Modeling Catastrophic Weather Events and the Risks of Animal Waste Spills in the Coastal Plain of North Carolina *

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Paper Prepared for 2004 AAEA Meetings

August 2-4, 2004

Abstract

This paper considers probabilistic models of hurricane-induced animal waste lagoon failures in North Carolina. A substantial number of waste lagoons exist in areas prone to hurricane damages. We evaluate expected losses which represent actuarially-fair insurance premium rates for a plan that would indemnify producers against damages from lagoon failures. Our results imply annual premiums ranging from under $100 per year to over $2,062 per year. An interesting result is that those areas with the highest levels of expected loss are also those areas with the greatest concentration of waste lagoons.

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1 Introduction

One of the most serious concerns facing North Carolina agriculture is the ever-present threat of livestock waste spills and lagoon failures. Nationally, about 40 waste lagoons overflow each year. In 1999, Hurricane Floyd brought high winds, torrential rains and extensive flooding to the Eastern Coastal Plain of North Carolina. As a result of the hurricane, more than 30,000 hogs, 2.5 million poultry, and hundreds of cattle were killed. Perhaps of even greater concern was the extensive flooding of waste lagoons that caused manure and other animal wastes to spill into local waterways. The storm resulted in the failure of at least 46 animal waste lagoons in North Carolina, some of which were several acres in size. The result was the release of millions of gallons of effluent into floodwaters, leading to substantial contamination of tributaries of the Cape Fear, Neuse, and Tar Rivers. The industry as a whole produces an estimated 37 billion gallons of waste which is processed by lagoon systems (ABC News, 2001). A single lagoon failure may release in excess of 25 million gallons of concentrated feces and urine (Mallin, 2000).

Although accidental lagoon failures and waste spills are a concern in normal weather, the risks posed by hurricanes, which have been common in recent years in the Coastal Plain of North Carolina, are of particular concern. Hurricane Fran in 1996 resulted in the rupture or overflow of 22 animal waste lagoons in the state. In 1998, a more modest hurricane named Bonnie resulted in only a single major swine lagoon failure, though substantial concerns were raised regarding the increased spraying of effluent in an attempt to prevent lagoon failures.[1]

The legacy of Hurricanes Fran and Floyd was apparent in September of 2003 as Hurricane Isabel approached the coast of North Carolina. Livestock producers hurried to draw down waste lagoons and secure backup power sources as the storm approached. Considerable concern was voiced regarding the impending risks to open-air waste lagoons. Recent research by Mallin et al. (1999) and Mallin (2000) confirmed that major storms have undermined or destroyed lagoons

[1] Such spraying, although legal, is thought by some to be environmentally unsound. For a detailed discussion, see Mallin (2000).

and washed their contents along with spray-field nutrients into rivers and estuaries. His research also demonstrated that, even when swine lagoons do not overflow in a heavy rain, wastes washed from spray-fields can severely degrade nearby waters. As noted, an approaching storm may induce animal producers to increase their rate of spray application to prevent lagoon failures which, in itself, may be a substantial source of ground and surface water contamination.

Legislators and policy analysts have debated whether policy might be developed to enable better management of the risks to producers and society from animal waste spills. Some have argued that a fundamental flaw exists in state legislation that limits the extent of liability faced by producers with regard to the damages from spills. One recent article argues that the optimal market-based solution would involve a requirement that producers carry private liability insurance that would cover any damages that a spill on their farms would cause (Powers, 1997). Other proposals have included the establishment of a mandatory risk pool whereby producers would be taxed in accordance with their risks and potential damages from spills in order to form an indemnity fund that would be used to address the costs associated with any spills. As the 2000 Agricultural Risk Protection Act was debated, federal legislators discussed expanding the federal crop insurance program to include a subsidized plan that would indemnify producers against the liability associated with livestock waste spills. Such a proposal found limited support in light of its perceived potential for moral hazard—the concern being that producers may take less care in preventing spills if their liability is protected by subsidized insurance.

Although a moratorium exists on the introduction of new concentrated swine operations in North Carolina, the issue of animal waste management remains paramount. An inspection system, administered by the Department of Environmental and Natural Resources (DENR), is used in an attempt to identify spills and to assign penalties that reflect the costs to society associated with spill damages.[2]

The objective of this paper is to evaluate the potential for establishing an insurance or indemnity fund that would address the risks to animal producers in North Carolina from hurricane-related waste spills. To the extent that risks and damages can be adequately modeled, such a plan may have the potential for internalizing the costs associated with such spills to the producers themselves. To

[2]Discussions with Keith Larrick of the NC-DENR office indicated that fines and penalties are assessed at a level consistent with the perceived degree of damages resulting from the spill violation. Of course, the proper measurement of damages from such spill events is a very difficult task, both for regulators and for researchers.

the extent that legislators desire to encourage participation in a voluntary plan, premium subsidies could be considered. Of course, any such action results in a sharing of risks between producers and taxpayers and may thus engender distortions in agents' behavior. The results presented in this paper are preliminary and represent only a single phase of a larger effort. In particular, our focus is largely on modeling the risks associated with hurricane strikes. The association of hurricane strength (as represented by wind speed) with lagoon failure is represented by assumed functional relationships.[3] Expectations regarding the degree of damages brought about by a lagoon failure are represented using data collected from the fines and penalties assessed for waste spills in North Carolina between 2000 and 2003.

The plan of our paper is as follows. The next section discusses general policy and market issues associated with risk management schemes for environmental damages. The third section reviews issues pertaining to the modeling of hurricane strike probabilities and the design of insurance contracts. The fourth section uses data drawn from the National Hurricane Center's "HURRDAT" database of 152 years of Atlantic Basin storm tracks to model hurricane strike probabilities for North Carolina. These risk assessments are then used in conjunction with the fine and penalty data and assumptions regarding storm risks and lagoon failures to price the risk associated with hurricane strikes. The final section offers some concluding remarks.

2 Mechanisms for the Management of Environmental Risks

Environmental risk is risk to property or health caused by natural disasters, or by degradation in environmental assets. Coping with natural disasters is an ancient problem, and there are a wide variety of government disaster programs and commercial insurance products that indemnify against property losses. Concern with pollution risk is much more recent, and mechanisms to manage this risk have only developed in the last several decades. After some serious setbacks in the early 1980's, pollution liability insurance is emerging as a valuable tool in managing certain types of environmental risks.

