# Probabilistic Modeling of Catastrophic Weather Risks: Implications for Indemnification Plans for Animal Waste Spills

**Ligia Vado**
**North Carolina State University**
lavadose@ncsu.edu

**Barry K. Goodwin**
**North Carolina State University**
**PO Box 8109**
**Raleigh, NC 27695**
**(919) 515-4620**
barry_goodwin@ncsu.edu

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# Probabilistic Modeling of Catastrophic Weather Risks: Implications for Indemnification Plans for Animal Waste Spills*

Ligia Vado
and
Barry K. Goodwin

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**Abstract**

This paper presents probabilistic and economic models of two dimensions of catastrophic weather risks that are important factors underlying lagoon failures and waste spills in North Carolina-hurricane risks and the risks associated with significant cumulative rainfall. Hurricane strike and excessive cumulative rainfall probabilities are estimated for the entire state. Expected losses, which represent actuarially-fair insurance premium rates for a plan that would indemnify producers against damages from lagoon failures, are evaluated. Results imply annual premiums ranging from under \$100 per year to over \$4, 192 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.

* Vado is a graduate research assistant in the Department of Economics at North Carolina State University and Goodwin is William Neal Reynolds Distinguished Professor in the Departments of Economics and Agricultural and Resource Economics at North Carolina State University. The valuable input of Daniel Hallstrom on this research is gratefully acknowledged. This research was supported by a North Carolina Agricultural Foundation grant and by the North Carolina Agricultural Research Service. Direct correspondence to Goodwin at PO Box 8109, Raleigh, NC, 27695, (919) 515-4620, E-mail: barry_goodwin@ncsu.edu.

# 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 and excessive cumulative rainfall, 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 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

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

itself, may be a substantial source of ground and surface water contamination.

Risks associated with prolonged wet periods due to excessive cumulative rainfall have also been pointed out as one of the main causes of animal waste lagoon spills. Recent research by Jia et al. (2004) and Evans (1999) indicate that, while waste lagoons have been designed for extreme storm events, lagoon overflows are more prone to occur under other weather conditions, such as prolonged wet periods. The major effects of excess cumulative rainfall is not only the accumulated precipitation runoff into the lagoon's surface but most importantly, the delay of lagoon waste water irrigation into crop fields due to saturated soils. Higher lagoon stage and delayed irrigation exacerbate the risk of animal waste spills.

Legislators and 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]

[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 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 and excessive rainfall-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 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. This paper presents probabilistic models of two dimensions of catastrophic weather risks that are important factors underlying lagoon failures and waste spills-hurricane risks and the risks associated with significant cumulative rainfall. Of course, these two aspects of risk are closely related to one another since an important characteristic of hurricanes is the significant degree of rainfall that they often bring about. Goodwin and Hallstrom (2003) evaluated probabilistic models that only considered the risks associated with the excessive winds associated with hurricanes. This paper extends their research to incorporate the effects of cumulative rainfall. This is important since the risk of a hurricane-induced waste spill may be much higher if the strike occurs after a period of heavy rains.

The plan of our paper is as follows. The next section reviews issues pertaining to the modeling of hurricane strike probabilities, the design of insurance contracts, empirical application and results. This 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 third section discusses issues pertaining to the modeling and pricing of excessive rainfall induced lagoon failures. This analysis utilizes daily precipitation data over a sample of 421 weather stations throughout North Carolina to construct probabilities estimates of different measures of excessive cumulative rainfall. Lagoon spills fine and penalty data are subsequently used to price waste spill risks associated with excessive rainfall. Alternative excessive rainfall insurance schemes are presented. The final section offers some concluding remarks.

## 2 Modeling and Pricing Hurricane-Induced Lagoon Failure Risks

The overall goal of this section 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.[3]

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 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:

$$E(Loss) = Pr(Loss) \cdot E(Loss|Loss\ Occurs). \tag{1}$$

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.

[3] 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.

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:

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

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.[4] 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.

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

## 2.1 Measuring Hurricane Strike Probabilities

The primary focus of the research reported in this section 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.[5]

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 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

[5]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.

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).[6] 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.

## 2.2 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 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

[6]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.

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 $\beta$ 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 $\gamma$ is given by 0.1·(wind speed)-2.4. The hazard functions for the two alternative values of $\beta$ 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.

### 2.3 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.[7] 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.

## 2.4 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

[7] 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.

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.[8] 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.

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

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

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.[9] 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 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

[9]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.

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.[10] 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.

# 3 Modeling and Pricing Excessive Rainfall-Induced Lagoon Failure Risks

The primary focus of this research is to measure the risks of lagoon failure associated with catastrophic weather events such as hurricane strikes and significant cumulative rainfall. The previous section evaluated lagoon failures and waste spill risks associated to hurricane strikes at each specific point in North Carolina. This analysis assumed a storm's intensity as the factor triggering lagoon failure and waste spills. Recent research (Jia et al., 2004, Evans, 1999) indicates that the most important storm factor associated with the failure of a waste lagoon is the cumulative amount of rainfall experienced at a point in space. This analysis focuses on assessing risks of excessive cumulative rainfall at each specific point in North Carolina. The objective is to obtain actuarially sound measures of the risks and expected losses associated with excessive rainfall- triggered animal waste lagoon failures. Several rainfall index insurance schemes are presented based on alternative definitions of excessive cumulative rainfall.

