Modeling of Conservation Practices on Two Priority HUC-12 Subwatersheds of the English River Watershed

by

Iowa Flood Center (IFC)

Sponsored by:

English River Watershed Management Authority

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Chapter 1

Introduction

1.1 The Iowa Watershed Approach

From 2011 to 2013, Iowa suffered eight Presidential Disaster Declarations encompassing 73 counties and more than 70% of the state. As devastating as these events were, this period is but a small portion of Iowas long history of enduring and recovering from major floods. Figure 1.1 shows just one example of devastation caused by the historic floods of 2008. Long-term data shows that heavy precipitation and flood events are increasing in frequency across the Midwest, and Iowans need to be prepared for the economic, social, and environmental impacts of these changing trends.

In January 2016, the state of Iowa received a $97 million award for the Iowa Watershed Approach (IWA). The grant was part of the U.S. Department of Housing and Urban Developments (HUD) National Disaster Resilience Competition, which funds cutting-edge projects to address unmet needs from past natural disasters and reduce Americans vulnerability to future disasters. The project will end in September 2021.

Figure 1.1: Flood waters of 2008 devastated the community of Coralville, IA

The Iowa Watershed Approach (IWA) program takes a holistic approach to address flooding at the watershed scale, recognizing that upstream and downstream communities need to voluntarily work together to increase community flood resilience. The IWA will accomplish six specific goals:

1. Reduce flood risk;
2. Improve water quality;
3. Increase community flood resilience;
4. Engage stakeholders through collaboration, outreach, and education;
5. Improve quality of life and health for Iowans, especially for vulnerable populations; and
6. Develop a program that is scalable and replicable throughout the Midwest and United States.

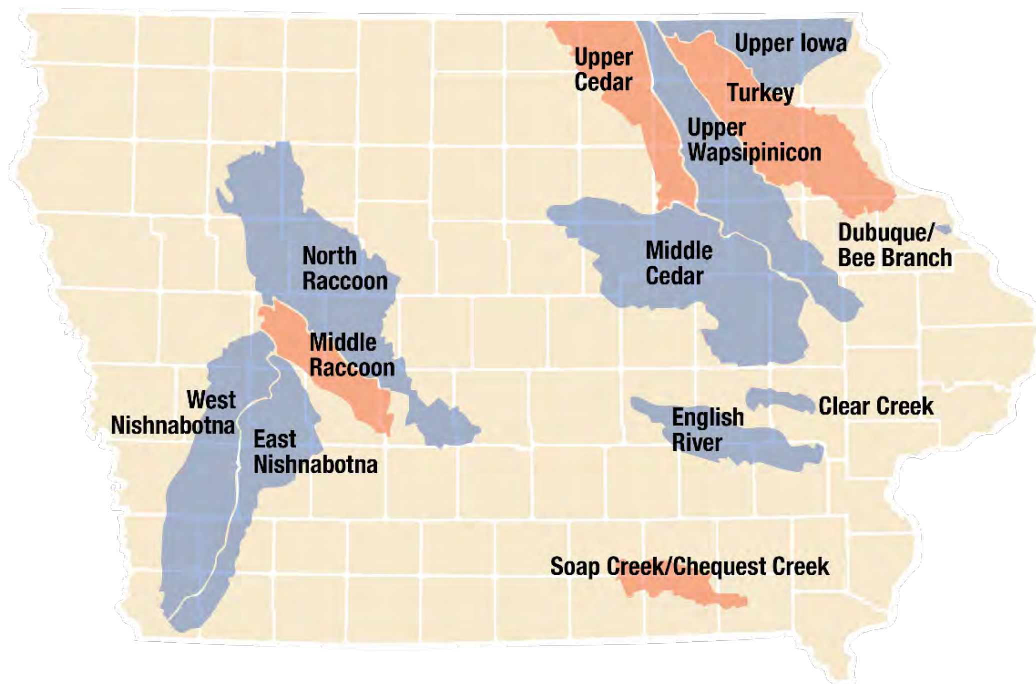

Figure 1.2: Current IWA watersheds in blue and completed IWP watershed in red.

The IWA brings Iowans together to address factors that contribute to floods. Nine distinct watersheds are involved in the project, including the Upper Iowa River, Upper Wapsipinicon River, Middle Cedar River, Clear Creek, English River, North Raccoon River, East Nishnabotna River, West Nishnabotna River, and Bee Branch Creek. In addition, urban projects in the cities of Dubuque, Coralville, and Storm Lake will focus on infrastructure improvements to mitigate flood risk (see Figure 1.2

Each watershed has formed a Watershed Management Authority (WMA) that brings local stakeholders together to prioritize their watershed improvement needs, share resources, and foster new partnerships and collaborations. IIHR–Hydroscience & Engineering (IIHR) and the Iowa Flood Center (IFC) are developing a hydrologic assessment of each watershed that will provide WMAs, local leaders, landowners, and residents with an understanding of the hydrology the movement of water within their watershed. This assessment will deliver valuable information to stakeholders to help guide strategic decision-making to efficiently address flooding and water-quality concerns.

Figure 1.3: Tour of a flood mitigation project in the Soap Creek Watershed, which was one of the basins that participated in the Iowa Watersheds Project (2010-16).

IIHR and IFC have developed this report for the English River Watershed. Information in this report will be integrated into a comprehensive watershed resiliency plan. The watershed resiliency plan will guide long-term watershed management initiatives and planning efforts, as well as identify goals and objectives to meet the current and future needs of local stakeholders and community members (see Figure 1.3.

WMAs in the IWA watersheds have identified eligible sub-watersheds (e.g., HUC 12s) for practice implementation efforts. This report will help guide the implementation of small-scale flood mitigation projects (see Figure 1.4. Through the IWA, volunteer landowners will be eligible to receive 90% cost-share assistance to implement best management practices (BMPs) such as ponds, wetlands, and water and sediment control basins (WASCOBS) to reduce the magnitude of downstream flooding and improve water quality during and after flood events. The implementation of BMPs is an essential step toward the long-term recovery to improve Iowas future flood resiliency.

Figure 1.4: Flood mitigation structure in the Soap Creek Watershed.

The success of the IWA depends on collaborative partnerships among many statewide organizations and local stakeholders who together will carry out the work necessary to achieve the goals of the IWA. Partnerships include, but are not limited to:

- U.S. Department of Housing and Urban Development (HUD)
- U.S. Army Corps of Engineers
- Iowa Silver Jackets Flood Risk Management Team
- Iowa Economic Development Authority
- Iowa Homeland Security and Emergency Management
- University of Iowa (IIHR–Hydroscience & Engineering, Iowa Flood Center, Center for Evaluation and Assessment)
- Iowa State University (Iowa Nutrient Research Center, Iowa Water Center, Daily Erosion Project, ISU Extension & Outreach)
- University of Northern Iowa (Tallgrass Prairie Center)
- Iowa Department of Natural Resources
- Iowa Department of Transportation
- Iowa Association of Counties
- Iowa Department of Agriculture and Land Stewardship

- Iowa Soybean Association
- Iowa Natural Heritage Foundation
- Iowa Corn Growers Association
- Iowa Farm Bureau
- Iowa Agricultural Water Alliance
- Cities of Dubuque, Coralville, and Storm Lake
- Local Resource Conservation and Development Offices
- Benton, Buena Vista, Fremont, Iowa, Johnson, Mills, Winneshiek, and Howard counties

1.2 The English River Watershed Study

The English River contains 639-square miles covering parts of six counties: Iowa, Johnson, Keokuk, Mahaska, Poweshiek, and Washington Counties. The English River WMA (ERWMA) formed in 2013 and proceeded to obtain an Iowa Department of Natural Resources (IDNR) grant to develop a watershed management plan. As part of the watershed management plan, the IFC was enlisted to create a hydrologic assessment (*Iowa Flood Center*, 2015). The model for the hydrologic assessment was created in 2015 by the IFC using the Hydrological Simulation Program — FORTRAN (HSPF) Version 12.2 (*Bicknell et al.*, 2001). HSPF is a software developed by the Environmental Protection Agency (EPA) that allows for long-term, continuous hydrologic simulations. A 64-year period was used for the simulation of English River hydrology and water quality (*Iowa Flood Center*, 2015).

To meet the goals of the IWA, local WMAs will design and build different conservation practices, known also as best management practices (BMP), to reduce flooding and improve water quality. It is also necessary to quantify the cumulative effects of practices on the watershed scale. Each conservation practice will affect water quantity and water quality differently. As such, it is necessary to know what types and how many conservation practices are needed to achieve the desired results. Using the existing model for the English River watershed, we have enhanced its resolution to simulate conservation practices at a finer scale. Findings from the new English River model are used quantify the benefits from built practices and their cumulative effects. Leveraging the existing model in this way will aid in planning for projects that will benefit all the IWA watersheds.

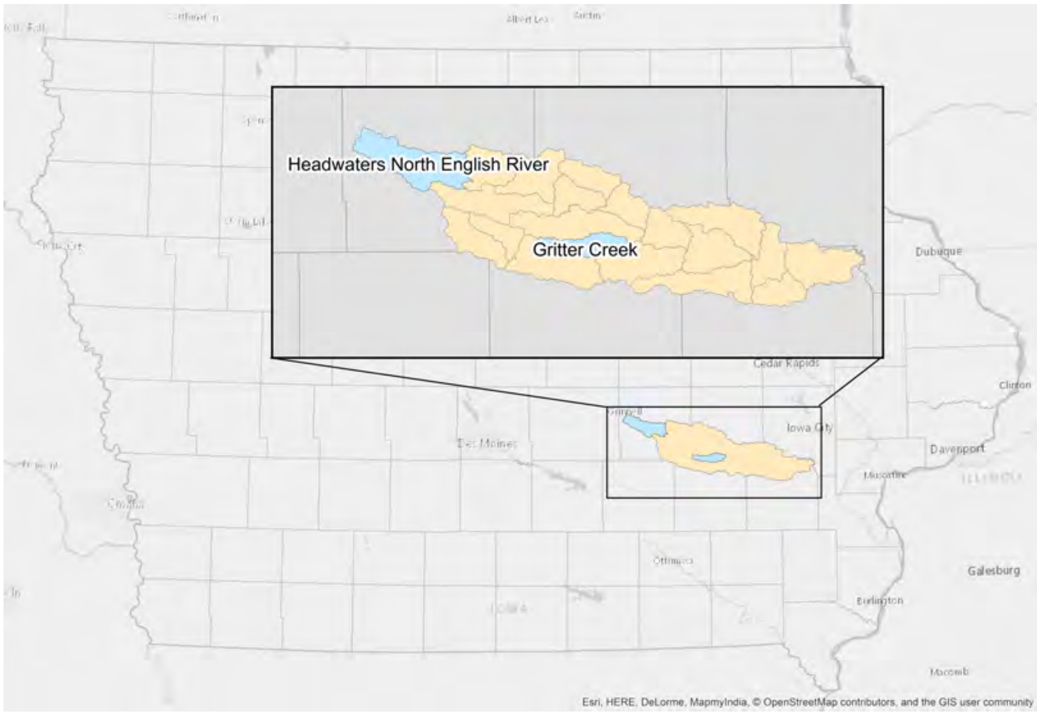

Figure 1.5: HUC-12 Watersheds Locations. Headwaters North English River and Gritter Creek are the two selected HUC-12 watersheds that will be modeled using the existing English River HSPF model with an enhanced resolution.

The focus of this report is on incorporating two conservation practices in the existing HSPF model for the English River for two U.S. Geological Survey (USGS) 12-digit hydrologic unit code (HUC) subwatersheds (HUC-12s). The two HUC-12 subwatersheds are Headwaters North English River (HUC 070802090401) and Gritter Creek (HUC 070802090301) (see Figure 1.5). The resolution of the existing model will be enhanced tremendously from 103 subbasins for the entire English River to several hundred subbasins within each selected HUC-12 subwatershed. Scenarios of potential conservation practice implementation will be run to determine effects of different amounts of implementation.

There are already many conservation practices in these HUC-12 watersheds. A current project at Iowa State, the Iowa BMP Mapping Project seeks to locate them (*Iowa BMP Mapping Project*, 2018). The potential sites of certain conservation practices can be also be identified using the recently developed geographical information system (GIS) based tool the Agricultural Conservation Planning Framework (ACPF) (*Tomer et al.*, 2013, 2015a,b). Another goal will be comparing the results from the IBMP and ACPF. The method used provides a process for direct comparison of three conservation practices between the datasets that contain structural differences. Investigating the differences between current conditions and potential conditions helps see what conservation Iowa is doing well and where there are areas for improvement.

Chapter 2

Watershed Description and Hydrology

2.1 Introduction

The landscape of Iowa has changed dramatically since the start of widespread intensive agriculture cultivation. The cultivation has decreased the coverage of original prairies and replaced it with row crops, largely. Iowa's land used to be 80% grasslands during the mid-1800s but now grasslands make up only 5% of the land area (*Gallant et al.*, 2011). As grasslands have decreased row crops have been increasing to the current condition where row crops cover 78% of the state (*Homer et al.*, 2004). Changes in land cover correlate with a change in available storage for water and a change in infiltration rates. The use of farm equipment compacts soils and reduces infiltration along with corn and soybean having much lower infiltration values than switchgrass, a native Iowa plant (*Radke and Berry*, 1993; *Bharati et al.*, 2002).

Adding to the decreased storage, the row cropping results in significant increases in erosion (*Mannering and Johnson*, 1969). Erosion is an issue for farmers as they lose fertile soils and an issue for the environment as the soils are conveyed to rivers. The erosion generated sediments also transport phosphorous from fertilizer into streams via overland flow (*McDowell et al.*, 2001). While phosphorous comes from overland flow, nitrogen is primarily delivered to rivers with subsurface drainage and base flow (*Schilling and Zhang*, 2004). There is also a trend of increasing base flow in Iowa and nitrate concentrations across the state that can be attributed to the increase of agriculture in Iowa (*Schilling and Libra*, 2003; *Li et al.*, 2013; *Schilling*, 2005).

While the English River does not show statistically significant shifts in either the annual average discharge or annual maximum peak discharge, across Iowa there are many watersheds showing statistically significant trends (*Iowa Flood Center*, 2015; *Mallakpour and Villarini*, 2015). Additionally within the state there is an increase in annual average discharge and annual maximum peak discharge variability since 1970 that the English River does exhibit. Water quality observations of the English River are very limited in temporal resolution and are difficult to draw conclusions from. The Iowa Soybean Assocation performed synoptic sampling three times in 2014: April 28th, July 17th, and October 21st (*Iowa Soybean Assocation*, 2014). The water quality component of the the English River model quality was able to make a preliminary investigation of nitrogen and compare the results to ISA's samples. It shows that the HSPF model can capture the spatial variations of nitrogen but no conclusions about long term nitrogen levels can be made.

Chapter 2 is an overview of the English River, including Headwaters North English River and Gritter Creek, both in a physical sense and a hydrologic one. Included in the chapter is information about the land use, soils, water cycle, and hydrologic alterations.

2.2 Land Use

Headwaters North English River is located within Poweshiek County. It has an area of 56.3 square miles and the landscape is dominated by row crops: 74% of the land use is corn and soybeans, 15% is grass and pasture, 7% urban, and 1% deciduous forest (*Iowa Soybean Assocation*, 2013).

Gritter Creek has an area of 23.0 square miles and is located within Iowa and Keokuk Counties. Less of the land is cultivated with corn and soybeans than Headwaters North English River at 42%. Grass and pasture take up a much larger portion, 39%, and the remaining land cover is 8% urban, 11% forest, and 1% wetlands. Figure 2.1 shows the land use for both HUC-12 subwatersheds.

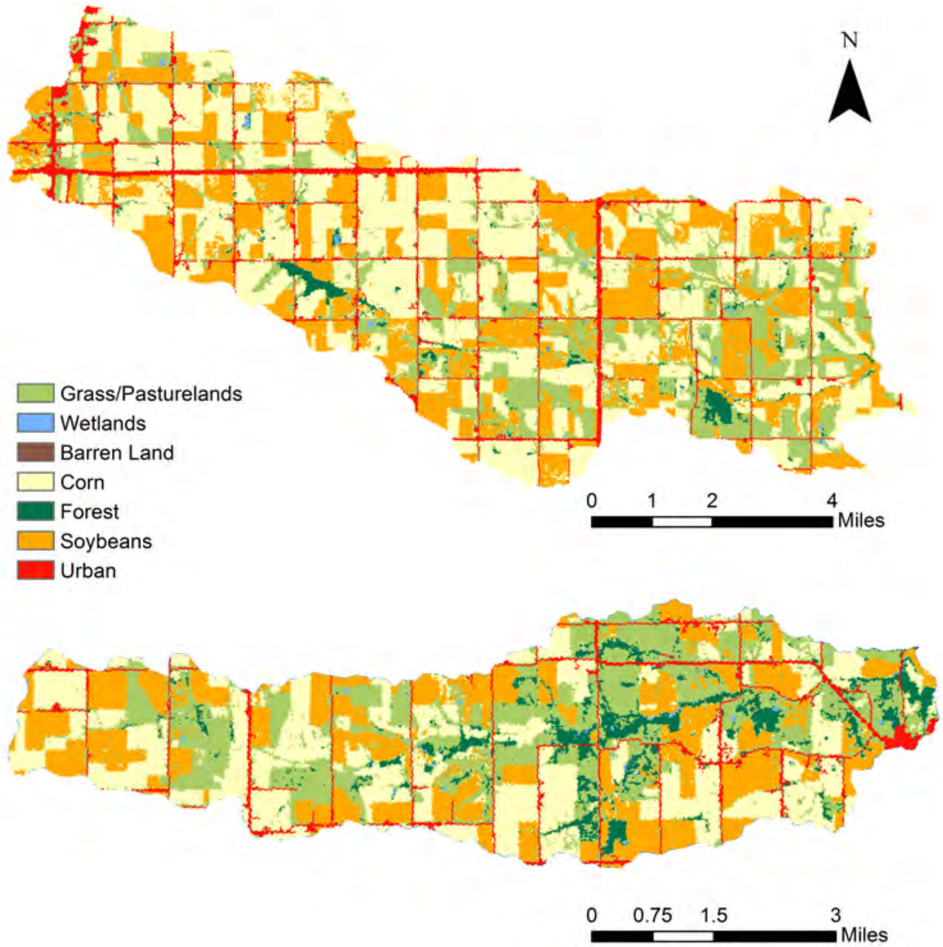

Figure 2.1: Land use of Headwaters North English River (top) and Gritter Creek (bottom). Land use data compiled by the Iowa Soybean Association showing the largest land use in both watersheds is row crops, soybeans are shown in orange and corn in yellow.

2.3 Soils

The soils of a watershed have an impact on the runoff potential of the landscape. One way soils can be categorized is by hydrologic soil group (HSG). HSG classifies soils based on the runoff potential under the thoroughly wet condition. Sand or gravel are much more prevalent in low runoff potential soils due to their higher hydraulic conductivity (*National Resources Conservation Service*, 2007a). Clay meanwhile is much more prevalent in high runoff soils as it has a lower hydraulic conductivity.

The HSGs of Headwaters North English River and Gritter Creek are shown in Figure 2.2. Headwaters North English River is 72.9% covered in HSG B soils, 12.0% in B/D soils, and 11.9% C soils. Gritter Creek is mainly HSG B with 63.3% followed by 21.7% C, and 11.4% B/D. The other HSG are all below 2%. The complete soil distribution is shown in Table 2.1.

Table 2.1: Hydrologic Soil Group Composition. HSG for Headwaters North English River and Gritter Creek by percentage.

Hydrologic Soil Group	Headwaters North English River %	Gritter Creek %
A	0.20	0.03
A/D	0.00	0.00
B	73.18	63.43
B/D	12.06	11.47
C	11.97	21.71
C/D	0.95	1.33
D	1.63	2.03

2.4 Hydrology

2.4.1 Annual Water Cycle

Iowa has average annual rainfall ranging from 40 inches to 26 inches. The wettest area is the southeast corner with precipitation decreasing moving to the northeast corner of the state. The average annual rainfall in the English River is 36.5 inches for the 30-year period between 1981 and 2010 (*Iowa Flood Center*, 2015).

The rainfall is partitioned into either evaporation or streamflow. Following the trend for all of Iowa, most of the rain that falls in the English River is evaporated, including direct evaporation from bodies of water exposed to the air or transpirated by plants and crops. Evaporation accounts for 69% of the precipitation. The remainder of the precipitation turns into streamflow

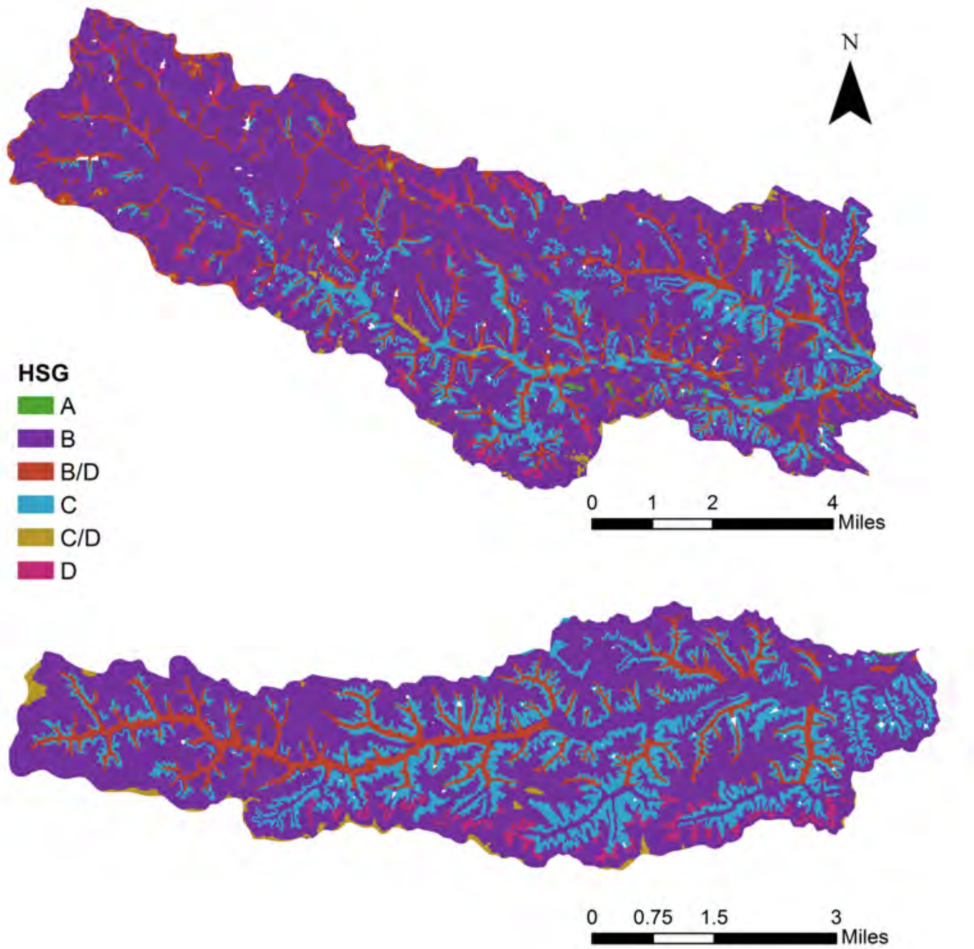

Figure 2.2: HSG of Headwaters North English River (top) and Gritter Creek (bottom). HSG B soils are the largest portion of both watersheds at 72.9% and 63.3%, respectively.

through two paths, surface flow and baseflow. Surface flow occurs as rain falls and travels on the land surface to streams. Baseflow is a slower process that entails the precipitation moving to the groundwater via infiltration and percolation. The groundwater then contributes to streamflow and is called baseflow. English River precipitation is divided into about 14% surface flow and 17% baseflow (*Iowa Flood Center*, 2015). The annual water cycle is shown in Table 2.2.

Table 2.2: English River Annual Water Cycle. The annual water cycle for the English River as a depth (inches) and as a percentage of precipitation (%) (*Iowa Flood Center*, 2015).

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

The simulated average monthly runoff for the 64-year period (Figure 2.3) of record using the original model shows significant seasonal variation with the largest runoff occurring from March through its peak June. The largest difference between the two watersheds also occurs in those months.

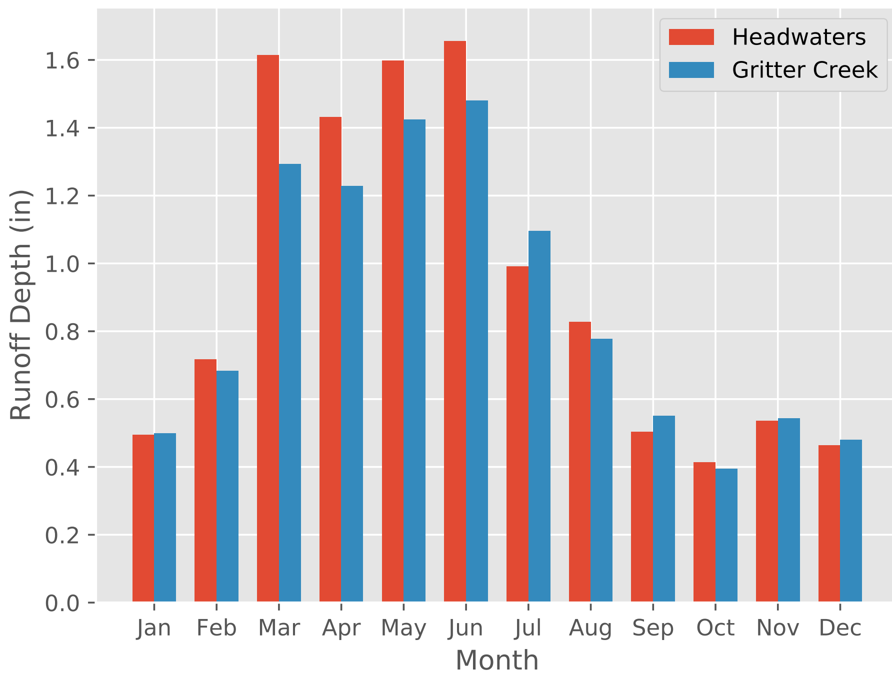

Figure 2.3: Original Model Monthly Runoff. Simulated average monthly runoff depth for the period of record (1949 to 2012) for Headwaters North English River and Gritter Creek.

