

## **ABSTRACT**

HILDERBRAND, DOUGLAS CLARENCE. Risk assessment of North Carolina tropical cyclones (1925-2000). (Under the direction of Dr. Lian Xie)

Previous tropical cyclone risk assessment studies have been national in scope. This study demonstrates the need for regional risk assessments, using the tropical cyclone history of North Carolina as an example. The standard normalization procedure for historical damage data was reevaluated. A housing factor was used instead of the more conventional population factor to go along with inflation and changes in wealth. For coastal counties in North Carolina, housing figures from 1940-2000 increased 780% while population figures increased only 370%. It is believed that use of housing data in lieu of population data in the normalization procedure provides a more realistic measure of impact. Using the new normalization method, 1954-55 tropical cyclone storm totals in North Carolina added together would have caused over \$18 billion in damage (expressed in 2000 dollars). By comparison, the destructive period from 1996 to 1999 in North Carolina added up to \$13 billion.

Storm damage totals were separated into damages caused by wind, flooding, and storm surge. For all 36 direct landfalling tropical cyclones in North Carolina from 1925-2000, flooding caused approximately 40% of all damages, while wind and storm surge caused an estimated 35% and 25%, respectively. From these results, it is clear that flooding produced relatively greater damage in North Carolina compared to the United States in general.

Rainfall was correlated to meteorological parameters of tropical cyclones making landfall in North Carolina. There was a weak relationship between intensity of the tropical cyclone and maximum rainfall totals. There was a stronger relationship between

rainfall and translation speed. For those tropical cyclones that did not directly interact with synoptic-scale features such as upper-level troughs, lows, or surface fronts, the relationship between rainfall and translation speed can be expressed by the equation  $Y=29.529X^{-0.6134}$  where Y is the average of the five highest recorded rainfall totals and X is the translation speed (expressed in knots). Rain volume calculations quantified the magnitude of the September 1999 flood event in eastern North Carolina. Hurricane Floyd yielded an estimated 4.14 cubic miles of water on North Carolina only 10 days after Tropical Storm Dennis brought North Carolina out of drought conditions with 3.67 cubic miles of water. The next-highest value from previous tropical cyclones was Hurricane Fran (1996) with 3.14 cubic miles of water.

While major hurricanes accounted for 83% of the overall damage due to hurricanes nationally, this percentage changes regionally. Using the total normalized damage numbers for North Carolina, 70 % of all tropical cyclone damage was caused by major hurricanes, while category-2 hurricanes added a significant percentage (21.4%). The results of this study suggest a stronger consideration for weaker tropical cyclones, especially category-2 hurricanes, in risk management decisions.

**RISK ASSESSMENT OF NORTH CAROLINA  
TROPICAL CYCLONES (1925-2000)**

by

**DOUGLAS C. HILDERBRAND**

A thesis submitted to the Graduate Faculty of  
North Carolina State University  
in partial fulfillment of the  
requirements for the Degree of  
Master of Science

**MARINE, EARTH, AND ATMOSPHERIC SCIENCES**

Raleigh

2002

**APPROVED BY:**

---

Dr. L. Pietrafesa

---

Dr. G. Lackmann

---

Dr. L. Xie  
Chair of Advisory Committee

## BIOGRAPHY

Douglas C. Hilderbrand was born on May 19, 1973 in Washington, D.C. and is the son of Robert H. Hilderbrand (deceased) and Sally H. Hilderbrand. After spending his childhood in Collegeville, PA and graduating from Methacton High School, Douglas attended Bucknell University in Lewisburg, PA. In 1995, he earned his Bachelor of Arts degree in geology and was accepted to the geology masters program at the University of South Florida in Tampa, FL. Douglas received his Master of Science degree in 1998. His thesis was titled “*Elemental Ratio Determination via ICP-MS and DCP-AES: Methodology to Extract Climate Records from Coral Aragonite*”.

Douglas entered the Graduate School at North Carolina State University in August of 1999 to pursue a Master of Science in meteorology. During his time at North Carolina State, he interned at the Blue Sky Foundation, working on hazard mitigation projects and building a comprehensive North Carolina tropical cyclone database. In February 2002, Douglas moved to Alexandria, VA and started working for the National Weather Service at the Hydrometeorological Prediction Center in Camp Springs, MD.

## ACKNOWLEDGEMENTS

I wish to genuinely extend my gratitude to my advisor Dr. Lian Xie for his guidance, support, expertise in tropical meteorology, and patience in the completion of this thesis. Further, I would like to thank my committee members, Dr. Gary Lackmann and Dr. Len Pietrafesa, for their objective comments. Also, a timely thank you to Dr. John Morrison for sitting in on the committee during the defense and helping me through the lowest point as a scientist-sea sick for two days over the Gulf Stream.

Sincere appreciation is extended to those who assisted in providing me with data used in this thesis. The United States Geological Survey provided flood data. Employees of the North Carolina Department of Emergency Management helped collect and direct me to North Carolina damage data. Thanks to Don Markle from the Blue Sky Foundation for the opportunity to work at the Blue Sky Foundation, Keith Brill of the Hydrometeorological Prediction Center (HPC) for statistical assistance and other co-workers who helped review my thesis, especially Pete Manousos, Mike Eckert, and Dave Roth. Thanks also to the HPC management for the time needed to finish this thesis.

I want to specially thank those closest to me-my mother, my family, my friends, and my dog. To succeed, you need to surround yourself with the best. In this case, I succeeded. I would like to dedicate this thesis to my father who was killed in an airplane crash on a rainy, foggy night. This was when my passion for weather started.

This study is part of the “Risk Assessment Tool and Development Project” funded by the NOAA Coastal Services Center under Grant NAO60C0.

## TABLE OF CONTENTS

LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
I. INTRODUCTION.....	1
A. Statement of Problem.....	1
B. Purpose/Objectives.....	1
C. Definition of Terms.....	2
D. Data Collection.....	3
II. DAMAGE ASSESSMENT.....	3
A. North Carolina Tropical Cyclone History.....	3
B. Normalization Methodology.....	4
C. Interpretation of Damage Data.....	15
D. Separation of Damages.....	20
III. FLOODING ASSESSMENT.....	43
A. Introduction.....	43
B. Tropical Cyclone Rainfall Characteristics.....	44
C. Previous Work.....	46
D. Methodology of Rainfall Database.....	48
E. Results of Rainfall Analyses.....	51
1. Relationship Between Intensity and Rainfall.....	51
2. Maximum Rainfall Distribution.....	53
3. Rainfall Relationship to Translation Speed.....	53
4. Rainfall Volume Determination.....	58
F. North Carolina Flood Events.....	60
IV. WINDASSESSMENT.....	70
V. STORM SURGE ASSESSMENT.....	73
VI. TROPICAL CYCLONE DATABASE.....	75
A. Database Methodology.....	75
B. Tropical Cyclone Data Inaccuracies and Difficulties.....	76