Expected losses represent the actuarially fair premium that should be charged in order to provide indemnities in the event of animal waste spills associated with excessive cumulative rainfall. An accurate assessment of such premiums is pertinent to any privately or publicly owned rainfall insurance program that would indemnify producers in the event of an excessive rainfall-induced waste spill loss. Moreover, knowledge of the actuarially fair premiums would also be a key compo-

[10] 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.

nent in determining mandatory rates that should be charged to producers under an indemnification "check-off" type plan. The present analysis is an initial step towards the formulation of a specific peril insurance plan to cover those waste spill related losses caused by significant cumulative rainfall.

Abstaining from managerial costs and profits related to the administration of an insurance program, the appropriate premium for an excessive rainfall insurance policy should be set at the level of expected loss under the terms of the coverage being offered. Equation 1 above expresses expected loss of a catastrophic weather event as the product of the probability of a loss and the expected level of loss given that a loss occurs. To the extent that the risk of a chronic rainfall event represents an accurate measure of the risk of waste spills related losses, the expected loss of an animal waste spill triggered by excessive rainfall event $i$ is given by:

$$E(Loss_i) = Pr(Excessive\ Rainfall_i) \cdot E(Loss|Loss\ Occurs). \tag{5}$$

Four different rainfall index insurance schemes are developed on this analysis. Each one based on a different definition of excessive rainfall, taken from lagoon overflows engineering studies. The first insurance scheme assumes an excessive rainfall event as 15 consecutive days of cumulative precipitation equivalent or exceeding the 25-year, 24-hour storm rainfall amount. [11]The second scheme takes this same excessive cumulative rainfall threshold, but only insures against the occurrence of one or more such events during the hurricane's season. The third scheme considers a 60-day cumulative rainfall of 20 inches or more as the event triggering a loss. Lastly, the fourth scheme links the risk of a waste spill to the probability of cumulative rainfall being greater than normal plus one standard deviation over the two-month period previous to the start of the non-irrigation period. To the extent that a producer's animal waste spill is correlated with either insurance plan, such insurance will constitute an appropriate risk management tool to cope with animal waste related losses.

In regards to the term of the contracts, all insurance schemes considered in this paper are consistent with annually based insurance contracts. As such, for the first and third schemes, indemnities will be paid if one or more loss events occur during a year. For the second insurance scheme, indemnities will be paid if one or more loss events occur during a year's hurricane's season. Finally, in the case of the fourth insurance plan, only one annual event can occur, and if so,

[11]See Note 10.

indemnities are paid to insured producers. As with the case of hurricane insurance, all insurance schemes developed in this analysis are based upon entirely exogenous events-excessive rainfall, and thus, premium measures do not account for deductibles or coinsurance.

Site-specific expected losses are estimated for all the insurance schemes presented above. To that end, the first component of equation 5, excessive rainfall probabilities, is estimated for each of the four rainfall insurance schemes explained above. Fine and penalty data are subsequently used to construct estimates of expected losses from spills at each location in North Carolina. The model estimates can then be used to price the risks associated with cumulative rainfall related spills and thus to price relevant risk management instruments, insurance programs, accordingly. The following section discuses issues pertaining to the empirical estimation of site-specific excessive rainfall probabilities.

### 3.1 Measuring Excessive Rainfall Probabilities

The primary focus of this section concerns measuring site-specific excessive rainfall risks for each of the four insurance schemes analyzed. Each insurance scheme takes into account a different "excessive" cumulative rainfall threshold as the rainfall event triggering lagoon failure and waste spill related losses. Excessive rainfall thresholds may vary by the time span of cumulative rainfall considered (over 15 days, 60 days, 365 days), or by the amount of cumulative rainfall considered as excessive (8 in, 20 in).

An excessive rainfall event, usually referred to as chronic rainfall, is defined by the EPA as series of wet weather conditions that preclude dewatering of properly maintained water retention structures (McFarland et al. 2002). The Natural Resource Conservation Service (NRCS) definition of "chronic rainfall" is more specific. Chronic rainfall is defined as a consecutive day period of cumulative precipitation equal to or exceeding the 25-year, 24-hour storm rainfall amount (Jia et al., 2004). The first and second insurance schemes are based on the latter definition. The first insurance scheme considers an excessive cumulative rainfall event as 15 consecutive days of cumulative precipitation equivalent to or exceeding the 25-year, 24-hour storm rainfall amount, which is from 7 to 8 inches of rain in eastern North Carolina. A 25-year, 24-hour storm rainfall amount of 8 inches was assumed for all North Carolina counties. The second insurance plan uses the same excessive rainfall threshold as the first one, with the difference being that it only covers such events occurring during a year's hurricane's season. The 15 days election is somewhat arbitrary.

The third insurance scheme considers a 60 day cumulative rainfall of 20 inches or more as the event triggering a loss. This insurance plan is based on the fact that the baseline lagoon design period recommended by the NRCS Conservation Practice Standards for waste treatment lagoon is 60 days (Code 359, NRCS, 1999). Moreover, most animal waste lagoons in North Carolina are designed to have 7 or 8 inches of temporary storage to handle a 25-year, 24-hour storm plus 12 inches of free board designed to protect the dam and prevent damage to spillways (Jia et al., 2004). Thus, most waste lagoons in North Carolina are designed to have about 20 inches of freeboard to prevent lagoon overflows. A cumulative rainfall volume greater than 20 inches at a specific point may lead to lagoon overtopping, and potentially to a waste spill.

