Hydrologic Modeling of the English River Watershed

by

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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.

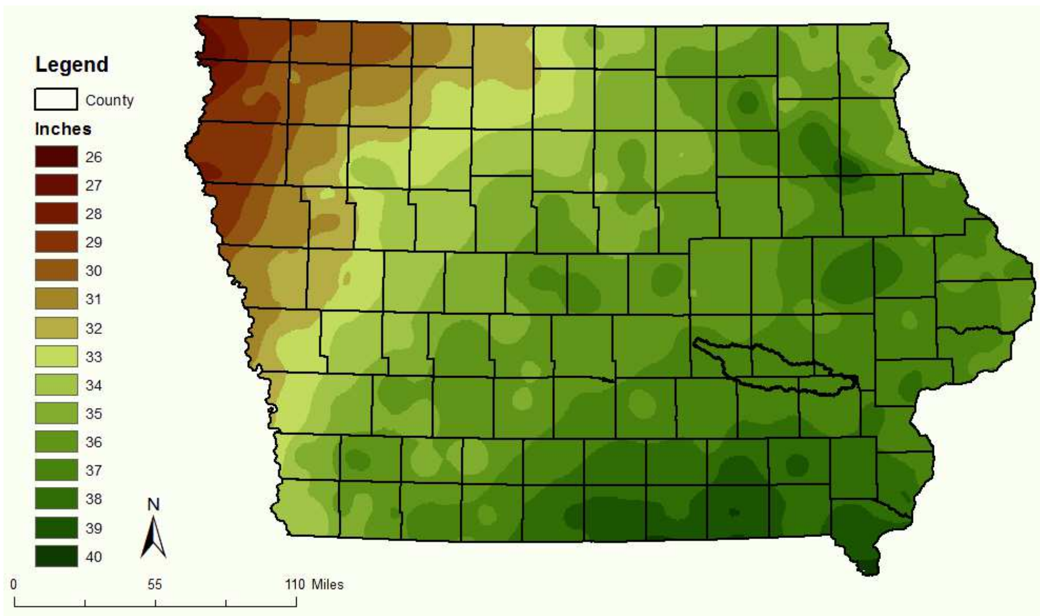

Figure 2.1: Average annual precipitation for Iowa. Precipitation estimates are based on the 30-year annual average (1981-2010) for precipitation gauge sites. Interpolation between gauge sites to an 800 m grid was done by the PRISM (parameter-elevation relationships on independent slopes model) method. (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).

Component	Depth (in)	Percentage (%)
Precipitation	36.5	100
Evaporation	25.3	69.3
Surface Flow	5.0	13.7
Baseflow	6.2	17.0

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.

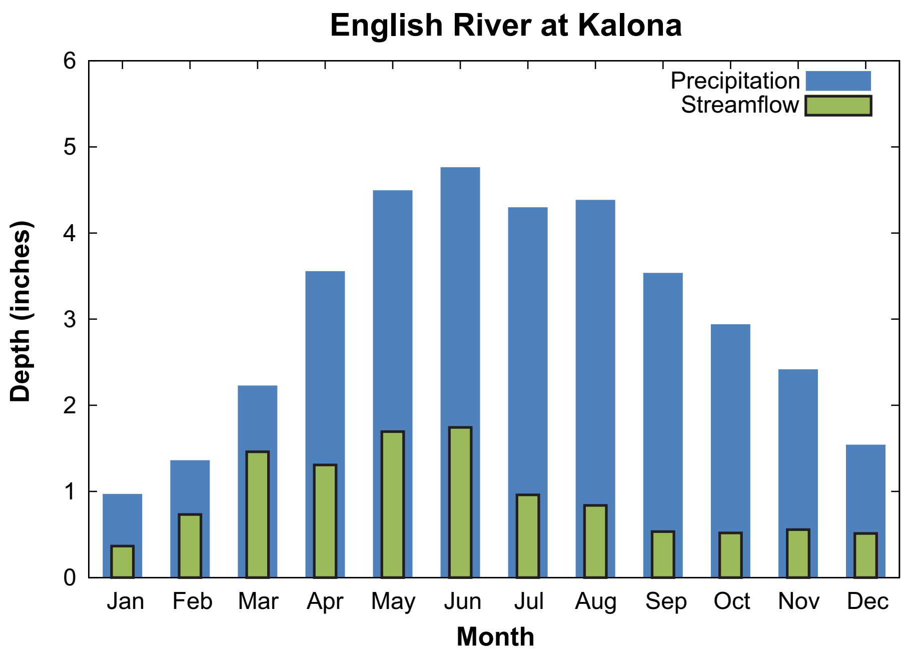

Figure 2.2: Monthly water cycle for the English River watershed. The plots show the average monthly precipitation (in inches) and the average monthly streamflow (in inches). The average monthly estimates for precipitation and streamflow are based on the same 30-year period (1983-2012).

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 stream flow 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,

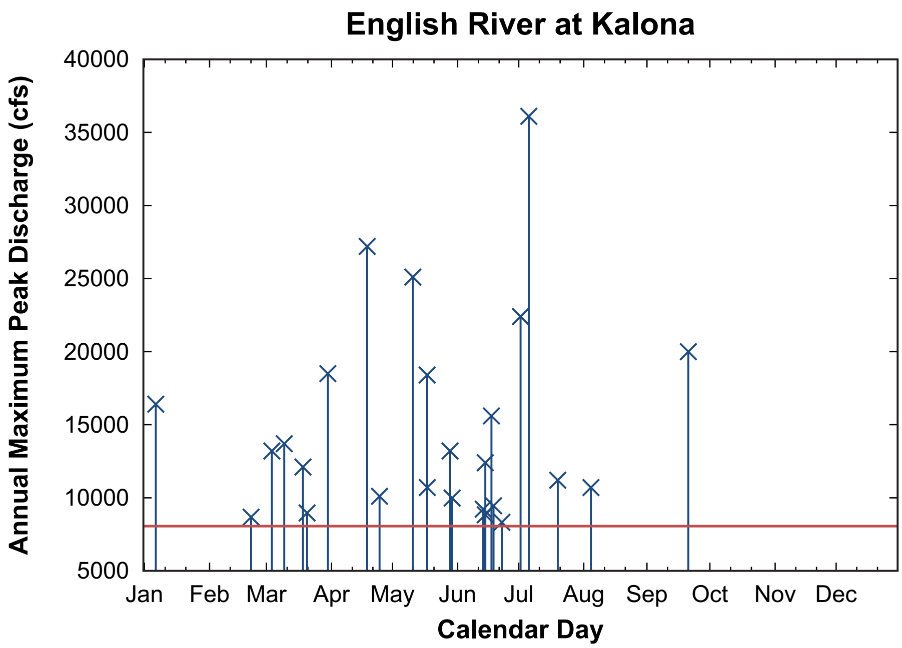

Figure 2.3: Annual maximum peak discharges and the calendar day of occurrence for the English River at Kalona (USGS 05455500). The plots show all annual maximums greater than the mean annual flood (horizontal line). The annual peaks are for the period of record from 1940 to 2014.

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 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 argriculture-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-

