Rift Valley Fever: An Economic Assessment of Agricultural and Human Vulnerability

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Abstract

This research focused on the assessment of the U.S. agricultural sector and human vulnerability to a Rift Valley Fever (RVF) outbreak and the implications of a select set of alternative disease control strategies. Livestock impact assessment is done by using an integrated epidemic/economic model to examine the extent of RVF spread in the Southeast Texas livestock population and its consequences plus the outcome of implementing two different control strategies: emergency vaccination and larvicide vector control separately plus when they are used simultaneously. Human impact assessment utilized an inferential procedure, which comprises of a cost of illness calculation to assess the dollar cost of human illnesses and deaths, as well as a Disability Adjusted Life Year calculation to give an estimate of the burden of disease on public health as a whole. Results indicate substantial potential losses to the U.S., where combined livestock and human national costs ranged from $121 million to $2.3 billion.

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Risks of foreign animal or zoonotic disease outbreak are high today and may be rising for several reasons such as: increased international trade and travel; population growth; changing patterns of human–animal contact; increased demand for animal protein; increased wealth; environmental changes; and human encroachment on farm land and previously undisturbed wildlife habitat (IOM-NRC, 2008). Disease outbreaks can cause substantial economic losses to the agricultural sector (as reviewed in Elbakidze et al. (2009), Hagerman (2009), and Junker et al. (2008)) and may disrupt agricultural commodity markets. Zoonotic diseases, such as Rift Valley Fever, can spread from animals to humans and vice versa raising an additional dimension of vulnerability- human health. This paper focuses on the economic assessment of the agricultural and human vulnerability to a Rift Valley Fever (RVF) outbreak plus the value of alternative disease control strategies in reducing disease impacts.

Meltzer et al. (1999) estimated what the economic impact would be for the U.S. if an influenza pandemic were to occur and found costs ranging from US$71.3 to $166.5 billion. Attavanich et al. (2010) looked at the effects of the 2009 H1N1 outbreak and its media coverage on consumer demand and agriculture markets and found that roughly $156.5 million was lost in market revenue for lean hogs alone. Therefore, in order to grasp the full economic impact of a zoonotic disease such as RVF, efforts must be made to value the impacts to both animals and humans.

The assessment involves examinations of livestock and human vulnerability. For the livestock assessment, an integrated epidemic/economic model is used to examine vulnerability and the effect of alternative control strategies in a case study region - Southeast Texas. Specifically, vaccination and larvicide for disease intervention used both independently and jointly, are examined. For the human assessment an inferential procedure is used involving a Disability Adjusted Life Year (DALY) calculation on public health cost. Information from West Nile Virus (WNV), another vector-borne disease that has been observed in the U.S., is used to infer disease spread.

1 DISEASE BACKGROUND

Rift Valley Fever is a vector-borne zoonotic disease which was first identified in Kenya in 1931. It is currently confined to the African continent and the Arabian Peninsula. RVF mainly affects humans, sheep, cattle and goats. In infected livestock, the main symptoms are pregnant female abortions and young animal mortality. Human infection may result in hemorrhagic fever among other illnesses (CDC 2010). The two main carriers or vectors of RVF are *Aedes* and *Culex* mosquitoes although other mosquito types and biting insects can also transmit the disease (Martin et al. 2008).

Historically, outbreaks of RVF have been strongly correlated with heavy rainfall in drier areas. This is most likely related to the fact that the disease is vertically transmitted by mosquitoes with drought resistant eggs that hatch under flooding (Peters and Linthicum 1994). This is why Southeast Texas was chosen for the case study as the conditions match.

The virus has become endemic in a number of countries, indicating that an outbreak in a disease-free country may also lead to RVF becoming endemic. For this reason, as well as others, RVF is viewed as a major disease threat to the United States.

2 Livestock Impact Analysis

Since there have been no U.S. outbreaks and U.S. production conditions are typically quite different from those in Africa, we will use a model to simulate a hypothetical outbreaks and then value the effects with an economic model.

2.1 Modeling Setup

The specific models being used are the RVF epidemic model developed by Gaff et al. (2007) and the Agricultural Sector Model (ASM) developed by McCarl and coworkers (as described in Adams et al. 2005).

