic losses from flooding. It is also the best protection against changes in the flood hydrology of the watershed, whether by changing weather patterns or by increased runoff from upstream lands.

Typical floodplain management seeks to avoid development within the 100-year return period floodplain. By definition, a structure located at the 100-year flood level has a 1% annual chance of flooding. However, over a 50-year period (the design life of some infrastructure), there is almost a 4-in-10 chance (39.5%) of experiencing flood damage. The chances are even greater for locations inside the 100-year limits. Some Iowa communities are now using the 500-year return period floodplain for management,
which has a 0.2% annual chance of flooding; over a 50-year period, there is less than a 1-in-10 chance (9.5%) experiencing a damaging flood.

To the extent possible, new development within the 500-year floodplain should be avoided. Relocating vulnerable infrastructure that is in the floodplain should also be considered when opportunities arise. And when flood damage occurs to existing development, re-development efforts should focus on relocating impacted structures outside the 500-year floodplain. All these efforts can reduce economic losses to public and private property.

Information to support these efforts is coming from the Iowa Statewide Floodplain Mapping Project, a partnership between the Iowa Department of Natural Resources (DNR) and the Iowa Flood Center. The project is preparing new floodplain maps for 85 Iowa counties, including those in the English River watershed. Floodplain maps for Poweshiek County (see Figure 6.1) have already been developed as part of the program’s pilot study. These floodplain mapping products should be used to help guide future development choices throughout the watershed.

Identify opportunities and implement practices and policies in urban and rural areas that reduce runoff and flood peaks, and enhance the water holding capacity of the soil: Conversion from Iowa’s tall-grass prairie landscape to agricultural and urban land used has had profound hydrologic impacts on rivers in the state. When it rains, more water runs off the landscape quickly and less water infiltrates into the ground. High storm flows increase flood peaks, erode channel banks and alter the river’s course, and transport sediment and nutrients downstream. During dry periods, river flows from groundwater (baseflow) are less. Working to reduce these impacts is an important objective for watershed management.

The watershed scenarios in Chapter 4 investigated the effects of some of these practices. Enhancing local infiltration through changes in land use has a significant impact on runoff. Obviously, converting the entire agricultural landscape back to tall-grass prairie is not a practical or economically desirable strategy. Still, from a hydrologic point of view, targeted projects that enhance infiltration by land-use change could be an effective part of a watersheds flood mitigation efforts. Infiltrating more water is effective because potential floodwaters are instead stored within the landscape.

Many conservation practices in agricultural watersheds aimed at re-
Figure 6.1: Floodplain mapping of the 100-year and 500-year floodplains for a portion of the North English River in Poweshiek County. The floodplain maps are available from the Iowa Flood Center (http://iowafloodcenter.org).
ducing erosion and protecting water quality do so by reducing runoff. Examples include no-till and contour farming, buffer strips, and grass waterways. Conservation reserve programs that provide assistance to convert highly erodible land and environmentally sensitive areas to landscapes with permanent protective cover also help enhance infiltration, reduce runoff, and prevent soil erosion. The use of cover crops for nutrient management also helps improve soil quality and reduce runoff. These and other practices should be considered where possible to reduce runoff and flooding. Areas identified in this study as having high runoff (Figure 4.1) would be a priority for projects to enhance infiltration.

Urban areas should also be targeted for enhanced infiltration practices. Indeed, the conversion of agricultural land to urban uses results in much less infiltration and increases runoff, because impervious surfaces like roads and buildings cover what was previously infiltrating soils. Traditionally, urban stormwater management focused on reducing the “nuisance” of excess runoff in the urban areas themselves, by quickly gathering and moving water away (e.g., curb and gutter systems). But conveying the water more quickly increases the flood hazard downstream. As a result, urban stormwater management also now focuses on delaying the movement of floodwaters downstream, by storing it temporarily for later release (e.g., stormwater detention ponds). However, in recent years, low-impact development (LID) stormwater management practices have gained wider acceptance for stormwater management.