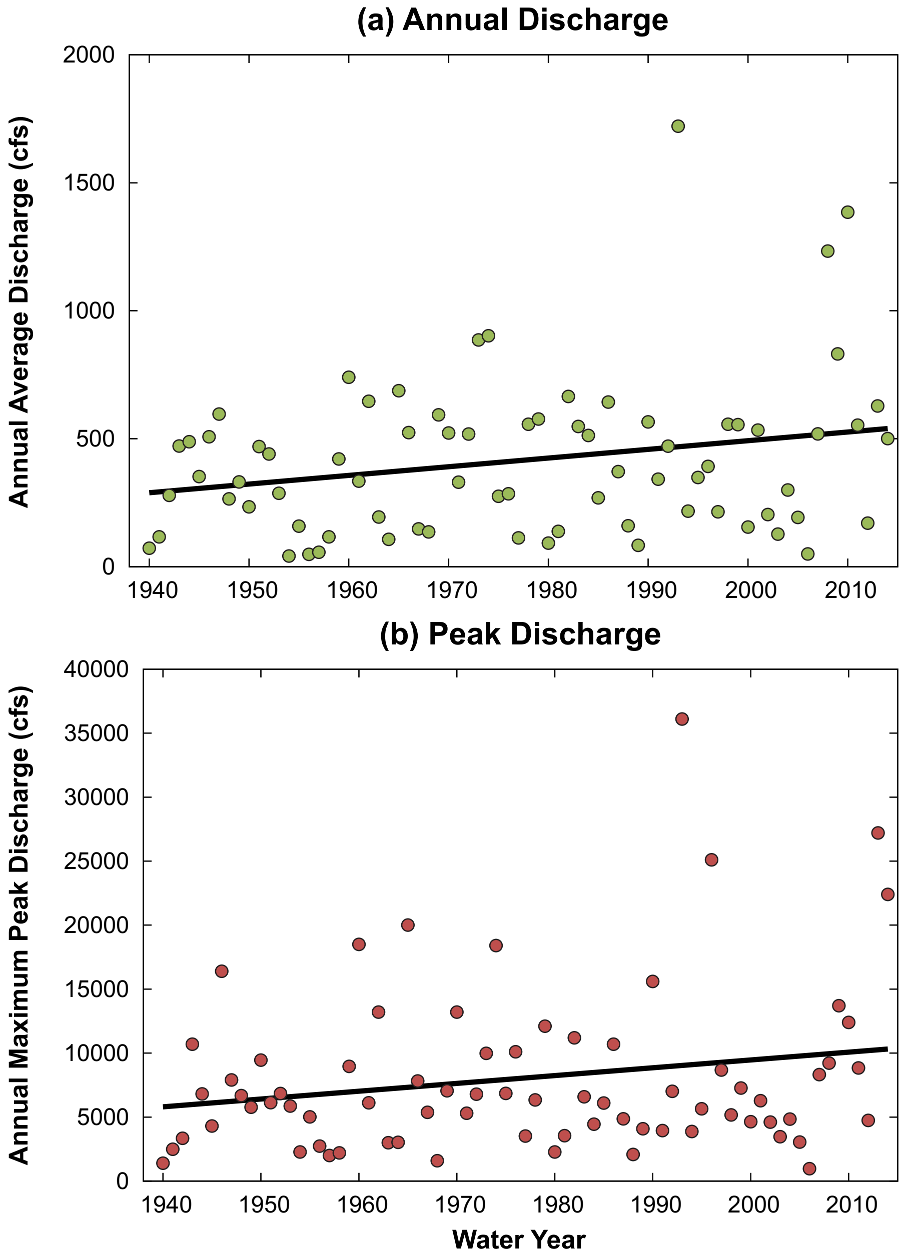

Figure 2.4: English River at Kalona (USGS 05455500) time series of: (a) annual average discharge (in cfs) and (b) annual maximum peak discharge (cfs). Results are shown for the period of record from 1940 to 2014. Although the trend lines shows an increase in flows over time, the trends observed are not 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., 1983, 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 dissaggregated 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.

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

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.

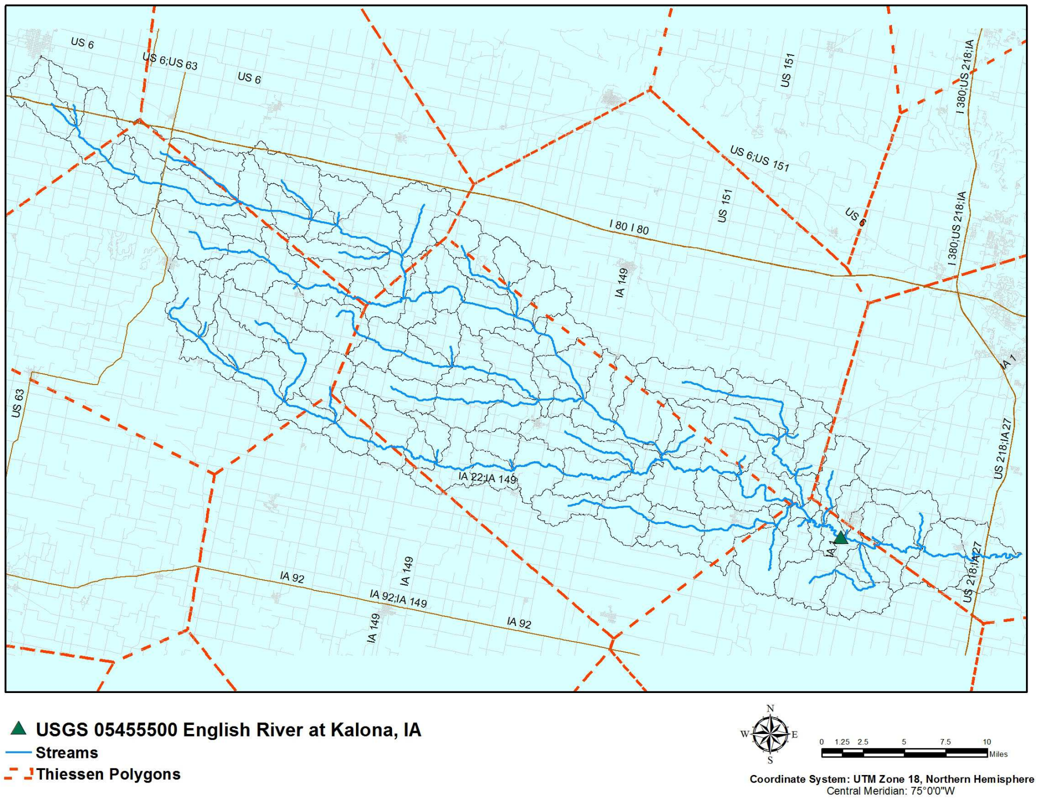

Figure 3.1: Location of the eight weather stations used in the English River HSPF model. The area that is closest to each station is indicated by the polygons; the station provides the precipitation and air temperature inputs used for these indicated areas.

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 relation-

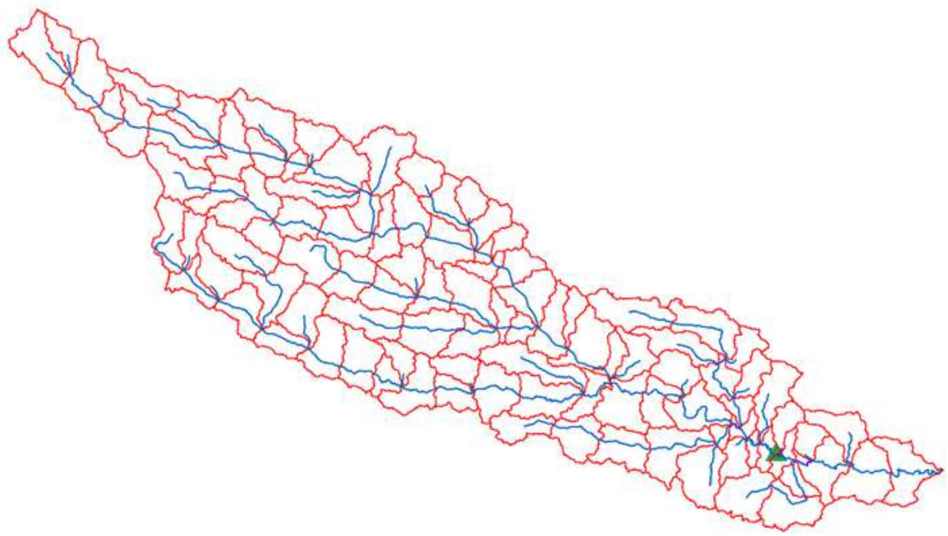

Figure 3.2: Subdivision of the English River watershed into HSPF RCHRES river reaches. The English River network of streams is indicated by the blue lines. The red lines show the drainage divide of the river reaches. The location of the USGS English River at Kalona stream-gage is indicated by the green 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.

ship. 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. Unfortunately, there are only two sites within the English River watershed with suitable stream-gage measurements — the English River at Kalona (USGS 05455500, 574 mi^2) and the South English River Tributary near Barnes City (USGS 05455280, 2.51 mi^2). 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 mi^2) and Rapid Creek near Iowa City (USGS 05454000, 25.3 mi^2), 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.

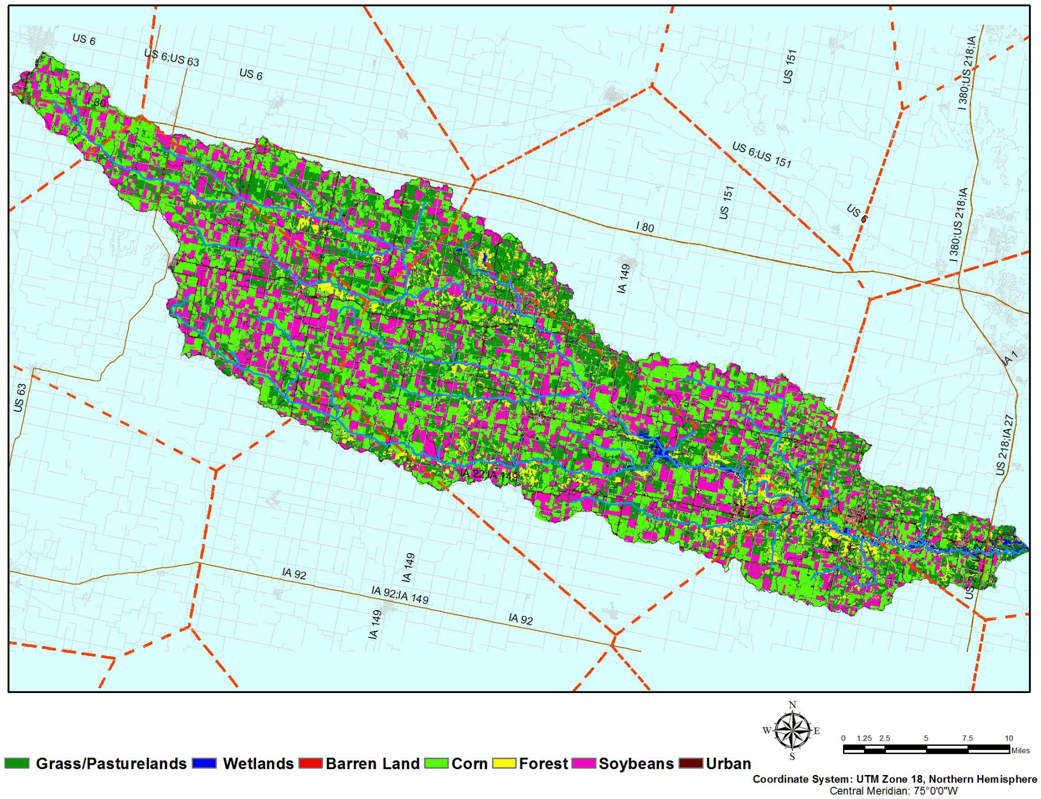

Figure 3.3: Land use classification for the English River watershed used to define HSPF land segments. The land use information was compiled by the Iowa Soybean Association for 2013 conditions.