Pollution liability is man-made. Standard insurance contracts cover property loss to the insured after an event occurs. Pollution damages oftentimes do not involve a loss of property or profits

[3] Ongoing research will focus on explicit modeling of hurricane strength and the risk of lagoon failure.

to the emitter. Instead, the damages are suffered by third-parties exposed to the environmental risk, or to the overall quality and functioning of natural resources. In response to a series of well-publicized toxic disasters such as the Love Canal in New York, a number of federal and state regulatory requirements were initiated in the 1970's and 1980's. For example, two of the more well-known federal acts passed at this time are the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund). The federal and state regulations use a variety of mechanisms to force polluters to internalize the social costs of their actions. Some impose statutory sanctions such as the system of fines used in this paper to calculate damages from an animal waste spill. They also establish standards of care that create environmental liability through the tort system. Within the United States the current liability for environmental damages is estimated to be approximately 20% of the total value of all property (Freeman and Kunreuther, 2002).

Insurance was envisaged as a tool to manage environmental liability from the beginning. Both the RCRA and Superfund require businesses dealing with hazardous waste to demonstrate financial responsibility for third party damages. Unless a firm can self-insure, the financial responsibility must be met by insurance (Katzman, 1988). Since standard commercial policies include a pollution exemption, the insurance requirement created by the host of new regulations created a gap in coverage. This gap was initially filled by Lloyd's of London who issued the first environmental liability policy in 1975 (Zagaski, 1992, pg. 392). The London market was followed by at least a dozen primary insurers who were offering pollution liability policies by 1983. However, at this time there was a great deal of uncertainty about the magnitude of losses from toxic torts. Court decisions were requiring insurers to pay for losses the policies were never intended to cover. There were also fundamental underwriting problems. Statistically valid information on the probability and magnitude of loss was unavailable. The combination of all these problems coupled with an overall loss of profitability in insurance caused the environmental insurance market to collapse in the mid 1980's. However, in the last 10 years the environmental insurance market has begun to rebuild as underwriters gained experience in pricing environmental policies and better data and modeling capabilities were developed. Total premium growth in the last decade has averaged in the double figures, and as of May 2000 total capacity in the environmental insurance market is in excess of $1 billion (Hannah, 2000).

The number and types of environmental insurance products has expanded continuously. One of the most successful is coverage for damages from accidental release of asbestos during abatement activities (Freeman and Kunreuther, 2002). A sampling of other products available include: contractors pollution liability, environmental and general liability exposures, cleanup cost caps, owners spill liability, and supplemental environmental auto liability (Bressler, 2002). There are also a number of products aimed at commercial lenders. These policies protect lenders from unforeseen expenses associated with loaning money to purchase and reclaim Brownfields Redevelopment (EPA). Finally, pilot experiments in Delaware and Pennsylvania are evaluating the effectiveness of preferential insurance rates in encouraging voluntary safety measures in ammonia and chlorine production.

Several of the commercial products currently available insure against events similar in nature to animal waste spills. Owners' spill liability and supplemental environmental auto liability provide coverage for bodily injury, property damage, and cleanup costs caused by pollution released from a transportation carrier. There is also an insurance product to indemnify petroleum distributors against damages from failure in underground storage tanks. Under current regulations owners of an underground storage tank are required to show the financial ability to cover the costs of corrective action as well as compensation for third party liability for accidental releases. In response to political pressure generated by predictions that 25% of all gas stations would go out of business if forced to purchase coverage from the private market, the EPA has allowed states to set up State Guarantee Funds that taxed gasoline sales to pay for ex post clean up costs. These funds have effectively barred the commercial spill liability insurance products from gaining wide acceptance (Freeman and Kunreuther, 1997).

Typically, mechanisms for managing natural disasters are developed and implemented independently from pollution risk. This separation is not possible on the coastal plain of North Carolina because the pollution risk from an animal waste spill is integrally related to catastrophic weather events. Hurricanes affect the probability of lagoon failure as well as the level of damages if a failure occurs. Risk management strategies must not only address the optimal mix of regulations and mechanisms for spreading risk as well as the catastrophe component. Given that politicians and society in general have strong motives to aid in disaster recovery it is difficult to impose stiff fines on swine producers already suffering from heavy hurricane losses. Current regulations completely exempt failures caused by severe storm events. While this may be the appropriate response after the fact, it causes problems by reducing the costs to producers of placing lagoons in areas exposed to hurricane risk. Insurance mechanisms require producers to pay a smaller fee before a hurricane occurs. The premium payments correspond to the polluter pays principle, which appeals to our sense of fairness and has been upheld in the tort system. In addition, by spreading the costs over time, and over a risk pool, insurance avoids placing undue hardships on producers at a time they are vulnerable to financial shocks.

3 Modeling and Pricing Hurricane-Induced Lagoon Failure Risks

The overall goal of our analysis is to obtain actuarially sound measures of the risks and expected losses associated with hurricane-triggered animal waste lagoon failures. Expected losses represent the actuarially fair premium that should be charged in order to provide indemnities in the event of a lagoon failure. Such premiums would be pertinent to any public or private liability insurance program whereby the insurer indemnifies livestock producers for any losses they incur as a result of fines or penalties for damages caused by a waste spill. Knowledge of the actuarially fair premium would also be important in determining the mandatory contribution rates that would face producers under an indemnification "check-off" type plan that taxed each producer in accordance with their risks and paid indemnities in the event of lagoon failures. To the extent that fines and penalties represent the true damages to society caused by spills, insurance plans and check-off programs provide one mechanism that serves to internalize the impact of the spills on producers.[4]

Agricultural insurance contracts are generally of two distinct types. The most common is "all-peril" or multiple-peril, meaning that any event that triggers a loss is indemnifiable. Of course, exceptions are generally made for losses that occur due to negligence or poor-management practices, though verification of such causes of loss often presents major obstacles to sound insurance plans. Almost all of the insurance provided by the Risk Management Agency of the USDA is of a multiple-peril type. A second form of insurance that is sometimes used to address risks in agriculture is a specific-peril plan, that covers losses resulting only from a specific cause. Hurricane insurance is one example of such a specific peril. Our analysis here applies to a specific-peril type of plan that

[4]The extent to which the fines represent actual damages is debatable. This is an important component of our larger research plan addressing the design of such risk management programs.

would cover only those losses triggered by a hurricane strike.