VII.	CONCLUSIONS.....	77
VIII.	REFERENCES.....	81
IX.	APPENDICES.....	84
A.	Appendix A: North Carolina Impacting Tropical Cyclones (1925-2000).....	85
B.	List of 36 Direct Landfalling North Carolina Tropical Cyclones.....	88
C.	List of 19 Tropical Cyclones Used in the Rainfall vs. Translation Speed Analysis.....	89
D.	Complete North Carolina Tropical Cyclone Summary.....	90

## LIST OF TABLES

Table 1.	List of North Carolina Tropical Cyclones with unadjusted and normalized damage totals in 2000 dollars.....	10
Table 2.	List of North Carolina tropical cyclones with unadjusted and normalized damage totals in 2000 dollars.....	12
Table 3a.	Damage statistics from direct landfalling North Carolina tropical cyclones (1925-2000) based on housing data.....	19
Table 3b.	Damage statistics from direct landfalling North Carolina tropical cyclones (1925-2000) based on population data.....	19
Table 4.	Causation of damage: wind/flood/storm surge from North Carolina impacting tropical cyclones (1925-2000).....	24
Table 5.	List of weather stations attributed to each river basin.....	50
Table 6.	List of river basin areas.....	50
Table 7.	Rain volume from 11 similar-tracking North Carolina landfalling tropical cyclones and the factors involved.....	59
Table 8.	Volume of rainfall on North Carolina river basins (expressed in cubic miles)..	61
Table 9.	North Carolina flood-producing tropical cyclones (1925-2000).....	62
Table 10.	Significant North Carolina tropical cyclone storm surge/coastal reosion events (1950-2000).....	74



## LIST OF FIGURES

Figure 1.	Annual number of tropical cyclones impacting North Carolina from 1925-2000.....	5
Figure 2a.	Annual North Carolina tropical cyclone unadjusted damage totals from 1925-2000.....	6
Figure 2b.	Annual North Carolina tropical cyclone unadjusted damage totals from 1925-2000 using a logarithmic scale.....	7
Figure 3.	North Carolina coastal population and housing trends from 1900-2000 based on U.S. Census data.....	9
Figure 4a.	Annual North Carolina tropical cyclone damage totals from 1925-2000 normalized to 2000 values.....	16
Figure 4b.	Comparison of annual North Carolina tropical cyclone normalized damage totals from 1925-2000 based on housing vs. population factor.....	17
Figure 5a.	Hurricane Andrew (1992) damage (%) distribution for individual sectors..	21
Figure 5b.	Hurricane Floyd (1999) damage (%) distribution for individual sectors....	22
Figure 6.	Hurricane Floyd (1999) rainfall distribution.....	27
Figure 7a.	Total North Carolina tropical cyclone damage assessment (1925-2000)...	39
Figure 7b.	North Carolina category-1,2 hurricanes, tropical storms, tropical depression damage assessment (1925-2000).....	40
Figure 7c.	North Carolina major hurricane (category-3,4) damage assessment (1925-2000).....	41
Figure 7d.	North Carolina category 1-3 hurricane damage assessment (1925-2000)...	42
Figure 8.	Map of North Carolina river basins and location of the 38 weather stations.....	49
Figure 9.	Maximum recorded rainfall from 31 direct landfalling tropical cyclones along the North Carolina coast (1925-2000).....	52
Figure 10.	Maximum rainfall distribution of direct landfalling North Carolina tropical cyclones (1925-2000).....	54

Figure 11.	Maximum rainfall distribution of direct landfalling North Carolina hurricanes (1925-2000).....	55
Figure 12.	Tropical cyclone rainfall versus translation speed over North Carolina....	57
Figure 13.	SSM/I color composite (passive microwave imagery) of Hurricane Floyd at 23Z on September 15, 1999.....	64
Figure 14.	Eta 500 mb heights and height changes on September 16 <sup>th</sup> , 1999 at 12Z...	65
Figure 15.	Surface analysis map of the eastern United States at 3Z on September 15 <sup>th</sup> , 1999.....	66
Figure 16.	Surface analysis map of the eastern United States at 3Z on September 16 <sup>th</sup> , 1999.....	67
Figure 17.	Hurricane Floyd (1999) location and flood levels (expressed in feet above flood stage) along the Neuse and Tar-Pamlico watersheds-areas of worst flood damage.....	69
Figure 18.	North Carolina tropical cyclone intensity distribution from 1925-2000.....	72

## **I. Introduction**

### **A. Statement of Problem**

Risk assessments based on past tropical cyclone damage records are crucial for prudent decision-making regarding hazard mitigation of property and reduction of fatalities by government policy makers and emergency management officials. Previous tropical cyclone damage studies (Pielke and Landsea, 1998; Pielke and Landsea, 1999) have focused on the United States in general. These studies, based on normalized historical damage data, indicated that over 80% of the total hurricane damage in the United States was caused by major (Saffir/Simpson categories 3, 4, 5; Simpson, 1974) hurricanes. As a result of this, some recent hurricane-related climate change studies have focused only on major hurricanes. However, this approach may not be appropriate for regional applications (i.e. individual states). More detailed risk assessments focusing on smaller regions of the country may better quantify risks associated with tropical systems, identify local trends, and predict future impacts.

### **B. Purpose/Objectives**

The objectives of this study are to 1) reevaluate and improve upon the normalization procedure for historical damage data, 2) separate storm damage totals of North Carolina tropical cyclones into categories of wind, flooding, and storm surge damage, 3) correlate meteorological characteristics to recorded rainfall totals, and 4) explain quantitatively and qualitatively the property risk from wind, rain, and storm surge damage based on the historical record from 1925-2000.

This study focuses on the state of North Carolina. Since 1996, Hurricanes Bertha (1996), Fran (1996), Bonnie (1998), and Floyd (1999), along with Tropical Depression

Danny (1997) and Tropical Storm Dennis (1999) have severely impacted the state with damage totaling over \$12 billion. The inland flooding attributed to Floyd in September 1999 has been regarded as the worst flooding in the state's history, while in September 1996 Fran's winds blew at hurricane strength well into the central part of the state. North Carolina was chosen for other reasons. North Carolina ranks only behind Florida and Texas in tropical cyclone direct hits and receives more activity proportional to its amount of coastline due to its geographic orientation (extends into the Atlantic Ocean close to the Gulf Stream). Furthermore, the Outer Banks region is extremely vulnerable and has seen a large increase in coastal development over the past 50 years.