2.1.1 Epidemic model

The epidemic model (Gaff et al. 2007) is a mathematical model for two populations of mosquito species, one that can transmit vertically and one that cannot, and for one livestock population. The two populations of mosquitoes assumed to be viable transmission vectors are *Aedes* and *Culex* mosquitoes. The *Aedes* mosquitoes become a carrier of the virus through either vertical transmission (parent was a carrier) or via feeding on an infected host. The *Culex* mosquito only transmits by feeding on infected hosts. In turn, the disease is transmitted by feeding on livestock. Once infectious, mosquitoes remain infectious for the remainder of their lifespan. The livestock fed upon then die or recover having lifelong immunity from re-infection. This model is the template used to create a simpler Monte Carlo simulation to estimate disease impact across a large number of scenarios. The simulation provides a good estimate of an outbreak for relative assessment of various regions, inputs or interventions. This simulation was created by Hartley et al. (2009).

2.1.2 Economic Model

The economic model is the ASM component of the Forest and Agricultural Sector Optimization Model (FASOM) which is a dynamic, nonlinear programming model of the forest and agricultural sectors in the United States, originally developed to evaluate the welfare and market impacts of alternative policies and documented in Adams et al. (2005). The ASM is a partial equilibrium agricultural sector model that endogenizes market prices as documented in Adams et al. (2005). The model depicts the allocation of land, over time, to competing activities in both the forest and agricultural sectors and is also designed to aid in the appraisal of a wider range of forest and agricultural sector policies. The modeling system of FASOM is designed to work on the forest and/or agricultural sectors either independently or simultaneously allowing for evaluation of independent sector issues, or across both sectors. This study examines only that of the agricultural sector.

Partial equilibrium models, like ASM, utilize sets of supply and demand relationships which recognize interdependencies between markets in the U.S. Through this model, there is ability to assess the direct and secondary effects of an animal disease outbreak by including not only initial prices and quantities, but price shifts as demand varies. This study will not directly vary the demand curves. However, there may be a shift in quantity demanded as the price adjusts in response to the supply shift.

The FASOM model is based on a joint, price-endogenous, market structure. Prices are endogenously determined given demand functions and supply processes. It simulates 36 primary crop and livestock commodities and 39 secondary commodities that compete for land, labor, and irrigation water at the regional level. Competition allows for simultaneous price determination in both sectors. Land use is capable of changing over time, and constraints on production possibilities can be relaxed, which is a valuable aspect when analyzing animal disease outbreaks which may become endemic.

Maximization of net present value of the sum of consumers' and producers' surplus for each sector allows the model to provide estimates of total welfare, as well as the distribution of welfare between producers and consumers as discussed in McCarl and Spreen (1980).

2.1.3 Model Integration

The integrated epidemic-economic model used is an extension of a previous RVF study done by Hartley et al. (2009). Outputs from the epidemic model are fed into the economic model. The epidemic model output will give a number of animals in each disease related state and is categorized as below.

- Young_Susceptible
- Adult_susceptible
- Pregnant_susceptile
- Young_Infected
- Young_dead

- Pregnant_Infected
- Pregnant_dead
- Abortions
- Adult_infected
- Adult_dead
- Young_vaccinated
- Pregnant_vaccinated
- Adult_vaccinated

These categories are used to alter the economic data for (1) cow/calf and (2) dairy operations.

In order to adjust the economic model to reflect the results from the epidemic model certain conversions of the data need to be made. Since budgets in the ASM are normalized as typical single animal budgets, the epidemic data in terms of head slaughtered, vaccinated, infected, culled and dead from the disease must also be normalized in terms of the proportions of the animals affected. This allows the impact of the outbreak to be spread evenly across the entire region reducing the per animal average production and cost. The cost increase reflects the costs of vaccination, carcass disposal, and culling. This study also incorporates a decrease in feed requirements as a result of loss of animals.

2.2 Case Study Region and Data

This study analyzes the economic impacts of a disease outbreak of RVF in Southeast Texas. This region was chosen under the assumption that it is vulnerable to a RVF outbreak due to several factors: 1) Similarity of the environment of the region to the areas in Africa where RVF now exists with high yearly rainfall, short cold period, prevalent swampy areas, 2) High livestock population with many cow/calf and beef operations, 3) High mosquito populations with many potential mosquito breeding sites;

4) Close proximity to the ocean and ports of entry and 5) High human population including the city of Houston.

To characterize the region we use cattle and herd size data collected from the National Agricultural Statistics Service (NASS 2010) for the Texas counties east of Interstate Highway 35 and south of Interstate Highway 10.

To avoid national security concerns and overcome missing regional data, regional cattle inventory data were plotted as a histogram and then smoothed to fit (using maximum likelihood estimation) a lognormal PDF[1]. Random draws were then taken to yield a representative sample of simulated county cattle inventories.