Abstracting from the costs associated with adminstration of an insurance program (including profits or returns to shareholders), the appropriate premium should be set at the level of expected loss under the terms of the coverage being offered. Expected loss is often expressed as the product of the probability of a loss and the expected level of loss, given that a loss occurs:

$$E(Loss) = Pr(Loss) \cdot E(Loss|Loss\ Occurs). \quad (1)$$

Thus, there are two components to the premium estimate—the probability of a loss and the expected level of loss when losses occur. The probability of a loss is determined by two components. Identification of the first component—the probability of a hurricane strike—is the primary focus of this paper. The second component concerns the probability that a lagoon fails, given the occurrence of a hurricane. Thus, for a storm of intensity i, expected loss is given by:

$$E(Loss_i) = Pr(Hurricane_i) \cdot Pr(Lagoon\ Failure|Hurricane_i\ Occurs) \cdot E(Loss|Loss\ Occurs). \quad (2)$$

A number of other issues are relevant to the design of an insurance contract. The term of the contract is one important consideration. Most contracts pertain to an annual basis for coverage–such that if one or more loss events occur over the space of a year, indemnities will be paid. In our case, the event triggering a loss is a hurricane and thus our risk models pertain to the damages associated with *one or more hurricane strikes* over the period of coverage. The Atlantic Basin hurricane season generally runs from June through November and thus annual coverage based on a calendar year is appropriate. Thus, we consider the risk of one or more hurricane strikes for a calendar year. Issues related to coinsurance and deductibles are also relevant to most insurance contracts. Coinsurance and deductibles force insured agents to bear a share of the risk and thus serve to inhibit claims for small losses or excessively frequent claims. In our case, insurance is based upon an entirely exogenous event—a hurricane strike. Agents are unable to affect the probability of such a strike and thus our simple premium measures do not account for deductibles or coinsurance, though the methods developed below are easily extendable to account for such contract provisions.

Equation (2) demonstrates that there are three primary components necessary to measure expected loss for the specific peril form of insurance being discussed here. First, one must have an accurate measure of the probability that a given location (e.g., a county) will experience a hurricane event. Second one must have an adequate understanding of the relationship between a hurricane event and the probability of failure for a waste lagoon. We abstract from differences in the design of lagoons and other idiosyncratic factors (e.g., soil type, management practices, age of lagoon, etc.) that may be related to failure risks.[5] Finally, one must be able to assess the expected fines or damages that result in the event of a spill. We address the identification of each aspect of the measurement of expected loss in the discussion that follows.

3.1 Measuring Hurricane Strike Probabilities

The primary focus of the research reported in this paper concerns our attention to measuring site-specific hurricane risks. To do so, we obtained the HURRDAT database from the National Hurricane Center. This database contains observations on the strength (wind speed), movement, barometric pressure, and precise location of each tropical cyclone taken at six hour intervals for each storm in the Atlantic Basin over the period covering 1851-2002. This database forms the basis for most if not all hurricane risk prediction models. Perhaps the best known of such models is the "HURISK" modeling system of Neumann (1987). The HURISK model uses Monte Carlo simulation methods that incorporate measures of wind speed, barometric pressure, and other important variables in assessing the likelihood of a hurricane strike of a particular intensity at a given site.

Our approach to measuring the probability of a hurricane strike is more straightforward in that we consider the frequency of strikes at any particular location over the 152 year period of data. Following the approach used in Neumann (1987), we consider a strike to occur when the center of a storm passes within a circle defined by a 75 nautical mile radius centered around the point of interest. Neumann (1987) notes that, when modeling hurricane return periods and strike probabilities, a distance of 75 nautical miles is a reasonable choice. We used spline interpolation to convert the location and wind-speed measurements into hourly observations over the life of each storm.[6]

To measure strike probabilities across the entire state of North Carolina, we constructed a grid of equally spaced points that ranged in increments of 0.2 degrees between 33.4 to 37.0 north latitude and 74.8 to 84.6 west longitude. The rectangular box defined by this grid encompasses

[5] Attention to such factors is a focus of current research.

[6] This interpolation is important in that a storm could move through an area of interest within a six hour period and thus not be observed to have passed through the area.

the entire state of North Carolina. For each point, a 75 nautical mile (great circle distance) area was considered and all storms of a given magnitude that passed through this circle were counted. Our goal is to assess annual probabilities of *one or more storm strikes* and thus we consider the number of years out of the 152 year period of data for which storm strikes were experienced. Strike probabilities were then given by the ratio of positive event years to 152.

As we discuss in greater detail below, we must tie different storm intensities into a variable probability of lagoon failure. To this end, we considered storm strikes within the following wind speed categories: 34-44 knots, 45-54 knots, . . . , 94-104 knots. A strike probability for each category of storm intensity was calculated. We used a monotonic spline (a quadratic spline restricted to be monotonic across differing storm intensities) to smooth the probabilities such that probabilities tended to fall monotonically as the storm intensity increased. An important point is that some storm events are never observed at certain points in the state. This is especially the case when one considers strong storm events at points away from the coastline. To address this issue, we extended the categories of storms out to a maximum of 144 knots. We assumed that the probability of a storm exceeding 144 knots was zero and then used linear interpolation between this point and the last positive probability to obtain measures of the probabilities between 144 knots and, for example, 94 knots (in a case where the empirical probability of a storm of 104 knots was zero).[7] These procedures provided a smooth set of strike probabilities based upon the observed frequencies of storms at each location. The strike probabilities decrease monotonically until reaching zero at 144 knots.

3.2 The Relationship Between Hurricane Intensity and Lagoon Failures

An important component of the expected loss associated with any waste spill liability plan involves the relationship between the intensity of a storm and the probability of a lagoon failing. In reality, the most critical storm factor associated with the failure of a waste lagoon is the amount of rainfall experienced at a point in space. Our focus in the preceding section was on wind speed as a measure of storm intensity. The relationship between wind speed, which is a standard indicator of the

[7] For example, suppose the empirical probability of a storm of 94 knots was 0.05 and no storm events of 104 knots or greater were ever observed. Linear interpolation between 0.005 at 94 knots and 0.0 at 144 knots implies probabilities of 0.004, 0.003, 0.002, and 0.001 for wind speeds of 104, 114, 124, and 134, respectively. This approach, while admittedly ad hoc, serves to approximate the probabilities associated with unlikely events that may not be observed to have occurred at a point over the span of available data.

intensity of a storm, and rain fall levels is certainly strong. However, other factors, including barometric pressure and the speed of movement of a storm are also likely to be relevant to the level of rainfall experienced at any particular location. Our current research is working to evaluate this relationship using weather prediction models and related research from the National Oceanic and Atmospheric Association (NOAA).