### **C. Definition of Terms**

In this study, a tropical cyclone is defined as a cyclone that originates over the tropical oceans (water temperatures  $>79^{\circ}\text{F}$ ) and includes hurricanes, tropical storms, and tropical depressions (Glossary of Meteorology, 2000). Only tropical cyclones that impacted North Carolina were included in the dataset. Impacting tropical cyclones are those storms that have struck North Carolina directly, made landfall in another state and later moved through North Carolina, or remained over water but passed close enough to the state to have caused coastal damage. Impacts include damages directly attributable to the storm, as defined by Changnon (1996) and include rainfall-induced flooding, high winds, tornadoes embedded within the storm, coastal storm surge and beach erosion. Although fatality statistics were included in the overall summary of tropical cyclones, fatalities were not included in the damage assessment.

## **D. Data Collection**

Damage data from 82 tropical cyclones that have impacted North Carolina between 1925-2000 were collected. Storm track data were based on National Oceanic and Atmospheric Administration's (NOAA) hurricane database<sup>1</sup>. Damage data prior to 1925 were deemed unreliable and too incomplete to be useful in this study. Final damage totals were taken from many different sources and included yearly summaries in the Monthly Weather Review, local newspapers (Wilmington News; News & Observer), historical accounts summarized by Barnes (1998), and data from the National Climate Data Center (NCDC). Where there were conflicting damage totals, government sources and the higher total took precedence.

## **II. Damage Assessment**

### **A. North Carolina Tropical Cyclone History**

A total of 82 tropical cyclones impacted North Carolina from 1925-2000 (an average of 1.1 impacting tropical cyclones per year). Of the 82 tropical cyclones, 36 made direct landfall along the coast, 12 remained offshore, 16 made landfall along the Gulf Coast and tracked into North Carolina, and 18 made landfall along the East Coast (mostly South Carolina) and moved into North Carolina. Of the 36 tropical cyclones that made direct landfall, 25 were hurricanes (11 major hurricanes), 9 tropical storms, and 2 tropical depressions. The classification distribution included 37 hurricanes, 29 tropical storms, and 16 tropical depressions.

<sup>1</sup>HURDAT project is described in <http://www.aoml.noaa.gov/hrd/hurdat/index.html>

Figure 1 shows the frequency of tropical cyclones impacting North Carolina from 1925-2000. Active individual years (>2 tropical cyclones) were 1944, 1954, 1955, 1964, 1985, 1995, 1996, and 1999. Periods of low tropical cyclone activity (<2 tropical cyclones annually) were 1929-1932, 1934-1943, 1977-1983 and 1986-1993.

Owing to inflation, economic growth, and changing development patterns, unadjusted damage totals are not useful when assessing climatological trends. In North Carolina since 1989, there have been four hurricanes that have caused more than \$1 billion in damages. Prior to 1989, the greatest annual loss was \$255 million in 1954 due mostly to Hurricane Hazel. A time series of annual tropical cyclone damage shows a large increase since 1989 (Figure 2a). In figure 2b, the unadjusted damage totals are shown using a logarithmic scale to illustrate better the magnitude change over the past 76 years. In fact, it appears from the unadjusted values of North Carolina tropical cyclone damage that the period of 1996-1999 has been unprecedented. However, to accurately compare damage totals from year-to-year, the data must be normalized to reflect changes in inflation, land-use, wealth and population of areas vulnerable to tropical cyclones.

## **B. Normalization Methodology**

Normalization of the damage data in previous studies involved three factors: inflation, population growth, and wealth changes (Pielke and Landsea, 1998). This study claims that population growth may not always be an accurate normalization factor. The population along the North Carolina coast has increased throughout the 20<sup>th</sup> century, especially since 1970. From 1940-2000, the coastal population has increased by 370%. Population growth implies that there is a proportional increase in property. However, one cannot assume that population and property are directly correlated. In the case of North