2.4.2 Hydrologic Alterations

Across Iowa long-term shifts in river flows have occurred (*Villarini et al.*, 2011). The English River gage at Kalona (United States Geological Survey (USGS) 05455500) shows similar shifts, but the changes are not statistically significant over the period from 1940 to 2014. Figures 2.4 and 2.4 shows the annual average discharge and annual maximum peak discharge at Kalona for the 75 year period. It is clear from the figures that the largest discharge have been in the more recent half of the period with an increase of variability as well. Other watersheds in Iowa do show a statistically significant change in annual discharge (*Iowa Flood Center*, 2015).

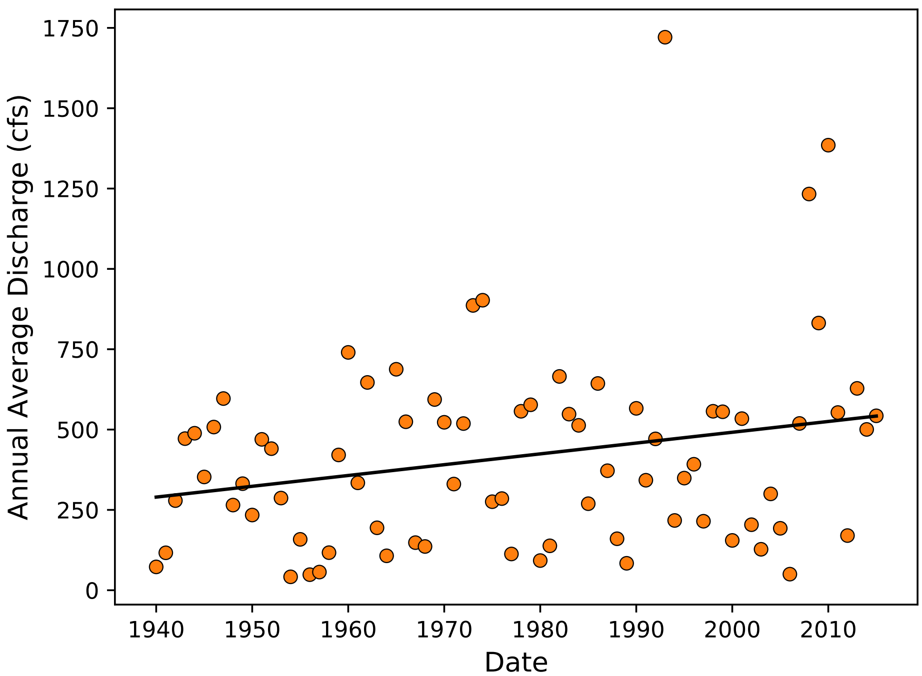

Figure 2.4: English River at Kalona Annual Average Discharge. Results are shown for the period from 1940 to 2014.

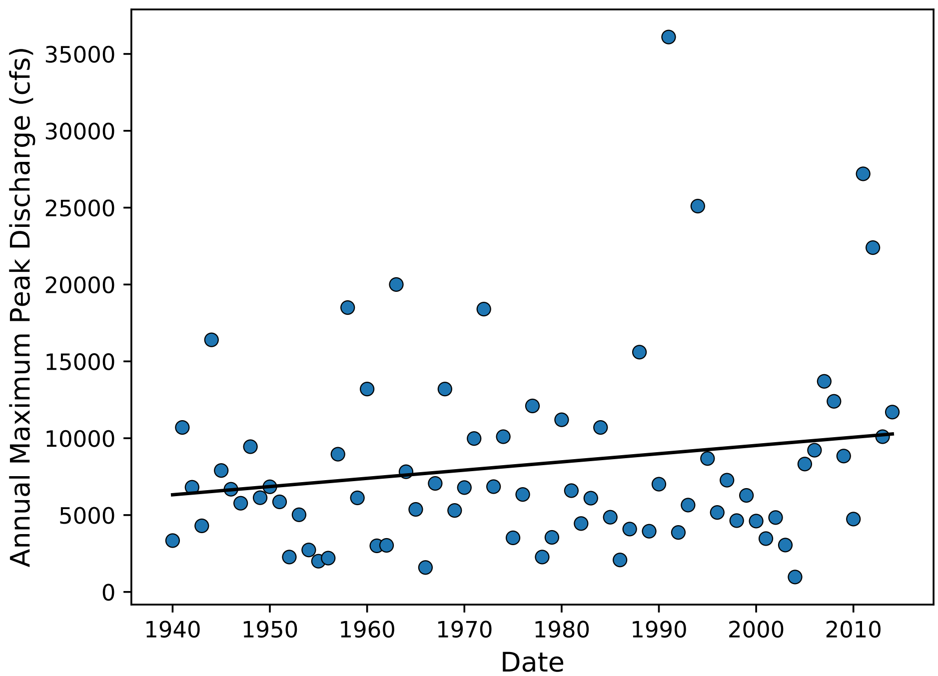

Figure 2.5: English River at Kalona Annual Maximum Peak Discharge. Results are shown for the period from 1940 to 2014.

2.5 Summary

This chapter covered the basic physical and hydrologic characteristics of the English River as a whole, and the HUC-12 subwatersheds of Headwaters North English River and Gritter Creek. Headwaters North English River's land use is dominated by row crops, which take up over 70% of the land use. Gritter Creek has a larger grass and pasture component with the land used for row crops and grass and pasture both about 40%. Both HUC-12 watersheds show moderately low runoff potential with HSG B soils covering over 60% of each watershed. The English River averages 36.5 inches of rainfall a year with the majority, 69%, of that evaporating. The remaining 31% is split into 14% surface flow and 17% baseflow with the largest runoff occurring from March to June. The English River shows increased varability in annual average discharge and annual maximum peak discharge, but the change is not statistically significant.

Chapter 3

Existing and Potential Conservation Practice Inventory, Selection, and Comparison

3.1 Introduction

Investigators have attempted to quantify the effects of conservation practices on runoff volumes, nutrient loss, and soil erosion through both hydrologic modeling and smaller field scale experiments. There have been hydrologic modeling studies based in Iowa for many years. *Donigian et al.* (1983) performed a qualitative study on how HSPF model parameters would be affected by conservation practices. A large scale study, with very coarse resolution, to model conservation practices over the Iowa River basin by *Bicknell et al.* (1985) followed. *Bicknell et al.* (1985) showed a 7% runoff reduction from the implementation of conservation tillage. The resolution and complexity of the models has increased since then.

Ponds and wetlands are one of the clearest examples of efforts to mitigate floods, the ponds and wetlands store excess water, regulating its release and in turn, reducing the peak discharge. They are also the most straightforward to place into models due to the stage-storage-discharge relationships for each structure. One such hydrologic model study showed a large number (144) of widely distributed small dams in a watershed of 660 square kilometers in Iowa showed a peak discharge reduction of 20 to 70% over a range of drainage areas (*Ayalew et al.*, 2017). A similar study performed by *Thomas et al.* (2016) using HydroGeosphere investigated the effects of nine retention basins on a considerably smaller basin of 45 square kilometers and saw peak flow reductions of 3 to 17%. *Babbar-Sebens et al.* (2013) specifically modeled wetlands using the Soil and Water Assessment Tool 2005 and showed peak reductions of up to 14.6%.

Grassed waterways are a common conservation practice as they help reduce soil erosion for the farmer while minimizing land that has to be taken out of rotation. The aim of grassed waterways is to receive overland flow from adjacent fields and convey the water out of the field while slowing it down with sod-forming grasses. While ponds are straightforward to include in models, grassed waterways present much more of a challenge and are usually encompassed in a roughness parameter. Due to this, a number of field and lab experiments are performed to gain specific reduction benefits. There is a wide range of outcomes for the different experiments. Lab experiments have shown reductions in flows of 47% and a large grassed waterway of 600 meters by 10 meters reduced total runoff volume 5% from an 84 acre basin (*Briggs et al.*, 1999; *Hjelmfelt and Wang*, 1997) An interesting study by *Dermisis et al.* (2010) used the Water Erosion Prediction Project model to evaluate grassed waterways for a small southeastern Iowa watershed. Their work showed runoff volume reductions of up to about 45% and an average of about 20% with a 600 meter long grassed waterway. They compared their results with *Hjelmfelt and Wang* (1997) and showed over triple the average volume reduction.

Another type of conservation practice is the water and sediment control basin (WASCOB). There are few published results studying the effects of WASCOBs, especially widespread implementation. One study, *Mielke* (1985) studied WASCOB implementation in Nebraska. The WASCOBs showed some flow reduction but the main benefit of the structures was potential for sediment-trapping of 97-99%.

Not knowing what conservation practices are already on Iowa's farm fields is a large impediment to watershed planning and achieving the goals of the IWA. Tracking conservation is traditionally done by tabulating the money spent in different areas (*Pavelis et al.*, 2011; *Feng et al.*, 2006). A more accurate alternative would be to track, for example, the miles of terraces or the area of contour buffer strips on the landscape. Another unanswered question is the potential for conservation. Until recently, the potential of conservation practices that can be placed in a watershed has been unquantifiable. In addition, there has been no way to determine what amount of potential implementation would meet specific goals. To meet these ends, two projects were conceived. The first is the Iowa BMP Mapping Project (IBMP) and the second is the Agricultural Conservation Planning Framework (ACPF) (*Tomer et al.*, 2013, 2015a,b). The IBMP is a statewide inventory of existing conservation practices while ACPF provides locations for potential conservation practices.

One goal of this work was to compare the results of the IBMP and ACPF. Comparing the results from the IBMP and ACPF shows which practices are widely utilized and which practices are lacking, and can inform the English River WMA's decisions to allocate resources on conservation practices. The three conservation practices chosen for comparison were nutrient removal wetlands and ponds, WASCOBs, and grassed waterways. Through a framework we developed, the results from the three conservation practices were directly compared for the IBMP and ACPF (*Rundhaug et al.*, 2018).

3.2 Iowa BMP Mapping Project

The Iowa BMP Mapping Project started in 2015 at Iowa State University's GIS Facility with the goal of providing a baseline measure of existing BMPs in Iowa for the period 2007-2010. Six different BMPs are being digitized: terraces, grassed waterways, WASCOBs, pond dams, contour strip cropping, and contour buffer strips. The BMPs are being inventoried at HUC-12 watershed level. To digitize the BMPs, LiDAR is being used along with comparisons between color-infrared (CIR) aerial photography from 2007-2010, historical photos, and National Agriculture Imagery Program (NAIP) photography.

The IBMP provides digitized inventories for each HUC-12 watershed in the form of GIS geodatabases. Each geodatabase can be downloaded from the Iowa State University GIS Facility's website. The geodatabases contain three polygon shapefiles and three line shapefiles. The polygons are contour buffer strips, grassed waterways, and contour strip cropping while pond dams, terraces, and WASCOBs are lines.

3.3 Agricultural Conservation Planning Framework

The ACPF is a GIS-based toolbox that sites potential conservation practices on the landscape. The toolbox was developed by the United States Department of Agriculture (USDA)/Agricultural Research Service (ARS) National Laboratory for Agriculture and the Environment in Ames, Iowa. Its goal is to provide assistance in improving the management of agricultural quality. Identification of conservation practices for in field and edge of field applications are included. Altogether there are eight conservation practices sited including grassed waterways, contour buffer strips, nutrient removal wetlands, and WASCOBs to name several examples. The toolbox sites practices that can be placed within and below fields to "reduce, trap, and treat hydrologic flows" (*Porter et al.*, 2017). Much of the Corn Belt has been included in the tool with data available for Iowa, Illinois, southern Minnesota, eastern Kansas, and northern Indiana. ACPF also works on 12-digit HUC watersheds.

To run ACPF requires running a series of scripts within the toolbox with user inputs at several crucial points in the process. The first set consists of standard GIS hydrology tools to create flow direction, flow accumulation, and hillshade rasters. Then the user must define an area threshold for the stream network definition. Creating a river network using a high resolution digital elevation model (DEM) causes water to back up behind culverts, roads, and other man-made structures. Using a water depth raster these ponded areas can be located and then manually "cut" through so that water can flow in the model as it does in real life. This process is known as hydro-enforcing the DEM. Figure 3.1 shows two examples of locations where hydro-enforcing is necessary. After the user draws the cut lines the corrected stream network is regenerated. This step is a vitally important component of accurately representing the real world conditions and, in turn, accurately siting conservation practices.

Next the user must use aerial photography to identify and label the perennial streams of the stream network. The perennial streams are used later in the process to limit the siting of conservation practices. The rest of the process includes running the remaining tools in sequence. There are a number of parameters that can be specified for practice spacing and other characteristics but ACPF provides suggested defaults that were used throughout this study.

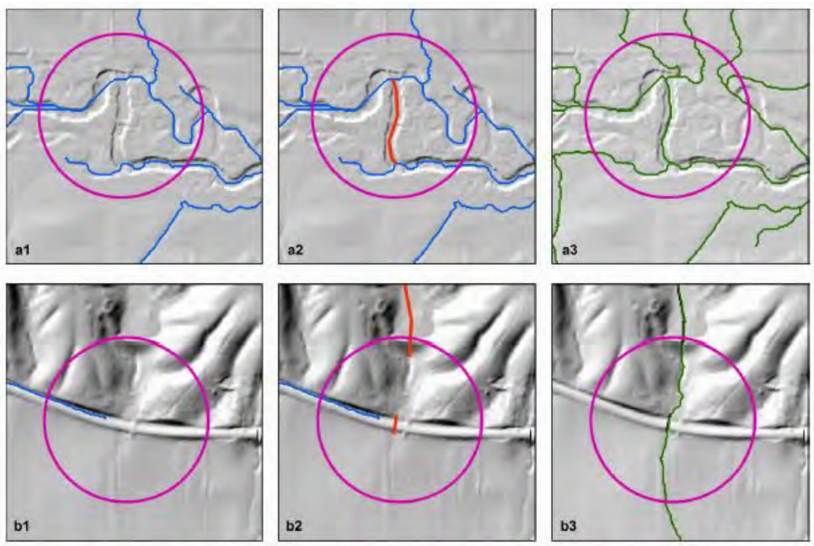

Figure 3.1: ACPF Example of Hydro Enforcing. Two examples of locations where there needs to be a cut drawn into the DEM so the water can flow correctly (*Porter et al.*, 2017). The first column identifies two locations the stream (in blue) should be, the second column shows the cut lines (in red), and the final column shows the new, corrected stream network.

3.4 Conservation Practice Selection

A goal of this study is to compare conservation practices from the IBMP and ACPF. There are differences between the two outputs that do not allow for a direct comparison though. For example, ACPF sites grassed waterways on the ACPF-defined stream network as a line while the IBMP locates grassed waterways as polygons that may not intersect the stream. In other cases the conservation practices are not shared between the two projects so it is not feasible to compare all the conservation practices from each project. Therefore three conservation practices were chosen that are part of both projects to develop a method for direct comparison: nutrient removal wetlands and ponds, WASCOBs, and grassed waterways.

3.4.1 Nutrient Removal Wetlands and Ponds

Following Iowas Conservation Reserve Enhancement Program (CREP) framework, ACPF identifies potential locations of a specific impoundment type, nutrient removal wetlands (NRWs). The tool finds locations for NRCS code 656 Constructed Wetlands and NRCS code 658 Wetland Creation (*Porter et al.*, 2017). NRWs are a specific type of pond. Their main purpose is providing off-site storage for runoff and tile drainage water. When storing the tile drainage water, the wetlands also reduce the nitrate content. The NRW siting tool was run using the default parameters recommended of 0.9 meter above the measured top of bank for impoundment height, 1.5 meters above the pooled height for buffer height, and 250 meter minimum spacing between NRWs. The NRWs have a minimum drainage area of 150 acres. The sited ACPF nutrient removal wetlands are shown in Figure 3.2.

The IBMP only identifies pond dams, not ponds. The type and purpose of each pond is not known and likely includes a wide range from small livestock watering ponds to larger flood storage ponds. While ACPF sites only a specific type of pond that may be on the landscape, the comparison is still useful to determine what types of ponds do exist on the landscape and what their purposes are. Due to only being able to locate pond dams, the IBMP results do not include any characteristics (pooled area, drainage area, etc.) of the ponds.

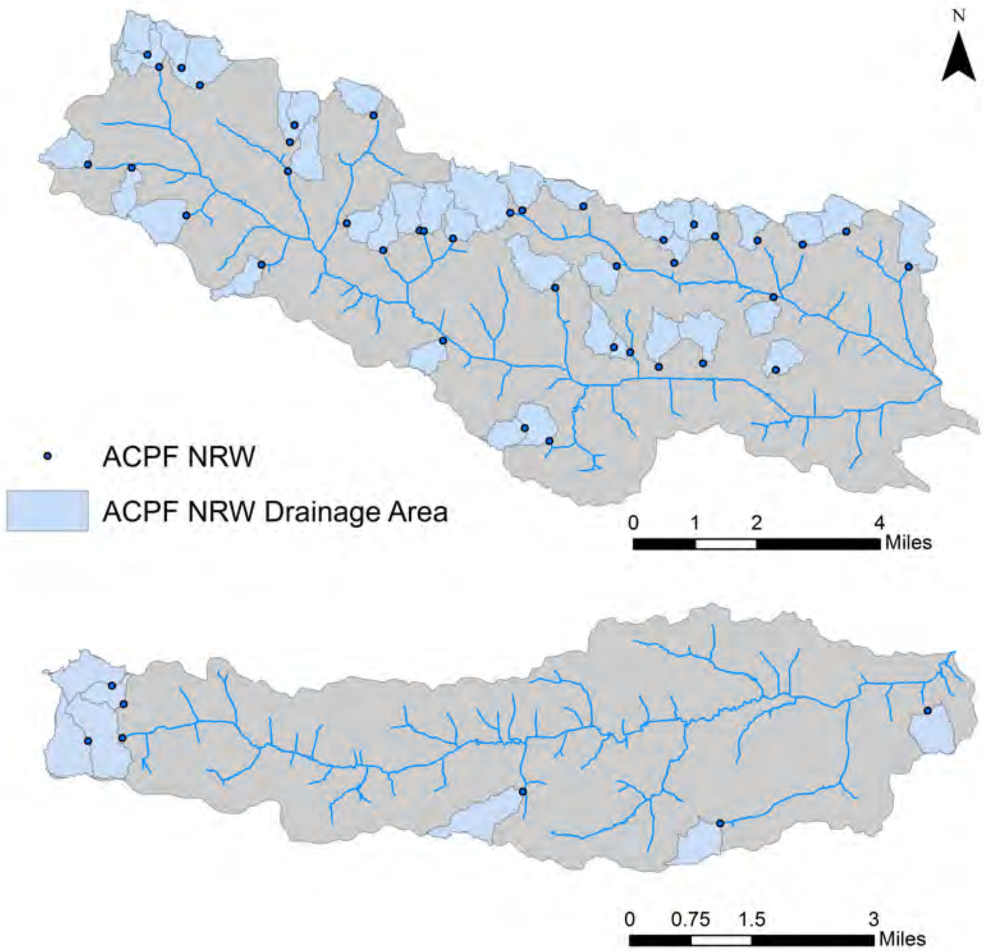

Figure 3.2: ACPF Sited Nutrient Removal Wetlands. ACPF Sited 39 nutrient removal wetlands in Headwaters North English River (top) and 7 in Gritter Creek (bottom).

3.4.2 WASCOB

Water and sediment control basins are earthen berms that cause water to pool behind them. They are constructed perpendicular to flow paths in fields to slow down water, reduce peak discharges, and reduce sediment loads into the streams. ACPF constructs 100 meter WASCOBs across the flow path with drainage areas of between 2 and 50 acres. Again, the recommended impoundment height of 1.5 meters was used for the WASCOBs. Figure 3.3 shows the sited ACPF WASCOBs for each watershed. WASCOBs are identified in a similar manner as pond dams by the IBMP. The berms do not contain a permanent pool like ponds. No characteristics besides length of the berm are reported in the IBMP.

3.4.3 Grassed Waterways

Grassed waterways convey runoff from agricultural fields and prevent gully erosion along the flow paths. There are water quality and water quantity benefits with reduced nutrient loads and reduced runoff volumes. Grassed waterways are a popular conservation practices due to being low cost and appropriate for areas that farmers would have problems farming normally due to gully erosion (*Chow et al.*, 1999). ACPF uses the stream power index (SPI), a metric of the erosive capacity of flowing water, to place grassed waterways. The SPI takes into account the slope gradient and specific catchment area. The default SPI threshold of three standard deviations above the mean was selected. An example of the ACPF sited grassed waterways is shown in Figure 3.4. IBMP grassed waterways are located using a polygon drawn encompassing the grassed waterway area. The IBMP therefore provides an area of grassed waterways for each HUC-12 watershed.

3.5 Existing and Potential Conservation Practice Comparison

3.5.1 Methodology

To be able to compare the practices identified by ACPF and IBMP, direct comparison methods had to be devised for the three conservation practices. The NRWs and ponds and WASCOBs used the line segment of each feature

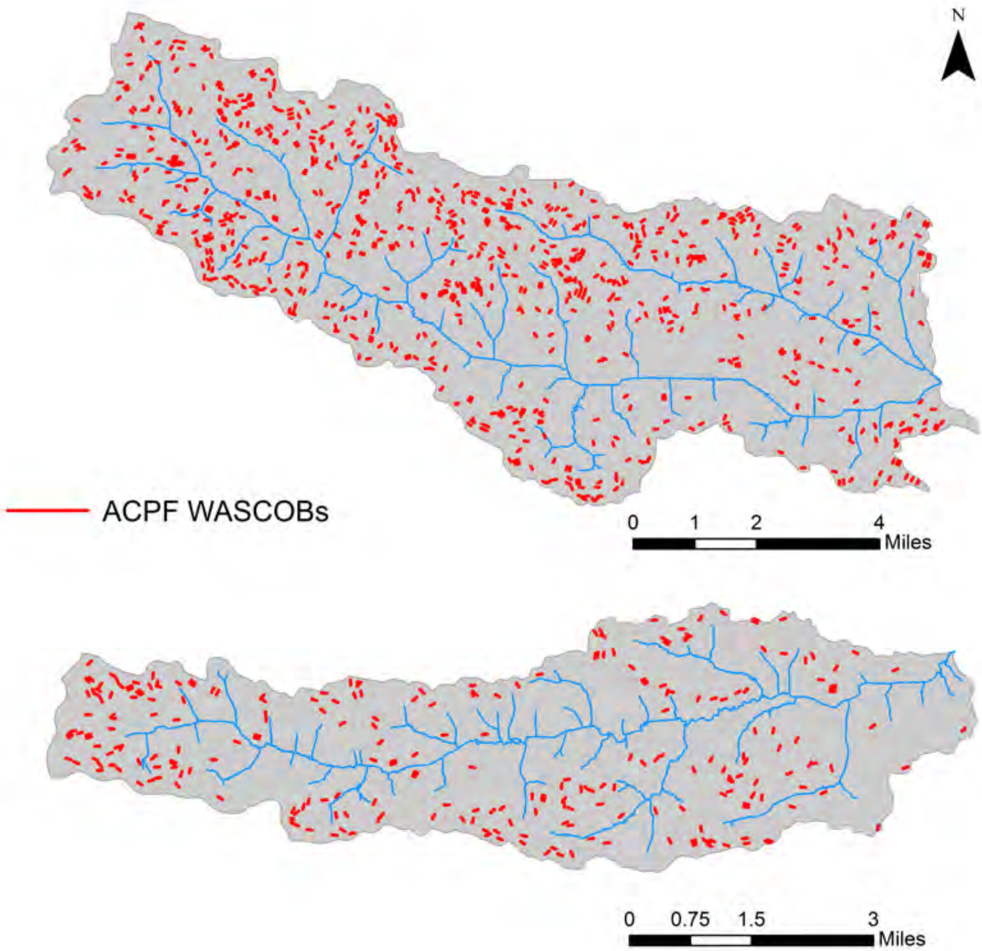

Figure 3.3: ACPF sited WASCOBs. ACPF sited 826 WASCOBs in Headwaters North English River (top) and 255 WASCOBs in Gritter Creek (bottom).

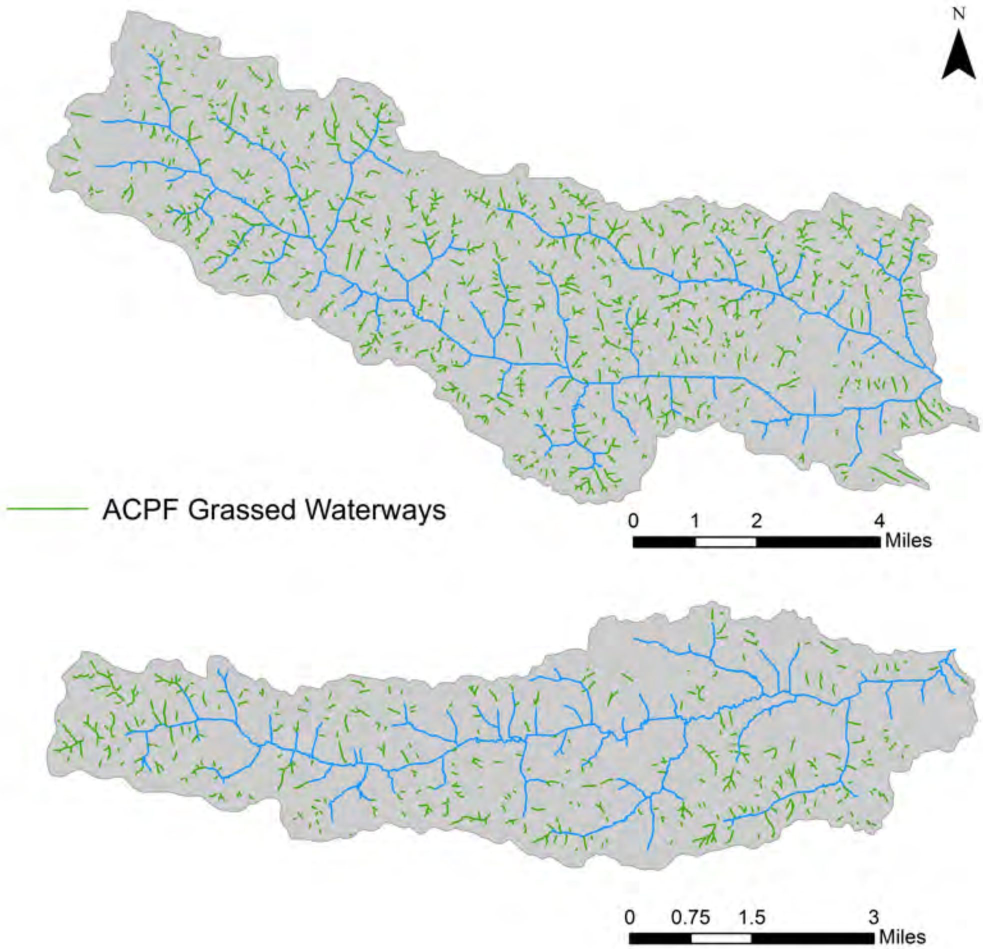

Figure 3.4: ACPF Sited Grassed Waterways. ACPF sited 99 miles of grassed waterways in Headwaters North English River (top) and 35 miles of grassed waterways in Gritter Creek (bottom).

to locate the maximum flow accumulation from the flow accumulation raster giving the number of cells contributing flow. The number of cells was then converted into a drainage area using the 2D resolution of the DEM cells.