Our initial research is based upon an assumed relationship between storm intensity, as represented by wind speed, and the probability of lagoon failure. As noted above, we do not differentiate the likelihood of failure by lagoon type or other site-specific factors, though such refinements are an important topic for future research. To represent a functional relationship between hurricane strength (a storm of intensity i) and the probability of waste lagoon failure, the following logistic-type function was assumed:

$$prob(failure|storm_i) = \frac{1}{1 + \beta \exp(-\gamma_i)}, \tag{3}$$

where β was chosen to be 500 to represent a higher likelihood of failure and 1900 to represent a lower likelihood of failure (at a given wind speed) and γ is given by 0.1·(wind speed)-2.4. The hazard functions for the two alternative values of β are illustrated in Figure 1. It is important to again emphasize that this relationship is based purely on assumption at this point and that current efforts are working to refine and better quantify this relationship.

3.3 Measurement of Damages

A final important component of the expected loss associated with a waste lagoon spill is the level of damages expected from a spill. Put differently, we need to measure the expected level of damages, conditional on a spill occurring. To obtain such measures, we obtained unpublished fine and penalty data from the North Carolina Department of Environment and Natural Resources (DENR) for the period encompassing 2000-2003. These data contained all fines and penalties issued over this period for waste discharges and stream standard violations. Of a total of 212 fines, 108 pertained to spill events, with the remainder being associated with permit condition violations or certification violations. The fines had a mean value of \$7,910 and ranged from a low of \$1,935 to a high of \$58,015. A nonparametric kernel estimate of the distribution of fines is presented in Figure 2. For purposes of comparison, a log-normal distribution is also presented. It is interesting to note that the log-normal density closely resembles the nonparametric estimate, suggesting that future efforts may benefit from assuming log-normality when modeling damages.

Several points are relevant to our representation of fines and damages. First, our approach implicitly assumes that fines are set at a level that represents the extent of damages resulting from a waste spill. This assumption is based upon conversations with DENR personnel who have the task of assigning penalty levels for waste spills. Measurement of the overall costs to society of environmental damages is a complex and difficult task that merits additional investigation. However, the observed penalties are relevant to any plan that addresses only the risks to producers from fines and penalties, regardless of the extent to which these penalties represent actual costs.

It is also pertinent to note that no hurricane strikes (storms with winds in excess of 64 knots) occurred in North Carolina over the period from which the fine data were taken. Two points are salient. First, it may be that larger spills and thus larger damage estimates could have been experienced had this period realized hurricane strikes. However, it is also pertinent to note that the legislation governing the waste lagoon system in North Carolina provides exceptions to fines in penalties when severe hurricane conditions are experienced. In recognizing that our data do not include a period that experienced hurricanes, it is possible that our fine data understate the possible damages that may occur from a strike.[8] In an attempt to account for the possibility that larger damages may occur under conditions of a hurricane, we repeated our analysis under the assumption that the actual distribution was a mixture of what we have actually observed and a higher though less likely level of damages that is not observed in our data. To simulate such a case, we used a mixture distribution consisting of the log-normal that was fit to the existing data and a normal distribution with a mean damage level of $100,000 and a variance of 5,000. We chose a mixing parameter of 0.15, implying that the higher damage portion of the distribution is only experienced 15% of the time. This mixture distribution is also illustrated in Figure 2. In the case of the mixture distribution, the mean damage level rises to $21,498. Of course, there is no basis in fact for choosing this particular distribution and refinement of this aspect of our analysis is the topic of current research.

[8]For example, our data may represent farms that experienced a spill from a single lagoon while a hurricane strike could induce multiple lagoon failures on a single operation.

4 Empirical Application and Results

As we have discussed above, expected loss is a key parameter for any indemnification plan or insurance program that would address the risks associated with hurricane-triggered livestock waste spills. Our goal is to provide measures of expected loss that vary by county in accordance with differences in hurricane strike risks and intensities. Hurricanes generally lose strength once over land and thus the risks and potential for damages are much higher near the coast than in the interior regions of the state. In order to gauge overall hurricane strike probabilities, we considered the probabilities associated with one or more strikes per year from tropical storms that are of hurricane strength (i.e., of at least 64 knots in wind speed while within the 75 nautical mile great circle search radius).

A spatially smoothed illustration of the implied probabilities is presented in Figure 3.[9] Note the substantial increases in strike probabilities near the coast and the rapid decline in probabilities as one moves inland. The expected patterns of hurricane risk are apparent in the diagram, with the highest risks being realized on the barrier islands of the Outer Banks. Figure 4 adds the locations of animal waste lagoons to the illustration of hurricane strike probabilities. The figure illustrates the fact that many lagoons are located in areas that have substantial risks of hurricane strikes. This fact underlies the basic motivation for our study—waste lagoons in North Carolina are located in hurricane-prone regions. In particular, note that the waste lagoons are concentrated in counties that have a probability of experiencing a category 1 or stronger storm of about 15-20% per year.

In the preceding section, we outlined the calculation of expected loss for a storm of a given intensity. In order to obtain the overall expected loss from any indemnifiable event, we must consider expected loss across a range of loss categories (i.e., different storm strengths). We considered expected loss (as determined by the probability of a hurricane of given strength i, the probability of lagoon failure with such a storm, and the penalty/damage function.) across a range of different storm strengths. In particular, we considered storms in eight different wind speed categories: 34-43.9, 44-53.9, ..., 134-143.9 knots. Total expected loss is then given by:

$$E(Loss) = \sum_{i=1}^{8} E(Loss_i) \tag{4}$$

where $i = 1$ corresponds to the first wind speed category of 34-43.9 knots and so forth.

[9]Spatial smoothing was accomplished using the kriging methods of ArcView 8.2.