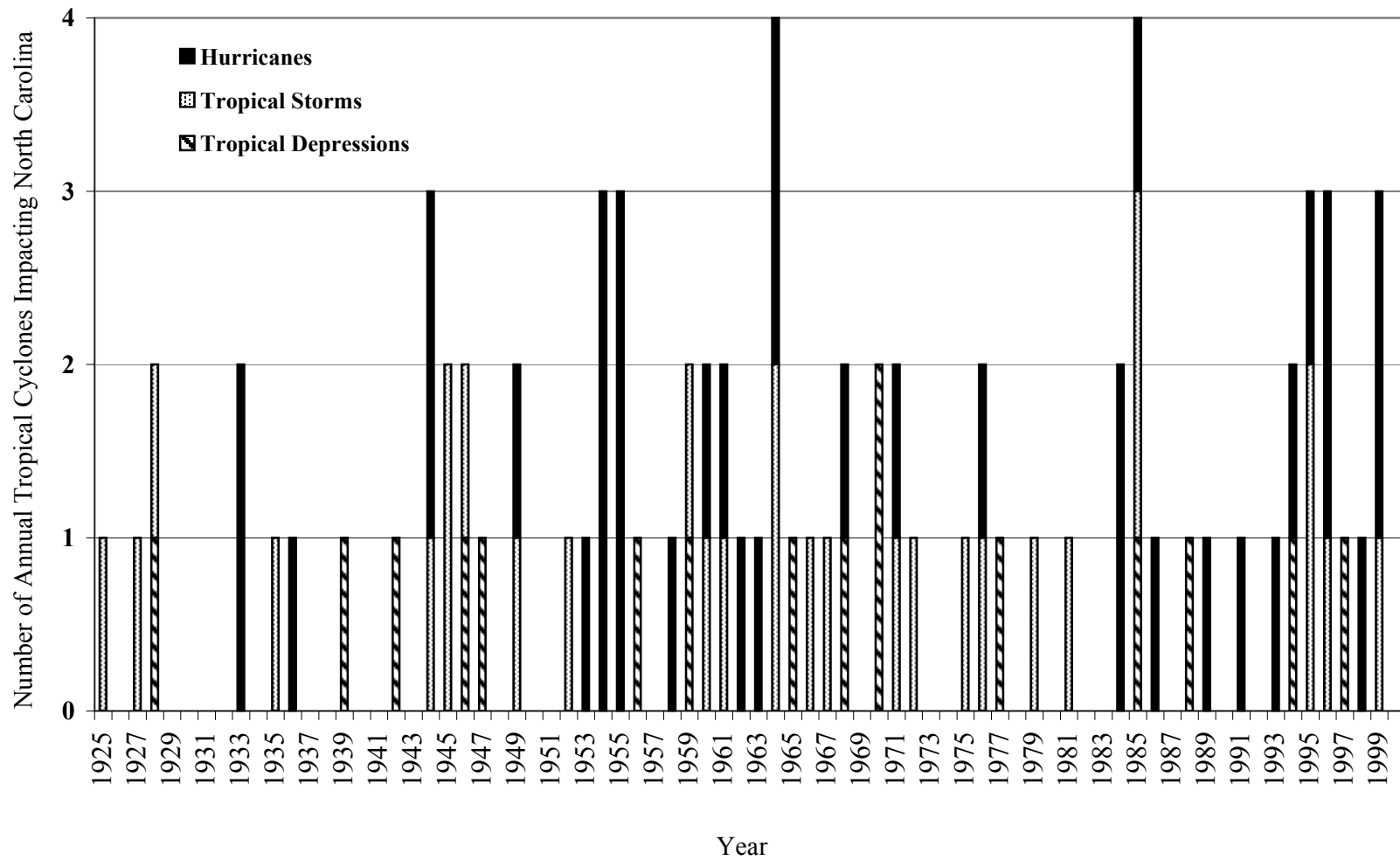


Figure 1. Annual number of tropical cyclones impacting North Carolina from 1925-2000.

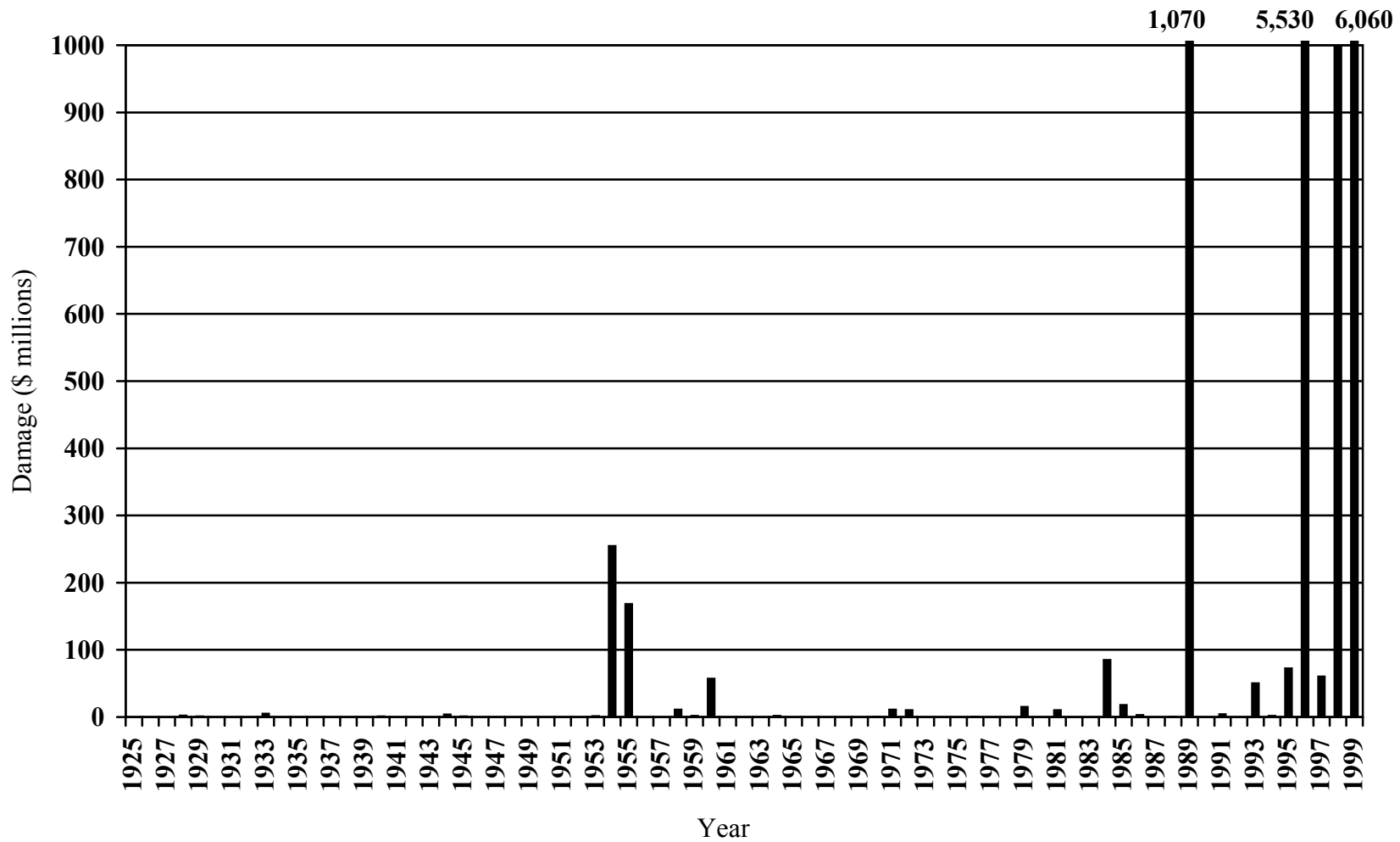


Figure 2a. Annual North Carolina tropical cyclone unadjusted damage totals from 1925-2000. Prior to 1925, damage estimates were deemed incomplete and unreliable. Damage totals are not normalized and therefore represent the values at the time the damage occurred.