For grassed waterways, to solve the problem of comparing different geometries, polygons and lines, the outputs were mapped onto a five acre flow accumulation threshold stream network. The length of each grassed waterway that was mapped onto the stream is designated as the "stream network length". Due to the manual nature of IBMP delineation, and the algorithm from ACPF, there were small spatial discrepancies between the stream and grassed waterways throughout the watersheds. In other words, there were grassed waterways that were not being included in the stream network length that should be. To fix this issue, a reasonable buffer was applied to both grassed waterway outputs. The buffer for the IBMP was chosen based on an iterative process comparing what was most reasonable and accurately reflected the landscape. A buffer of 5 meters, shown in Figure 3.5, captured the differences of the IBMP polygons and the stream network without capturing erroneous streams.

The width for ACPF grassed waterways entailed designing grassed waterways for each ACPF location. The design was based on the USDA-NRCS Code 412 Grassed Waterways (*National Resources Conservation Service*, 2014). Sizing the grassed waterway met the peak flow of a 10 year, 24 hour storm based on the National Oceanic and Atmospheric Administration Atlas 14 precipitation and a Soil Conservation Service (SCS) unit hydrograph (*Rundhaug*, 2018).

The process yielded a top width for the grassed waterway that was used as the ACPF buffer. After the buffers were applied, the grassed waterways were intersected with the stream to give lengths of grassed waterways. An additional benefit of designing grassed waterways from ACPF results was the new polygons could be used for areal comparisons between IBMP and ACPF.

One metric used to compare the conservation practices was their distribution based on the size of stream. Typically in hydrology the Strahler stream order is used to define stream size (*Strahler*, 1957). Strahler stream order is often used to refer to only perennial streams and many of the stream segments in this analysis are intermittent or ephemeral. In order to differentiate from the Strahler stream order the term flow path order is used for the analysis. Flow path order uses the same convention of Strahler numbering but begins at the defined 5 acre stream threshold, instead of the first perennial

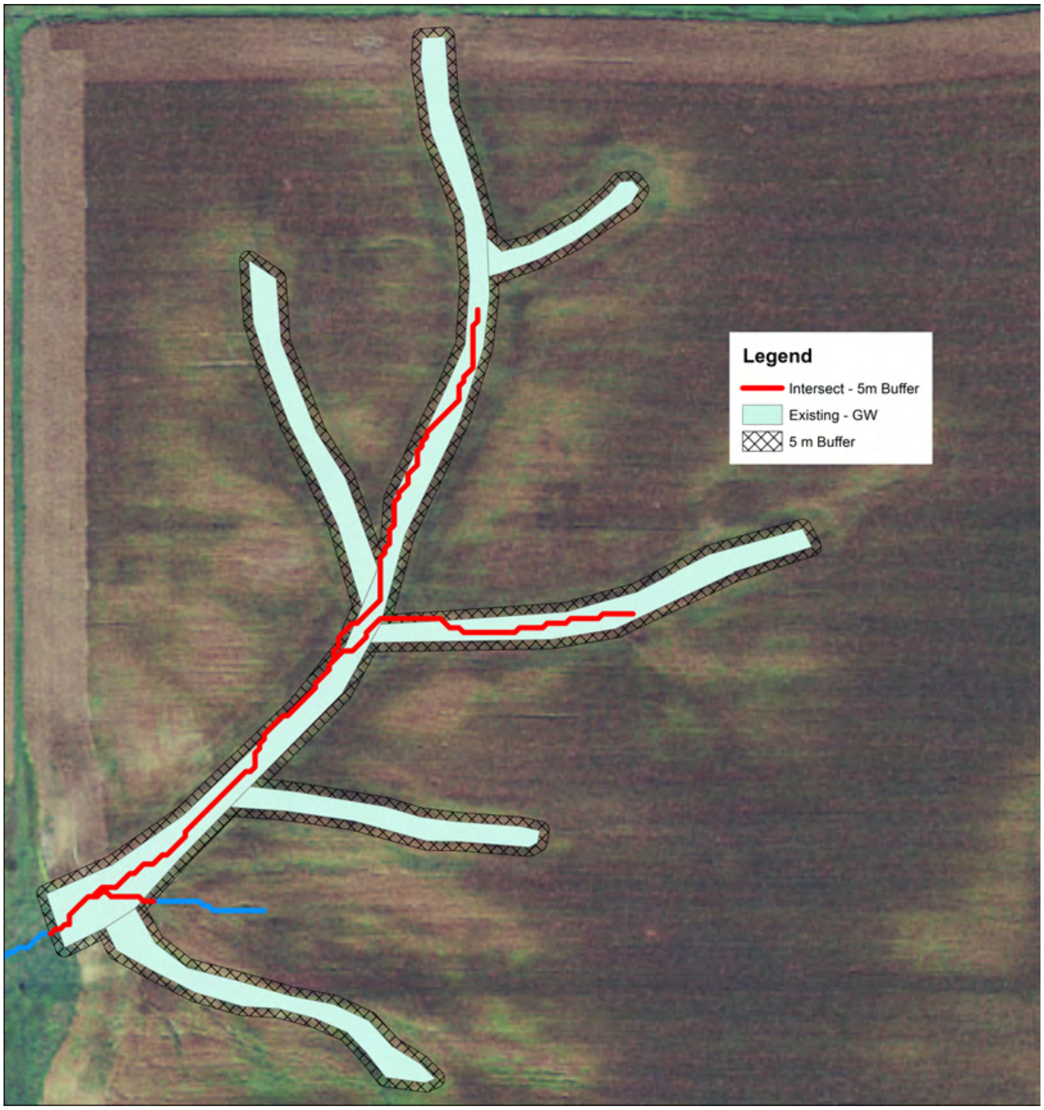

Figure 3.5: Example of Existing GW Buffer. A reasonable buffer was applied to the existing grassed waterway polygon to account for it being manually identified from aerial imagery.

stream. The procedure to compare the conservation practices can be used in other watersheds across Iowa and provide meaningful information to the communities and decision makers in those areas.

3.5.2 Comparison Between IBMP and ACPF

Nutrient Removal Wetlands and Ponds

In the Headwaters North English River there are a total of 89 identified existing ponds and 39 identified potential sites for NRWs. Even though the existing ponds number over double the NRWs, the total watershed area regulated by ponds is only 7.3% compared to the 20.8% by NRWs. This is attributed to the existing ponds having much smaller drainage areas on average, 33.9 acres, than the suggested NRWs average, 220.7 acres. Gritter Creek's existing ponds numbered 60 and ACPF NRWs only 7. The existing ponds are nearly 10 times as numerous, yet the watershed percentage regulated is about the same at 6.9% for existing ponds and 8.9% for NRWs.

Table 3.1: Pond and Wetland Drainage Area Comparison. Comparison of the number, average drainage area, and fraction of the watershed that is regulated by both existing ponds and ACPF NRW in Headwaters North English River and Gritter Creek.

	Headwaters North English River	Gritter Creek
	Existing Ponds	
Count	89	60
Average Drainage Area (acres)	33.9	17.0
Watershed Fraction Regulated (%)	7.3	6.9
	ACPF NRW	
Count	39	7
Average Drainage Area (acres)	220.7	188.0
Watershed Fraction Regulated (%)	20.8	8.9

The drainage area distributions in Figure 3.6 and Figure 3.7 for both watersheds shows how the existing ponds are mainly very small with only several near the same magnitude of ACPF NRWs. Within Headwaters North

English River 72% of the existing pond drainage areas are below 40 acres and 88% are below 40 acres in Gritter Creek. It also is noted that the ACPF tool does not site NRWs smaller than 60 hectares (148 acres). The summarized comparison statistics between existing ponds and ACPF nutrient removal wetlands are shown in Table 3.1.

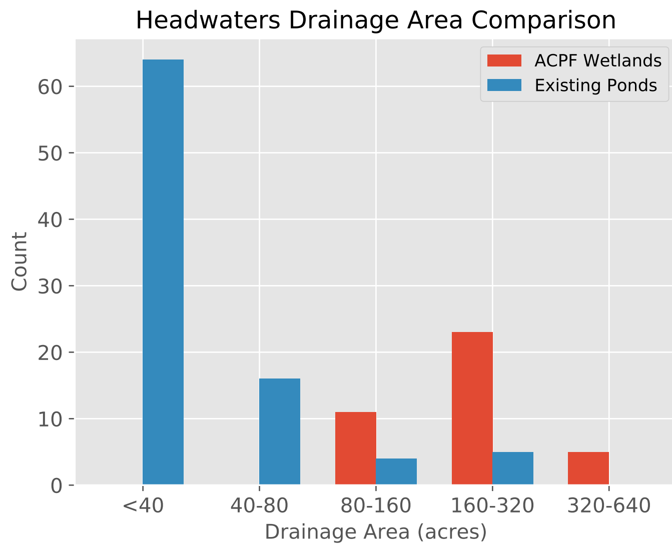

Figure 3.6: Headwaters North English River Pond Drainage Area Comparison. Headwaters North English has numerous existing ponds and recommended ACPF NRWs, but there is a stark difference in the drainage areas.

There are similar trends when looking at the flow path order of the ponds and NRWs in Figures 3.8 and 3.9. The ponds in Headwaters North English River are 90% on streams of flow path order 2 and below. In Gritter Creek, all but one, or 98% of the ponds are on flow path order 2 and below. The fact that there are existing ponds of flow path order zero, not on the stream network at all, suggests what exists on the landscape presently are not NRWs and there is potential for NRWs. For NRWS, in Headwaters North English River 95% are on flow path order 3 and above while 6 of the 7 NRWs in Gritter are on order 3 and above.

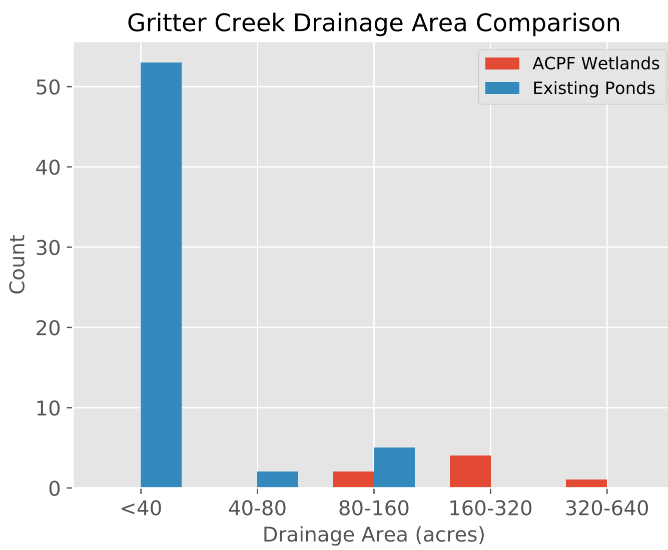

Figure 3.7: Gritter Creek Pond Drainage Area Comparison. Gritter Creek has less ponds and NRWs than Headwaters North English but exhibits the same trend of small existing pond drainage areas and much larger NRW drainage areas.

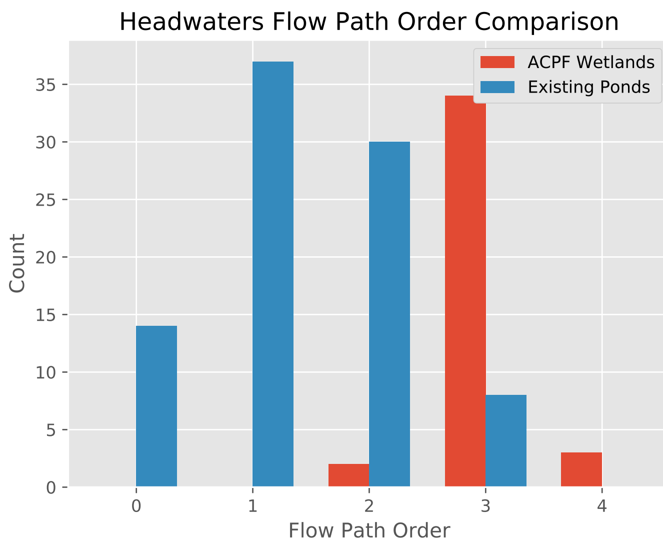

Figure 3.8: Headwaters North English River Pond Flow Path Order Comparison. Headwaters North English River shows that many of the existing ponds are on small streams with a flow path order of 2 or less. Some existing ponds are not even on the stream network. ACPF NRW are on larger streams, mainly flow path order 3.

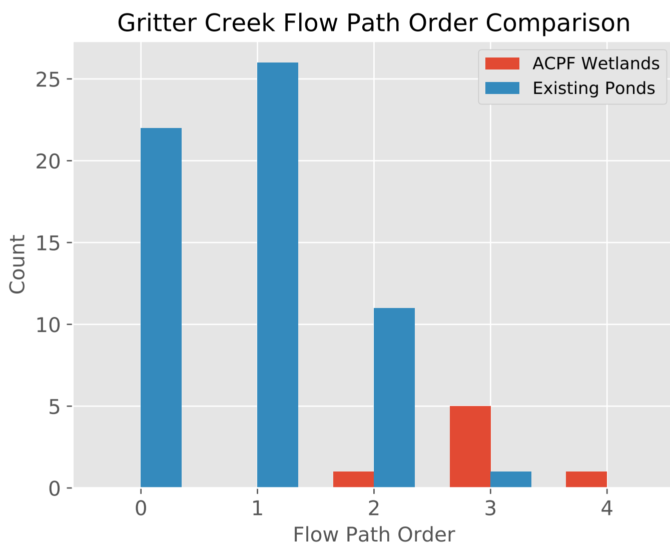

Figure 3.9: Gritter Creek Pond Flow Path Order Comparison. Gritter Creek has a similar trend to the Headwaters, existing ponds mainly on low flow path order streams, in this case mainly 0th and 1st order. There are fewer NRW but they are concentrated on 3rd flow path order streams.

WASCOB

WASCOBs are widely implemented across both watersheds as there are 648 in Headwaters and 252 in Gritter Creek. The number of existing WASCOBs is similar to the potential WASCOBs numbers of 826 and 255, respectively. Interestingly the average drainage area of WASCOBs in Headwaters North English River is nearly the same as well with 3.7 acres for existing and 3.8 acres for ACPF. Gritter Creek shows a similar trend to pond and wetlands with the existing WASCOBs having a much smaller average drainage area of 2.4 acres to the 8.9 acres average for ACPF. The ACPF suggested WASCOBs for both watersheds can be seen in Figure 3.3.

Table 3.2: WASCOB Drainage Area Comparison. WASCOBs are widely utilized in the Headwaters North English River and Gritter Creek. Headwaters has 78% of the potential implemented and Gritter Creek has nearly 100% of the potential fulfilled.

	Headwaters North English River	Gritter Creek
	Existing WASCOBs	
Count	648	252
Average Drainage Area (acres)	3.7	2.4
Watershed Fraction Regulated (%)	12.2	8.1
	ACPF WASCOBs	
Count	826	255
Average Drainage Area (acres)	3.8	8.9
Watershed Fraction Regulated (%)	16.5	17.4

The Headwaters drainage area distribution, Figure 3.10, for existing WASCOBs is fairly uniform but the ACPF WASCOBs skew towards larger (> 2 acre) drainage areas. In Gritter Creek, Figure 3.11, only 4.7% of ACPF WASCOBs have drainage areas under 2 acres compared to 44.8% for existing WASCOBs. For Headwaters North English River that number is 12.7% for ACPF and 31.2% for existing. Looking at the flow path order distribution, Figures 3.12 and 3.13, Headwaters North English River has the bulk of WASCOBs, both existing and ACPF, on 0th and 1st order streams with just 11.8% on 2nd and 3rd order streams for ACPF and only 6.3% for existing. Gritter Creek has 88.2% of ACPF WASCOBs and 93.7% of existing WASCOBs on 0th and 1st order streams.

The analysis of WASCOBs in (*Rundhaug et al.*, 2018) showed that across three HUC-12 watersheds in three different landform regions of Iowa, only Headwaters North English River contained a significant number of WASCOBs. The other two HUC-12 watersheds, Hinkle Creek and Ten Mile Creek, contained less than 10 WASCOBs suggesting that the English River may be an anomaly with WASCOB implementation in Iowa. The WASCOB potential in other watersheds across the state may be much greater.

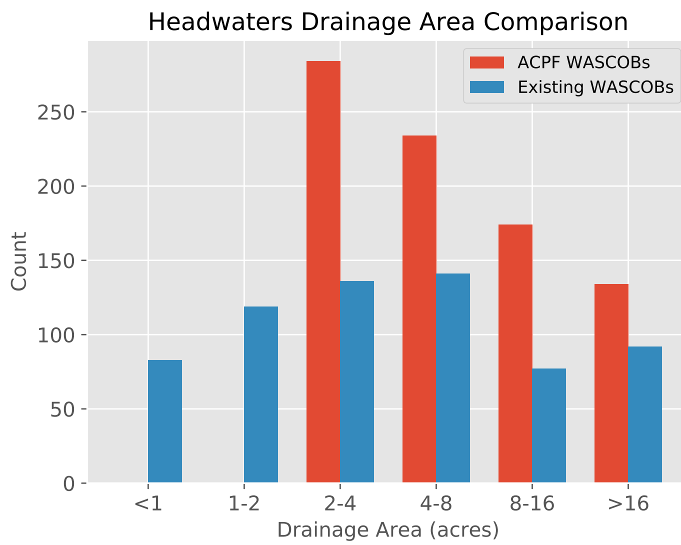

Figure 3.10: Headwaters North English River WASCOB Drainage Area Comparison.

Grassed Waterways

Of the three practices, grassed waterways show the closest correspondence between ACPF and IBMP. Grassed waterways show wide adoption in both watersheds with 568 acres in Headwaters North English River and 672 acres in Gritter Creek already. Mapping those areas onto the stream network results in stream network lengths of 112 miles and 34 miles respectively. The ACPF analysis for grassed waterways in Headwaters North English River yields a similar 103 miles. In Gritter Creek ACPF gives the same stream

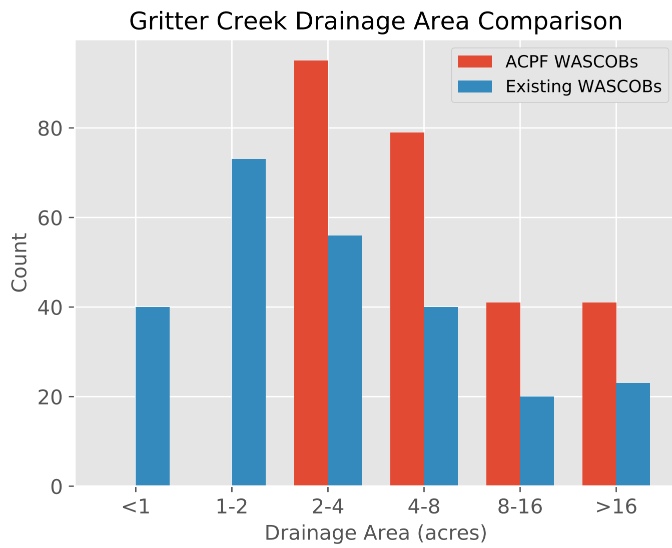

Figure 3.11: Gritter Creek WASCOB Drainage Area Comparison.

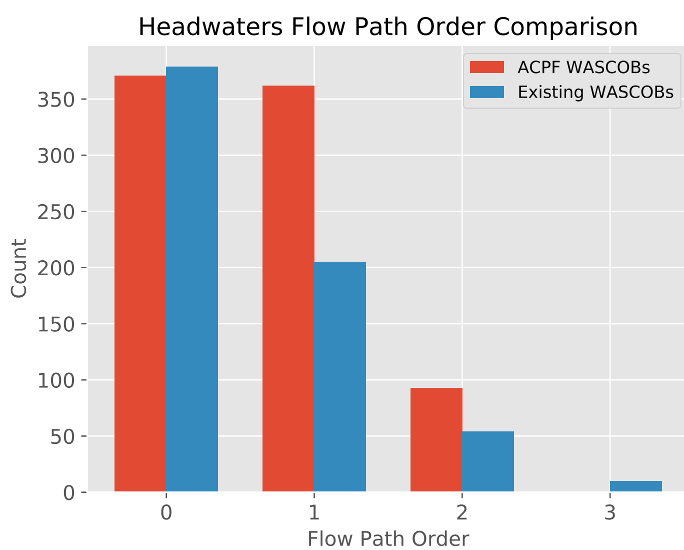

Figure 3.12: Headwaters North English River WASCOB Flow Path Order Comparison.

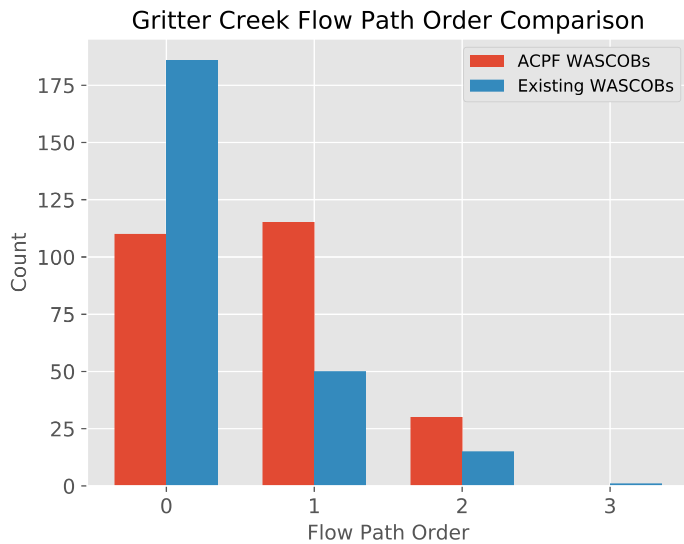

Figure 3.13: Gritter Creek WASCOB Flow Path Order Comparison.

network length of 34 miles as is existing, implying that Gritter Creek is fulfilling 100% of its potential with grassed waterways by that measure. The summary of the grassed waterway comparison is shown in Table 3.3.

Comparing grassed waterways by flow path order in Figures 3.14 and 3.15 shows a similar level of correspondence to the lump comparison. Of 1st and 2nd order streams, over 20% are covered by grassed waterways for ACPF and existing in both watersheds with the highest percentages for 2nd order streams in Headwaters North English River with 36.1% covered by ACPF grassed waterways and 32.2% covered by existing grassed waterways. The agreement between the two methods is also promising with overlap accounting for 12.2% of 1st, 22.5% of 2nd, and 9.6% of 3rd order streams in Headwaters North English River and 10.2% of 1st, 13.0% of 2nd, and 5% of 3rd in Gritter Creek.

Table 3.3: Grassed Waterway Comparison. Grassed waterway comparison by ACPF total length, area, and stream network length.

	Headwaters North English River	Gritter Creek
	Length (miles)	
ACPF	99	35
	Area (acres)	
Existing	568	672
ACPF	472	474
	Stream Network Length (miles)	
Existing	112	34
ACPF	103	34

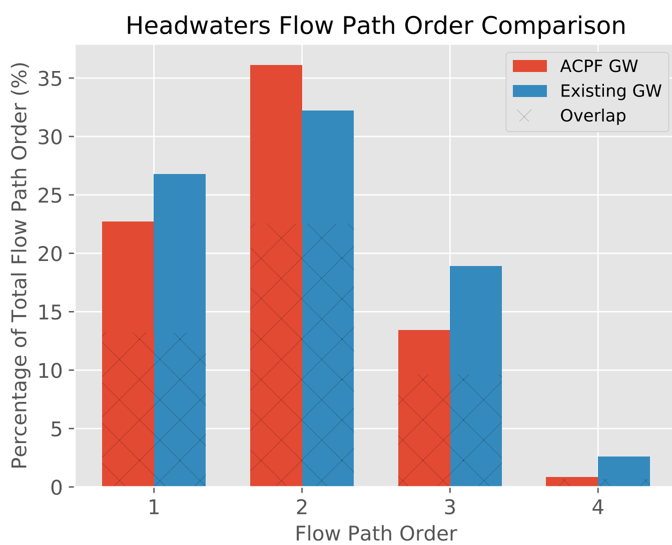

Figure 3.14: Headwaters North English River Grassed Waterways by Flow Path Order. Percentage of total flow path order length covered by existing and ACPF grassed waterways in Headwaters North English River, including the overlap between the two shown in black hatches.