Using these methods, we estimated the expected loss associated with hurricane-induced waste spills for each county. This expected loss represents the actuarially-fair total premium that should be charged to indemnify an operation against the penalties and/or damages that would result from a lagoon failure and resulting waste spill. Such indemnification could result from a conventional voluntary (public or private) insurance program or a mandatory check-off fund. Recall that the expected loss figures depend upon a number of critical assumptions. In particular, we have assumed a relationship between the risk of a hurricane strike and the risk of lagoon failure. Perhaps of greater importance is the fact that we are representing expected losses resulting from a spill with the fines and penalties assessed to operations from spills over the 2000-2003 period.

Figure 5 illustrates expected losses for each county in North Carolina. Patterns of expected loss closely parallel those associated with strike probabilities. Expected loss is highest in the area that is within about 50 miles of the coast. Again, it is relevant to compare this to Figure 4 above, which illustrates the fact that lagoons tend to be located in the areas of highest expected loss. In these areas, expected loss exceeds $800 per year. Expected loss falls rapidly once one moves inland past the 50 mile band of high expected losses near the coast. By the time one moves to about 150 miles from the coast, expected losses fall to the lowest category, with values ranging from nearly zero to $300 per year.

In order to evaluate the sensitivity of expected loss to several of our assumptions, we present expected loss levels for the four counties having the most waste lagoons in North Carolina. Duplin county, the county with the most lagoons in the state, also has the highest expected loss per operation at $759 per year.[10] We see similarly high expected losses for Sampson county ($590 per year), Wayne county ($493 per year), and Bladen county ($721 per year).

We considered expected losses for alternative hazard function illustrated in Figure 1. Recall that this hazard function implied significantly lower probabilities of failure at a given wind speed. These are expected to be much smaller in that the assumed probabilities of failure are lower. As expected, the expected losses are much smaller than those that are obtained for the alternative hazard function. The substantial difference in the alternative expected loss estimates reflects the

[10]Note that there is no inherent or assumed relationship between the number of lagoons in a county and expected losses per operation. The important point is that areas with the highest concentration of lagoons are also areas with the highest expected losses due to lagoon failures. If lagoons were located with regard to the expected costs associated with failures, one would expect to see exactly the opposite result. Of course, other criteria obviously underlie the location decisions for livestock confined feeding operations.

significant sensitivity of the expected loss estimates to assumptions about the likelihood of lagoon failure under given storm conditions. This reinforces the importance of ongoing research to better quantify the relationship between storm strength and lagoon failure probabilities.

Recall that the penalty/damage data used to assess expected losses in the event of a spill were taken over a period (2000-2003) that did not experience a hurricane strike. We have argued that it may be possible that the damages realized by livestock operations may be substantially higher if a hurricane strike occurs. We considered expected losses generated from the mixture distribution described above. These estimates, denoted as Expected Loss 3 in Table 1, are considerably higher. This reflects the substantially higher expected damages in the event of a spill that are implied by the mixture distribution.

Finally, we have noted that the current legislation governing waste spills typically provides exceptions to any penalties in the event of a major storm.[11] To examine how expected loss may differ if spills that occur during major storms are exempt from penalties, we excluded those damages resulting from wind speeds that exceeded 104 knots. These estimates are only slightly below those obtained over the entire range of storm strengths. This reflects the simple fact that the probabilities assigned to such strong storm events are relatively low in most areas.

5 Concluding Remarks

This paper reports on our initial efforts to evaluate the potential for an insurance or indemnity program that would target the risks of animal waste lagoon failures under hurricanes in North Carolina. The focus of this segment of our analysis is on empirical estimation of hurricane strike probabilities. We utilize the "HURRDAT" database which contains historical hurricane records from 1851-2002. We use monotonically smoothed empirical probability estimates to represent hurricane strike probabilities for a spatial grid that covers the entire state of North Carolina. We calculated expected losses, which represent actuarially fair insurance premiums for coverage against the liability associated with lagoon failures, using assumed lagoon failure functions and historical data on fines and penalties assessed in response to lagoon failures. Future work will focus on improved quantification of damages. Likewise, current research efforts are being directed at an

[11] To be precise, spills that occur during a rain that exceeds a 25-year, 24-hour event will not result in penalties. A 25-year, 24-hour rain event is the maximum 24 hour rainfall that is expected to occur once in a 25 year period.

assessment of the relationship between hurricane strength, barometric pressure, storm progress, and lagoon failures.

One aspect of our results is especially striking, though not surprising. The regions of North Carolina that have the greatest expected losses from lagoon spills are also those regions where livestock waste lagoons are concentrated. If spill hazards played a major influence on the location of these lagoons, one would expect to observe just the opposite. We found that Duplin county, the county with the most waste lagoons, also happened to have the highest expected loss from hurricane-triggered lagoon failures. In particular, the expected loss ranged from $759 to $2,062 per year, depending on the hazard function adopted. If one moves only a short distance inland, these expected loss levels drop substantially to levels under $300 per year.

Current research is focusing on other issues associated with the design and implementation of lagoon spill risk management plans. In addition to the aforementioned needs for better estimates of damage and hazard functions, issues related to the potential interest on the part of producers and policy makers are relevant to our analysis. Future analysis will also consider other factors related to the risks of waste spills, including soil types and the design of specific lagoons.

Table 1. Expected Loss / Actuarially-Fair Insurance Premiums:

Major North Carolina Counties with Waste Lagoons

County	Number of Lagoons	Expected Loss 1	Expected Loss 2	Expected Loss 3	Expected Loss 4
Bladen	191	721	284	1959	705
Duplin	766	759	290	2062	753
Johnston	101	362	118	985	362
Sampson	652	590	215	1604	590
Wayne	200	493	170	1341	493

Notes: Expected Loss 1 and Expected Loss 2 calculated using the two lagoon failure functions in figure 1. Expected Loss 3 calculated using mixture density in figure 3. Expected Loss 4 uses same lagoon failure function as in Expected Loss 1, but sets damages equal to zero if windspeed is greater than 104 knots per hour. All expected losses are county averages. Averages are calculated from kriged prediction maps of expected losses constructed in ArcView 8.2.