One goal of low-impact development is to control stormwater at the source by the use of small-scale controls that are distributed throughout the site. Some practices include the development site planning to reduce the effectiveness of impervious surface, by lengthening the flow paths for water (and the time it takes to reach a stream), and by re-routing water to pervious area (for infiltration). Others include the construction of raingardens in residential and commercial areas, or bioswales along sidewalks and roadways, to focus recharge of urban runoff (which restores baseflow and reducing downstream stormflow). And still others include replacing traditional asphalt and concrete surfaces in parking lots with pervious pavement (which allows water to infiltrate). For the most part, low-impact development practices are most effective at reducing the extra runoff for common “everyday-type” rainfall events, which are not handled by other more traditional stormwater management practice. For very heavy rainstorms, urban areas still need stormwater detention to enhance flood pro-
Establish a hydrologic monitoring network — streamflow, precipitation, soil conditions, water quality, shallow groundwater wells — to understand current conditions, document changes in the watershed, and provide critical information for decision makers during high water events: Our understanding of the movement of water and nutrients within the English River watershed depends on observations. The long records of U.S. Geological Survey (USGS) streamflow observations at the English at Kalona, and of National Weather Service (NWS) Cooperative Observer Program precipitation observations at North English and surrounding stations, help provide a baseline on the water cycle and flooding. The USGS has also has eight crest stage sites where annual peak discharges were measured, but only three remain in operation today. Unfortunately, water quality sampling in the English River water is more limited. Monthly observations are available on the English River at Riverside since 1998 from the Iowa Department of Natural Resources (DNR). Other sporadic measurements of water quality have occurred at the USGS stream-gage site, and at locations within the watershed by the DNRs Watershed Monitoring and Assessment Section and its volunteer water quality monitoring program IOWATER. Still, these observations provide valuable information on the physical and biological characteristics of the river.

Some expansion of monitoring in the English River watershed is already underway. For example, the USGS has establish continuous real-time monitor of streamflow on Deep River (USGS 05455230 Deep River at Deep River) in 2014, a former crest stage site where annual peak discharges have been monitored since 1960. The Iowa Flood Center has recently installed two of its stream stage sensors in watershed (see Figure 6.2, on the North English River (West of Q Avenue) and the South English River (East of 33th Avenue, County W18). Both sites are just upstream of the confluence of these two tributaries, and can provide valuable information about flows to a high flood area identified in this study (downstream of their confluence). Additional installation of one or two sensors is planned in the future. Also, as part of IIHR–Hydroscience & Engineering’s Nutrient Monitoring Network, continuous nitrate and nitrite data are being collected during the warm season for the English River at Kalona since 2013. Furthermore, in 2014, the Iowa Soybean Association performed syn-
optic sampling of water quality at 20 locations, providing a snapshot of water quality at three times of the year (April 28, July 17, and October 21). Their observations paint a remarkable picture of the spatial variations of water quality within the watershed, and provide insights that can help us better understand why water quality levels are higher (or lower) in certain locations of the watershed (Iowa Soybean Association, 2014).

Figure 6.2: Existing river flow and stage monitoring stations in the English River watershed from the Iowa Flood Center’s Iowa Flood Information System (IFIS) (http://iowafloodcenter.org).

Expanding the monitoring of hydrologic and water quality conditions of the watershed would help improve our understanding of these processes. Monitoring is also important when implementing projects within the watershed target at flood mitigation and water quality improvement. Monitoring helps to gauge the effectiveness of the projects and their cumulative effect over time. Expanded monitoring would also help improve the computer modeling of hydrologic and water quality processes. When there are more data available for comparison of model predictions with
observations, refinements of the model can be made to better represent the variability of processes throughout the watershed. The improved models could then be used to make predictions for watershed planning and proposed project activities. Therefore, continued expansion of measurement, and establishment of a permanent hydrologic monitoring network for the English River watershed, should be pursued.
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Zhang, Y. K. and K. E. Schilling, 2006a: Effects of land cover on water table, soil moisture, evapotranspiration, and groundwater recharge: A

Appendix A

HSPF Parameter Adjustments for a Prairie Land Segment

Table A.1 summarizes the adjustments made to the English River HSPF model parameters to represent a tall-grass prairie landscape. What follows is a discussion of the parameter adjustments.

Table A.1: Adjustments in HSPF model parameters from those calibrated for croplands to reflect a tall-grass prairie landscape.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEPSC</td>
<td>Same maximum as corn with adjusted annual cycle for growing and dormant season</td>
</tr>
<tr>
<td>LZSN</td>
<td>$2 \times$ calibrated value for corn/soybeans</td>
</tr>
<tr>
<td>UZSN</td>
<td>$2.5 \times$ calibrated value and adjusted annual cycle</td>
</tr>
<tr>
<td>INFILT</td>
<td>$4.65 \times$ calibrated value for corn/soybeans</td>
</tr>
<tr>
<td>NSUR</td>
<td>Increase to a constant 0.30 for continuous prairie vegetation</td>
</tr>
<tr>
<td>LZETP</td>
<td>Increased maximum to 0.90 and adjusted annual cycle</td>
</tr>
</tbody>
</table>

CEPSC is interception storage capacity (depth). It represents the storage of water on vegetation and depressions at the surface. Corn crops have extensive interception storage at maturity; after harvesting the interception storage is quite low. For the prairie land segments, we assumed the
maximum interception storage was the same as mature corn. However, we adjusted its annual cycle to reflect the higher interception storage of a prairie’s continuous vegetation cover during the growing and dormant seasons.