Jia et al. (2004) found that the main factors directly causing lagoon overflows were high lagoon levels entering the winter months, and wet field conditions that limit waste application in February. According to these findings, the probability of lagoon overtopping is closely related to the probability of excessive cumulative rainfall during the two-month period previous to entering the non-irrigation period. Higher than normal rainfall during this period may be indicative of high initial lagoon stage, and higher probabilities of saturated soils, preventing fields irrigation during early spring. Based on these arguments, the fourth insurance scheme links the probability of a waste spill loss to the probability of having cumulative precipitation higher than normal plus one standard deviation over the 60 days previous to entering the non-irrigation period. The traditional non-irrigation period in North Carolina occurs during winter and early spring, when fields are historically too wet. Following Evans' (1999) engineering lagoon stage simulation, it is assumed that the irrigation period starts on December 1 and ends on February 30 of the next year. Under this assumption, the probability of cumulative rainfall from October 1st to November 30th being higher than normal plus one standard deviation is calculated as an assessment of lagoon overtopping risks.

According to the insurance contracts explained above, indemnities are paid if the excessive rainfall event occurs one or more times in a given year. Probabilities of getting one or more of these events in a given year is calculated for each specific weather station in North Carolina as an assessment of lagoon failure and waste spill risks. These probabilities were calculated as the frequency of years presenting one or more loss-triggering events divided by the total number of years. Daily precipitation data for a sample of 421 weather stations throughout the state of North Carolina were used to construct rainfall indices. Precipitation data were compiled from the National Climatic Data Center (NCDC) for the period between 1920 and 2005. Normal daily precipitation used in this analysis were computed by the NCDC based on 30 years of data encompassing the period from 1970 to 2000. Loss triggering events probabilities were constructed for stations with 50 or more years of observations in order to throw out of the analysis those weather stations that did not have sufficient years of data. Spatial smoothing methods (kriging) were then used to construct probability surfaces to represent excessive cumulative rainfall for the entire state of North Carolina.

The focus of this section was to assess waste spill risks arising from excessive cumulative rainfall events. Four different rainfall index insurance schemes were developed based on differing assumptions concerning the definition of excessive cumulative rainfall. To the extent that a producer's waste spill risks are correlated with the risks gauged by any of these schemes, an insurance contract of that type would provide the producer with a relevant risk management tool to cope with waste spill related losses. It is pertinent to note that none of the insurance plans developed in this section takes into account other important factors associated with waste spill risks, such as lagoon stage management and irrigation practices. These factors are the focus of ongoing research. The next section discuses issues pertaining to empirical estimation and results.

### 3.2 Empirical Estimation and Results

The final objective of this analysis is to provide measures of actuarially fair premium rates that would be a key component to any indemnification plan or insurance contract which aims to address risks associated with excessive rainfall-triggered livestock waste spills. To that end, county specific estimates of expected loss were developed according to the county's risk of excessive cumulative rainfall for each of the insurance plans analyzed. In order to gauge excessive rainfall probabilities, the probability of one or more loss triggering events, as defined for each of the four insurance schemes, was calculated for each specific location in North Carolina. The second component of waste lagoon spills expected losses, the level of damage expected from a spill, is estimated using average waste spills fine and penalties data obtained from the North Carolina Department of Environment and Natural Resources (DENR).

A spatially smoothed illustration of excessive cumulative rainfall probabilities during hurricane season in North Carolina (scheme 2) is presented in Figure 6. Probabilities of excessive rainfall follow the same pattern as hurricane strike probabilities, being greater near the coast and lower in the interior regions of the state. Waste lagoon locations are also illustrated in the graph. The map illustrates the fact that waste lagoons are mostly located in southeastern North Carolina, where the probabilities of excessive cumulative rainfall events are highest at 25% to 45%. It is important to point out that the probability range of getting one or more heavy rainfall events over a years' hurricane season of 17% to 45% is similar to the probability range of getting such events over an entire year at 19% to 53%. This result suggests that excessive rainfall events as defined for scheme 1 and 2 are most likely to occur during the hurricane season. As pointed out above, waste lagoons have been designed for extreme storm events (25-year, 24-hour event). However, waste lagoon spills are more prone to occur under other weather conditions, such as prolonged wet periods. An important finding is that although the probability of an extreme storm event is typically assumed to be 4%, the probability of getting the equivalent amount of cumulative rainfall during 15 consecutive days is between 19% and 53% throughout North Carolina. Thus, the fact that chronic rainfall events are more likely to occur than traditionally considered in waste lagoon design represents a major source of lagoon overflows risks.

Excessive rainfall probabilities corresponding to the third and fourth insurance schemes are lower than those obtained for insurance schemes 1 and 2. Probabilities corresponding to the third scheme range from 2% to 30%, being highest near the coast and in the mountains, and lower in the interior counties of the state. On the other hand, the probabilities of excessive rainfall, as defined by insurance scheme 4, range from 9% to 15%. These probabilities are relatively high in southeastern North Carolina, where many waste lagoons are located.