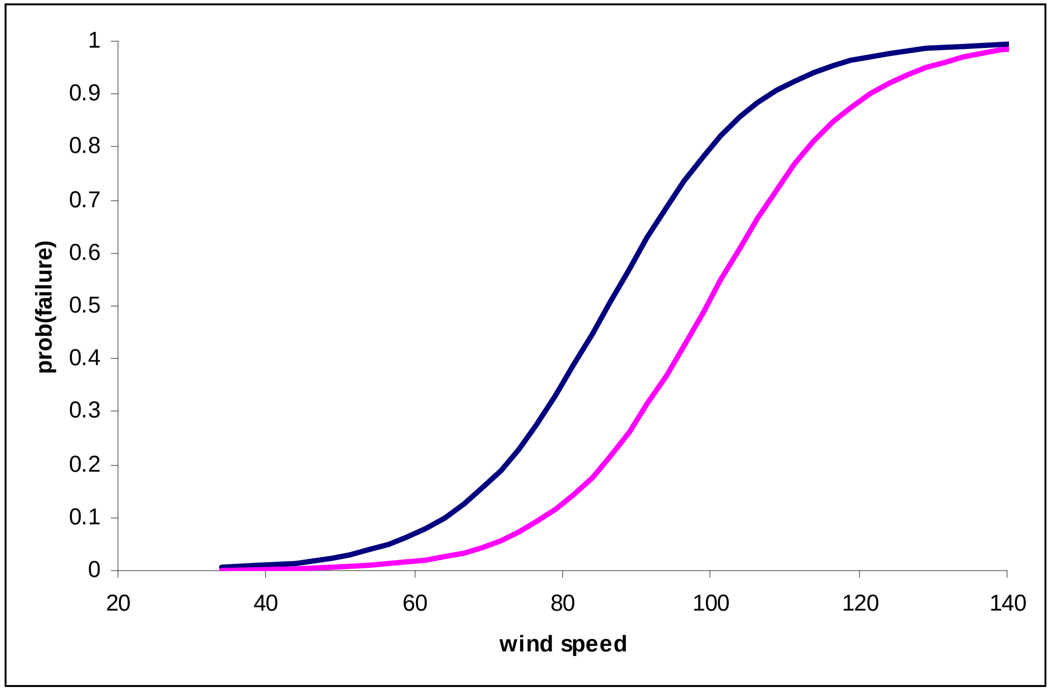

Figure 1: Assumed Wind-Speed / Lagoon Failure Functions

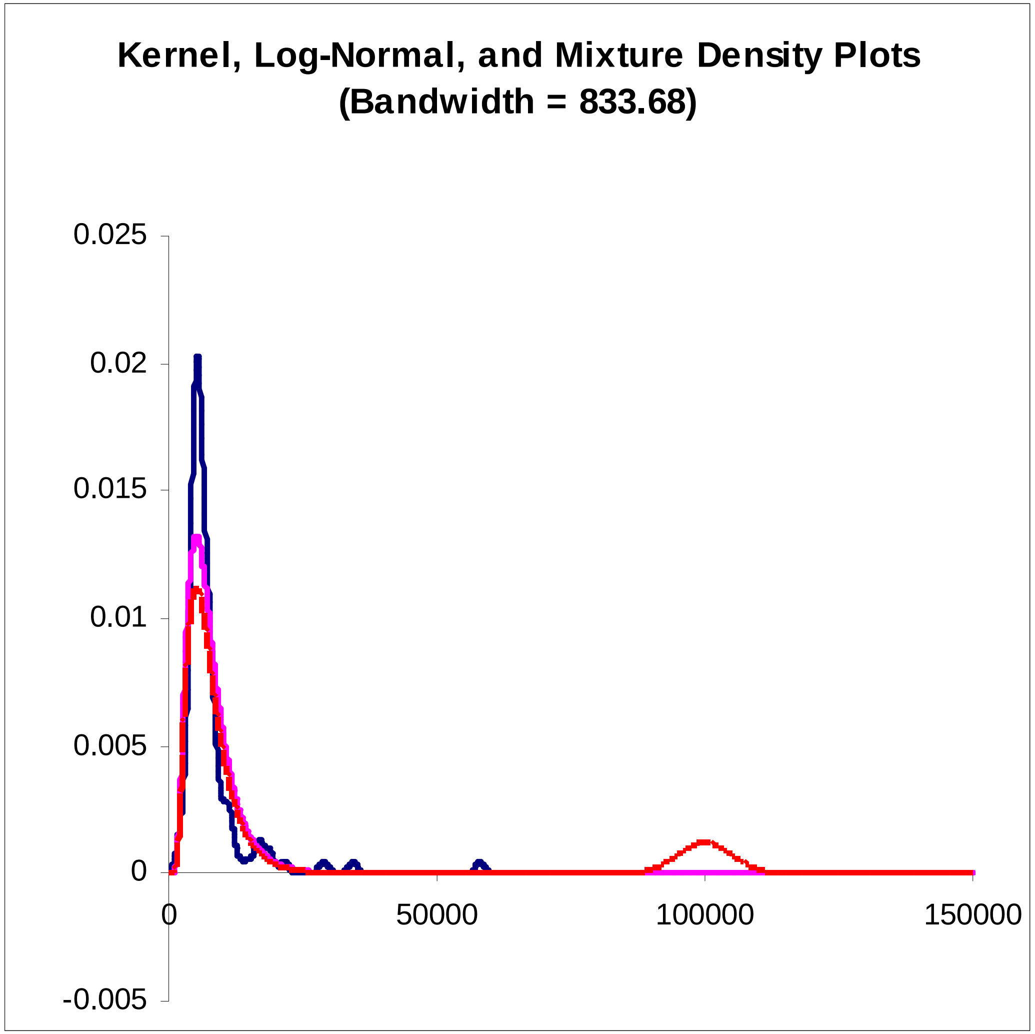

Figure 2: Densities Associated