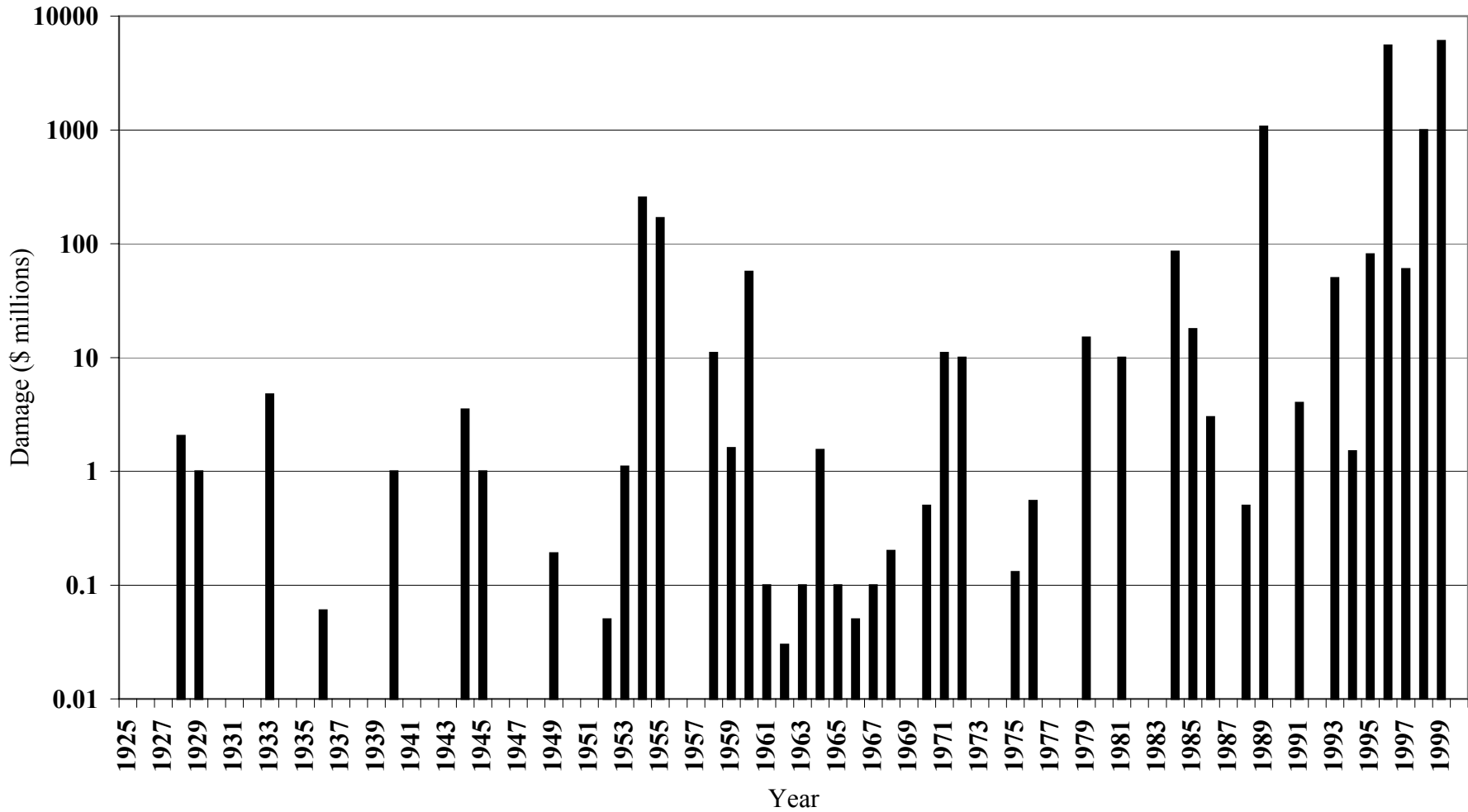


Figure 2b. Annual North Carolina tropical cyclone unadjusted damage totals from 1925-2000 using a logarithmic scale. Damage totals are not normalized and therefore represent the values at the time the damage occurred. Notice how weighted the most recent years appear compared to the destructive decade of the 1950's.

Carolina, from 1940-2000, housing totals throughout the coastal counties have increased 780%. Figure 3 illustrates the population and housing increases in the coastal counties of North Carolina. An explanation of the dichotomy might be that North Carolina depends heavily on tourism along most of the coastline. Many owners of vacation homes, rental homes, etc. are not counted in the population figures for each county. By using a housing factor instead of population factor, storm damage totals are twice as high in some cases.

The inflation factor is well represented by two economic statistics. Either the implicit price deflator or the consumer price index (CPI) can be used. This study used the CPI as it is the standard measure of inflation<sup>2</sup>. The wealth factor was determined by the “fixed reproducible tangible wealth”. This economic statistic, kept by the Bureau of Economic Analysis (1993), accounts for the trend that Americans have more wealth today than in the past (bigger houses, more expensive cars, etc.).

Table 1 summarizes the normalization values for each impacting tropical cyclone that caused significant damage. Those storms that only caused minor or no damage were not normalized. Table 1 includes the housing factor recommended by this study. A comparison of the storm damage totals can be made with Table 2 that uses the population factor. Deviation between the storm damage totals is greatest for storms from 1940-1960. For example, in 1955, housing factor values are 2.96 while population values are lower at 2.2.

<sup>2</sup> Bloomberg News (2001) is quoted as stating “CPI is one of the most widely recognized price measures for tracking the price of a market basket of goods and services purchased by individuals. The weights of the components are based on consumer spending patterns.”