The disease spread model assumes that all cattle begin as "susceptible". The susceptible populations are those that are vulnerable to infection and death, this number is reduced under vaccination scenarios. Under vaccination we assume that 43.87% (arbitrarily chosen in the epidemic model from a range of 25%-75%) of each susceptible population is vaccinated resulting in a 33% reduction in infection, abortions and death. The epidemic is assumed to be confined to Texas, but state, regional, and national economic impacts will be evaluated.

2.2.1 Economic assumptions

The direct cost incurred as a result of an RVF outbreak is captured in our disease management cost estimates. Disease management cost is the number of animals infected times the cost per head of disease management. The disease management cost component consists of costs to clean and disinfect the premises plus the cost of surveillance. These costs are incurred under all scenarios. The vaccination scenario also includes the cost to vaccinate. The larvicide scenario includes the costs of the larvicides. The costs are based on a schedule that varies by the size of the herd, and are adapted

[1] The lognormal was chosen arbitrarily. However, the basic properties of the lognormal function reflect the characteristics of the cattle inventory data, namely that a few counties have zero or very few cattle while some counties have extremely high populations of cattle.

from Galli's (2009) cost estimates, adjusted for herd size specific to the regions in Texas for this study. All cost assumptions include cost of personnel, supplies, and equipment. The affected animals in the ASM were limited to cow/calf beef operations and dairy operations. Affected calves were limited to calves for slaughter, dairy calves, steer calves, and heifer calves.

- The cost of disposal for beef and dairy cattle were assumed to be a fixed cost of $50 each head.
- The cost of cleaning and disinfecting for beef and dairy cattle was assumed to be $37 and $23 per head, respectively.
- Vaccination costs for beef and dairy cattle were assumed to be $32 and $10 per head, respectively.
- Cost of surveillance the beef and dairy cattle were assumed to be $113 and $34 per head, respectively.
- Cost to apply larvicide at the 5% reduction rate was assumed to be $187 per head infected. We assumed a constant square mile coverage of 27.5 sq mi. To develop a per-head cost we divided this by the number of infected cattle under base practices.

Further assumptions were made regarding disposal and culling of infected animals. It was assumed that 100% of dead animals will be disposed of, while 50% of adult and pregnant infected animals will be disposed and 50% will be culled for disease management purposes. Seventy-five percent of young infected animals will be disposed of for disease management purposes. We assume that the RVF outbreak results in a short term shock in production, but that no producers will exit the market as a result; therefore, replacement heifer populations are adjusted as well. The population of potential replacement heifers is reduced by abortions, young heifer deaths and pregnant cow deaths as well as those young heifer cattle that are culled or disposed of due to infection. Outside of the reduced replacements, cow/calf budgets also need to be reduced directly by non-pregnant adult deaths, young deaths, abortions, pregnant adult deaths, and infected animals that are culled or disposed of. Dairy cattle are treated similarly. There will also be a reduced milk supply by abortions, young deaths, pregnant cow deaths as well as young cattle culled or disposed due to infection. Only those animals culled due to abortion are assumed to increase meat sale. Labor requirements are also decreased by .04 times the number of infected animals to better simulate the conditions under an outbreak. With fewer animals in the region due to abortions, death and culling of infected animals, fewer labor hours would be needed due to smaller herd numbers.

All feed budgets will be decreased by the number of dead animals and infected animals that are culled or disposed of for disease management purposes. The reason for this being simply that the demand for feed will be reduced due to a decrease in number of livestock; fewer animals will need to be fed and therefore less feed will be bought. This decrease in demand of feed in the infected region will result in an increase in the overall national supply of feed, which could lead to a change in price for the related feeds.

2.3 Case study set up

The epidemic model was used to simulate a base case and alternative control strategies. In particular, we modeled the effect of an outbreak under base practices, along with vaccination, larvicide, and vaccination and larvicide together, as compared to a base scenario of no disease. Specifically, four scenarios will be run

- Base practices. We simulate the disease spread with the control strategieslimited to culling and standard veterinary (called base below) practices.
- Vaccination of the herds plus the base practices. Specifically, we assume 43.87% of the herd is vaccinated resulting in a 33% reduction in infection, death and abortion.
- Larvicide applied to the vector population plus the base practices. Specifically, we assume that larvicide usage causes a 5% reduction in mosquito population.
- Vaccination and larvicide used together plus the base practices.