LZSN (lower zone nominal storage) is related to the available water capacity (depth) of the root zone. Since the root zone depth of tall-grass prairie vegetation is typically about twice that of mature corn, we increased the calibrated LZSN by a factor of 2.

UZSN (upper zone nominal storage) is related to the depression and pore storage in the near-surface soils. Donigian et al. (1983a) illustrate using the Natural Resource Conservation Service (NRCS) runoff curve number (CN) for initial estimates of UZSN. We used this approach to determine the ratio of the initial estimate of UZSN for a prairie to that for row crops (using a mixture of conventional tillage, no tillage, terraces, and contours). As a result, we increased the calibrated UZSN by a factor of 2.5 for the prairie land segment.

INFILT is an index to the infiltration capacity of the soil. Donigian et al. (1983a) illustrate using Holtan’s infiltration equation for initial estimates of INFILT. We used this approach to determine the ratio of the initial estimate of INFILT for a prairie to that for a row crop mixture. As a result, we increased the calibrated INFILT by a factor of 4.65 for the prairie land segment.

NSUR is a measure of the roughness of the surface for water flowing (known as Manning’s n). Donigian et al. (1983a) provide recommended NSUR values for different land uses. Using these values as guidance, we increased the maximum NSUR value from 0.25 to 0.30. The roughness for row crops varies throughout the growing season; we assumed the roughness for prairie remains constant throughout the year.

LZETP (lower zone evapotranspiration parameter) is an index to the density of deep rooted vegetation. The parameter determines the amount (depth) of evapotranspiration from the lower zone, given the lower zone soil moisture condition. Given its empirical nature, we assumed that the maximum LZETP increases from 0.80 (calibrated for corn and soybeans) to 0.90. We also adjusted the annual cycle to reflect the higher evaporation potential of a prairie’s continuous vegetation cover during the growing and dormant seasons.
Appendix B

HSPF Parameter Adjustments for a Agricultural Best Management Practices

Table B.1 summarizes the adjustments made to the English River HSPF model parameters to represent a landscape with agricultural best management practices fully implemented in row crop areas. What follows is a discussion of the parameter adjustments.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Adjustment</th>
</tr>
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<tbody>
<tr>
<td>CEPSC</td>
<td>Same maximum as corn with adjusted annual cycle for growing and dormant season</td>
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<tr>
<td>LZSN</td>
<td>$2 \times$ calibrated value for corn/soybeans</td>
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<td>INFILT</td>
<td>$4.65 \times$ calibrated value for corn/soybeans</td>
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<tr>
<td>NSUR</td>
<td>Increase to a constant 0.30 for continuous prairie vegetation</td>
</tr>
<tr>
<td>LZETP</td>
<td>Increased maximum to 0.90 and adjusted annual cycle</td>
</tr>
</tbody>
</table>

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age of water on vegetation and depressions at the surface. Corn crops have extensive interception storage at maturity; after harvesting the interception storage is quite low. For the prairie land segments, we assumed the maximum interception storage was the same as mature corn. However, we adjusted its annual cycle to reflect the higher interception storage of a prairie’s continuous vegetation cover during the growing and dormant seasons.

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NSUR is a measure of the roughness of the surface for water flowing (known as Manning’s n). Donigian et al. (1983a) provide recommended NSUR values for different land uses. Using these values as guidance, we increased the maximum NSUR value from 0.25 to 0.30. The roughness for row crops varies throughout the growing season; we assumed the roughness for prairie remains constant throughout the year.

LZETP (lower zone evapotranspiration parameter) is an index to the density of deep rooted vegetation. The parameter determines the amount (depth) of evapotranspiration from the lower zone, given the lower zone soil moisture condition. Given its empirical nature, we assumed that the maximum LZETP increases from 0.80 (calibrated for corn and soybeans) to 0.90. We also adjusted the annual cycle to reflect the higher evaporation potential of a prairie’s continuous vegetation cover during the growing
and dormant seasons.
Appendix C

HSPF Parameters for the Nutrient Simulation

Table C.1 summarizes HSPF land surface parameters (Section PERLND-NUTRX) for the English River HSPF model nutrient simulation. The parameters were transferred from the Iowa River basin water quality study by Imhoff et al. (1983).

Table C.2 summarizes HSPF nitrogen plant uptake parameters (Section PERLND-NUTRX) for the English River HSPF model nutrient simulation. The parameters were transferred from the Iowa River basin water quality study by Imhoff et al. (1983).
Table C.1: Land surface nutrient parameters.

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Table C.2: Monthly nitrogen uptake parameter (/day).

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