with Penalties/Damages, 2000-2003

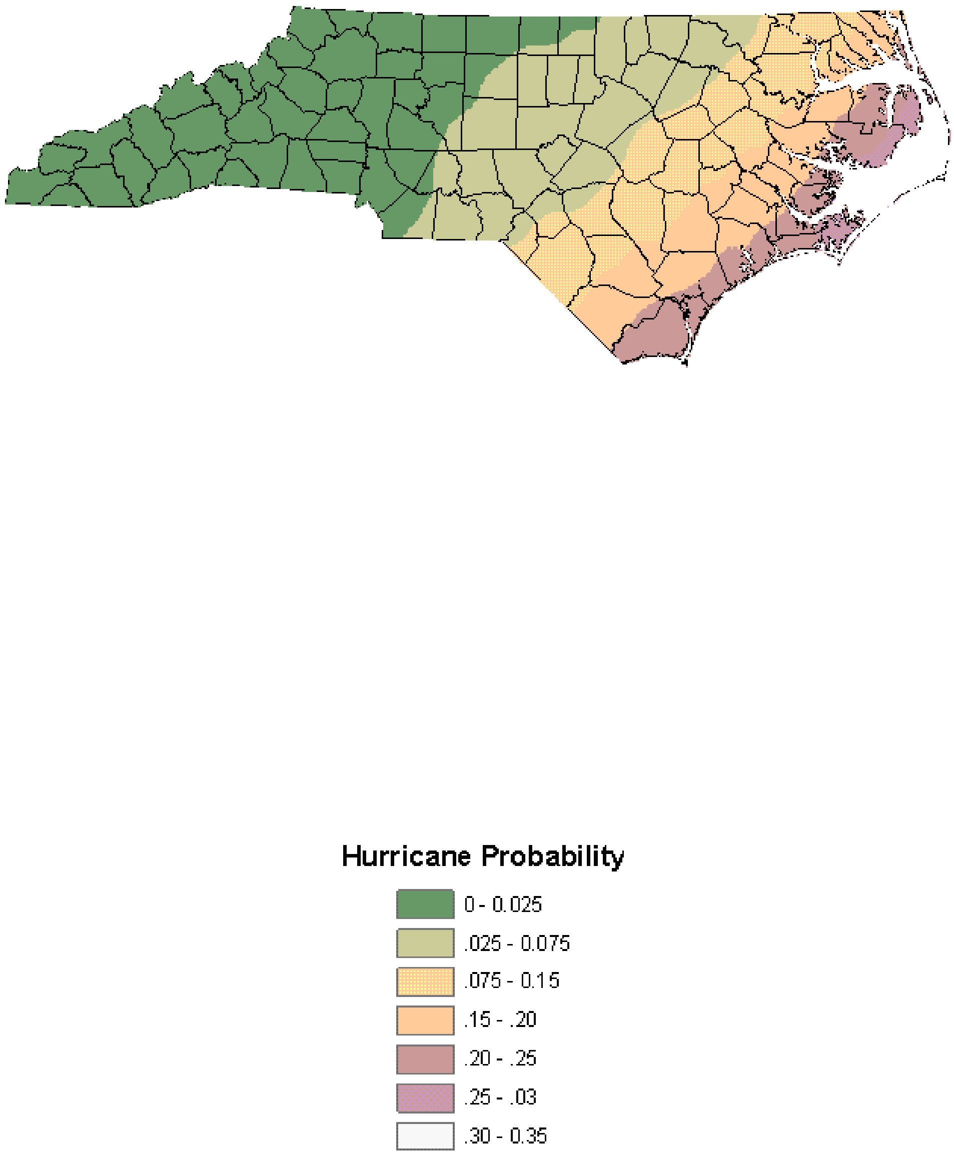

Figure 3: Empirical Estimates of North Carolina Hurricane (>64 knots) Strike Probabilities

