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Economic Assessment of a Highly Pathogenic Avian Influenza Outbreak in Washington and Benton Counties in Arkansas

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Economic Assessment of a Highly Pathogenic Avian Influenza Outbreak in Washington and Benton Counties in Arkansas

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by

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Abstract

Highly Pathogenic Avian Influenza (HPAI) presents a substantial economic risk to the poultry industry. Domesticated fowl contract HPAI initially through exposure, direct or indirect with migratory waterfowl and outbreaks can result in significant economic losses to growers and the poultry industry at large. A HPAI outbreak occurred in Minnesota and Iowa and spread across over 13 other states in 2014 and 2015. This caused an estimated $1.6 billion in losses (CDC, 2016) and led to shortages of eggs and turkeys together with elevated prices (Anni et al. 2005). Even small outbreaks of HPAI inflict substantial damages as USDA-APHIS guidelines necessitate a 10-km radius quarantine area and possible cull from the site of infection. Previous literature evaluates economic damages from AI predominantly using case studies of past outbreaks, but *a priori* estimation of potential economic losses resulting from HPAI outbreaks in critical industry regions has been given less attention. We assess economic damages to poultry growers, companies, and the federal government resulting from a simulated HPAI outbreaks across spatially specific poultry house locations in the high-value poultry-growing region of Washington and Benton counties in Arkansas. With a simulation model built using Statistical Analysis System (SAS 9.4), we assigned poultry operation types (Broilers, Breeders, Pullets, Turkeys, and Layers) to facilities using discrete non-uniform probabilities from known county-level poultry type distributions reported by USDA. A single facility is randomly infected with HPAI, and houses within the quarantine zone are identified based on a distance matrix calculated in a GIS (ArcGIS for Desktop 10.4). The value of economic damages is determined using mean bird values by poultry type on the lifecycle of the birds. Because the total damages and number of impacted houses depend on house types and the location of the initial infection, we ran the model one thousand times with the location of infection randomly to account for spatial variability. Results show that on average, an infection in Benton

or Washington County, impacts 162 poultry houses, including Broiler (119), Pullet (7), Breeder (17), Brown Layer (2), Turkey (16), and White Layer (1) houses, the federal government through indemnity payments incurs the greatest economic losses ($57.4 million), while poultry companies and grower incur $17.3 and $3.1 million, respectively, in opportunity costs from quarantine time.

Acknowledgements

“Trust in the LORD with all your heart and lean not on your own understanding; in all your ways submit to him, and he will make your paths straight” Proverb 3:5-6.

Proverbs 3:5-6 was constantly in my head during the hard times of my master’s program. This verse allowed me to accomplished things I only had dreamed about. Trusting the LORD in everything I did along the way kept me from falling apart during difficult times. This verse was first introduced to me by Dr. Goodwin while informing me that hard work and determination can overcome anything in life. We should always trust the LORD along the way.

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All glory be to God!

Dedication

This work is dedicated to my mother Iliana Itzel Guerra de Beitia, my father Antonio Beitia Rueda, and my brothers Ismael Beitia Guerra and Ruger Beitia Guerra.

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Chapter I: Poultry Industry Background and Research Problem Overview

1.1 Poultry Industry Background

Commercial poultry production began in the United States in the 1800's. The main purpose of the early poultry industry was to provide eggs for households and chickens for Sunday or special dinners. Broiler production began in the 1920's when farmers began to specialize in either egg production or meat production, as some birds were better at producing eggs and some at producing meat (U.S. Poultry & Egg Association 2016). In the 1940's, the industry took a new step toward modernization as producers began to sell their birds already processed (U.S. Poultry & Egg Association 2016). In the 1960's, poultry companies were becoming fully integrated where the companies owned and controlled multiple stages of production allowing them to expand rapidly (U.S. Poultry & Egg Association 2016). In the 1950's and 1960's, commercial American poultry production began and help moved the poultry industry more toward vertical integration where the integrator was involved in all stages of production, processing, and marketing (U.S. Poultry & Egg Association 2016).

The 1970's were the dawn of modern poultry production across the United States. Poultry nutrition, genetics, and diseases were beginning to gain more research traction (U.S. Poultry & Egg Association 2016). New processing technologies were developed resulting in poultry meat becoming an efficient, reliable, and healthy source of protein (U.S. Poultry & Egg Association 2016). During the late 1970's, poultry consumption increased drastically due to the health perceptions that poultry meat was healthier than red meat. In 1992, poultry consumption surpassed beef consumption in the United Sates (National Chicken Council 2012). During the late 70's, per capita egg consumption increased due to the fast food implementation of eggs in breakfast foods.

Determination of the nutritional composition of eggs helped consumers have a better perception of the health benefits of eggs (U.S. Poultry & Egg Association 2016).

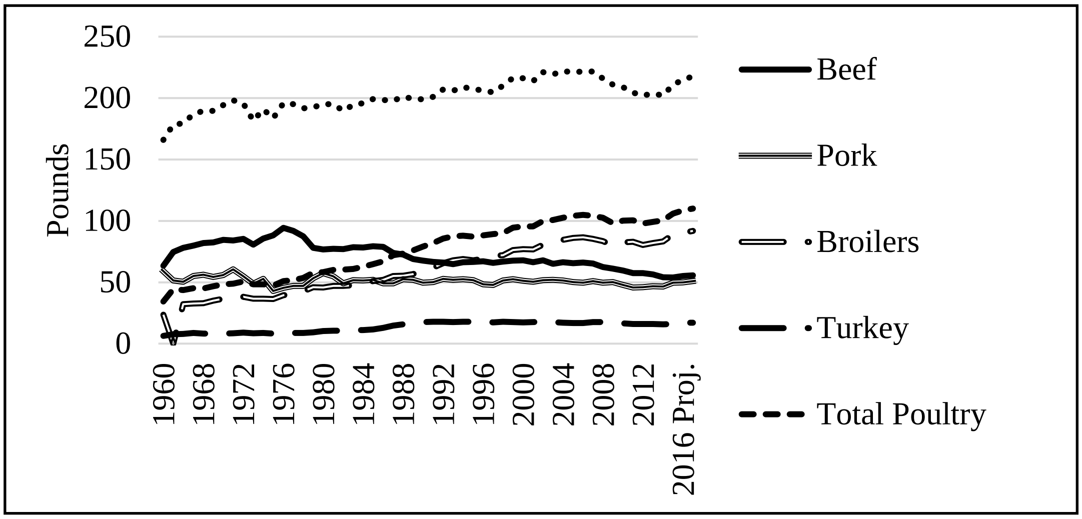
During the 1990's and 2000's, the American poultry industry began large-scale exporting globally (U.S. Poultry & Egg Association 2016). High demand for leg quarters and paws moved the industry to new markets such as Russia, Latin American, and China (U.S. Poultry & Egg Association 2016). Given this rapid increase in demand both domestically and abroad, the United States became the largest poultry producer in the world, accounting for about 25% of the global poultry production from 2006 – 2012 (Food and Agriculture Organization of the United Nations 2017))

The industry success can be attributed to the efficient structural organization, improvement in production and processing technologies, genetics, nutrition, and most importantly continuous response to consumer demands (National Chicken Council 2012)

1.1.1 Poultry Meat Consumption

In 1965, Americans consumed 44.4 pounds of poultry meat per capita (National Chicken Council 2012). American poultry meat consumption increased to almost 104 pounds per person in 2007 (National Chicken Council 2012). In 2015, per capita consumption of poultry meat was 106 pounds of meat per person and the projections for 2016 and 2017 are 108 and 110, respectively, as shown in Figure 1. (National Chicken Council 2012). In addition, all poultry meat consumption around the world is increasing and this trend is predicted to continue, as shown in Table 1.

Figure 1. U.S. Per Capita Consumption of Poultry and Livestock, 1965 to Estimated 2016, in Pounds



Source: National Chicken Council, 2016

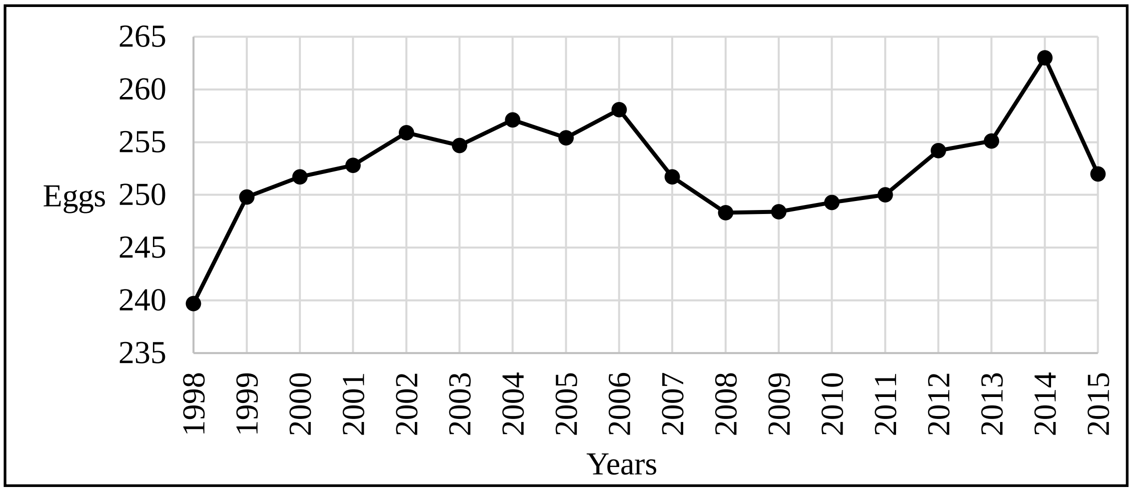
For eggs, the U.S. had a *per capita* consumption of 252.9 eggs in 2015 (United Egg Producer 2016). Per capita consumption of eggs remained relatively steady from 1998 to 2015. Figure 2 shows a decrease in consumption of eggs from 2014 to 2015 due to higher prices resulting from a major HPAI outbreak in Iowa and Minnesota (United Egg Producer 2016)

Table 1. Per Capita Consumption of Poultry by Continents, 2006 to 2011, in Kg.

Location	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Africa	10.6	11.5	12.1	12.3	13.4	13.7
Americas	77.8	79.4	81.8	79.1	82.9	85.1
Asia	16.8	17.9	18.7	19.8	20.3	20.7
Europe	42.3	44.5	47.0	47.8	47.2	47.8
Oceania	78.7	81.1	78.0	78.5	82.5	92.8
WORLD	27.6	28.9	30.0	30.2	31.1	31.7

Source: FAO STAST

Figure 2. U.S. Per Capita Consumption of Eggs from 1998 to 2015



Source: United Egg Producers, 2016

1.1.2 Arkansas Poultry Industry

In Arkansas, the poultry industry is one of the largest components of not only the agricultural economy but the economy as a whole. Broilers, turkeys, and table eggs contributed over 40,000 jobs to Arkansas and almost 43% of total agriculture cash receipts in 2013 (University of Arkansas Division of Agriculture Research and Extension 2014). Broilers were the top poultry production segment in Arkansas with production in 53 counties out of 75 total counties. The value of the broiler industry in Arkansas is 3.6 billion dollars with eggs valued at almost 480 million dollars, and turkeys at over 372 million dollars (University of Arkansas Division of Agriculture Research and Extension 2014). Washington and Benton Counties, in Northwest Arkansas, are the largest broiler producing counties in the state (University of Arkansas Division of Agriculture Research and Extension 2014) and are home to the corporate offices of Tyson Foods, George's Inc. and Simmons Foods Inc.; six primary processing plants also call these counties home. These counties were the subjects of the present study.

In 2016, Arkansas was ranked third in broiler production, second in turkey production, and eighth in egg production in the United States (The Poultry Federation 2016). The poultry industry in Arkansas contributes 107,999 jobs with an economic impact of $34.9 billion annually, making it the most important agricultural commodity in the state (The Poultry Federation 2016). The broiler industry has the highest economic impact with 37.3% of total cash receipts from Arkansas farm marketing in 2014 (The Poultry Federation 2016). The turkey industry also has a significant impact on the Arkansas economy, creating an estimated 12,011 jobs across the state with an economic impact of $3.3 billion annually (The Poultry Federation 2016). The largest broiler integrators in Arkansas consist of George's Inc., Mountaire Corporation, Simmons Foods, OK Foods, Pilgrim's Pride, Peco Foods, Wayne Farms LLC, Ozark Mountain Poultry, and Tyson Foods. Major turkey integrators in Arkansas include Butterball and Cargill. Major breeding companies in Arkansas are Cobb-Vantress Inc., and Aviagen. Major egg companies in Arkansas include Cal-Maine, Caldwell Eggs, and England Farms.

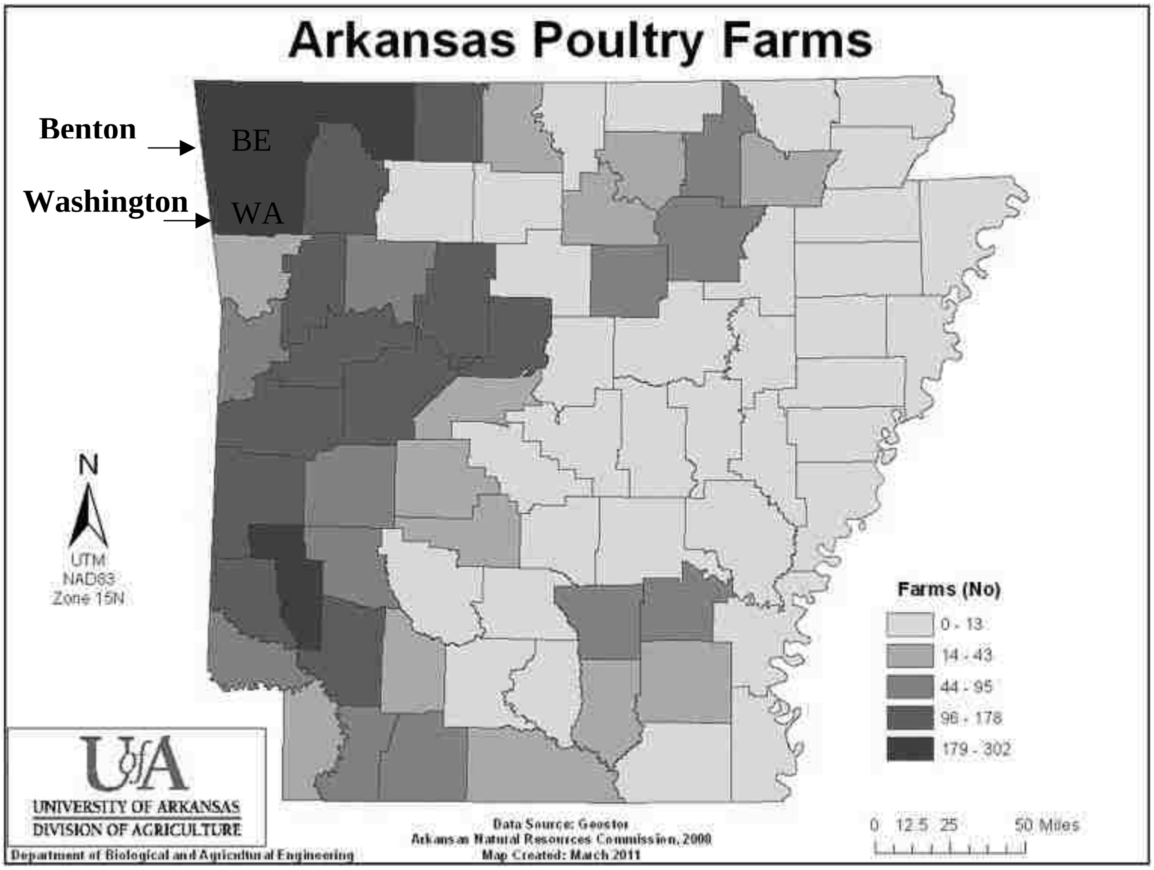
Washington and Benton counties are a key component in the production of poultry meat in Arkansas (Figure 3). Benton County historically has ranked number one in broiler and layer production in Arkansas with an inventory of over 17.7 million broilers and over 1.6 million layers (Table 2). Washington County has a slightly lower quantity of broilers with over 14.6 million and layers with over 1.1 million, but includes double the number of turkeys in inventory with over 1.0 million, as shown in Table 3 (United States Departament of Agriculture 2012).

Table 2. 2012 Census of Agriculture: Top 2 Broiler Producers Counties in Arkansas

County	Number of broiler chickens (million / year)
Benton	17.8 M
Washington	14.7 M

Source: United States Department of Agriculture – National Agricultural Statistic Services, 2016.

Figure 3. Number of Poultry Farms in Arkansas in 2011



Source: Arkansas Natural Resource Commission, 2011

Table 3. Ranking of Benton and Washington Counties for Livestock Inventories in 2012

Item	County	Quantity	Rank in Arkansas	Rank in U.S.A.
Broilers and other meat-type chickens	Benton	17,760,938	1	5
Layers	Benton	1,672,147	1	52
Broilers and other meat-type chickens	Washington	14,656,546	2	7
Turkeys	Washington	1,096,418	3	84
Layers	Washington	1,143,943	4	24
Pullets for laying flock replacement	Benton	468,442	5	59
Pullets for laying flock replacement	Washington	426,162	6	63
Turkeys	Benton	518,672	8	54

Source: 2012 Census of Agriculture County Profile

1.2 Research Problem Overview

Avian influenza represents a great economic risk for the poultry industry in Northwest Arkansas (NWA). Assessments of the magnitude of risk presented by a highly pathogenic avian influenza (HPAI) outbreak in a high strategic poultry region like NWA has not been assessed.

Health challenges such as HPAI are an increasing threat to the poultry industry, it is forced to deal with uncertainty about where and when an outbreak may occur. As such, monitoring the flock health status will be essential for the safe expansion of the poultry industry in the United States (Penz Junior and Bruno 2011).

1.2.1 Past Avian Influenza Outbreaks

Avian Influenza (AI) was first detected in Italy in 1878 and was known as the Fowl Plague (Blanca and Reddy 2009). HPAI first occurred in the United States in 1924 – 1925 (Alexander and Capua 2008). An additional outbreak occurred in 1929 due to the movement of live birds and the unsanitary market conditions during that time (Alexander and Capua 2008). In 1955, the United States determined that the virus causing the Fowl Plague was a reestablished influenza virus, more specifically an influenza type A virus. In 1983, there was an outbreak of H5N2 influenza in a commercial poultry operation in Pennsylvania. This became the world's largest outbreak of AI and, at the time, the costliest animal disease control process in the history of the United States with over 17 million chickens affected (Extension 2012). In 1997, a new strain of AI, H5N1, was detected in Hong Kong and was called the bird flu (World Health Organization 2016). Thousands of chickens died due to this outbreak and many people were affected because the high population density of Hong Kong and its proximity to the birds with the virus (World Health Organization 2016). An increasing concern amongst public health organizations around the world is H5N1 mutating into a viral form that could be spread from human to human (World Health Organization 2016). To date, the cases of H5N1 in humans have been from direct contact with infected birds.

From 1997 until 2016, there were only three major outbreaks of HPAI (H5) virus in the U.S. commercial poultry industry (Centers for Disease Control and Prevention 2016). In 2004, an outbreak of H5N2 was reported in a flock of 7,000 chickens in Texas, which was the first outbreak of HPAI in the U.S. in the last 20 years (Centers for Disease Control and Prevention 2016).

Since 2008, HPAI outbreaks have been more common in densely populated poultry areas around the world such as China (Alexander and Capua 2008). These have been predominantly caused by the subtype H5N1 HPAI virus that was initially isolated in China in 2007 (Alexander and Capua 2008). This spread across Asia and Europe in the same year, causing the death or culling of millions of birds and carrying a significant zoonotic threat to the human population (Alexander and Capua 2008). The next outbreak in the U.S. occurred in 2014 – 2015, where an HPAI (H5) outbreak was reported in a commercial poultry operation in the Midwest and spread across 21 U.S. states including Oregon, California, Washington, Indiana, North Dakota, South Dakota, Montana, Minnesota, Idaho, Kansas, Missouri, Arkansas, Wisconsin, Nebraska, and Iowa causing substantial economic losses (Centers for Disease Control and Prevention 2016).

In 2014 – 2015, the United States Department of Agriculture (USDA) and the Animal and Plant Health Inspection Services (APHIS) reported 223 cases of HPAI in 15 different states across the United States (Greene 2015). From the outbreak's inception in 2014 in the United States, more than 48 million chickens, turkeys, and other poultry were euthanized to reduce the spread of the disease to additional states (Greene 2015). The 2014-15 HPAI outbreak cost the poultry industry nearly $1.6 billion (Greene 2015). Total economic losses were estimated to be around $3.3 billion (Greene 2015). In addition, 18 international trading partners imposed bans on shipments of U.S. poultry meat, while 38 countries imposed partials or local bans (Greene 2015). The 2014-15 outbreak put the USDA-APHIS under pressure to be more proactive, and new protocols were developed to handle future outbreaks. Currently, in 2016, an H7N8 virus was reported in commercial turkey flock in Indiana (Centers for Disease Control and Prevention 2016).

1.3 Objectives

The overall objective of this study is to simulate the economic effect of a HPAI outbreak in Washington and Benton Counties in Arkansas. We disaggregated the efect (lost production) of an outbreak on growers, companies and the effect on the federal government (compensation in the form of indemnity payments).

Specific objectives of this project are: 1) to determine the production type and the current number of poultry houses in Washington and Benton counties in Arkansas; 2) to estimate the lost revenue for the poultry growers, companies, the cost to the federal government due to an HPAI outbreak; 3) to develop a two-stage simulation model for evaluating a potential outbreak a HPAI in Washington and Benton counties; 4) to create a general risk assessment model that initiates a random infection and calculate the cost across reiterations of the outbreak simulation; 5) to create a spatial visual assessment model that evaluates costs relative to specific locations of a random outbreak; and 6) to allocate the lost revenue due to an HPAI outbreak to all the houses infected during HPAI outbreak in Washington and Benton counties.

1.4 Research Approach

To accomplish the objectives laid out above, a two-stage simulation model focused on Washington and Benton counties' poultry operations was estimated. Following are the general descriptions of the models used to achieve the objectives of the study.

1) General Risk Assessment Model: This model was developed to estimate the economic effect from a random HPAI infection across iterations of the simulation based on different initial sites of infection. The 2012 USDA Ag Census county level data was used to determine the number and location of houses and production types in each county. The model estimated the loss in revenue due to a HPAI outbreak to each poultry house based on their assigned production type. There were 11 total poultry type output variables, 6 for Benton County and 5 for Washington County as shown in Table 4 (note that categories repeat). Benton County has one more variable, accounting for the two specific table egg layers in this specific location; there was only one table egg type in Washington County. Output variables represent the different poultry house types based on their production outputs as used in the study (broilers, pullets, breeders, layers (white), layers (brown), and turkeys). Ultimately, the lost revenue per house for each production type then determined the costs to growers, companies, and the federal government. Lost revenues were based on the average number of infected houses within a 10km circumference from a random HPAI infection simulated 1000 times across both counties.

Table 4. 11 Variables Used in The General Risk Assessment Model and Spatial Visual Assessment Model Output Variables by County and Poultry Type

Output Variable	**County**	**Poultry Type**	**Number of Houses**
1	Benton	Broilers	777
2	Benton	Pullets	43
3	Benton	Breeders	87
4	Benton	Layers (White)	8
5	Benton	Layers (Brown)	15
6	Benton	Turkeys	61
7	Washington	Broilers	641
8	Washington	Pullets	39
9	Washington	Breeders	127
10	Washington	Layers (Brown)	7
11	Washington	Turkeys	135

2) Spatial Visual Assessment Model: This model determined the cost of a HPAI outbreak relative to a specific location at the time of the outbreak and the top resource allocation strategies based on the model outputs for broilers, pullets, breeders, layers (white), layers (brown), and turkeys. The model quantified risk based on an infection in any giving point creating a complementary assessment for the General Risk Assessment model estimating the probability of an outbreak in a specific location across both Washington and Benton counties at the same time.

Chapter II: Review of Literature

2.1 Avian Influenza Virus

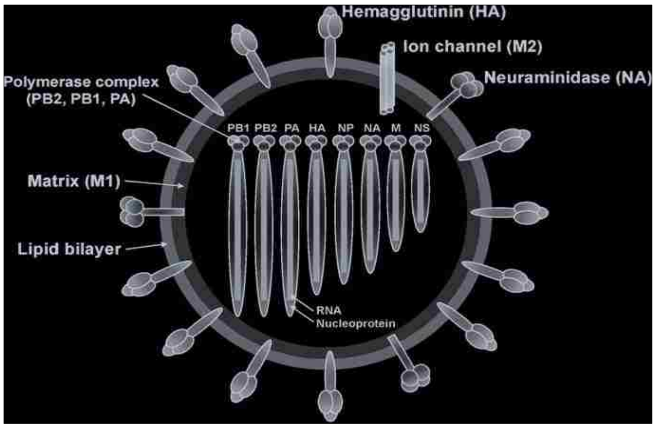
The avian influenza virus is part of *Orthomyxoviridae,* which contains four genera. These four genera are influenza A, B, and C viruses, and Thogotovirus (Chang-Won and Yehia 2009). Currently, there are three different types of influenza viruses (A, B, and C) and this can be further classified based on the antigenic differences between the nucleocapsid (NP) and matrix (M) proteins (Chang-Won and Yehia 2009). Most importantly, this influenza A virus can be further divided into hemagglutinin (HA) and neuraminidase (NA) which are surface glycoproteins (Chang-Won and Yehia 2009).

These glycoproteins HA and NA have many genes that are extremely variables and are constantly changing. With all the gene changes, less than 30% of all the amino acid are conserved among the subtypes (Frieden 2015). As of 2009, there had been 16 different HA and nine different NA subtypes identified (Frieden 2015). This number has changed in the past year. In 2015, there were 18 known HA subtypes and 11 known NA types (Frieden 2015). All but two A viruses can infect birds (Frieden 2015). Out of the three types of influenza virus (A, B, C), only influenza A virus can infect animals (swine and horses), humans, and birds (Chang-Won and Yehia 2009). All avian influenza (AI) viruses are classified under type A influenza virus. In 2015, there were only two influenza A virus subtypes that circulated among people, H1N1 and H3N2 (Frieden 2015).