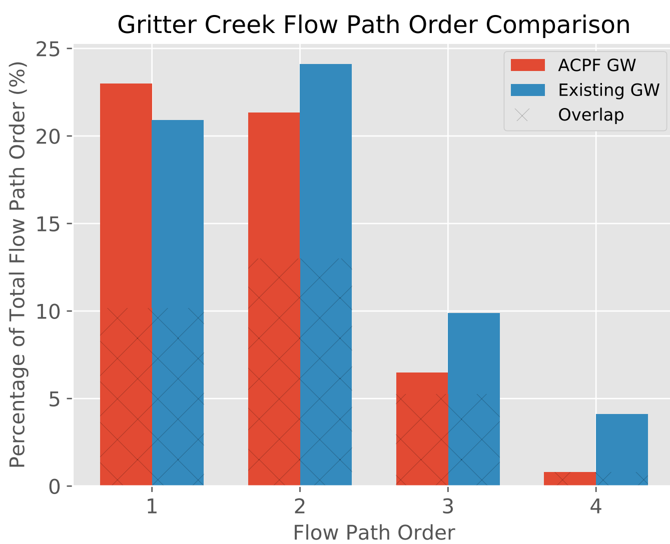

Figure 3.15: Gritter Creek Grassed Waterways by Flow Path Order. Percentage of total flow path order length covered by existing and ACPF grassed waterways in Gritter Creek, including the overlap between the two shown in black hatches.

3.6 Summary

There is great value in being able to answer the questions, what conservation practices are in a watershed and what potential for practices is there? Two efforts, the Iowa BMP Mapping Project and the application of the Agricultural Conservation Planning Framework, seek to answer those questions. The IBMP is an effort to identify six conservation practices across the entire state of Iowa. ACPF is a GIS toolbox to site conservation practices in Midwestern agricultural areas. There are structural differences between the datasets that require work to bridge so the two can be directly compared.

Three conservation practices that are shared between the projects were chosen for comparison: nutrient removal wetlands and ponds, WASCOBs, and grassed waterways. A process was developed to directly compare the three conservation practices from ACPF and the IBMP. The process involved designing ACPF grassed waterways to be mapped onto a stream network along with the IBMP grassed waterways. Nutrient removal wetlands, ponds, and WASCOBs were compared based on drainage areas obtained from GIS. All three practices were also mapped via the flow path order.

The comparison shows that ponds are widely used in both Headwaters North English River and Gritter Creek. However, they are much smaller in size than ACPF nutrient removal wetlands, and are located on smaller drainage areas. Adding nutrient removal wetlands — because of their larger size — would provide needed flood mitigation benefits. Hence, ACPF shows there is significant potential to reduce flooding and nutrient loads with the addition of nutrient removal wetlands. In contrast, the potential benefits of additional WASCOBs and grassed waterways is low. Both are widely adopted in the two HUC-12 watersheds. Although there are differences in the locations of existing practices and the potential practices predicted by ACPF, their numbers and size are of similar magnitude. This suggests that existing WASCOBs and grassed waterways may already fulfill the potential indicated by ACPF.

Chapter 4

Development of Fine Resolution HUC-12 Watershed Hydrologic Models

4.1 Introduction

Hydrological Simulation Program — FORTRAN (HSPF) is a hydrogic model with its roots in the Stanford Watershed Model from the 1960s (*Crawford and Linsely*, 1966). HSPF uses defined land areas that drain into the stream to model runoff. The upstream discharges are combined with the river reach drainage area runoff to get the total discharge. The outlets of river reaches are where the model predictions are made. Linking the reaches together gives the model its routing.

4.2 HSPF Overview

HSPF was derived from the combination and expansion of a number of models that were developed in the 1970s including Hydrocomp Simulation Programming (HSP) (*Hydrocomp, Inc.*, 1976; *Hydrocomp, Inc*, 1977), NonPoint Source (NPS) Model (*Donigian and Crawford*, 1976a), Agricultural Runoff Management (ARM) Model (*Donigian and Crawford*, 1976b; *Donigian et al.*, 1977), and Sediment and Radionuclides Transport (SERATRA) (*Onishi and Wise*, 1979). HSPF is valued for its flexibility in handling a variety of pollutants and ability to handle complex land uses. Using meteorological time series inputs and parameters values that describe watershed characteristics, HSPF can generate time series for runoff, stream flow, and pollutant and nutrient concentrations.

HSPF is a lumped-parameter, continuous simulation hydrologic model that contains three main modules to simulate water movement: PERLND, IMPLND, and RCHRES. PERLND is used to simulate the water quality and quantity processes that occur on a pervious land segment while IMPLND does the same for impervious land segments. HSPF considers land segments that infiltrate enough water to influence the water budget as pervious. The impervious area represented by IMPLND should only be the effective impervious area (EIA). EIA is the portion of total impervious area directly connected to drainage systems. RCHRES models free-flowing reaches, or mixed reservoirs and the processes that occur in them. Connections between RCHRES sections represent the routing of the river network. RCHRES flow is unidirectional (*Bicknell et al.*, 2001). Other subroutines model the individual processes, such as HYDR simulating hydraulic behavior for RCHRES and IWATER simulating the water budget in IMPLND blocks.

4.3 Subwatershed Delineation

To create the more detailed model for each HUC-12, subwatershed outlets were designated at each point where flows may be wanted: ACPF NRWs, existing ponds, road crossings, and stream junctions. Arc Hydro was used to manually delineate the watersheds from the points. Some of the existing ponds have drainage areas that are small enough that even when using a 5 acre stream threshold, the ponds were still not "on-network" therefore those ponds were not used for subwatershed delineation.

Figure 4.1 shows the results of the new subwatershed delineation. The new routing resulted in 407 reaches for Headwaters North English River with an average area of 88.6 acres (0.19 square miles). Gritter Creek contains 215 river reaches with an average area of 68.5 acres (0.11 square miles). For comparison, the original English River model was composed of 103 river reaches with an average area of 3,904 acres (6.10 square miles). The new monthly average runoff can be seen in Figure 4.2. The differences are slight between the old monthly runoff in Figure 2.3 and the new, refined routing. The largest runoff still occurs in March through June.

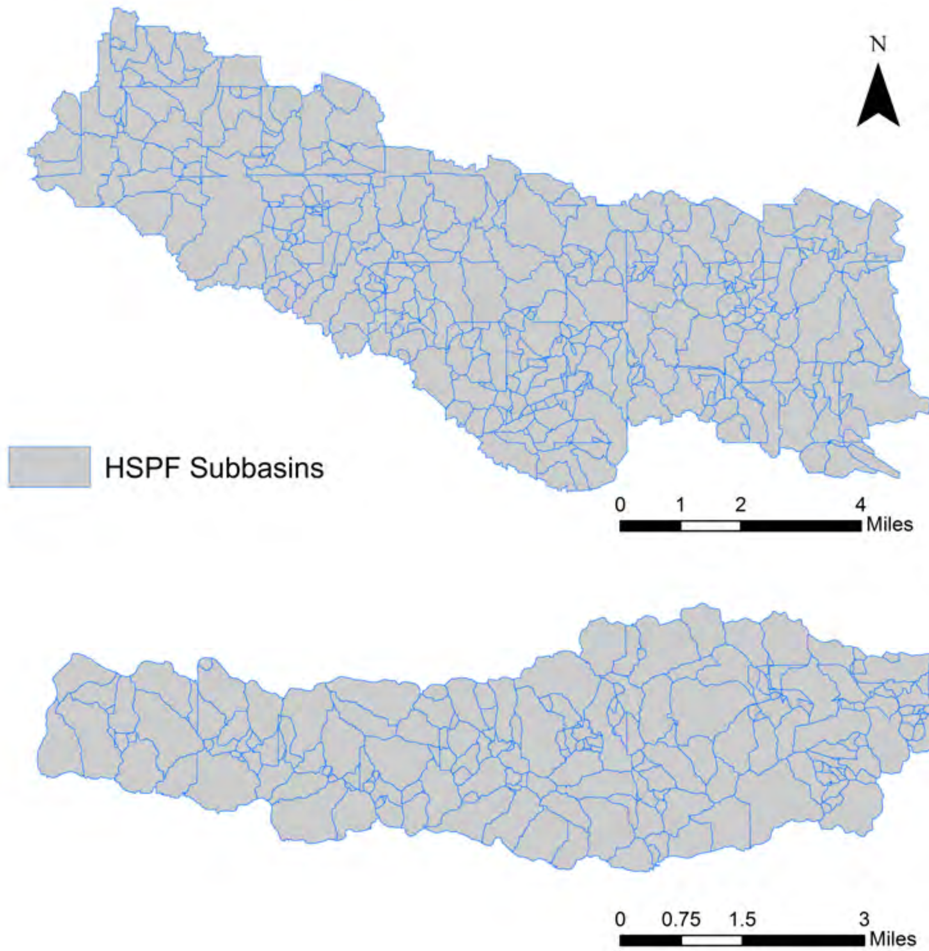

Figure 4.1: Refined Model Subbasins. The refined routing of the Headwaters North English River (top) with 407 subbasins and the refined routing of Gritter Creek (bottom) with 215 subbasins.

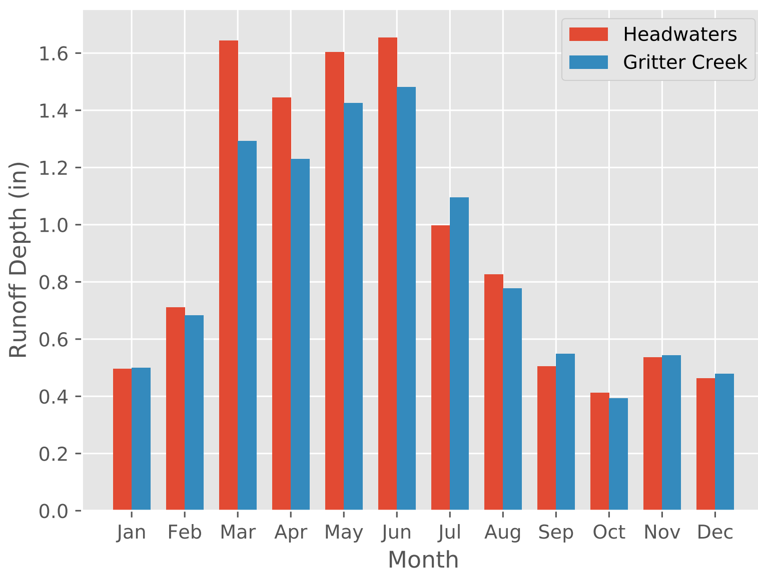

Figure 4.2: Refined Model Monthly Runoff. Simulated average monthly runoff depth for the period of record (1949 to 2012) for Headwaters North English River and Gritter Creek using the refined routing.

4.4 Routing Comparison

To ensure the model consistency of the new model a comparison between the original routing and the new, refined routing was necessary. The original model has outlets matching the outlets for each HUC-12 subwatershed so it was adjusted to get the discharge time series at Headwaters North English River and Gritter Creek. It was also necessary to remove any variation between the models except for the routing. Therefore the small areas differences due to the resolution of DEM used were manually adjusted by land cover percentage so the areas matched. The new routing is also being modeled using a single weather station for each HUC-12 subwatershed while the original English River model utilized two weather stations for these subwatersheds. The weather station being used for Headwaters North English River, Grinnell, was applied to the original model and for Gritter Creek the station is North English.

Figures 4.3 and 4.4 are two comparisons between the Headwaters North English River routing. The cumulative runoff depth in Figure 4.3 was calculated at an hourly time step over the entire period of record. It shows very good correspondence and no systematic error with final accumulated runoff depths of 719.57 inches for the old and 722.63 inches for the new. The difference is 3.05 inches, or only 0.42% and can be attributed to slight (tenths of a percent) differences in land cover percentages between the two delineations. The annual runoff depths shown in Figure 4.4 also agree. The largest difference of 0.22 inches occurs in 1974.

The same comparisons were done for Gritter Creek in Figures 4.5 and 4.6. The totals at the end of the period of record for accumulated runoff depth were 272.97 inches and 273.11 inches for the old and new routing respectively. That difference is only 0.14 inches, or 0.50% and can be attributed to the same difference in land cover percentage that the Headwaters North English River had. The annual runoff depths show very small differences with the largest difference being a mere 0.01 inches in 1993.

Changing the routing significantly as has been done likely changes the timing of the hydrograph. This will not affect the results of the project since only the new routing is being used for analysis, but it is worth taking a look at the differences. Figure 4.7 shows the 2008 Iowa Flood at the Headwaters North English River outlet with an hourly time step. There are small differences, mainly with the new routing peaking slightly after the old routing, but they are very reasonable for the changes in routing.

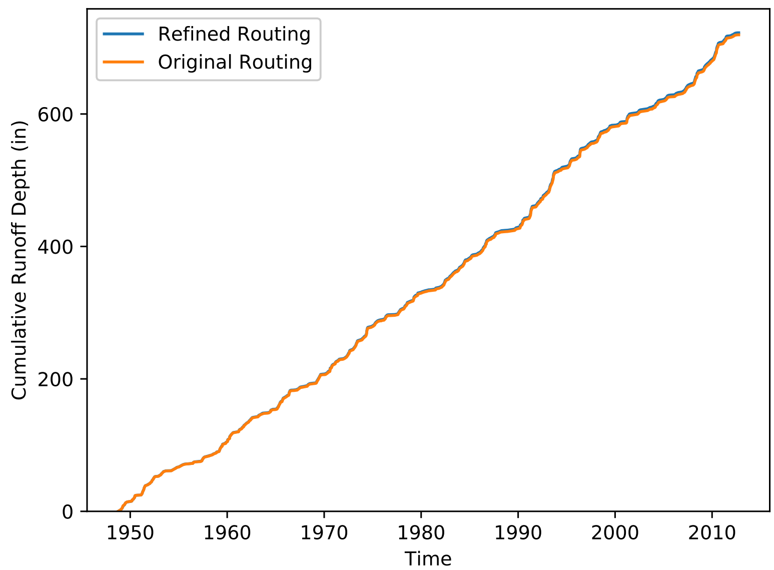

Figure 4.3: Cumulative Runoff Depth of Original and Refined Headwaters North English River Routing. Cumulative runoff depth showing accumulated runoff depth for Headwaters North English River for the original and refined routing.

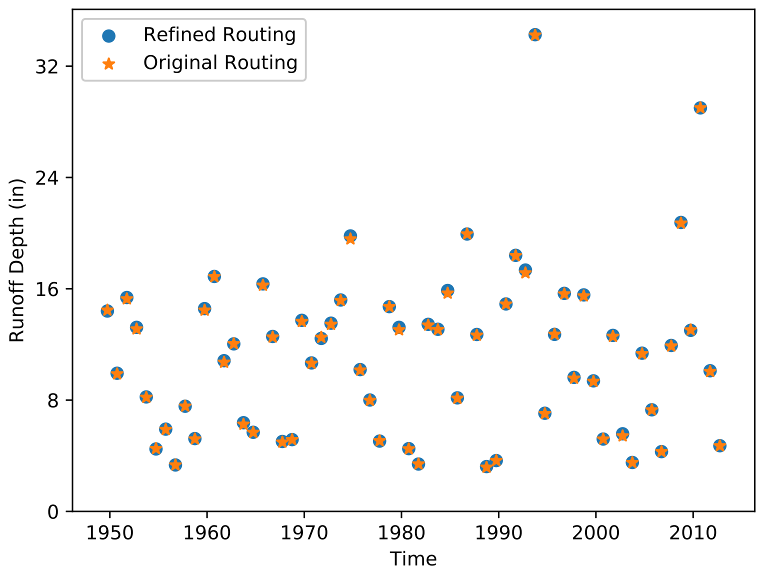

Figure 4.4: Annual Runoff Depth of Orginal and Refined Headwaters North English River Routing

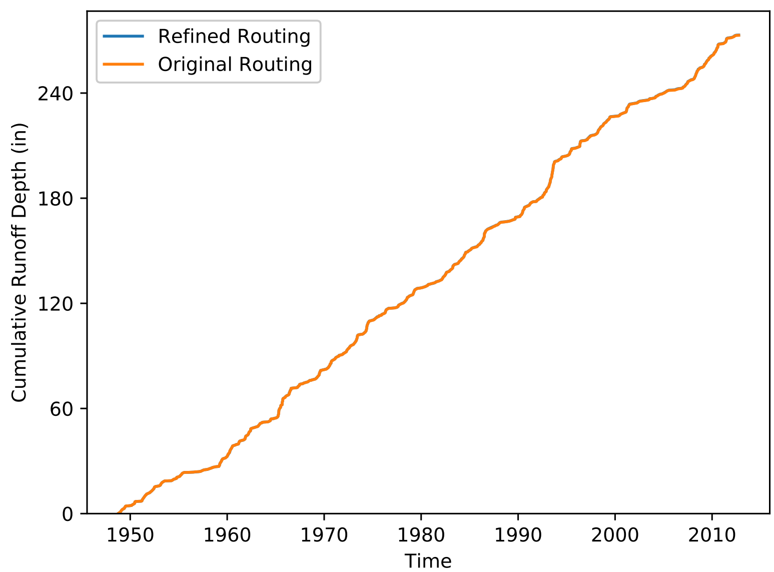

Figure 4.5: Cumulative Runoff Depth of Original And Refined Gritter Creek Routing. Cumulative runoff depth showing accumulated runoff depth for Gritter Creek for the original and refined routing.

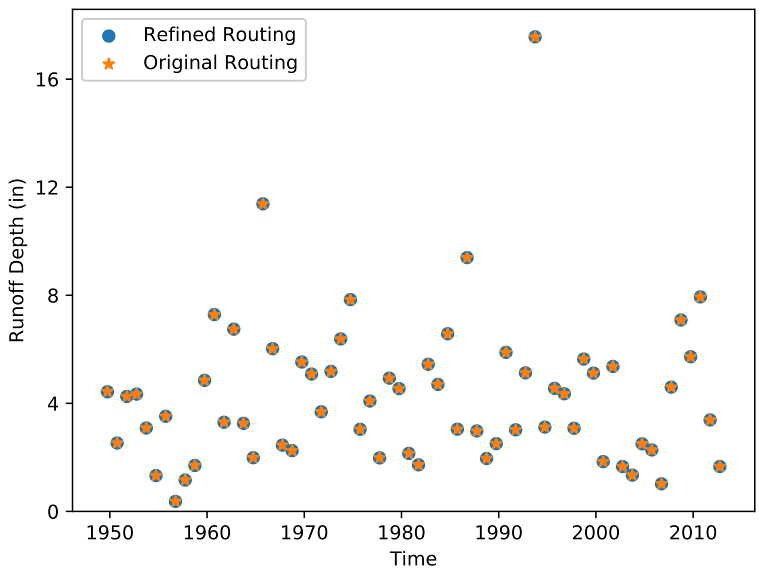

Figure 4.6: Annual Runoff Depth of Original and Refined Gritter Creek Routing.

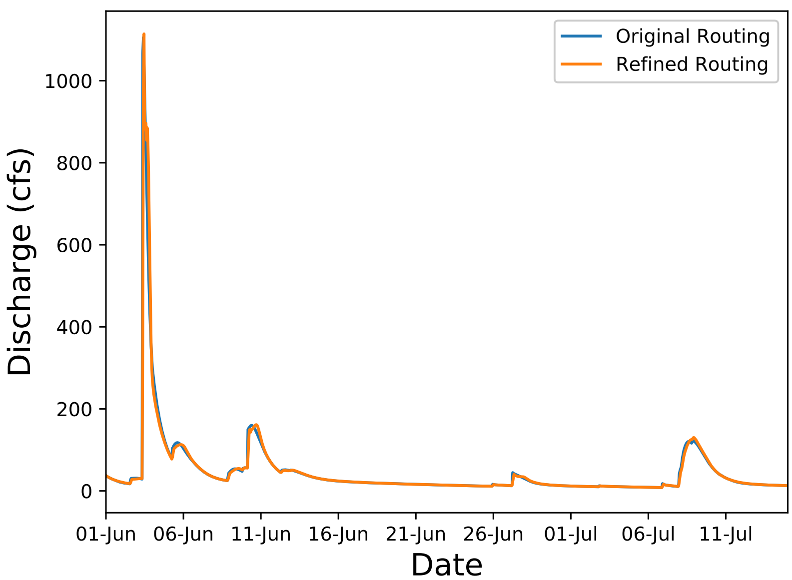

Figure 4.7: Comparison of Routing Timing for Headwaters North English River at 2008 Flood. The differences in the timing of the the hydrographs between original and refined routing for the 2008 flood.

4.5 Summary

In this chapter a brief history and overview of the HSPF model was provided. The model is widely used due to its flexibility in modeling watershed characteristics. The previously constructed English River model was enhanced to have have the resolution necessary to model individual conservation practices. The new HUC-12 subwatershed models were delineated to give a model outlet at each road crossing, tributary junction, ACPF NRW location, and existing pond location. To ensure the new model accurately represented the original, calibrated model a comparison of the two routings was necessary. Using a cumulative runoff depth analysis, annual runoff depth comparison, and flood hydrograph analysis Headwaters North English River and Gritter Creek showed good agreement between the two routings.

Chapter 5

ACPF Nutrient Removal Wetland Characterization and Effects on High Runoff

5.1 Introduction

To accurately model ACPF nutrient removal wetlands (NRWs), site-specific pond designs are necessary. ACPF provides the following site characteristics for NRW: drainage area, pool elevation, stream elevation, pool area and volume, and buffer area and volume. For this study the NRW are designed and simulated as ponds. Existing ponds identified by the IBMP were not included in the simulation. Existing ponds are smaller in size than ACPF wetlands, and site-specific topographic and hydraulic information is not readily available for modeling their effects.

Wetlands have been modeled and shown to reduce peak flows in the Midwest using other models (*Babbar-Sebens et al.*, 2013). Previous studies have incorporated generic ponds or utilized plans from existing, constructed ponds in modeling scenarios (*Drake*, 2014; *Ayalew et al.*, 2017). Without a pond siting tool like ACPF the site-specific information needed to individually design ponds was not available. However, with ACPF and utilization of additional GIS tools, it is possible for site-specific designs. For this study, ACPF provides the location and site characteristics, GIS tools provide the stage-area-storage relationship at those locations, and the NRCS Water Resources Site Analysis Program (SITES) computes the hydraulic design (*National Re-*

sources Conservation Service, 2007b).

To design the ponds, a Python script was written that enables efficient design with minimal manual data handling required. The script first uses the ACPF site-specific information to create the wetland's stage-storage relationship. The script then uses that stage-storage relationship for an iterative process running SITES with varying principal spillway sizes, or pipe diameters, until a suitable design is achieved. The suitable design is defined as the smallest pipe diameter such that the auxiliary spillway is not activated during the design storm.

The designed ponds are then placed into the HSPF model to simulate the effect of increased flood storage in the watersheds. Simulations were run to understand the individual and cumulative effects of the ponds on flood peaks. Ponds contain a permanent pool full of water but have additional volume, flood storage, that can be utilized during rain events to store water and reduce peak discharges. The ponds do not reduce the total volume of runoff but regulate the rate it is discharged at resulting in a lower hydrograph peak. This particular approach uses site-specific pond designs whereas previous studies modeling the effects of ponds on peak discharges used prototype ponds and hypothetical scenarios (*Drake*, 2014; *Leach*, 2015; *Iowa Flood Center*, 2015).

5.2 Pond Design Methodology

In previous studies the SITES program has been used to generate pond designs and stage-discharge curves (*Iowa Flood Center*, 2016). Each pond was designed by manually editing the inputs until they met the suitable design criteria mentioned above. While this approach is acceptable for a small number of ponds, the goal of this approach was to allow it to be applied to other IWA watersheds in an efficient manner. The number of ponds quickly becomes prohibitively large for manual design. Therefore the goal of the script was to enable design of thousands of ponds using an automated, iterative process.

The script operates on a spreadsheet populated with the raw ACPF NRW output, with several additional columns of information. The user must utilize GIS to compute the average curve number and average slope of each NRW drainage area and add that information to the spreadsheet. Conveniently average curve number and average slope are necessary parameters that must be calculated to develop certain models such as HEC-HMS. A necessary

SITES input is the time of concentration for each pond found using the Watershed Lag method from the National Engineering Handbook (NEH) Part 630, Chapter 15 (*National Resources Conservation Service*, 2010). The flow length (ℓ) is estimated using:

$$\ell = 209A^{0.6} \tag{5.1}$$

where A is the drainage area in acres and ℓ is in feet. The flow length is then used to compute the time of concentration T_c. The time of concentration is computed with:

$$T_c = \frac{\ell^{0.8}(S+1)^{0.7}}{1,140Y^{0.5}} \tag{5.2}$$

where Y is the average watershed land slope in percentage, and S is the maximum potential retention in inches inches calculated by:

$$S = \frac{1,000}{CN} - 10 \tag{5.3}$$

where CN is the curve number. The auxiliary spillway was set to the ACPF buffer elevation, 1.5 meters above the permanent pool elevation.

The script then computes the stage-area-storage curve information above the ACPF NRW pool elevation, which is used as the permanent pool elevation. Any storage under the pool elevation is part of the permanent pool and therefore does not provide flood storage. The stage-area curve is formatted into the necessary SITES format along with the ACPF information of drainage area, pool elevation, auxiliary spillway elevation, stream elevation and the user computed average curve number and time of concentration.

The script estimates a cross-sectional shape of the pond dam and uses varying circular pipe principal spillway diameters. The principal spillway size begins at 10 inches and iterates through in 6 inch increments until a successful design is found. The design storm was the 25-year, 24-hour NRCS Type II storm, which for the English River is 5.1 inches (*National Resources Conservation Service*, 2015). The pond design is then output for the user and all discharge curves are aggregated into a single file to allow for convenient placement into the model. The complete code can be found in the Appendix.

5.2.1 NRCS SITES Program

The aim of SITES is to help engineers analyze dams by providing hydraulic and hydrologic designs. The dams can range in size from several acres to hundreds of square miles and allows for testing of alternative principal and auxiliary spillway designs. SITES models watershed runoff and creates a corresponding hydrograph which is then routed through a dam to determine the discharge of the principal spillway and the auxiliary spillway (*National Resources Conservation Service*, 2007b). SITES can be used to design a NRCS TR-60 watershed dam or NHCP 378 pond (*National Resources Conservation Service*, 2005, 2011). These dams are typical in agricultural areas and are typically low head (effective dam height under 35 feet) and classified as Low Hazard Class. SITES can be run using an Integrated Development Environment (IDE) or via command line arguments using the computational routine, DAMSITE.