Expected loss for each of the four insurance schemes were calculated as the product of excessive rainfall probability and expected loss given that a loss occurs. This last component, the expected loss of a spill, was computed as the total penalty average over the fine/penalty data available (2000-2003), resulting in an expected loss of $7,910. Another set of county expected losses were calculated using an expected loss of $21, 498 resulting from the mixture distribution explained in Section 3.3. The analysis is limited to the first set of county expected losses.

Spatially smoothed counties' waste spill expected losses follow the same pattern as excessive cumulative rainfall probabilities (Figure 6). Smoothed expected loss range varies from $1,532 to

$4,192 per year for the first insurance scheme, being highest for the counties near the outer banks, and lower for counties located in the interior of the state. Counties located in the mountains also show higher excessive rainfall probabilities and thus, higher expected losses. The second insurance scheme expected losses are lower, varying from $1,366 to $3,597 per year. The pattern of rainfall-induced lagoon failure expected losses is parallel to the pattern of hurricane-induced waste spill expected losses shown in Figure 5. The major difference between insurance plans 1 and 2 is that for insurance plan 1, expected losses decrease for the interior part of the state, and increases again for counties located in the mountains. This happens with less intensity for hurricane season expected losses, which are highest at the coast, and recede as one moves toward the interior counties of North Carolina. Insurance scheme 3 expected losses vary from $218 to $2,405 per year. These expected losses are somewhat smaller than those calculated for other insurance plans, due to the lower likelihood of getting one or more heavy cumulative rainfall events of 20 inches over 60 days. Moreover, these expected losses follow the same pattern as insurance scheme 1, being greater at the coast and in the mountains, and lower in the interior part of North Carolina. The fourth insurance scheme expected losses are between $755 and $1,256 per year, being highest in Southeastern North Carolina, where many animal lagoons are located.

The overall result of spatially smoothed expected losses is that animal waste lagoons are located in counties that have the highest waste spill losses related to excessive cumulative rainfall events. Table 2 contains expected losses for the major North Carolina counties with waste lagoons. Expected losses computed with the mixed penalty distribution are presented in Table 3. It is particularly striking that Duplin county, the county with the most lagoons in the state, has the highest or second highest expected loss for most insurance schemes. Results support findings obtained from the hurricane based probabilistic model. Animal waste lagoons in North Carolina are concentrated in areas that are more prone to experience hurricane events. As such, they are in areas that are more likely to experience excessive cumulative rainfall events. To the extent that risks of excessive cumulative rainfall assessments are accurately measured, expected losses presented in this analysis constitute a fundamental step towards the formulation of a rainfall based animal waste-spill insurance or indemnification plan.

# 4 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 and excessive rainfall in North Carolina. The focus of the first section 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. The second probabilistic model focused on the empirical estimation of excessive cumulative rainfall probabilities throughout the state of North Carolina. Four rainfall insurance schemes were developed using different excessive rainfall definitions. Daily precipitation data for a dense sample of weather stations in North Carolina from 1920-2005, and spatial smoothing methods were used to estimate excessive cumulative rainfall probabilities and expected losses for the entire state.

One aspect of our results is especially striking, though not surprising. The regions of North Carolina that have the greatest probabilities of hurricane strikes and of excessive cumulative rainfall are also the regions where livestock waste lagoons are concentrated. Thus, animal waste lagoons are concentrated in regions that have the greatest expected losses from lagoon spills. 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 losses 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. Of all reported counties, Duplin county also has the highest or second highest expected losses from excessive rainfall-triggered lagoon failure, with expected losses ranging from $1,123 to $2,655 per year, depending on the insurance plan analyzed. However, these expected losses can be as low as $218 per year in counties located in the interior of the state.

Current research efforts are being directed at an assessment of the relationship between hurricane strength, barometric pressure, storm progress, excessive rainfall and lagoon failures. Moreover, other issues associated with site-specific lagoon design and lagoon stage management practices are also being considered. Besides the need of improved quantification of damages and hazard functions, other issues related to the potential interest on the part of producers and policy makers are relevant to our analysis and are the focus of ongoing research.

Table 1. Expected Loss / Actuarially-Fair Hurricane 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.

Table 2. Expected Loss/ Actuarially-Fair Excessive Rainfall 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 | 2635 | 2604 | 1165 | 1196 |
| Duplin | 766 | 2655 | 2588 | 1137 | 1123 |
| Johnston | 101 | 2075 | 1989 | 549 | 1117 |
| Sampson | 652 | 2360 | 2308 | 897 | 1154 |
| Wayne | 200 | 2346 | 2277 | 676 | 1102 |

Notes: Expected losses 1-4 correspond to the four excessive rainfall insurance schemes. They are calculated using average total waste spill damage/penalties equivalent to $ 7, 910. All expected losses are county averages. Averages are calculated from kriged prediction maps of expected losses constructed in ArcGIS 9.2.

Table 3. Expected Loss/ Actuarially-Fair Excessive Rainfall 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 | 7160 | 7077 | 2581 | 3251 |
| Duplin | 766 | 7216 | 7033 | 2701 | 3054 |
| Johnston | 101 | 5640 | 5406 | 1613 | 3038 |
| Sampson | 652 | 6413 | 6274 | 2113 | 3138 |
| Wayne | 200 | 6375 | 6187 | 2171 | 2997 |

Notes: Expected losses 1-4 correspond to the four excessive rainfall insurance schemes. Expected losses calculated using mixture density in figure 3, with an expected loss of $ 21, 498. All expected losses are county averages. Averages are calculated from kriged prediction maps of expected losses constructed in ArcGIS 9.2.