2.1.1 <u>Structure, Genes, and Proteins</u>

Even though the virions in this virus can exhibit some different shapes and sizes depending on the strain and passage history, the most common shapes are the two types of glycoproteins: one is rod-shaped HA, the other a mushroom-shaped tetramer of NA (Chang-Won and Yehia 2009). A schematic diagram of the structure of the influenza virus is shown in Figure 4. (Chang-Won and Yehia 2009)

Figure 4. Schematic Diagrams of The Structure of The Influenza A Virus.



Pathogenicity

The effects of the AI virus in poultry can range from an asymptomatic infection to an acute fatal disease (Chang-Won and Yehia 2009). This virus can be categorized by using an intravenous pathogenicity index (IVPI). The World Organization for Animal Health (OIE) defines the notifiable form of avian influenza (NAI) as avian influenza A virus that has caused at least 75% mortality (Chang-Won and Yehia 2009).

2.1.2 High Pathogenicity vs. Low Pathogenicity (Definitions and Key Differences)

The primary difference between HPAI and low pathogenic AI (LPAI) is local versus systematic replication (Frieden 2015). Based on these molecular characteristics, the AI virus can be further differentiated into HPAI or LPAI based upon the virus' ability to cause disease and mortality in poultry in a laboratory setting (Frieden 2015). Only type A influenza viruses are known to cause natural infections in birds, but many combinations of influenza A subtype viruses have been isolated from avian species (Dennis 2000). It is important to mention that LPAI can mutate and become HPAI, resulting in higher mortality rates in the poultry population (Dennis 2000). HPAI is very virulent and can cause mortality as high as 100% often within 48 hours (Dennis 2000).

2.1.3 Clinical Signs

The AI virus can cause a broad range of symptoms based on its virulence (Sharif, Muhammad and Ahmad 2014). Many LPAI viruses can be in a flock and be undetected, but LPAI viruses can shift and mutate to a HPAI virus (Sharif, Muhammad and Ahmad 2014). During an infection of HPAI, viral birds exhibit reduced feed intake, dull and lethargic behaviors, and a high mortality rate (Sharif, Muhammad and Ahmad 2014). Usually, birds infected with AI have difficulty breathing and noticeable respiratory congestion along with nostril and ocular discharge (Sharif, Muhammad and Ahmad 2014). Other clinical signs can include an inflamed head, dark coloration of comb and wattle, an imbalance in the nervous system in conjunction with diarrhea (Sharif, Muhammad and Ahmad 2014). HPAI virus has a sudden onset; after an incubation period of 2-3 days, birds will suddenly start dying; and by this point, it is already too late for any treatment.

In layer flocks, AI infection is usually accompanied by a sharp decrease in egg production, weak eggshells, and uneven surface of eggshells. If the virus is HPAI, mortality will range from 90-100%. (Ficken, Guy and Gonder 1989). If the virus is LPAI, only clinical signs will be present, flu-like symptoms and many times coryza (Sharif, Muhammad and Ahmad 2014). Gross lesions of the AI virus include hyperemic trachea and congested lungs (Muhammad, et al. 2001).

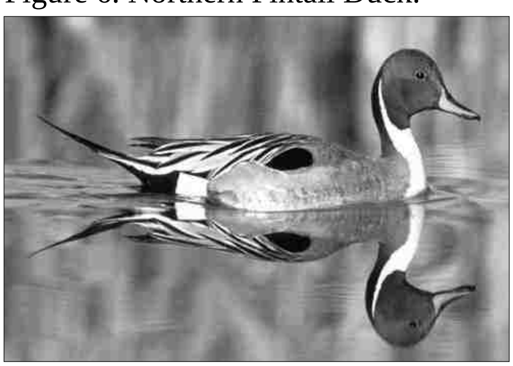
2.1.4 Naturally Occurring Avian Influenza

Wild waterfowl and shore birds are the reservoirs of LPAI (Yee, Carpenter and Cardona 2009). In these species, the virus can easily replicate and the birds show little sign of the disease (Yee, Carpenter and Cardona 2009). When HPAI is present as indicated by surveillance there may be clinical evidence of infection in wild birds. Usually, birds, like the Mallard duck and the Northern pintail (see Figure 5 and 6) can carry and shed the HPAI (H5N1) without any clinical signs (Yee, Carpenter and Cardona 2009). Other birds like geese and muted swans usually die from this HPAI infection (Yee, Carpenter and Cardona 2009). Transmission of the virus from wild birds to poultry requires multiple steps, discussed in the following sections.

Figure 5. Male and Female Mallard ducks.

Source: Photo by Cameron Rognan.

Figure 6. Northern Pintail Duck.



Source: Photo by Dave Menke, USFWS.

2.1.5 Transmission

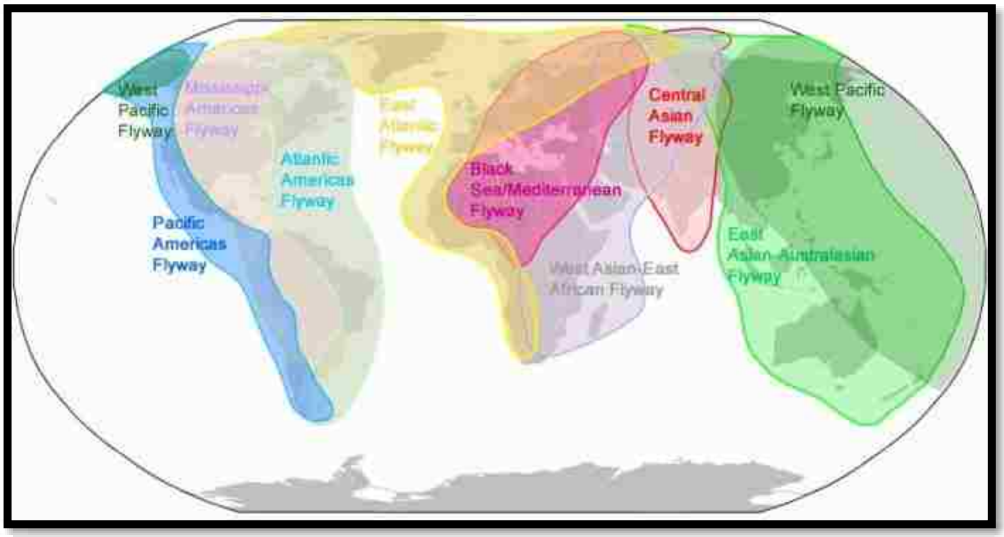
Over 100 different species of wild birds carry the influenza A virus (Prevention 2015). These species of birds are often categorized as reservoirs or hosts for avian influenza A viruses (Prevention 2015). In birds, LPAI viruses infect the intestinal tract cell lining and subsequently are excreted in high concentrations in their feces (Olsen, et al. 2006). Past studies have shown that the influenza virus can remain viable in lake water up to 4 days at 22 degrees Celsius and more than 30 days at 0 degrees Celsius (Webster, et al. 1978). Therefore, AI can be found in birds living in aquatic environments and is efficiently transmitted through the fecal-oral route.

2.1.6 Migratory Bird Flyways

In the past decade, there have been many occurrences of HPAI around the world. Migratory birds are the host for many of the subtypes of AI virus (Alexander 2000). LPAI viruses have been isolated from 100 different wild bird species of 26 different families (Alexander 2000). Species carrying this virus move between seasonal habitats, these ranging from short local movement to intercontinental migration (Olsen, et al. 2006). Therefore, the distribution of LPAI viruses between countries or even continents can occur quickly due to migratory patterns.

Many wild birds follow ancient pathways from their breeding grounds to wintering areas (Olsen, et al. 2006). Each fall, millions of waterfowl migrate to warmer regions. Migratory birds around the globe fly over nine main migratory routes or flyways: Pacific Americas Flyway; Mississippi Americas Flyway; Atlantic Americas Flyway; East Atlantic Flyway; Black Sea/Mediterranean Flyway; West Asian-East African Flyway; Central Asian Flyway; East Asian-Australasian Flyway; and West Pacific Flyway as shown in Figure 7. (Olsen, et al. 2006). The four major North America flyways are Atlantic Americas Flyway, Mississippi Americas Flyways, Central Americas Flyways, and Pacific Americas Flyway as shown in Figure 8. Marm and colleagues (2006) demonstrated that an H5N1 is more likely to be introduced into the Western Hemisphere by migratory birds and then to poultry.

Figure 7. Main Flyways of Migratory Birds



Source: based on commons.wikimedia.org main international flyways of bird migration, Wikigraphists of the Graphic Lab (Fr)

Figure 8. North America Birds Flyways

Source: Credit: Michael A Johnson, North Dakota Game and Fish.

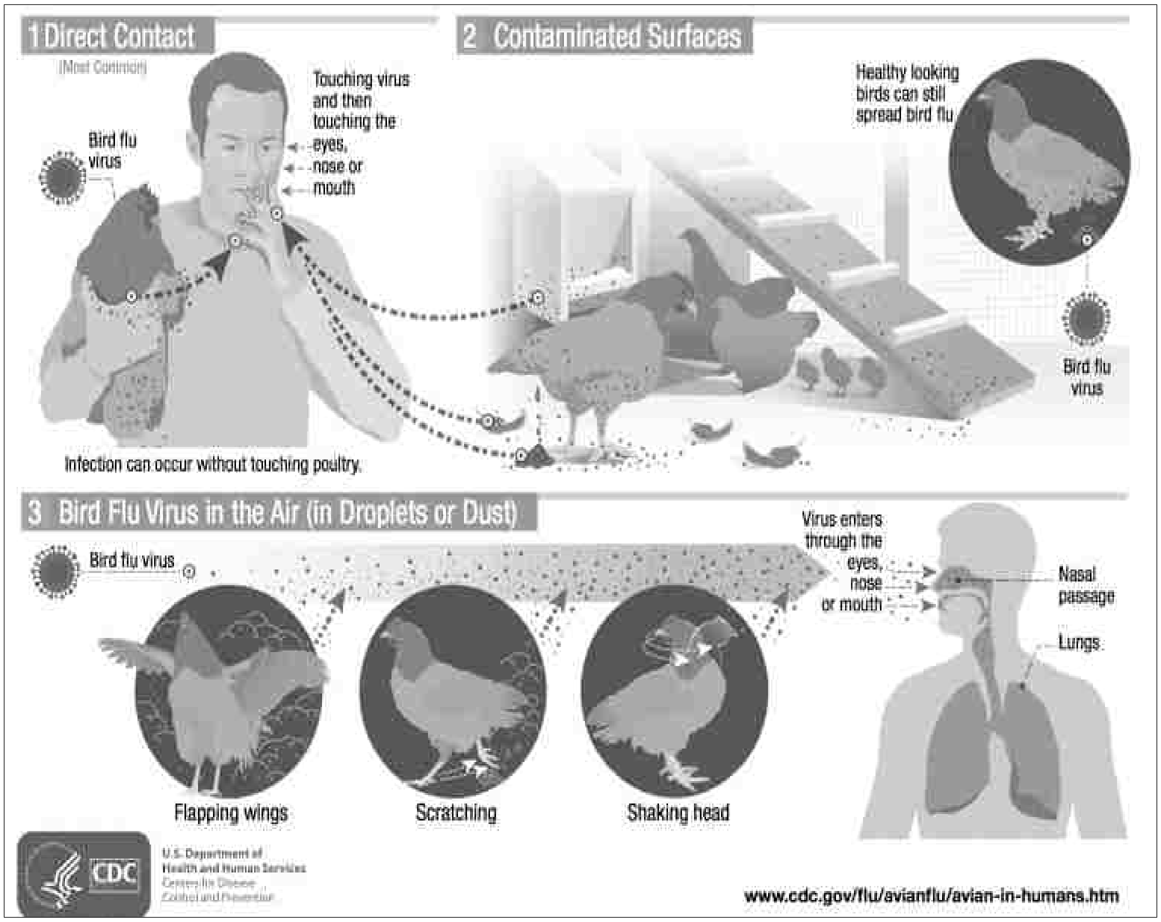
2.2 Zoonotic Disease Information

A zoonotic disease is a disease that can be spread between animals and humans (Center for Disease Control and Prevention 2013). It is estimated that more than 60% of infectious diseases in humans are spread from animals (Center for Disease Control and Prevention 2013).

Sporadic cases of human infection with HPAI (H5N1) viruses have occurred after direct contact with diseased or dead poultry in Asia (Pham, et al. 2006) (Areechokchai, et al. 2006). Although clinical cases are usually uncommon in people, rare cases of human infections with these viruses have been reported (Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases (NCIRD) 2016). Rare human infections with the avian influenza virus have often occurred after unprotected contact with infected birds or surfaces contaminated with avian influenza virus as shown in Figure 9. (Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases (NCIRD) 2016).

The concern to public health is the potential for the virus to mutate to a form that could easily spread from person to person, a characteristic that could result in a human influenza pandemic (National Advisory Committee on Meat and Poultry Inspection 2006). There is no evidence for this anywhere in the world (National Advisory Committee on Meat and Poultry Inspection 2006). Studies have shown that cooking eggs and poultry products to the recommended cooking temperature destroys the virus (Ellin, et al. 2007).

Figure 9. How Infected Backyard Poultry Could Spread Bird Flu to People.



Source: Center for Disease Control and Prevention.

2.3 Prevention of Highly Pathogenic Avian Influenza Outbreaks

HPAI remains a high-priority concern for the USDA. The recent outbreak of AI in the United States shows the critical threat that HPAI poses to animal health and agriculture in general. The USDA regularly works in developing new response plans to ensure the prevention, control, and eradication of AI in the mainland U.S. (United States Departament of Agriculture 2016). The best protection against any disease is to avert outbreaks in the first place (United States Departament of Agriculture 2016). Animal and Plant Health Inspection Service (APHIS), States, and producers all have a role in preventing or reducing HPAI outbreaks (United States

Departament of Agriculture 2016). This includes fostering appropriate biosecurity measures in poultry production.

2.3.1 Importance of Biosecurity

The Food and Agriculture Organization of the United Nations (FAO) refers to appropiate AI biosecurity measures as "those measures that should be taken to minimize the risk of incursion of HPAI into individual production units (biocontainment) and forward transmission through the market chain" (Food and Agriculture Organization of the United Nations; The World Bank; The World Organisation for Animal Health (OIE) 2007). Biosecurity is one of the most important methods for prevention and spread of AI in the poultry industry. The primary broad actions involved in preventing disease from entering the premises are following: keep the facility clean, restrict access to the property, know the warning signs of infectious bird diseases, rodent and insect control, sanitation of all equipment, and report sick birds.

The cost-benefit assessment of biosecurity measurements can be determined about the level of risk to which integrators, growers, and their birds are exposed (Vaillancourt 2001). The important step is to educate all poultry staff about the impact of their actions on the risks of a disease outbreak (Vaillancourt 2001). Biosecurity is the first line of defense against AI around the world. Biosecurity is about minimizing the risk of any infectious agent affecting farm performance. It is crucial to invest in good biosecurity to diminish the probabilities of a vector coming into a livestock operation.

Gifford (1987) demonstrated from his broiler breeder models that "expenditures on protective measures can be justified by both the risk of introducing a disease and the magnitude of losses that may occur following infection". Morris (1995) worked on an economic model that was developed to assess the value of biosecurity systems in which he suggested that prevention of diseases, in the end, is always less expensive than treatment.

2.3.2 Biosecurity Checklist under Highly Pathogenic Avian Influenza

HPAI affected over 200 poultry operations in the upper Midwest in 2015 (U.S. Poultry and Egg Association 2016). The catastrophic results from this HPAI outbreak proved that the biosecurity of poultry facilities must be the top priority to reduce the risk of future infections. Biosecurity measures need to be strictly followed during an outbreak to deter spreading disease into other locations. This biosecurity practice has proven to be a cost-effective technique to control and prevent the spread of AI in poultry operations. To monitor and eradicate HPAI virus, all segments of the industry need to follow comprehensive and stringent biosecurity practices.

U.S. Poultry and Egg Association (2016) in conjunction with other industry organizations, developed practical biosecurity resources for commercial poultry operations. The USDA, has developed a checklist to help the poultry industry follow biosecurity practices on an ongoing basis (United States Departament of Agriculture 2016). This biosecurity checklist is divided into five parts as follow: protect premises; clean equipment; close monitoring of personnel; visitors; and vehicles. Each of these sections is then broken down individually with easy-to-follow checkpoints, which allow commercial poultry companies stringent their biosecurity programs (United States Departament of Agriculture 2016) (see Appendix A for biosecurity checklist).

2.3.3 Preparation for an Outbreak

One area of focus of USDA-APHIS (2013) is on preventing, searching and responding to the detection of the virus in wild birds and poultry. APHIS works together with other federal government agencies, such as the Center for Disease Control and Prevention (CDC), to detect and track any AI impacts on human health. The Department of the Interior and state wildlife agencies oversee the wildlife surveillance program (Animal and Plant Health Inspection Services 2013). USDA, in combination with public bodies around the country, is finding ways to improve the current response and detection of AI virus.

2.3.4 2016 HPAI Preparedness and Response Plan from the USDA

The USDA has learned much about response activities since the 2015 HPAI outbreak. To prepare for future outbreaks, USDA–APHIS performed a simulation study where they assumed the worst-case scenario of an HPAI outbreak occurring simultaneously in multiple sectors of the poultry industry. The results of the study are shown in the 2016 HPAI Preparedness and Response Plan. This study provides a series of models, which shows the outcomes under the worst-case scenario of 500 or more commercial operations of various sizes across a broad geographical area, affected by this outbreak (United States Departament of Agriculture 2016).

Based on the worst-case scenario, USDA–APHIS would focus their planning on the following areas:

1) Preventing or reducing future outbreaks by strengthening biosecurity and enhancing bird surveillance (United States Departament of Agriculture 2016).

2) Enhance preparedness by improving State and industry response capability, and increasing the ability to deploy personnel to an outbreak. Enhance training, safety and information technology support for responders; improve capacity for depopulation and disposal; enhance diagnostic laboratories preparedness; assist the community in prevention and response; and improved public communication (United States Departament of Agriculture 2016).

3) Enhanced and streamline response capability by evaluation of the impacts and response action, increased speed of detection of affected premises, and preparation for depopulation of all affected areas within 24 hours. Focused on cleaning and disinfect affected areas; streamline the payment indemnities; disposal and virus elimination, develop other HPAI related policies; and revise surveillance plans for control zones (United States Departament of Agriculture 2016).

4) Preparing for a potential use of AI vaccines by preparation to deploy avian influenza vaccines (United States Departament of Agriculture 2016). The HPAI response plan is a very dynamic process. APHIS has made a tremendous work effort to be prepared for a future HPAI outbreak in poultry.

2.3.5 Highly pathogenic Avian Influenza Response Plan

The HAPI Response Plan: The Red Book incorporates guidance developed during the 2014 -2015 HPAI outbreak in the United States. The objective of this plan is to identify the following: 1) the capabilities needed to respond to an HPAI outbreak and 2) the critical activities that are involved in response to that outbreak (Foreign Animal Disease Preparedness & Response Plan 2015). This plan complements not replaces, existing Regional, States, Tribal, local, and industry plans (United States Departament of Agriculture 2016).

2.3.6 2015 HPAI Avian Influenza Response Process

The United States Department of Agriculture has put a guide into place to help understand the steps taken during the response process (United States Departament of Agriculture 2016). First, it is necessary to detect signs of the virus by looking for unusual signs of illness or sudden death in the flock (United States Departament of Agriculture 2016). It is then obligatory to report these signs to the private or State veterinarians for them to obtain samples to be tested. If the flock is positive for HPAI, USDA establishes a quarantine zone (United States Departament of Agriculture 2016). At this point, the USDA and State personnel will visit the farm and assign a case manager who will be the main point of contact (United States Departament of Agriculture 2016). This case manager will answer questions and provide guidance. When an operation is under quarantine, only authorized personnel are allowed on and off the premise and movement of poultry, poultry products, and equipment is restricted (United States Departament of Agriculture 2016). The USDA will contact neighboring poultry farms, and AI testing on their birds will begin to see if they are affected (United States Departament of Agriculture 2016). The next step is the appraisal. USDA works with the grower to create a flock inventory and other details that will help create a fair market value for the birds being euthanized because of the outbreak (United States Departament of Agriculture 2016). Depopulation will occur after the appraisal. It is important to depopulate all infected flocks as quick as possible, ideally within 24 hours of the first HPAI detection, to stop the spread of the virus (United States Departament of Agriculture 2016). Shortly after the response with the process is in place, and depopulation completed, the grower will get their first indemnity payment and a standard amount for virus elimination activities, like cleanup work (United States Departament of Agriculture 2016).

Disposal management of after depopulation is one of the most challenging parts during a massive HPAI outbreak. In the 2015 outbreak, millions of birds were euthanized. This was a challenge for the sector due to the difficulty of composting millions of birds at one time. Eliminating the virus following the disposal is important. Testing for AI after the cleanup is critical to making sure the property is completely virus free. The poultry barns should be empty for at least 21 days; then USDA will collect environmental samples (United States Departament of

Agriculture 2016). Once the USDA and the state assure the facility is virus free, the farm is available for restocking and production can recommence (United States Departament of Agriculture 2016). It is critical at the end of the response process to maintain high biosecurity standards and to prevent future outbreaks (United States Departament of Agriculture 2016).

2.3.7 Movement and Permitting Process into and out of Control Area

Controlling bird movement is critical to prevent transmission of HPAI from infected premises. (Agriculture 2015). Most likely, a quarantine zone will be imposed on infected and suspected premises. The movement and permit process will change over time depending on situational awareness and operational capabilities (Agriculture 2015).

2.3.8 Federal government Effort

In the event of HPAI outbreak in Arkansas, the State Veterinarian, in cooperation with the Poultry Federation, announces a list of emergency regulations that are put in place and applied to the production or sale of poultry and poultry products (Arkansas Livestock & Poultry Commission 2000). Act 87 of 1963 and Act 150 of 1985, by the Arkansas Livestock & Poultry Commission, prohibits the introduction of AI into the state of Arkansas. This acts states, "All live poultry, hatching eggs, domestic waterfowls, waterfowl being transported into Arkansas, or other avian species entering Arkansas will do so accompanied by an official certificate of veterinarian inspection signed by a licensed, accredited veterinarian (Arkansas Livestock & Poultry Commission 2000)." The same rule applies for all table eggs, including graded eggs, nest run, along with all eggs to be processed by breakage will be accompanied by a certificate of origin attesting "all the eggs originated in an area where there is any known avian influenza H5 or H7 infection" (Arkansas Livestock & Poultry Commission 2000). Also, "All AI vaccinations on any species is prohibited, unless authorized by the State Veterinarian, this regulation is put into place, because is almost impossible to distinguish an infected from a vaccinated bird using routine serology" (Arkansas Livestock & Poultry Commission 2000).

2.3.8.1 Arkansas Regulations for Poultry Disease Identification, Monitoring & Eradication

The Commission will determine quarantine and removal of pet birds. They may issue a quarantine or terminate any birds that present a hazard of passing any disease to the industry. (Arkansas Livestock & Poultry Commission 1998).

No poultry infected or exposed to any infectious, or contagious disease can be imported into Arkansas for any purpose (Arkansas Livestock & Poultry Commission 1998). All eggs for hatching purposes and all chicks imported into Arkansas must be accompanied by an official health certificate or federal form issued by the Commission. The Arkansas and Livestock & Poultry Commission slaughter regulations for poultry disease identification, monitoring, and eradication states that any healthy poultry may be shipped into Arkansas without an official health certificate when shipped directly to an approved slaughtering establishment (Arkansas Livestock & Poultry Commission 1998).

2.3.8.2 Federal Government Spending in Most Recent AI Outbreaks

The 2014 -2015 HPAI outbreak was first detected in the Pacific Northwest and spread across 21 states, affecting 211 commercial poultry operations and 21 backyard poultry flocks. This outbreak resulted in tremendous losses to the federal government, who acted in a very rapid way to contain the disease (Seitzinger, Johansson and Preston 2016). The federal expenditures totaled approximately $879 million, including $610 million expended in depopulation, cleaning, and disinfection. Indemnification at 100% of the fair market value of birds totaled $200 million (Seitzinger, Johansson and Preston 2016).

2.3.8.3 Indemnity and Compensation Process

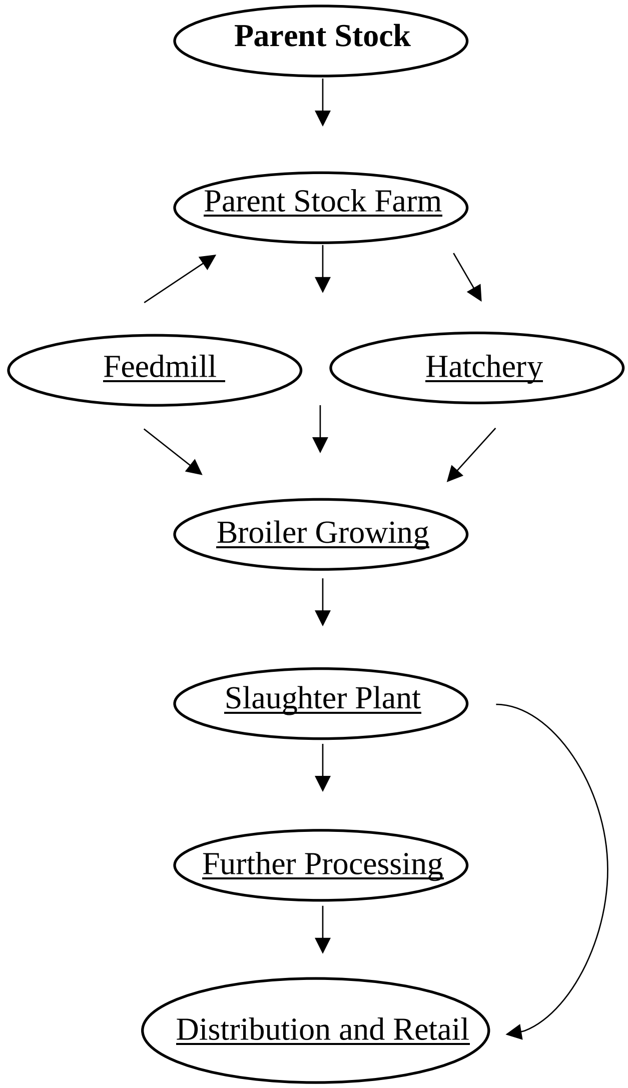
The Animal Health Protection Act authorizes the USDA to provide indemnity payments to producers for birds and eggs that must be destroyed during a diseases response (United States Departament of Agriculture 2016). The terms of the Animal Health Protection Act state that the USDA cannot offer indemnity for income or production losses during downtime or other business disruptions due to HPAI (United States Departament of Agriculture 2016).