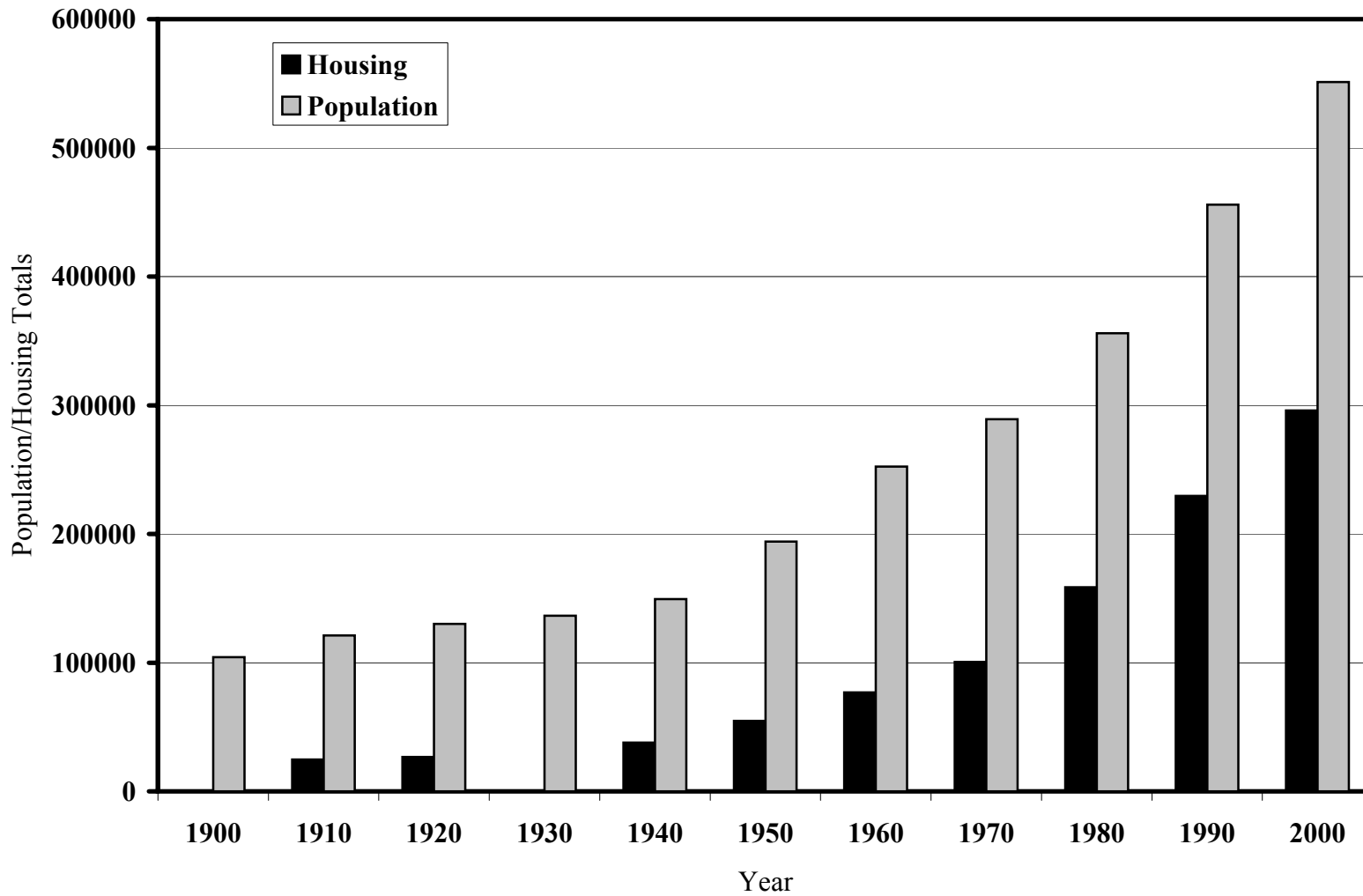


Figure 3. North Carolina coastal population and housing trends from 1900-2000 based on U.S. Census data. Housing data for 1900 and 1930 were not available. Coastal counties included in the study are Brunswick, Carteret, Currituck, Dare, Hyde, New Hanover, Onslow, Pamlico, and Pender.

Table 1: List of North Carolina Tropical Cyclones with unadjusted and normalized damage totals in 2000 dollars. Inflation, wealth, and housing factors for each storm are also listed. Housing factor replaced the population factor that was used in Pielke and Landsea (1998).

Tropical Cyclone	Date of Landfall	Unadjusted damage	Inflation	Wealth	Housing	Normalized Damage
Hurricane Irene	10/17/1999	minor	---	---	---	minor
Hurricane Floyd	9/16/1999	\$6 billion	1.03	1.02	1.02	\$6.36 billion
T.S. Dennis	9/4/1999	\$60 million	1.03	1.02	1.02	\$64.3 million
Hurricane Bonnie	8/26/1998	\$1 billion	1.05	1.02	1.04	\$1.125 billion
T.D. Danny	7/24/1997	\$60 million	1.07	1.03	1.04	\$72 million
T.S. Arthur	6/19/1996	no damage	---	---	---	none
Hurricane Bertha	7/12/1996	\$330 million	1.1	1.04	1.09	\$411 million
Hurricane Fran	9/6/1996	\$5.2 billion	1.09	1.04	1.08	\$6.36 billion
T.S. Jerry	8/28/1995	\$9 million	1.12	1.08	1.1	\$12 million
Hurricane Felix	8/17/1995	\$2 million	1.12	1.08	1.1	\$3 million
T.S. Opal	10/5/1995	\$70 million	1.12	1.08	1.1	\$93 million
T.D. Beryl	8/17/1994	\$1 million	1.15	1.09	1.2	\$2 million
H. Gordon	11/18/1994	\$0.5 million	1.15	1.09	1.2	\$1 million
Hurricane Emily	8/31/1993	\$50 million	1.19	1.1	1.2	\$78 million
Hurricane Bob	8/19/1991	\$4 million	1.22	1.11	1.25	\$7 million
Hurricane Hugo	9/22/1989	\$1.07 billion	1.38	1.12	1.28	\$2.12 billion
T.D. Chris	8/29/1988	\$0.5 million	1.4	1.14	1.3	\$1 million
Hurricane Charley	8/17/1986	\$3 million	1.5	1.16	1.4	\$7 million
T.S. Bob	7/25/1985	\$1.5 million	1.55	1.16	1.4	\$4 million
T.D. Danny	8/17/1985	\$2.5 million	1.55	1.16	1.4	\$6 million
Hurricane Gloria	9/27/1985	\$14 million	1.59	1.17	1.49	\$38 million
T.S. Kate	11/23/1985	minor	---	---	---	minor
Hurricane Diana	9/13/1984	\$79 million	1.64	1.18	1.63	\$249 million
Hurricane Josephine	10/12/1984	minor	---	---	---	minor
T.S. Dennis	8/20/1981	\$10 million	2.07	1.26	1.69	\$44 million
T.S. David	9/5/1979	\$15 million	2.31	1.3	1.95	\$88 million
T.D. Babe	9/9/1977	no damage	---	---	---	none
Hurricane Belle	8/9/1976	minor	---	---	---	minor
T.S. Dottie	8/21/1976	\$0.5 million	2.9	1.4	2.2	\$4 million
T.S. Eloise	9/24/1975	minor	---	---	---	minor
T.S. Agnes	6/21/1972	\$10 million	4.13	1.4	1.99	\$115 million
T.S. Doria	8/27/1971	\$1 million	4.22	1.43	2.78	\$17 million
Hurricane Ginger	9/30/1971	\$10 million	4.22	1.43	2.78	\$168 million
T.D. Alma	5/26/1970	no damage	---	---	---	none
T.S. #4	8/17/1970	\$0.5 million	4.25	1.44	2.8	\$9 million
T.D. Abby	6/8/1968	minor	---	---	---	minor
Hurricane Gladys	10/20/1968	minor	---	---	---	none
T.S. Doria	9/17/1967	minor	---	---	---	minor
T.S. Alma	6/11/1966	minor	---	---	---	minor
T.D. #1	6/16/1965	minor	---	---	---	minor
T.S. Cleo	8/31/1964	\$0.5 million	5.55	1.65	4.5	\$21 million
T.S. Dora	9/13/1964	\$0.1 million	5.55	1.65	5	\$5 million
Hurricane Gladys	9/21/1964	\$0.1 million	5.55	1.65	5	\$5 million
Hurricane Isbell	10/16/1964	\$1 million	5.55	1.65	5.93	\$54 million

Table 1: continued.