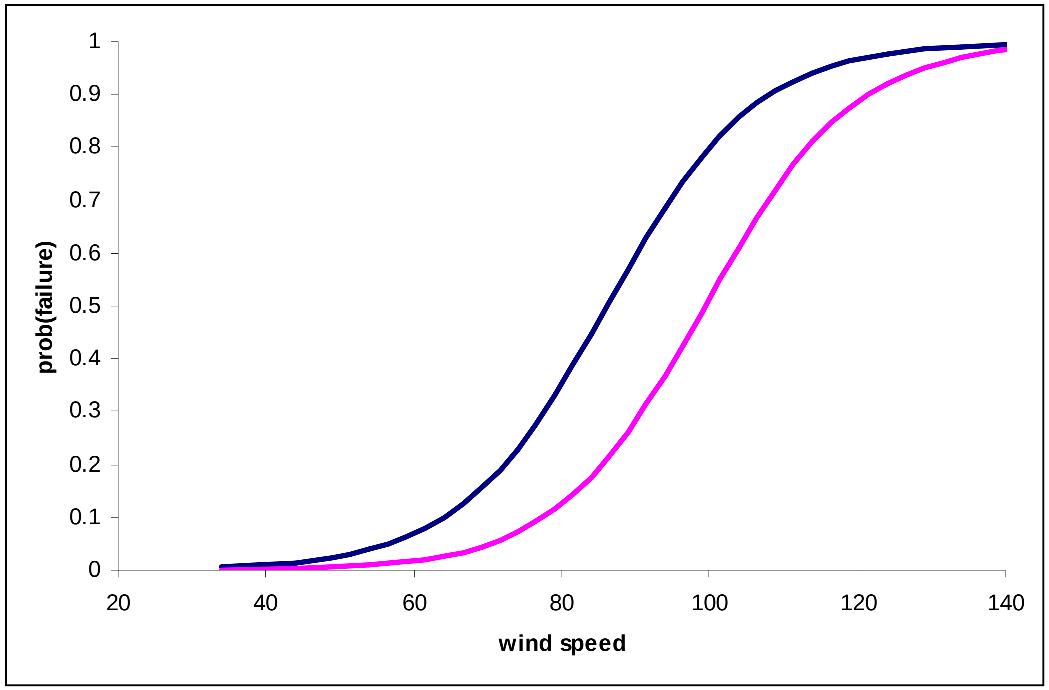


Figure 1: Assumed Wind-Speed / Lagoon Failure Functions

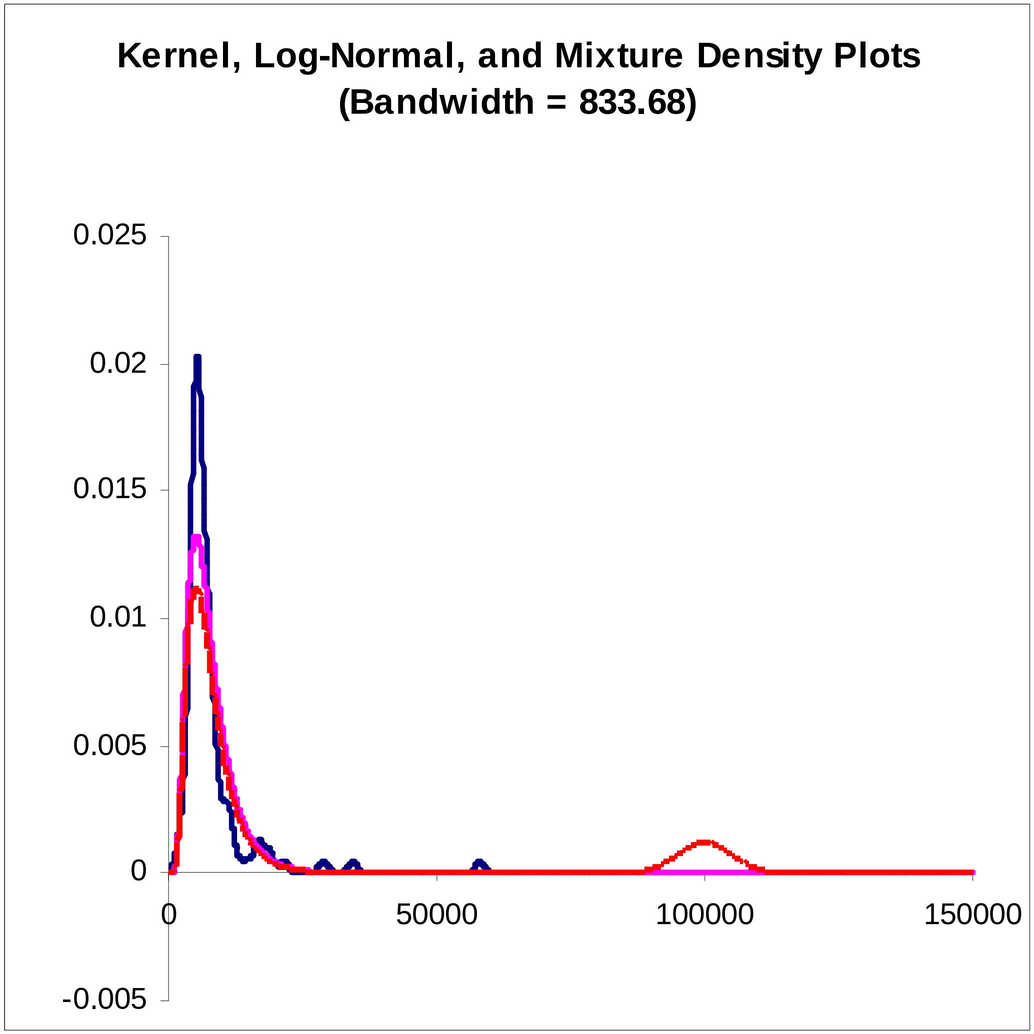


Figure 2: Densities Associated