USDA covers the cost of depopulation and disposing of HPAI affected flocks (United States Departament of Agriculture of Agriculture 2016). In most cases, the USDA or their contractors will carry out these activities and pay the costs directly. USDA provides compensation for materials that must be disposed of because they cannot be safely cleaned (United States Departament of Agriculture 2016). Virus elimination is a crucial step to resume operations. The USDA will compensate for virus elimination activities based on a flat rate per bird (United States Departament of Agriculture 2016).

2.4 Poultry Industry Structure

The success of the United States poultry industry can be attributed to the production systems in place that result in high efficiency. The poultry industry uses a vertical integration system (Figure 10). The integrators firms will provide the chicks, feed, veterinary supplies and services, field personnel, and transportation for the birds to the farm and from the farm. The grower cares for the chickens, provides land, housing facilities, labor, and all operating expenses (National Chicken Council 2012).

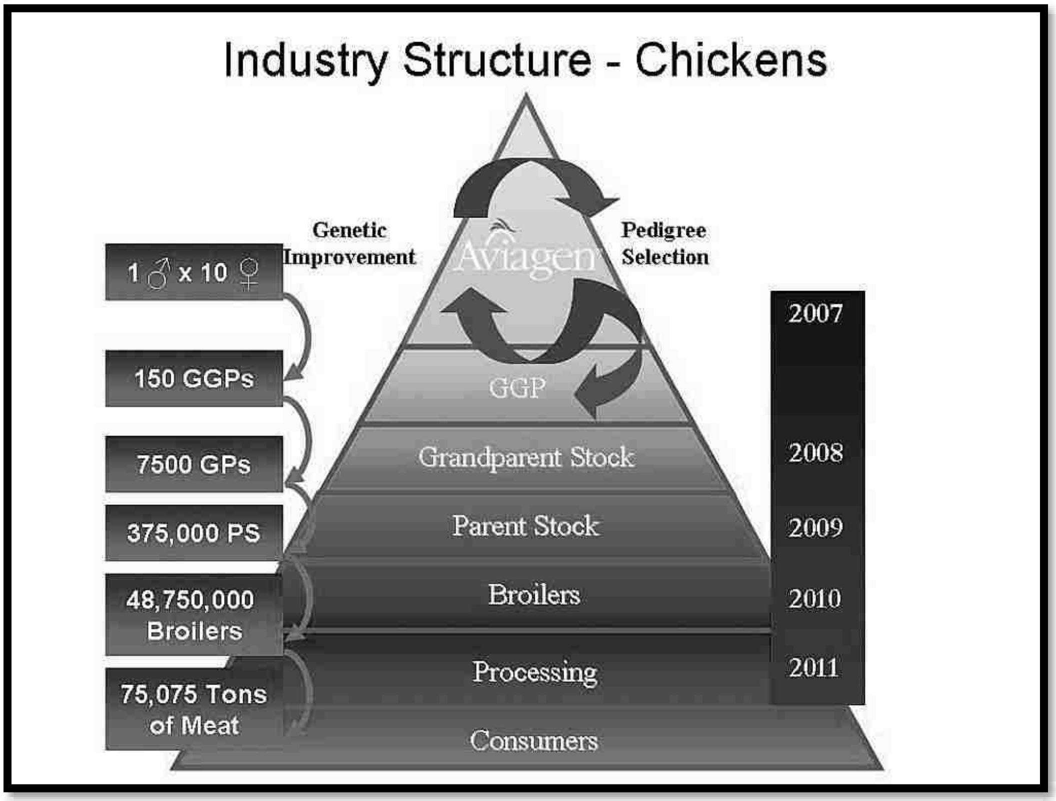
Figure 10. Poultry Vertical Integration System.



Source: The World Poultry Industry by Henry & Graeme, 1995

The 'genetic pipeline' is a strategic point to produce modern broilers (Figure 11). The primary breeder performs genetic selections. Genetic selection is the most critical step in the breeding process. The companies who have genetic lines have the responsibility in providing excellent genetics through parent stock to the poultry industry. Management problems that may arise in any of the stages of the genetic pipeline will have devastating effects on the ability of the broiler meat companies to meet the demand for poultry products (Leeson and Summer 2009). (McAdam 2006). About 10 females from the pedigree birds can supply 48,750, 000 broilers to the poultry market around the world (Reference of McAdam) (Figure 11). Broiler breeding ultimately comes down to generational multiplication to meet demand (Leeson and Summer 2009).

Figure 11. Multiplication of genetic progress from selection at the pedigree level to the volume of live broilers on commercial farms (modified from MCADAM 2006).



The genetic pipeline is a pyramid with at the apex, research lines or pedigree lines. Under this are the great grandparents, grandparents, parent stock and ending with the broilers. Each generation results in a multiplication by a factor of 50 or 100 depending on whether both sexes are needed or only one (Leeson and Summer 2009). Lesson & Summer (2009) state that "Problems at the grandparent breeder level often lead to a regional loss in the commercial broiler market for at least 2-4 years". Is very important to pay close attention to any disease threat that may cause an effect on the genetic pipeline since the economic losses can be devastating for the poultry industry.

According to the USDA, approximately 95 percent of broilers produced in the United States is grown under contract with the integrators production and processing companies (National Chicken Council 2012). The farmers are paid based on their type of production, varying by the specie being raising. The most common poultry types being raised include broilers, pullets, breeders, turkeys, or layers. Many farmers who grow poultry under contract with the integrators could provide a source of income for their families. Poultry contract growing worked well over the years, allowing the poultry industry to produce a high-quality poultry product with high levels of consistency (National Chicken Council 2012).

2.4.1 Broilers

The broiler industry accounts for the major part of poultry production in the United States. Broilers are defined as chickens raised specifically for meat production (Service 2002). In comparison to other sources of meat, broiler production has been increasing. Since 1945, broiler production has increased at a greater rate than that of beef and pork (Martinez 1999). These changes in production and the relatively low price for chicken have allowed the industry to expand production. In 2014, 8.54 billion broilers were produced in the United States, 99.8 billion eggs, and 238 million turkeys (National Agricultural Statistics Service 2015).

2.4.2 Broiler Breeder, Pullets, and Males

The production process usually starts in the replacement broiler breeder pullet houses, where broiler breeder pullets are raised until 20 weeks of age and then become breeder hens. These hens lay eggs to be hatched as broilers chicks (Agri Stats, Inc. 2014). The breeder hens will usually be in production until the hens reach 65 weeks of age, producing 161.2 eggs per hen under standard conditions (Agri Stats, Inc. 2014). Males are raised separately and move into the breeder house when they are 23 weeks of age at a rate of eight -10 % of the total number of breeder hens per house. For breeder hens to produce fertile eggs, mating must occur. The multiplication of the genetic progress from selection at the pedigree level can be was described by McAdam (2006) as a very strategic point of the poultry industry. One female from the pedigree level (Figure 11) can account for 15 great grandparents, 750 grandparents, 37,500 parents, and 4,875,000 broilers in a period of 4 years.

2.4.3 Table Egg Layers

The production of table eggs involves the production of high-quality eggs for human consumption. Laying hens are usually housed in well-designed cages in control environmental conditions. A white-egg layer will lay 250 eggs on average per hen from 25 weeks to 60 weeks of age (Agri Stats, Inc. 2012). The laying process usually occurs in houses with up to 100,000 laying hens. After eggs are laid, they are collected by automated gathering belts, washed, candled, and graded into different categories. Subsequently, the eggs are sorted, packaged, and shipped to wholesale or retail outlets (American Egg Board 2016). Another egg production system that was part of this study was the cage-free type production. In this, hens are maintaned in a house without of cages. In 2015, the United States table egg production was 83 billion eggs (United Egg Producer 2016). Arkansas placed 8th in the top 10 egg producing states (United Egg Producer 2016).

2.4.4 Turkeys (Toms and Hens)

Due to its rapid growth and eventual large size, the modern turkey is unable to breed naturally safely; therefore, turkey companies use artificial insemination for all breeding hens in production (Phillip 2016). The production of turkey meat starts at hatcheries followed by grow-out farms. Poults are placed in environmentally controlled houses for around 10,000 birds. Turkey hens are raised to 14 – 20 pounds in 12 – 14 weeks and turkey toms are raised to weigh around 35 – 42 lbs. in 16 – 19 weeks (Phillip 2016). In 2011, the United States produced 5.79 billion pounds of turkey and Arkansas placed number two in the top eight turkey producing states (United States Departament of Agriculture Economic Research Service 2016).

2.5 Product Loss in a HPAI Outbreak

Animal disease outbreaks like HPAI have strong negative economic impacts on agriculture. HPAI outbreaks have long-term implications depending on the production type they affect. For example, if an outbreak occurs in a genetic facility or a table egg facility the impact would be higher because the restocking period is longer (Regan and Prisloe 2003). In a layer facility, it usually takes 25 weeks before they pullets can come into production; in comparison, to a broiler facility where birds can be placed within 28 days of the outbreak and market ready in 42 additional days on average (Regan and Prisloe 2003).

2.5.1 Restocking process

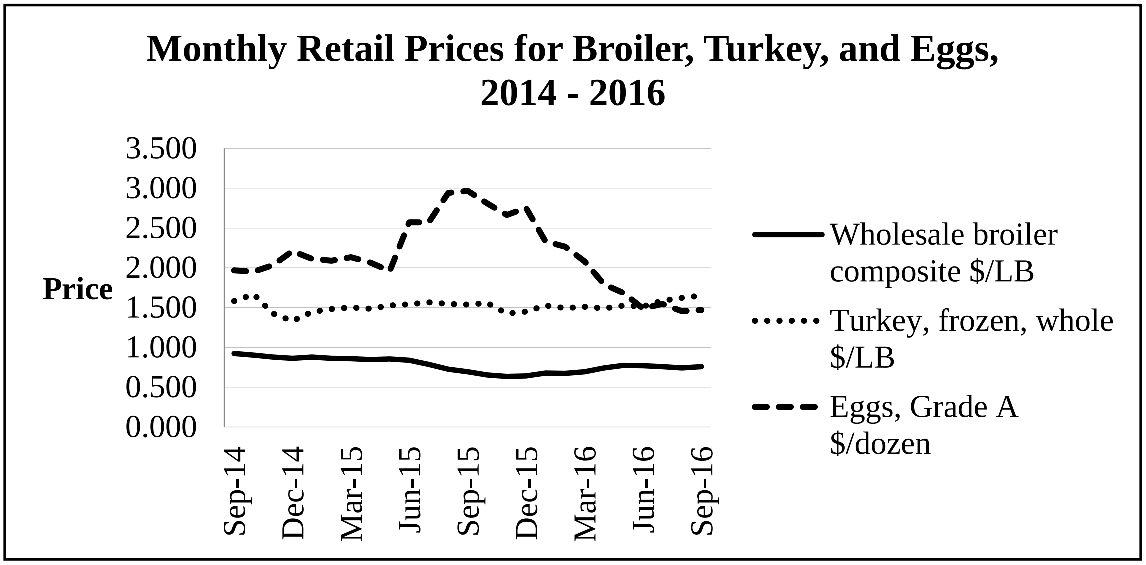
For a facility to begin restocking, they must test negative for any sign of HPAI in the affected location and be approved by the USDA. It is important for the company and growers to restart production as soon as possible because of losses due to extra downtime. Usually, within 28 days of the outbreak production can restart (United States Departament of Agriculture 2016). Biosecurity levels, monitoring and testing to ensure there is no presence of a virus tend, to increase after an outbreak in a specific location.

Restocking varies based on the type of operation. According to Greene (2015), "*Egg-laying hens operations will phase restocking to reestablish variable hen age in the flock. The age variability allows for even, year-round egg production. This phased restocking could take 18 months or more to accomplish before the producer reestablishes a normal income flow."* On the other hand, Greene (2015) mentioned that a turkey operation would restock the barns with birds that will be market-ready in about the same time as before depopulation. Reinforcing previous discussion Greene (2015) states that "*An HPAI outbreak results in a significant income disruption for the producers, which existing indemnities address only in part."*

2.5.2 Egg mitigation- Supply and Demand

During the outbreak in 2014 – 2015, consumers had to pay an increased price for eggs and meat due to the bird losses. In 2016, egg prices were $1.35 to $1.45 per dozen a huge drop from record high prices in 2014 – 2015 when eggs were $2.35 – $2.45 per dozen as shown in Figure 12. (Sterk 2016). The USDA reported in April 2016, that total production from Iowa was down 38% from the previous year and U.S. egg production was 5% below the previous year's production (Sterk 2016).

Figure 12. Monthly Retail Prices for Broiler, Turkeys, and Eggs.



Source: USDA Economic Research Service.

Regan and Prisloe (2003) noted that although economic losses can be overcome with time, it is more difficult to regain trust and relationships with trading partners. After many U. S trading partners placed national bans due to an AI outbreak, the U.S. must regain their trust to open their market to exports. They point out that this can take a long time, and politics are involved.

2.6 Economic Considerations

2.6.1 Local Economy Effects

Economic shifts caused by disease disasters produce a chain reaction that affects local economies. HPAI outbreaks involve federal government planning and responding to help local communities (Kamina K., Riley M. and and Thomas L. 2016).

From the most recent HPAI outbreak, Johnson and colleagues (2016) estimated the economic losses and costs to the local economy. The direct losses were attributed to losses in physical output (eggs and birds for slaughter) and assets (hens) (Johnson, Seeger and Marsh 2016).

Johnson and colleagues (2016) also noted that many indirect losses arose due to the following physical damages: transportation and commuter disruption; losses of local tax revenue; and reduction in tourism. Moreover, the *ex-post* cost mitigation expenditure was extremely high. This cost included clean up, recovery, personal protective equipment, organic material, equipment rental, labor, food, and lodging. Johnson and colleagues (2016) describe the market impact and *ex-ante* cost of the outbreak by showing the changes in commodity prices for inputs, outputs, and assets. *Ex-ante* cost expands in preventions, stockpiling, biosecurity, and surveillance to prevent future outbreaks.

2.6.2 2014 - 2015 Avian Influenza Outbreak

Impact on Production: According to USDA-APHIS, 233 cases of HPAI in domestic flocks were reported in 15 states. More than 48 million chickens, turkeys, and other poultry were euthanized to reduce the spread of the disease. Iowa and Minnesota faced the worst losses due to this outbreak as shown in Table 5. (Greene 2015). The outbreak in 2014 – 2015 caused a shortage of eggs in the United States, which increased the overall egg price for consumers (Windhorst 2015). Windhorst (2015) estimated it would take United States egg producers a year to recover from the 2015 outbreak. Reports issued from the APHIS on the epidemiology of the outbreak shows that wild birds introduced the virus into U.S. poultry flock. APHIS considers that gaps in biosecurity practices contributed to the spread of the virus (Greene 2015). It is likely that the U.S. will have another HPAI outbreak due to transmission of the virus from wild birds during migration.

Impact on the Economy: As of July 7, 2015, APHIS committed to cover $500 million out of the $700 million to help producers, including $190 million for indemnity payments (Greene 2015). The economic loss of this last outbreak was catastrophic for the poultry industry. The value of turkeys and laying hens loss was estimated at $1.6 billion. Economic wide losses were even higher with an estimated total of $3.3 billion (Greene 2015). A repeat of the 2014 – 2015 outbreak will have substantial economic implications. Currently, the USDA and the APHIS are taking many precautions to contain and eliminate any disease outbreak, but the risk is still out there.

Table 5. HPAI Cases in Domestic Flocks in the United States in 2014 – 2015, Last finding was on June 17, 2015.

State	**Cases**	**Species Infected**	**# of Affected Birds**
Arkansas	1	Turkey	40,020
California	2	Chicken, Turkey	243,300
Idaho	1	Mixed Poultry	30
Indiana	1	Mixed Poultry	N/A[1]
Iowa	75	Chicken, Turkey, Mixed Poultry, Duck	31, 723,300
Kansas	1	Mixed Poultry	10
Minnesota	105	Turkey, Chicken, Mixed Poultry	8,996,050
Missouri	3	Turkey, Mixed Poultry	53,100
Montana	1	Mixed Poultry	40
Nebraska	4	Chicken	3,794,100
North Dakota	2	Turkey, Mixed Poultry	111,500
Oregon	2	Mixed Poultry	200
South Dakota	10	Chicken, Turkey	1,168,200
Washington	5	Mixed Poultry	6,710
Wisconsin	10	Turkey, Chicken, Mixed Poultry	1,950,733
TOTAL	223		48,091,293

Source: USDA, APHIS. Data from December 2014 through June 17, 2015.

Impact on Trade: The international consequences of an HPAI outbreak are clear as major U.S. poultry meat destinations imposed a ban on U.S. poultry products. Many of these trading partners can impose a ban on poultry from specific U.S. states. This allows other U.S. states to export U.S. poultry products to the country. During the 2014 – 2015 HPAI outbreak, many countries imposed

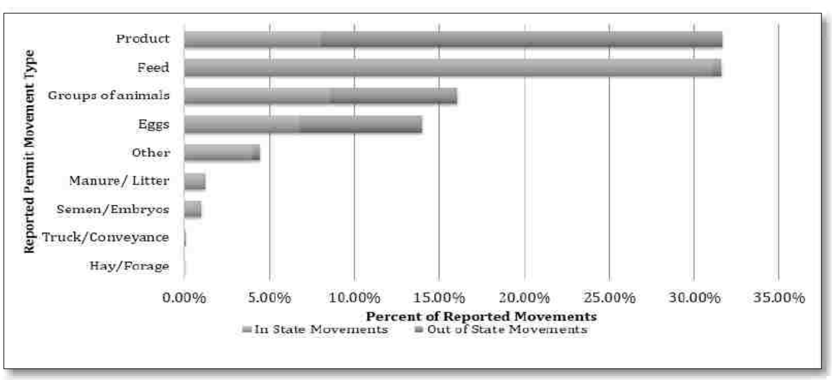
[1] N/A means not available. Mixed poultry cases are usually from backyard flocks. Chicken (egg-laying hens, pullets) and turkey cases are in commercial operations.

bans in all shipments of U.S. poultry products (Greene 2015). In December 2014, 18 trading partners imposed state bans in all U.S. poultry products, and 38 trading partners imposed partial or regional bans on shipments from altered states (Greene 2015). Even though there were many domestic losses, the international impact was higher since the United States is a major poultry exporter. Three of the top ten destinations for U.S. poultry meat (China, Russia, and South Korea) banned all imports of U.S poultry in 2014 (Greene 2015).

2.6.3 Domestic Market Effects of Quarantine Zones

The state veterinarian rigorously controls any movement into and out of AI infected premises. This can have an adverse impact on the local economy around quarantine zones (Thompson and Pendel 2016). A control area is usually defined as the area in which disease management protocols dictate the movement into or out of specific radius, commonly 10 kilometers. According to the USDA- Emergency Management Response System (EMRS), most movement out of control areas was products, feed, groups of animals, and eggs (see Figure 13).

Figure 13. Movement Types into and out of Control Areas for the 2014-2015 HPAI Outbreak.



Source: (Thompson and Pendel 2016)

During the 2014 – 2015 outbreak, approximately 7,800 permits for movement into or out of the quarantine area were awarded, accounting for approximately 20,000 movements as shown in Figure 13. (Thompson and Pendel 2016). “Currently, there are no permitting guidelines for secure movement. All movements of any products are at the discretion of state health officials (Thompson and Pendel 2016)." It was very clear that non-essential movement was restricted during the outbreak. However, necessary movement was allowed, which help reduce the impact on local business due to the HPAI outbreak (Thompson and Pendel 2016).

Business continuity is vital for the local economy. Issuing permits to restrict the movement of goods into and out of restricted areas allow local business to keep functioning (Thompson and Pendel 2016). For example, egg layer and broiler breeder producers do not have the capacity to store eggs longer than three to four days. If these egg producers cannot move eggs out of the infected areas, the eggs must be properly disposed of in a waste facility. Without permitting during the 2014 -2015 outbreak, fewer eggs would have been put into the supply chain causing a greater increase in prices.

The Center for Food Security and Public Health (CFSPH) at Iowa State University is leading the development of the Secure Egg Supply (SESP), the Secure Turkey Supply (STS), and the Secure Broiler Supply (SBS) in a multidisciplinary team. They are working to promote food security and animal health through market planning for HPAI outbreaks. These make science and risk-based recommendations to emergency decision makers. They can use this to decide immediately whether to issue or deny permits for movement of egg industry products during an HPAI outbreak thus increasing business continuity in affected areas (The Center for Food Security & Public Health 2016).

2.6.4 Environmental Impact

There are multiple indirect costs associated with AI outbreaks. Some of the most frequently cited include water use and excess demand for landfills. Unless plans to reduce the environmental footprint are in place before the outbreak, any increase in natural resources usage can have an adverse impact on the environment. In the case of an AI outbreak, it is essential to take the necessary steps to properly manage the disposal of dead animals on the premises to reduce the risk of disease spread and environmental impacts.

Bird disposal is a major step in properly dealing with an outbreak. The preferred methods for dealing with mass mortalities are composting or on-site burial. Other methods used included landfill, incineration, and fermentation (Pennsylvania Department of Environmental Protection 2015). In the 2014-2015 outbreak, the principal method of disposal of mortality was composting. Different bird disposal methods were also used. For outdoor composting, it is necessary to have a carbon source available to use in the composting process (Pennsylvania Department of Environmental Protection 2015). Burial of mortalities has the greatest impact on the environment, public health, and safety considerations.

The type of poultry operation can influence the method of mortality disposal. In the 2014 -2015 AI outbreak, the number of dead birds was so large that it was dificult to find enough space for composting. In addition, a significant proportion of the operations impacted were turkey flocks with larger birds.

2.6.5 Cost of the Outbreak Response Activities

Cost-response activities were predominantly on poultry premises during the 2014-2015 outbreak. A proxy for the costs was the increased demand for supplies, labor, and equipment in the local surrounding communities (Johnson, Seeger and Marsh 2016). Kamina and colleagues (2016) determined that the average cost per bird in Minnesota be $4.63 and $14.47 in Iowa. They explain the lower cost in Minnesota can be attributed to the operation types (turkeys rather than layers) impacted in each state (Johnson, Seeger and Marsh 2016).

In January of 2016, the USDA-APHIS announced that they were implementing flat rate payments for virus elimination. This was intended to reduce the time needed for payments to reach affected producers (Johnson, Seeger and Marsh 2016). The payments are as follow: $1.15 per bird for broilers, $3.55 per birds for turkeys, and $6.45 per bird for layers (Johnson, Seeger and Marsh 2016). These flat rates were used in the Indiana outbreak in 2016 and were helpful in speeding the response process (Johnson, Seeger and Marsh 2016).

2.7 Avian Influenza Outbreak Impact on International Trade

2.7.1 Sanitary and Phytosanitary Measures (SPS)

Sanitary and Phytosanitary Measures (SPS) are laws, regulations, requirements, and procedures that The Federal Government places to protect human, animal, plant life, or health from the risks arising from entry and spread of plant or animal born pest or disease. Frequently, there are SPS barriers to trade, not grounded in science, that create substantial obstacles to U.S. exports (Office of United States Trade Representative 2014). For example, many countries have used the threat of AI as a reason to block trade in U.S. poultry meat ignoring “science-based” standards and in causing devastating losses for the U.S. (Office of United States Trade Representative 2014).

Artificial SPS barriers decrease poultry exports and have a critical impact on the U.S. poultry industry. It is in the best interest of all countries to use “science-based” SPS measures (Office of United States Trade Representative 2014).

2.7.2 National Poultry Improvement Plan (NPIP)

The National Poultry Improvement Plan (NPIP) was first established in 1930. The NPIP provides a program for the detection of diseases with new diagnostic technology (U.S. Poultry and Egg Association 2015). The initial purpose of the NPIP was to eliminate Pullorum disease. This disease is caused by *Salmonella Pullorum* and caused devastating losses in the 1930's (U.S. Poultry and Egg Association 2015). Later, the plan was extended to test and monitor *Salmonella typhoid*, *Salmonella enteritidis*, *Mycoplasma gallisepticum*, *Mycoplasma synoviae*, *Mycoplasma meleagridis*, and Avian influenza (U.S. Poultry and Egg Association 2015). Currently, the NPIP includes commercial poultry, turkeys, waterfowl, exhibition poultry, backyard poultry and game birds (U.S. Poultry and Egg Association 2015). The NPIP facilitates movement of hatching eggs or live birds within the state limits, across the country, and to other nations (Arkansas Livestock & Poultry Commission 2011). The NPIP is critically important to the poultry industry and beneficial for participants. Many states required that any poultry is entering their state be from a certified NPIP participant.

2.8 Epidemiological Model

Epidemiology allows identification of the primary factors that place some locations at a greater risk than others at a given point in time (Center for Control Disease and Prevention 2012). *"A critical premise of epidemiology is that disease and other health events do not occur randomly in a population, but are more likely to arise in some members of the population than others because* *of risk factors that may not be distributed randomly in the population"* (Center for Control Disease and Prevention 2012). Simulation models of disease are performed as a part of an epidemic contingency plan. The assumptions need to be well positioned to evaluate their strengths and weaknesses and therefore allowing informed decisions in planning for an outbreak (Stevenson, et al. 2013).

"*Incorporating epidemiological model outputs into the economic analysis is recommended to capture a range of uncertainty in how the disease and the control measures might behave under different conditions*" (Johansson, Preston and Seitzinger 2016). Johansson and collagues (2016), incorporate an epidemiological model into their anaylsis of the 2014-2015 outbreak. Their economic model estimated market prices for all livestock and feed changes. The inputs to their model were the number of mortalities, their location, and the length of the outbreak.