<u>Tropical Cyclone</u>	<u>Date of Landfall</u>	<u>Unadjusted damage</u>	<u>Inflation</u>	<u>Wealth</u>	<u>Housing</u>	<u>Normalized Damage</u>
Hurricane Ginny	10/21/1963	\$0.1 million	5.6	1.68	5.5	\$5 million
Hurricane Alma	8/28/1962	minor	---	---	---	minor
T.S. #6	9/14/1961	no damage	---	---	---	none
Hurricane Esther	9/20/1961	\$0.1 million	5.8	1.78	3.7	\$4 million
T.S. Brenda	7/30/1960	\$0.25 million	5.82	1.8	3.9	\$10 million
Hurricane Donna	9/12/1960	\$56.5 million	5.82	1.8	3.95	\$2.34 billion
T.D. Cindy	7/10/1959	\$1.1 million	5.87	1.8	4	\$46 million
T.S. Gracie	9/30/1959	\$0.5 million	5.87	1.8	4	\$21 million
Hurricane Helene	9/27/1958	\$11 million	5.96	1.9	4.2	\$523 million
T.D. Flossy	9/26/1956	no damage	---	---	---	none
Hurricane Connie	8/12/1955	\$40 million	6.4	2.06	2.96	\$1.56 billion
Hurricane Diane	8/17/1955	\$80 million	6.4	2.06	2.96	\$2.54 billion
Hurricane Ione	9/19/1955	\$88 million	6.4	2.06	2.96	\$3.44 billion
Hurricane Carol	8/31/1954	\$0.25 million	6.42	2.06	3.4	\$11 million
Hurricane Edna	9/11/1954	\$0.1 million	6.42	2.06	3.4	\$4 million
Hurricane Hazel	10/15/1954	\$254 million	6.42	2.06	3.4/3.0	\$10.52 billion
Hurricane Barbara	8/14/1953	\$1.1 million	6.5	2.08	3.65	\$54 million
T.S. Able	8/31/1952	minor	---	---	---	minor
Hurricane #1	8/24/1949	\$0.2 million	7	2.2	4	\$12 million
Hurricane #2 (T.S.)	8/29/1949	minor	---	---	---	minor
T.S. #6 (T.D.)	9/24/1947	minor	---	---	---	minor
Hurricane #2 (T.S.)	7/6/1946	minor	---	---	---	minor
Hurricane #5 (T.D.)	10/9/1946	no damage	---	---	---	none
Hurricane #1 (TS)	6/26/1945	minor	---	---	---	minor
Hurricane #9 (T.S.)	9/18/1945	\$2 million	9.7	2.4	4.5	\$209 million
Hurricane #3	8/1/1944	\$2 million	9.75	2.4	5	\$234 million
Hurricane #7	9/14/1944	\$1.5 million	9.75	2.4	4.8	\$168 million
Hurricane #11 (T.S.)	10/20/1944	minor	---	---	---	minor
T.S. #8 (T.D.)	10/12/1942	minor	---	---	---	minor
Hurricane #2 (T.D.)	8/18/1939	\$1 million	12.5	2.5	5	\$156 million
Hurricane #13	9/18/1936	\$0.1 million	12.3	2.5	5	\$15 million
Hurricane #2 (T.S.)	9/5/1935	minor	---	---	---	minor
Hurricane #8	8/23/1933	\$0.25 million	13	2.5	5	\$40 million
Hurricane #13	9/16/1933	\$4.5 million	13	2.5	5	\$731 million
Hurricane #1 (T.D.)	8/11/1928	\$0.05 million	10.1	2.5	5	\$6 million
Hurricane #4 (T.S.)	9/19/1928	\$2 million	10.1	2.5	5	\$252 million
T.S. #5	10/3/1927	no damage	---	---	---	none
Hurricane #2 (T.S.)	12/2/1925	no damage	---	---	---	none

Table 2: List of North Carolina tropical cyclones with unadjusted and normalized damage totals in 2000 dollars. The normalized totals are based on the Pielke and Landsea (1998) normalization method, including the use of the population factor.

Tropical Cyclone	Date of Landfall	Unadjusted damage	Inflation	Wealth	Population	Normalized Damage
Hurricane Irene	10/17/1999	minor	---	---	---	minor
Hurricane Floyd	9/16/1999	\$6 billion	1.03	1.02	1.01	\$6.36 billion
T.S. Dennis	9/4/1999	\$60 million	1.03	1.02	1.01	\$64 million
Hurricane Bonnie	8/26/1998	\$1 billion	1.05	1.02	1.02	\$1.092 billion
T.D. Danny	7/24/1997	\$60 million	1.07	1.03	1.02	\$67 million
T.S. Arthur	6/19/1996	no damage	---	---	---	none
Hurricane Bertha	7/12/1996	\$330 million	1.1	1.04	1.06	\$400 million
Hurricane Fran	9/6/1996	\$5.2 billion	1.09	1.04	1.06	\$6.25 billion
T.S. Jerry	8/28/1995	\$9 million	1.12	1.08	1.07	\$12 million
Hurricane Felix	8/17/1995	\$2 million	1.12	1.08	1.1	\$3 million
T.S. Opal	10/5/1995	\$70 million	1.12	1.08	1.08	\$91 million
T.D. Beryl	8/17/1994	\$1 million	1.15	1.09	1.1	\$2 million
H. Gordon	11/18/1994	\$0.5 million	1.15	1.09	1.1	\$1 million
Hurricane Emily	8/31/1993	\$50 million	1.19	1.1	1.12	\$76 million
Hurricane Bob	8/19/1991	\$4 million	1.22	1.11	1.16	\$6 million
Hurricane Hugo	9/22/1989	\$1.07 billion	1.38	1.12	1.18	\$1.836 billion
T.D. Chris	8/29/1988	\$0.5 million	1.4	1.14	1.19	\$1 million
Hurricane Charley	8/17/1986	\$3 million	1.5	1.16	1.2	\$6 million
T.S. Bob	7/25/1985	\$1.5 million	1.55	1.16	1.22	\$3 million
T.D. Danny	8/17/1985	\$2.5 million	1.55	1.16	1.22	\$5 million
Hurricane Gloria	9/27/1985	\$14 million	1.59	1.17	1.25	\$33 million
T.S. Kate	11/23/1985	minor	---	---	---	minor
Hurricane Diana	9/13/1984	\$79 million	1.64	1.18	1.22	\$187 million
Hurricane Josephine	10/12/1984	minor	---	---	---	minor
T.S. Dennis	8/20/1981	\$10 million	2.07	1.26	1.25	\$33 million
T.S. David	9/5/1979	\$15 million	2.31	1.3	1.3	\$59 million
T.D. Babe	9/9/1977	no damage	---	---	---	none
Hurricane Belle	8/9/1976	minor	---	---	---	minor
T.S. Dottie	8/21/1976	\$0.5 million	2.9	1.4	1.25	\$3 million
T.S. Eloise	9/24/1975	minor	---	---	---	minor
T.S. Agnes	6/21/1972	\$10 million	4.13	1.4	1.37	\$79 million
T.S. Doria	8/27/1971	\$1 million	4.22	1.43	1.75	\$11 million
Hurricane Ginger	9/30/1971	\$10 million	4.22	1.43	1.75	\$105 million
T.D. Alma	5/26/1970	no damage	---	---	---	none
T.S. #4	8/17/1970	\$0.5 million	4.25	1.44	2.2	\$7 million
T.D. Abby	6/8/1968	minor	---	---	---	minor
Hurricane Gladys	10/20/1968	minor	---	---	---	none
T.S. Doria	9/17/1967	minor	---	---	---	minor
T.S. Alma	6/11/1966	minor	---	---	---	minor
T.D. #1	6/16/1965	minor	---	---	---	minor
T.S. Cleo	8/31/1964	\$0.5 million	5.55	1.65	2.2	\$10 million
T.S. Dora	9/13/1964	\$0.1 million	5.55	1.65	2	\$2 million
Hurricane Gladys	9/21/1964	\$0.1 million	5.55	1.65	3.3	\$3 million
Hurricane Isbell	10/16/1964	\$1 million	5.55	1.65	4.1	\$38 million

Table 2: continued.