To determine the capacity of principal spillways typical hydraulic formulas for pipe, orifice, and weir flows are used with an assumption of constant tailwater (*Soil Conservation Service*, 1979). WSPVRT is a SITES algorithm that is used to develop water surface profiles (WSP) for the auxiliary spillway rating curves. A fixed auxiliary spillway width of 12 feet was used with Class B Retardance. WSPs are created from a combination of the direct step and standard step methods. If supercritical conditions exist in any of the reaches being analyzed the computation begins at the upstream end of the first reach. Otherwise, computation begins using the normal depth at the upstream end of the first reach above the tailwater. The ratings are based on the energy head at the reservoir end of the inlet channel. Figure 5.1 shows the design of a typical SITES pond. An open-top drop inlet riser was selected for each pond as the inlet type.

5.2.2 Pond Design Script with Linear Regression Stage - Area Relationship

One issue with the original script is that determining site-specific stage-area-storage curves for each pond was a time consuming step. Doing so for hundreds of ponds would take an unreasonable amount of time. By investigating the relationships of the 39 Headwaters North English River ponds, where stage-area-storage was explicitly calculated, it can be seen in Figure 5.2 that the relationship can be effectively modeled with a linear relationship. There-

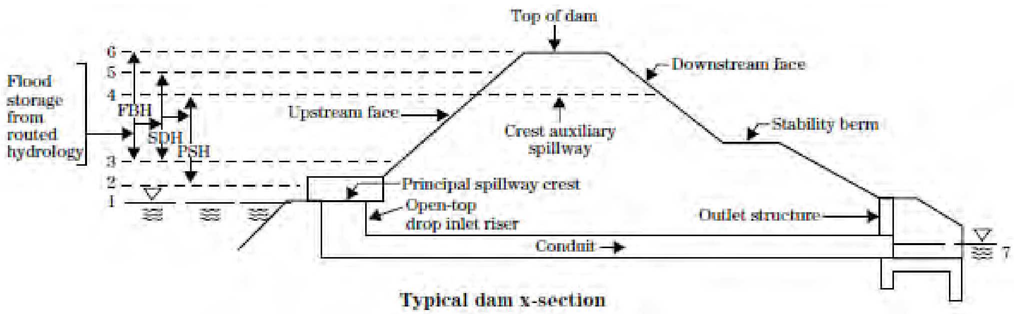

Figure 5.1: SITES Pond Diagram. Diagram of typical SITES pond (*National Resources Conservation Service*, 2007b).

fore with an additional step in the script that fits a linear regression to the two known points of pool elevation and pool storage and auxiliary spillway elevation and total storage the pond design process could be approximated without GIS calculation of an explicit stage-area-storage curve.

5.2.3 Comparison of Methods

Running the new script with approximate stage-area relationships adds a negligible amount of time to designing the ponds but saves hours of time that would be required to get stage-area-storage curves with GIS for every pond. Removing that data requirement means that now to design site-specific ponds, the user only needs to provide average curve number and average slope for each pond drainage area; all other script inputs directly correspond to ACPF outputs. Figure 5.3 shows the stage-area relationship from the new script. The results are very similar to Figure 5.2 with GIS calculated stage-area relationships.

Another way to compare the two methods is to look at the accepted design principal spillway pipe size for the 39 ponds. Of the 39 ponds, 29, or 74%, had the same pipe size for both design methods. Using the linear regression method, the pipe diameter selected for the remaining 10 ponds was one iteration, 6 inches, smaller than using the explicit method. Some variation between the two methods is to be expected due to the stage-area relationship not being truly linear for each. The agreement between the two is acceptable though for the time saved using the linear regression method.

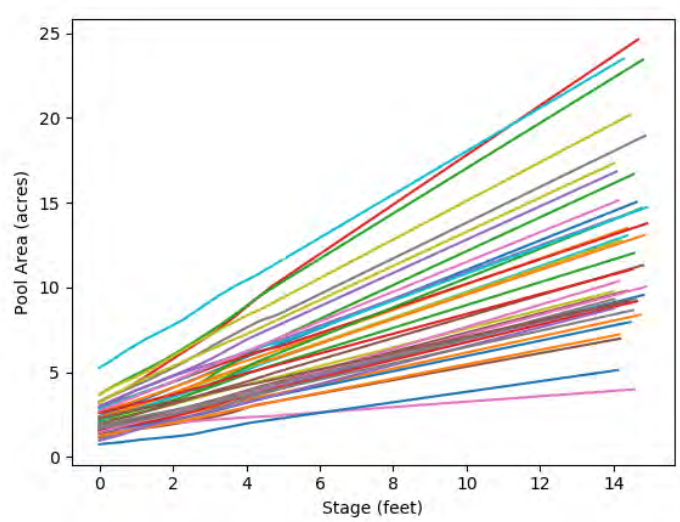

Figure 5.2: Stage-Area Relationship for Headwaters North English River NRW. Calculated stage-area relationship using GIS and DEMs for each site-specific NRW showing the largely linear relationship in Headwaters North English River.

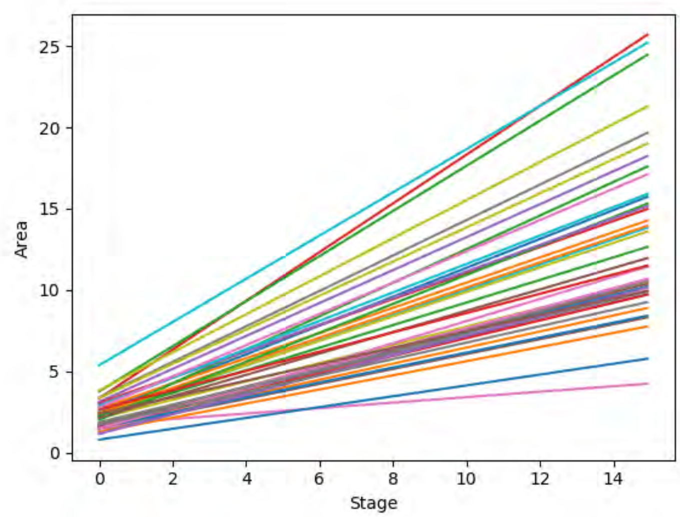

Figure 5.3: Stage-Area Linear Regression for Headwaters North English River NRW. Linear regression stage-area relationship for each site-specific NRW in Headwaters North English River.

5.2.4 Implementation of Output into Models

HSPF uses hydraulic function tables, FTABLES, to simulate the hydraulics of river reaches or reservoirs. The FTABLES represent a functional relationship between multiple variables. FTABLES specify the depth-volume-discharge relationship for each pond. The SITES program outputs a file with elevation, combined principal and auxiliary spillway discharge, principal spillway discharge, storage, and area. The relevant data from the SITES output file and appended to a final file in the correct FTABLE format. The final file is then simply copied and pasted into the HSPF model. An example FTABLE is shown in Figure 5.4. The script is flexible enough to allow for other model input formats if needed.

```
 FTABLE     53
ROWS COLS ***
  16    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.000     0.000     0.000     0.000       0.0
     0.385     0.273     0.053     0.043     878.0
     0.769     0.546     0.210     0.276     553.0
     1.154     0.820     0.473     0.814     422.0
     1.539     1.093     0.841     1.753     348.3
     1.923     1.366     1.314     3.178     300.1
     2.565     1.821     2.336     6.845     247.7
     3.206     2.277     3.649     12.41     213.5
     3.847     2.732     5.255     20.18     189.0
     5.129   118.312    82.863    235.67     255.3
     6.412   233.895   308.691    1279.3     175.2
     7.694   349.475   682.725    3653.9     135.7
     8.976   465.055  1204.969    7774.5     112.5
    10.259   580.638  1875.445   14010.7      97.2
    11.541   696.218  2694.114   22701.3      86.2
    15.388  1042.961  6039.424   66586.8      65.8
 END FTABLE 53
```

Figure 5.4: Example FTABLE. An example of an HSPF FTABLE that describes the functional relationship between multiple variables (depth (stage), surface area, volume, discharge, and flow through time.)

Table 5.1: Characteristics of ACPF NRW. Summary of the NRW characteristics implemented into the model.

HUC-12 Watershed	Number of ACPF NRW	Watershed Fraction Regulated (%)	Total Flood Storage (ac-ft)	Total Flood Storage Depth (in)
Headwaters North English River	39	20.8	768.1	1.23
Gritter Creek	7	8.9	154.9	1.41

5.3 Evaluation of Peak Discharge Reduction with Pond Implementation

5.3.1 Full Pond Implementation

In this section the ponds are implemented into the HSPF model to simulate their effects on flood peaks. Table 5.1 shows the characteristics of all the ponds for each of the HUC-12 watersheds. The percent of the watershed regulated by ponds is 20.8% for Headwaters North English River and about half that, 8.9% for Gritter Creek. Headwaters North English River has much more flood storage, 768.1 acre-feet compared to 154.9 acre-feet, due to having a much larger number of ponds; the normalized total flood storage depth for the watersheds are similar at 1.23 inches for Headwaters North English River and 1.41 inches for Gritter Creek. The total flood storage depth indicates that depth of runoff that can be temporarily retained when it falls during a storm event.

Figures 5.5 and 5.6 show six index locations that were selected in each watershed to compare scenario results with and without ponds. The index locations were selected to evaluate the flood reduction benefits locally (directly downstream of projects) and at larger scales moving downstream in the watershed. The summary of pond characteristics at the locations is shown in Figures 5.2 and 5.3.

To evaluate the effects of ponds on reducing flood peak discharges, a flood frequency analysis was performed at the six index locations in each watershed comparing peak discharges with and without ponds, shown in Figures 5.7 and 5.8. Each analysis shows the probability distribution for the baseline simulation (no ponds) and the ponds simulation. 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. Added to the estimates of exceedance probability is

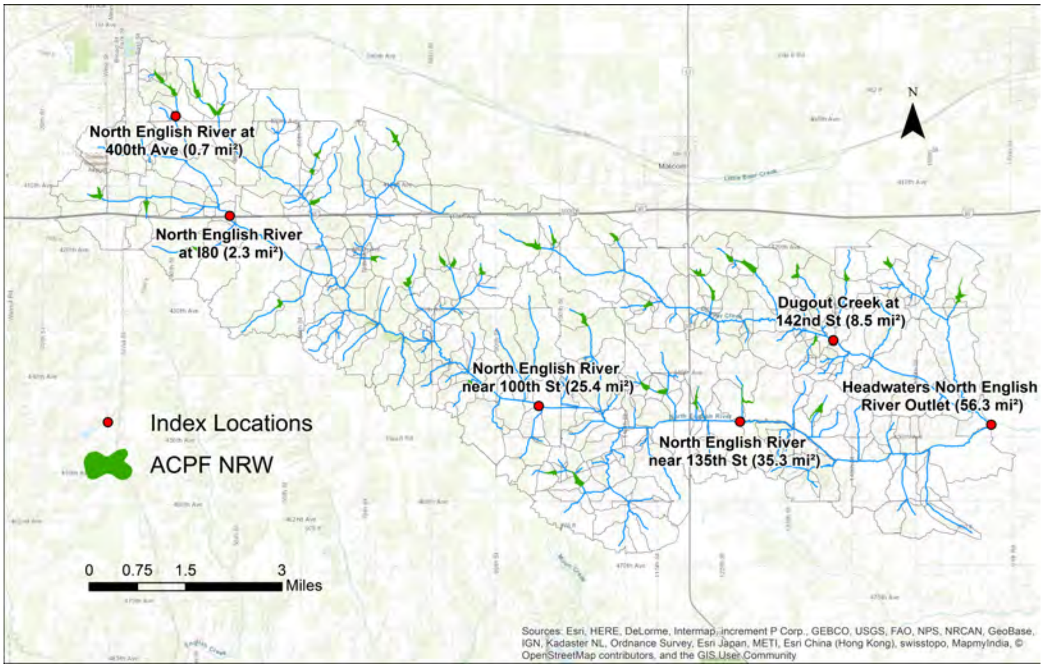

Figure 5.5: Headwaters North English River Index Locations. Location of the six selected index points for Headwaters North English River, also showing the locations of NRW.

Table 5.2: Headwaters North English River Index Location Pond Characteristics. Summary of pond characteristics at Headwaters North English River index locations. The upstream drainage area, the number of ponds, and the drainage area upstream of the ponds is indicated by index location.

Location	Drainage Area (mi^2)	Ponds Upstream (#)	Area Upstream From Ponds (mi^2)	(%)
North English River at 400th Ave	0.7	2	0.55	78.6
North English River at I80	2.3	4	1.32	57.0
Dugout Creek at 142nd St	8.5	11	3.22	37.9
North English River near 100th St	25.4	18	5.29	20.8
North English River near 135th St	35.3	24	6.70	19.0
Headwaters North English River Outlet	56.3	39	11.69	20.8

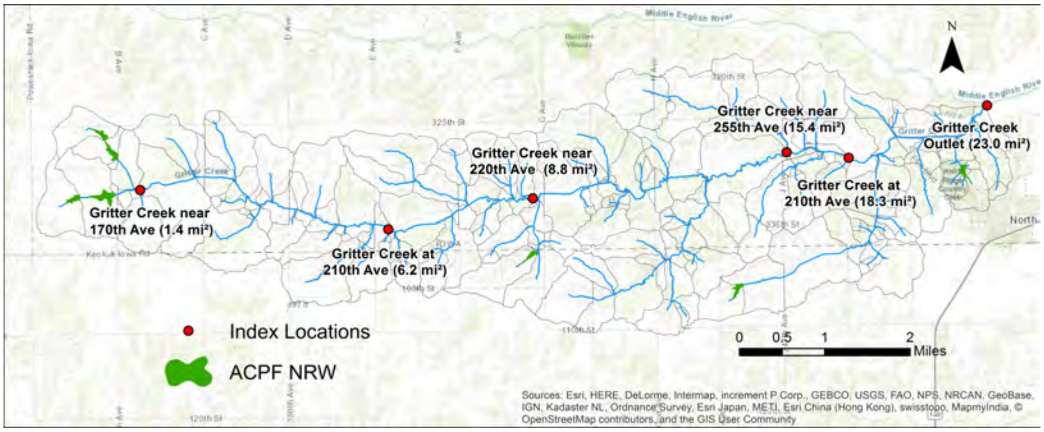

Figure 5.6: Gritter Creek Index Locations. Location of the six selected index points for Gritter Creek, also showing the locations of NRW.

Table 5.3: Gritter Creek Index Location Pond Characteristics. Summary of pond characteristics at Gritter Creek index locations. The upstream drainage area, the number of ponds, and the drainage area upstream of the ponds is indicated by index location.

Location	Drainage Area (mi^2)	Ponds Upstream (#)	Area Upstream From Ponds (mi^2)	(%)
Gritter Creek near 170th Ave	1.4	4	1.23	87.9
Gritter Creek at 210th Ave	6.2	4	1.23	19.8
Gritter Creek near 170th Ave	8.8	4	1.23	14.0
Gritter Creek near 255th Ave	15.4	5	2.22	14.4
Gritter Creek near 247th Ave	18.3	5	2.22	12.1
Gritter Creek Outlet	23.0	7	2.70	11.7

the “average peak reduction” which is the percentage reduction in the pond scenario discharges relative to that of the baseline simulation calculated for each year of the simulation.

Starting in the upper left panel, each panel shows an increasing upstream drainage area. The plots show the decreasing effect of the ponds on reducing peak discharges as the drainage area upstream of the location increases, culminating in the lowest reduction at the outlet of each watershed. Headwaters North English River shows average peak reductions from 54.7% at North English River at 400th Ave (0.7 mi^2: 78.6% regulated by ponds) to 2.5% at Headwaters North English River Outlet (56.3 mi^2: 20.8% regulated by ponds). North English River at 400th Ave is directly downstream of a pair of ponds that are located in series, leading to North English River at 400th Ave having 78.6% of its upstream area regulated by ponds causing the large peak reductions. For Gritter Creek the reductions range from 51.3% at Gritter Creek near 170th Ave (1.23 mi^2: 87.9% regulated by ponds) to 0.5% at Gritter Creek Outlet (23.0 mi^2: 11.7% regulated by ponds). Similar to the situation in Headwaters North English River, Gritter Creek near 170th Ave is at the confluence of two tributaries that each have two ponds causing the large peak reduction. Gritter Creek near 170th Ave has 87.9% of its drainage area regulated by ponds.

The diminishing effect of ponds on reducing peak discharges at further downstream locations can be seen also in Figures 5.9 and 5.10. In the figures, each subbasin’s color corresponds to the average peak reduction over the 64-year simulation period where red shows the highest peak reductions and green shows lower. All subbasins that are upstream of ponds, and therefore have no peak reduction, are shown in grey. The smaller basins show large reductions and decrease moving down the main stream. Ponds are especially beneficial to preventing flooding in headwater basins, but they provide benefit throughout the watershed. There are basins that exhibit peak reductions as high as 54% in Headwaters North English River and 78% in Gritter Creek but the reductions decrease moving downstream to 2.5% and 0.5% near the outlets respectively.

The decreasing effect of ponds as drainage area increases is illustrated for each subbasin in Figures 5.11 and 5.12. The figures show the average peak reduction for each subbasin with the upstream area, or drainage area, located on the x-axis. Each point is also designated by whether it is downstream of ponds, upstream of ponds, or at the pond itself. Small basins, especially those where the ponds were sited, show large reductions of up to 100%. There is

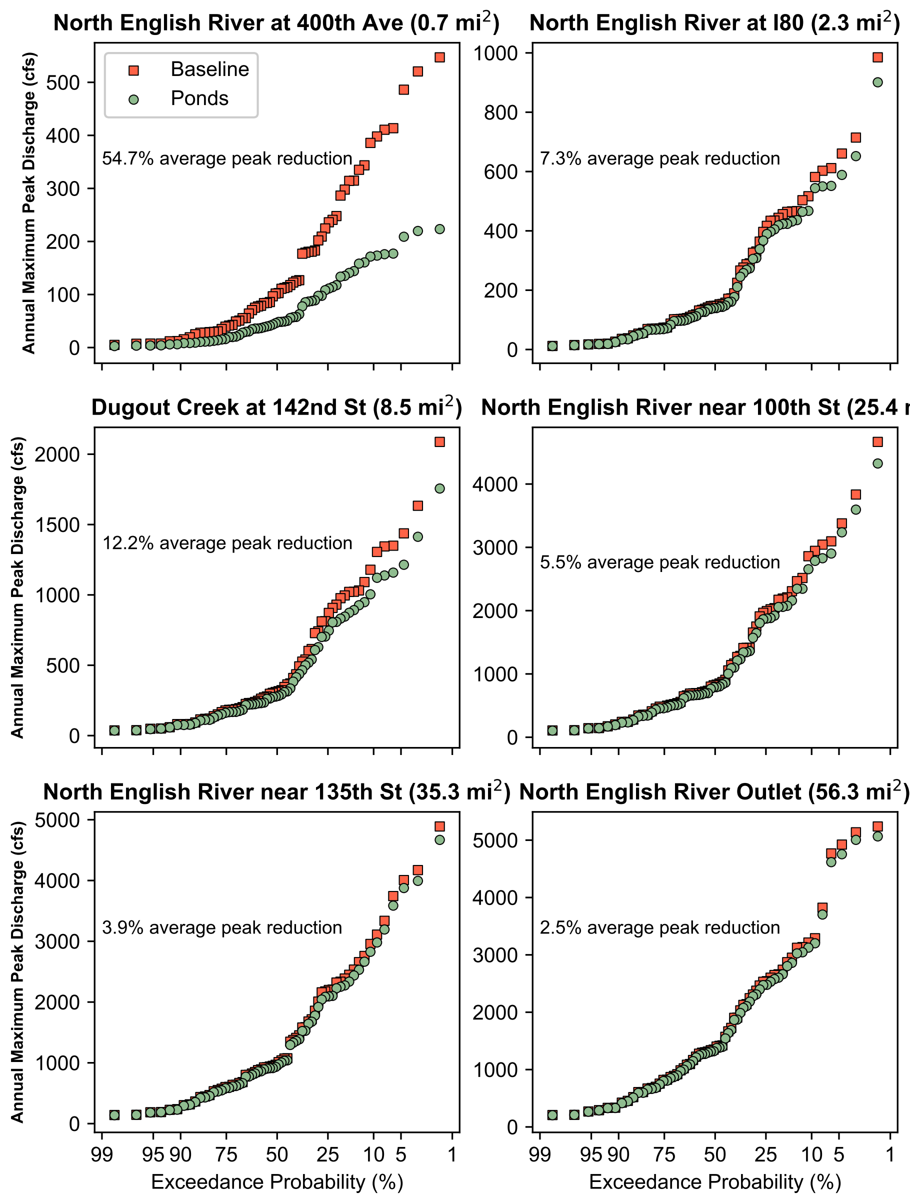

Figure 5.7: Headwaters North English River Flood Frequency Analysis for Full Pond Implementation. Probability distribution of annual maximum peak discharges for the baseline simulation and the pond implementation simulation for Headwaters North English River.

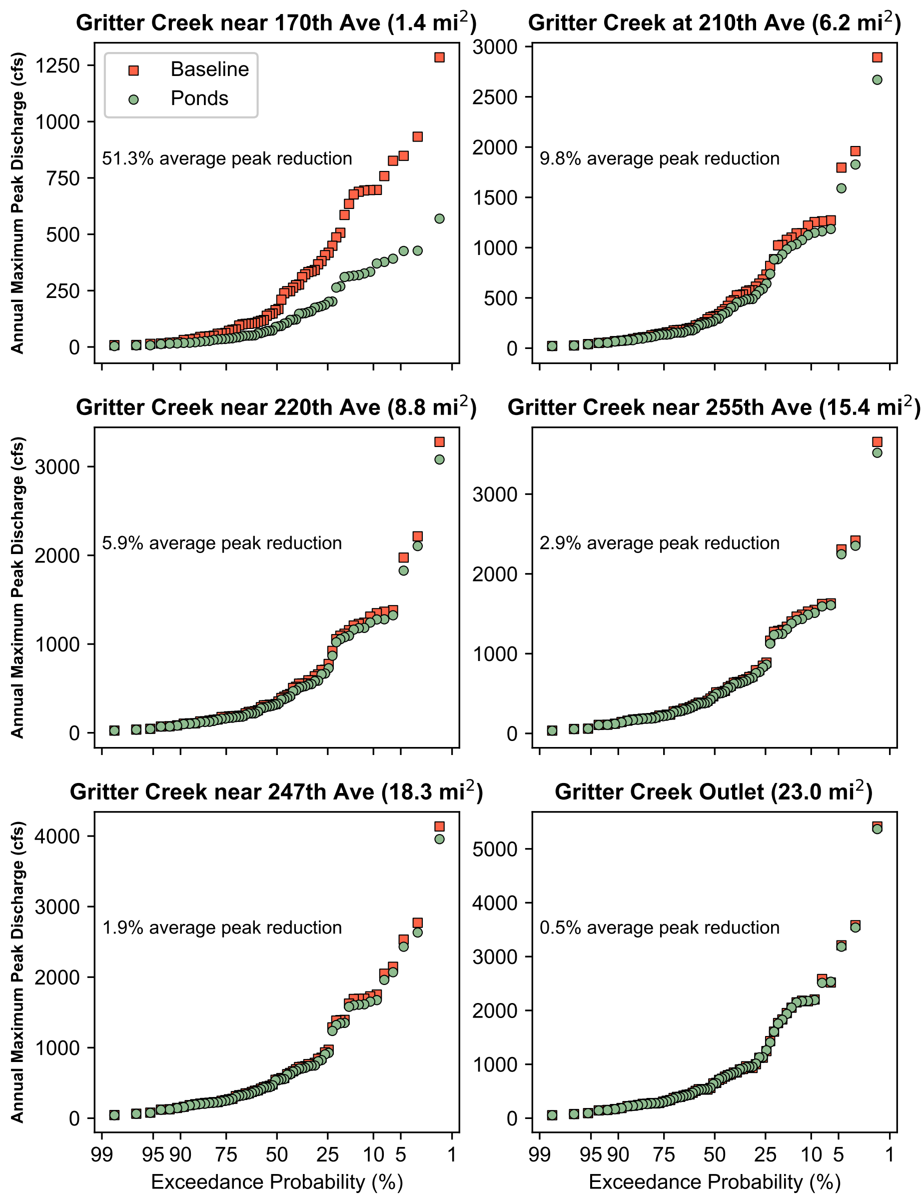

Figure 5.8: Gritter Creek Flood Frequency Analysis for Full Pond Implementation. Probability distribution of annual maximum peak discharges for the baseline simulation and the pond implementation simulation for Gritter Creek.

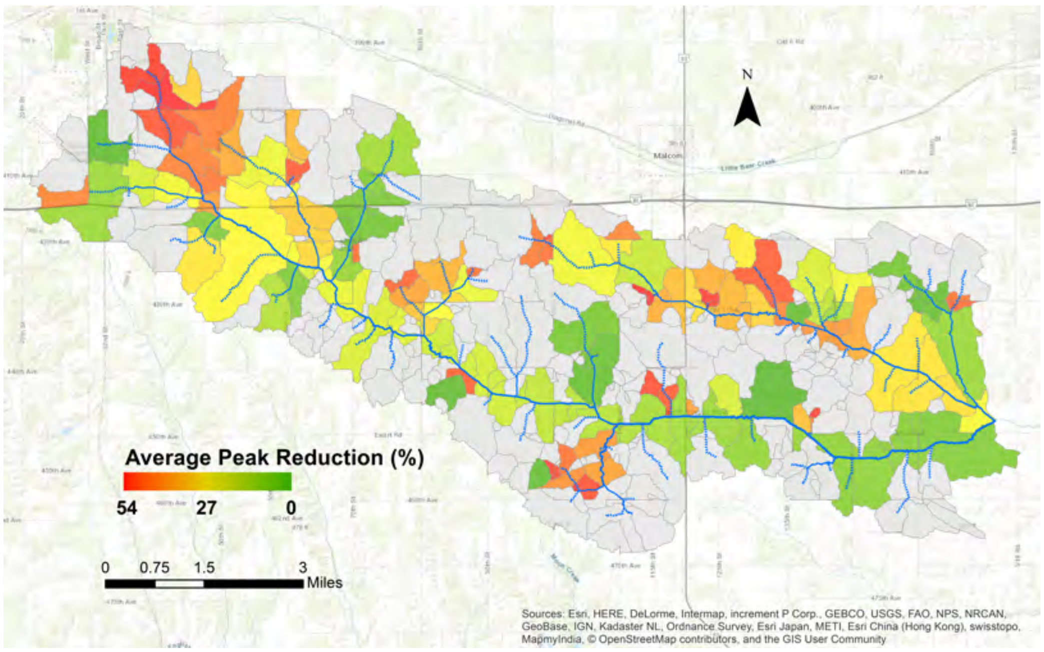

Figure 5.9: Headwaters North English River Average Peak Reduction Map with ACPF NRW. Average peak discharge reduction (in %) for each subbasin in Headwaters North English River between the baseline simulation and pond implementation scenario.

