ASSESSMENT OF THE FEMA HAZUS-MH 2.0 CROP LOSS TOOL FREMONT COUNTY, IOWA 2011

By

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A Thesis Presented to the
FACULTY OF THE USC GRADUATE SCHOOL
UNIVERSITY OF SOUTHERN CALIFORNIA
In Partial Fulfillment of the
Requirements for the Degree
MASTER OF SCIENCE
(GEOGRAPHIC INFORMATION SCIENCE AND TECHNOLOGY)

May 2014

Contents

Acknowledgements

I would like to thank those that have supported me through this process. I would especially like to thank my advising professor, Dr. Jordan Hastings. Professor Hastings guided me through the process and I will forever be in his debt for his advice and guidance. I would also like to thank Dr. Jennifer Swift and Dr. Flora Paganelli who also served on my committee and offered guidance.

Additionally, I would like to thank Nikolay Todorov for his technical assistance with the FEMA Hazus software and Tim Johnson and Spencer Parkinson for their data on Fremont County, Iowa and their cooperation in sharing their IMPLAN results.

List of Tables

List of Figures

Abstract

The Federal Emergency Management Agency (FEMA) has broad responsibility for both hazard mitigation and response throughout the United States. For natural hazards, FEMA in 2011 released a major update of its GIS-based predictive modeling tool, HAZUS-MH 2.0® (hereafter HAZUS), which deals with earthquakes, floods, and severe weather events. For the latter two perils, losses to agriculture are modeled along with losses to life and property. This study offers an assessment of the HAZUS crop flood loss modeling methodology for Fremont County Iowa, specifically for heavy flooding that occurred there in June-August 2011. Fremont County had the largest estimated financial losses due to crop damage amongst all Iowa counties from the 2011 flood. This assessment compares HAZUS model runs against actual crop losses as determined by both the National Agricultural Statistical Service (NASS) and by the Iowa Farm Bureau Federation (IFBF). Predicted agricultural losses were generated using both HAZUS' riverine method and the HAZUS user defined depth-grid methods. These results were compared against the actual NASS harvested acreage and yield results. The HAZUS results were also compared against a special IFBF study for Fremont County, which used the USDA IMPLAN® economic impact tool. Overall, differences among the HAZUS predictions and reality varied by up to 390%; differences between HAZUS and the IFBF predictions varied by up to 214%. FEMA's HAZUS consistently overestimated. Based on the Fremont County flood, improvements in the HAZUS crop loss methodology are urgently recommended.

Figure 1. Aerial view of Fremont County, Iowa, June 20th 2011, after Gavins Point Dam release and L-575 Levee breach (U.S. Army photo)

Introduction

The United States is a major world food producer and exporter. The Midwest, comprising 35 percent of U.S. agricultural production, exports $26 billion annually in grain crops (USDA). However, grain production is a risky business, subject to factors beyond the control of even the largest farmers.

Weather is arguably the least controllable factor in grain farming. The number of extreme meteorological and hydrological events, defined in terms of economic and human impacts, has more than doubled over the past 20 years (Lubchenco and Karl, 2012) and projected changes in the frequency and severity of extreme climate events will have more serious consequences for food production, and food security, than will changes in projected means of temperature and precipitation (Easterling et al., 2007), as evidenced by Figure 1. Weather-related crop losses are a concern not only for farmers, but also for traders and policy makers, and ultimately for consumers. With growing world population, in the face of essentially fixed agricultural land and increasingly erratic weather patterns, attending to food security (Kogan et al., 2011) is an imperative.

Global grain consumption has exceeded production in 8 of the last 13 years, leading to a drawdown in reserves. Worldwide, carryover grain stocks—the amount "left in the bin" when the new harvest begins—stands at 423 million tons (1/17/2013), enough to cover 68 days of consumption. This is just 6 days more than the low that preceded the 2007–08 grain crisis, when several countries restricted exports and food riots broke out in dozens of countries because of the spike in prices (Larsen, 2013). World grain reserves are so dangerously low that severe weather in the United States or other food-exporting countries could trigger a major hunger crisis, the United Nations has warned (Lacey, 2012).

The Federal Emergency Management Agency (FEMA) has broad responsibilities for both hazard mitigation and response throughout the United States. To assist with its mission, FEMA has produced the loss modeling tool HAZUS-MH 2.0 ® (hereafter HAZUS). The HAZUS software has been designed to model losses attributable to a variety of natural hazards that affect the U.S., including earthquakes, wind, and flood. The main purpose of HAZUS is to assist states and local communities in pre-mitigating the likely effects of such hazards and to serve the state governors in preparing formal declarations of emergency when hazards become realities. States are strongly encouraged to have HAZUS models in place to substantiate federal declarations of emergency.

The HAZUS software includes a module for calculating potential crop losses due to flooding. Crop loss modeling is one way to understand and predict the risks of weather on the food supply, and thereby address food security. The 2011 Missouri River flood event, particularly for Fremont County, Iowa, provided an opportunity to assess HAZUS crop loss modeling, vetted by an Iowa Farm Bureau Federation (IFBF) study of that event and the United States Department of Agriculture (USDA) acreage and yield numbers for Fremont County, Iowa post-2011 harvest. The goal of this study is to compare the results of the HAZUS crop loss calculations against IFBF crop loss calculations and against the "ground truth" losses as reported to the USDA for Fremont County, Iowa 2011.

Background

The Midwest, as defined by the United States Census Bureau, is a region of the United States that includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. The Corn Belt is a sub-region of the Midwest where corn has, since the 1850s, been the predominant crop, replacing the native tall grasses. Geographic definitions of the Corn Belt region vary but it is typically defined to include Iowa, Illinois, Indiana, Michigan, and eastern Nebraska, eastern Kansas, southern Minnesota and parts of Missouri. The U.S. produces 40% of the world's corn in any given year with the top four corn-producing states being Iowa, Illinois, Nebraska, and Minnesota, together accounting for more than half of the corn grown in the United States.

Iowa lies within the Central Lowlands region of the United States and consists mostly of relatively level land and deep, fertile soils high in organic matter. Iowa is bordered on the West by the Missouri River and on the East by the Mississippi River. Iowa has a continental climate, with hot summers and cold winters. July temperatures average near 75° F. (24° C.) throughout the state and normally reach daily highs of 85° to 90° F. (29° to 32° C.). January temperatures average about 14° to 22° F. (-10° to -6° C.), increasing from north to south. Daily lows during January are normally between 8° and 18° F. (-13° and -8° C.). Annual precipitation ranges from about 25 inches (635 mm) in the northwest to 35 inches in the southwest (NOAA, 2013).

Iowa ranks first in the nation in corn and soybean production. In 2011, Iowa's corn crops accounted for 19 percent of the total U.S. corn crop (USDA), which is used for many purposes. A bushel of corn can sweeten 400 cans of soda, make 38 boxes of corn flakes, or produce more than 2.5 gallons of ethanol. Iowa produces 25% of the country's supply of ethanol, twice as much as any other state. Studies show without ethanol, Americans would pay 20 to 40 cents more per gallon of gasoline (IFBF, 2013).

Roughly 10 percent of U.S. grain is sold abroad (USDA, 2013), while at the same time grain is required nationally for economic activity as well as consumption. Modeling can help in understanding the important balance between export and internal use, and allow decision makers to predict potential crop shortfalls. The U.S. is a grain donor country to many others; historically we have helped those in need and we will continue to do so. Donor countries' decisions to assist the nations in need of food could also rely heavily on predicted crop losses.

Grain crops are strongly influenced by the weather. Over the last century, there has been a 50% increase in the frequency of days with rainfall over four inches per day in the upper Midwest (Groisman et al., 2001). According to the Intergovernmental Panel on Climate Change, aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones have intensified (IPCC, 2007) and trends are expected to strengthen over the coming decades (Groisman et al., 2004).

Excessive moisture from persistent precipitation or flooding is damaging to crops in several ways. Wet soils are problematic for many reasons: they cause plants to drown (Kozdroj and Van Elsas, 2000); they are anoxic causing pathogens to bloom (Conley et al., 2011); and weakened plants are generally more susceptible to plant diseases and insect infestations (Ashraf and Habib-ur-Rehman, 1999). A corn plant that has not yet pollinated cannot withstand submersion in water for more than 24 to 36 hours (Parker, 2007). If the plant has pollinated then it is possible for corn to survive up to 48 hours of submersion. Soybeans less than 6 inches tall will not survive if they are under water for more than 24 hours (Parker, 2007).

Research indicates that the oxygen concentration levels in flooded fields approaches zero after 24-hours in a flooded soil (Thomison, 1995). Without oxygen, the plant cannot perform critical life sustaining functions such as nutrient and water uptake and root growth. Even if flooding does not kill plants outright, it may have a long term negative impact on crop performance. If excess moisture in the early vegetative stages retards root development, plants may be subject to greater injury during a dry summer because root systems are not sufficiently developed to access available subsoil water.

While saturated soil is a large contributor in crop loss during floods, other factors can make a crop non-salvageable even if the crop does survive initial flooding.

Floodwaters can contaminate crops with sewage, raw manure, agricultural or industrial chemicals, heavy metals, or other chemical contaminants. Microbial pathogens in floodwaters include bacteria, viruses, and parasites, which may come from upstream farms and rural septic systems, urban lawns, roadways, buildings and industrial sites, or overflow from municipal sewage systems. No practical method exists for reconditioning contaminated crops, certainly none that provides a reasonable assurance of safety for human consumption.

Notwithstanding its productivity, the Midwest is subject to chronic flooding. During the era from the late 1940s through the early 1950s, the Missouri River flooded every year. It was not uncommon for residents living in communities along the basin to reside in portable homes and villages so that when the river meandered out of its channel or sent a torrent of water rushing downstream, they could move out of its path.

Years of violent floods prompted Congress to pass the Flood Control Act of 1944, which authorized the construction of hydroelectric dams on the “mainstem” of the Missouri. During the 1960s, a system of six federal dams on the Missouri was completed, providing hydroelectric power along with irrigation and flood control focused at the 500-year flood protection level (Figure 2). This series of six hydroelectric dams and the reservoirs behind them comprise the Missouri River Mainstem Reservoir System.