To start the epidemic we assume the virus was introduced into a randomly selected Texas county, and in turn the disease spread was stochastic based on the vector density. One thousand random draws were used and fed into the ASM.

2.4 Livestock Results

Detailed results for the integrated epidemic and economic modelling will first be presented. The cost of illness and DALY results will comprise the last part of this section.

2.4.1 Epidemic Model Results

The epidemic model yields results on animal losses by animal category and control scenario, which are used as input into the economic model. Summary statistics for the corresponding herd category under each scenario can be seen in Table 1. The control scenario with the most infections, deaths, and abortions is the base practices case. Each of the three more aggressive control strategies reduces the number of infections, deaths and abortions. The largest reduction in animal losses from the base practices is combining vaccination along with larvicide, which results in having less infection, abortions and death among the herd population. The strategy with the smallest reduction is the larvicide case and vaccination falls in between with much larger reductions than vaccination

Table 1. Summary Statistics for Number of Head Infected, Dead, or Aborted in 1000's, for RVF Outbreak with Base practices

	Base		With vaccination		With larvicide		With larv and vac	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
young_infected	4.1	4.0	2.7	2.7	3.9	3.9	2.7	2.6
young_dead	2.0	2.4	1.4	1.6	2.0	2.3	1.3	1.6
abortions	26.1	16.3	17.6	10.9	25.3	15.8	17.0	10.6
pregnant_dead	4.1	2.7	2.8	1.8	4.0	2.6	2.7	1.7
pregnant_infected	34.8	20.3	23.4	13.7	33.7	19.7	22.7	13.3
adult_infected	38.3	20.1	25.8	13.5	37.1	19.5	25.0	13.1
adult_dead	4.2	2.7	2.8	1.8	4.1	2.6	2.8	1.7

Economic Model Results

The epidemic model results were used to adjust the corresponding budgets in the ASM. This study restricts the outbreak to that of the Southwest and Southcentral region of the model. Since these regions contribute significantly to the national supply of livestock, the impacts in other regions may occur as a result of national price changes. This section will display the results of national welfare loss, as well as total livestock producer welfare and regional producer welfare effects of a RVF outbreak.

Total Welfare Loss Under Alternative Control Strategies

The total welfare loss results are presented in millions of 2004$ and can be seen in Table 2 and Figure 1. Base practices results in the lowest level of economic damages despite the fact that it results in the highest livestock damage, which indicates that the costs of these control strategies outweigh their benefits in terms of the value of reduced animal losses. The highest loss occurs under the larvicide control strategy, which is likely the direct result of the practice cost coupled with relatively low effectiveness (5%). Vaccination results in the lowest mean loss across the more aggressive control strategies; however, it has the highest median loss and a high standard deviation compared to the other control strategies. Thus, vaccination has the potential to result in a lower economic loss but there is a risk of high losses. The vaccination and larvicide combined strategy, which resulted in the smallest amount of livestock damages results in the second highest average economic damages, falling between vaccination and larvicide as might be expected. These results indicate that, under these particular control strategies, there is little opportunity to reduce national welfare damages. However, policy makers may not base decisions on the national welfare damages, rather the focus may shift to those strategies that provide the greatest chances of survivability to livestock producers.