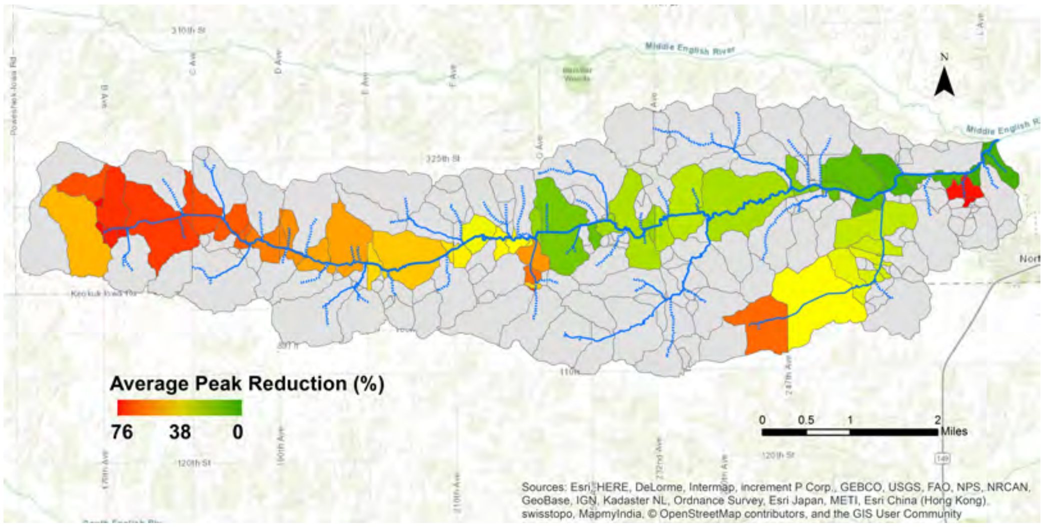

Figure 5.10: Gritter Creek Average Peak Reduction Map with ACPF NRW. Average peak discharge reduction (in %) for each subbasin in Gritter Creek between the baseline simulation and pond implementation scenario.

no reduction seen at any subbasin that is located upstream of ponds, or in other words subbasins that have no area regulated by ponds. In Headwaters North English River, 177, or 43.5% of the subbasins were upstream of ponds and therefore were unaffected while 137, or 63.7% were upstream in Gritter Creek.

Finally the reductions can be seen across the index locations for different return period events in Tables 5.4 and 5.5. The event peak discharges were calculated from the 64-year annual peak discharge, where each event is equal to the expected frequency of that size event, i.e., for the 50-year event the chance of occurrence is 2% each year. As seen before the reductions decrease as upstream area increases. At each location the reduction between the 2, 10, 25, and 50 year event is fairly uniform. Since the large and small events show similar reductions the pond flood storage is not being exhausted in the smaller events.

5.3.2 Partial Pond Implementation

Another scenario was considered with partial implementation of ACPF ponds in Headwaters North English River. Twenty of the 39 ACPF NRW were

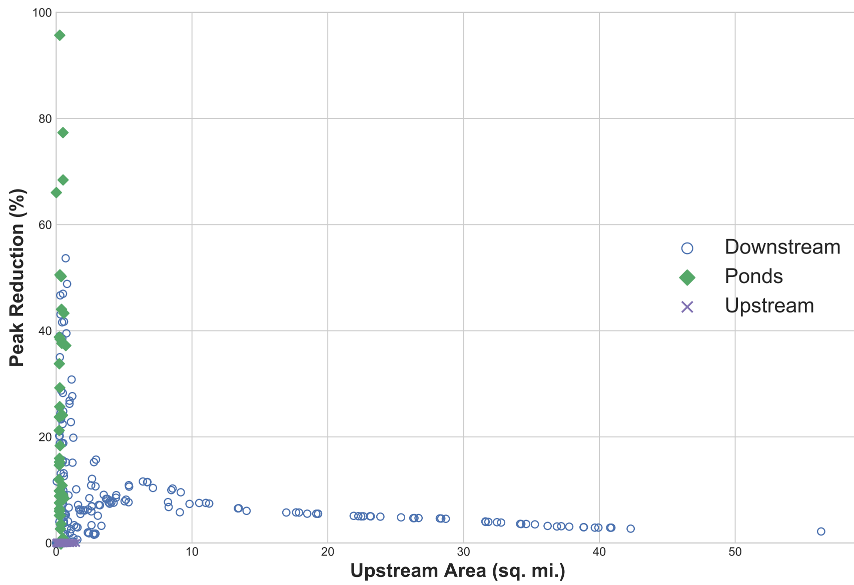

Figure 5.11: Headwaters North English River Peak Reduction with ACPF NRW. Average peak reduction for each subbasin in Headwaters North English River. The points are labeled by whether they are upstream of ponds, at the site of a pond, or downstream of ponds.

Table 5.4: Headwaters North English River Pond Peak Reductions. Peak reduction in Headwaters North English River at the six index locations. The average over 64 years is shown along with the 2-, 10-, 25-, and 50-year events (in %). The upstream drainage area is also shown for each point.

			Return Period			
Location	Upstream Area (mi^2)	Average	2-year	10-year	25-year	50-year
North English River at 400th Ave	0.7	54.7	53.9	56.0	57.4	58.8
North English River at I80	2.3	7.3	5.4	7.9	10.0	8.6
Dugout Creek at 142nd St	8.5	12.6	10.5	14.4	14.7	15.3
North English River near 100th St	25.4	5.5	4.3	6.3	5.1	7.0
North English River near 135th St	35.3	3.9	3.6	4.3	3.7	4.5
Headwaters North English River Outlet	56.3	2.5	2.0	2.7	3.1	3.1

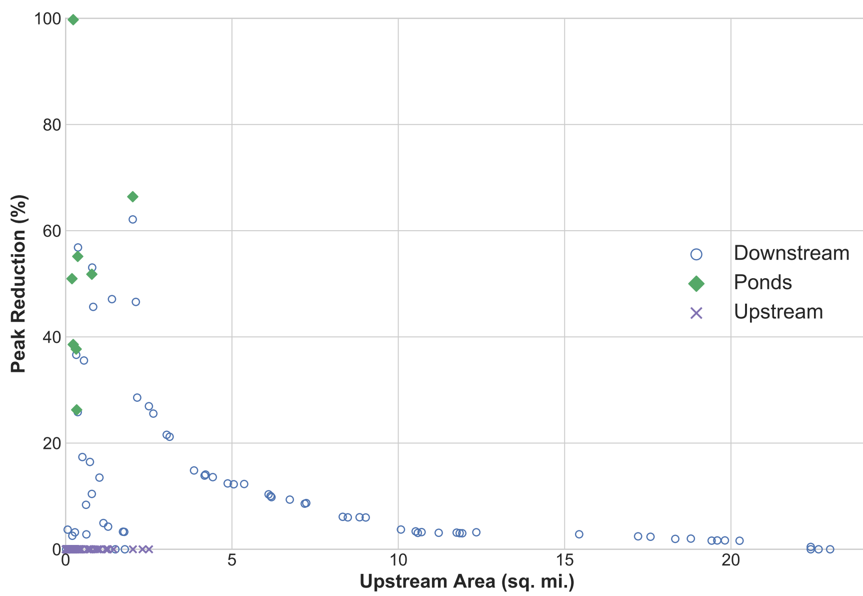

Figure 5.12: Gritter Creek Peak Reduction with ACPF NRW. Average peak reduction for each subbasin in Gritter Creek. The points are labeled by whether they are upstream of ponds, at the site of a pond, or downstream of ponds.

Table 5.5: Gritter Creek Pond Peak Reductions. Peak reduction in Gritter Creek at the six index locations. The average over 64 years is shown along with the 2-, 10-, 25-, and 50-year events (in %). The upstream drainage area is also shown for each point.

Location	Upstream Area (mi^2)	Average	Return Period 2-year	10-year	25-year	50-year
Gritter Creek near 170th Ave	1.4	51.3	45.7	49.5	51.7	55.4
Gritter Creek at 210th Ave	6.2	9.8	12.1	8.2	9.5	7.5
Gritter Creek near 170th Ave	8.8	5.9	4.4	5.2	6.4	5.8
Gritter Creek near 255th Ave	15.4	2.9	2.4	2.6	2.7	3.5
Gritter Creek near 247th Ave	18.3	1.9	2.1	0.4	1.2	1.5
Gritter Creek Outlet	23.0	0.5	1.3	0.4	1.0	1.0

randomly selected. The new summary of pond characteristics for the index points is shown in Table 5.6. North English River at I80 had all of its upstream ponds removed for this simulation and at the outlet the area regulated by ponds is 13.28% instead of 20.8% for the full implementation scenario.

Table 5.6: Headwaters North English River Index Location Pond Characteristics for Partial Implementation. Summary of pond characteristics at Headwaters North English River index locations for the first partial implementation scenario of 20 ponds. The upstream drainage area, the number of ponds, and the drainage area upstream of the ponds is indicated by index location.

Location	Drainage Area (mi^2)	Ponds Upstream (#)	Area Upstream From Ponds (mi^2)	Area Upstream From Ponds (%)
North English River at 400th Ave	0.7	2	0.55	78.6
North English River at I80	2.3	0	0.00	0.0
Dugout Creek at 142nd St	8.5	4	1.29	15.2
North English River near 100th St	25.4	10	3.67	14.4
North English River near 135th St	35.3	13	4.83	13.7
Headwaters North English River Outlet	56.3	20	7.47	13.3

Finally, another scenario of 20 random ponds was run for Headwaters North English River and is shown with the full implementation and the 1st 20 pond run in Figure 5.13. The annual average peak reduction is shown for each subbasin that was downstream of ponds, i.e., greater than zero annual average peak reduction. The two 20 pond scenarios show a similar trend of tracking the reductions of the full implementation closely but with a slightly lower magnitude.

A partial pond implementation scenario was not run for Gritter Creek due to there only being seven ponds total in the watershed.

5.4 Summary

Using ACPF allows specific sites to be identified for practices, including nutrient removal wetlands. Since nutrient removal wetlands are a specific type of pond, they can be reasonably designed as ponds to get a stage-storage-discharge relationship necessary for hydrologic modeling. The sites

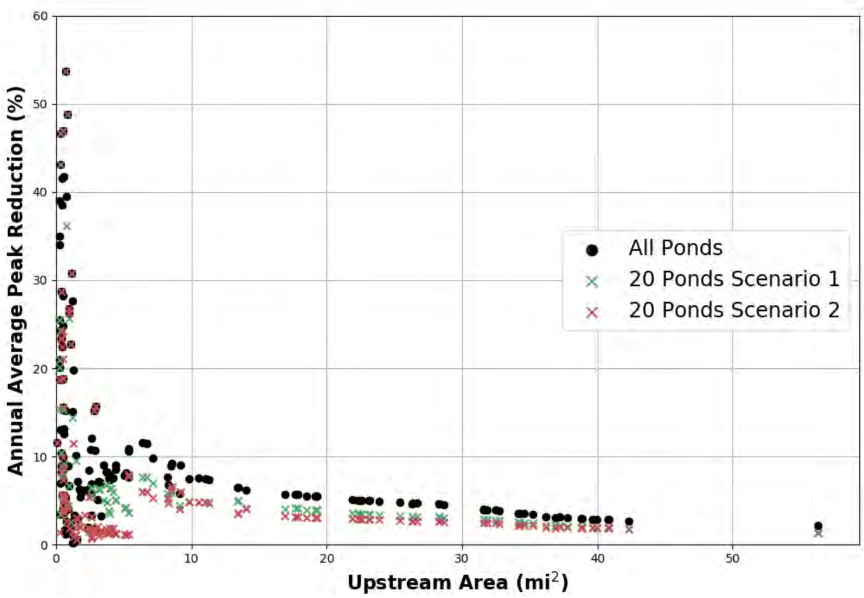

Figure 5.13: Headwaters North English River Average Peak Reduction for NRW Implementation Scenarios. Average peak reduction for each subbasin downstream of a pond for three simulations. The first is the full implementation, the second is one scenario with 20 randome ponds, and the third is a different random set of 20 ponds.

then have associated physical characteristics such as the permanent pool area or permanent pool storage. With the addition of a stage-area-storage relationship derived from a DEM using GIS tools, a pond design can be performed for each location using NRCS's SITES program. A Python script enabled the efficient design of numerous ponds in an automated manner.

Deriving the stage-area-storage relationship turned out to be a time-consuming step and examination of the stage-area curves showed they could be reliably modeled using linear regression and the ACPF-provided pool elevation and storage, and auxilary spillway elevation and total storage. The script was modified to include the linear regression and removed the need for site-specific stage-area-storage curves explicity from a DEM, thereby greatly speeding up the process. The developed pond design script features flexible outputs that are quick to place into HSPF, or can be tailored to other hydrologic models as necessary.

The new refined HSPF model was then used to evaluate the effects of the designed ponds on the flooding characteristics in Headwaters North English River and Gritter Creek. Both watersheds showed reductions in peak flows throughout. The highest reductions were seen in headwater subbasins characterized by smaller drainage areas and a greater percent of upstream area regulated by ponds. Flood reductions diminished downstream as the fraction of area regulated by ponds decreased. Full ACPF NRW implementation into Headwaters North English River produced reduced peak discharges of up to 54% down to 2.5% at the outlet. Gritter Creek had reductions of up to 76% and 0.5% at the outlet. Half pond implementations in Headwaters North English River showed a similar trend of reduced peak discharges across the watershed at a slightly lower magnitude.

Chapter 6

ACPF WASCOB Characterization and Effects on High Runoff

6.1 Introduction

In addition to ponds, WASCOBs are another practice that shows considerable potential for implementation in the two watersheds. In order to measure the effects of fulfilling that potential WASCOBs were designed and included in the HSPF model. Following a similar process to ponds a design methodology was created to explicitly model ACPF WASCOBs. The ACPF information was aggregated based on subbasin and modeled using a combination of the traditional orifice equation and SITES. Existing WASCOBs identified by the IBMP were not included in the simulation. Even though numerous in the each watershed, site-specific topographic and hydraulic information is not readily available for modeling existing WASCOBs effects.

WASCOBs were implemented into the model in two scenarios to evaluate their effects on peak discharges in Headwaters North English River and Gritter Creek. The first scenario was a complete implementation of all WASCOBs and the second was an implementation of half the WASCOBs. WASCOBs act similar to ponds in that they hold back and delay runoff but do not reduce the overall volume. Additionally WASCOBs contain no permanent pool, so all storage provided by WASCOBs is considered flood storage.

6.2 WASCOB Design Script

Following the NRW pond design a process was designed to model the WASCOBs within each model subbasin. The ACPF WASCOB locations contain site information just as the NRWs did. Many of the subbasins contains multiple WASCOBs. To model the WASCOBs efficiently, the WASCOBs were combined within each subbasin. The single aggregated WASCOB was the sum of each WASCOBs storage, basin area, and drainage area. For example, if a subbasin contains four WASCOBs, each with 1 acre-foot of storage, the single aggregated WASCOB would have 4 acre-feet of storage.

The combined drainage area is the total area of each subwatershed regulated, or the watershed percentage regulated as shown in Figure 6.1. That area was routed through the WASCOB while the remaining area was unregulated. Using the combined area and storage, polynomials are fit for each WASCOB to determine the storage and area relationships. Then for the stages between the bottom and top of the WASCOB area, storage, and discharge are solved for. Each WASCOB is assumed to have a 6 inch perforated riser inlet located 3 inches off the ground. The discharge (Q) is then regulated by an orifice equation shown in Equation 6.1,

$$Q = C_d(\pi \frac{D^2}{4})\sqrt{2gh} \tag{6.1}$$

where C_d is the dimensionless coefficient of discharge, D is the pipe diameter, g is the acceleration due to gravity, and h is the effective head. Once the stage is above the WASCOB berm, then the discharge changes to a combination of the orifice flow and weir flow over the berm. To model the weir flow SITES was utilized again. Using a prototype small pond, a 10-foot wide, 8-feet long auxiliary spillway rating curve was developed for stages of 0 to 4 feet over the auxiliary spillway. The rating table was then used to interpolate for the stages above the WASCOB berm to find the weir discharge. The orifice and weir discharges are combined to find the total discharge. As with the NRW pond design, a Python script was written to automate the process. It enables the user to compute WASCOB rating curves for hundreds of subbasins in a matter of seconds. The outputs are also in the form of the pond design script with one file containing all the FTABLES that can be simply copied and pasted into HSPF. The complete code can be found in the Appendix.

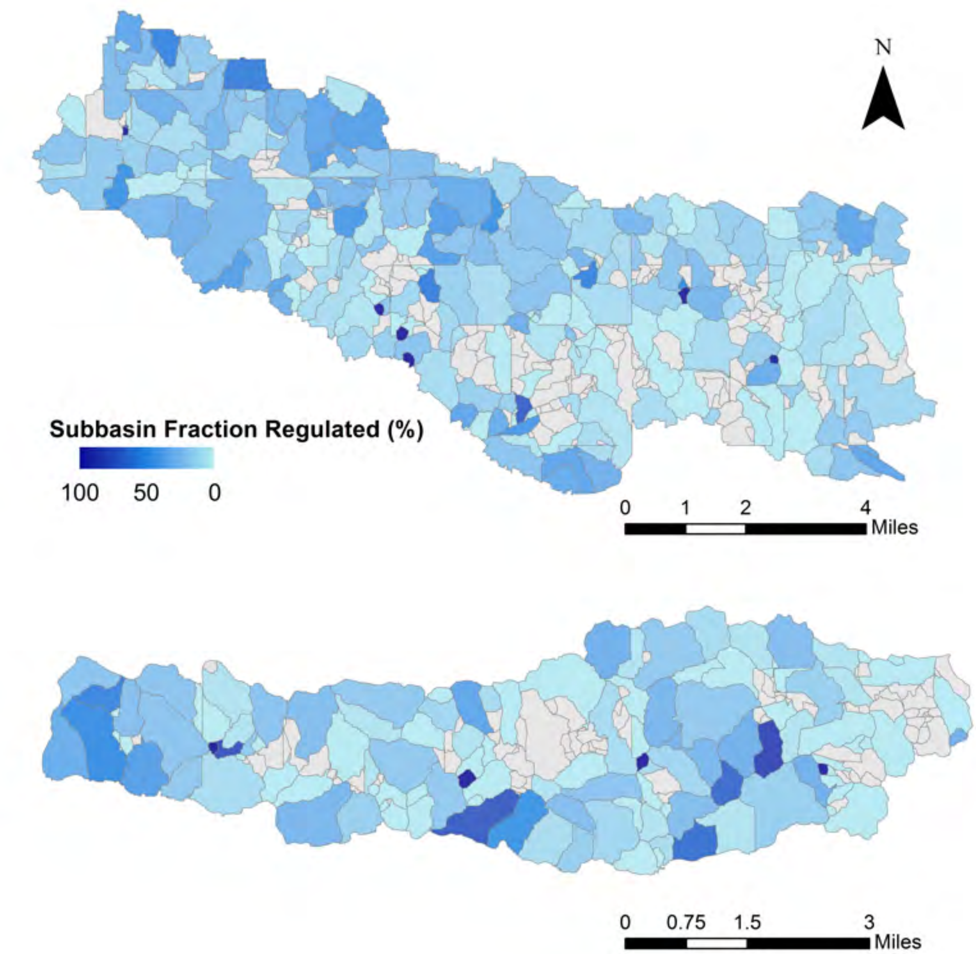

Figure 6.1: WASCOB Subwatershed Regulation. The combined area of each subbasin regulated by a WASCOB in Headwaters North English River (top) and Gritter Creek (bottom).

Table 6.1: Characteristics of WASCOBs for Full Implementation. Summary of the WASCOB characteristics implemented into the model for full implementation scenario.

HUC-12 Watershed	Number of ACPF WASCOB	Watershed Fraction Regulated (%)	Total Flood Storage (ac-ft)	Total Flood Storage Depth (in)
Headwaters North English River	826	16.3	947.2	1.94
Gritter Creek	255	16.6	232.5	1.14

6.3 Evaluation of Peak Discharge Reduction with Full WASCOB Implementation

With the expectation that WASCOB will affect the peak flows more subtly than ponds the HSPF model time step was reduced. The original model ran at a one hour time step but for the WASCOB simulations the time step was reduced to five minutes for the routing portion of the model. Table 6.1 shows a summary of the characteristics of the WASCOBs implemented into the model. Both watersheds have a similar fraction of the watershed regulated by WASCOBs at 16.3% for Headwaters North English River and 16.6% for Gritter Creek. Headwaters North English River has 826 WASCOBs compared to only 255 in Gritter Creek and correspondingly has 947.2 acre-feet of flood storage versus 232.5 acre-feet in Gritter Creek. The total flood storage depth is also considerably higher, 1.94 inches, compared to 1.14 inches.

To analyze the effects of WASCOB's flood storage on the peak discharges, a flood frequency analysis for each watershed is shown in Figures 6.2 and 6.3. The flood frequency analysis followed the process previously mentioned in Chapter 6. The largest average peak reduction in Headwaters North English River is 26.3% at North English River at 400th Ave. The outlet shows a considerable average peak reduction as well of 12.4%, this is much larger than the full pond implementation outlet reduction of 2.5%. Gritter Creek has a largest average peak reduction of 7.8% at Gritter Creek at 210th Ave and shows only a 2.9% average peak reduction at the outlet. The outlet reduction is more than for ponds though which was 0.5%.

WASCOBs show more even peak discharge reductions across the watershed compared to ponds. Figures 6.4 and 6.5 show there are still several basins with high average peak reductions of up to 90% and 100%, the majority show lower reductions throughout the watershed. The wide, consistent peak reductions is due to the number of WASCOBs and how many basins are

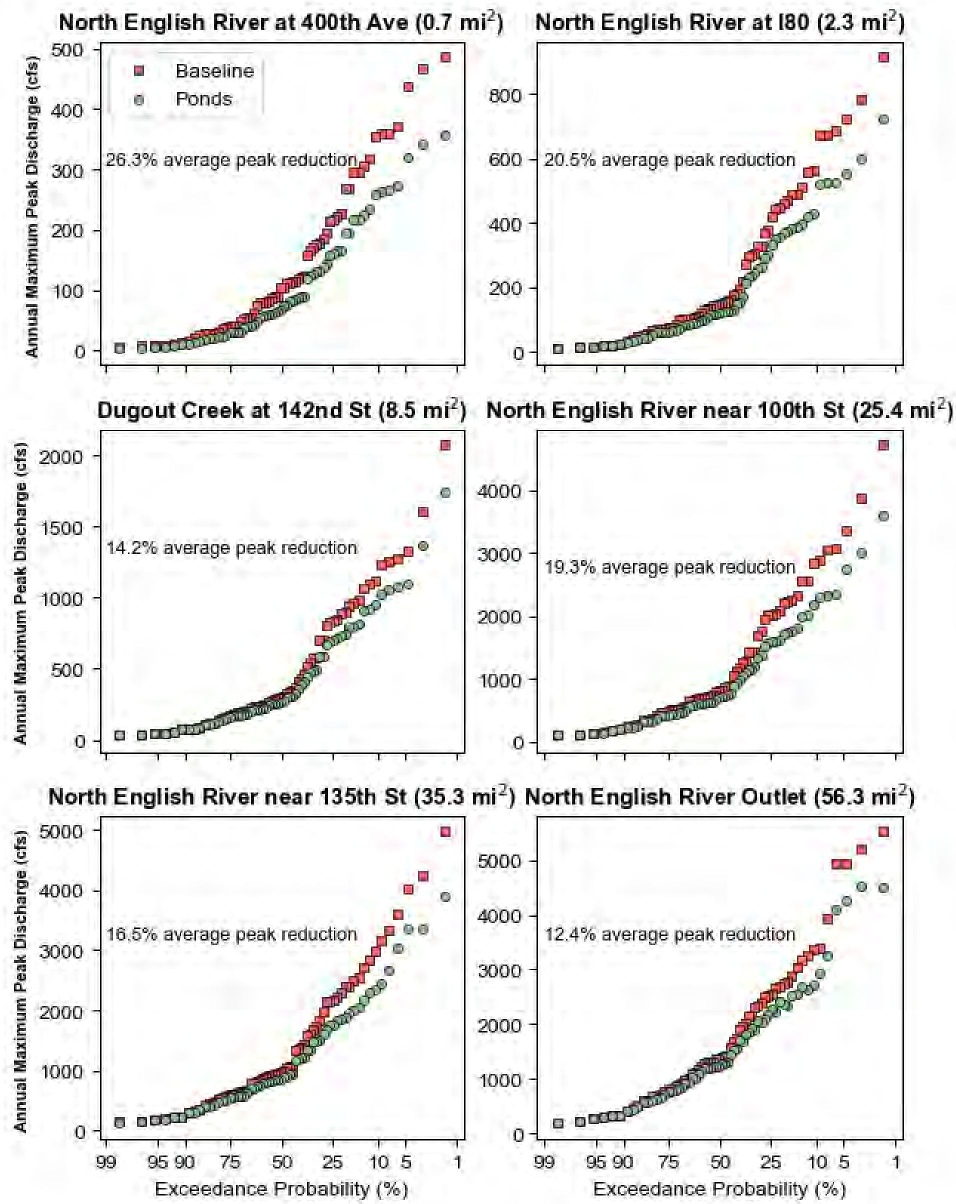

Figure 6.2: Headwaters North English River Flood Frequency Analysis for Full WASCOB Implementation. Probability distribution of annual maximum peak discharges for the baseline simulation and the full WASCOB implementation simulation for Headwaters North English River.