2.9 Modeling Utilizing Monte Carlo Simulation

The Monte Carlo method is a prevalent approach to utilize random numbers to solve problems (James 1980). In 1970, Halton defined the Monte Carlo method as representing the solution of a problem as a parameter of a hypothetical population in which statistical estimates of different parameters can be obtained at the end (James 1980). Whether a Monte Carlo method can be applied to a problem does not depend on the stochastic nature of the problem. Instead, it depends on the ability of someone to frame the issue in a way that random numbers need to be used to determine the solution (James 1980). In 1990, Horst and colleagues used a Monte Carlo model to simulate the introduction of different viruses into the Netherlands. This was performed to improve understanding of the risks from a disease outbreak in the Netherlands (Horst, et al. 1999). Later, a

Monte Carlo simulation of a classical swine fever epidemic was used to describe the spread of classical swine fever virus between farms (Karsten, Rave and Krieter 2005).

2.10 Cost Benefit Analysis of Avian Influenza Controls

Karki and colleagues (2015) examined cost benefits of an alternative method to control avian influenza through surveillance and culling of infected poultry flocks in Nepal. The current control program included surveillance, depopulation of specific infected flocks, compensation, training, communication and information dissemination (Karki , et al. 2015). In the alternative method, the Nepalese government would not take action to control the AI outbreak. Farmers would not receive compensation for losses. There would not be a ban period for outbreak zones. Therefore, the cost of the alternative method would be zero to the Nepalese government (Karki , et al. 2015). The study demonstrated that the current control programs were superior to the alternative, as expected (Karki , et al. 2015).

Chapter III: Data and Methods

3.1 Models

This study is based on two separate but related simulation models. The first model simulates to obtain the average number of poultry houses infected, given the 10km quarantine radius, by random insertion of a highly pathogenic avian influenza virus using actual house GPS coordinates. Call this model a general risk assessment model. The second model will quantify the risk of a highly pathogenic avian influenza infection in any area of Washington and Benton counties all at once meaning every house will get infected. Call this model a spatial visual assessment model. The spatial visual assessment model allows a better understanding how resources to combat HPAI should be allocated spatially. The following chapter will explore in more detail the overall objective of each model.

One limitation of the general risk assessment model and the spatial visual assessment model is the fact that we do not account for the net loss of the outbreak, due to the lack of production cost information. Some production costs information for most of the production types were obtained, but ultimately it became exponentially complex to account for all the production cost, due to the complexity of the industry and all the different production types. Thus, to minimize the number of assumptions made we simply estimate lost revenue. Future studies may want to invest effort to estimate net losses to provide a more realistic value as far as total economic losses due to a simulated outbreak of HPAI.

3.1.1 General Risk Assessment Model

Using the general risk assessment model the economic damages to poultry growers, poultry companies and the federal government resulting from an HPAI outbreak across spatially explicit poultry house locations in the high-value poultry-growing region of Washington and Benton Counties in Arkansas are estimated. The general risk assessment model assigns poultry types to houses across *n* number of poultry types *j*, including Broilers, Pullets, Breeders, Layers (white), Layers (brown), and Turkeys. Using Statistical Analysis System (SAS 9.4), the model randomly applies assignments to houses according to discrete non-uniform probabilities from known county-level poultry type distributions reported by USDA (Tables 3 and 4). A single facility is randomly infected with HPAI and all houses within the 10-km exposure zone are identified using a look-up with a distance matrix of the 10km area, calculated in a GIS (ArcGIS for Desktop 10.4). F_j denotes the average frequency of houses of type *j* within the exposure zone of the infection. Because the total economic damages and number of impacted houses depends on house type and the location of the initial infection, we simulate the model 1000 times and use mean results to account for random spatial variability and house type uncertainty.

Equation (1) shows the average monetary damages to poultry producers, PD, as

$$PD = \frac{\sum_{s=1}^{1000} \sum_{j}^{n} (PC_j)(F_j)}{1000} \qquad \text{Eq. 1}$$

where PC_j denotes the costs incurred by a producer resulting from HPAI exposure of a single house of type *j*, and *s* denotes the simulation. The cost values were determined using mean bird values as shown in Table 12 with respect to lifecycle determine from our monetary calculations.

Equation (2) shows the average damages to the poultry company, CD, as

$$CD = \frac{\sum_{s=1}^{1000} \sum_{j}^{n} (CC_j)(F_j)}{1000} \qquad \text{Eq. 2}$$

where CC_j denotes the costs incurred by the poultry company resulting from HPAI exposure of a single house of type *j*. Equation (3) shows the average damages to the federal government, GD, as

$$GD = \frac{\sum_{s=1}^{1000} \sum_{j}^{n} (GC_j)(F_j)}{1000} \qquad \text{Eq. 3}$$

where GC_j denotes the costs incurred by the federal government resulting from HPAI exposure of a single house of type j. Equation (4) shows the average, across 1,000 iterations, total economic damages, TD, resulting from a single random infection of HPAI as

$$TD = PD + CD + GD \qquad \text{Eq. 4}$$

3.1.2 Spatial Visual Assessment Model

This model will quantify the risk of an infection in all poultry locations for Washington and Benton counties, giving a visual map of the outbreak for both counties. The model will simulate these 100 times to account for random spatial variability. The same monetary calculations used on the General Risk Assessment model to acquire the spatial assessment of an HPAI in Washington and Benton counties are applied to each frequency as mentioned before, the spatial visual assessment model will be a complementary assessment for the general risk assessment model, used to determine where to allocated resource in case of an outbreak.

This model was created considering the density and spatial distribution of risk with respect to the economic impact of potential HPAI outbreaks. To calculate risk as a function of the location of a HPAI infection, a grid of 6048 1-km^2 cells (84-km long by 72-km wide) was overlaid upon the two-county study area. As before, the model assigned poultry types to houses across *n* number of poultry types *j*, including Broilers, Pullets, Breeders, Layers (white), Layers (brown), and Turkeys. The number of poultry houses of each type within the 10-km exposure zone of each grid cell centroid using a new distance matrix calculated between grid centroids and poultry house locations in a GIS (ArcGIS for Desktop 10.4) were evaluated. For each grid cell centroid, the model is simulated 100 times to account for house type uncertainty. That is, the location of houses is known via GPS coordinates but the production type *j* is unknown for a given location. F_{ji} denotes the frequency of houses of type *j* within the exposure zone of an infection at site *i*.

Equation (5) shows the average damages to poultry producers from an infection at site *i*, PD_i, as

$$PD_i = \frac{\sum_{s=1}^{100}\sum_j^n (PC_j)(F_{ji})}{100} \qquad \text{Eq. 5}$$

Equation (6) shows the average damages to the poultry company from an infection at site *i*, CD_i, as

$$CD_i = \frac{\sum_{s=1}^{100}\sum_j^n (CC_j)(F_{ji})}{100} \qquad \text{Eq. 6}$$

Equation (7) shows the average damages to the federal government from an infection at site *i*, GD_i, as

$$GD_i = \frac{\sum_{s=1}^{100}\sum_j^n (GC_j)(F_{ji})}{100} \qquad \text{Eq. 7}$$

Equation (8) shows the average total economic damages from an infection at site *i*, TD_i, as

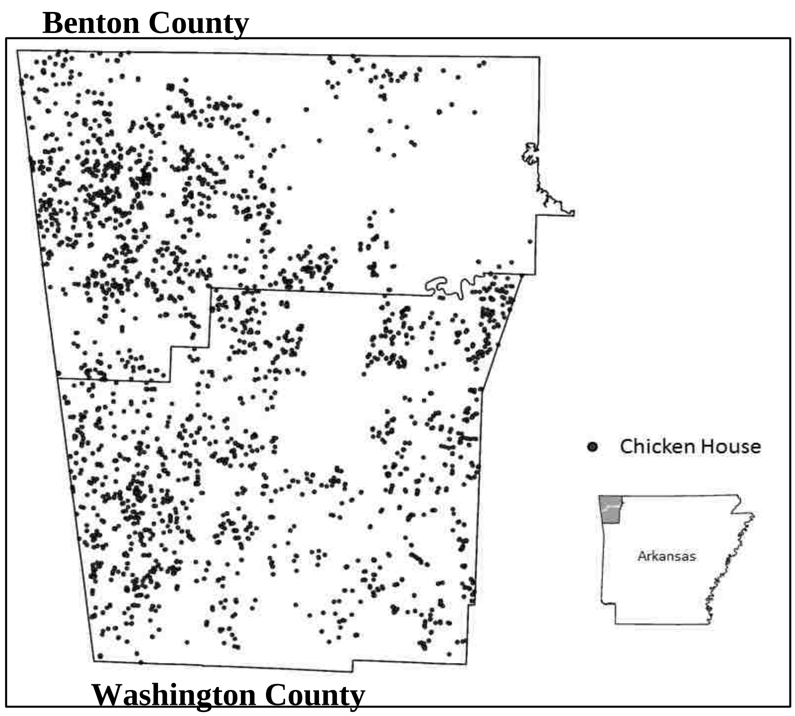
$$TD_i = PD_i + CD_i + GD_i \qquad \text{Eq. 8}$$

The results from the spatial visualization assessment model are presented in map format. The maps indicate both frequency and monetary value displaying the different amounts of spatial variability of infected houses for each county. The sum of grid cells will yield different 'hotspots' across the two counties. These 'hotspots' will show the areas where resources to combat HPAI should be allocated before a potential outbreak to best mitigate economic losses.

3.2 Data

A dataset consisting of the total number of poultry houses, production types, and current revenue from each output type was created for Benton and Washington counties in Arkansas. These data were used to determine the direct economic effects on poultry growers, companies, and the federal government from a simulated highly pathogenic avian influenza outbreak. The foundation for the general risk assessment model and the spatial visual assessment model was set by determining the number of poultry houses in Washington and Benton counties in Arkansas using a dataset of poultry house points from the Arkansas GIS Office published on August 29, 2006, and last updated on October 16, 2014, as shown in Figure 14. This dataset was created by the Arkansas Highway and Transportation Department to represent the most certain structures (chicken houses) that are currently presented within the state (Figure 14).

Figure 14. Location of all Poultry Houses in Washington and Benton County Arkansas: 2016.



3.2.1 County Data for Poultry Production Types from the USDA and NASS

Figure 14 illustrates the location of each house but there is uncertainty about what type of production is being implemented at each location. Given no survey was enumerated to determine the poultry houses location and production type, we randomly assigned poultry operation types

(Broilers, Pullets, Breeders, Layers, and Turkeys) based upon their relative densities to all the houses in both counties using discrete non-uniform probabilities from known county level poultry type distribution reported by the United States Department of Agriculture (USDA) and the National Agricultural Statistics Service (NASS) (2012 Census of Agriculture). Percentages of poultry houses by type for each county are shown in Table 6 and 7 and were used to assign poultry house type to each house utilized in the study.

3.2.2 Monetary Calculation Data

The economic data, which includes the current monetary value of each production type used in the study, was determined by using production data from AgriStats (Agri Stats, Inc. 2014) (Agri Stats, Inc. 2012) and present poultry market prices data from USDA (United States Departament of Agriculture 2016). The monetary value of each house was determined by calculating an estimated bird value for each production type under prevailing commercial production regimes production. The estimations for broilers, pullets, breeders, turkeys, generic egg layers, and organic egg layers were developed based on three main direct effects: the company gross revenue loss, the grower gross revenue lost and the federal government cost due to a HPAI outbreak. Results of this process are shown in Table 8.

Broiler, Pullet, and Breeder Value Estimation: For the broilers, pullets, and breeder value estimation, production data were gathered from the annual live production 2014-year summary from AgriStats (Agri Stats, Inc. 2014), using the average numbers for region 52, which includes Arkansas poultry production locations for broilers, pullets, and breeders. The current market price data for broiler meat was gathered from the USDA Broilers Market News Report July 7, 2016.

Table 6. 2012 Benton County Arkansas County Level Poultry Type Distribution

Production Type	Year	Number of Farms	One-time Inventory	Number Birds per Farm	Houses per Farm	Total Number of houses	Percentage
Broilers	2012	165	17,760,938	107,642	5	777	78%
Pullets	2012	30	468,442	15,615	1	43	4%
Breeders	2012	46	692,147	15,047	2	87	9%
Layers (White)	2012	1	800,000	800,000	8	8	1%
Layers (Brown)	2012	5	180,000	36,000	3	15	2%
Turkeys	2012	18	518,672	28,815	3	61	6%

Table 7. 2012 Washington County Arkansas County Level Poultry Type Distribution

Production Type	Year	Number of Farms	One-time Inventory	Number Birds per Farm	Houses per Farm	Total Number of houses	Percentage
Broilers	2012	154	14,656,546	95,172	5	641	68%
Pullets	2012	37	426,162	11,518	1	39	4%
Breeders	2012	45	1,012,418	22,498	2	127	13%
Layers (Brown)	2012	4	84,000	21,000	3	7	1%
Turkeys	2012	41	1,143,943	27,901	3	135	14%

Table 8. 2014 Average Weights and Commercial Production for Sub-Region 52, NWA, Missouri and Oklahoma.

Production Type	Production	Quantity of Production	Value of Production
Broilers	42 days	5.2 lb. avg. weight	$.8403 per pound WOG
Pullets	20 weeks	96% livability	$.1095 per week per pullet
Breeder Hens	45 weeks	137 hatched chicks per hen and 161 egg per hen	$ .50 per dozen eggs
Turkey	140 days	44.42 lb. avg. weight	$1.13 per pound WOG
Layer (Brown)	45 weeks	236 eggs per hen	$2.30 per dozen
White Layer	45 weeks	250 eggs per hen	$.435 per dozen

Source: AgriStats.

Turkey Value Estimation: For the turkey value estimation, the production data collected from AgriStats officials, and the monthly turkey grow out a report for December 2012 from AgriStats (Agri Stats, Inc. 2012) using average numbers from region 52 which includes Arkansas turkey production locations. Production data was gathered from current poultry industry weighted averages values from turkey companies around the area of the study and professor from the Center of Excellence for Poultry Science at the University of Arkansas. The current market price data for poultry meat gathered from the USDA Turkey Market News Report.

White Layers and Brown Layer Value Estimations: For the white egg, layers, and brown egg layers' value estimations the production data gathered from the monthly commercial egg production report for December 2012 from AgriStats (Agri Stats, Inc. 2012) using average numbers from the performance by the flock, which included egg types groups weighted averages. Also, data for these value estimations were gathered from current poultry industry weighted averages values from white and brown egg companies around the area of the study, and the United States Department of Agriculture egg market news report from October 10, 2016. White layers are layers that are keep in battery cages for commercial egg production their eggs can also be call generic eggs. Brown layers are cage free layers and their eggs can also be call organic eggs

3.3 Methods

To determine the direct impact of a highly pathogenic avian influenza outbreak in the poultry grower, company, and the federal government a general risk assessment model and a spatial visual assessment model, were built using a Statistical Analysis System (SAS 9.4). When calculating the direct impact of the outbreak this dataset represent operational houses and houses no longer in operation. Because of this, final results are then scale back proportionally to the number of houses currently in operation according to USDA-NASS.

3.3.1 General Risk Assessment Model - Simulation

The general risk assessment model was used to estimate the average number of poultry houses infected by a random infection based on 1000 iterations. The total average number of poultry houses infected in Washington and Benton counties were aggregated and the monetary value for each house type incorporated into the model. Summing these monetary values provides an estimate of the effect of an HPAI outbreak in each county.

3.3.2 Spatial Visual Assessment Model - Simulation

The Spatial Visual Assessment model is a complementary simulation model to the general risk assessment model. This model was used to estimate an explicit analysis of general risk and quantify the risk of an infection in any area of Washington and Benton counties at once. After the model determined the outbreak frequency for each county, the monetary calculations were incorporated into the model to assess the spatial risk and to have a superior visual understating of where to allocate resources during an HPAI outbreak. A series of maps of each county with the 'hotspots' of an outbreak are shown and discussed in Chapter 4, Empirical Results. This model used the same data as the risk assessment model.

3.3.3 Fundamental Models Assumptions

1. Integrators in the study will have uniform age distribution of each flock for all different production types.

2. On average, outbreaks will occur at the average production age for each production type; 21days for broilers, 70 days for broiler pullets, 297 days for broilers breeders, 70 days for turkeys, 297 days for brown layers and 297 days for white layers based upon the bird half-life or laying period half-life.
3. Birds in each production type will follow a linear growth curve based upon the breed guidelines depending on the kind of production.
4. There is a uniform distribution of probability of a highly pathogenic avian influenza outbreak for both counties.
5. If a poultry house is infected, it will cause a 100% mortality in the same flock and total depopulation of the house infected or houses affected in the guaranty zone of 10 kilometers.
6. 100% indemnity payments will be assigned to affected producers from the federal government. These compensation payments will be based on the current market value for each type of production.
7. The value of the birds will be equal to the opportunity cost in gross revenue at market age.
8. Opportunity cost will be equal to the direct loss of revenue, due to downtime established by the United States Department of Agriculture of 21 days for all different production types during an avian influenza outbreak.

3.3.4 Monetary Value Estimates

Each value estimate was created to determine the approximate value of each poultry house based on their production type and the fundamental assumptions listed in section 3.3.3. All value estimations have been set up for one flock of birds. The monetary value estimates for each production type represent the actual value of the operation at any giving time. Later, these values will be used to determine opportunity costs for growers and companies. The approached used to determine the opportunity costs for growers and companies will be explained later in the study.

Broiler Estimation: To determine the company loss in gross revenue from losing broiler production to an outbreak, the model established the value of a broiler house by outlining the possible number of pounds of meat a broiler house would produce under normal conditions, equal to 536,229,387 pounds, from which the total number of pounds of poultry meat the company could have sold without an outbreak of avian influenza was calculated. Grower gross revenue loss was determined by summing the grower revenue per farm for 42-day old broilers and the litter revenue. The total number of possible live pounds (536,229,384) was multiplied by the current average grower pay of $0.0659 for the region as reported in AgriStats (Agri Stats, Inc. 2014). The results of total number of possible live pounds multiplied by the average grower pay equaled $35,337. It was estimated that each house would produce 150 tons of litter per flock and the current market value for poultry litter is $15 per ton (Christensen 2016). The amount of litter per house was determined from the fact that each time the floor of the house was cleaned, 150 tons of litter would be recovered regardless of the flock considered (Christensen 2016). This litter includes the original litter bedding and the fecal material added by the birds (Christensen 2016).

To determine the additional revenue from poultry litter, the total number of the houses per farm was multiplied by 150 tons and then by the current poultry litter price of $15 per ton to get $11,250. Summing the $35,337 plus $11,250 equals $46,587. We determined the opportunity cost to a grower in revenue per house for a 42-day old broiler was $9,317, calculated by taking $46,587 and dividing it by the number of houses per farm (5 houses) (see Appendix B for Broiler Revenue Value Estimation).

The company gross revenue loss was estimated by determining the total number of houses per farm, for this study five; this number was estimated from the 2012 Census of Agriculture – County Data – USDA and the National Agricultural Statistic Services. The average numbers of birds placed per farm was 107,602, estimated from the 2012 Census of Agriculture – County Data – USDA and the National Agricultural Statistic Services. The number of birds per farm from county data (Table 6 and 7) averaged 21,528 birds per house. The mortality under normal conditions was determined to be 4% and thus was incorporated into the model. After this normal mortality was subtracted, the total number of birds lost per farm in the outbreaks was 103,121. The total number of birds lost in the outbreak multiplied by 5.2 pounds, which is the average weight for a 42-day old bird in sub-region 52 from AgriStats. It can be ascertained that the total number of possible pounds of liveweight loss in the outbreak was 536,229,387 per farm. From this amount, we can determine the actual total number of possible WOG[2] pounds of meat to be 402,172 by multiplying the total number of possible pounds of meat by 0.75, which is the current industry WOG percentage (yield)[3]. The company gross revenue lost per broiler house was $67,589 determined by multiplying the total number of possible WOG pounds of meat by the current USDA whole bird price (see Appendix B for Broiler Loss Revenue Value Estimates).

The federal government loss per broiler farm from was estimating by determining the total number of additional birds lost in the outbreak which is 103,121 multiplied by $1.55 from the USDA–APHIS flat rate payments for virus elimination. This aggregates to $33,369 per broiler

[2] WOG is the abbreviation for "Without Giblets," which is a whole chicken that the head, feet, and internal organs have been removed.

[3] WOG yield is the weight of the carcass after the birds have been processed, in broilers this is usually between 0.75 to 0.78 of the live weight.

house that the federal government would pay the company and the poultry grower (see Appendix B for Broiler Revenue Value Estimates).

Pullet Value Estimation: To determine the company gross revenue loss from an HPAI outbreak in a pullet house, the possible number of broiler chicks a pullet house would produce under normal conditions was estimated. From there, the total number of pounds of poultry meat the company could have sold without an outbreak of avian influenza was calculated, as described in the below.

Grower gross revenue loss was estimated by determining the grower revenue per farm for a 20-week old pullet. The litter revenue was not added in this value estimation because there is little to no value to the litter from a pullet farm since litter from a pullet house is has low nutrient content (Ruiz-Diaz , Shoup and Tomlinson 2013). The total number of pullets lost in the outbreak after mortality multiplied by the current grower pay per pullet of $0.1095 per week (Henderson 2016) multiplied 20 (length in weeks of growing time) determines the opportunity cost to a grower in revenue per house for a 20-week old pullet to be $21,104.34. The opportunity cost in this study is considered to be the amount of money a grower could have made if an outbreak of avian influenza would not have occurred (see Appendix C for Broiler Pullets Revenue Value Estimate).

The poultry company gross revenue loss was estimated by determining the average number of pullets per farm. To determine this, the average number of birds per house of 11,153 multiplied by the average number of houses per farm equals 15,615 (2012 Census of Agriculture – County Data – USDA and the National Agricultural Statistic Services) (Table 6 and 7). To determine the actual number of birds lost in the outbreak, birds lost under normal conditions before the outbreak must be accounted by considering flock mortality. The mortality for a pullet was determined to be 10% for males and 4% for pullets before the outbreak for 20 weeks (Agri Stats, Inc. 2014), a total number lost before the outbreak of 156 males and 562 females due to mortality. During the outbreak, the total loss of males and females was 14,897.

Pullets lost in the outbreak equal the total number of live females minus the mortality before the outbreak, resulting in average of 13,491 females lost due to the outbreak after mortality was accounted for. It is assumed these pullets will become laying hens that will produce broilers chicks, so the hen mortality should also be considered. Hen mortality was determined to be 6.4% on average (Cobb-Vantress, Inc. 2013); therefore, the total number of hens to be placed in production was 12,628. This value was determined by taking the hen mortality percentage (6.4%) from the resulting number of females (13,491). From these calculations, the study can determine the total number of possible eggs. To acquire the total number of possible eggs we multiply the number of hens after mortality (12,628) by the number of eggs a hen can produce until 40 weeks (161.2) (Agri Stats, Inc. 2014), this equal to 2,035,619 the total number of possible eggs. The total number of possible chicks was determined by multiplying the total number of hens after mortality (12,628) by the number of chicks a hen can produce through 40 weeks (137) (Agri Stats, Inc. 2014), which equals to 1,730,024 possible chicks. The total number of possible pounds of meat was determined by taking the total number of birds lost in the outbreak multiplied by 5.2, which is the average weight for a 42-day old bird from AgriStats, and a broiler mortality of 4.2%. The total number of possible pounds of meat of was 8,628,288. From this number, we can determine the actual total number of possible WOG pounds of meat by multiplying the total number of possible pounds of meat by 0.75, which is the current industry WOG percentage (yield) this equal to be 6,463,716.

The company gross revenue loss per house was $3,878,229 determined by multiplying the total number of possible WOG pounds of meat by the current USDA whole bird price (see

Appendix C for Broiler Pullet Revenue Value Estimation). Federal government loses from virus elimination were estimated by determining the total number of birds per house lost in the outbreak which is 14,897 and multiplied them by $6.45 from the USDA – APHIS flat rates payments for virus elimination. This aggregates to $68,631.27 per house in federal government loss from virus removal (see Appendix C for Broiler Pullet Revenue Value Estimate).

Breeder Value Estimation: To determine the gross revenue loss from losing a breeder house due to the outbreak, the value of a breeder house was established by outlining the possible number of broiler birds a breeder house produces under normal conditions. This estimate will allow for the total number of pounds of broiler meat the company could have sold without an outbreak of avian influenza was calculated. Grower gross revenue loss was estimated by determining the grower revenue per farm for a 65-week old hen. The litter revenue was not added in this value estimation because there is little to no value to the litter from a hen farm. First, the total number of eggs produced by a hen in 65 weeks was estimated and divided by 12 to get the total number of dozen eggs per hen. The total number of dozen eggs per hen was then multiplied by the total number of hens lost in the outbreak after mortality. Finally, the total number of dozen eggs lost multiplied by the current grower paid for dozen eggs of $0.50 per dozen from current industry weighted averages (Personal Communication 2017). We determined the opportunity cost of a grower in revenue per house for a 65-week old pullet to be $43,478.46 (see Appendix D for Breeder Revenue Value Estimation).

Company gross revenue loss was estimated by first determining the total number of house per farm. For this study, the number was equal to the number of birds place per farm (15,047), which is the number of birds per farm from County data (Table 6 and 7). To determine the actual number of birds lost in the outbreak, birds lost under normal conditions before the outbreak must be accounted for by considering normal flock mortality. The mortality for a breeder flock was determined to be 25% for males and 4% for hens before the outbreak (Agri Stats, Inc. 2014). A total number lost before the outbreak of 373 males and 596 females. During the outbreak, the total loss of males and females was 14,078.

To determine the impact of the resulting in 12,946 females lost due to the outbreak, the total number of hens after mortality (12,946) by the number of chicks a hen can produce through 40 weeks (137) (Agri Stats, Inc. 2014) the number of possible chicks being 1,773,662. The value estimate quantifies the total number of the possible pounds of meat lost during the outbreak by taking the total number of birds loss in the outbreak multiplied by 5.2, which is the average weight for a 42-day old bird from AgriStats and a broiler mortality of 4.2% (Agri Stats, Inc. 2014). The total number of possible pounds of meat was determined to be 8,835,675 From the 8,835,675 possible pounds of meat, we can determine the actual total number of possible WOG pounds of meat to be 6,626,756 by multiplying the total number of possible pounds of meat by 0.75, which is the current industry WOG percentage (yield). The company gross revenue loss per house was $2,784,231 determined by multiplying the total number of possible WOG pounds of meat by the current USDA whole bird price of .84 cents per lb. (see Appendix D for Breeder Revenue Value Estimation).