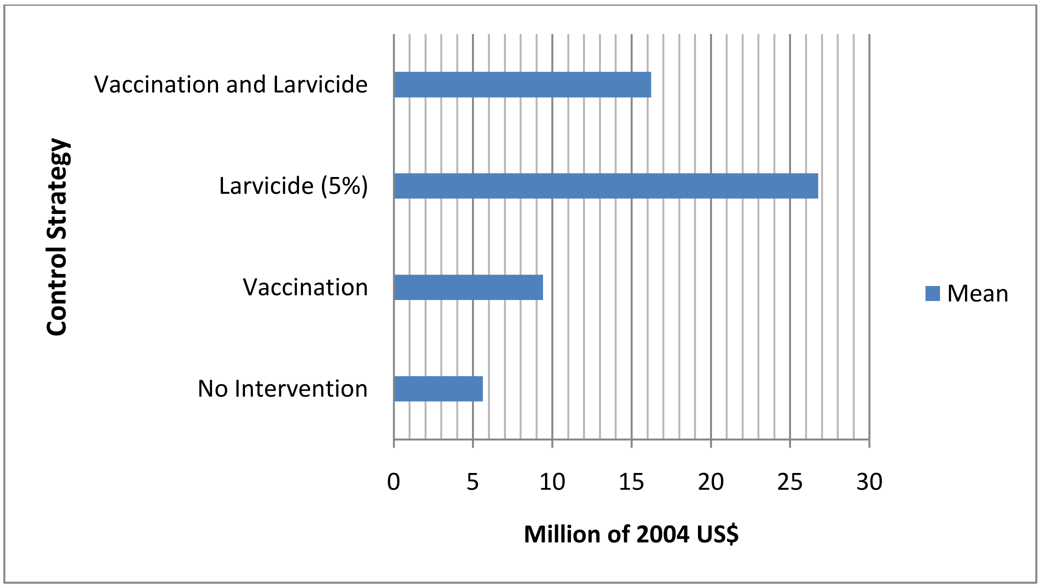

Figure 1. Graphical Representation of Total National Welfare Loss

Table 2. Total National Welfare Loss in Millions of 2004$

	Base practices	Vaccination	Larvicide (5%)	Vaccination and Larvicide
Mean	-5.61	-9.42	-26.76	-16.23
StDev	17.00	19.94	5.06	16.82

Regional Producer Surplus Impacts

The economic model divides the U.S. into 10 different production regions, which can be seen in **Error! Reference source not found.**2 below. With the U.S. livestock industry being concentrated in certain regions, such as the dairy regions in the Pacific Southwest, Lake States and Northeast or the concentrated beef feeding regions in the Southwest, Rocky Mountains and Great Plains, impacts of an animal disease outbreak will most likely have stronger impacts on some regions rather than others depending on the region in which it originates. For this reason, producer impacts are broken out by regions.

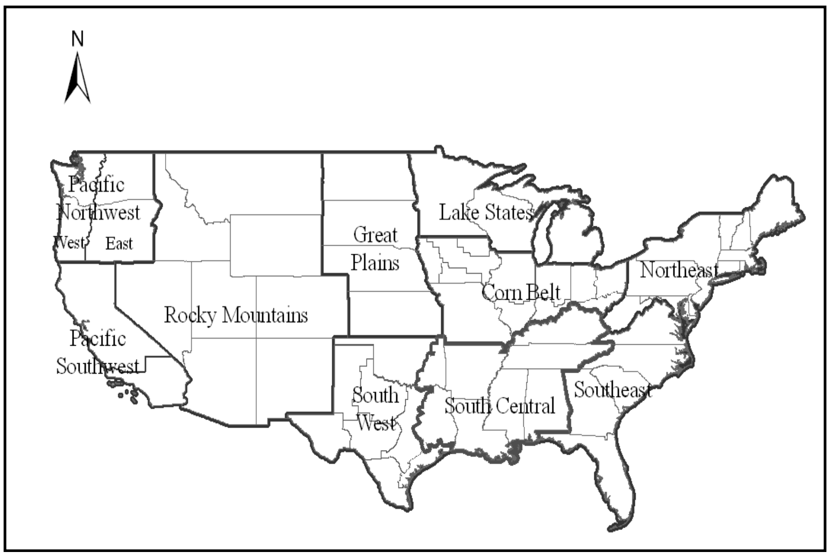

Figure 2. Regions in ASM Model

While there is an overall loss in welfare with each control strategy that exceeds the national loss in welfare from the base practices scenario, results indicate that under some conditions, producers in regions outside of the outbreak can gain due to price changes. Average results for regional producer (both crop and livestock producers) surplus impacts in both the infected and non-infected regions under the 4 scenarios can be seen in Figure 3 below. Detailed producer surplus loss for each of the 10 regions can be seen in the table given in the appendix. The two regions with the higher damages in each scenario are South Central (SC) and South West (SW), where the outbreak occurred. Although the overall national welfare experiences the least damages under the base practices scenario, the regions where the outbreak occurred (SC and SW) experience the most damages under this scenario. The least damages for the outbreak region occur under the vaccination and larvicide together scenario and vaccination alone scenario, for the SC and SW regions respectively, more in line with the results from the epidemic analysis. Under these two control strategies cattle prices increase and fewer animals are lost; therefore opportunities exist for other livestock producers to sell their animals at the higher price. Thus, the cost of investing in these control strategies may be beneficial for the producers in the infected region. However, these scenarios also result in higher damages to those producers outside the infected regions, and increases overall national welfare loss. Here the assumption has been made that producers will remain in operation after the outbreak has occurred; however, if policy makers wish to select a disease control program that offers the better chance of this occurring it may result in higher national losses due to the cost of implementing those control strategies.