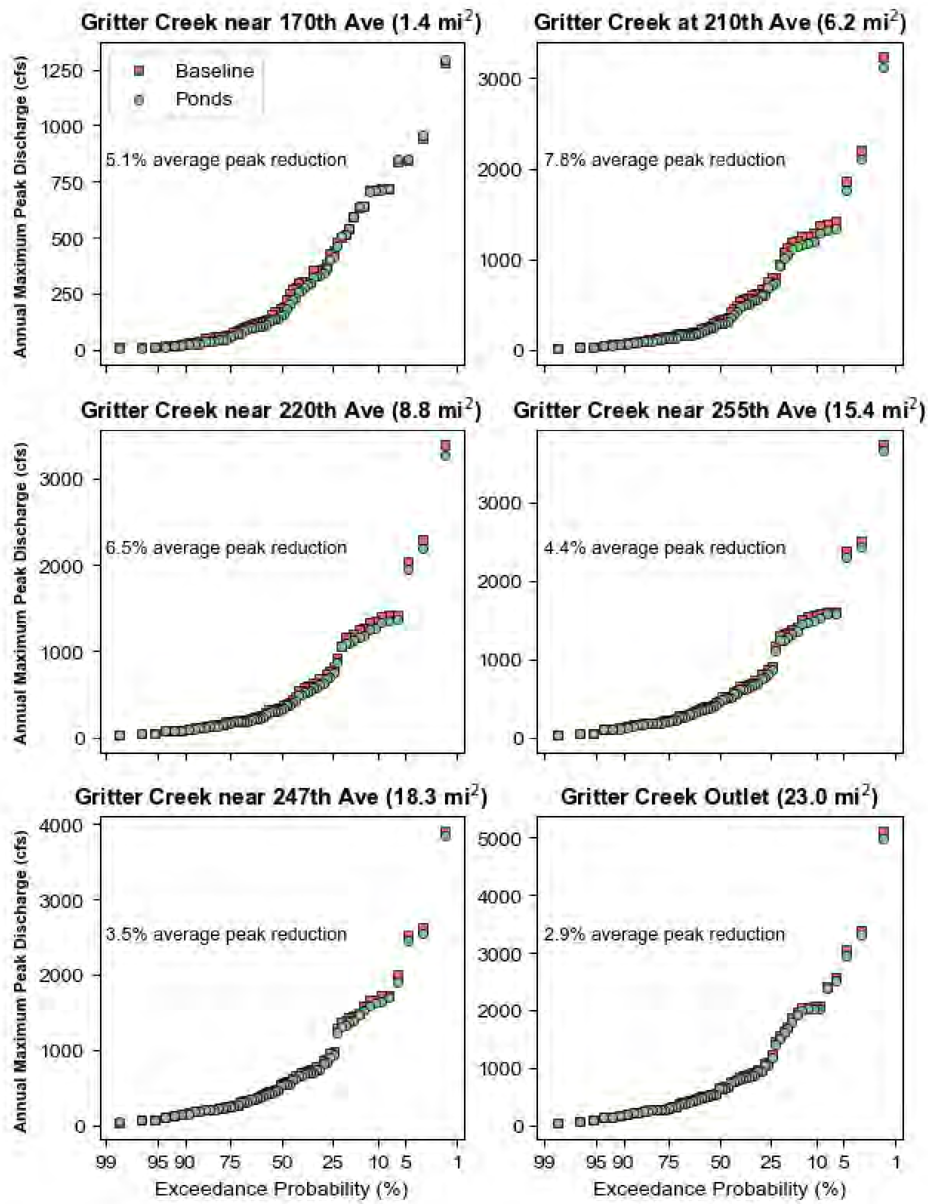

Figure 6.3: Gritter Creek Flood Frequency Analysis for Full WASCOB Implementation. Probability distribution of annual maximum peak discharges for the baseline simulation and the full WASCOB implementation simulation for Gritter Creek.

directly affected by WASCOBs regulating flow as shown in Figure 6.1. Over half, 64.4% (262 of 406), of the subbasins in Headwaters North English River and in Gritter Creek, 52.1% (112 of 215), have some percentage of their area regulated by WASCOBs.

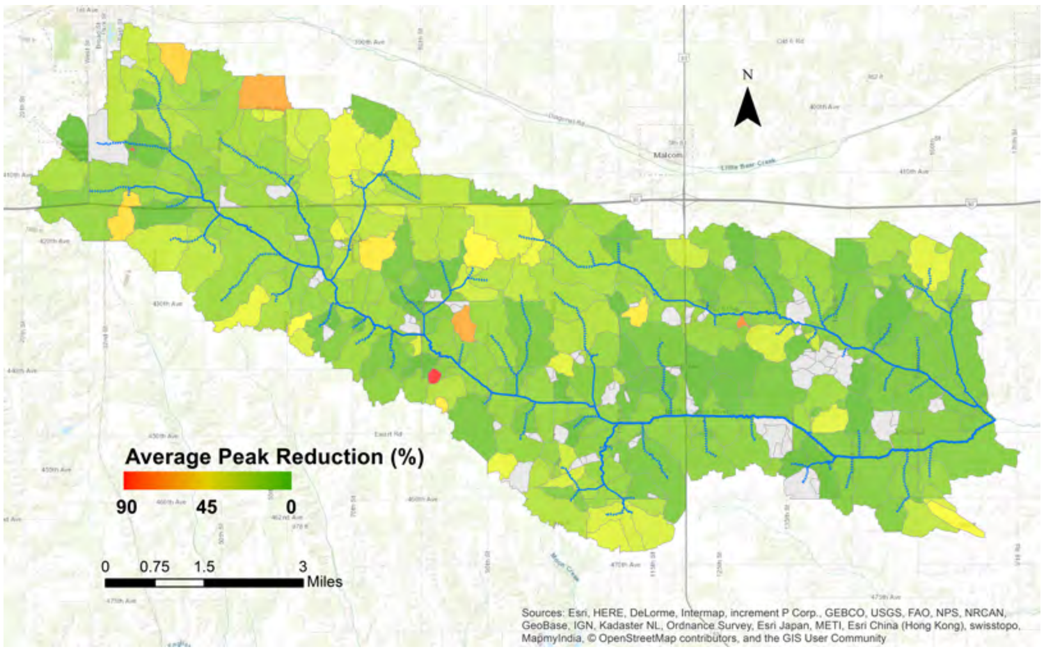

Figure 6.4: Headwaters North English River Peak Reduction with Full WASCOB Implementation. Average peak discharge reduction (in %) for each subbasin in Headwaters North English River between the baseline simulation and the complete WASCOB implementation scenario.

To further investigate the effect of WASCOBs on peak discharge, a single subbasin from Headwaters North English River was selected for an event analysis. RCHRES 126 is a headwater basin that drains 200 acres and contains 8 ACPF WASCOBs that regulate 22.6%, or 45.2 acres of the subbasin. The subbasin has an average peak reduction of 28.5% for the entire simulation period. The hourly hydrograph is seen in Figure 6.6. The clear peak reductions are seen for the four peaks over the event. The largest reduction correlates with the largest peak. The WASCOB discharge is regulated by the orifice and shows an elongated tailing limb after each peak. Since the WASCOB discharge has a smooth curve the WASCOB is never overtopped otherwise there would be a large increase in flow as weir flow is added to

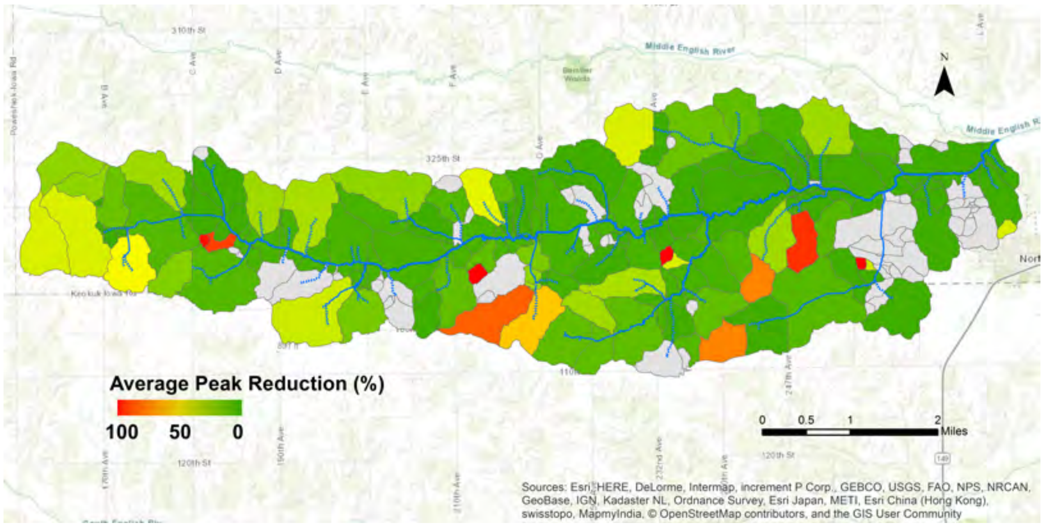

Figure 6.5: Gritter Creek Peak Reduction with Full WASCOB Implementation. Average peak discharge reduction (in %) for each subbasin in Gritter Creek between the baseline simulation and the complete WASCOB implementation scenario.

the orifice flow. The WASCOBs act very similar to ponds as they hold back water, and then slowly release it.

6.4 Evaluation of Peak Discharge Reduction with Partial WASCOB Implementation

A second scenario was simulated for both watersheds with a random selection of half the WASCOBs implemented. Since the design of WASCOBs was done based on aggregation over a subbasin, the selection of half the WASCOBs was done by subbasin as well. Half the subbasins containing WASCOBs were removed so the number of WASCOBs themselves may slightly vary from half. Table 6.2 shows the new WASCOB characteristics. Headwaters North English River ended up having the same total flood storage depth of 1.94 inches for both scenarios while Gritter Creek decreased from 1.14 inches to 1.09 inches.

Figures 6.7 and 6.8 show the average annual peak reduction for each subbasin that is downstream of any WASCOBs. The half WASCOB scenarios

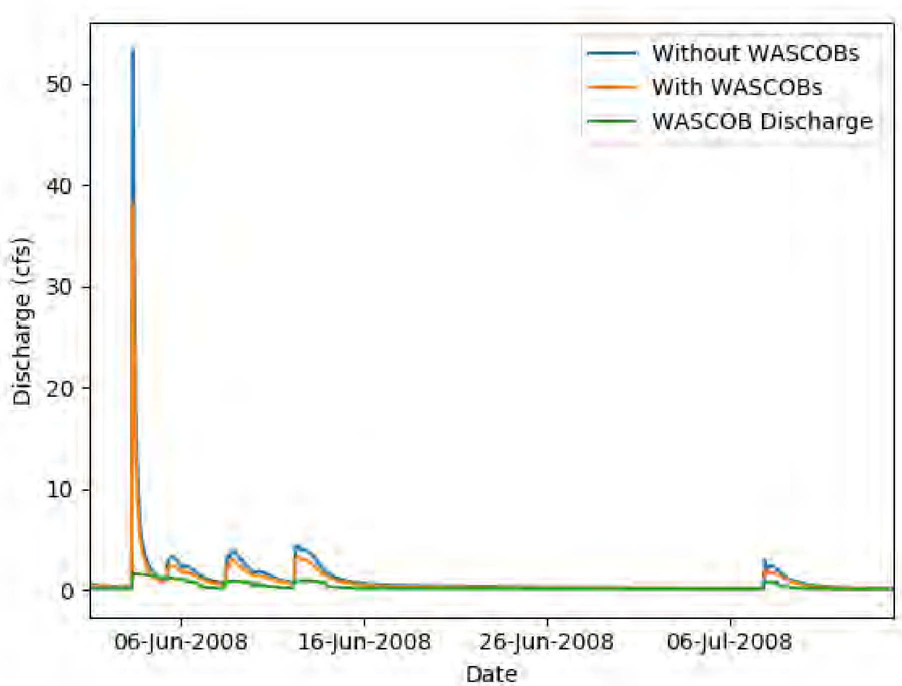

Figure 6.6: Single Subbasin Event Analysis. Hourly discharges for the 2008 flood with the original model (blue), with WASCOBs included (orange), and just the WASCOB outlet (green).

Table 6.2: Characteristics of WASCOBs for Partial Implementation. Summary of the WASCOB characteristics implemented into the model for partial implementation scenario.

HUC-12 Watershed	Number of ACPF WASCOB	Watershed Fraction Regulated (%)	Total Flood Storage (ac-ft)	Total Flood Storage Depth (in)
Headwaters North English River	392	7.9	460.3	1.94
Gritter Creek	134	9.3	125.9	1.09

show less reduction, but follow a similar pattern of lessening peak discharge reduction as the upstream area grows. The pattern is not as pronounced as the pond scenarios shown in Figure 5.13. The peak reduction from WASCOBs continues throughout the subbasins with larger drainage area whereas the ponds shown a sharper decrease. For WASCOBs the outlet for Headwaters North English River still shows a considerable peak reduction of 5.0% for the half implementation scenario while Gritter Creek's outlet showed only a reduction of 2.0%.

Summarizing the effectiveness of each scenario at the six index locations is shown in Figures 6.9 and Figures 6.10 for the 25-year return period. The index locations are listed by increasing drainage area starting with the smallest on the left. Within Headwaters North English River the full WASCOB implementation showed the largest average peak reduction at every location besides North English River at 400th Ave which is located directly downstream from two ponds. Gritter Creek only shows three scenarios due to no partial pond implementation scenarios being run. The pond scenario shows the largest reduction at the three smallest drainage area index locations (Gritter Creek near 170th Ave, Gritter Creek at 210th Ave, and Gritter Creek near 220th Ave). The other three locations have the largest peak reductions from full WASCOB implementation. Across both watersheds WASCOBs showed less reduction in effectiveness as the drainage area grew.

6.5 Summary

Incorporating WASCOBs into the HSPF model was detailed in this chapter. The design was performed for WASCOBs aggregated within each subbasin. The combined characteristics were used to fit a stage-area relationship that determined the orifice flow discharge when the stage was below the top of the WASCOB. Above the WASCOB, weir flow was modeled using a prototype

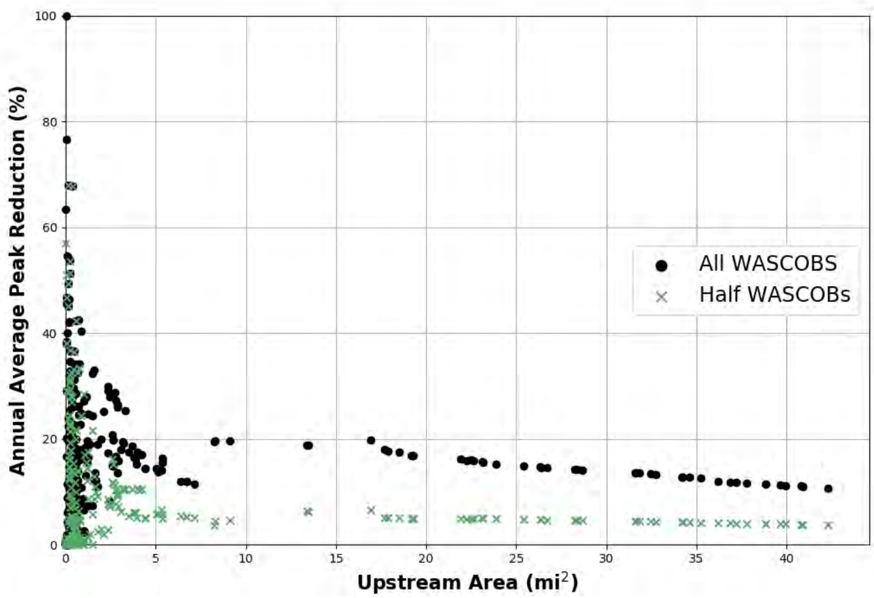

Figure 6.7: Headwaters North English River Peak Reduction with WASCOB Implementation. Average peak reduction in Headwaters North English River for each subbasin downstream of a WASCOB for the two simulations. The first is a full implementation of WASCOBs and the second is a random selection of half the WASCOBs.

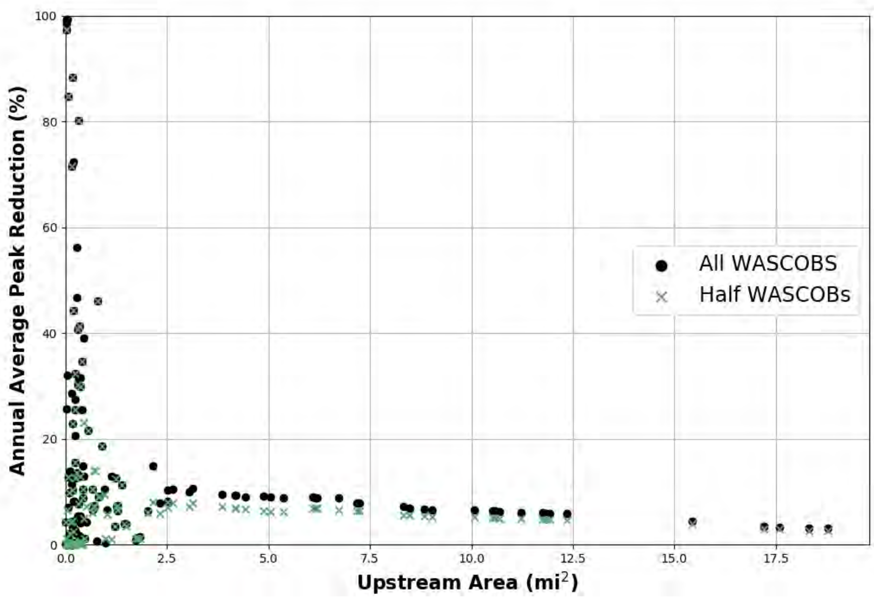

Figure 6.8: Gritter Creek Peak Reduction with WASCOB Implementation. Average peak reduction in Gritter Creek for each subbasin downstream of a WASCOB for the two simulations. The first is a full implementation of WASCOBs and the second is a random selection of half the WASCOBs.

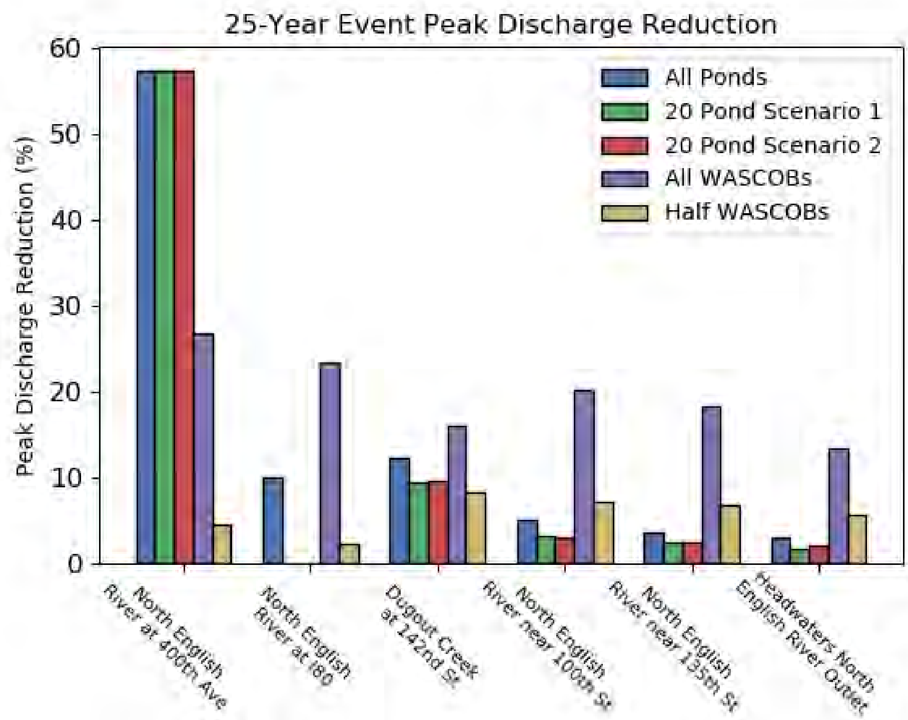

Figure 6.9: 25-Year Event Headwaters North English River Peak Reduction. The 25-year return period peak reduction for all scenarios simulated in Headwaters North English River.

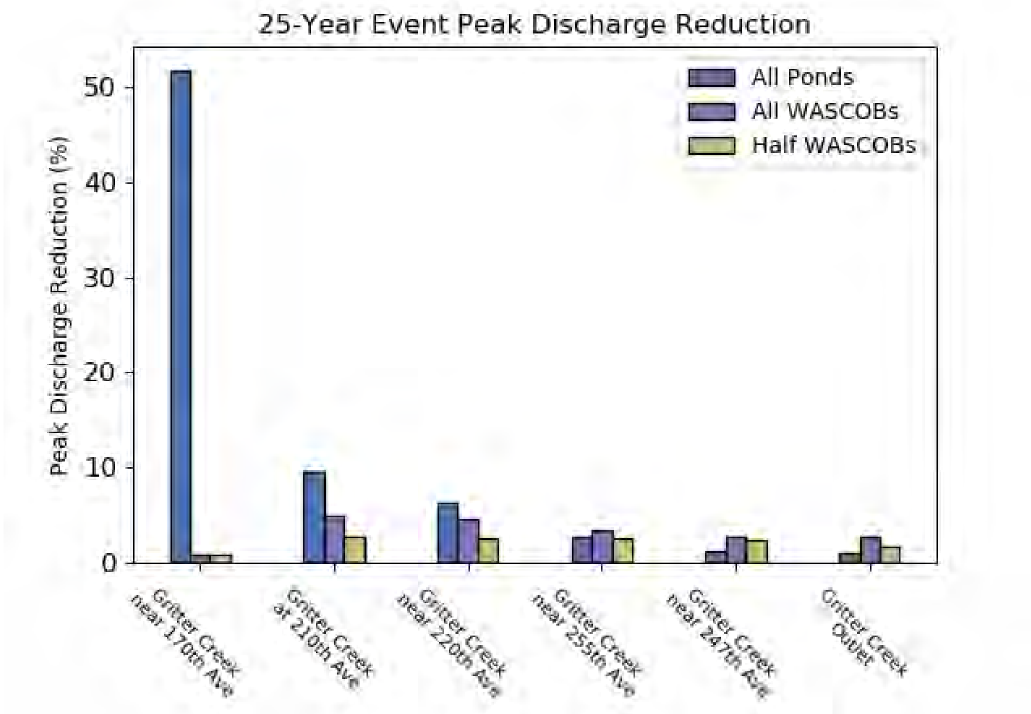

Figure 6.10: 25-Year Event Gritter Creek Peak Reduction. The 25-year return period peak reduction for all scenarios simulated in Gritter Creek.

pond in SITES. The combination gives a unique FTABLE to use in the model. The designed WASCOBs were used in simulations to analyze the reduction on peak discharges via full and partial implementation within Headwaters North English River and Gritter Creek.

Because WASCOBs are more numerous than nutrient removal wetlands, and are widely distributed throughout the watershed, WASCOBs reduce peak discharges in more of the subbasins within the two watersheds. For the subbasins, we saw average peak reductions of up to 90% in Headwaters North English River and 100% in Gritter Creek. An event analysis showed how the WASCOBs acted as ponds and released water slowly from large events and reduced peak discharges. The partial implementation scenarios showed lower magnitude peak reductions but similar trends in each watershed. It is clear that the widespread implementation of WASCOBs, which has already occurred in the Headwaters and Gritter Creek, is helping to reduce flood discharges in the watersheds.

We compared the peak reduction effects of nutrient removal wetlands and WASCOBs for the 25-year return period. Nutrient removal wetlands showed larger reductions for one index location in Headwaters North English River and three in Gritter Creek. WASCOBs provided larger peak reductions for the other eight locations. WASCOBs also showed more consistent peak reductions across the range of drainage areas because of their wide distribution throughout the watersheds; nutrient removal wetlands are most effective immediately downstream of the wetland, and their peak reduction effect diminishes moving downstream to the watershed outlet.

Chapter 7

Summary and Conclusions

As a part of the Iowa Watersheds Approach, this work aimed to assess the potential of conservation practices within the English River watershed. The assessment focuses on two priority HUC-12 watersheds within the English River: Headwaters North English River and Gritter Creek.

To gain insight into the current state of conservation in the two HUC-12 watersheds, a comparison of existing and potential conservation practices was undertaken using the products of the Iowa BMP Mapping Project (IBMP) and the application of the Agricultural Conservation Planning Framework (ACPF). Both identify a number of practices, and for this study, grassed waterways, water and sediment control basins (WASCOBs), and nutrient removal wetlands and ponds were compared. The results show that grassed waterways and WASCOBs are widely implemented in the two watersheds; their quantity and location of closely matches the practice potential. In contrast, the comparison shows significant potential for adding nutrient removal wetlands in the watersheds.

The next task was to model conservation practices in the watershed to quantify their effects. The English River WMA had previously commissioned the IFC to create a hydrologic assessment including a hydrologic model. Refining the existing model enabled high resolution modeling of nutrient removal wetlands and WASCOBs. A process to model both from ACPF outputs was encompassed in a Python script that enables efficient design for hydrologic modeling. The designs were placed into the model to simulate full and partial implementation scenarios. The results showed significant reductions, especially on small drainage areas, for both practices.

7.1 Implementation of Conservation Practices

Conservation practices are one of the main tools used to mitigate floods and restore the natural resiliency of the landscape. The knowledge of what practices are present on the landscape and what potential the landscape has for practice implementation is an important step in planning conservation. The Iowa BMP Mapping Project (IBMP) and the Agricultural Conservation Planning Framework (ACPF) have been developed to answer those questions. The IBMP identifies six existing conservation practices on the landscape through manual delineation using LIDAR, aerial photography, and other available data. The ACPF suggests locations for implementation for a number of conservation practices based on a number of GIS data inputs including soils, elevation, and land use.