Note that a further subdivision of land segments is accomplished in the English River HSPF model based on the weather inputs. For example, the 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.

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

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.

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

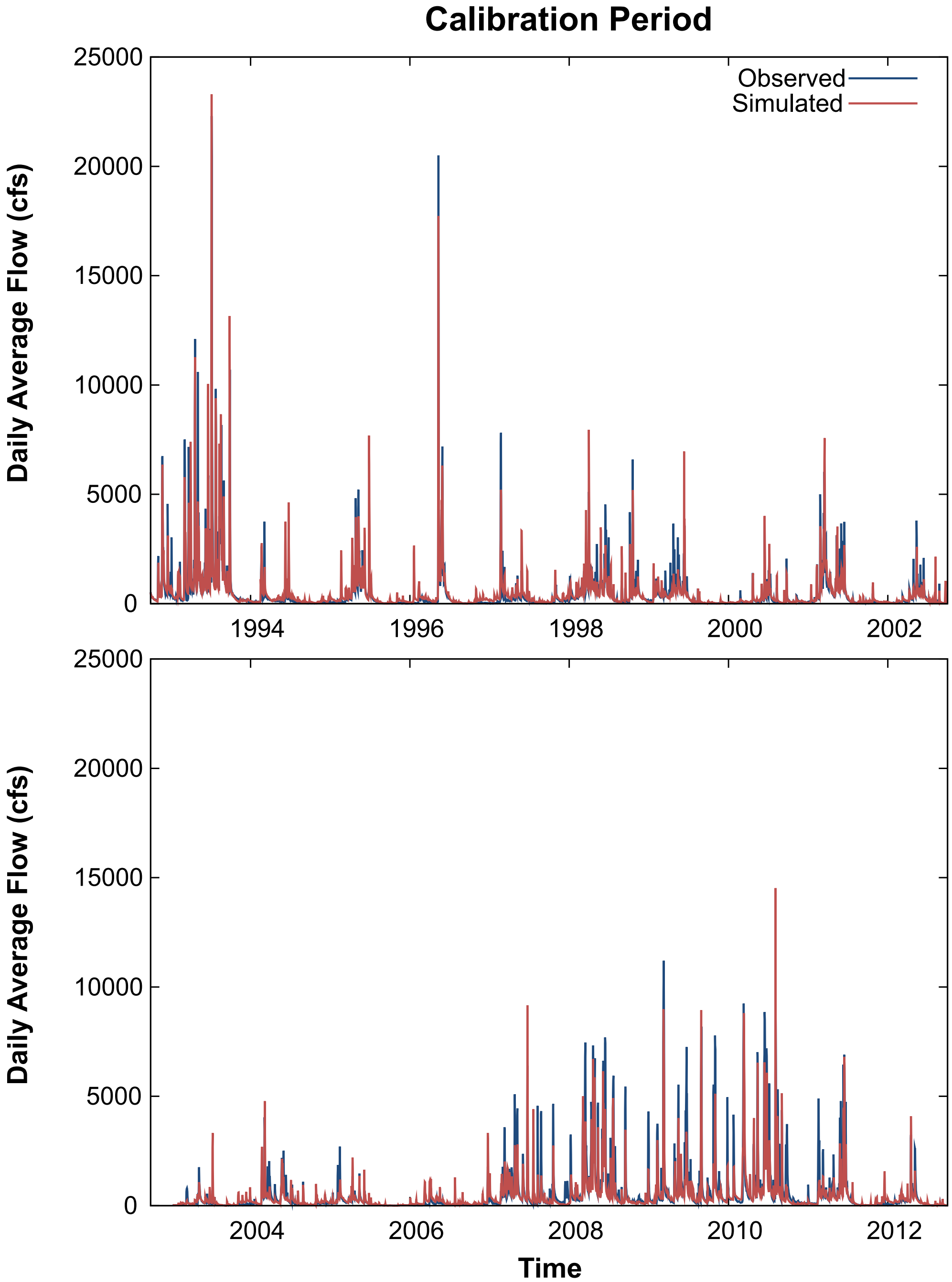

Figure 3.4: Observed and simulated daily flow time series for the English River at Kalona (USGS 05455500) for the calibration water years from 1993 to 2012.

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 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

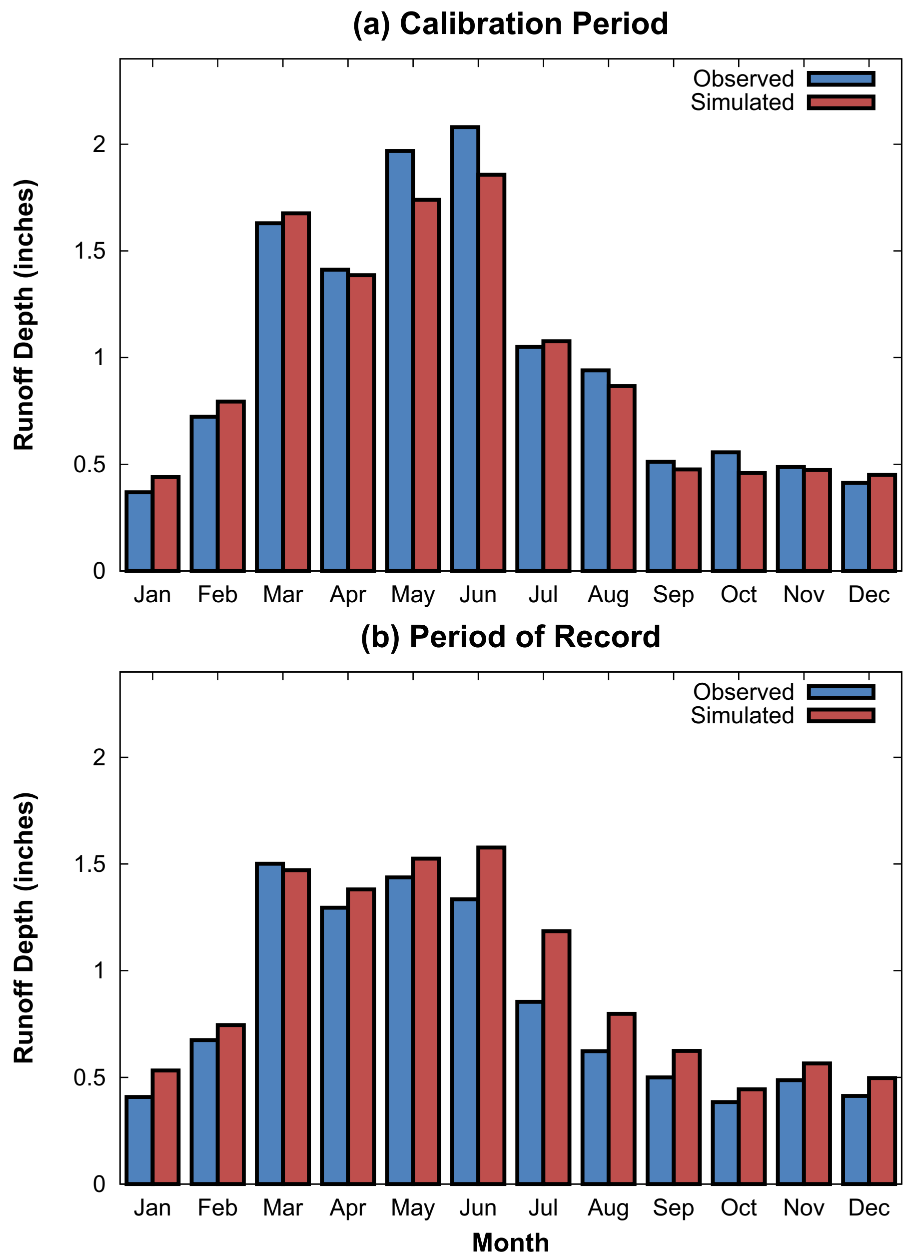

Figure 3.5: Observed and simulated average monthly runoff depth (in inches) for the English River watershed. Results are shown for (a) the calibration period from 1993 to 2012, and (b) the period of record from 1949 to 2012.

(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).