Figure 2. Flood-control hydroelectric dams along the mainstem of Missouri River (USACE)

Even with the completion of the dams and levees along the Missouri River, there have still been memorable flooding events in 1967, 1984, and 1990. The floods of 1993 were particularly damaging with an estimated $15 billion in flood losses (Larson, 1997). The crop losses in 1993 amounted to a 40% reduction in production in comparison to the previous years for corn and soybeans (Kliesen, 1994).

Given a 50% increase in world population since then and extreme weather variability, food security is an urgent issue. Early assessment of crop losses in response to weather fluctuations is an important task for the estimation of global, regional and national food supplies. In the 1980s, the U.S. Army Corp of Engineers (USACE) developed the Agricultural Flood Damage Analysis Program (AGDAM) to evaluate the agricultural flood damage potential of flood-plain areas. The primary purpose of the program was to calculate expected annual damages, by crop, and flooded areas.

Another tool, IMPLAN® (developed by MIG Inc.), also has been used by the U.S. Department of Agriculture (USDA) to calculate economic crop loss. IMPLAN is not a spatial modeling tool, but rather an input/output database for calculating economic losses and community impact analysis (MIG, 2004). IMPLAN provides both induced and indirect economic effects to a direct shock of measured or projected crop losses; thus IMPLAN calculates the decline in aggregate economic activity from the lost value of crop production (Brown et al., 2011). The IMPLAN tool can use a combination of state or regional crop budgets (corn, soybean, and forage), USDA yield data, and economic multipliers within the IMPLAN software to estimate the impact of a flooding event.

A third tool for crop loss modeling is HAZUS, developed by the Federal Emergency Management Agency (FEMA), which is designed to produce direct loss estimates for use by federal and state governments in planning for hazard mitigation, emergency preparedness, response and recovery. By contrast to IMPLAN, HAZUS software is a spatial model tool that runs on top of Esri® ArcGIS™. HAZUS includes specific methodologies to analyze the impact of severe weather events within a spatial context; these deal with a wide range of direct losses, including damage to the built environment, lost economic production, and loss of life. Extensive national databases are embedded within HAZUS, containing demographics, inventories of the general building stock, including square footage for different occupancies of buildings, and the locations of “essential facilities” (police stations, fires stations, and schools), and also “utility lifelines” (pipelines, roads, bridges, etc.).

For floods, HAZUS requires the inundation boundary together with a digital elevation model (DEM), which it obtains from the United States Geological Survey (USGS). Additionally, to estimate agricultural losses, HAZUS requires a crop distribution layer called National Resources Inventory (NRI) and prices for those crops from the National Agricultural Statistics Service (NASS), both from the USDA, along with hydrological inputs. Users carry out loss estimates for a *study region* by selecting the rivers that will be flooding, either theoretically, at various return intervals or depth stages, or explicitly. For more accuracy, users can supply flood depth-grids, a format of spatial data in a grid pattern where each cell represents the depth of standing water by geographic location. Depth-grids are generally considered more accurate than hydrological analyses. The HAZUS methodology and software are flexible enough so that locally developed inventories and other data that more accurately reflect the local environment can be supplied, resulting in increased loss estimation accuracy.

Uncertainties are inherent in any loss estimation methodology. These arise in part from incomplete scientific knowledge concerning the hazards, as well as the approximations and simplifications that are necessary for modeling. Incomplete or inaccurate inventories of the built environment, demographics and economic parameters add to the uncertainty. These factors can result in a range of uncertainty in loss estimates produced by HAZUS, by a factor of two or more. According to the HAZUS documentation, the “HAZUS methodology has been tested against the judgment of experts and, to the extent possible, against records from several past earthquakes, floods and hurricanes. However, limited and incomplete data about damage from these events precludes complete calibration of the methodology."

As of 2011, the year of the Missouri River flooding analyzed in this study, a major new version of HAZUS, so-called 2.0, had just been released. The primary objective of the study was to assess how the HAZUS 2.0 performed with regard to flooding in general and crop loss in particular, as this version was the best available at the time. Government agencies are often slow to adopt new versions of software, and it is likely that HAZUS 2.0 version will be in use long into the future.

Case Study

In Spring of 2011, high levels of runoff from both the Montana snowpack melt and Midwest rainfall generated the largest volume of flood waters on the Missouri River since initiation of record-keeping in 1898 (Grigg et al., 2012). The runoff events along the Missouri River in 2011 were 230 percent above normal (USACE, 2011). This combination of events stressed the Missouri River Mainstem Reservoir System's capacity to control flood waters.

In May of 2011, the USACE made the decision to begin discharging water from dams along the upper Missouri River basin (see Figure 2), which had severe implications for the farmers along the Missouri River basin. In most cases, farmers had already incurred costs associated with planting and raising crops. The releases from multiple dams along the Missouri River flooded an estimated 150,000 acres of Iowa farmland

(Piller, 2011). Although necessary, the releases from the dams also caused the breaching of many levees along the Missouri River.

Fremont County, Iowa was selected as the study area for HAZUS flood crop loss assessment because it experienced significant damage due to the release of water from dams upstream in the upper Missouri River basin. Additionally, the Iowa Farm Bureau Federation (IFBF) had predicted agricultural losses using the USDA IMPLAN tool. The IFBF study provided an opportunity to compare HAZUS with another, aspatial approach to economic crop loss modeling. Food production and food security are crucial concerns for the nation both for reasons of sustenance and financial security, consequently predicting and understanding the accuracy of crop loss predictions is a serious business and tools that predict such loss should strive to be as accurate as possible.

Figure 3 shows the geography and topography of Fremont County, Iowa. The Missouri River creates the western border of Fremont County, which is where the most extensive flooding took place during June – August 2011. The Nishnabotna River, a tributary to the Missouri River, flowing SW through Riverton and Hamburg, also experienced flooding when levees L-550 and L-575 gave way in June, 2011. These levees had been built in the 1950's as part of the Missouri River Levee System, with the intention of maximizing protected land area. However, some levees were located too close to the river, resulting in negative hydrologic impacts and ultimately failure (IFMRC, 2012).

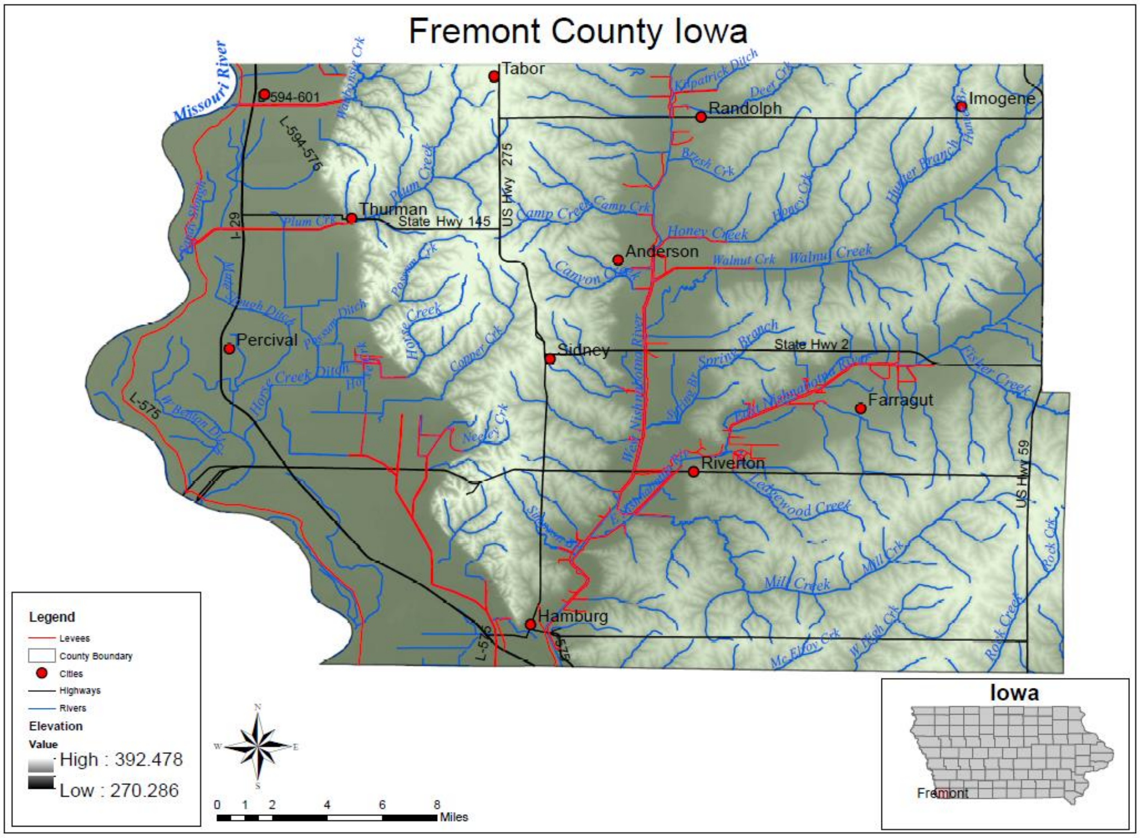

Figure 3. Reference map, Fremont County, Iowa. Many smaller rivers have been channelized to ditches, which appear squared off.

Methodology

This study estimates crop losses for Fremont County, Iowa pursuant to the flooding of 2011, via two approaches: 1) econometric analysis, prepared by Parkinson and Johnson (2011) at IFBF using the IMPLAN input-output model (MIG, 1999); and 2) potential loss estimation using the HAZUS geospatial model and the embedded AGDAM sub-model (USACE, 1985). Both approaches could be used in a future flood event to anticipate and perhaps prepare for the economic consequences of crop losses. The objective of this study is to validate the two modeling approaches by comparison to “reality”, as determined after-the-fact (Results section).

IMPLAN Econometric Losses

Due to the rural nature of Fremont County, the economic implications of the 2011 flooding were acute and prompted a prospective study by IFBF early in August, 2011. The IFBF study utilized a combination of satellite imagery, Iowa State crop budgets, USDA/NASS yield data, and IMPLAN software to estimate the overall economic impact of the 2011 flood event.

In IFBF terminology, *direct acres* are non-harvestable acres that were covered by flood water (as of an August 2nd satellite image, see below) and *peripheral acres* are partially harvestable acres within 1/2 mile of the flood boundary. For direct acres, loss comprised all costs associated with planting and protecting (herbicides and fertilizers) the crops that were not directly recoverable. IFBF determined that the direct acres suffered a total loss (direct effect) and the peripheral acres split evenly with fifty percent suffering a 20% loss and fifty percent suffering a 50% loss (indirect effect).