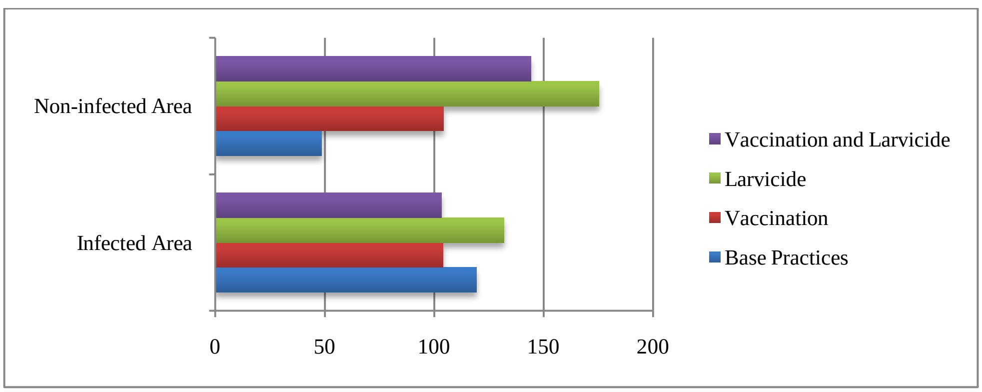

Figure 3. Infected and Non-infected Area Mean Producer Welfare Loss for All Scenarios in Millions

3 HUMAN VALUATION

To analyze the effect of a RVF outbreak on public health, we need to develop assumptions on the extent of the outbreak. However, there has never been a RVF outbreak in the U.S. The way humans interact with animals and are exposed to mosquito bites is different in the U.S. from that of the Arabian Peninsula and Africa as are animal slaughter procedures, which creates different degrees of potential disease exposure. Therefore, using data from human illness in Africa and applying it to U.S. human health estimators is inappropriate.

As a consequence this study uses spread data from the initial outbreak of 1999 West Nile Virus (WNV) to estimate human infections. Data from the CDC on costs of illness, deaths, and hospitalizations are then applied to assess the economic costs. More specifically the rate of infection we use will be that given in Nash et al. (2001) and the calculation of the cost utilizes the data given in Meltzer et al. (1999)

3.1 Employing the West Nile Virus Spread Data

WNV first originated in the U.S. in Queens County in 1999 and had spread to a total of 10 adjacent counties by 2000. We will apply this geographic spread rate to construct a potential human spread rate of RVF. A random outbreak county is chosen in the region of Texas used for the livestock outbreak simulation. To construct this outbreak we followed 3 basic steps:

Step 1. Assemble the infection rates from Nash et al. (2001) which can be seen in Appendix **Error! Reference source not found.**.

Step 2. Assemble data on the population in the study region from the U.S. census bureau.

Step 3. Apply the infection rates to the population yielding the infected population of 24.4, which can be seen below in Table 3.

Table 3. Number of Estimated Infected Persons in Corresponding Texas Counties

	Age group 0-17	Age group 18-65	Age group 65+	Total
Brazoria	0.10	0.85	0.56	1.51
Galveston	0.09	0.95	0.55	1.58
Matagorda	0.01	0.16	0.07	0.23
Harris	1.34	9.69	7.45	18.49
Fort Bend	0.17	1.08	1.06	2.31
Wharton	0.01	0.18	0.07	0.26
Total	1.72	12.92	9.77	24.4

3.2 Cost of Illness

To calculate the total cost of illness for the first year of a hypothetical outbreak, the number of hospitalized cases was rounded up to 25. The categorization of outcomes was as follows:

- Death
- Hospitalized
- Outpatient Visits
- Ill, but no medical care sought

For this study, we use the rates of underreporting given by the CDC for influenza to better estimate total human vulnerability. Each reported hospitalized case represents 2.7 unreported hospitalized cases of which one percent results in death. Each case of infection also represents a certain number of illnesses that go unreported. Estimates were made under four different levels of underreporting of infection (non-hospitalized) cases. This means for each reported hospitalized case there are 10, 20, 50 or 80 unreported hospitalized cases.

The number of reported cases was varied from 25 to 6,000. These different levels reflect possibilities for the reportedly more virulent character of RVF (see Gay et al. 2006 for discussion) as WNV reached a total of 9,862 reported cases in 2003. The assumed number of hospitalized cases are reported in Table 4. The dollar cost for each case is computed by using the estimated cost per case from Meltzer et al. (1999), for each category and each age group (Appendix **Error! Reference source not found.**).