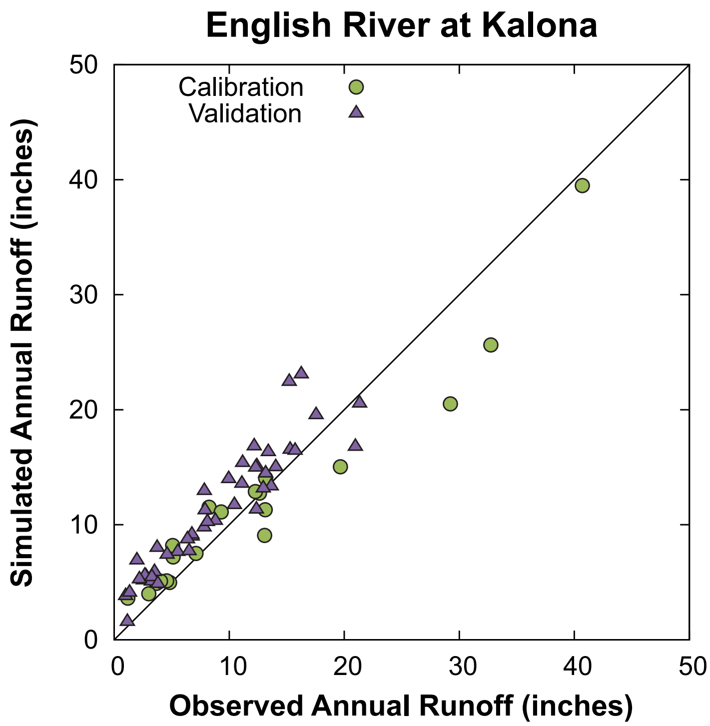

Figure 3.6: Simulated versus observed annual flow depth (in inches) for the English River at Kalona. Results are shown for the calibration period from 1993 to 2012 (green circles) and the validation period from 1949 to 2012 (purple triangles).

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.

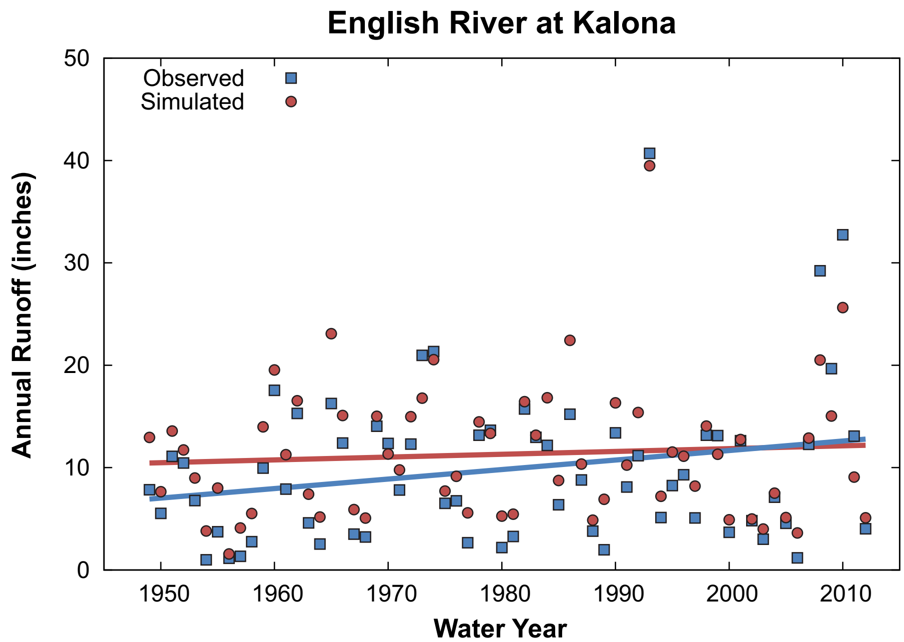

Figure 3.7: Annual runoff time series for simulated and observed flows for the English River at Kalona (USGS 05455500). The trend lines for the simulated and observed time series were evaluated with linear regression.

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.

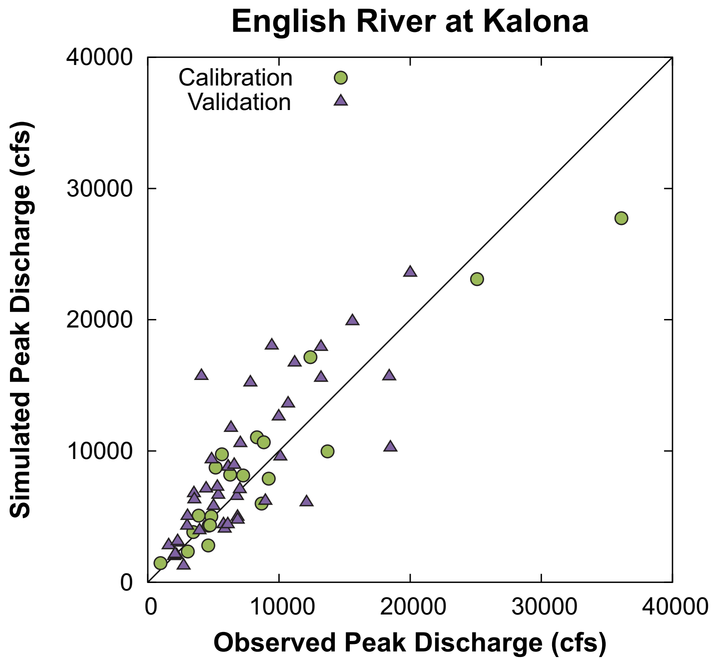

Figure 3.8: Simulated versus observed annual maximum peak discharges for the English River at Kalona (USGS 05455500). Results are shown for the calibration period from 1993 to 2012 (green circles) and the validation period from 1949 to 2012 (purple triangles).

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.

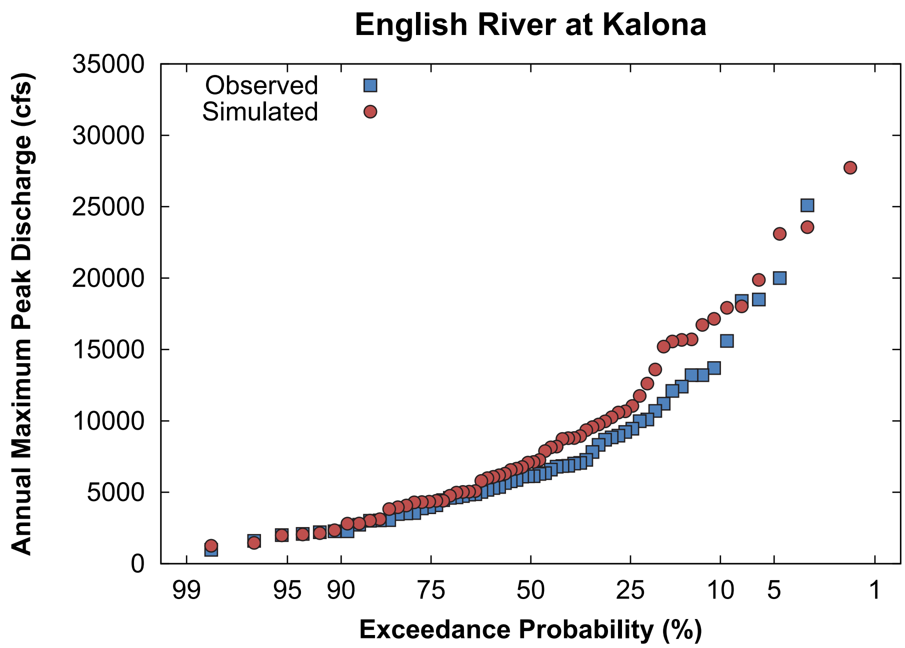

Figure 3.9: Flood frequency analysis of annual maximum peak discharges for simulated and observed flows for the English River at Kalona (USGS 05455500). The annual maximums are for the entire for water years 1949 to 2012 (the entire simulation period).

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. The range of simulated average annual runoff depth is shown for each of the 103 subbasins in Figure 4.1. Some subbasins have higher runoff; others have lower runoff. Based on the distribution of average runoff depths, we classified the top third as subbasins with high average runoff (runoff depths of 11.44 inches or more), the middle third as subbasins with medium average runoff (runoff depths between 10.27 and 11.44 inches), and the bottom third as subbasin with low average runoff (runoff depths of 10.27 inches or less).

Figure 4.2 maps the location of high, medium, and low average runoff areas across the English River watershed. Areas in the basin with high average 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 the Unamed Creek-South English River. Another area with high average 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.

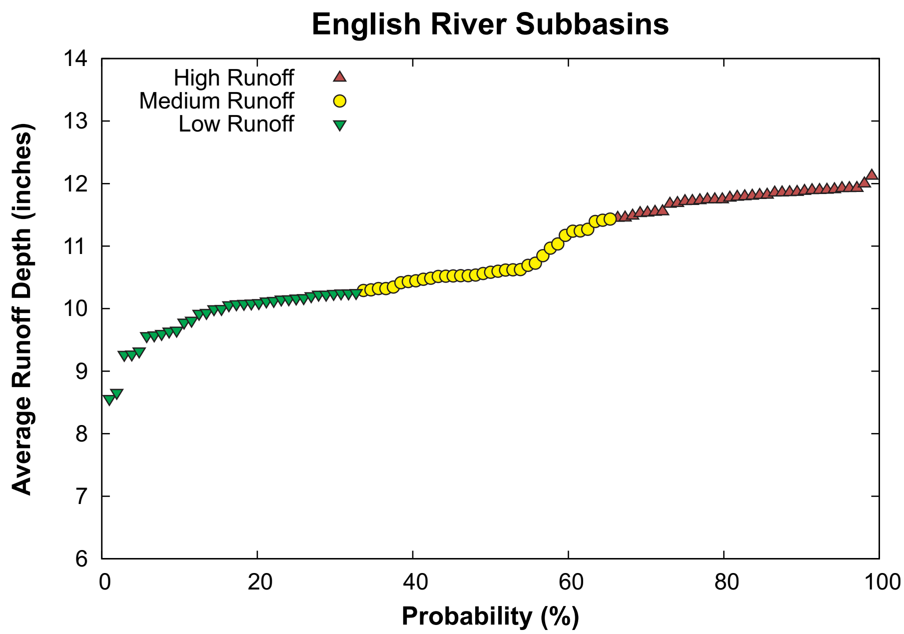

Figure 4.1: The distribution of average runoff depth for Enghlish River HSPF model subbasins. The average annual runoff depth is computed for all 103 HSPF RCHRES subbasins from the 64-year simulations. The top third is classified as high runoff (red), the middle third is classified as medium runoff (yellow), and the bottom third is classified as low runoff (green).