As part of its study, the IFBF produced a GIS shapefile depicting the spatial extent of the 2011 flood. This shapefile was generated by tracing the outline of standing water on a Landsat satellite image from August 2, 2011, representing direct loss, and adding a 1/2 mile buffer perimeter for indirect loss (Figure 4). In some areas the 1/2 mile buffer was eliminated for indirect acres because of the known presence of the Loess Hills formation. (In Western Iowa, soils underlain by loess tend to be quickly and completely drained.) In addition, areas of 5% slope or greater as determined using IFBF’s LiDAR data were removed from the direct acres as being unfarmable. (Typically these slopes arise from levees and highway overpasses.)

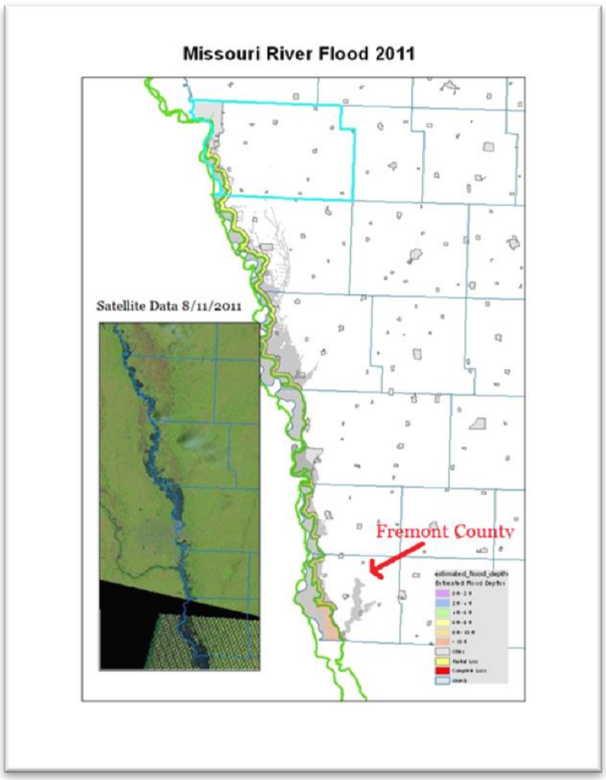

Figure 4. IFBF Shapefile creation from Landsat satellite imagery

There are two components to the IMPLAN system (MIG, 2004), the software and an extensive suite of data sets. The data sets include, but are not limited to, information from the U.S. Bureau of Labor Statistics (BLS), the U.S. Census Bureau, the U.S. Bureau of Economic Analysis, and the U.S. Department of Agriculture. The model elements and procedures are described in the Analysis Guide, while the methodologies used to derive the data are in the Database Guide.

At the heart of an IMPLAN model is an input-output dollar flow table. For a specified region, the input-output table accounts for all dollar flows between different sectors of the economy. Thus, IMPLAN models the way a dollar injected into one sector is spent and re-spent in other sectors of the economy, generating waves of economic activity, or so-called "economic multiplier" effects. The model uses national industry data and county-level economic data to generate a series of multipliers, which in turn estimate the total economic implications of economic activity.

In all IMPLAN impact analysis cases, the first step is to develop multiplier tables i.e., a predictive model. Multipliers are a numeric way of describing the secondary impacts stemming from a change. For example, an employment multiplier of 1.8 indicates that for every 10 employees hired in the given industry, 8 additional jobs would be created in other industries, such that 18 total jobs would be added to the given economic region (McIntosh, 1997). Despite the complexities of the IMPLAN model the multiplier predictive model can be summarized by the equation shown in Figure 5.

Through algebraic manipulation of the A Matrix, we derive the multipliers. The resulting equation is the ***predictive model***:

$$\mathbf{X = (I - A)^{-1} * Y}$$

where:

X = Total industry output

I = Identity matrix

A = A Matrix

Y = Final Demand.

This can also be interpreted as:

$$\mathbf{\Delta X = (I - A)^{-1} * \Delta Y}$$

or Change in Total Industry Output = $(I - A)^{-1}$ * Change in Final Demand.

The predictive model shows how output will change with a given change in final demand. The (I - A) inverse is the matrix of multipliers also known as the ***Leontief inverse***.

Figure 5. IMPLAN formula for econometric modeling (verbatim from IMPLAN technical manual)

The results from IMPLAN provide the user with a report that demonstrates the detailed effects of local changes on supporting industries and households. Reports can provide both detailed and summary information related to job creation, income, production, and taxes.

The IFBF study concluded that a total of $52.1 million of agricultural production were lost in Fremont County Iowa in 2011, nearly $44 million from direct acres and over $6 million from peripheral acres, plus approximately $2 million more from induced economic effects in the farming community. (Table 1).

Table 1. Economic impacts as determined by IFBF study

Impact Type	$ Millions
Direct Effect	43.9
Indirect Effect	6.34
Induced Effect	1.94
Total Effect	52.1

HAZUS Economic Losses

By contrast to IMPLAN, HAZUS is GIS-supported software, focused on occurrences of specific natural hazard(s), which are modeled in spatially explicit *scenarios*. Figure 6, from the HAZUS Technical Manual, shows the overall *methodology* of flood modeling in the HAZUS system. Agricultural Products and Vehicles (circled), comprising the crop loss sub-model, fit within the Direct Physical Damage section of the HAZUS methodology.

HAZUS provides two basic methods of flood modeling, a simple method called *riverine* (also known as “Level 1”), which derives flooding from gauged river flows, and

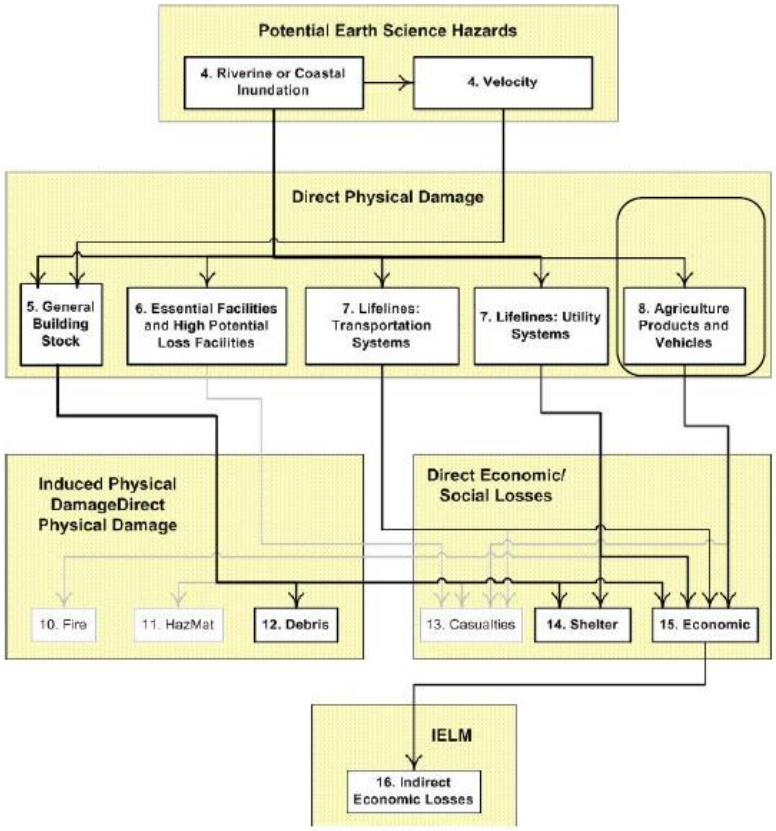

Figure 6. HAZUS flood methodology (FEMA)

the more precise user-defined *depth-grid* ("Level 2"). In the riverine method, the user selects river reaches[1] that are flooding, or soon to be flooding. Together with the DEM from USGS, HAZUS can calculate an approximate depth-grid based on hydrology for the study area. In the depth-grid method, the user provides an explicit raster of water depth for the flooded region.

Two depth-grids were used in the HAZUS testing, one derived from the IFBF flood boundary shapefile, itself sketched from satellite imagery, intersected with the

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[1] River reach is the length of a stream between any two points, typically junctions or gauging stations.

USGS 10-meter DEM, and another produced by the Iowa Department of Natural Resources (DNR) using a refined 3-meter DEM from Light Detection and Ranging (LiDAR) measurements and based on a flow of 150,000 cubic feet per second of the Missouri River at the Gavins Point Dam. Levees were not accounted for in the Iowa DNR depth-grid.

The HAZUS crop loss sub-model is based on AGDAM and utilizes the loss formula shown in Figure 7.

$$L = A(pY_0 - H) \cdot D(t) \cdot R(t)$$

where:

L	=	loss ($),
A	=	cultivated area (acres),
P	=	price ($/bushel),
Y_0	=	normal annual yield (bushels/acre),
H I	=	harvest cost ($/acre),
D(t)	=	crop loss at day t of the year (% of maximum net revenue), and
R(t)	=	the crop loss modifier for flood duration (percent of maximum potential loss).

Figure 7. HAZUS formula for agricultural loss (verbatim from HAZUS technical manual)

The AGDAM formula within HAZUS can be described as follows:

- Determine affected area as the intersection of the floodplain polygon with the agriculture polygon (A)
- Identify the maximum potential crop in the affected area ($A*Y_0$)
- Identify damage to crop in rough relation to crop stage and duration of flooding (D(t)*r(t))
- Calculate economic loss of the unharvestable crop (L)

For its agricultural calculations, the HAZUS flood model performs an assessment of the amount of flooding that has occurred within so-called *sub-county polygons* generated from the intersection of the 8-digit USGS Hydrologic Unit Codes (HUCs) and agricultural land classifications in the USGS Land Use / Land Cover (LULC) dataset, clipped to US Census county boundaries where appropriate (FEMA, 2012). By associating the crop types from the USDA National Resources Inventory (NRI), HAZUS is able to obtain the crop price per unit of production (e.g., $ per bushel). The NASS data is compiled annually reflecting the average price for a wide range of crops.

In assessing crop damage from floods, the HAZUS crop loss model uses *damage functions*, one for each crop species (Figure 8), which state maximum crop loss according to crop growth stage. These damage functions are tabulated based on the Julian calendar[2], assuming a single crop per year planted in Spring and harvested in Fall. A set of damage functions for common crops was developed based on averages collected from three USACE Districts: Sacramento (California), St. Paul (Minnesota), and Vicksburg (Mississippi). The maximum crop loss is attenuated according to floods of 0, 3, 7, and 14 days' duration, the latter equated to total loss; the same attenuation applies to all crops.