with Penalties/Damages, 2000-2003

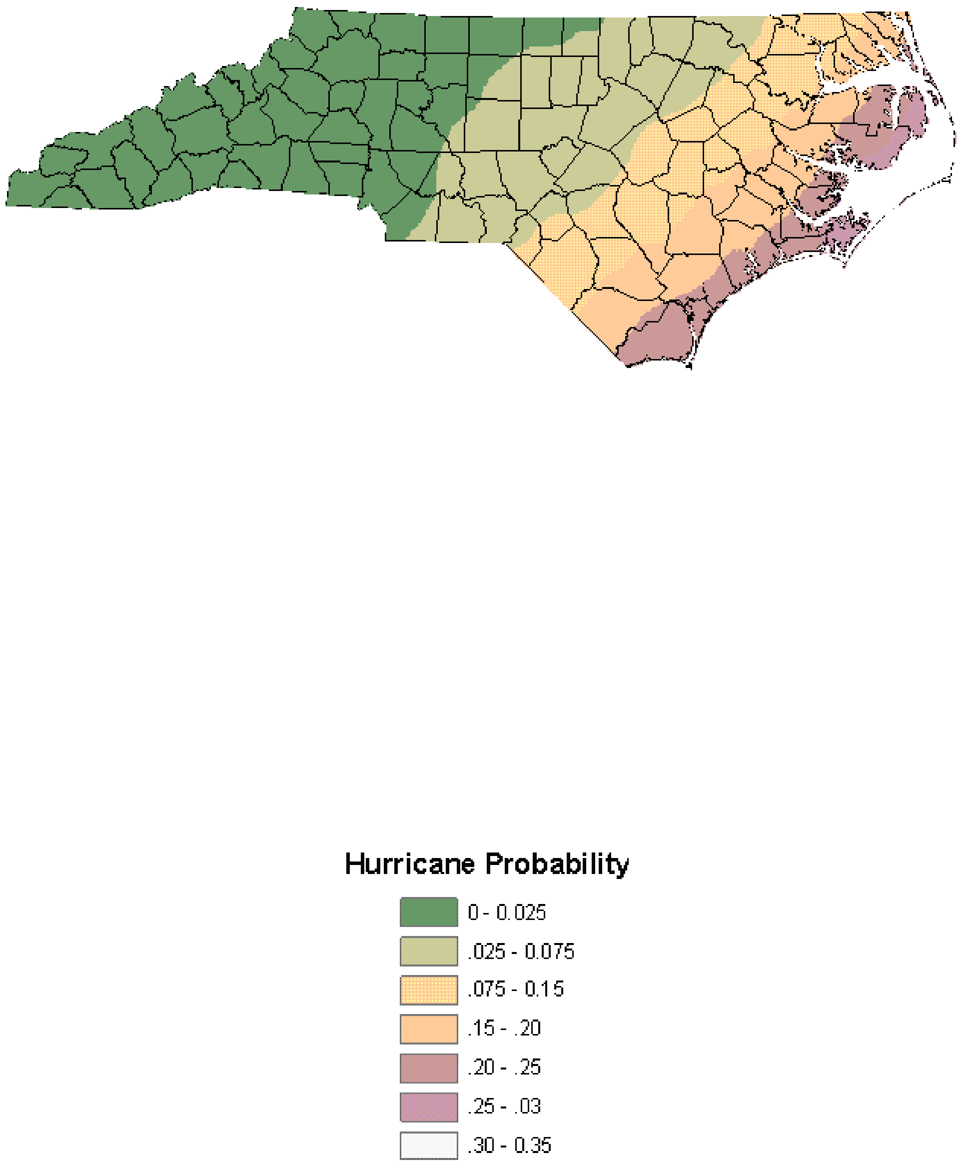


Figure 3: Empirical Estimates of North Carolina Hurricane (>64 knots) Strike Probabilities