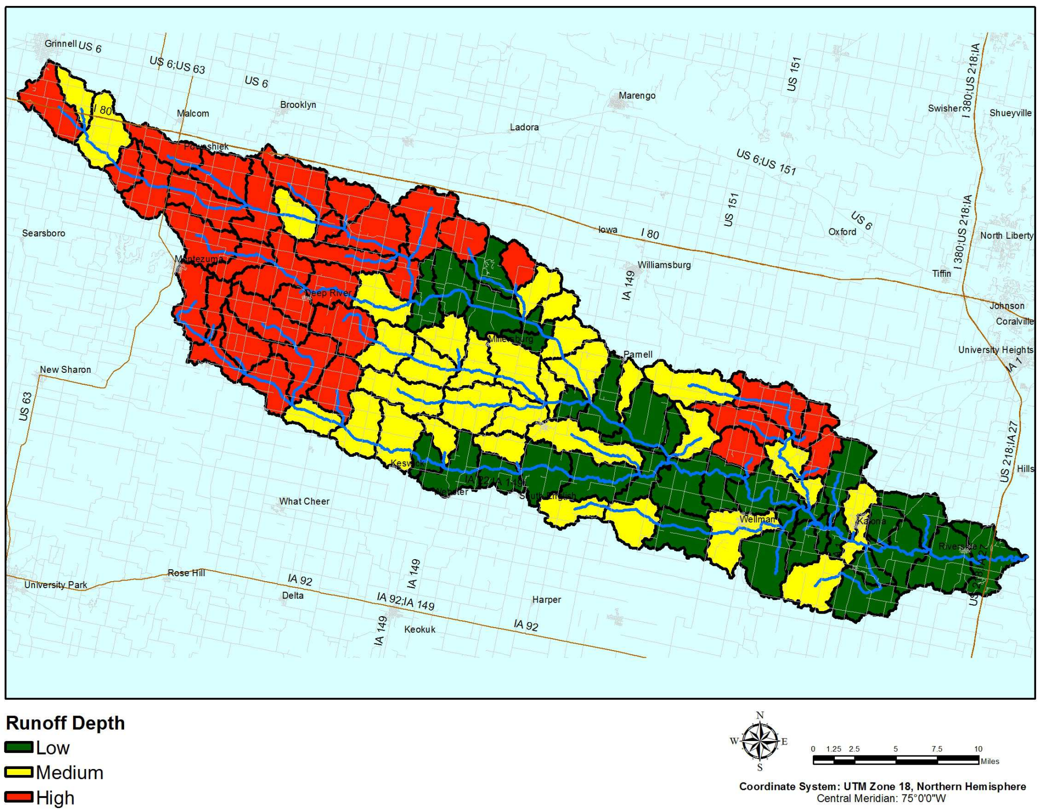

Figure 4.2: Average runoff depth in the Enghlish River watershed. The average annual runoff depth is computed for the HSPF RCHRES subbasins from the 64-year simulations. Higher average runoff depths are shown in red.

Still, high runoff is but one factor in selecting locations for potential projects. Alone, it has limitations. For example, some of the highest runoff 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 events, to show downstream areas most impacted by high runoff.

At subbasin outlets, the annual maximum 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 higher mean annual floods 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 4.3 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 annual floods at the location. The top third are classified as locations with high annual floods, the middle third (closest to the mathematical model prediction) as locations with medium annual floods, and the bottom third as locations with low annual floods.

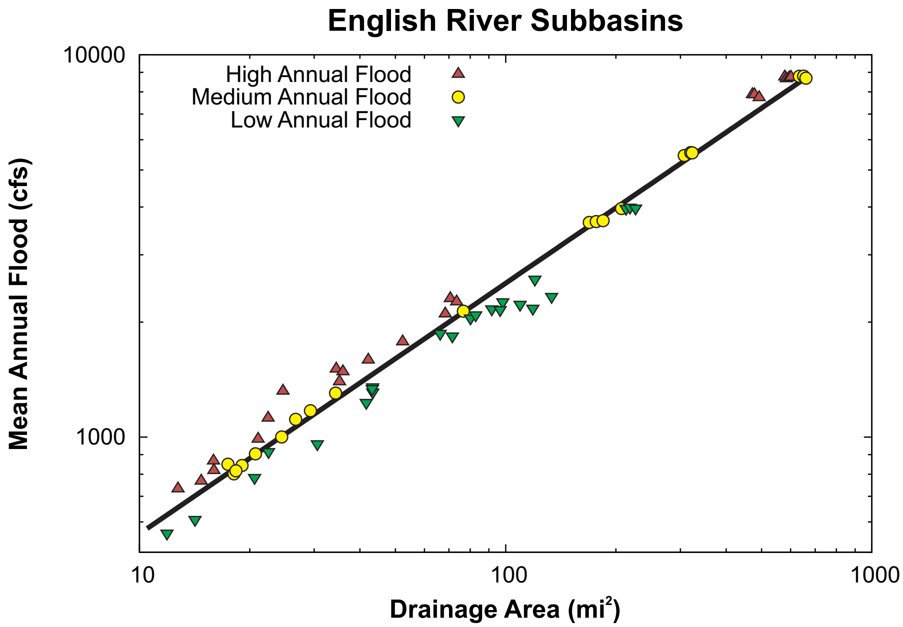

Figure 4.3: The relationship between the mean annual flood and drainage area in the English River watershed. The mean annual flood computed for the HSPF RCHRES subbasin outlets from the 64-year simulations is plotted against the total upstream drainage area at the outlet; headwater subbasins are excluded 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 high annual flood (red), the middle third is classified as medium annual (yellow), and the bottom third is classified as low annual (green).

Figure 4.4 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 areas 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 transition 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 4.2), 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 4.2), 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 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

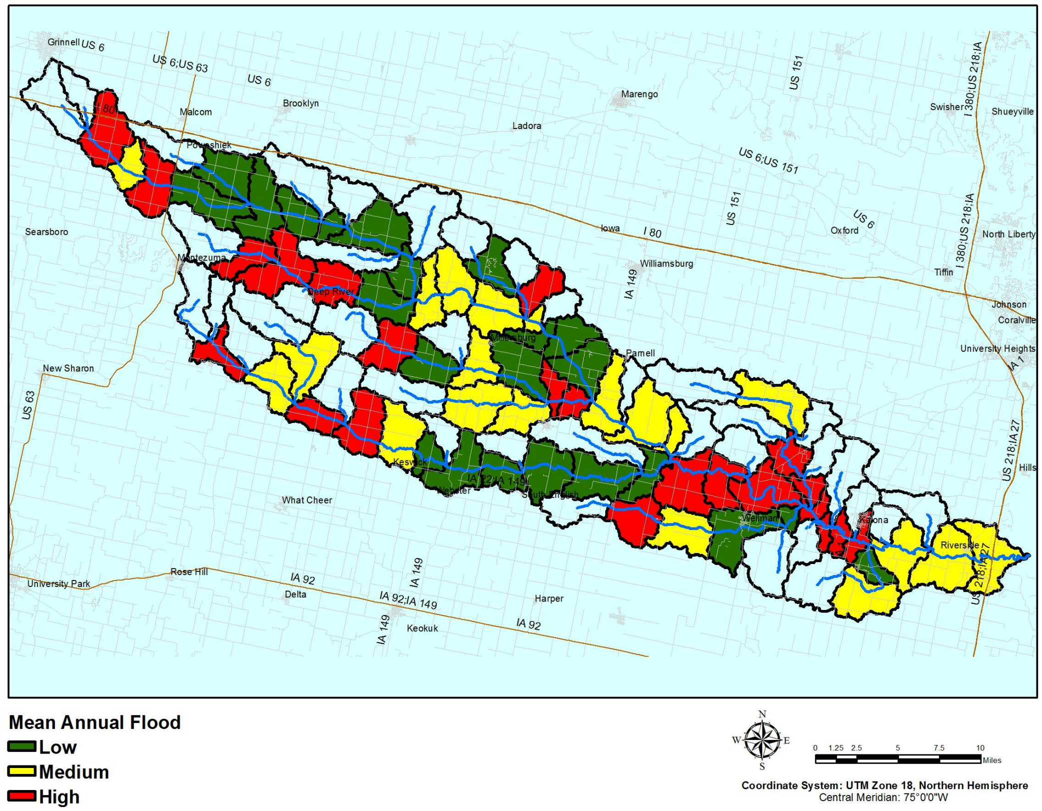

Figure 4.4: Mean annual flood anomalies for locations in the English River watershed. The mean annual flood computed for the HSPF RCHRES subbasin outlets from the 64-year simulations is compared against a mathematical relation of mean annual flood and drainage area for the entire basin; headwater subbasins are excluded from this analysis. Locations with higher mean annual floods are shown in red.

downstream. But these measures can also change the timing of flows. High flood locations, which tend to be situated downstream of river confluences, 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 dependance on where and when it rains within the watershed, high flood areas make good locations for assessing the overall impact of upstream mitigation project.