[2] Julian date is the ordinal day number within the year: e.g. January 1st is day 1, and July 11th is day 192, in a non leap-year. For user convenience, the HAZUS user provides a Gregorian date for a flood scenario, from which the software determines the Julian date and indexes the appropriate damage function(s) internally.

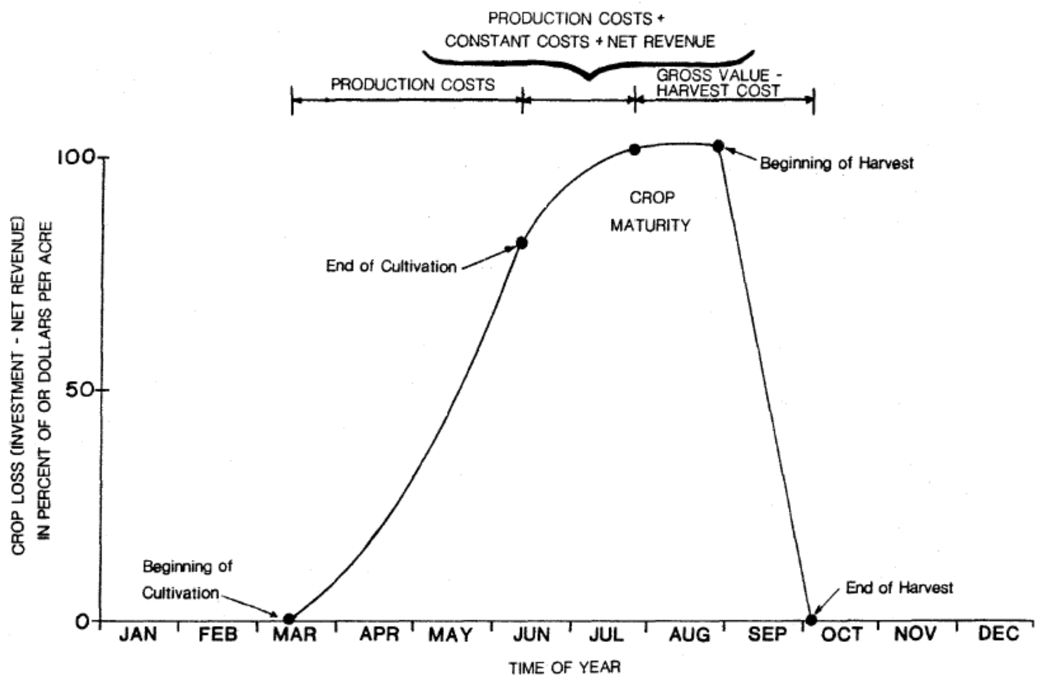

Figure 8. Example AGDAM damage function (USACE)

Although important in reality, the calculated depth of the flood water does not have any impact on the agricultural losses in the HAZUS/AGDAM methodology. The depth of the water was not deemed a significant component when the HAZUS crop loss module was designed (FEMA, 2010).

Crop stage is also important: plants in their main-growth stage, from about a month after planting until they begin maturing, are at most risk. The HAZUS “damage function” (Figure 8) only crudely represents crop growth stage. The HAZUS crop loss model is further simplistic in that it does not take either crop species or geographic location into account when determining crop growth stage. This study was fortunate in that the Iowa growing season is reasonably matched by the three averaged USACE districts.

HAZUS does not explicitly model flood duration; rather duration, R(t) is stipulated to be one of four intervals: 0-day (a flash-flood), 3-day, 7-day, and 14-day. A 0-day flood will produce no loss, a 3-day flood will produce a 75% loss, and 7- or 14-day floods will produce 100% loss. This study uses the 14-day flood duration, as the actual flood duration in Fremont County was 2-3 months.

Altogether four HAZUS scenarios were run in this study, using a flood-onset date of 27 June, 2011 for consistency with the date of the highest flood level (post levee breaches). The first scenario, shown in figure 9, used a depth-grid derived from the IFBF flood shapefile (clipped to Fremont County); the second scenario, figure 10, used a depth-grid directly from Iowa DNR. The third and fourth scenarios, figures 11 and 12, used those same depth-grids, respectively, as a reference for selecting the river reaches that had flooded (riverine methodology). Step by step HAZUS instructions appear in Appendix B.

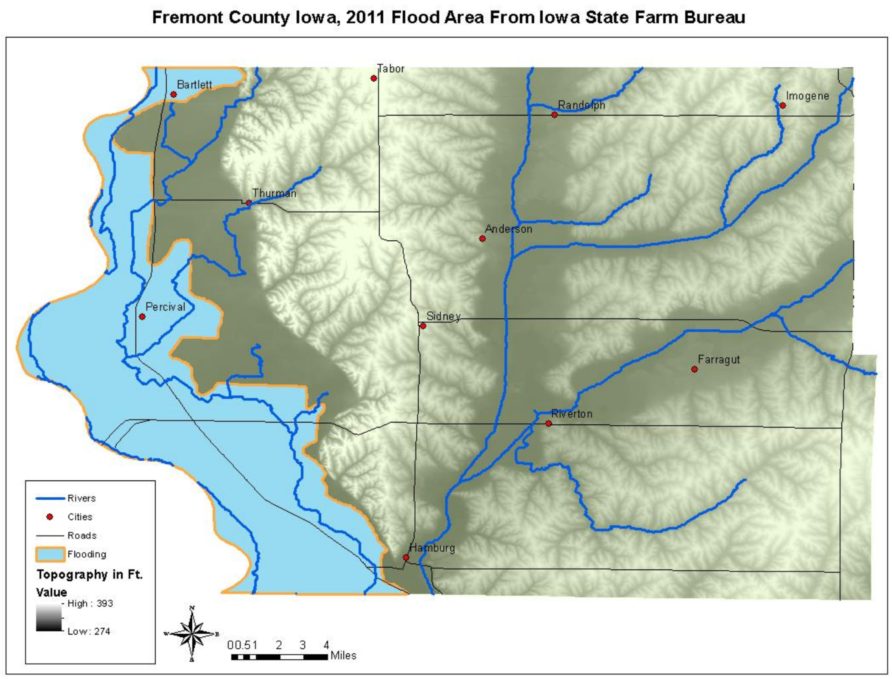

Figure 9. HAZUS model using IFBF shapefile and depth-grid. Scenario #1, $76.4 million

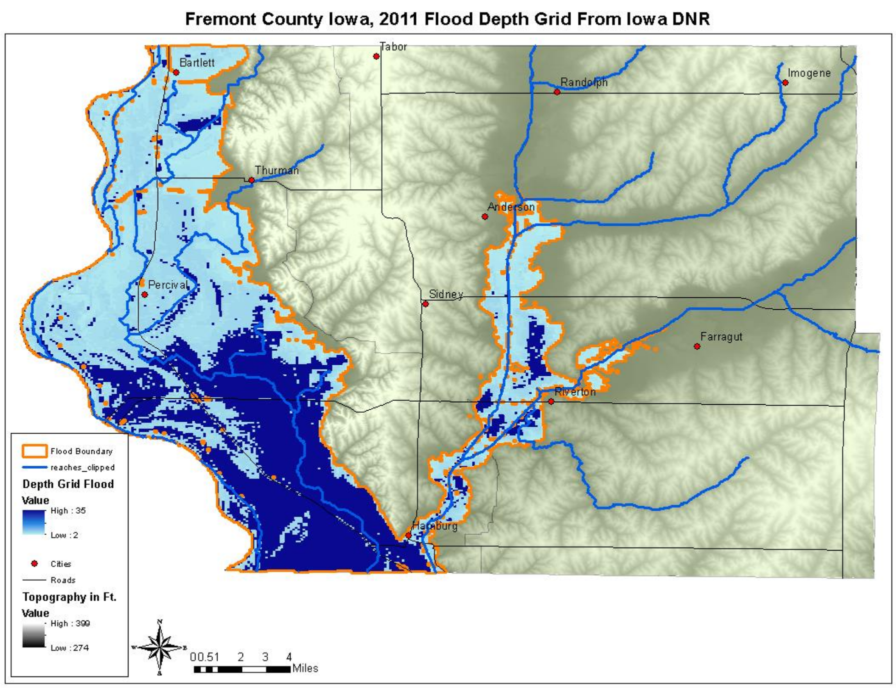

Figure 10. HAZUS model using Iowa DNR shapefile and depth-grid. Scenario #2, $135 million

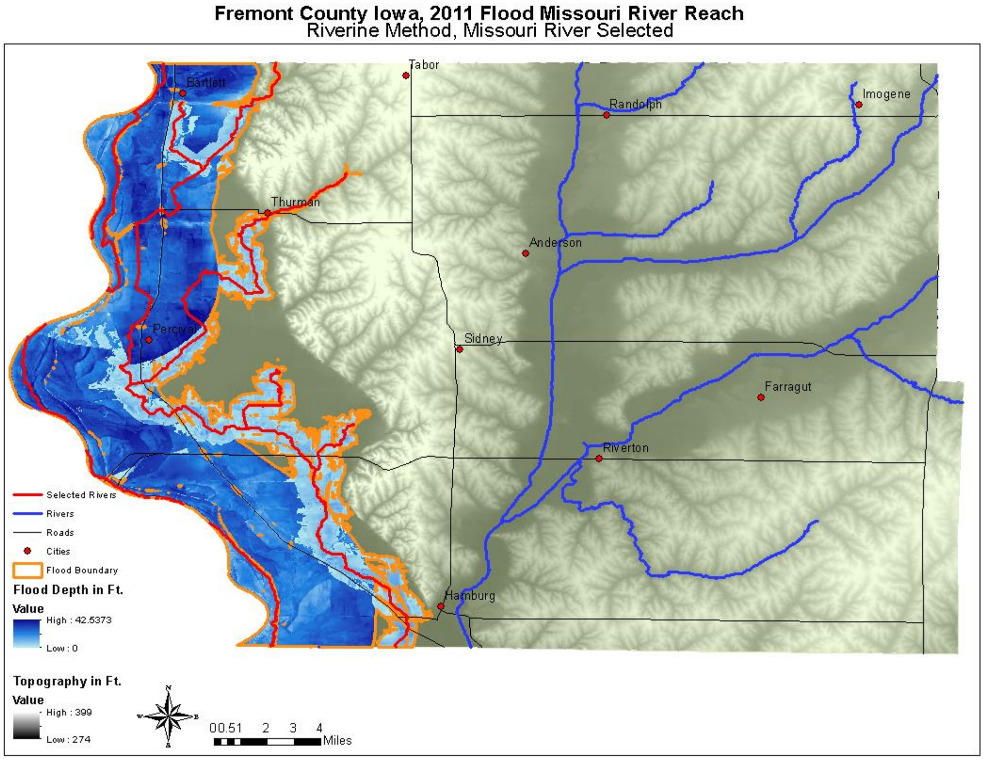

Figure 11. HAZUS model using riverine method based on IFBF. Scenario #3, $94.1 million