Lastly, federal government loses from virus elimination was estimated by multiplying the total number of birds lost in the outbreak, 14,078, by $6.45 from the USDA – APHIS flat rates payments for virus elimination. This aggregates to $45,401 per breeder house in federal government payouts from virus removal (see Appendix D for Breeder Revenue Value Estimation).

Federal government loses from virus elimination were estimated by determining the total number of birds lost in the outbreak which is 14,897 and multiplied them by $6.45 from the USDA – APHIS flat rates payments for virus elimination. This aggregates to $68,631.27 per house in federal government lose from virus removal (see Appendix C for Broiler Pullet Revenue Value Estimate).

Turkey Value Estimation: Loss estimates for turkeys are conducted on a one flock of Toms basis. To determine the company gross revenue loss from losing a turkey house due to an outbreak, the value of a turkey house was established by estimating the possible number of pounds of meat a turkey house would produce under normal conditions. The total number of pounds of turkey meat the company could have sold without an outbreak of avian influenza was calculated, as described in the following discussion.

Grower gross revenue loss was estimated by determining the grower revenue per farm for a 140-day old Tom and the litter revenue. First, the total number of possible live pounds was multiplied by the current grower pay of $0.09 per pound from AgriStats, 2014) which results in a revenue of $94,740 per house. Growers also get a significant portion of their revenue from selling or utilizing turkey litter for fertilizer. It is estimated that each house will produce 150 tons of litter per flock and the current market value for poultry litter is $15 per ton (Christensen 2016). To determine the extra revenue from poultry litter we took the total number of the houses (3) per farm from the 2012 Census of Agriculture – County Data – USDA and the National Agricultural Statistic Services, multiplied by 150, then multiplied the total number of tons of turkey litter by the current turkey litter price of $15 for a total of $6,750 per farm. Summing the $94,739 plus

$6,750 we determine the opportunity cost of a grower in lost revenue per house for a 140-day old Tom is $33,830 (see Appendix E for Turkey Revenue Value Estimation).

Company gross revenue loss was estimated by first determining the total number of houses per farm, determined to be 3 from the 2012 Census of Agriculture – County Data – USDA and the National Agricultural Statistic Services. The numbers of birds place per farm 27,880, is the number of birds per farm from County level data (Table 6 and 7), yielding an average of 9,293 birds per house. To determine the actual number of birds lost in the outbreak first loss under normal conditions with normal mortality needs to be calculated. Mortality was determined to be 15% (Agri Stats, Inc. 2014). Therefore, under normal conditions a given turkey house would have 23,698 birds of an average weight of 44.42 pounds (AgriStats, 2014) per Tom. The total number of possible pounds of meat lost in the outbreak was calculated to be 1,052,665. From this value, we can determine the actual total number of possible WOG pounds of meat by multiplying the total number of possible pounds of meat by 0.785, which is the current industry WOG percentage yield for Toms. The resulting 826, 342,151 pounds of meat by the value per pound yield a gross revenue loss per house of $311,255. 54 (USDA whole bird price) (see Appendix E for Turkey Value Estimation).

Federal government from virus elimination were delineated by determining the total number of birds lost in the outbreak which, is 23,698, multiplied by $3.55 from the USDA – APHIS flat rates payments for virus elimination. These aggregate to $32, 991 per house in federal government losses from virus removal (see Appendix E Turkey Revenue Value Estimation).

Brown Layers Value Estimation: To determine the company gross revenue loss from losing a brown layer production due to a HPAI outbreak, the value of a brown layer house was established by estimated the possible number of brown eggs a brown layer house would produce under normal conditions.

Grower gross revenue loss was estimated by determining the grower revenue per farm for a 65-week old hen. The litter revenue was not added in this value estimation since is little to no value to the litter from a layer farm. First, we took the total number of eggs produce by a layer in 65 weeks and divided by 12 to get the total number of dozen eggs per layer which is 20 dozen per layer on average. Then we took the total number of dozen eggs per hen and multiplied them by the total number of layers lost in the outbreak after normal mortality. Finally, we took the total number of dozen eggs loss and multiplied them by the current grower paid for dozen eggs of $0.24 cents per dozen from current industry weighted averages (Personal Communication 2017). We determine the opportunity cost of a grower in revenue per house for a 65-week old brown layer to be $54,940 (see Appendix F for Brown Revenue Value Estimates).

Company gross revenue loss was estimated by determining the total number of houses per farm, 3 for this study (2012 Census of Agriculture – County Data – USDA and the National Agricultural Statistic Services). After determining the number of houses, we decided the numbers of birds placed per farm to be 36,000, which is the number of birds per farm from the County level data shown in Table 6 and 7. Under normal conditions before the outbreak the mortality for this flock of brown layers was 3% (Agri Stats, Inc. 2012). Thus normal mortality was estimated to be 1,080 per farm. During the outbreak, the complete loss of layers was equal to 34,920 per farm. From this the model can determine the total number of possible eggs, which equal to 8,241,120 per farm by multiplying the total number of layers loss in the outbreak by the current average number of eggs produce by an organic egg layer which is 236 per layer (Agri Stats, Inc. 2012). The value estimate will determine the total number of possible dozens of eggs lost in the outbreak by taking the total number of bird's loss in the outbreak multiplied by 236, which is the average number of eggs produce for an organic egg layer from AgriStats (year). These figures them are divided by 12 which is the number of eggs per dozen which equal to 686,760 dozen eggs. Company gross revenue loss per house was $6,318,192 (see Appendix F for Brown Layer Revenue Value Estimates).

Lastly, the federal government loss per farm from virus elimination were estimated by determining the total number of birds lost in the outbreak estimated to be 34,920 and multiplied them by $6.45 from the USDA – APHIS flat rates payments for virus elimination. This aggregate to $75,078 per house in federal government lose from virus elimination (see Appendix F for Brown Layer Revenue Value Estimates).

<u>White layers Value Estimates:</u> To determine the company gross revenue loss from losing white layer production due to a HPAI outbreak, the value of each white layer house was established by estimating the possible number of white layers a house would produce under normal conditions. From there, the total number of dozen eggs, of poultry meat the company could have sold without an outbreak of avian influenza was calculated.

Company gross revenue loss was estimated by first determining the total number of houses per farm. For this study, we determined the number of houses was 8 (2012 Census of Agriculture – County Data – USDA and the National Agricultural Statistic Services). The number of birds placed per farm was 800,000, which is the number of birds per farm from County level data (Table 6 and 7). This averages to 100,000 birds per house. Under normal conditions before the outbreak the mortality was determined to be 3% for white layers. (Agri Stats, Inc. 2012). Thus under normal production conditions mortality loss would be equal to 24,000 birds per farm. During the outbreak, the total loss of layers was equal to 776,000 per farm. The total number of possible dozens of eggs lost in the outbreak is determined by taking the total number possible eggs loss by multiplying the number of females 776,000 during the outbreak times the possible number of eggs (250) they would have produced (Agri Stats, Inc. 2012). This equals 194,000,000 possible eggs lost in the outbreak, or 16,166,667 dozen per farm. The company gross revenue loss per house was $879,062 determined by multiplying the total number of possible dozen eggs by the current USDA egg price of 0.435 cents (see Appendix G for White Layer Revenue Value Estimate). There is no grower revenue loss for this value estimate because the farms for white eggs are mainly company owned.

Lastly, the federal government loss from virus elimination were estimated by determining the total number of additional birds lost in the outbreak which is 776,000 multiplied this by $6.45 from the USDA – APHIS flat rates payments for virus elimination. This aggregate to $625,650 per house in federal government lose from virus removal (see Appendix G for White Layer Revenue Value Estimates).

3.3.5 Grower and Company Opportunity Cost Calculation and Federal Government Cost

Because the total damage and number of impacted houses depends on poultry house type and the location of the initial infection, the model was simulated 1000 times to account for the random spatial variability. After estimating the aggregate value of the poultry houses infected, the federal government cost and opportunity costs for the grower and the company were determined as seen in Table 12. The model multiplied the values from Table 12 by the average number of houses and the type of houses that were infected during the simulated HPAI outbreak, to determine the economic effect of the HPAI in Washington and Benton counties.

3.3.6 Grower Opportunity Cost Estimation: The grower opportunity cost was determined to be the same with the same fundamentals from Equation 10 as the company opportunity cost, the only difference being the β is the grower lost revenue per house per flock. For example: for a pullet operation, the following equation will determine the opportunity cost of the grower per house per flock (A):

$$21{,}104.34\left(\frac{28}{20*7}\right) = \$4{,}220.87(\mathrm{A}) \quad \text{Eq. 9}$$

21,104 .34 is the grower revenue per house from the pullet value estimation section mentioned above. The Eq. 9 was used for all the other different production types based on their specifications for their correct production type.

3.3.6.1 Company Opportunity Cost Estimation: The opportunity cost of the company was determined with the fundamental assumption that their losses will be a representation of the time they were not producing since an infected house was under a quarantine and before any house could be restocked, they would be required to wait at least 28 days based on USDA rules. Therefore, the opportunity cost will be equal to the loss in revenue due to the quarantine period before restocking which is 28 days. Because each production type has a different production lifecycle a modest equation was used for each production time to account for the actual loss due to downtime. The equation is as follows (Equation 10):

$$\mathrm{A} = \beta * \left(\frac{\gamma}{\delta*\varepsilon}\right) \qquad \text{Eq. 10}$$

where β is the company value of the house, γ is the 28 days before restocking occurs, δ is the entire production lifespan in weeks value, and ε equals to the number of days in a week. For example; for a pullet operation, the opportunity cost of the company per house per flock (A) will be determined by the following equation:

$$3{,}879{,}614.65 * \left(\frac{28}{20*7}\right) = \$775{,}923 \text{ (A)} \quad \text{Eq. 10}$$

3,387,614.65 is the company value of the house per house from the pullet value estimation section mentioned above equation (10) was used for all the other different production types based on their specifications for their correct production type.

3.3.6.2 Federal government Cost: To determine the federal government cost per house at outbreak we created a modest equation (Equation 7):

$$A = B + \Gamma + Z \qquad \text{Eq. 11}$$

where B is equal to Company Value of $House_x$ at Outbreak, Γ is equal to Grower Value of $House_x$ at Outbreak, and Z is equal to Virus Elimination Cost based on the production type; thus, A is equivalent to total federal government cost. A proxy for the indemnity payment will be nested within B and Γ in equation (11) because under the fundamental model assumptions mentioned above, the federal government will be paying companies and growers a 100% indemnity payment for the current fair market value of their birds based on the poultry operation type. Virus elimination is represented by Z. Depopulation cost is not estimated given the lack of literature to get a value for depopulation cost based on the different production types.

B in Equation (11) was determined by taking the company value estimated in the previous section and dividing it by 2 to get the company value of the house at the outbreak period. Dividing this value by 2 gave us the actual value of the house when the outbreak occurred, because we are assuming that the outbreak will happen when each production type is in its midway point, thus, the average of initial delivery time and harvesting time, into production. For example: for broilers, the lifespan is 42 days; assuming each day has an equal probability of an outbreak, it is assumed that the average outbreak will occur at 21 days and the same for all the other production types.

Γ is estimated by taking the grower value of the house and dividing by 2 to get the company value of the house at the outbreak period. Z was estimated the same way that B and Γ were estimated above; no other changes were made after the value were identified for Z. To conclude, all values were added up to determine the federal government cost per house at the outbreak which is express as the letter Z.

Chapter IV: Empirical Results

This study has two empirical analyses, one for the general risk assessment model and another for the spatial visualization assessment model, which allowed us to achieve the objectives stated in the introduction. The first analysis assesses the average economic damage inflicted by a random outbreak of HPAI in Washington and Benton. A monetary value for the grower, company, and federal government was assigned to the total number of infected houses to quantify average economic damage each county, respectively. The second analysis for the spatial visual assessment model complements the first model; however, this analysis assessed the variability of risk across both counties with the outbreak being stimulated 100 times. Monetary calculations were performed to determine the estimated loss for each production type.

4.1 General Risk Assessment Model

Given 1,000 random infections of poultry houses for each County, we can analyze the effect of a HPAI outbreak by determining the value of each house by production type and attaching the monetary value estimates into the model. Table 10 displays the results of the average number of houses and the type of houses infected from the simulated outbreak. A monetary value estimate will be added to the number of houses infected to see the economic effect of the random HPAI outbreak. Broiler houses had the highest probability of infection and white layers the lowest. The sum of the number of houses infected during the simulation was 162 poultry house on average (Table 10).

Table 9. Average Total Number of Houses Damaged from an HPAI Infection based on 1,000 Random Infections in Washington and Benton Counties

Production Type	**Houses in Quarantine Zone**	**% of Total**
Broiler	119	73.46
Pullets	7	4.32
Breeders	17	10.49
Brown Layers	2	1.23
Turkey	16	9.88
White Layers	1	0.62
Total	162	-

The model determined the average number of house infected during simulated HPAI outbreaks: broiler production (119); pullets (7); breeders (17); brown layers (2); turkeys (16); and white layers (1) (Table 19). Monetary values were then added into the model to determine the total economic damage from the simulated outbreak.

4.1.1 Total Economic Effects, by Poultry Type

Table 10 and Figure 15 display the average economic damage to the different production types due to the simulated outbreak from the general risk assessment model.

Broilers: Of all six production types (Table 9), broilers have the highest number of total houses across Washington and Benton counties and thus the highest number of infections with 119 broiler houses being infected on average. The average total economic damage from the infection to the broiler operations was $22.8 million. This total value includes the economic damage to the grower, company and federal government. These results can be further broken down to the average total economic damage of $191,675 per broiler house. Broilers had the second highest percentage (30%) of total losses (Table 10).

Table 10. Average Total Economic Damages from a Randomized HPAI Infection, by Production Type in Washington and Benton Counties, Arkansas

Production Type	**Economic Damages**	**Percentage of Total Lost**	**Houses in Quarantine Zone**
Broiler	$22,809,437	30%	119
Pullets	$19,135,346	25%	7
Breeders	$28,227,041	37%	17
Brown Layers	$744,246	.9%	2
Turkey	$4,617,735	6%	16
White Layers	$537,581	.7%	1
Total	$76,071,389	100%	162

Pullets: A total of 7 pullet houses were infected on average during the simulated HPAI outbreaks with a total economic damage of $19.1 million. Pullets have the third highest percentage (25%) of total losses after breeders and broilers (Table 10). Given that the economic damage per house is $2.7 million this low infection rate still results in considerable economic losses.

Breeders: Of all six production types (Table10), breeders had the greatest economic damage with a total of $28.2 million in losses to the grower, company and federal government. On average, 17 houses were infected from simulated HPAI outbreaks. The percentage of total loss in comparison to other production types is 37%, the highest of all six production types. The per house damage is $1.6 million, 8 times higher than the economic damage per house for the broilers.

Layers: For brown layers a total of two houses on average were infected during each simulated HPAI outbreak with an economic damage of $744,246. The per house economic damage is $372,123 per house. This is the second lowest percentage (0.9%) of total loss. White layers had an economic damage of $537,581 with one house infected during the simulated HPAI outbreak. White layers placed last on the percentage of total lost (0.7%).

Turkeys: Turkeys had an economic damage of $4.6 million from the simulated HPAI outbreak. An average of 16 houses were infected during each outbreak. Per house economic damage sums to be $288,608 per house. The percentage of total damage is 6%, being the 4th highest percentage lost during the outbreak (Table 10).

To summarize, the greatest economic damages can be attributed to the breeders with an average $28.2 million in economic damages. Broilers got the second most economic damage with $22.8 million in direct losses and a total of 119 houses infected. Although broilers had 119 houses infected and breeders have a smaller quantity of 17 houses infected, breeders economic damage surpasses that of broilers. We can see the same trend with the pullets with only 7 houses affected and the third highest economic damage.

These results demonstrate that the higher we go on the genetic line (Figure 11) the greater amount of economic damage due to the economic value of the birds. On average, brown layers and white layers were the fifth ($744,246) and six ($537,581) lowest economic damages, respectively, from the HPAI outbreak; they also have the smallest percentage of houses in both counties. Table 10 shows the average total economic damage of the outbreak sums up to be $76,071,389, with a largest portion of the damages coming from birds high in the genetic line. To have a clear understanding of the economic effect of a HPAI outbreak the results were further analyzed into the economic effect on the grower, company, and federal government, described in the following discussion.

4.1.2 Total Economic Effects, by Sector

Grower: The direct economic effect on the grower resulting from the HPAI outbreak is $1.2 million losses in (Table 11) opportunity cost due to down time. Growers are the least economically affected sector of the poultry industry during a simulated HPAI outbreak.

Company: The direct economic effect on the company resulting from the HPAI was $17.3 million losses in opportunity cost due to down time (Table 11). The company is the second highest affected sectors in the poultry industry.

Federal government: The federal government have the highest economic direct effect of $57.4 million in losses resulting from the HPAI outbreak. This can be attributed to the federal government expense on high amount of money in indemnity payments and virus elimination.

Table 11. Average Total Economic Damages from a Simulated HPAI Infection in Washington and Benton Counties in Arkansas.

Section of Poultry Industry Affected	**Direct Economic Effect**	**Percentage of Total Economic Effect**
Average Cost to the Federal Government	$57,421,039	75%
Average Damage to Company	$17,355,760	23%
Average Damage to Grower	$1,294,589	2%
Total	$76,071,389	100%

Determining the total economic damage from a HPAI infection on the federal government, company, and grower was a main objective of this study. Results from Table 11 show that the federal government will have the highest economic damage ($57.4 million) which equal to a 75% of the total effect. The company will have the second highest economic damage ($17.3 million) which equal to 23% of the total effect, and the grower will have the lowest one of all three with $1.2 million in economic damage which equal to 2% of the total effect. These results include all the houses that were infected on average during the simulation (162).

Figure 15 shows the average total damage from a randomize HPAI outbreak production type. Table 12 and Figure 17 shows the average direct economic effect of the simulated outbreak on the federal government, company and poultry grower. Figure 16 shows the number of houses infected on average from the simulated HPAI outbreak. The following sections will discuss in more detail the economic effect of the simulated HPAI outbreak on each poultry type and the total economic effect by sector

Table 12. Average Total Estimated Cost of HPAI Outbreak by Poultry Type, by Sector, per House Flock

Production Type	**Federal Government Cost**	**Percentage of Total Loss Attributed to the Government**	**Opportunity Cost of Company**	**Percentage of Total Loss Attributed to the Company**	**Opportunity Cost of Grower**	**Percentage of Total Loss Attributed to the Grower**
Broiler	$114,879	60%	$67,589	35%	$9,317	5%
Broiler Breeders Pullets	$2,014,840	72%	$775,922	28%	$4,220	.002%
Broiler Breeders Hens	$1,456,511	89%	$171,337	11%	$2,675	.002%
Turkey (Toms)	$228,860	77%	$62,251	21%	$6,765	2%
Egg Layers (Brown Eggs)	$361,266	91%	$32,400	8%	$3,380	1%
Egg Layers (White Eggs)	$1,027,351	95%	$54,096	5%	$ 0	0%

Figure 15. Average Total Damages from a Randomize HPAI Infection on Production Types.

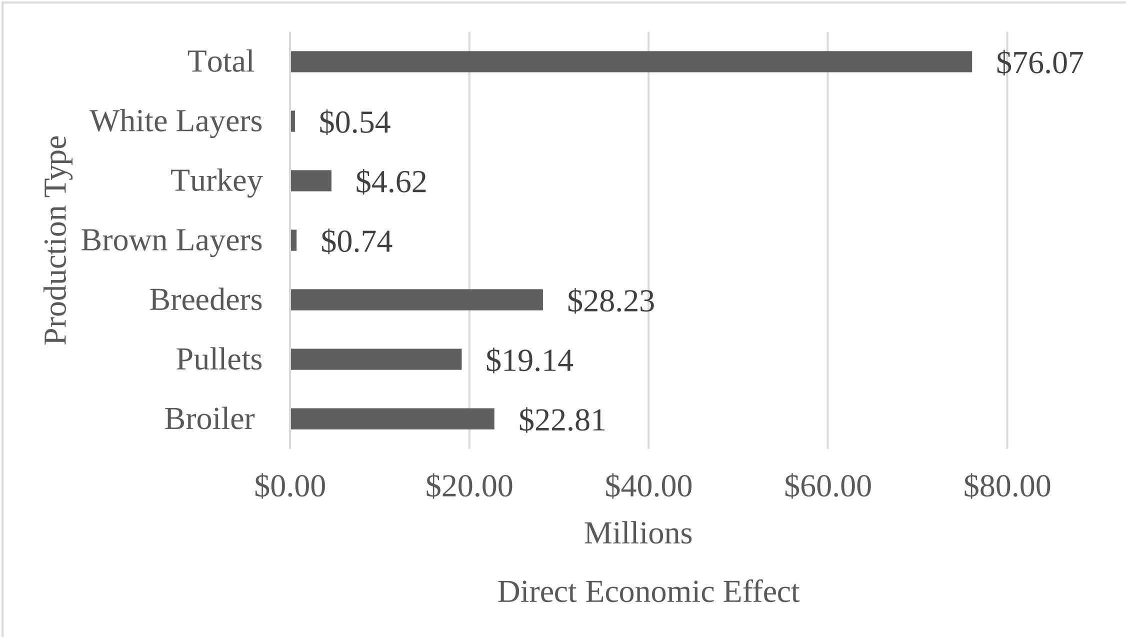


Figure 15. Average Total Number of Infected houses from a Radon HPAI Infection.

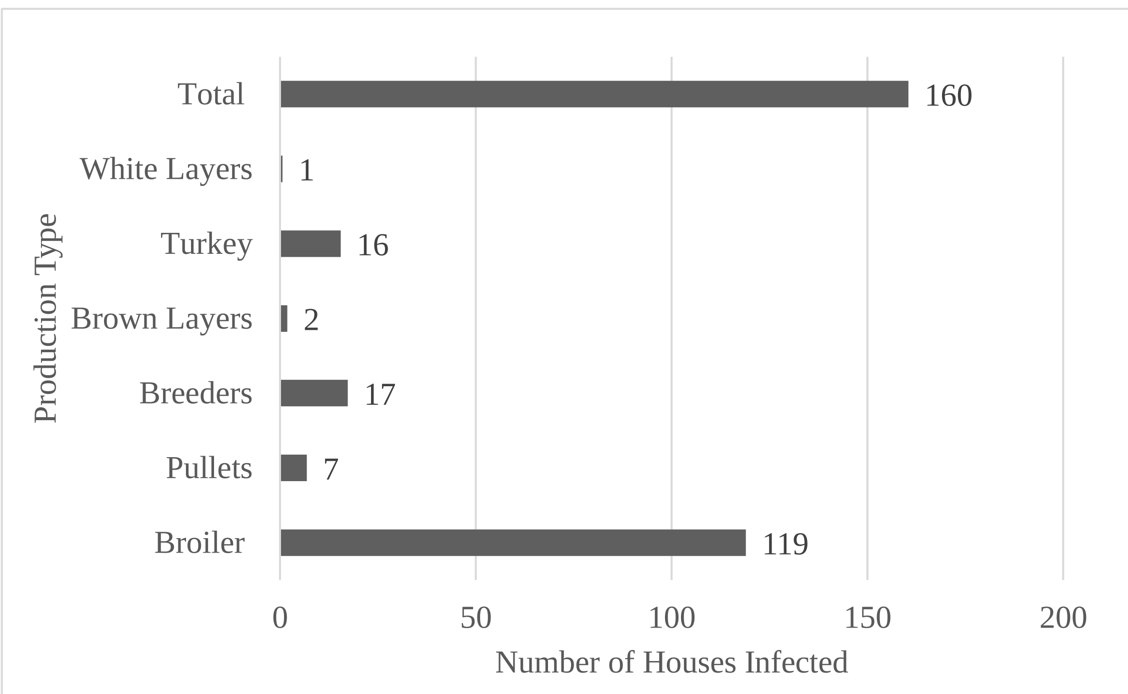
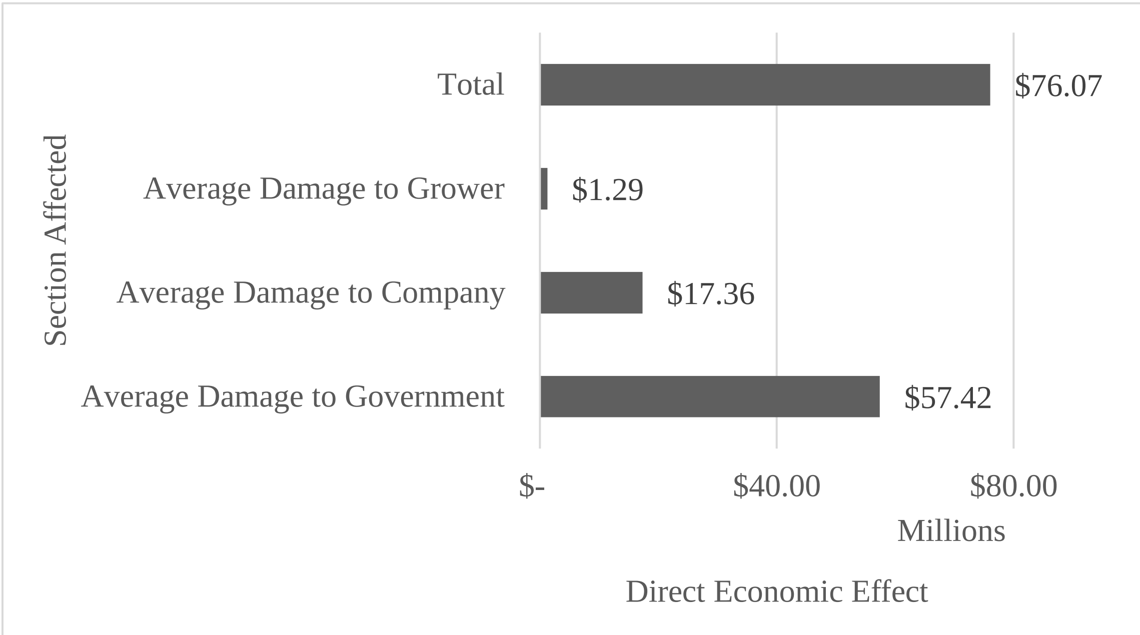


Figure 16. Average Total Economic Damages from an Infection on Grower, Company, and Federal government.