4.1.3 Intensity and Extent of Extreme Floods

Our examination of high flood areas summarizes the average flood characteristics over the 64-year simulation period. However, using the simulated 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 index 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 discharge 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 4.5 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 produce flooding. Although the intensity varies with location, it is high and much more uniform across the watershed than for any other flood year.

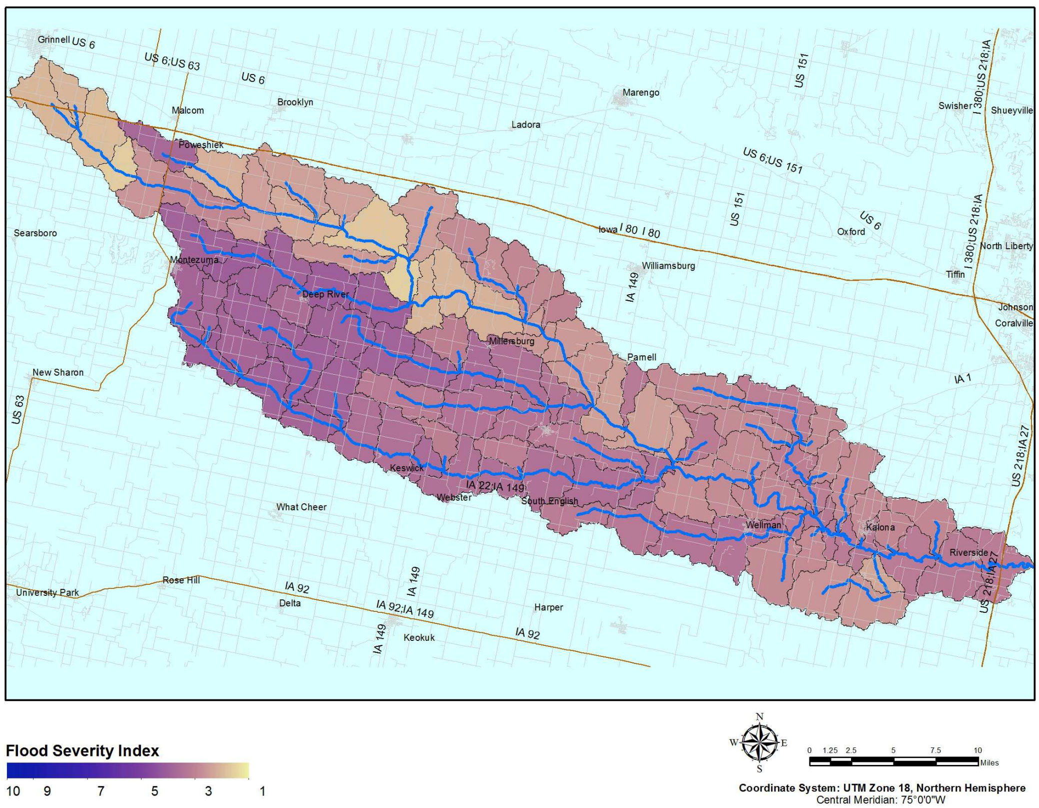

Figure 4.5: Flooding intensity and extent for the 1993 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity.

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.

Rank	Water Year	Average	Maximum	Minimum
1	1993	3.50	3.99	1.57
2	1965	2.58	5.50	0.83
3	2010	2.50	4.41	0.80
4	1982	2.39	6.14	0.98
5	1950	2.35	4.31	0.67

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 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 4.6 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).

Maps of the flood severity index for the remaining top floods — 2010, 1982, and 1950 — are shown in Figures 4.7-4.9. 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

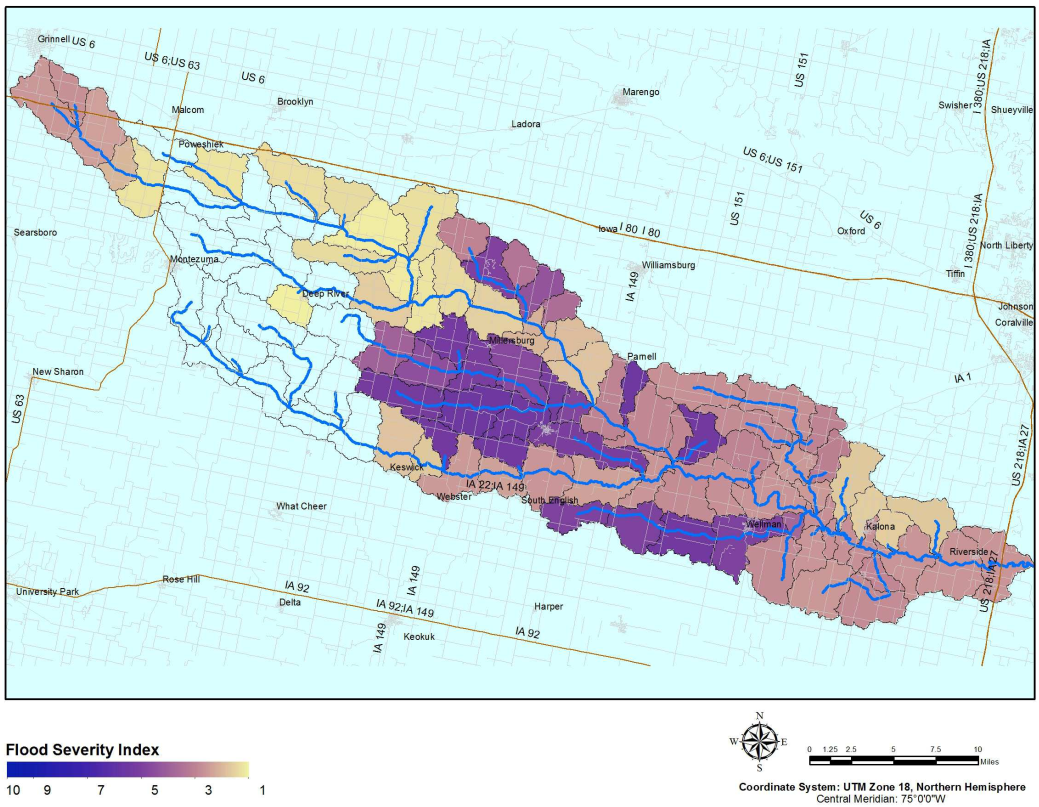

Figure 4.6: Flooding intensity and extent for the 1965 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.

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.

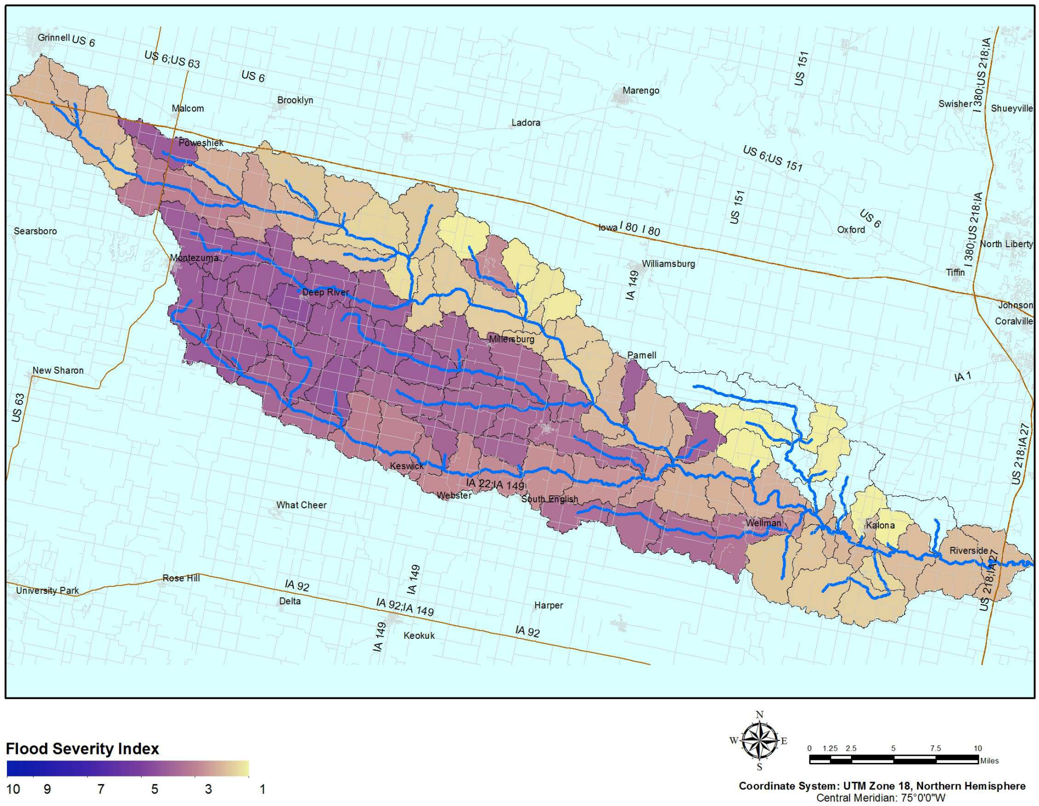

Figure 4.7: Flooding intensity and extent for the 2010 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.