Table 4. Reported and Unreported Hospitalized Cases

Reported	Unreported	Total
25	43	68
625	1,063	1,688
2,000	3,400	5,400
6,000	10,200	16,200

The cost of the outbreak was computed using the DALY concept which is global measure of disease burden (WHO, 2010). One DALY can be thought of as one lost year of healthy life. It is calculated as the number of Years of Life Lost (YLL) plus the number of Years of Life lost due to Disability (YLD) where

$$DALY = YLL + YLD$$

where

YLL = N x L

N = Number of deaths

L = Life expectancy at age of death

YLD = I x DW x L

I = Number of incident cases

DW = Disability weight

L = Average duration of case until remission or death in years

Average life expectancy was taken from the Internal Revenue Service (IRS). The average number of deaths and number of incident cases were taken from Table 5. Since

RVF does not have a unique disability weight[2], the disability weight for dengue fever and dengue hemorrhagic fever are used which are 0.197 and 0.545 respectively. Since the average duration of illness under RVF is 3-7 days (WHO) we used 5 days and divided by 365 to get on a scale of years.

Cost of Illness Results

The cost of illness results for the alternative cases was reported with alternative numbers of unreported cases (10, 20, 50, or 80 per reported case) as can be seen in Table 5 below.

Table 5. Cost of Illness for alternative numbers of cases in Million $

	Cases				
	25	**625**	**2000**	**3000**	**6000**
1 to 10	4.47	114.50	366.41	549.62	1,099.23
1 to 20	5.14	131.66	421.31	631.96	1,263.92
1 to 50	7.15	183.12	409.79	878.99	1,757.99
1 to 80	9.16	234.59	750.69	1,126.03	2,252.06

If RVF were to be introduced into the U.S. and follow the path of WNV, which reached over 9,000 reported cases in 2003, economic damages can be expected to be in the billions. The results for the reported cases of 6,000 with a low estimate of total cases shows a total cost of $1.1 billion while the high estimate shows a total cost of $2.3 billion.

Disability Adjusted Life Years Results

The results from the Disability Adjusted Life Years (DALYs) can be seen in Table 6 below. As would be expected, the DALYs increase as number of cases increase. With a number of reported cases equal to 25, the total number of DALYs lost is 297. As this

[2] A disability weight is a weight factor that reflects the severity of a disease on a scale from 0 (perfect health) to 1 (equivalent to death). It quantifies judgments on overall health at different health states, it does not quantify or value the quality of life or the value of live.

number increases, or as the virus spreads throughout the country to a number of reported cases equal to 6000, the total number of DALYs lost is equal to 71,216.

Table 6. DALY Results

Number of Cases	DALY
25	297
625	7418
2000	23739
6000	71216

As stated by Meltzer (2010), one of the more important components of a DALY is the YLL value, the value that shows how many deaths and to which age group they belong. Another important factor when dealing with public health issues and disease outbreak is who is going to get sick and how many. **Error! Reference source not found.** gives a breakdown of the number of hospitalizations, sick, dead, YLL, and YLD for the given three age groups (under 18, between 18 and 65, and 65+). As the table shows, those aged between 18 and 65 have the most cases of hospitalization, sickness, and deaths. The most YLL occurs for those under age 18, seeing as how the younger population would have a greater number of life expectancy, with more to lose in this parameter.

Table 7. Breakdown of Case Severity and YLL by Age Group

Number of Cases = 25	Hospitalized	Sick	Dead	YLD	YLL
under 18	24	6,305	0.876	17	129
18< x <65	37	9,819	1.364	27	115
above 65	7	1,876	0.261	5	4
Number of Cases = 625					
under 18	591	157,635	22	427	3231
18< x <65	921	245,475	34	666	2863
above 65	176	46,890	7	127	105
Number of Cases = 2000					
under 18	1,892	504,432	70	1368	10338
18< x <65	2,946	785,520	109	2130	9160
above 65	563	150,048	21	407	336
Number of Cases = 6000					
under 18	5,675	1,513,296	210	4103	31014
18< x <65	8,837	2,356,560	327	6389	27481
above 65	1,688	450,144	63	1220	1009

4 CONCLUDING COMMENTS

Zoonotic disease outbreaks can cause economic losses for both livestock and humans. This study developed information on the potential livestock and human vulnerability to RVF. In addition, the economic implications for livestock of using a number of control strategies for RVF are examined.