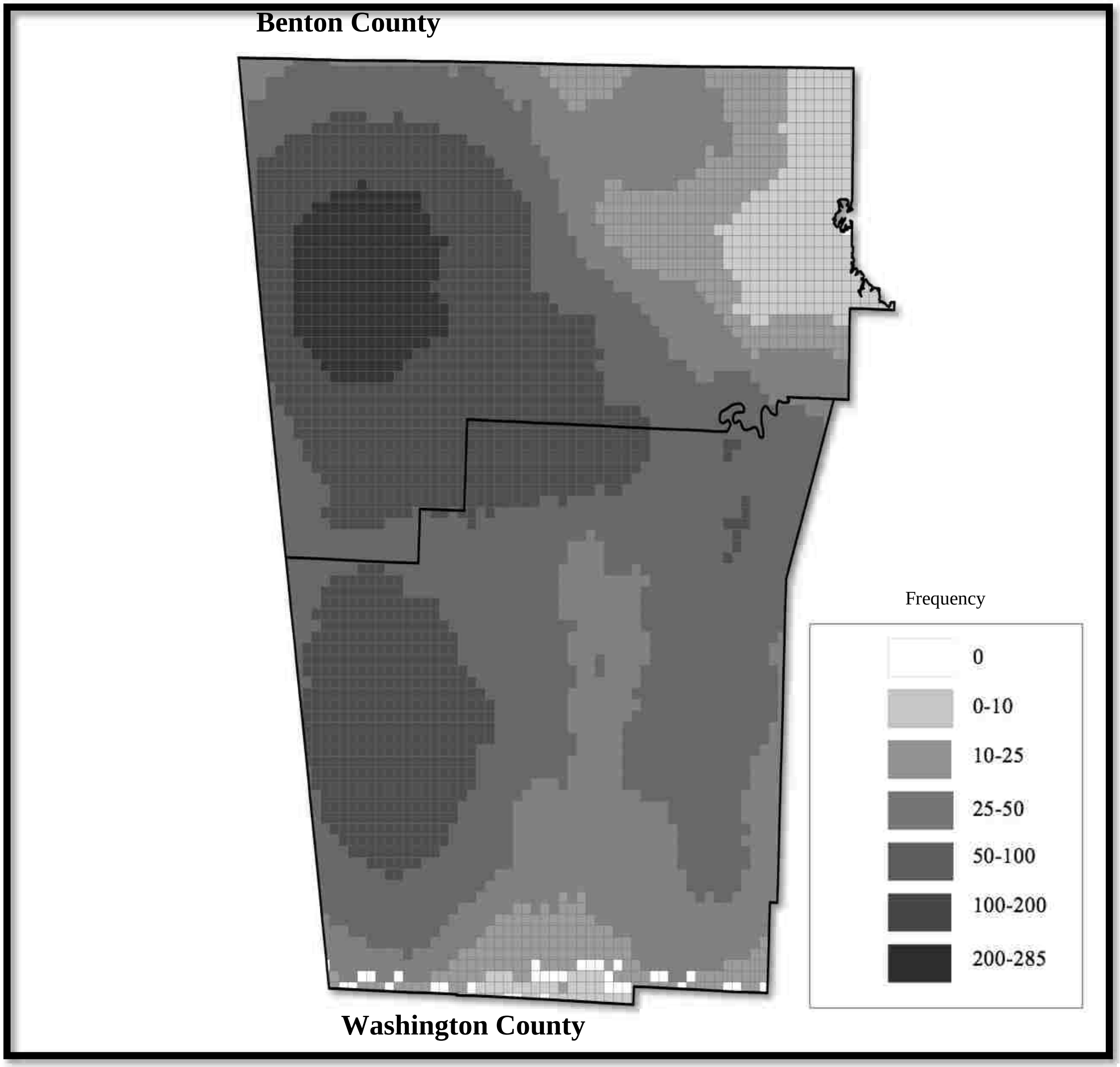
4.2 Visualization Model

After determining the outbreak frequency for the Spatial Visual Assessment Model, the damage per house type maps were created showing the outbreak frequency and monetary value displaying spatial variability of infected houses for each county. Each grid cell in the map contains economic damages for the study areas. This map serves as a spatial outlook of the outbreak and is useful as a complementary analysis for determining resources allocation for the poultry growers companies, and the federal government. Maps of the different production types are shown below. Also shown are maps of the total damage and the total outbreak frequency for both counties and all production types. The damages from the simulated outbreak in the Spatial Visual Assessment Model range from $0.00 to $55,000,000 in losses. The frequencies of houses that were at risk during the simulated HPAI outbreak range from 0 to 285.

4.2.1 Houses Affected

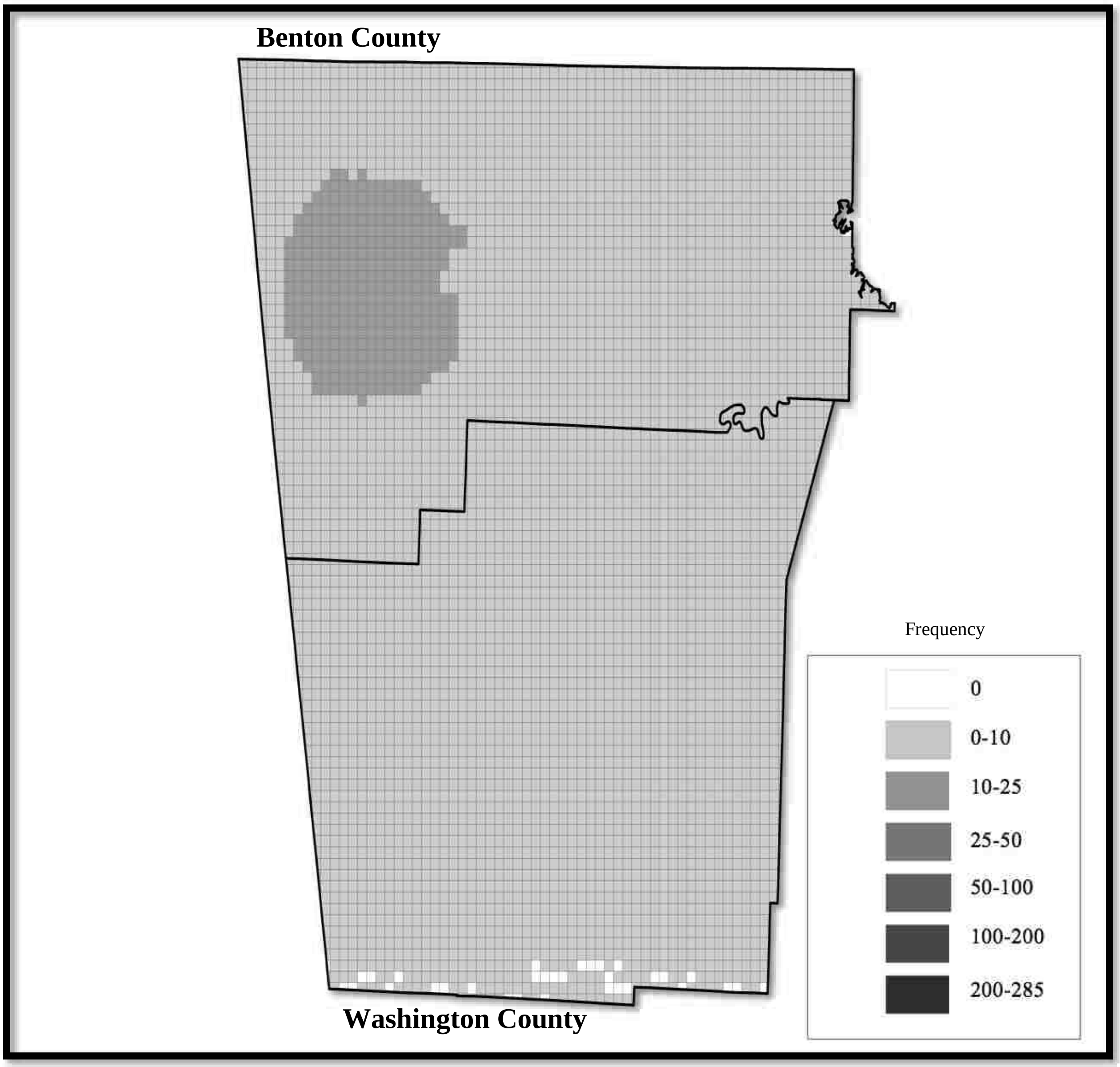
Broilers: A higher density of houses at risk in both Washington and Benton counties. The darkest areas on the map show the highest number of houses at risk of an outbreak (Figure 18).

Figure 17. Number of Broiler Houses at Risk of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



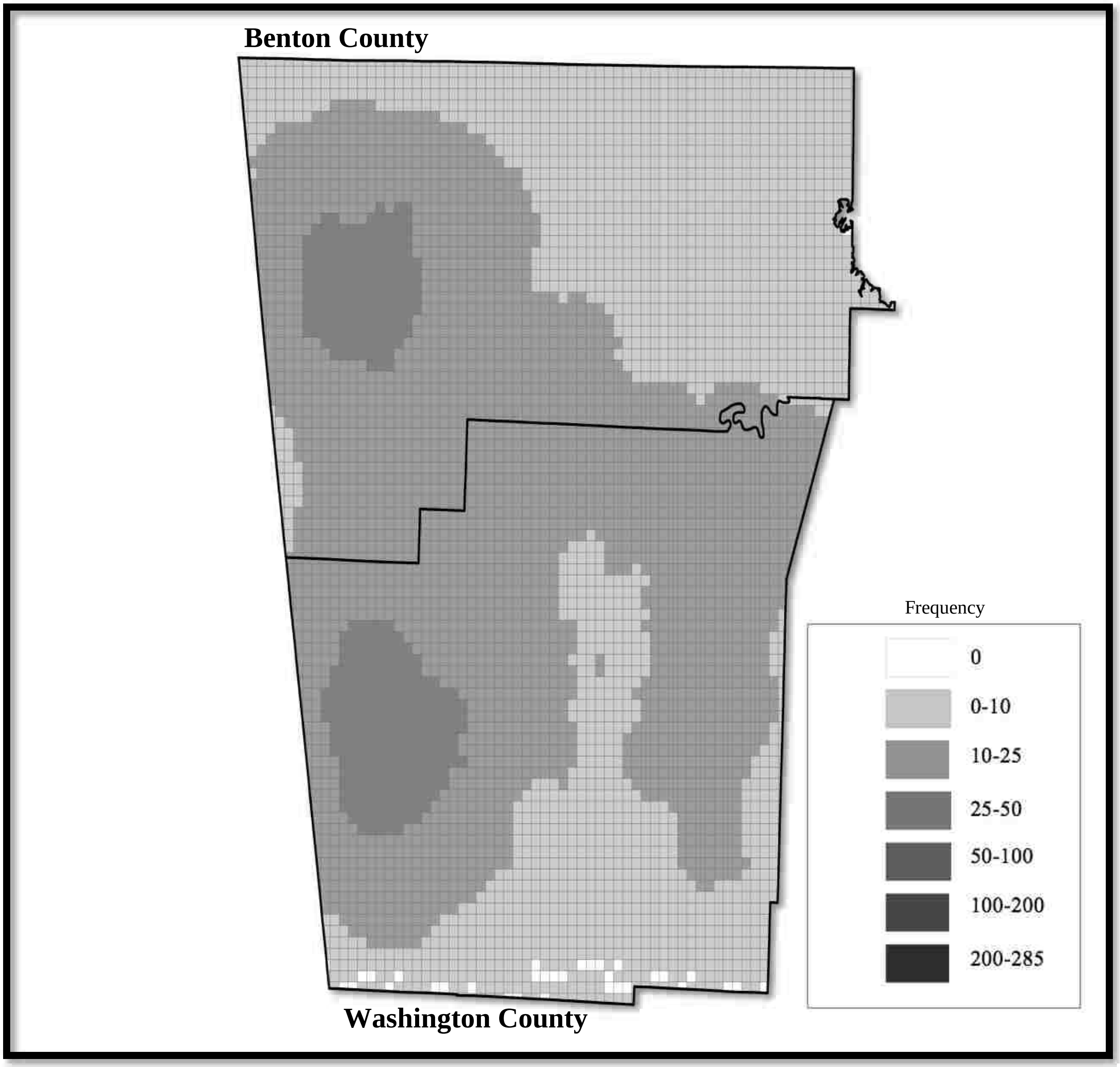
<u>Pullets:</u> Figure 19 is the number of pullet houses at risk all concentrated in the Benton County area (the northern most county on the map) in comparison to Washington County (the southernmost county on the map).

Figure 18. Number of Pullet Houses at Risk of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



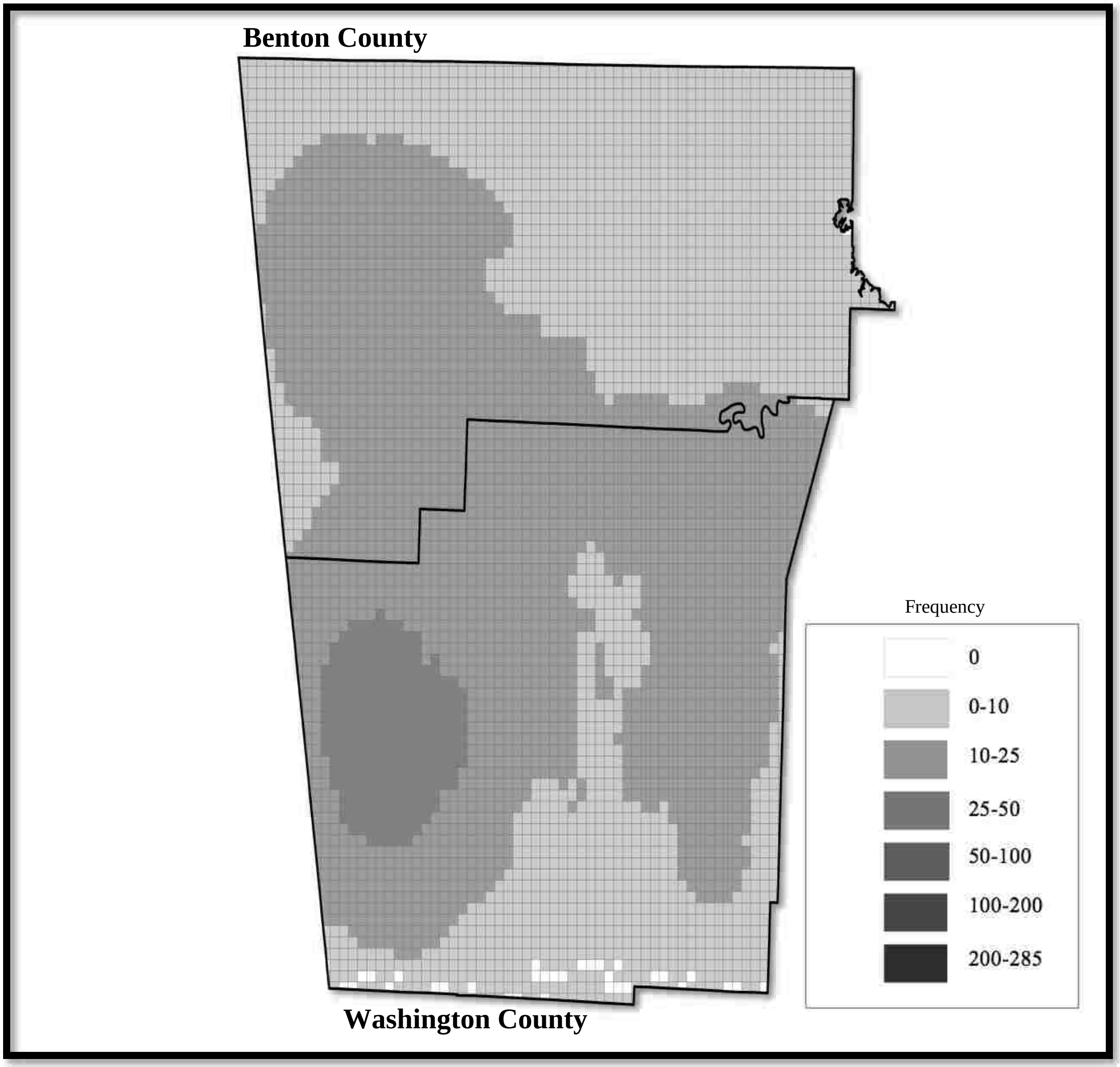
Breeders: There is higher density of houses at risk (Figure 20). We can determine from Figure 20 that Washington County has a larger number of breeder houses at risk than Benton County.

Figure 19. Number of Breeders Houses at Risk of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



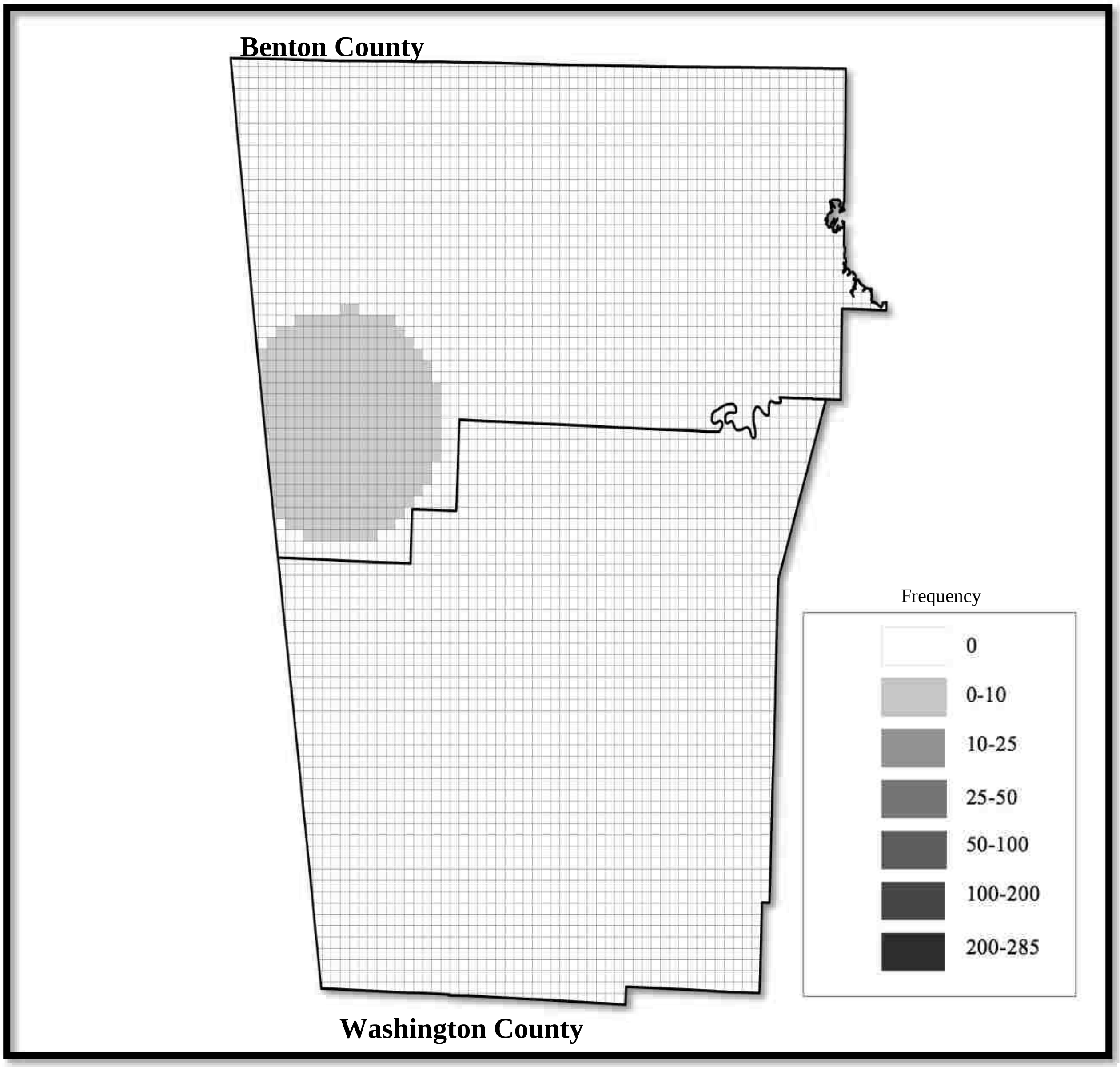
Turkeys: There is a higher density of turkey houses at risk across Washington County than in Benton County (Figure 21).

Figure 20. Number of Turkeys Houses at Risk of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



White Layers: There is one specific location in Benton County that has the largest number of houses at risk across both counties (Figure 22). Benton County Foods LLC is in that hotspot area (shown later in Figure 29). There is also a high density of other houses around this specific location.

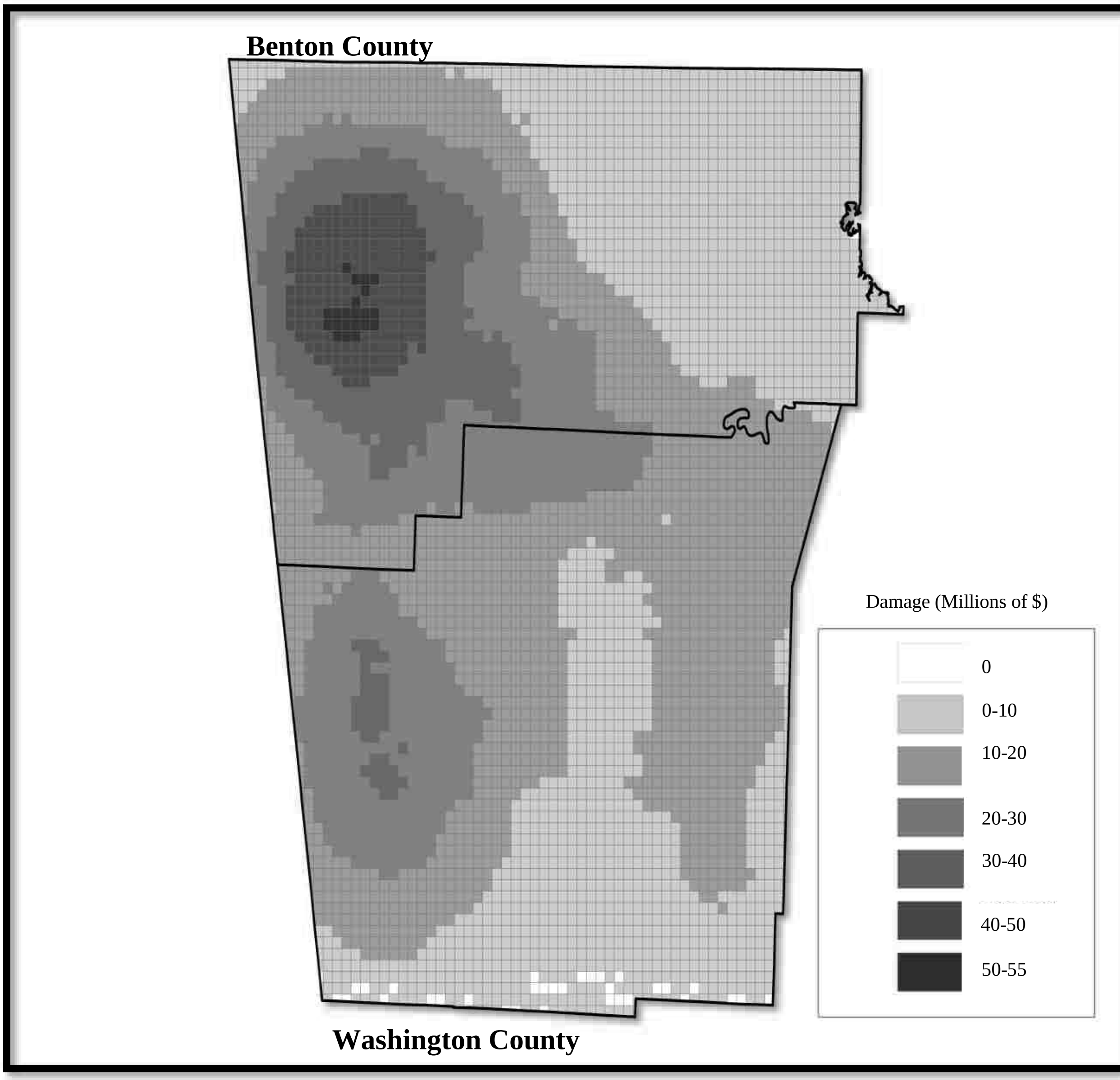
Figure 21. Number of White Layers Houses at Risk of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



4.2.2 Total Economic Effect, by Poultry Type

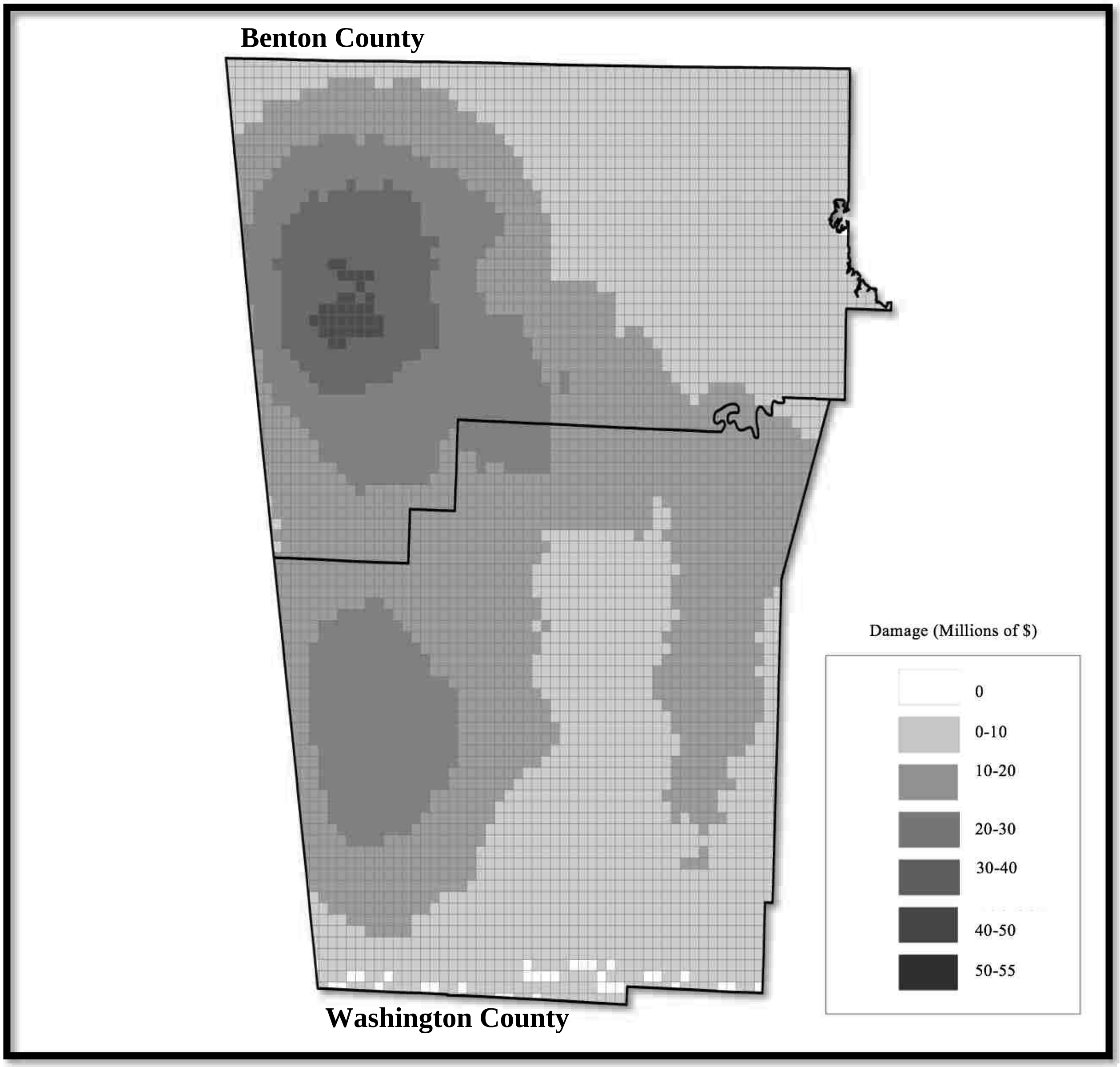
Broilers: In Figure 23, a larger amount of money at risk may be seen in comparison to Figure 21 especially in the Benton County area.