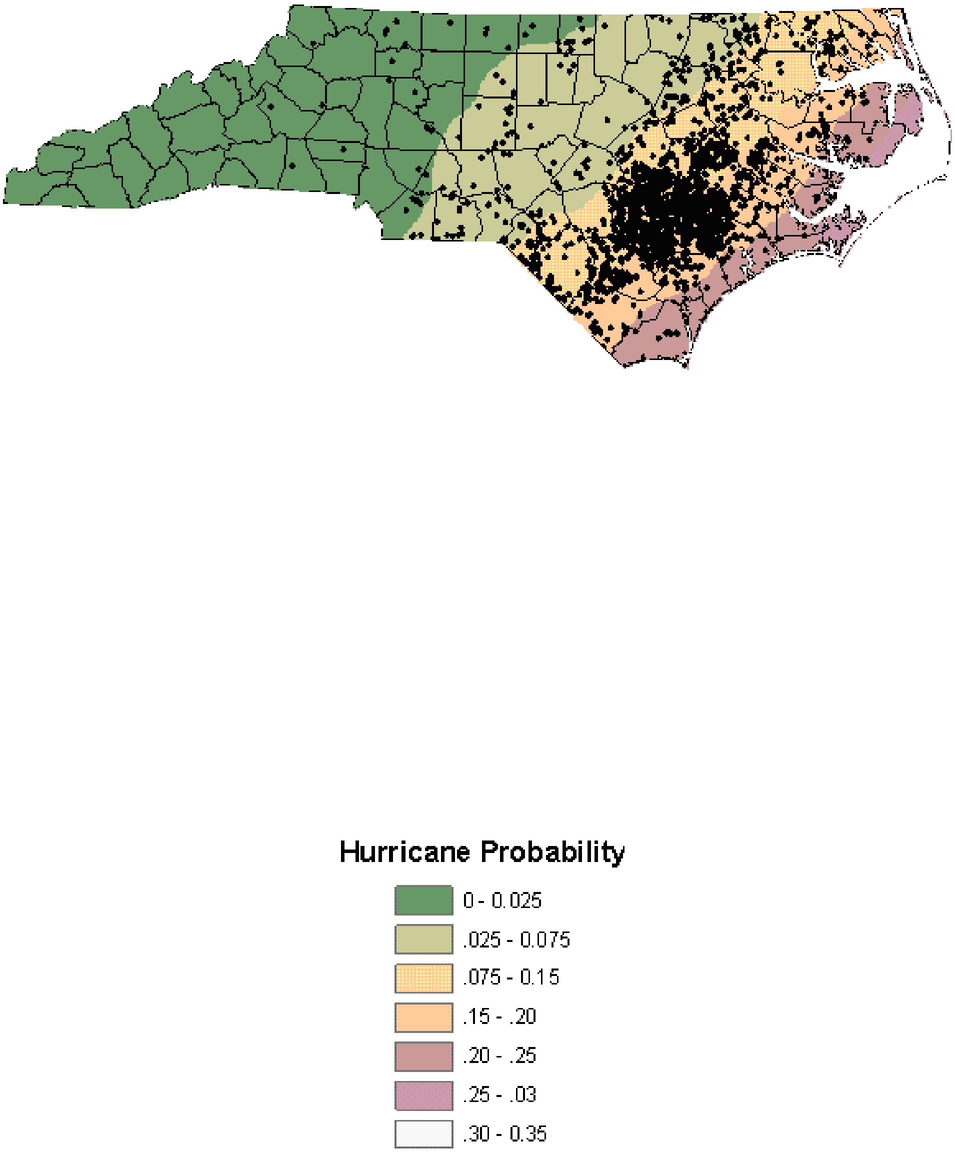

Figure 4: Hurricane Strike Probabilities and Waste Lagoon Locations

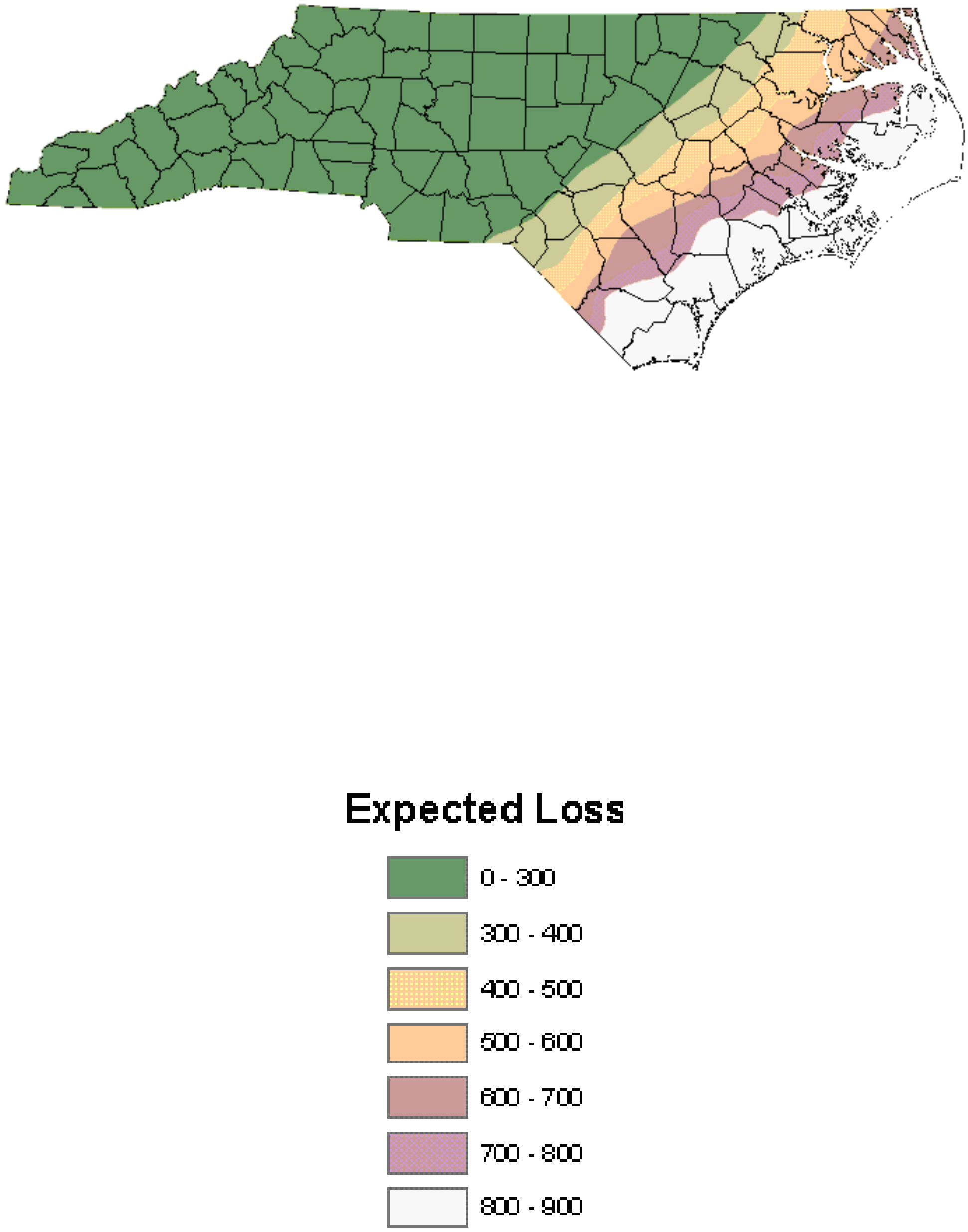

Figure 5: Expected Loss / Premium for Lagoon Failure Indemnity Program

References

ABC News, "Environmentalists, Hog Industry Continue to Battle," World News Tonight Report, July 30, 2001.

Bressler, Alan. *Navigating the U.S. Environmental Liability Market (Part 1)*, Available at www.irmi.com/expert/articles/2002/Bressler03a.aspx.

EPA. *Environmental Insurance Helps Ensure Redevelopment.* EPA 500-F-03-232, July 2003.

Freeman, Paul K. and Howard Kunreuther. *Managing Environmental Risk Through Insurance.* Washington, D.C.: The AEI Press, 1997.

Freeman, Paul K. and Howard Kunreuther. Managing Environmental Risk Through Insurance. In *The International Yearbook of Environmental and Resource Economics 2002/2003.* Tom Tietenberg and Henk Folmer, eds. Northampton, MA, Edward Elgar Publishing, 2002.

Hannah, John A. *The U.S. Environmental Liability Insurance Market-Reaching New Frontiers*, Available at www.irmi.com/expert/articles/2000/Hannah05.aspx

Katzman, Martin T. Pollution Liability Insurance and Catastrophic Environmental Risk, *The Journal of Risk and Insurance*, March, 1988 55(1)75-100.

Mallin, M. A. "Impacts of Industrial Animal Production of Rivers and Estuaries," *American Scientist* 88(2000):26-38.

Mallin, M. A., M. H. Posey, G. C. Shank, M. R. McIver, S. H. Ensign, and T. D. Alphin. "Hurricane Effects on Water Quality and Benthos in the Cape Fear Watershed: Natural and Anthropogenic Impacts," *Ecological Applications* 9(1999):350-62.

Powers, C. S. "How to Stop Hog Waste Pollution," Online Article, Libertarian Party of North Carolina, 1997, available at www.lpnc.org/issues/hogs.html.

Zagaski, Chester A. Jr. *Environmental Risk and Insurance.* Chelsea, MI:Lewis Publishers, Inc., 1992.