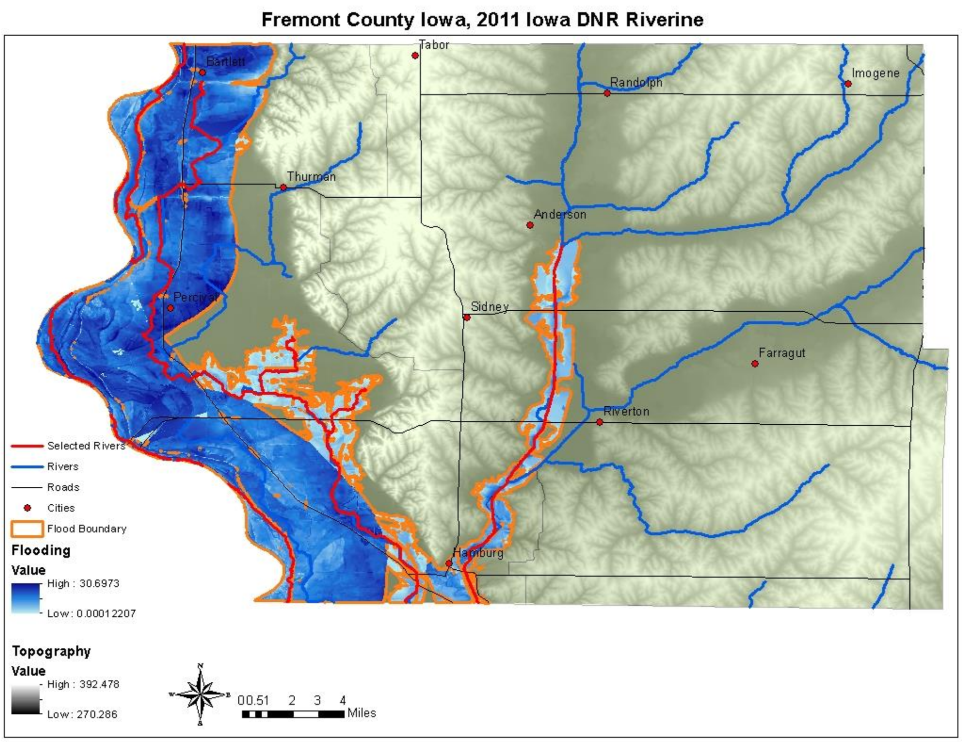

Figure 12. HAZUS model using riverine method based on Iowa DNR. Scenario #4, $101 million

The four HAZUS scenarios produced a wide range of crop losses varying from a minimum of approximately 54,000 ac and $76 million (using IFBF flood layer) to maximum of approx. 91,000 ac and $134 million (using Iowa DNR depth-grid). Thus, all the HAZUS agricultural flood loss estimates are substantially larger – up to 3 times larger - than the IMPLAN direct economic loss estimates.

Results

Establishing "ground truth" for the agricultural losses in Fremont County, Iowa following the 2011 flood is, regrettably, impossible now: the fields have been replanted and reharvested twice since that event. The best data available, after the fact, comes from the the USDA's NASS Cropscape tool, which relies on complex but mandatory, standardized agricultural production reporting. Cropscape "reality" is the term used in this thesis is the surrogate for "ground truth" going forward.

Figures 13 and 14 show the NASS Cropscape statistics for Eastern Nebraska and Western Iowa (Fremont County, Iowa) 2010- 2011. Each pixel in Cropscape represents a 30m x 30m area, color-coded according to the crop present. Flooded areas appear as light blue, corn appears as yellow, soybeans dark green, hay and alfalfa are light green, and non-agricultural areas are grey. Although quantized, approximate, and subject to reporting errors, these NASS statistics are the best data available on U.S. agricultural production. Comparing the 2010 and 2011 Cropscapes for Fremont County visually provides a quick reference for how much cropland was lost in the 2011 flooding. The light blue area surrounding the Nishnabotna River (southeastern quadrant of Fremont

County) did experience flooding in the 2011; however, it was not included in the flood shapefile provided by the IFBF. Table 2 summarizes the acreage in Fremont County that was harvested as corn, beans, or flooded in each of 2010 and 2011. For Fremont County, Iowa only two crops, Corn (labeled "corn, for all purposes" in NASS statistics) and Soybeans (labeled "soybeans for beans"), are significant in 2010 and 2011.

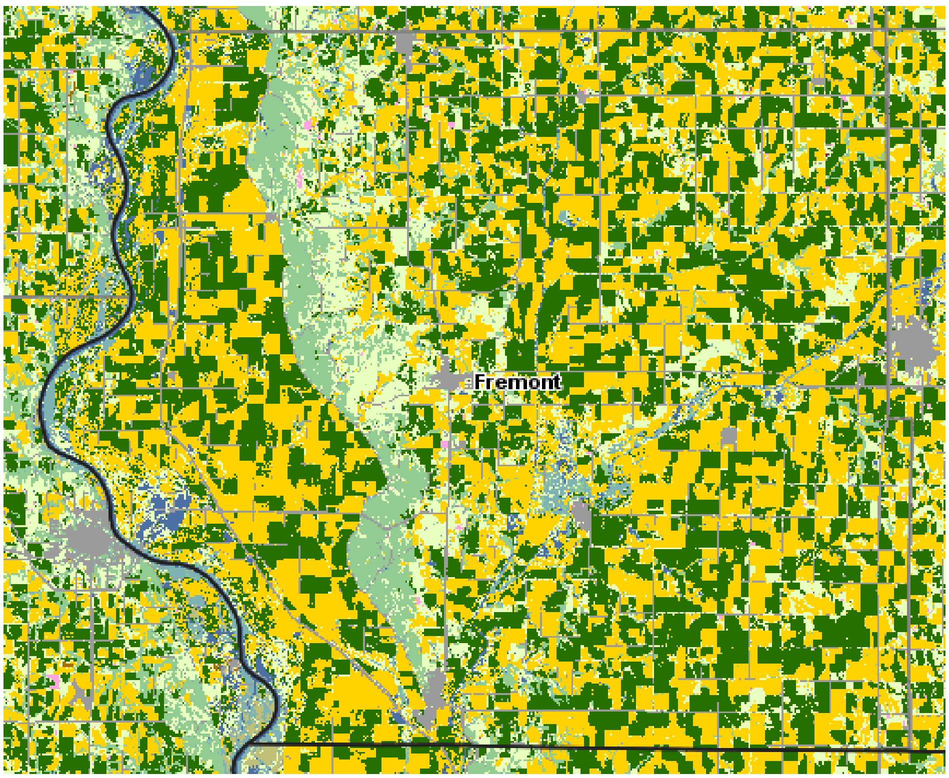

Figure 13. Fremont County, Iowa Cropscape 2010 (USDA/NASS)

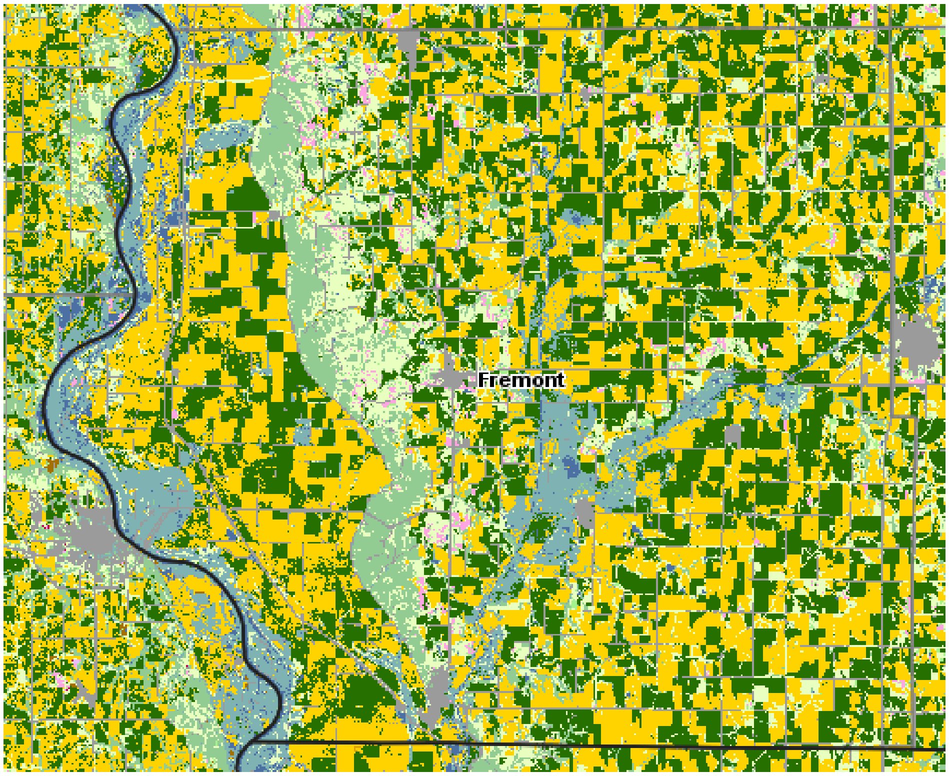

Figure 14. Fremont County, Iowa Cropscape 2011 (USDA/NASS)

Table 2. Selected agricultural statistics for Fremont County, Iowa (USDA/NASS)

	Corn		**Soybeans**	
	2010	2011	2010	2011
Planted (ac)	109,500	118,500	110,500	103,000
Harvested (ac)	104,500	95,800	107,900	86,000
Lost (ac)	5,000	22,700	2,600	17,000
Standard Loss*(ac)	2,725	2,725	1,442	1,442
Harvested (000 bu)	15,960	14,910	5,075	3,802
Yield (bu/ac)	152.7	157.0	47.0	49.0
Price ($ / bu)	3.83	7.00	9.97	13.65

* calculated average 2006-2010; see text

Three methods may be used to derive "real" crop losses in 2011 beyond the irreducible *standard loss* that occurs every year in agriculture from causes such as ponding in low lying areas, insect feeding, and nitrogen deficiencies. The first method, *Lost Acreage*, simply considers the difference between acreage planted and acreage harvested in 2011, minus the standard loss in acres, as all attributable to flood losses; this is monetized by the average yield per acre and harvest price that year. The second method, *Lost Production*, considers the reduction in acreage harvested in 2011 as compared to 2010, minus the standard loss in acres, monetized by the average yield per acre and the harvest price in 2011. The third method, *Lost Yield*, is similar to the second, but directly considers bushels harvested in 2011 as compared to 2010, minus the standard loss in bushels, monetized by the harvest price in 2011. (Because of sharply increased prices in 2011 over 2010, both corn and soybeans crops actually *gained* in market value despite their reduced production in 2011.) Source data for all three methods comes from NASS (Appendix A), summarized in Table 2 for convenience. Standard losses were calculated from the preceding 5 years, 2006 through 2010.