Figure 22. Potential Economic Loss for Broilers given a HPAI Outbreak, in Benton and Washington Counties, Arkansas.



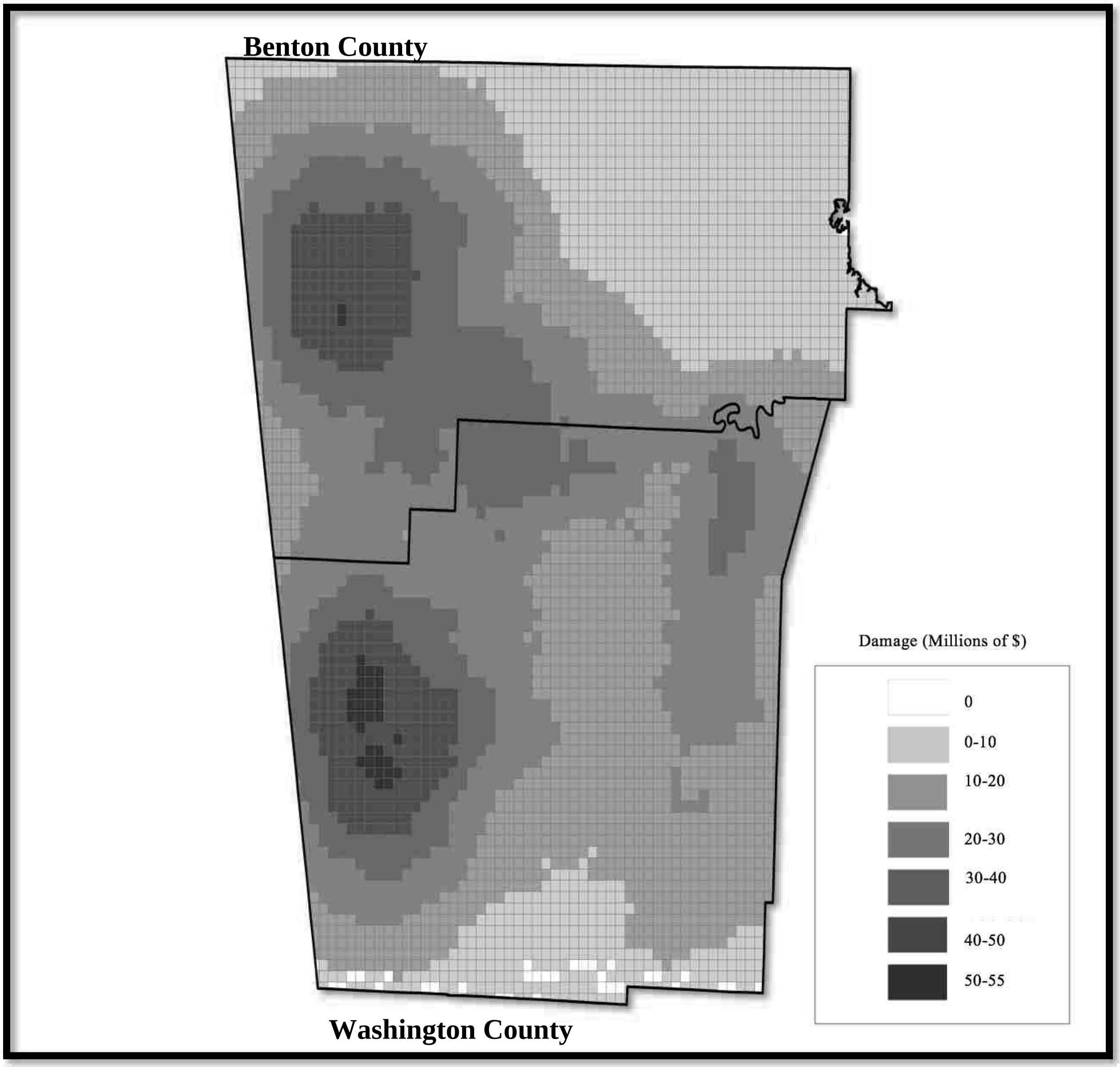
Pullets: In Figure 24, it can be seen there is a high monetary for pullets in both counties, but the Benton County area is more greatly affected than Washington County.

Figure 23. Potential Economic Loss for Pullets given a HPAI Outbreak, in Benton and Washington Counties, Arkansas.



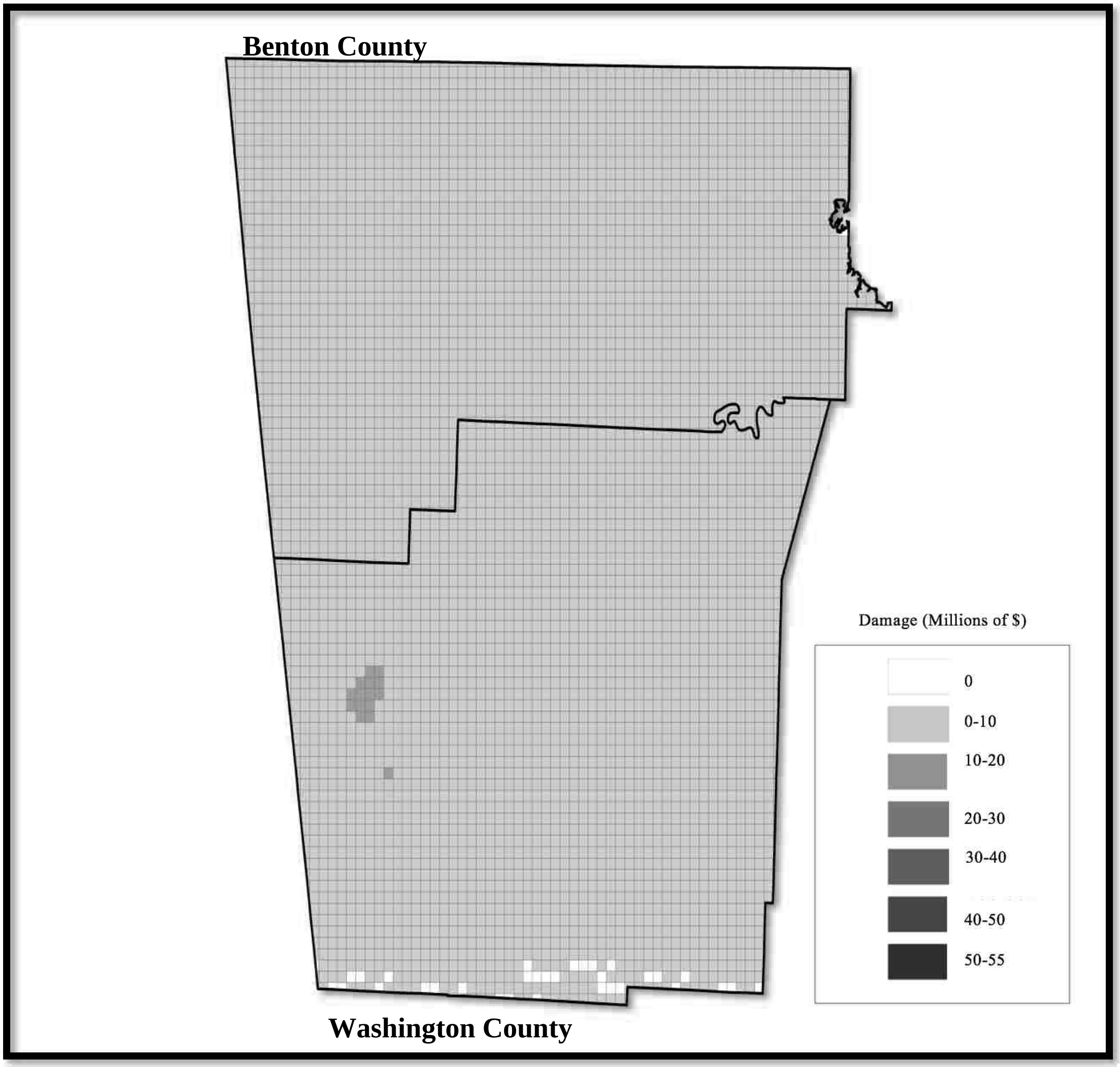
Breeders: There is large monetary risk across both counties (Figure 25). Washington County is potentially more affected than Benton County in case of a HPAI outbreak.

Figure 24. Potential Economic Loss for Breeders given a HPAI Outbreak, in Benton and Washington Counties, Arkansas.



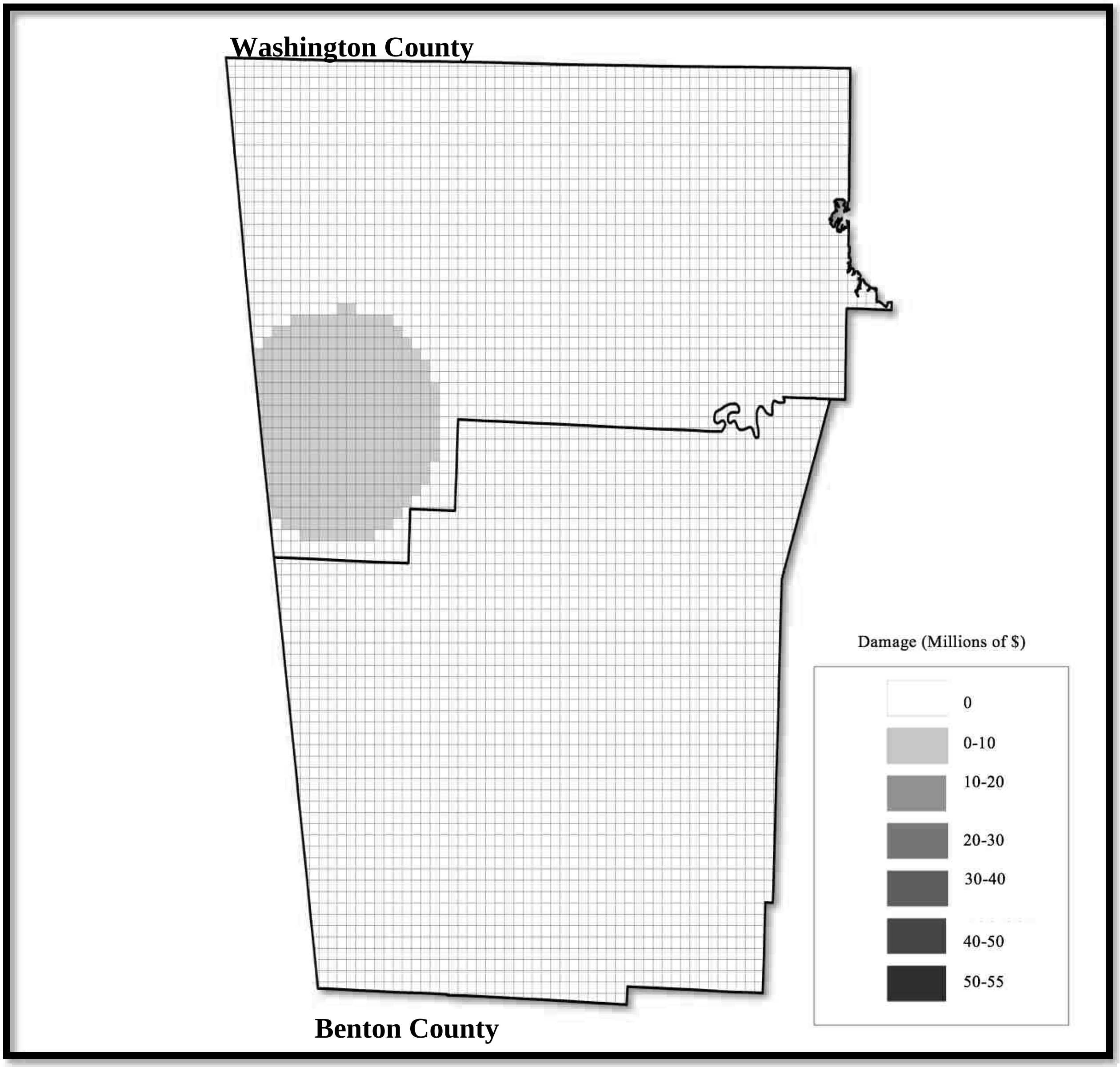
Turkeys: Figure 26 reflects a low density of houses at risk across both counties, but we can see a larger monetary risk from turkey houses in Washington County in comparison to Benton County.

Figure 25. Potential Economic Loss for Turkeys given a HPAI Outbreak, in Benton and Washington Counties, Arkansas.



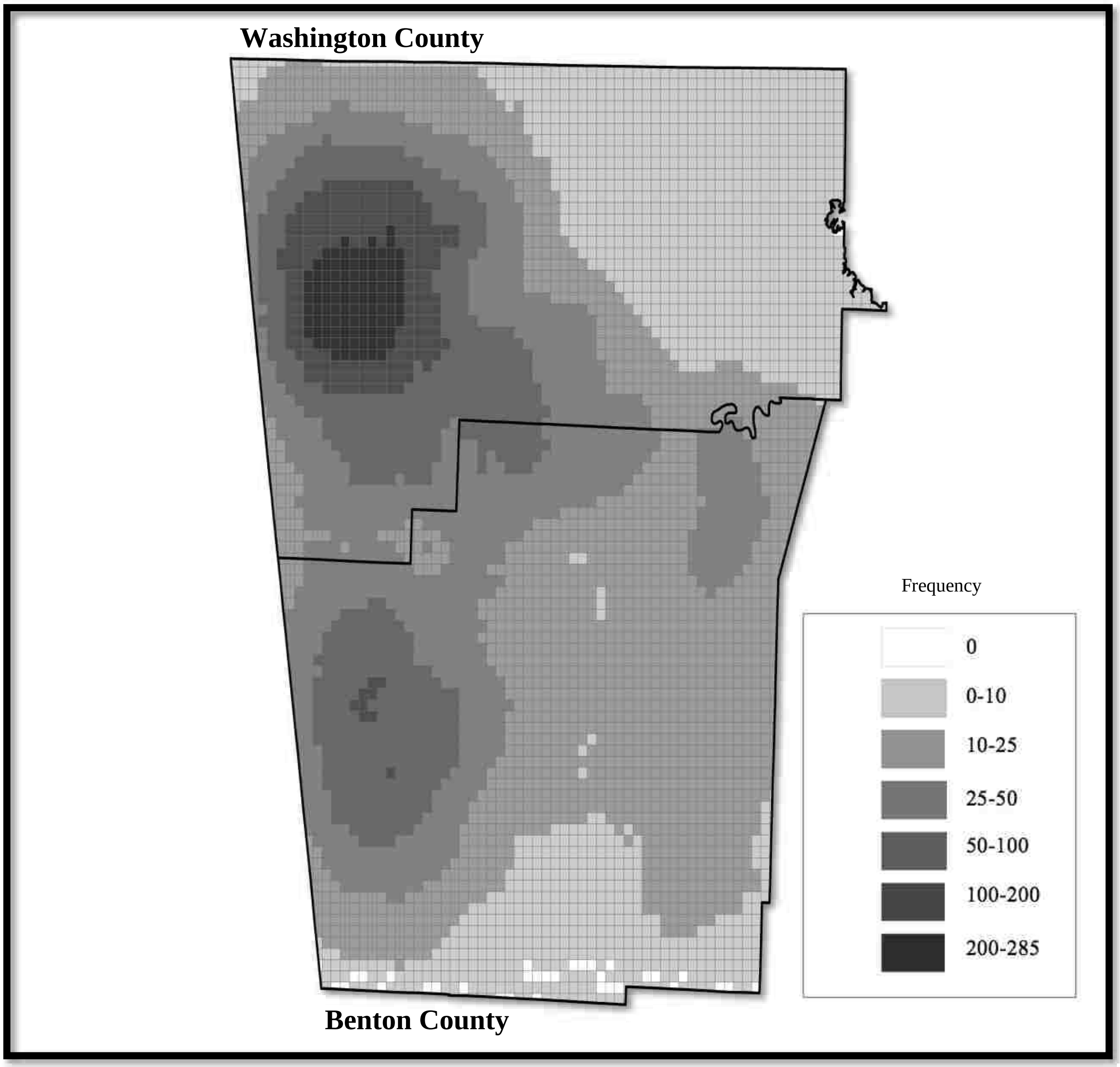
White Layers: Figure 27. Potential Economic Loss for White Layers given a HPAI Outbreak, in Benton and Washington Counties, Arkansas.

Figure 27. Potential Economic Loss for White Layers given a HPAI Outbreak, in Benton and Washington Counties, Arkansas.



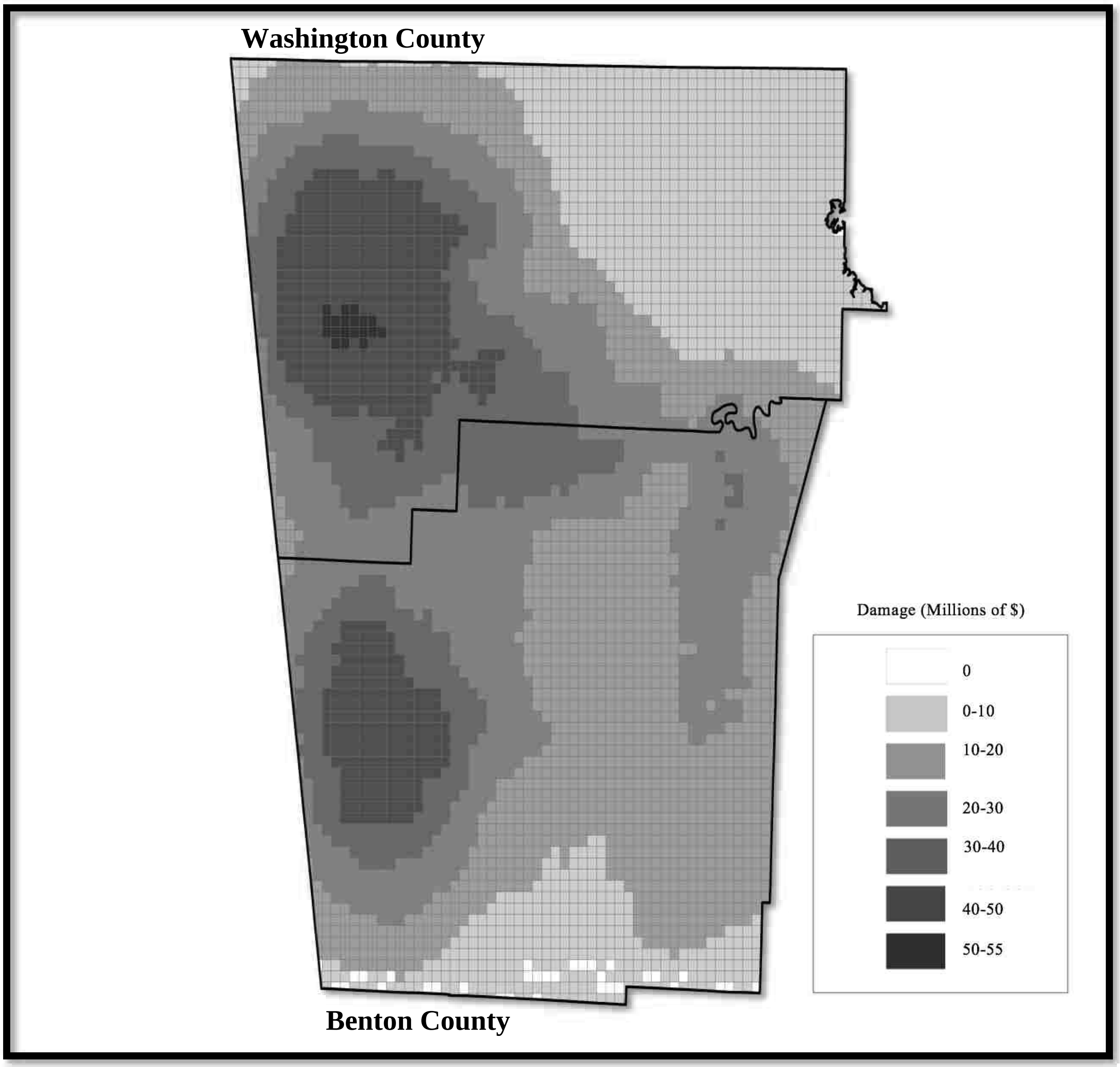
Total Houses Affected: There is a great spatial variability in poultry houses affected across both counties, with most houses at risk being in the Benton County area (Figure 28). Once again, the 'hot spots' analysis reveals focal areas of houses affected concentrated in the west–central portion of each county.

Figure 26. Total Number Houses at Risk of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



Total Economic Effect: Figure 29 illustrates greater spatial variability in economic loss compared to the houses affected. Even though fewer houses are at risk in Washington County compared to Benton County, there is a greater economic effect. By combining the concentration of each type of bird, it can be seen, particularly for pullets and breeders, that the epicenter of economic losses is as shown above.

Figure 27. Total Potential Economic Loss in Dollars for a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



Chapter V: Conclusion and Implications

The economic effects of a HPAI outbreak can be catastrophic for all sectors in the poultry industry in the United States. Billions of dollars have been lost due to past outbreaks like the one in 2014-2015. HPAI is a constant disease threat for the poultry industry and given the uncertainty of where and when an outbreak could occur, preparing for its effects has proven difficult. It is critical to find ways to mitigate future losses due to disease outbreaks like HPAI. This study provides poultry growers, the poultry industry in Northwest Arkansas, and the federal government information about the potential economic effects of a HPAI outbreak in Washington and Benton counties in Arkansas. This chapter summarizes estimations of two models (spatial risk assessment model and general risk assessment model) and summarizes the main conclusions of the analyses. Furthermore, this chapter contains a section that clarifies implications and limitations of the study. The conclusions drawn from this study are limited by the origin of the data, the fundamental model assumptions, and the method of analysis. It is essential to recall that the scenario presented herein will be the worst-case scenario of an HPAI outbreak in Benton and Washington counties in Arkansas due to the main assumptions mentioned in Chapter III. The worst-case scenario is a starting point for future research that aims to identify economic losses of an AI outbreak in a location by using simulation models. This study fulfills the objectives of determining the economic effect of a simulated HPAI outbreak in Washington and Benton counties, specifically to the extent of the direct effects of an outbreak on growers, companies, and the federal government.

General Risk Assessment Model: An outbreak of HPAI could have large economic consequences for Benton and Washington counties in Arkansas due to the large poultry population in the area, and would have a substantial negative impact on the entire state of Arkansas who relies on poultry as the primary agricultural sector in the state. The key findings from the general risk assessment model were: 1) The average total economic loss from a randomized HPAI infection in Washington and Benton counties in Arkansas is $76 million. This difference between losses across different sectors can be attributed to the fact that the federal government cover indemnity payments and virus elimination which comprise a large portion of the total costs (Table 12). 2) During the worst-case scenario of a randomized HPAI infection in Washington and Benton counties in Arkansas the most affected production type in terms of economics was the broiler breeders with an average of 17 houses infected and $28.2 million in economic losses for the grower, the company and cost to the federal government for each randomized outbreak. 3) Of the three sectors evaluated in this study the most affected during the randomized HPAI infection was the federal government with damage of $57.4 million on average.

In the worst-case scenario of HPAI outbreak in these two counties, the total average direct economic effects are $76 million. The results from our general risk assessment model showed the damaging effect of one simulated outbreak of HPAI. The average losses by poultry type are: broilers with 119 houses infected during a simulated HPAI outbreak and an average economic damage of $22,809,437; pullets with an average of 7 houses infected and an average economic damage of $19,135,346; breeders with average of 17 houses infected and an economic damage of $28,227,04; turkeys with 16 houses infected and an economic damage of $4,617,735; white layers with 1 house infected and an economic damage of $537,58; and brown layers with 2 houses infected and an economic damage of $744,246, A total of 162 houses were infected on average from the simulated HPAI outbreak in Washington and Benton counties in Arkansas and a total economic damage of $76,071,389 on average. The economic damages by sector on average across both counties are: Economic damage from a HPAI simulated outbreak on the grower is

$1,294,589; economic damage to companies is $17,355,760; and economic damage to the federal government is $57,421,039.