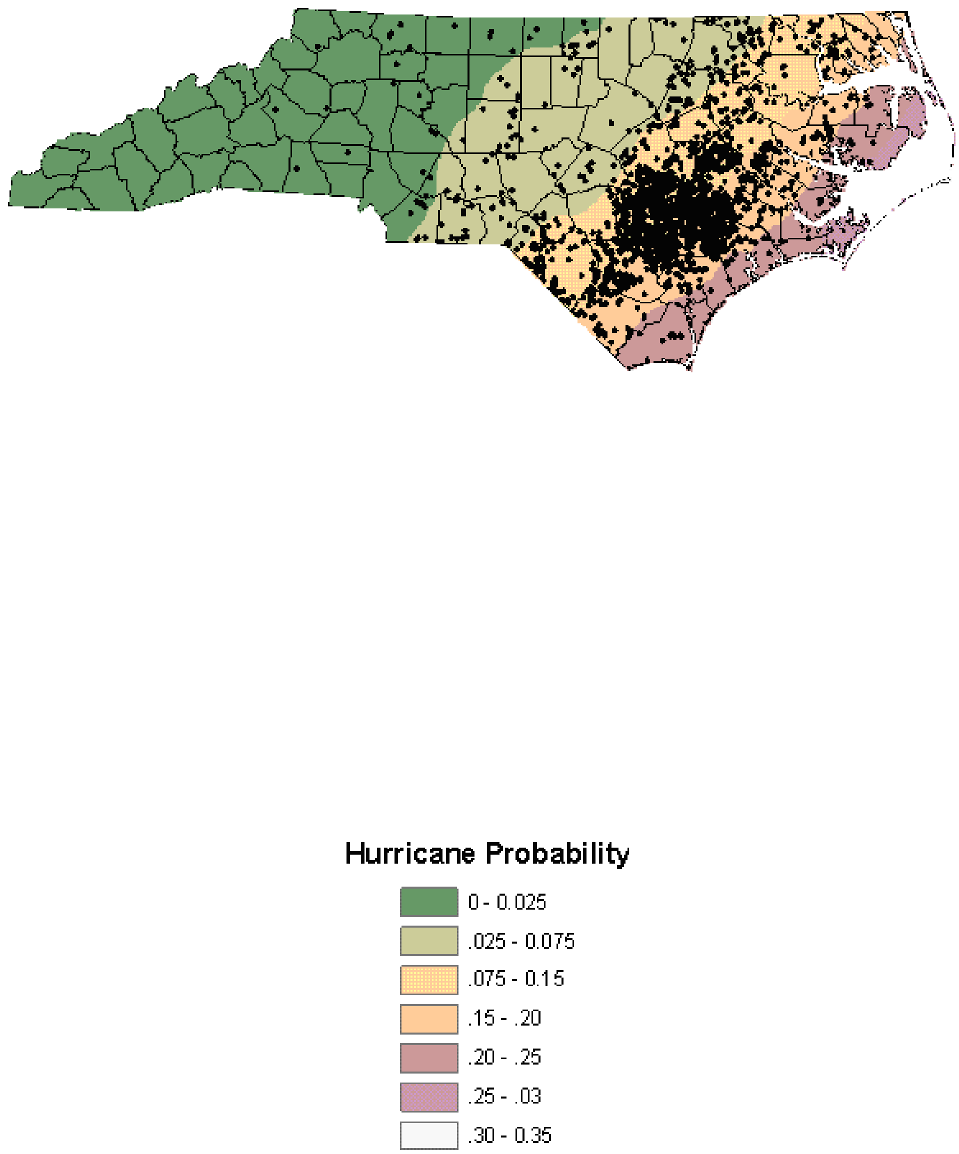


Figure 4: Hurricane Strike Probabilities and Waste Lagoon Locations

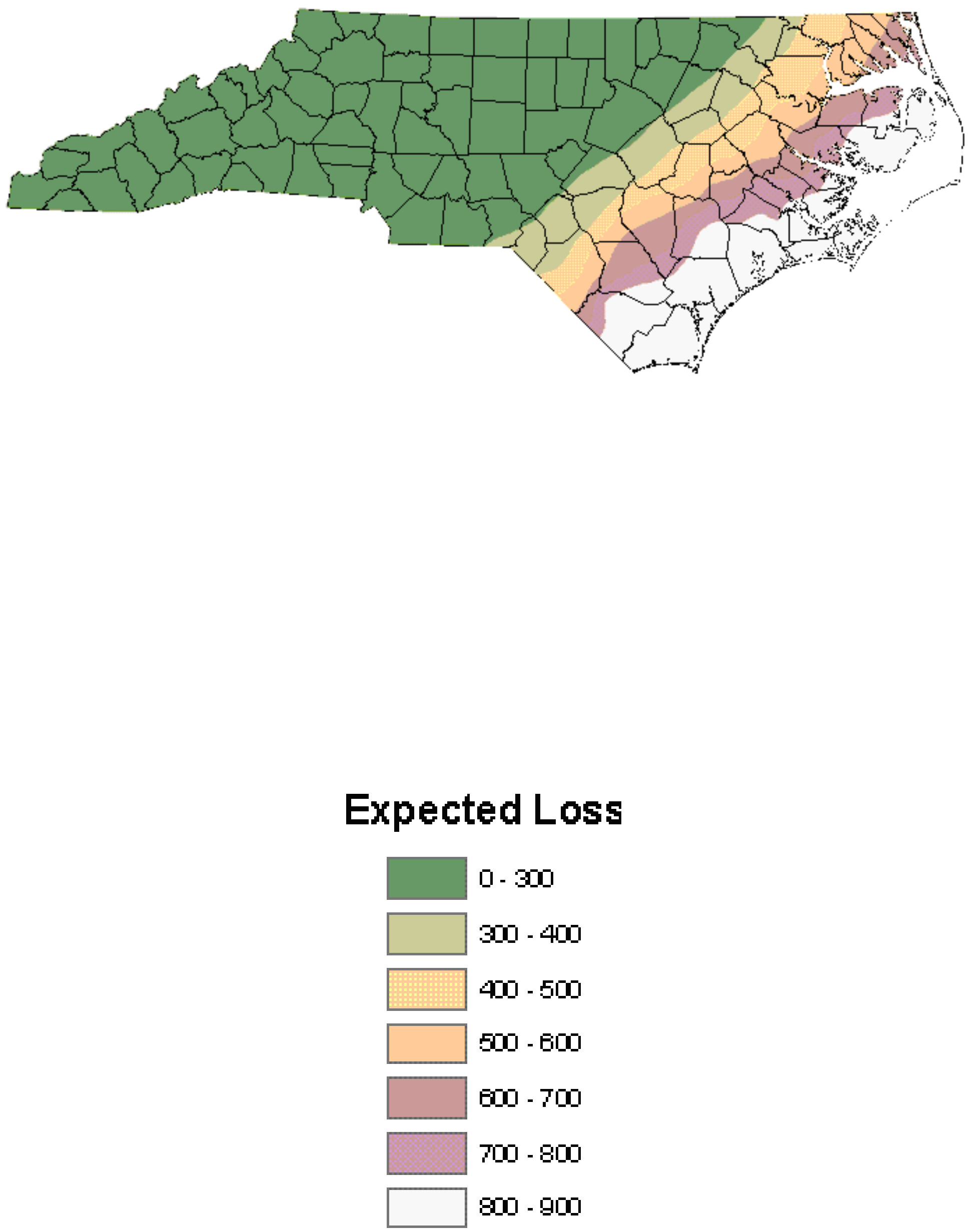


Figure 5: Expected Loss / Premium for Lagoon Failure Indemnity Program