Table 3 shows the monetized loss of the reality numbers from NASS. The three methods for calculating "reality" were averaged then added together to produce a summary result of real agricultural loss for Fremont County of $24.5M in 2011. This number will be considered the reality of combined losses for corn and soybeans due to the Missouri River flooding of 2011.

Table 3. Crop losses calculated using three methods, taking into account average loss average over previous five years

		Corn		Soybeans	
METHOD		Quantity	$ Millions	Quantity	$ Millions
Lost Acreage	Gross	22,700 ac		17,000 ac	
	Net*	19,975 ac	22.0	15,558 ac	10.4
Lost Production	Gross	8,700 ac		21,900 ac	
	Net*	5,975 ac	6.57	20,458 ac	13.7
Lost Yield	Gross	1,050,000 bu		1,273,000 bu	
	Net*	662,175 bu	4.36	1,202,342 bu	16.4
		Average	11.0	Average	13.5

* excluding standard loss

Table 4 shows the losses calculated for the four HAZUS scenarios using corn yield of 157 bu/ac at a price of $7.00 a bushel and a soybean yield of 49 bu/ac at a price of $13.65 a bushel. There is a noticeable difference in the flood acreages with each scenario. The depth-grid derived from the IFBF flood shapefile produced the smallest losses (acreage and dollars) and the Iowa DNR provided depth-grid produced the greatest. When the IFBF flood layer was used as a guide for selecting river reaches for flooding (scenario #3), more acreage ended up being flooded resulting in higher loss predictions. Referring to figures 9-12, the wide range of flooded acres is clearly apparent; all exceed the "reality", $24.5 million, by unacceptably large amounts.

Table 4. HAZUS predicted crop losses for Fremont County, Iowa 2011

Scenario	Flooded Area (ac)	$ Millions
#1 IFBF shapefile used to derive depth grid	53,968	$76.4
#2 Iowa DNR stipulated depth-grid	90,774	$135
#3 IFBF derived depth-grid as reference for river reach selections	65,003	$94.1
#4 Iowa DNR stipulated depth-grid as reference for river reach selections	67,412	$101

Analysis of Scenario 1 vs. “Reality” results:

The HAZUS crop loss tool produced a result of $76.4M for agricultural loss in Fremont County when using the IFBF flood layer. The reality calculation of direct crop loss dollars is $24.5M. Thus, HAZUS overstates reality by 3.1 times.

Analysis of Scenario 2 vs. “Reality” results:

The HAZUS crop loss tool produced a result of $135M for agricultural loss in Fremont County when using the Iowa DNR flood layer. The reality calculation of direct crop loss dollars is $24.5M. Thus, HAZUS overstates reality by 5.5 times.

Analysis of Scenario 3 vs. “Reality” results:

The HAZUS crop loss tool produced a result of $94.1M for agricultural loss in Fremont County when using the IFBF flood layer for further riverine river reach selection. The reality calculation of direct crop loss is $24.5M. Thus, HAZUS overstates reality by 3.8 times.

Analysis of Scenario 4 vs. “Reality” results:

The HAZUS crop loss tool produced a result of $101M for agricultural loss in Fremont County when using the Iowa DNR flood layer for further riverine river reach selection. The reality calculation of direct crop loss is $24.5M. Thus, HAZUS overstates reality by 4.1 times.

Table 5 makes it apparent that both the IMPLAN study and all of the HAZUS scenarios are overstating lost acreage. The HAZUS numbers were particularly large.

Table 5. Flood loss acres as reported by HAZUS, IFBF, and USDA

	HAZUS	IFBF	USDA/NASS
Corn	44,723	31,794	22,700
Soybeans	40,736	24,111	17,000

Upon study, it became apparent that the HAZUS code had an egregious error: when HAZUS clips the agricultural sub-county polygon layer to the flood plain boundary the area in the clipped polygons is not updated, thus leaving the much larger unclipped area in place. All subsequent loss estimates are affected by this mis-calculation, resulting in overstatement of up to 5.5 times “reality” as determined above. Direct economic losses were overestimated by the IMPLAN study also, but by a much smaller factor, only 1.8 times “reality”. Figure 15 shows the worst offending polygons (outlined in cyan) with erroneous area values. The error regularly occurs when HAZUS clips the agricultural polygons to the flood boundary. This error must be fixed before HAZUS can be usefully applied in crop loss estimation work.

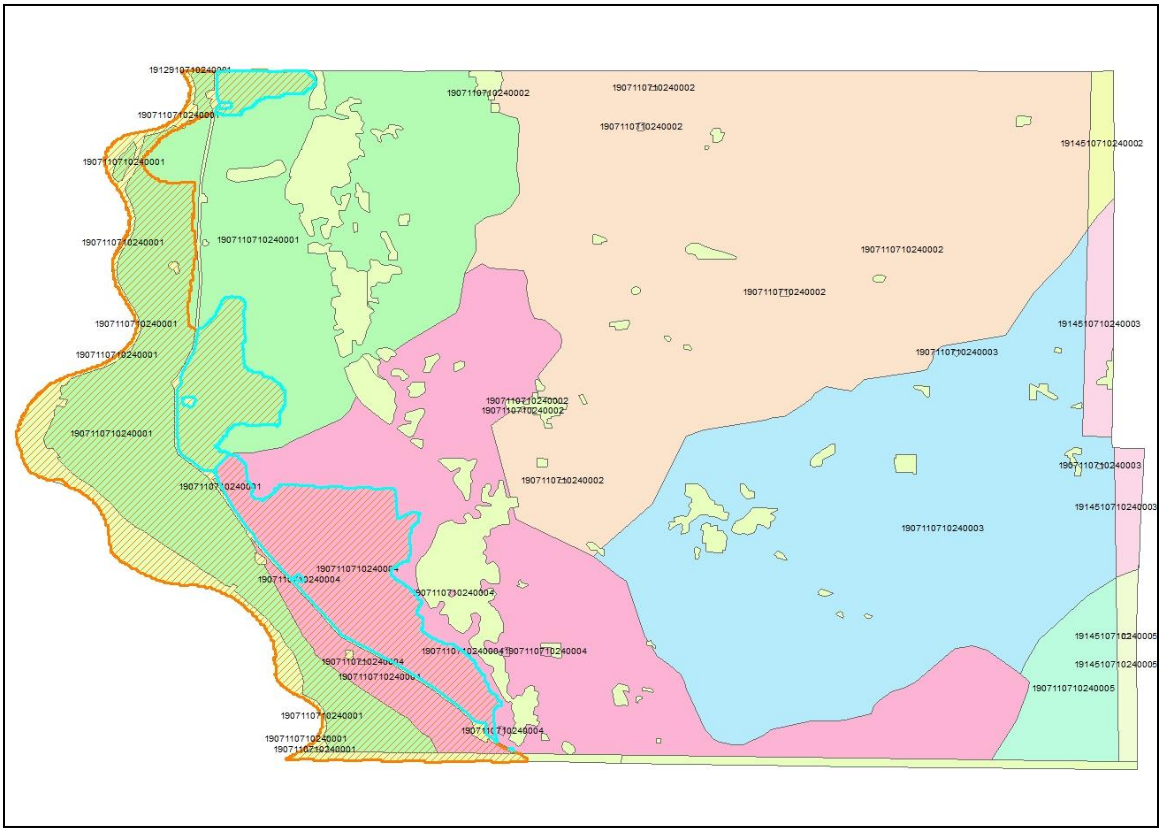

Figure 15. Agricultural polygons miscalculated in HAZUS, for Fremont County, Iowa. IFBF flood boundary shown in orange outline; polygons with significantly miscalculated area outlined in cyan. (N. Todorov, pers. comm., June 27, 2013)

As confirmation, the error in the flooded area calculation is documented in Table 6. The flood model maintains an AREA column that should be the same as the one that ArcGIS maintains, here Shape_Area, when a clip is performed. The RatioTest column, created by dividing the AREA column by the Shape_Area column, should be unity if the AREA column were being updated appropriately. Evidently it is not for over half the polygons in the study area. The two largest polygons in error are highlighted.

Table 6. Confirmation of areal miscalculation in HAZUS (N.Todorov, pers. comm., June 27, 2013)

Table

flAgMap_Clip_Project

Shape_Length	OBJECTID *	PolygonID	AREA	Shape_Area	RatioTest
892.920027	14	1912910710240001	28142256.6254	4615.008907	6097.985333
2905.242646	2	1907110710240001	2102699.75177	19070.513077	110.259212
3120.678069	7	1907110710240001	4413479.15105	46966.991882	93.969807
7115.538963	11	1907110710240001	3991176.74107	107438.623569	37.148435
5467.827784	9	1907110710240001	1968307.58067	117999.681526	16.680618
41729.268863	13	1907110710240001	163673866.204	25987451.797462	6.298188
51965.28022	8	1907110710240004	225846584.387	51014773.785256	4.427082
95995.822638	12	1907110710240001	96955363.7742	89584505.776814	1.082278
35071.214654	5	1907110710240004	17365666.0276	17374092.539997	0.999515
981.472979	3	1907110710240004	61537.470689	61568.376675	0.999498
1378.355402	1	1907110710240001	66572.840394	66607.656997	0.999477
1203.256207	4	1907110710240004	93214.829839	93264.116174	0.999472
3294.907462	6	1907110710240001	117798.271755	117867.337218	0.999414
4681.282409	10	1907110710240001	847113.880945	847621.714833	0.999401

Another, smaller but surprising error in HAZUS is the incorrect projection of the agricultural layer onto the study region: The flAgMap[3] Feature Class does not align with the Census TIGER county boundaries. As a consequence, small parts (slivers) of mistakenly flooded agricultural crops (also some mistakenly UNflooded crops) occur everywhere. The improper projection of the agricultural layer onto the study region appears to affect every county in the U.S.