Spatial Visual Assessment Model: The spatial visual assessment model results help identify the most affected areas with respect to number of houses at risk areas and economic losses across both counties. This spatial analysis can be use by the different segments of the poultry industry and the federal government as a reference point for resource allocation and to educate policy makers and the poultry industry about the economic effects of AI areas of Arkansas.

The key findings from the spatial visual assessment model were: 1) The largest number of poultry houses at risk from an HPAI infection are in Benton County; 2) The impact in Washington County is more pronounced in terms of economic loss as compared to number of houses affected because of incorporating economic damages by production type, there being more breeders concentrated in west-central Washington County; 3) Having a spatial view of a simulated HPAI outbreak is beneficial to determine the specific areas at high risk of an outbreak.

5.1 Implications

The finding from this study provide economic estimates of a potential HPAI outbreak in Washington and Benton Counties in Arkansas. This section will discuss the effects on those three core areas as well as implications for further research.

Poultry Grower Implications: Results from the previous analyses show that the damage to poultry producers in Washington and Benton counties from one simulated HPAI outbreak was on average $1.2 million in losses due to the opportunity cost. Opportunity cost of the grower and the farm was defined as the difference in the amount of poultry meat or eggs sold with and without the outbreak. This highlights the economic importance of educating poultry growers regarding the economic losses caused by an AI outbreak and undertaking biosecurity measures to help prevent an outbreak. Poultry growers are the foremost line of defense when it comes to prevention or decreased probability of an outbreak and the spread of one as well. Therefore, is important to educate them about this the potential economic losses associated with an outbreak and provide them with assistance to increase biosecurity practices that can ultimately be beneficial for the entire poultry industry and the federal government in the effort to reduce the total damage induce by an outbreak of HPAI.

Poultry Company Implications: Based on the study, on average poultry integrators will have the second largest economic loss due to an outbreak of HPAI with $17 million in total losses. These losses are attributed the opportunity cost, defined as the difference in the amount of poultry meat or eggs sold with and without the outbreak. It is also important for the integrator to take into consideration the trade-off between helping the poultry growers with the implementation of higher biosecurity standards in their poultry operations and the losses incurred by a possible HPAI outbreak. The poultry integrator can also have the effect of having trade restrictions which can affect their exports due to an outbreak of AI. Increasing the awareness of the economic losses of an AI outbreak can help reduce both, the probabilities and total effects of an outbreak. The results from the spatial analysis suggest that a poultry integrator can determine where to enhance biosecurity standards and then estimate the economic value of assisting with heightened biosecurity on farms.

Federal Government Implication: Based on the study results, the federal government would incur the largest portion of the total economic damage from the simulated HPAI outbreak. The $57 million average economic loss to the federal government includes indemnity payments and depopulation costs only. A significant amount of the total damage is due to indemnity payments to growers and companies. The level of biosecurity poultry operations has in place may not be high enough to prevent an HPAI outbreak, but increasing awareness of biosecurity importance to the federal government could help reduce the number of houses infected during an AI outbreak. This study presented the worst-case scenario to better communicate the amount of money at stake in the case of an outbreak. This approach focuses on the tradeoff between having an outbreak and increasing biosecurity to help prevent or lesson the effect of a possible outbreak.

Implications for Research: Understanding the worst-case scenario of an HPAI outbreak provides a starting point for comprehending the effects of an HPAI outbreak in Washington and Benton counties. This implication will be helpful to raise more questions regarding how to prevent and deal with probabilities of an outbreak. Future research should focus on understanding the tradeoff between implementing different biosecurity levels and reducing the economic effect of an outbreak in a location like the one used in this study. Previous literature indicates that industry is better off having higher biosecurity standards to prevent a disease outbreak. Prevention is the best weapon to protect us against any future disease outbreak. Even though the unknown probabilities of an outbreak will always be there, good biosecurity practices will help reduce these probabilities.

5.2 Limitations:

HPAI is a very challenging disease; having a full understanding of how it will behave across a location at a time can be difficult. As such modeling an outbreak and how it will spread spatially is a challenge. Ultimately, the poultry industry does not know exactly when an outbreak will occur, where it will happen, or how many birds will be affected; therefore, it is very complicated to predict the economic effect of a HPAI outbreak.

Another limitation of this study was that a fundamental assumption was that an outbreak will infect each house in a 10-km area of the initial simulated infection and those locations will have a 100 percent mortality. This assumption was made because we didn't have reliable information about the probabilities of an outbreak infecting different houses and how that probability would change based on the type of production; therefore, we assumed the worst-case scenario based on the information we had available.

An additional limitation was that this study did not take into consideration the trade implications of the simulated outbreak. Large losses could be incurred by the industry because export of non-infected healthy birds would face trade restrictions as a result of an outbreak. Such analysis would require a more in-depth investigation of the simulated outbreak. Furthermore, a cost-benefit analysis of the effects of implementing different biosecurity levels across all the poultry houses in Washington and Benton counties would contribute to the understanding of what could be done to reduce the probabilities of an HPAI outbreak in the future.

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Appendices

APPENDIX A

HPAI Biosecurity Checklist

Premises

- A comprehensive biosecurity plan has been implemented and shared with all employees.
- Signs warning people not to enter the farm or any of its buildings because of disease control (No Admittance Biosecurity Zone) are posted at all entrances.
- External entrances to poultry houses are kept locked during nonbusiness hours.
- Houses are bird-proofed against wild or free- flying birds.
- Procedures are in place to prevent the accidental entrance of wildlife and to remove them from poultry houses and other areas should they gain entrance. More often if the footbath collects dirt, egg contents, or manure.
- Hand washing or hand-sanitizing stations are available at entrances.
- Equipment and tools brought to the farm are thoroughly cleaned and disinfected prior to use.
- Chicken transport equipment (carts, loaders, ramps) is cleaned and disinfected prior to use.
- For egg-laying facilities, only clean, sanitized, and disinfected plastic egg flats or new disposable egg flats are allowed on the premises.
- Cleaned and disinfected equipment is held under conditions that prevent exposure to wild birds.

Personnel

- Everyone is required to clean and disinfect their footwear or wear site-provided footwear or footwear covers prior to entering chicken houses, processing areas, and of office areas.
- Everyone is required to wash/sanitize their hands before entering and after leaving poultry houses and processing areas.
- Employees receive biosecurity training when hired, and annually after that. Records of biosecurity training should be kept up to date.
- Farm policy requires that employees do not own other birds—including pet birds, domestic chickens, fighting chickens, ducks, geese, waterfowl, exotic birds, quail, partridge, or pheasants.
- Backyard poultry are prohibited from the premises. o Dogs and cats are not allowed in chicken houses and egg processing areas.
- Feed bins are secured to prevent contamination by wild birds or rodents, and spilled feed is cleaned up promptly to prevent attracting wild birds and rodents.
- Water is drawn from secure sources that cannot be accessed by free- flying birds or rodents.

Equipment

- Footwear disinfection stations, site-provided footwear, or site-provided foot covers are available outside all external entrances. If footbaths are used, they must be changed at least daily or
- Employees sign a document when hired and during annual biosecurity training sessions stating that they will avoid contact with other birds not owned by the business. Employees should not be shared between operations.

- In the event that contact is made with other birds, employees agree that they will comply with a 2-day waiting period prior to any entry into any portion of the farm to include the barns, processing plant, and office.
- Farm policy prohibits exposure to equipment from other farms that has not been washed and disinfected.
- Farm policy requires personnel who have visited a rendering plant to shower and change clothes before entering the farm or any of its buildings.
- Spent hen removal crews are prohibited from entering other chicken houses or egg processing areas.

Visitors

- Visitors do not enter chicken houses unless absolutely necessary.
- Visitors Logbook records the (a) visitor's name, (b) company, (c) time of entry, (d) statement confirming no contact with premises containing birds or rendering activities during the preceding 2 days, (e) time of leaving, and (f) a contact telephone number.
- Visitors and contractors who have had contact with birds during the preceding 2 days are prohibited from entering chicken houses or egg processing areas.
- Clean coveralls (or disposable suits), disinfected boots (or shoe covers), and hairnets are available and required for visitors and contractors to wear before entering barns, egg processing areas, or other work areas.

Vehicles

- All vehicles that have traveled to a location where other birds are present—even the feed store—are cleaned and disinfected before entering the premises.
- If drivers are required to make multiple stops at more than one individual farm in any given day, they are prohibited from entering chicken houses or egg processing areas.
- Farm policy requires cleaning and disinfection of vehicles and containers from a rendering plant before they enter an egg layer premises.
- Manure trucks never go from one poultry farm to another on the same day. However, if required, the manure trucks must be washed with detergent and disinfected prior to arrival at the next farm.

APPENDIX B

Broiler Estimation

Broiler Estimation

- The value estimation will be for 1 flock of broilers
- Market wt. is 5.21 lbs. – *Source: AgriStats Avg. for Region 52*
- Grower paid per lb. of live wt.= 0.0659 – *Source: AgriStats Avg. for Region 52*

COMPANY GROSS REVENUE

1. Total Number of houses = **5 houses**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

2. Total Number of farms = **1 farm**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

3. Birds placed per farm = **107,642**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

4. % mortality = ***4.20 %***

   Source: 2014 Year Summary AgriStats

5. Total number of birds = **103,121**

   (Birds placed * % mortality) = (107,642 * .0420) = 4,520 (Mortality)

   Total number of birds loss = (107,642 – 4,520) = **103,121**

6. Total number of live lbs. of meat = (103,121 * 2.6) = **268,114.60**
7. Total number of POSSIBLE live lbs. of meat = (103,121 * 5.2) = **536,229.20**
8. WOG % = 75%

   Source: University of Arkansas Poultry Science Professor

9. Total number of POSSIBLE WOG lbs. of meat = (536,229.20 * .75) = **402,171.75**
10. Market value = **$ .8403 cents per lb.**

    Source: USDA Broilers Market News Report Vol. 63 No. 28 (7/15/2016)

11. Value per Farm at 42 days = (402,171.75 * .8403) = **$ 337,944.92**
12. Value per House at 42 days = (402,171.75 * .8403) / 5 = **$ 67,588.98**

POULTRY GROWER GROSS REVENUE

13. Value per farm at 42 days (payments) = (536,229.20 * 0.0659) = **$ 35,337.50**
14. Value per farm at 42 days (litter) = 150 tons per house * $15 per ton = $**11,250**
    Source: University of Arkansas Poultry Science Professor – UofA Savoy Research Farm
15. Total revenue per farm at 42 days (payments + litter) = **$ 46,587.5**
16. Total revenue per house at 42 days = 46,587.5 / 5 = **$ 9,317.5**

APPENDIX C

Broiler Breeder Pullets Value Estimates

Broiler Breeder Pullets Estimation

- The value estimation will be for one flock of pullets
- Eggs at 65 wks. = 161.2 - Source: AgriStats Avg. for Region 52
- Chicks at 65 weeks = 137 - Source: AgriStats Avg. for Region 52
- House Size = 16,000 sq. ft. – Source: Industry Standard Size
- Grower paid per sq. ft. = 0.045 - *Source: Poultry Industry Companies Weighted Average*
- Avg. pullet grower paid per good pullet per house at 25 weeks of age = $2.19
  Source: AgriStats

COMPANY GROSS REVENUE

1. Total Number of houses = **1.4 house**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

2. Total Number of farms = **1 farm**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

3. Total Birds placed per farm = **15,615**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

4. % male mortality = **10 %**

   % pullet mortality = **4 %**

   Source: 2014 Year Summary AgriStats

5. Total number of birds loss= (15,615 – 562 - 156) = **14,897**

   Female = (Birds placed * % mortality) = (14, 053 * .04) = 562(Mortality)

   Male = (Birds placed * % mortality) = (1,561 * .10) = 156 (Mortality)

   Total number of female birds loss= (14,053 – 562) = **13,491**

6. Hen mortality = **6.4%**
7. Total number of Hens = (mortality – Total number of female birds) = 863 – 13,491 = **12,627**
8. Total number of possible eggs loss = (12,627 * 161.2) = **2,035,472**
9. Total number of possible chicks loss = (12,627 * 137) = **1,729,899**
10. Total number of POSSIBLE live lbs. of meat = (1,657,244 * 5.2) = **8,617,668**

    (1,729,899 * .0420) = 72,655 (mortality)

Total number of broiler birds = (1,729,899 – 72,655) = **1,657,244**

11. WOG % = 75%

    Source: University of Arkansas Poultry Science Professor

12. Total number of POSSIBLE WOG lbs. of meat = (8,617,668 * .75) = **6,463,251**

13. Market value = **$ .8403 cents per lb.**

    Source: USDA Broilers Market News Report Vol. 63 No. 28 (7/15/2016)

14. Revenue per Farm for broilers at 42 days of age = (6,463,251* .8403) =

    $ 5,431,069.82

15. Revenue per House for broilers at 42 days of age = 5,431,069.82/ 1.4 =

    $ 3,879,614.65

POULTRY GROWER GROSS REVENUE

16. Revenue per farm at 20 wks. (payment) = **$29,545.29**

17. Weekly grower paid per farm (13,491 * 2.19) = **$29,545.29**

18. Revenue per house at 20 wks. (payment) (29,545.29 / 1.4) = **$21,103.77**

APPENDIX D

Broiler Breeders Value Estimates

Broiler Breeders Estimation

- The value estimation will be for one flock of pullets
- Eggs at 65 wks. = 161.2 - *Source: AgriStats Avg. for Region 52*
- Chicks at 65 weeks = 137 - *Source: AgriStats Avg. for Region 52*
- House Size = 16,000 sq. ft. – *Source: Industry Standard Size*
- Grower paid per doz. = 0.50 - *Source: Poultry Industry Companies Weighted Average*

COMPANY GROSS REVENUE

1. Total Number of houses = **2 house**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

2. Total Number of farms = **1 farm**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

3. Total Birds placed per farm = **15,047**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

4. % Male mortality = **24.8 %**

   % Hen mortality at 40 weeks = **4.4%**

   Source: 2014 Year Summary AgriStats

5. Total number of birds loss= (15,047 – 595 – 373) = **14,079**

   Female = (Birds placed * % mortality) = (13,542 * .044) = 595 (Mortality)

   Male = (Birds placed * % mortality) = (1,504 * .248) = 373 (Mortality)

   Total number of female birds loss = (13,542 – 595) = **12,947**

6. Total number of possible eggs loss = **2,087,056**

   (161.2*12,947) = 2,087,056 eggs. @42.5 wks.

7. Total number of possible chicks loss = **1,773,739**

   (137*12,947) = 1,773,739 chicks. @42.5 wks.

8. Total number of POSSIBLE live lbs. of meat = (1,699,242* 5.2) = **8,836,058**

   (1,773,739 * .0420) = 74,497 (mortality)

   Total number of broiler birds = (1,773,739– 74,497) = **1,699,242**

9. WOG % = 75%

Source: University of Arkansas Poultry Science Professor

10. Total number of POSSIBLE WOG lbs. of meat = (8,836,058* .75) = **6,627,043.8**
11. Market value = **$ .8403 per lb.**

    Source: USDA Broilers Market News Report Vol. 63 No. 28 (7/15/2016)

12. Gross revenue per Farm at 42 days = (6,627,043.8* .8403) = **$ 5,568,704.90**
13. Gross revenue per House at 42 days = (5,568,704.90/2) = **$ 2,784,352.45**

POULTRY GROWER GROSS REVENUE

14. Revenue per farm (payments) **= $86,482.48**

    (161.2) /12 = 13.43 doz. @42.5 wks.

    (13.43 *12,879) = 172,964.97 doz. @42.5 wks.

    (172,964.97 * 0.50) = **$ 86,482.48**

15. Total revenue per farm @42.5 wks. = **$86,482.48**
16. Total loss per house @42.5 wks. = (86,482.48/ 2) = **$43,241.24**

APPENDIX E

Turkey Value Estimates

Turkey Estimation

- The value estimate will be for 1 flock of TOMS
- Market wt. is lbs. 44.42 – *Source: AgriStats Avg. for Region 52*
- Grower paid per lb. of live wt.= 0.09 – *Source: Poultry Industry Companies Weighted Average*

COMPANY GROSS REVENUE

1. Total Number of houses = **3 houses**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services
2. Total Number of farms = **1 farm**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services
3. Birds placed per farm = **27,880**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services
4. % mortality (toms) = **15 %**

   Source: 2014 Year Summary AgriStats
5. Total number of birds loss =

   (Birds placed * % mortality) = (27,880* .15) = 4,182 (Mortality)

   Total number of birds loss = (27,880 – 4,182) = **23,698**
6. Total number of live lbs. of meat loss = (23,698 * 22.21) = **526,332.58**
7. Total number of POSSIBLE live lbs. of meat = (23,698* 44.42) = **1,052,665.16**
8. WOG % = 78.50%

   Source: Poultry Industry Companies Weighted Average
9. Total number of POSSIBLE WOG lbs. of meat = (1,052,665* .7850) = **826,342.025**
10. Market value = **$ 1.13 per lb.**

    Source: USDA Turkey Market News Report
11. Loss in gross revenue per Farm at 140 days = (826,342.025 * 1.13) = **$ 933,766.63**
12. Loss in gross revenue per House at 140 days = (826,342.025 * 1.13) / 3 = **$ 311,255.49**

POULTRY GROWER GROSS REVENUE

13. Loss in revenue per farm at 140 days (payments) = (1,052,665.16 * 0.09) = **$ 94,739.86**
14. Loss in revenue per farm at 140 days (litter) = (150 (tons of litter per house) * $15) *3 = **$6,750**

    Source: *Poultry Industry Companies*
15. Total Loss in revenue per farm at 140 days (payments + litter) = **$ 101,489.86**
16. Loss in revenue per house at 140 days = 101,489.86/ 3 = **$ 33,829.95**

APPENDIX F

Egg layers – Cage Free (Brown) Value Estimates

Egg layers – Cage Free (Brown) Estimation

- The value estimate will be for one flock of organic brown eggs w/o molting
- Eggs at 65 wks. (generic eggs) = 250 - *Source: AgriStats Avg. for Layers Pag: 4.8-2*
- Eggs at 65 wks. (organic eggs) = 236 - *Source: AgriStats Avg. for Layers Pag: 4.8-2*
- *House Size = 16,000 sq. ft. – Source: Industry Standard Size*
- Grower paid per doz. (generic eggs). = 0.21 - *Source: Poultry Industry Companies Weighted Average*
- Grower paid per doz. (organic eggs). = 0.24 - *Source: Poultry Industry Companies Weighted Average*

COMPANY GROSS REVENUE

1. Total Number of houses = **3 house**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

2. Total Number of farms = **1 farm**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

3. Total Birds placed per farm = **36,000**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services

4. % Hen mortality = **3%**

   Source: 2014 Year Summary AgriStats

5. Total number of birds loss = (36,000 – 1,080) = **34,920**

   Layers = (Birds placed * % mortality) = (36,000 * .03) = 1080 (Mortality)

6. Total number of possible eggs loss = **343,263.6 doz.**

   (236) /12 = 19.66 doz.

   (19.66 * 34,920) = 686,760 doz.

7. Market value = **$ 2.30 per doz.**

   Source: USDA egg market news report (10/28/2016)

8. Gross revenue per Farm at 65 weeks = (686,760 * 2.30) = **$ 1,579,548.00**

9. Gross revenue per House at 65 weeks = $ 789,506.28 / 3 = **$ 526,516.00**

POULTRY GROWER GROSS REVENUE

10. Revenue per farm @45 wks. (payments) = **$ 164,860.00**

    (236) /12 = 19.6 doz. @22.5 wks.

    (19.6 * 34,920) = 684,432 doz. @45 wks.

    (686,920 * 0.24) = **$ 164,860.00**

11. Total revenue per farm @45 wks. = **$164,860.00**

12. Revenue per house @45 wks. = (164,860.00/ 3) = **$54,953.33**

APPENDIX G

Egg layers – In Line (White) Production Value Estimates

Egg layers – In Line (White) Production Estimation

- The value estimet will be for one flock of generic white eggs w/o molting
- Eggs at 65 wks. (generic eggs) = 250 - *Source: AgriStats Avg. for Layers Pag: 4.8-2*
- Eggs at 65 wks. (organic eggs) = 236 - *Source: AgriStats Avg. for Layers Pag: 4.8-2*
- Grower paid per doz. (generic eggs). = 0.21 - *Source: Poultry Industry Companies Weighted Average*
- Grower paid per doz. (organic eggs). = 0.24 - *Source: Poultry Industry Companies Weighted Average*

COMPANY GROSS REVENUE

1. Total Number of houses = **8 house**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services
2. Total Number of farms = **1 farm**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services
3. Total Birds placed per farm = **800,000**

   Source: 2012 Census of Agriculture – County Data – USDA, National Agricultural Statistic Services
4. % Hen mortality = **3%**

   Source: 2014 Year Summary AgriStats
5. Total number of birds loss = (800,000 – 24,000) = **$776,000**

   Layers = (Birds placed * % mortality) = (800,000 * .03) = 24,000 (Mortality)
6. Total number of possible eggs loss = **16,164,080 doz.**

   (250) /12 = 20.83 doz.

   (20.83 * 776,000) = 16,164,080 doz.
7. Market value = **$ 0.435 per doz.**

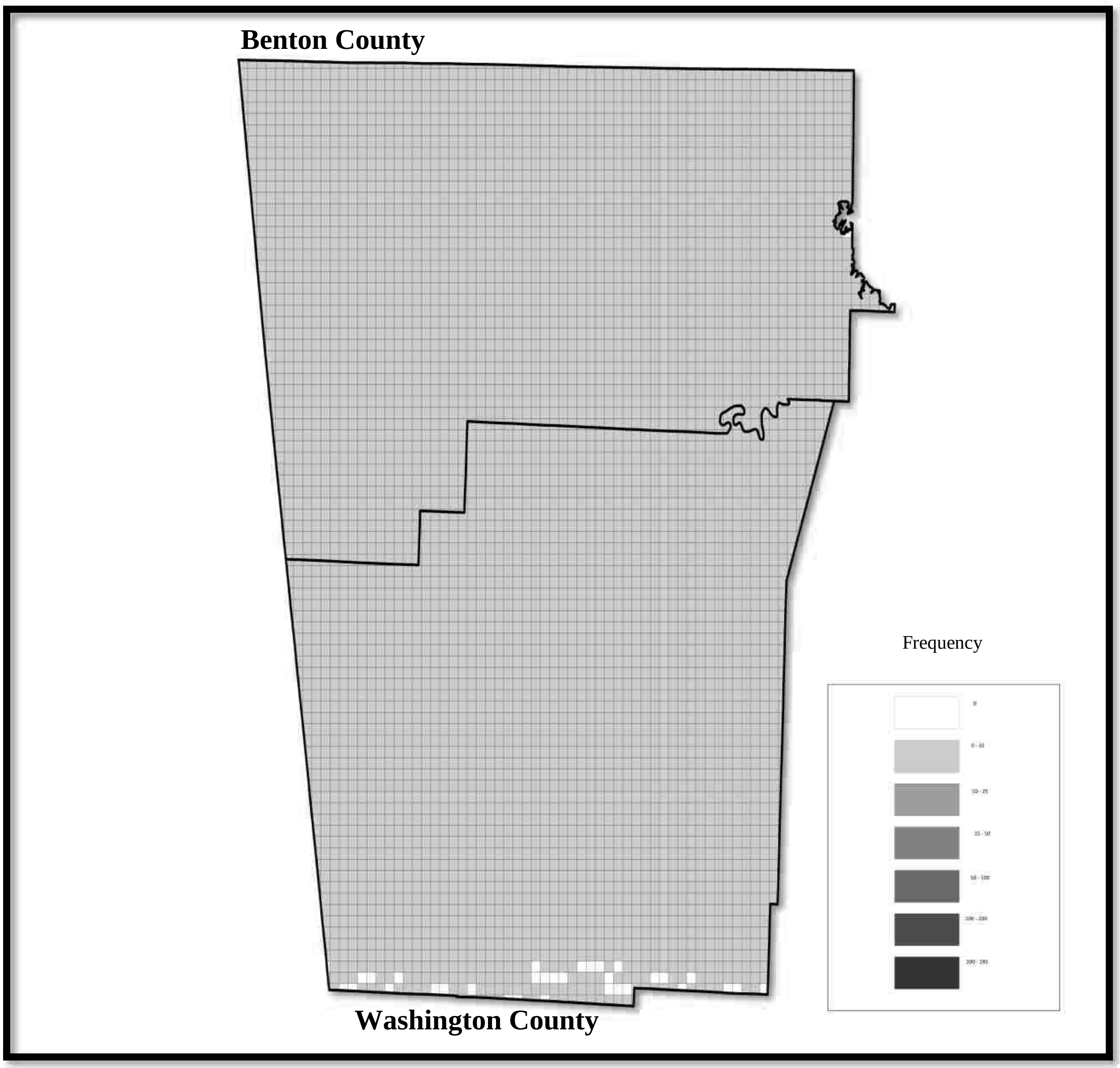
   Source: USDA egg market news report- Average prices on sales to volume buyers, delivered warehouse – Large eggs for South Central Region (10/28/2016)
8. Gross revenue per Farm at 65 weeks = (16,164,080 * .435) = **$ 7,031,374.8**
9. Gross revenue per House at 65 weeks = $ 7,031,274.8 / 8 = **$ 878,921.85**

APPENDIX H

Number of Brown Layers Houses at Risk

This figure doesn’t show as much spatial variability across both counties as previews figures do. We can conclude that's this is because there was not a high ratio of some brown layer houses in both counties in comparison to the other production types; therefore, the houses at risk is relatively small.

Number of Brown Layers Houses at Risk of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.



APPENDIX I

Amount of Money at Stake for Brown Layers

This figure shows the same trend as we saw in Figure 30. The sum of money at stake is not broad enough to show any spatial variability across both counties.

Amount of Money at Stake for Brown Layers of a HPAI Outbreak, In Benton and Washington Counties, Arkansas.