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 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

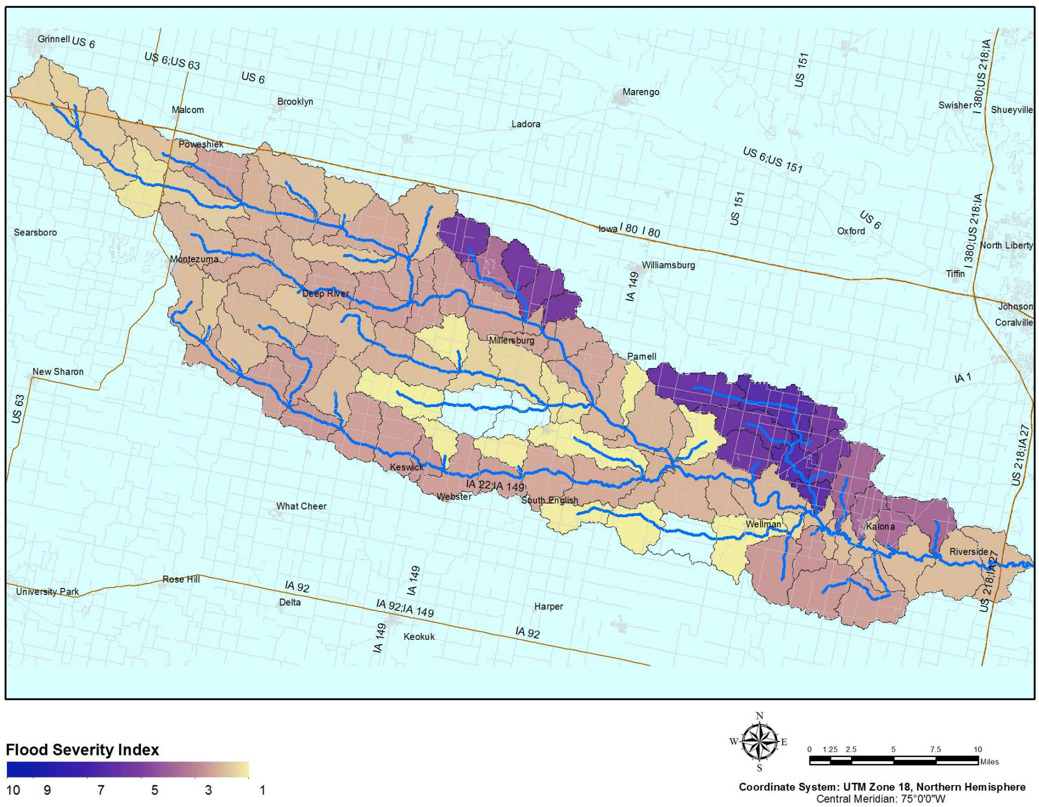

Figure 4.8: Flooding intensity and extent for the 1982 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.

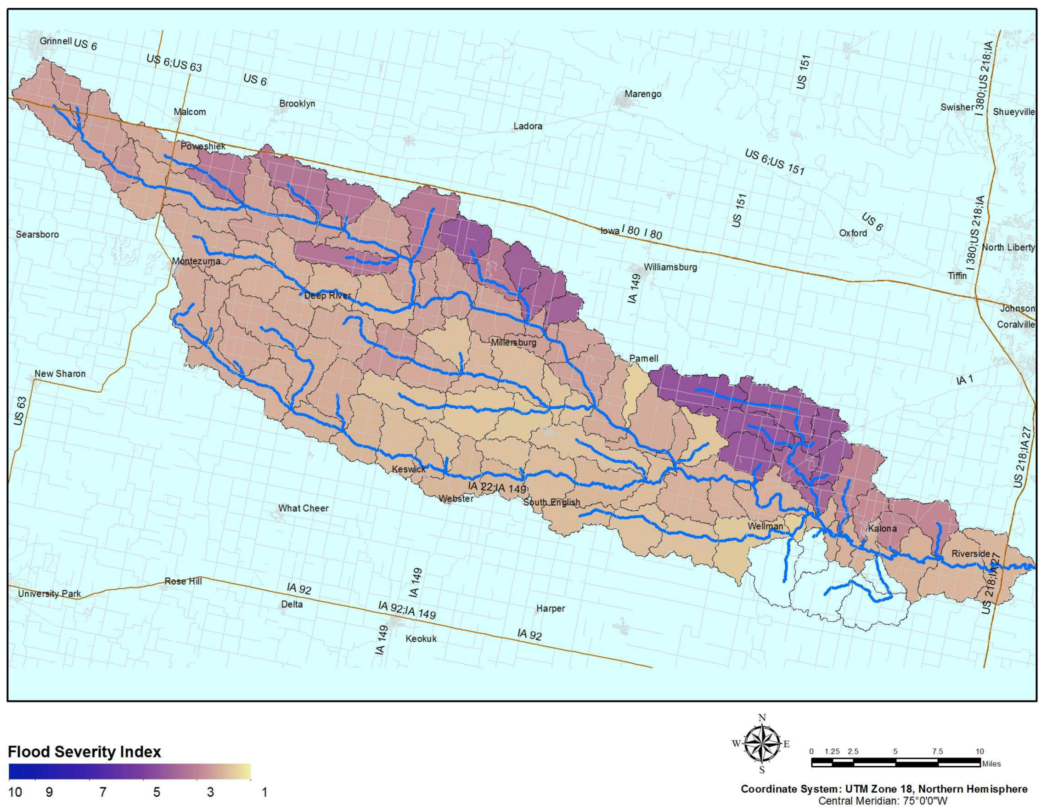

Figure 4.9: Flooding intensity and extent for the 1950 flood year. The map shows the estimated flood severity index at each subbasin outlet. Darker colors indicate a higher flood intensity. Areas without simulated flooding are not shaded.

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.

Chapter 5

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.

5.1 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.

5.2 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.

5.3 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 depth from the 64-year simulation, subbasin areas with higher runoff were mapped (Figure 4.2). 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 4.4). 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 he 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.

5.4 Hypothetical Watershed Scenarios

5.5 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 5.1) 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.

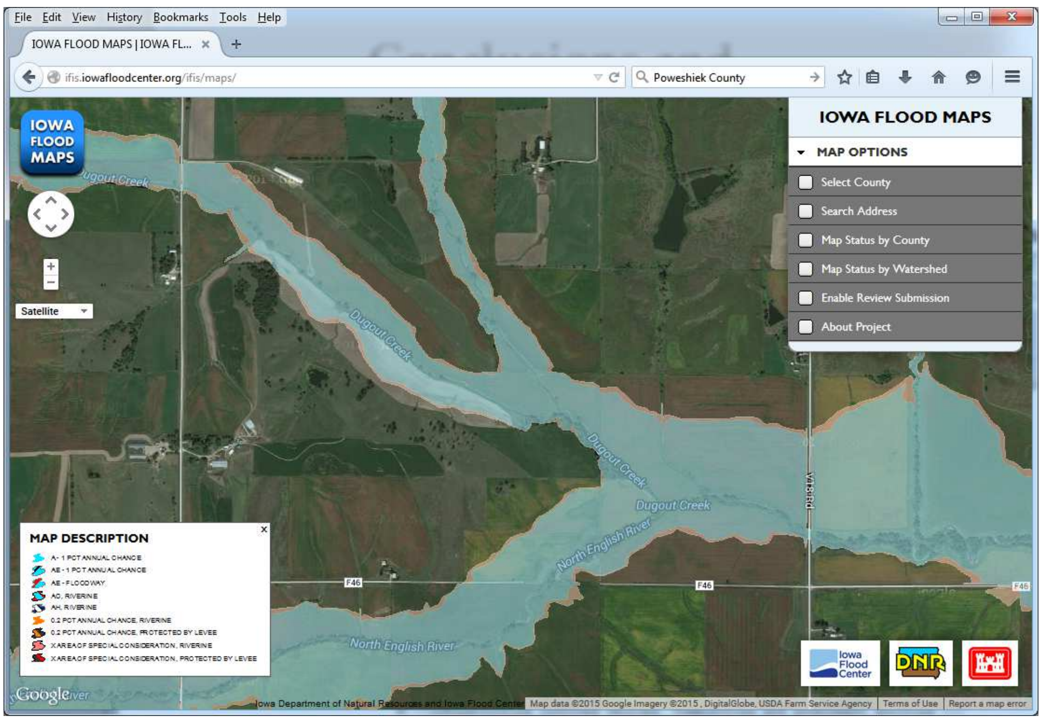

Figure 5.1: Floodplain mapping of the 100-year and 500-year floodplains for a portion of the North English River in Poweshiek County. The floodplain maps are available from the Iowa Flood Center (`http://iowafloodcenter.org`).

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 a 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 reducing 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 4.2) 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 commericial 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 protection (Holman-Dodds et al., 2003).

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 5.2, 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 synoptic 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).