In the course of this study, several other deficiencies in the HAZUS flood loss methodology were noted. As previously stated, HAZUS does not currently take flood depth into account when calculating flood damage to crops. This will certainly lead to erroneous calculations in most cases. For example, corn is particularly sensitive to flooding in the early vegetative stages (especially prior to the fifth or sixth leaf stage). In general, during early growth stages plants can survive for only two to four days under

[3] Flood Agricultural Map, this feature class is an ArcGis layer that contains the agricultural information for a given study region.

water in anaerobic conditions. Moderate water movement can reduce flood damage by allowing some oxygen to get to the plants, keeping them respiring and alive. Drainage within one to two days increases the chance of survival. The extent of injury to seedlings is determined by the plant stage of development at ponding, duration of flooding and the air/soil temperatures as well as if axillary buds are present on damaged plants (NDSU, 2013).

In addition, the HAZUS damage functions are naïve with regards to local growing conditions and hence flood impacts in relation to crop stage. For each crop, one growth curve is applied for the entire country, irrespective of planting date, which obviously affects percentages of flood loss. A flood date in mid-May, for example, will have no impact in the upper Midwest if the farmers have not even planted their corn yet, while that same date could result in total loss of a developing corn crop in Texas or California. It is essential to adjust the damage functions to account for the growth stage of the crops in a given study area in order to calculate the proper loss.

As well, different crops mature at different rates, and their periods of maximum vulnerability to flooding, among other risks, varies. As an illustration of this principle, Figures 16 and 17 show growth curves for Iowa corn and various North Dakota crops: clearly demonstrated are differences within crop phenology both within different species and within different years for a given species. Figure 16 demonstrates that in 2008 corn was two weeks slower in maturing (“behind”) than it was in 2006 and 2007. Figure 17 shows that each crop’s phenology is different even within a given area.

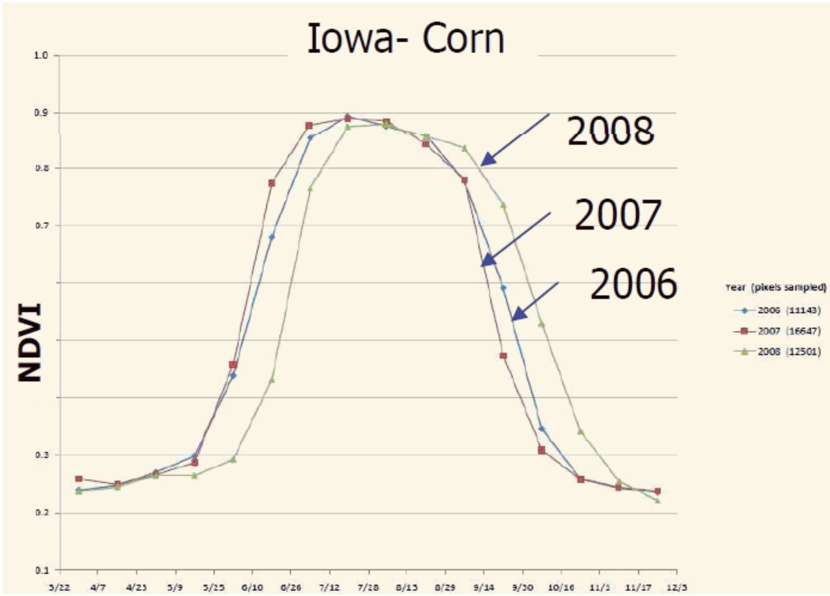

Figure 16. Iowa corn phenology chart 2006-2008 (USDA/NASS)

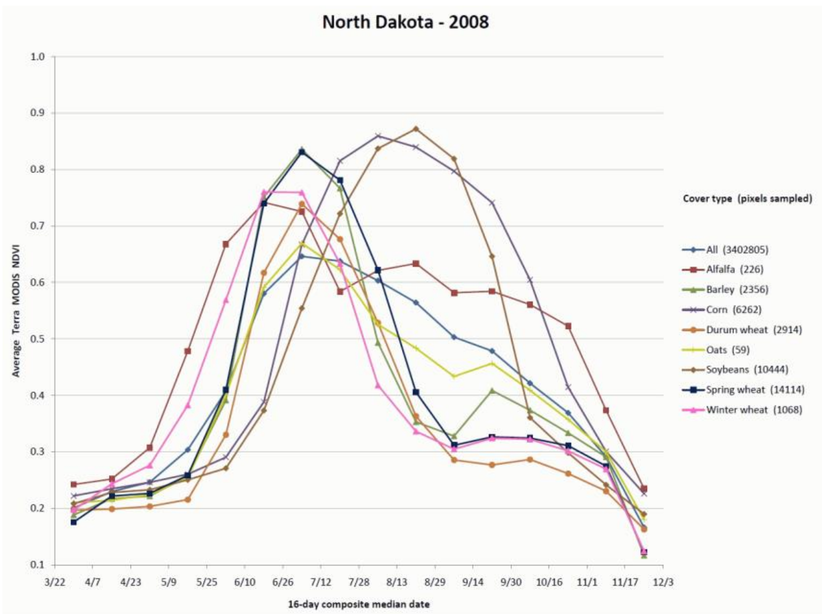

Figure 17. North Dakota phenology of various crops (USDA/NASS)

A related issue is that the HAZUS crop loss tool does not take elevation into account in its damage functions. Crops at higher altitude generally fall “behind” the same crops at lower altitude developmentally, owing to cooler temperatures at elevation.

Finally, the HAZUS crop loss tool does not take water or soil temperature at time of flooding into account. As previously discussed, the temperature of the flood water critically impacts young plants. The cooler the water the longer seedlings can survive without damage, although cooler temperatures can make them more prone to disease. If temperatures are warm during flooding (greater than 77 F), plants may not survive 24 hours.

Seed treatments do offer limited protection against flood-caused disease. However, seedling development slowed by several weeks of flooding allows soil-borne pathogens a greater opportunity to cause damage. Seed rots, seedling blight, corn smut and crazy-top affect corn plant development later even though ponding occurred earlier. Delayed soybean growth allows diseases such as Fusarium root rot, Phytophthora rot and Pythium rot to establish and weaken or destroy seedlings (NDSU, 2013).

Follow-Up Research

This study was based on HAZUS v2.0 results, in order to simulate what a planner or official would have understood from the HAZUS model that was available in 2011. The HAZUS v2.1 update was released 18 months later, in the Winter of 2012. For completeness, re-runs of the four HAZUS scenarios were made in HAZUS v2.1. The v2.1 flood module did have modifications made to it that changed the overall flooded region; however, the lost crop area was still being overstated by approximately a factor of two. Overall results nearly identical to those obtained from the HAZUS v2.0 runs. This demonstrates that all the problems described above still exist: the area of lost crop is still being over-calculated, the agricultural layer does not align with the study region boundary after projection, and the multiple deficiencies in the damage functions have not been addressed.

Conclusion

Crop growth modeling, and hence crop loss prediction, is complicated. If the FEMA HAZUS crop loss tool is to be used to reliably predict agricultural losses it is apparent that both some code corrections and some "tuning" of the algorithm will be required.

The most critical aspect of the HAZUS flood prediction process is deciding upon the flood region: ensuring that the flooded areas are correctly represented. For the purpose of this study, the predictive Iowa DNR flood layer was taken verbatim: this overstated the flood area by a factor of 1.7. The IFBF flood layer, by contrast, was created post-flood; in a predictive situation this layer would not exist. This study demonstrates how inaccurate the acreage of crops in a predicted flood region may be when compared with "reality".

The incorrect calculations for lost crop acreage, regardless of flood layers, is the most glaring problem found with the HAZUS crop loss tool. Several systematic errors within HAZUS' treatment of crop losses have already been pointed out.

A significant addition to HAZUS capabilities would be calculations of crop losses due to drought, which can be equally damaging to crops as floods. HAZUS needs to cover predicting both meteorological extremes' effects on crop loss to become a more complete tool for agricultural policy makers Modeling drought will require further refinement of the agricultural sub-model in HAZUS.

Finally, the IMPLAN logic for calculating indirect and induced losses due to economic multiplier effects should be re-introduced into the HAZUS. (It was included prior to v2.0.) In an increasingly populous and precarious world, the aftermath of a loss or shock can be much more damaging than the event itself.

Currently, approximately 10 percent of U.S. grain is sold abroad, with the U.S. producing 40 percent of the world's corn in any given year. The United Nations warns that world grain reserves have grown dangerously low, so much so that severe weather events in the United States or another grain exporting country could trigger a major hunger crisis. In the face of essentially fixed agricultural land and increasingly erratic weather combined with a growing world population, attending to food security has become an imperative. The importance of crop exports and their international impact make crop failure an issue that has global ramifications, not just impacting those in crop-growing regions: food insecurity can rapidly spiral into social unrest.

Extreme meteorological and hydrological events have more than doubled in the last 20 years and are predicted to continue, with serious consequences for food production and distribution. With the planet's weather becoming more erratic, tools that can help accurately predict losses due to flooding will become of ever greater importance.

Food security for this country, along with others, will depend on accurate forecasts of crop production and emergent losses to help make well informed decisions regarding domestic allocations, exports and reserves.