Three of the common conservation practices between the two were selected for comparison to gain insight into the current implementation level in these watersheds. Grassed waterways, WASCOBs, and nutrient removal wetlands and ponds were the chosen. To compare the practices required designing grassed waterways using the ACPF locations according to NRCS codes. The locations of WASCOBs and pond dams were used to find their respective drainage areas. The practices were then compared based on drainage area and the flow path order stream they were present on. From the comparison, conservation is prevalent across the watersheds with grassed waterways nearing full implementation showing that the benefit is nearly fully realized from them. For ponds, there are many across the landscape but the drainage area comparison showed that they are of a smaller magnitude than wetlands leaving potential for wetland implementation. WASCOBs are numerous in the two watersheds, with limited potential for more implementation. In contrast, studies in other Iowa HUC-12 watersheds showed almost zero WASCOB implementation, suggesting significant benefits could be realized elsewhere with WASCOB use (*Rundhaug et al.*, 2018).

7.2 Enhanced Resolution HSPF Model

Hydrological Simulation Program — FORTRAN (HSPF) is a well-established hydrologic model developed in the 1970s. It allows for flexibility in handling complex land uses and continuous modeling for simulations covering many years. An existing, calibrated English River HSPF model was used as the basis for creating a higher resolution, refined model (*Iowa Flood Center*, 2015). New models were created for two HUC-12 watersheds within the English River, Headwaters North English River and Gritter Creek. The new delineation included a subbasin at each ACPF nutrient removal wetland, existing pond, road crossing, and stream junction. The new models decreased the average subbasin size from 3,904 acres to 88.6 acres in Headwaters North English River and 68.5 acres in Gritter Creek. The number of subbasins increased from 103 for the entire English River to 407 in Headwaters North English River and 215 in Gritter Creek. It was shown through a cumulative runoff depth analysis, annual runoff depth comparison, and flood hydrograph analysis that the new routing did not change significantly the timing and runoff from the original model.

7.3 ACPF Nutrient Removal Wetland Simulation

To determine the effects of conservation practice implementation in each watershed ponds needed to be included into the HSPF models. Using a combination of GIS and the NRCS SITES program, a process was developed to design site-specific ponds at each ACPF nutrient removal wetland location. Existing ponds identified by the IBMP were not included in the simulation. To enable efficient design across a number of watersheds, a Python script was written to largely automate the process. To further optimize the process up, the script was adapted so a linear stage-area could be used instead of GIS derived stage-area which was shown to be approximately linear.

Implementation scenarios of the ponds included full implementation with all the ponds and partial scenarios with a random selection of half the ponds. For the full implementation scenario, average peak reductions of up to 54% were seen in Headwaters North English River in headwater basins down to a 0.5% average peak reduction at the outlet. Gritter Creek showed average peak reductions up to 76% and an average peak reduction of 2.5% at the outlet. As the upstream area grew moving downstream in the watersheds the peak reductions diminished. The two partial implementation scenarios in Headwaters North English River showed similarly large reductions in small basins with the outlet reductions down to 1.8% and 1.5%.

7.4 ACPF WASCOB Simulation

For the design of WASCOB aggregation was performed for each subbasin. The combined characteristics of the WASCOBs within that basin were used as the design criteria. Using the known information a polynomial relationship was fit to the stage-area relationship and stage-storage relationship. The flow was then orifice controlled until the WASCOB is overtopped whereupon weir flow is added. The weir flow was estimated using a small prototype pond modeled using SITES again. Another Python script was written to automate the WASCOB design. The scripts developed are applicable for different models and can be used in other watersheds that are a part of the IWA.

Implementation scenarios for WASCOBs followed the ponds and had both full and half implementation. Existing WASCOBs identified by the IBMP were not included in the simulation. WASCOBs showed wide peak reductions across many of the subbasins within each watershed. Headwaters North English River had average peak reductions of up to 90% and 12.4% at the outlet for full implementation. Gritter Creek had average peak reductions of up to nearly 100% and of 2.9% at the outlet. The WASCOB scenarios' peak reductions did not diminish as quickly going downstream as ponds did with even the half WASCOB scenarios showing reductions of 5.0% and 1.7% for Headwaters North English River and Gritter Creek respectively.

A comparison between all the scenarios for the 25-year return period, a significant flood level, showed for Headwaters North English River that full WASCOB implementation provided the most significant average peak reduction at five of six of the index locations. The sole index location where ponds provided the most peak reduction was also the smallest drainage area of only 0.7 mi^2. The scenarios run in Gritter Creek had half, three of six, of the index locations showing the most peak reduction from the full WASCOB scenario and the remaining three from the full pond scenario. The ponds had the most reduction for the three smallest drainage areas, while WASCOBs did for the three largest drainage areas. Overall the study showed that WASCOBs provide large potential, even moreso than wetlands, for peak reductions with widespread implementation across a HUC-12 watershed.

7.5 Concluding Remarks

Conservation practices will be implemented in the English River watershed as part of the Iowa Water Approach. Our assessment shows that there are opportunities for reducing flood discharges and nutrient loads with the implementation of nutrient removal wetlands at drainage areas of around 160 acres or larger. Few such practices now exist in the watersheds. The reductions will be large near the wetlands, but their effects diminish moving downstream; overall reductions at the outlet are small (a few percent). Our assessment shows that there limited opportunities for new grass waterways and WASCOBs in the English River. These practices are already widely implemented within the two watersheds studied. Still, our assessment shows that the existing widespread implementation of WASCOBs may already be having a significant impact on flood discharges. And because their locations are more widely distributed than wetlands, they may produce larger reductions at the outlet and wetlands (3 to 12 percent). Although the potential for WASCOBs is limited in the English River, their potential is significant in many other Iowa watersheds where few WASCOBs have been built.

Appendix A

Pond Design Script

```
#!/usr/bin/env python

## pond_design.py
## ACPF Pond Design---------------------------------------------------
##
## GOAL: Create site specific ponds for each ACPF NRW location.
##
## REQUIRED PYTHON MODULES: sys, subprocess, os, glob, re, time, shutil, pandas, numpy
##
## Currently, the script requires some preprocessing to get additional
## data not provided from ACPF. This includes the average curve number of the pond
## contributing area, average slope of the contributing area, and time of concentration (found
## using NEH630 Ch. 15 eq. 15-5.
##
## The following data needs to be in the spreadsheet with matching names:
## SiteID, ContAreaAC, StrmElev, BankElev, Avg CN, Avg Slope, Tc
##
##
## To run the script, place the .py file, the stage-storage .csv files, the ponds spreadsheet,
## the .bat file, and DamSitesSim.exe in a single folder. The outputs will be placed in the same
## folder.
##
```

```
## The design is run for pipe sizes from 6 to 60 inches until the pipe size is found that causes
## no auxiliary spillway activation from the design storm.
##
##
##
##


## Python modules needed
import sys, subprocess, os, glob, re, time, shutil
import pandas as pd
import numpy as np


## Inputs -------------------------------------------------------
## use the first option to call the script with command line arguments
## use the second to run the script using IDE(i.e. IDLE)
##ponds = sys.argv[1]
ponds = 'PondsData.xlsx'
## End of inputs ------------------------------------------------


## Take current folder as working directory and build paths
folder = os.getcwd()
ponddata = os.path.join(folder,ponds)

## Checking for necessary files

check = [glob.glob('./*.xlsx'),glob.glob('./*.xls')]
if not check:
    print 'Missing Excel file, exiting'
    sys.exit()

check = glob.glob('./*.bat')
if not check:
    print 'Missing batch file, exiting'
    sys.exit()

check = glob.glob('./DamSitesSim.exe')
```

```
if not check:
    print 'Missing DamSitesSim.exe, exiting'
    sys.exit()

check = [glob.glob('./*.csv'),glob.glob('./*.txt')]
if not check:
    print 'No stage-storage .csv files present, exiting'
    sys.exit()


## removes existing FTABLE file if it exists so an empty file is used
tfile = os.path.join(folder,'ftable.txt')
if os.path.exists(tfile):
    os.remove(tfile)


## DEFINING FUNCTIONS-----------------------------------------

# defining cross section of dam (ASCOORD in SITES)
def ascoord(AuxElev, GroundElev):
    length = float((AuxElev-GroundElev)/(0.04))
    x1 = 0.0
    x2 = 40.0
    x3 = 75.0
    x4 = 100.0
    x5 = x4+length
    y3 = AuxElev
    y2 = y3 - (x3-x2)*0.02
    y1 = y2 - (x2-x1)*0.02
    y4 = y3
    y5 = y4-(x5-x4)*0.04
    return (x1,x2,x3,x4,x5), (y1,y2,y3,y4,y5)

#check .OUT file for auxiliary spillway activation
def checkoutput(file):
        for line in file:
            if re.findall('AUXILIARY SPILLWAY DURATION FLOW',line):
                auxsplit = line.split(' ')
                #print auxsplit
```

```
                if any('0.0' in s for s in auxsplit):
                    ##print 'Good design!'
                    return '1'
                else:
                   ##print 'Pipe no good!'
                    return '0'

            if re.findall('ERROR',line):
                return '2'
##-----------------------------------------------------------


# Read in the principal spillway elevation and auxiliary spillway elevation from Pond Spreadsheet

df = pd.read_excel(ponddata,
                      convert_float = True,)
df.columns = [c.replace(' ','_') for c in df.columns]
print 'NUMBER OF PONDS: ' + str(len(df))
## print df.columns.values
df['PoolElev'] = (df['BankElev']+90)*0.0328084
df['ASElev'] = (df['BankElev']+240)*0.0328084
df['ValleyElev'] = (df['StrmElev'])*0.0328084

## later used for HSPF FTABLE
loopindex = 1


##iterates through PondsData Spreadsheet
for row in df.itertuples():

    ## pulls relevant column values for each iteration
    pondid = getattr(row,'SiteID')
    contarea = getattr(row, 'ContAreaAc')
    poolelev = getattr(row,'PoolElev')
    auxelev = getattr(row,'ASElev')
    valleyelev = getattr(row,'ValleyElev')
    avgCN = getattr(row,'Avg_CN')
    avgslope = getattr(row, 'Avg_Slope')
    tc = getattr(row, 'Tc')
```

```
## reads in each stage/storage .csv
df2 = pd.read_csv(os.path.join(folder,'Pond{}_storageCSV.txt'.format(pondid)),
                  )
print "Pond Number: " + str(pondid) + " Pool Elevation: " + str(poolelev)

## converts data from cm to ft and and m3 to ac-ft, extracts only Plane Height and Area 2D columns from stage/storage
df2['Plane_Height'] = df2[' Plane_Height']*0.0328084
df2['Area_2D'] = df2[' Area_2D'] * 0.0002471054
df2fin = df2[['Plane_Height','Area_2D']]
##df2fin = df2fin.round({'Plane_Height': 0})

## selects only stage/storage data above the pool elevation
df2_conditions = df2fin[df2fin['Plane_Height'] > poolelev]


## finds the rate of change between stage and area
a1 = df2_conditions['Area_2D'].iloc[0]
h1= df2_conditions['Plane_Height'].iloc[0]
a2 = df2_conditions['Area_2D'].iloc[-1]
h2 = df2_conditions['Plane_Height'].iloc[-1]
slope = (a1-a2)/(h1-h2)
## creates stage/area point at the pool elevation
poolarea = a1-slope*(h1-poolelev)
maxpoolarea = a1+slope*(10)
## creates maximum pool area point 10 ft above highest stage
maxheight = h1 + 10

## adds new points to new dataframe
dftemp = pd.DataFrame({'Plane_Height': [poolelev,maxheight],
                       'Area_2D': [poolarea, maxpoolarea]})
dftemp = dftemp[dftemp.columns[::-1]]

## appends new data points to existing dataframe
result = pd.concat([df2_conditions,dftemp])
## sorts stage/area data by stage
result = result.sort_values(['Plane_Height','Area_2D'], ascending=[True,False])

## checks the first two elevations to see if they're the same due to coming from differen sources
```

```
## if they are, add 0.1 ft to the 2nd
print '{:0.1f}'.format(result['Plane_Height'].iloc[0])
v1 = '{:0.1f}'.format(result['Plane_Height'].iloc[0])
print '{:0.1f}'.format(result['Plane_Height'].iloc[1])
v2 = '{:0.1f}'.format(result['Plane_Height'].iloc[1])
if v1 == v2:
    print 'First elevations the same!'
    result['Plane_Height'].iloc[1] = (result['Plane_Height'].iloc[1]) + 0.1
    print 'New 2nd elevation: {:0.1f}'.format(result['Plane_Height'].iloc[1])

## set the storage to 0.000 for the first row of stage/area
result['init'] = ''
result = result.reset_index(drop=True)
result.set_value(0,'init','0.000')

## calls function to solve for ASCOORD
horz,vert = ascoord(auxelev, valleyelev)

## Pipe sizes that will be iterated through until a suitable design is found
pipes = [6,8,10,12,15,18,24,30,36,42,48,54,60]
for i in pipes:
    pipesize = i
    print'Attempting pipe size ' + str(pipesize) + ' for pond ' + str(pondid)

    ## formats and writes data to SITES input .d2c file
    sfile = os.path.join(folder,'pond.d2c')
    np.savetxt(sfile,
               result.values,
               fmt = ('%25.1f', '%11.4f', '%28s'),
               header = 'SITES     01/01/2005RCH101     HEADWATERS POND #{}\n'
               'STRUCTURE 111AA     HEADWATERS POND #{} POND DATA'.format(pondid,pondid),
               comments='')

    with open(sfile, 'a') as file:
        file.write('ENDTABLE \n'
                   'WSDATA     A1X   AC {:2.1f}      {:03.2f}    {:04.3f}'.format(avgCN,contarea,tc))
        file.write('\nPDIRECT   1.0       5.10                           25\n'
                   'POOLDATA  ELEV      {:>06.1f}    {:>06.1f}'
                   '             {:>06.1f}    {:>06.1f}'.format(poolelev,poolelev,auxelev,valleyelev))
```

```
    file.write('\nPSDATA    1         91.0      {:>2.0f}                  0.024     {:>06.1f}'.format(pipesize,(poolelev-
    file.write('\nPSINLET   ELEV      1.0       7.85'
               '\nASDATA    41B 100   100                 3'
               '\nBTMWIDTH  FEET      12')
    file.write('\nASCOORD   1         Alluvium  Y\n'
               '          {:>03.0f}       {:>06.1f}    {:>03.0f}       {:>06.1f}'
               '    {:>03.0f}       {:>06.1f}'
               '\n          {:>03.0f}       {:>06.1f}    {:>03.0f}       {:>06.1f}'
               .format(horz[0],vert[0],horz[1],vert[1],horz[2],vert[2],horz[3],vert[3],horz[4],vert[4]))
    file.write('\nENDTABLE'
              '\nGRAPHICS  L  P'
              '\nHOODETL'
              '\nGO,STORM  NL        TYPE2     5.1                           {:>06.1f}'.format(poolelev))
    file.write('\nENDJOB'
               '\nENDRUN'
               '\n*    x    1    x    2    x    3    x    4    x    5    x    6    x    7    x    8')

##print "Rest of input file saved"

## Locates .bat file and calls it to run DamSiteSim.exe
filepath = os.path.join(folder,'job.bat')
subprocess.call(filepath)

## Delay script so SITES can run
time.sleep(0.20)

## Opens .OUT file from SITES to check it for Auxiliary Spillway Activation
pond_OUT = open(os.path.join(folder,'pond.OUT'))
## Calls checkout function and checks result

if checkoutput(pond_OUT) == '1':
    ## Design is successful and the appropriate pipe size is selected
    ## Copies the .DRG and saves it with pond number label
    print 'Good design for pond ' +str(pondid) +' with pipe size of ' + str(pipesize)
    shutil.copyfile(os.path.join(folder,'pond.DRG'),
                    os.path.join(folder,'pond{}.DRG'.format(pondid)))
    shutil.copyfile(os.path.join(folder,'pond.OUT'),
                    os.path.join(folder,'pond{}.OUT'.format(pondid)))
```

```
        break



    if checkoutput(pond_OUT) == ’2’:
        ## The simulation run was not completed due to likely error in .d2c file
        ## Copies the .OUT file and saves it with pond number label for user error
        ## checking after run
        print ’Error in SITES simulation, printing .OUT file for error checking’
        shutil.copyfile(os.path.join(folder,’pond.OUT’),
                        os.path.join(folder,’pond{}.OUT’.format(pondid)))
        shutil.copyfile(os.path.join(folder,’pond.d2c’),
                        os.path.join(folder,’pond{}.d2c’.format(pondid)))

        break

## BELOW SECTION ONLY USED FOR HSPF FTABLE OUTPUTS, COMMENT OUT TO ONLY PERFORM SITES DESIGN


## read in the SITES output rating tables
df3 = pd.read_table(os.path.join(folder,’pond{}.DRG’.format(pondid)),
            delim_whitespace = True,
            names = [’col1’,’Elev’,’Q_total’,’Q_PS’,’Volume’,’Area’],
            skiprows = 3
            )

## sets the FTABLE number to start at 501
ftablenum = 500 + loopindex
## checks number of rows in ratings table
numrows = len(df3)
##print numrows

## organizing columns and setting the pool elevation as 0.00 for elevation, area, and volume
df3 = df3[[’Elev’,’Area’,’Volume’,’Q_total’,’col1’,’Q_PS’]]
df3[’Elev’] = df3[’Elev’] - df3[’Elev’].iloc[0]
df3[’Area’] = df3[’Area’] - df3[’Area’].iloc[0]
df3[’Volume’] = df3[’Volume’] - df3[’Volume’].iloc[0]

## calculating flo-thru time and setting NaNs to 0
```

```
    df3['Flo-Thru'] = df3['Volume']/df3['Q_total']*43560/60
    where_are_NaNs = np.isnan(df3['Flo-Thru'])
    df3[where_are_NaNs] = 0

    ## organizing columns for FTABLE
    df3 = df3[['Elev','Area','Volume','Q_total','Flo-Thru','col1','Q_PS']]
    print df3.head(5)

    ## opens ftable.txt file
    with open(tfile, 'a') as f:
        ## saves and formats the FTABLE for each pond, appends to ftable.txt file
        np.savetxt(f,
                   df3.values[:,0:5],
                   fmt = ('%10.3f','%9.2f','%9.2f','%9.2f','%10.1f'),
                   header =' FTABLE    {}\n'
                   ' ROWS COLS ***\n'
                   '  {}  4\n'
                   '     DEPTH      AREA    VOLUME     DISCH    FLO-THRU***\n'
                   '       (ft)   (ACRES)   (AC-FT)     (CFS)      (min)***'.format(ftablenum,numrows,ftablenum),
                   comments = '',
                   footer = '  END FTABLE{}\n'.format(ftablenum))
    ## sets up next FTABLE number
    loopindex += 1


## Housekeeping
os.remove(os.path.join(folder,'pond.d2c'))
os.remove(os.path.join(folder,'pond.DRG'))
os.remove(os.path.join(folder,'pond.DHY'))
os.remove(os.path.join(folder,'pond.DIS'))
os.remove(os.path.join(folder,'pond.DG2'))

print 'Done'

print 'If any errors were encountered it is advised to go back and manually edit .d2c file'
'and rerun SITES manually'
```

Appendix B

WASCOB Design Script

```
# -*- coding: utf-8 -*-
"""
Created on Wed May 16 10:00:09 2018

@author: Greg Geimer
"""


## Script to design WASCOBs that are aggregated by model subbasin
##
## The following information is needed for each subbasin: Subbasin label,
## ACPF WASCOB drainage area, number of ACPF WASCOBs, ACPF WASCOB Storage,
## and ACPF WASCOB basin area
##
## The following data needs to be in the spreadsheet with matching names:
## RCHRES, DA, ACPF_WASCOBs, ACPF_Stor, ACPF_Area
##
##
## Sheet with data should be named 'script_read'


import numpy as np
```

```
import pandas as pd
from scipy.optimize import fsolve
import os

## Inputs ----------------------------------------------------------
## use the first option to call the script with command line arguments
## use the second to run the script using an IDE (i.e. IDLE)
##WASCOBDATA = sys.argv[1]
WASCOBdata = r'Z:\For_Greg\EnglishRiver\Headwaters\ModelingWASCOBdata_Storages.xlsx'
## End of inputs ---------------------------------------------------


## DEFINING FUNCTIONS------------------------------------------------------------------------------------------------------

## Fitting a quadratic relationship to the stage-storage relationship
def equations(p):
    a = p
    return (a*y  - A)

## Fitting a linear relationship to the stage-area relationship
def area(y, a):
    A = a*y
    return A

## Solving for the storage at a given stage
def storage(y1,y2,a1,a2):
    S = (y2-y1)*(a1+a2)/2
    return S

## Solving for discharge using the orifice equation, 6 inch pipe, coefficient=0.6, inlet 0.25 above ground
def orifice(head):
    if head == 0:
        Q = 0
    else:
        Q = 0.6*(np.pi*0.5**2/4)*(2*32.2*(head-0.25))**(0.5)
    return Q

## Solving for discharge using the weir equation (weir coefficient=2.68)
def weir(head):
```

```
    Cw = 2.68
    Le = 10
    g = 32.2
    Q = Cw*Le*(2*g*head)**(1.5)
    return Q
##------------------------------------------------------------------------------------------------------------------------


## Take current folder as working directory and build paths
folder = os.getcwd()
## removes existing FTABLE file if it exists so an empty file is used
tfile = os.path.join(folder,'ftable.txt')
if os.path.exists(tfile):
    os.remove(tfile)

sfile = os.path.join(folder,'RCHRES.txt')
if os.path.exists(sfile):
    os.remove(sfile)

dfile = os.path.join(folder,'hydrparm.txt')
if os.path.exists(dfile):
    os.remove(dfile)

## Reading in the WASCOB data spreadsheet
df = pd.read_excel(WASCOBdata,
                      sheet_name = 'script_read',
                      header = 0)

## SITES data for auxiliary spillway discharge interpolation
s1 = pd.Series([4.92, 5.12, 5.32, 5.68, 6.12, 6.92, 7.92, 8.92], name='Stage')
s2 = pd.Series([0,0.69,1.38,2.77,6.83,69.46,187.83,355.50], name='Q')

## Start iteration through the WASCOB spreadsheet
for row in df.itertuples():

    subbasin = getattr(row, 'RCHRES')
    A = getattr(row, 'ACPF_Area')
    S = getattr(row, 'ACPF_Stor')
    count = getattr(row, 'ACPF_WASCOBs')
```

```
y = 4.92

## Skips the subbasins with 0 WASCOBs
if count == 0:
    continue
else:
    index += 1

## Solving for the coefficients for polynomial fits
a = fsolve(equations, (1))

## Sets up a vector of stages
ssa = pd.DataFrame({'Stage': np.linspace(0.0, 10, 15)})

## Specifies a value of 4.92 feet, the height of the ACPF WASCOB
ssa['Stage'].iloc[14] = 4.92
## Sorting values and resetting index
ssa = ssa.sort_values(by=['Stage'])
ssa = ssa.reset_index(drop=True)

## Applies the functions for Area, Storage, Discharge, PS Discharge, and AS Discharge
for i in range(1, len(ssa)):
    ssa.loc[i, 'Area'] = area(ssa.loc[i, 'Stage'], a)
    ssa.loc[i, 'IncStorage'] = storage(ssa.loc[i-1, 'Stage'], ssa.loc[i, 'Stage'], ssa.loc[i-1, 'Area'], ssa.loc[i, 'Area'])

ssa['Storage'] = ssa['IncStorage'].cumsum(axis=0)
if np.isnan(ssa.Storage.iloc[1]) == True:
    ssa.Storage.iloc[1] = 0

ssa['Total Discharge'] = ssa.apply(lambda row: orifice(row.Stage) if row.Stage <= 4.92 \
   else orifice(row.Stage) + np.interp(row.Stage, s1, s2), axis = 1)
ssa['PS Discharge'] = ssa.apply(lambda row: orifice(row.Stage), axis = 1)
ssa['AS Discharge'] = ssa.apply(lambda row: np.interp(row.Stage,s1,s1) if row.Stage >= 4.92 else 0, axis = 1)

ssa['Stage'].iloc[0] = 0
ssa['Area'].iloc[0] = 0
ssa['Storage'].iloc[0] = 0

# Setting up the numbering of FTABLEs
```

```
        ftablenum = subbasin + 500
        print 'Done with WASCOBs in subbasin ' + str(subbasin) + ' in FTABLE ' + str(ftablenum)

        ## checks number of rows in ratings table
        numrows = len(ssa)
        ssa = ssa[['Stage','Area','Storage','Total Discharge','IncStorage','PS Discharge','AS Discharge']]
        ## Opens FTABLE file for appending
        with open(tfile, 'a') as f:
                    ## saves and formats the FTABLE for each pond, appends to ftable.txt file
                    np.savetxt(f,
                               ssa.values[:,0:4],
                               fmt = ('%10.3f','%9.2f','%9.2f','%9.2f'),
                               header ='  FTABLE    {}\n'
                               ' ROWS COLS ***\n'
                               '  {}  4\n'
                               '     DEPTH      AREA    VOLUME     DISCH***\n'
                               '       (ft)   (ACRES)   (AC-FT)     (CFS)***'.format(ftablenum,numrows,ftablenum),
                               comments = '',
                               footer = '  END FTABLE{}\n'.format(ftablenum))
        with open(sfile, 'a') as f:
            f.write('      RCHRES     {:03.0f}\n'.format(ftablenum))

        with open(dfile, 'a') as f:
            f.write('  {}         0  {}    0.1000       1.0         0       0.5      0.1\n'.format(ftablenum,ftablenum))

    print 'Total number of subbasins with WASCOBS ' + str(index)
    ## Joins all the vectors for checking data
    #checkWASCOBs = pd.DataFrame({'reach': reach,'WASCOBArea': WASCOBArea,'WASCOBStorage': WASCOBStorage, 'a': avec, 'b': bvec})
```

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