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

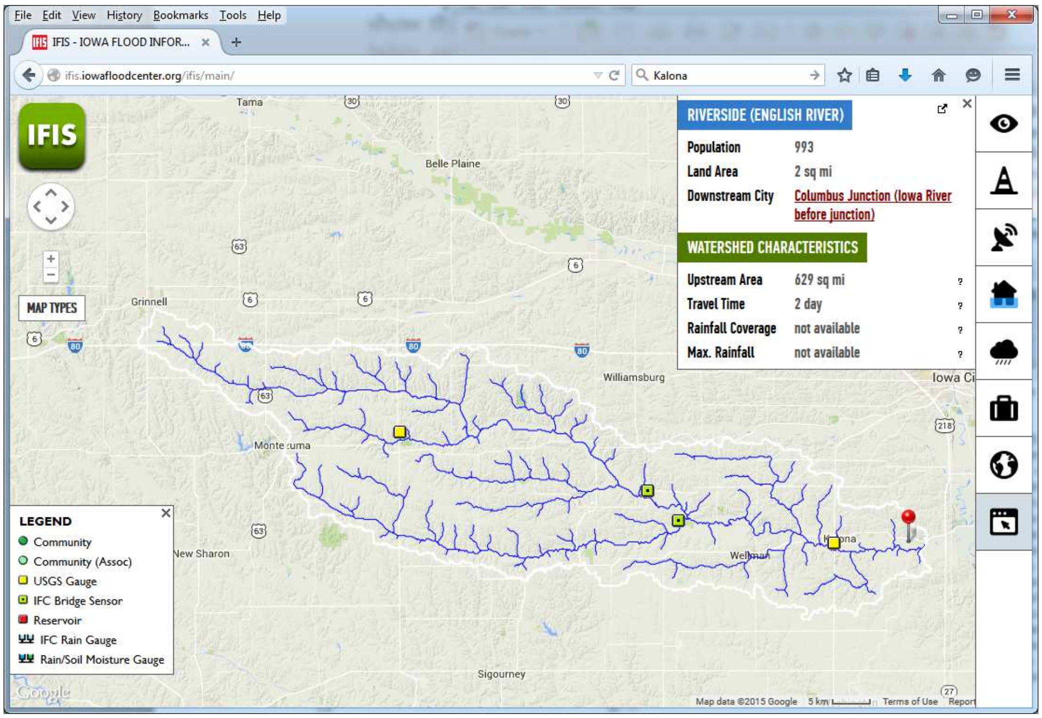

Figure 5.2: Existing river flow and stage monitoring stations in the English River watershed from the Iowa Flood Center's Iowa Flood Information System (IFIS) (`http://iowafloodcenter.org`).

English River watershed, should be pursued.

Bibliography

Bicknell, B., J. Imhoff, J. Kittle, Jr., T. Jobes, and A. Donigian, Jr., 2005: HSPF Version 12.2 User's Manual. AQUA TERRA Consultants, Mountain View, California, in cooperation with the Office of Surface Water, U.S. Geological Survey, Reston, Virginia, and the National Exposure Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia.

Burkart, M., 2010: The hydrologic footprint of annual crops, in *A Watershed Year: Anatomy of the Iowa Floods of 2008*, C. Mutel (editor), University of Iowa Press, Iowa City, Iowa, 78–85.

Donigian, A., Jr., D. Baker, D. Haith, and M. Walter, 1983: HSPF Parameter Adjustments to Evaluate the Effects of Agricultural Nest Management Practices. U.S. Environmental Protections Agency, Environmental Research Laboratory, Athens, Georgia, EPA Contract No. 68-03-2895, PB-83-247171.

Donigian, A., Jr., J. Imhoff, B. Bicknell, and J. Kittle, Jr., 1984: Application Guide for the Hydrological Simulation Program - FORTRA. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, EPA/600/3-84-066.

Duan, Q., S. Sorooshian, and V. Gupta, 1992: Effective and efficient global optimization for conceptual rainfall-runoff models. *Water Resources Research*, **28 (4)**, 1015–1031, doi:10.1029/91WR02985.

Frans, C., E. Istanbulluoglu, V. Mishra, F. Munoz-Arriola, and D. P. Lettenmaier, 2013: Are climatic or land cover changes the dominant cause of runoff trends in the Upper Mississippi River basin? *Geophysical Research Letters*, **40 (6)**, 1104–1110, doi:10.1002/grl.50262.

Holman-Dodds, J. K., A. A. Bradley, and K. W. Potter, 2003: Evaluation of hydrologic benefits of infiltration based urban storm water management1. *JAWRA Journal of the American Water Resources Association*, **39 (1)**, 205–215, doi:10.1111/j.1752-1688.2003.tb01572.x.

Iowa Soybean Association, 2014: English River Watershed: Water Quality Snapshots 2014. URL `http://www.englishriverwma.org/uploads/2/0/9/1/20912844/english_river_watershed_snapshot_report.pdf`.

Jones, C. S. and K. E. Schilling, 2011: From agricultural intensification to conservation: Sediment transport in the Raccoon River, Iowa, 19162009. *J. Environ. Qual.*, **40 (6)**, 1911–1923, doi:10.2134/jeq2010.0507.

Knox, J. C., 2001: Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. *CATENA*, **42 (24)**, 193–224, doi:http://dx.doi.org/10.1016/S0341-8162(00)00138-7.

Meierdiercks, K. L., J. A. Smith, M. L. Baeck, and A. J. Miller, 2010: Analyses of urban drainage network structure and its impact on hydrologic response. *JAWRA Journal of the American Water Resources Association*, **46 (5)**, 932–943, doi:10.1111/j.1752-1688.2010.00465.x.

Meja, A. I. and G. E. Moglen, 2010: Impact of the spatial distribution of imperviousness on the hydrologic response of an urbanizing basin. *Hydrological Processes*, **24 (23)**, 3359–3373, doi:10.1002/hyp.7755.

Mora, C., et al., 2013: The projected timing of climate departure from recent variability. *Nature*, **502 (7470)**, 183–187, doi:10.1038/nature12540.

Pimentel, D., 2012: *Biofuels causing malnutrition in the world*, 1–13. CRC Press, Taylor & Francis Group, Boca Raton, Florida.

Ryberg, K., W. Lin, and A. Vecchia, 2014: Impact of climate variability on runoff in the North-Central United States. *Journal of Hydrologic Engineering*, **19 (1)**, 148–158, doi:doi:10.1061/(ASCE)HE.1943-5584.0000775.

Schilling, K. E., K.-S. Chan, H. Liu, and Y.-K. Zhang, 2010: Quantifying the effect of land use land cover change on increasing discharge in the Upper Mississippi River. *Journal of Hydrology*, **387 (34)**, 343–345, doi:http://dx.doi.org/10.1016/j.jhydrol.2010.04.019.

Schilling, K. E., M. K. Jha, Y.-K. Zhang, P. W. Gassman, and C. F. Wolter, 2008: Impact of land use and land cover change on the water balance of a large agricultural watershed: Historical effects and future directions. *Water Resources Research*, **44 (7)**, W00A09, doi:10.1029/2007WR006644.

Schottler, S. P., J. Ulrich, P. Belmont, R. Moore, J. W. Lauer, D. R. Engstrom, and J. E. Almendinger, 2014: Twentieth century agricultural drainage creates more erosive rivers. *Hydrological Processes*, **28 (4)**, 1951–1961, doi: 10.1002/hyp.9738.

Shuttleworth, W., 1993: Evaporation, Chapter 4, *Handbook of Hydrology*, D.R. Maidment (editor), 4.1–4.53. McGraw-Hill, New York.

Takle, E., 2010: Was climate change involved?, in *A Watershed Year: Anatomy of the Iowa Floods of 2008*, C. Mutel (editor), University of Iowa Press, Iowa City, Iowa, 111–116.

Thompson, J., 2002: *Wetlands Drainage, River Modification, and Sectoral Conflict in the Lower Illinois Valley, 1890-1930*. Southern Illinois University Press.

Urban, M. A. and B. L. Rhoads, 2003: Catastrophic human-induced change in stream-channel planform and geometry in an agricultural watershed, Illinois, usa. *Annals of the Association of American Geographers*, **93 (4)**, 783–796, doi:10.1111/j.1467-8306.2003.09304001.x.

Villarini, G., J. A. Smith, M. L. Baeck, and W. F. Krajewski, 2011: Examining flood frequency distributions in the Midwest U.S. *JAWRA Journal of the American Water Resources Association*, **47 (3)**, 447–463, doi: 10.1111/j.1752-1688.2011.00540.x.

Vrugt, J. A., H. V. Gupta, L. A. Bastidas, W. Bouten, and S. Sorooshian, 2003: Effective and efficient algorithm for multiobjective optimization of hydrologic models. *Water Resources Research*, **39 (8)**, 1214, doi:10.1029/2002WR001746.

Wehmeyer, L. L., F. H. Weirich, and T. F. Cuffney, 2011: Effect of land cover change on runoff curve number estimation in Iowa, 18322001. *Ecohydrology*, **4 (2)**, 315–321, doi:10.1002/eco.162.

Winsor, R., 1975: Artificial drainage of East Central Illinois 1820-1920. Thesis.

Wu, Y., S. Liu, T. L. Sohl, and C. J. Young, 2013: Projecting the land cover change and its environmental impacts in the Cedar River basin in the Midwestern United States. *Environmental Research Letters*, **8 (2)**, 024 025, URL http://stacks.iop.org/1748-9326/8/i=2/a=024025.

Zhang, Y. K. and K. E. Schilling, 2006a: Effects of land cover on water table, soil moisture, evapotranspiration, and groundwater recharge: A field observation and analysis. *Journal of Hydrology*, **319 (14)**, 328–338, doi:http://dx.doi.org/10.1016/j.jhydrol.2005.06.044.

Zhang, Y. K. and K. E. Schilling, 2006b: Increasing streamflow and baseflow in Mississippi River since the 1940s: Effect of land use change. *Journal of Hydrology*, **324 (14)**, 412–422, doi:http://dx.doi.org/10.1016/j.jhydrol.2005.09.033.