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Appendix A: Agricultural Statistics

Corn: Area Planted For All Purposes, Harvested for Grain, Yield and Production, Iowa by County, 2010-2011

County and District	Area Planted for all Purposes		Area Harvested for Grain		Yield		Production	
	2010	2011	2010	2011	2010	2011	2010	2011
	(acres)	(acres)	(acres)	(acres)	(bushels)	(bushels)	(1,000 bushels)	(1,000 bushels)
Benton	197,500	209,000	193,500	205,500	179.0	157.2	34,630	32,300
Cedar	162,000	173,500	160,500	172,000	174.4	184.9	27,990	31,800
Clinton	197,000	207,500	193,000	202,000	171.2	180.0	33,050	36,370
Iowa	120,500	126,000	117,000	121,600	158.5	171.6	18,540	20,870
Jackson	108,000	115,500	102,500	105,000	157.2	178.3	16,110	18,720
Johnson	110,500	119,500	106,500	117,500	150.9	171.9	16,070	20,200
Jones	158,000	164,500	154,000	159,900	168.9	171.4	26,010	27,410
Linn	150,000	165,500	146,000	163,500	170.3	169.1	24,870	27,650
Muscatine	93,500	96,000	91,500	94,000	144.8	164.6	13,250	15,470
Scott	113,000	118,000	110,500	114,000	151.9	174.2	16,780	19,860
East Central	**1,410,000**	**1,495,000**	**1,375,000**	**1,455,000**	**165.3**	**172.3**	**227,300**	**250,650**
Adair	105,500	112,000	104,500	109,300	139.1	152.8	14,540	16,700
Adams	71,000	73,000	69,000	71,000	139.3	151.7	9,610	10,770
Cass	137,500	140,500	135,000	136,500	155.1	175.2	20,940	23,910
Fremont	109,500	118,500	104,500	95,800	152.7	155.6	15,960	14,910
Mills	99,000	102,500	97,000	96,700	160.2	155.0	15,540	14,990
Montgomery	92,000	96,500	90,000	94,000	157.0	153.2	14,130	14,400
Page	110,000	114,500	109,000	107,000	150.1	136.2	16,360	14,570
Pottawattamie ...	232,000	248,500	228,500	233,000	164.8	170.9	37,650	39,820
Taylor	78,500	89,000	77,500	86,700	122.2	140.5	9,470	12,180
Southwest	**1,035,000**	**1,095,000**	**1,015,000**	**1,030,000**	**151.9**	**157.5**	**154,200**	**162,250**

Soybeans for Beans: Area Planted, Harvested, Yield and Production, Iowa by County, 2010-2011 (continued)

County and District	Area Planted		Area Harvested		Yield		Production	
	2010	2011	2010	2011	2010	2011	2010	2011
	(Acres)	(Acres)	(Acres)	(Acres)	(Bushels)	(Bushels)	(1,000 Bushels)	(1,000 Bushels)
Benton	151,500	143,000	151,100	142,300	52.7	56.2	7,960	7,997
Cedar	110,000	99,700	109,600	99,200	53.1	61.2	5,818	6,071
Clinton	111,500	104,000	111,000	103,500	51.4	60.5	5,704	6,262
Iowa	91,500	91,200	91,000	90,600	52.3	54.0	4,758	4,893
Jackson	54,800	46,900	54,300	46,500	52.4	55.6	2,845	2,585
Johnson	86,500	82,700	86,000	82,100	48.9	54.2	4,206	4,450
Jones	66,400	62,300	65,900	61,900	52.6	59.3	3,465	3,671
Linn	103,000	90,500	102,600	90,000	53.8	56.0	5,518	5,040
Muscatine	67,300	67,500	66,800	67,100	48.9	55.6	3,267	3,731
Scott	67,500	63,200	66,700	62,800	52.4	62.8	3,494	3,943
East Central	**910,000**	**851,000**	**905,000**	**846,000**	**52.0**	**57.5**	**47,035**	**48,643**
Adair	102,000	103,500	101,300	101,900	48.7	49.4	4,935	5,034
Adams	65,000	67,800	64,200	66,800	47.7	46.0	3,064	3,073
Cass	108,000	109,500	107,300	107,900	53.2	51.4	5,708	5,547
Fremont	110,500	103,000	107,900	86,000	47.0	44.2	5,075	3,802
Mills	93,200	90,200	92,000	86,000	51.0	44.5	4,693	3,828
Montgomery	87,500	85,800	86,800	84,100	49.7	45.0	4,315	3,785
Page	108,000	109,500	107,200	101,200	47.8	37.1	5,127	3,755
Pottawattamie	210,500	190,000	208,500	177,500	52.3	51.6	10,905	9,159
Taylor	85,300	81,700	84,800	80,600	46.7	37.8	3,963	3,047
Southwest	**970,000**	**941,000**	**960,000**	**892,000**	**49.8**	**46.0**	**47,785**	**41,030**

Standardization processes:
Data to normalize

Corn Planted	2010 109,500	2011 118,500	2011 Loss 22,700 ac	2010 Loss 5,000 ac	2009 Loss 500 ac	2008 Loss 6,000 ac	2007 Loss 1300 ac	2006 Loss 400 ac
Beans Planted	110,500	103,000	17,000 ac	2,600 ac	500 ac	3,000 ac	800 ac	600 ac
Corn Harvested	104,500	95,800						
Beans Harvested	107,900	86,000						

Data

2011 Loss	2010 Loss	2009 Loss	2008 Loss	2007 Loss	2006 Loss		
22,700 ac	5,000 ac	500 ac	6,000 ac	1300 ac	400 ac	= 2640 ac average over the 5 other years	(excluding 2011 flood year)
17,000 ac	2,600 ac	500 ac	3,000 ac	800 ac	600 ac	= 1500 ac average over the 5 other years	(excluding 2011 flood year)

	2010	2011
Corn Planted	109,500	118,500
Beans Planted	110,500	103,000
Corn Harvested	104,500	95,800
Beans Harvested	107,900	86,000

av corn planted over other 5 years is 114,700 ac avg loss 2640 ac 2.3% loss avg.
av beans planted over other 5 years is 110,600 ac avg loss 1500 ac 1.4% loss avg.

Corn									
	2010	2011 (1000 bushels)	2011 Loss	2010 Loss	2009 Loss	2008 Loss	2007 Loss	2006 Loss	
	15,960	14,910	1050	7955	+7765	3363	+2141	1578	av 598 (1000 bushels) per year loss = $4,186,000
Beans	2010	2011 (1000 bushels)							
	5075	3802	1273	917	+1402	779	143.2	+107.2	av 66 (1000 bushels) per year loss = $900,900

Appendix B: HAZUS Procedures

The process for running a HAZUS scenario using a User Defined depth-grid is as follows:

- Create a new region in HAZUS
- Select Hazard type Flood
- Select Aggregation Level County
- Select State Iowa
- Select County Fremont
- Select Complete Create New Region
- Open the newly created region
- Enter Agricultural Inventory changes at the sub-county level ie. change yield of corn to 157 bushels per acre and soybeans to 49 bushels per acre, change price on corn to 7.00 per bushel and 13.65 per bushel for soybeans. (prices and yield provided by IFBF so a direct comparison could be made)
- Enter date of flood under Analysis then Parameters then Agricultural (Jun 27 used for this study)
- Import the DEM for the extent to be modeled, this is accomplished by selecting Hazard-> User Data -> Under Dem tab select determine DEM Extent -> download NED from USGS.
- After DEM is downloaded and location is noted, unzip NED and go back into the User Data section of Hazard
- In the Dem tab select Vertical Datum of NAVD88 for the USGS Dem
- Enter Vertical Units of Meters for the USGS Ned
- Browse to find your newly acquired NED and select it
- Pop-up will say that HAZUS needs to generate a raster using the NED and do not cancel, say OK
- Go back into Hazard option and select User Data and Depth-grid tab
- Select Depth-grid and find the depth-grid you generated
- Enter Units Meters
- Enter return period 100, representing 100 years flood return period
- Enter Hazard option and select Develop Stream Network (takes several minutes to run)
- Enter Hazard and select New Scenario
- Select User Defined Depth-grid

- Select Add to Selection button
- Use cursor to highlight an area within the user depth-grid which should now be showing overlaid on the DEM, this should highlight the entire depth-grid area
- Click on Save
- Enter Hazard option
- Select Delineate Floodplain
- When pop-up interface appears select Single Return Period, 100 and then ok
- Enter Analysis option
- Select Run (this can take over 1 hour so be patient)
- To view results, enter Results option, Select View Results By, then select Available Results and 100 should be selected, Select OK
- Go back to Results option and now Agricultural Loss will be selectable, select Agricultural Loss
- View the predicted agricultural losses for any crops located within the extent for which you are running the HAZUS flood model.

The process for running a HAZUS Riverine scenario where river reaches are manually selected is as follows:

- Create a new region in HAZUS
- Select Hazard type Flood
- Select Aggregation Level County
- Select State Iowa
- Select County Fremont
- Select Complete Create New Region
- Open the newly created region
- Enter Agricultural Inventory changes at the sub-county level ie change yield of corn to 157 bushels per acre and soybeans to 49 bushels per acre, change price on corn to 7.00 per bushel and 13.65 per bushel for soybeans. (prices and yield provided by IFBF so a direct comparison could be made)
- Enter date for flood under Analysis then Parameters then Agricultural (Jun 27 used for this study)
- Enter date of flood under User Data Agriculture
- Import the DEM for the extent to be modeled, this is accomplished by selecting Hazard-> User Data -> Under Dem tab select determine DEM Extent -> download NED from USGS.
- After DEM is downloaded and location is noted, unzip NED and go back into the User Data section of Hazard

- In the Dem tab select Vertical Datum of NAVD88 for the USGS Dem
- Enter Vertical Units of Meters for the USGS Ned
- Browse to find your newly acquired NED and select it
- Pop-up will say that HAZUS needs to generate a raster using the NED and do not cancel, say OK
- Enter Hazard option
- Select Develop Stream Network
- Input Stream Drainage 10.0 square miles (this will provide a stream network detailed enough to select the river reaches needed for this study)
- Select the river reaches that correspond with the rivers known to be flooding or are expected to be flooding. (for this study the river reaches were determined by examining flood shapefiles that were received from the IFBF and the Iowa DNR)
- Enter Hazard option and select Hydrology (this can take several minutes)
- Enter Hazard option and select Delineate Floodplain
- Select Single Return Period, 100 should be the value showing (this can take 1 hour or more depending on number of river reaches, in this study 16 river reaches ran approximately 1 hour 15 minutes)
- River reaches selected for the runs in this study are shown in figure 11 and figure 12
- To view results, enter Results option, Select View Results By, then select Available Results and 100 should be selected, Select OK
- Go back to Results option and now Agricultural Loss will be selectable, select Agricultural Loss
- View the predicted agricultural losses for any crops located within the extent for which you are running the HAZUS flood model.