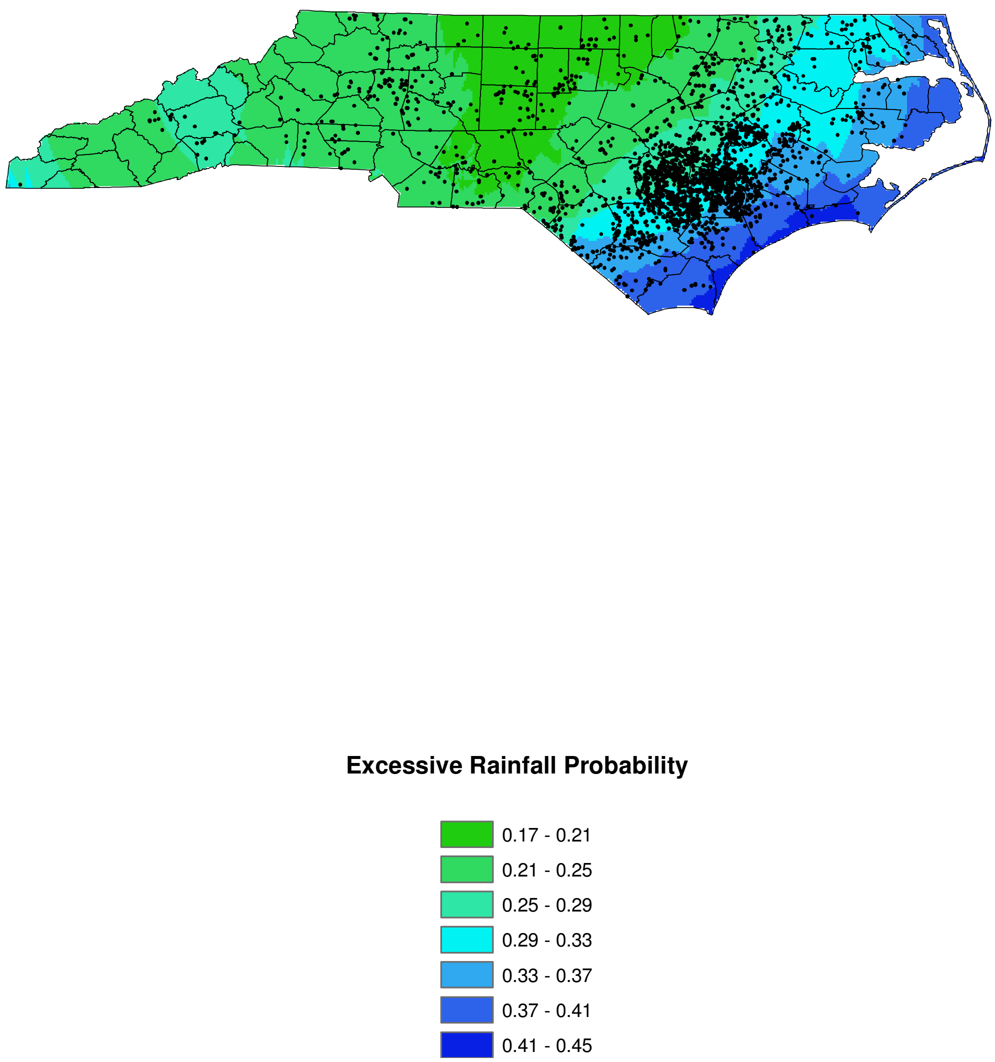


Figure 6: Excessive Cumulative Rainfall Probabilities and Waste Lagoon Locations in North Carolina

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