Results indicate that a lower vulnerability in terms of the number of infected, aborted, and dead animals is achieved by coupling vaccination along with larvicide. On the cost side RVF results in a national welfare loss ranging from approximately $6 million to $26 million on average across scenarios examined. None of the control strategies examined here were successful in reducing the national welfare loss under base practices, indicating that the treatment costs exceeds the value of the reduced livestock damage vulnerability from the control strategies. Therefore, the strategy selected among these alternatives will depend on the policy makers' criteria for ranking strategies. If the ultimate goal is to reduce infections, abortions and deaths in the livestock population, then vaccination along with larvicide is the best answer. However, if the goal is to reduce economic impact, then selecting any of the three control strategies examined here does not offer significant benefit over standard culling and veterinary practices. .

Yet another alternative decision making criteria is to select that control strategy that offers that highest producer survivability by reducing losses in the region where infection occurs. The losses from the outbreak fall to livestock producers and processors, as consumer welfare is increased with each scenario due to a drop in prices of some commodities, and in some instances, an increase in supply as well. The highest livestock producer damages are seen in the regions of the outbreak, but other regions with significant livestock industries or feed grain production (such as the Corn Belt, Lake States, and Southeast regions) also see high damages due to price changes. Vaccination and vaccination plus larvicide result in lower infected regional producer surplus losses than in the base practices scenario, indicating potential benefits in terms of producer survivability but at the cost of greater national welfare losses.

In terms of the public health sector the costs are higher. Results indicate that the age group most affected by an outbreak would be those aged 18-65. Since we do not have RVF infection rates for humans, this is due to the fact that this age group makes up the highest percentage of population in the selected outbreak region.

Combining total loss estimates from the cost of illness and ASM models, potential damage of a RVF outbreak could range from $121 million to $2.3 billion. The results of this study show the economic damages of an outbreak in year one to be roughly three times greater in the livestock population relative to the human population. It should be pointed out that both cost estimates are most likely under estimated. The animal outbreak is not incorporating all susceptible livestock (e.g. hogs and goats), and the human illness is not incorporating other damages to society (e.g. damages due to loss of tourism).

This study could be extended by using an appropriate human disease spread model plus consideration of species other than cattle, as well as control strategies for both public health and agriculture sectors. Future follow up research could also incorporate demand issues including domestic beef demand reduction based on food safety concerns and trade bans.

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Data Appendix

Table 8. Infection Rate of WNV Per Million Population Adapted from Nash et al. 2001

Age	Rate of Infection per million pop
0-17	0.9
18-59	3.425
60+	30.8

Table 9. Regional Producer Surplus Loss in Millions

	Base practices	Vaccination	Larvicide	Vaccination and Larvicide
CB	-11.619	-34.777	-41.459	-36.633
GP	24.720	8.187	0.192	7.193
LS	-11.314	-27.510	-52.212	-51.027
NE	2.062	-0.056	-3.995	-1.949
RM	-3.476	3.941	-10.741	-4.367
PSW	0.748	0.728	-0.342	0.587
PNWE	-4.187	-3.907	-7.633	-6.581
SC	-96.039	-84.643	-104.916	-81.001
SE	-45.649	-50.891	-59.192	-51.406
SW	-23.317	-19.412	-26.990	-22.405

Table 10. Values Used to Calculate Cost of Illness 2010 US$ adapted from Meltzer 1999

		Age group	
	0-19	20-64	65+
Deaths			
avg. age	9	35	74
PV lost earning($)	1,016,101	1,037,673	65,837
hosp. cost($)	3,435±2,632	7,605±3,888	8,309±3,692
subtotal($)	1,019,536	1,045,278	74,146
Hospitalizations			
hosp. cost($)	2,936±2,099	6,016±2,086	6,856±3,200
net pay for outpatient visit($)	74±40	94±70	102±60
avg. copayment for outpatient($)	5	4	4
net payment for drug claims($)	26±9	42±30	41±10
days lost	5±2.7	8±4.8	10±5.4
value of 1 day lost($)	65	100	or
subtotal($)	3,366	6,842	7,653
Outpatient visits			
avg. no. visits	1.52	1.52	1.52
net payment per visit($)	49±13	38±12	50±16
avg. copayment for outpatient visit($)	5	4	4
net payment per prescription($)	25±18	36±27	36±22
avg. prescriptions per visit	0.9	1.8	1.4
avg. copayment per prescription($)	3	3	3
days lost	3	2	5
value 1 day lost($)	65	100	65
subtotal($)	300	330	458
Ill, no medical care sought			
Days lost	3	2	5
Value 1 day lost($)	65	100	65
over-the-counter drugs($)	2	2	2
subtotal($)	197	202	327