<u>Tropical Cyclone</u>	<u>Date of Landfall</u>	<u>Unadjusted damage</u>	<u>Inflation</u>	<u>Wealth</u>	<u>Population</u>	<u>Normalized Damage</u>
Hurricane Alma	8/28/1962	minor	---	---	---	minor
T.S. #6	9/14/1961	no damage	---	---	---	none
Hurricane Esther	9/20/1961	\$0.1 million	5.8	1.78	3.5	\$4 million
T.S. Brenda	7/30/1960	\$0.25 million	5.82	1.8	2.2	\$6 million
Hurricane Donna	9/12/1960	\$56.5 million	5.82	1.8	2.2	\$1.302 billion
T.D. Cindy	7/10/1959	\$1.1 million	5.87	1.8	2.3	\$27 million
T.S. Gracie	9/30/1959	\$0.5 million	5.87	1.8	2.3	\$12 million
Hurricane Helene	9/27/1958	\$11 million	5.96	1.9	2.4	\$299 million
T.D. Flossy	9/26/1956	no damage	---	---	---	none
Hurricane Connie	8/12/1955	\$40 million	6.4	2.06	2.2	\$1.16 billion
Hurricane Diane	8/17/1955	\$80 million	6.4	2.06	2.2	\$2.32 billion
Hurricane Ione	9/19/1955	\$88 million	6.4	2.06	2.2	\$2.552 billion
Hurricane Carol	8/31/1954	\$0.25 million	6.42	2.06	2.2	\$7 million
Hurricane Edna	9/11/1954	\$0.1 million	6.42	2.06	2.2	\$3 million
Hurricane Hazel	10/15/1954	\$254 million	6.42	2.06	2.2	\$7.39 billion
Hurricane Barbara	8/14/1953	\$1.1 million	6.5	2.08	3.5	\$52 million
T.S. Able	8/31/1952	minor	---	---	---	minor
Hurricane #1	8/24/1949	\$0.2 million	7	2.2	2.4	\$7 million
Hurricane #2 (T.S.)	8/29/1949	minor	---	---	---	minor
T.S. #6 (T.D.)	9/24/1947	minor	---	---	---	minor
Hurricane #2 (T.S.)	7/6/1946	minor	---	---	---	minor
Hurricane #5 (T.D.)	10/9/1946	no damage	---	---	---	none
Hurricane #1 (TS)	6/26/1945	minor	---	---	---	minor
Hurricane #9 (T.S.)	9/18/1945	\$2 million	9.7	2.4	2.6	\$121 million
Hurricane #3	8/1/1944	\$2 million	9.75	2.4	2.6	\$122 million
Hurricane #7	9/14/1944	\$1.5 million	9.75	2.4	2.6	\$91 million
Hurricane #11 (T.S.)	10/20/1944	minor	---	---	---	minor
T.S. #8 (T.D.)	10/12/1942	minor	---	---	---	minor
Hurricane #2 (T.D.)	8/18/1939	\$1 million	12.5	2.5	2.9	\$91 million
Hurricane #13	9/18/1936	\$0.1 million	12.3	2.5	3.1	\$10 million
Hurricane #2 (T.S.)	9/5/1935	minor	---	---	---	minor
Hurricane #8	8/23/1933	\$0.25 million	13	2.5	4	\$33 million
Hurricane #13	9/16/1933	\$4.5 million	13	2.5	4	\$585 million
Hurricane #1 (T.D.)	8/11/1928	\$0.05 million	10.1	2.5	4.5	\$6 million
Hurricane #4 (T.S.)	9/19/1928	\$2 million	10.1	2.5	4.5	\$227 million
T.S. #5	10/3/1927	no damage	---	---	---	none
Hurricane #2 (T.S.)	12/2/1925	no damage	---	---	---	none

Although the normalization procedure is highly simplified, it does give a fair comparison of tropical cyclones throughout the past 75 years. The normalization method used in this study is:

$$NL_{2000} = L_y \times I_y \times W_y \times H_{y,c} \quad (1)$$

where:

- NL<sub>2000</sub> = normalized loss to 2000 value
- y = year of storm's impact
- c = all counties affected by storm including inland counties
- L<sub>y</sub> = storm's damage (unadjusted)
- I<sub>y</sub> = inflation factor based on 2000 Consumer Price Index to that of year y.
- W<sub>y</sub> = wealth factor based 2000 fixed reproducible tangible wealth expressed as per capita (state) to that of year y.
- H<sub>y,c</sub> = housing factor, based on the change in the number of houses from year y to 2000. Data includes only counties most affected by storm, including inland counties.

For example, application of (1) to Hurricane Hazel yields the following:

$$L_{1954} = \$254,000,000 (\$72M \text{ along coast}/\$182M \text{ inland})$$

$$I_{1954} = 5.86$$

$$W_{1954} = 1.96$$

$$H_{1954} = 3.4/3.03 (3.4 \text{ used for the coastal damage}/3.03 \text{ used for inland damage})$$

Coastal counties represented include: New Hanover, Brunswick, Columbus,

Pender, Onslow, Bladen, Duplin, Sampson, and Carteret.

Normalized Total Damage:  $NL_{2000} = \$10,520,000,000$ .



The time series of normalized annual North Carolina tropical cyclone damage totals (figure 4a) reveals a different trend compared to the unadjusted trend (figure 2). Figure 4a indicates that the damage totals of the 1990's are not unprecedented although over \$13 billion in damage occurred from 1996-1999, the active hurricane period of the mid 1950's would have caused over \$18 billion in damage had these storms taken place in 2000. In between these active periods in the 1950's and 1990's, there was relative calm. Only four storms provided significant damages to North Carolina during the period of 1956-1995. In those forty years, only hurricanes Helene (1958), Donna (1960), and Diana (1984), and Hugo (1989) caused greater than \$200 million damage. Not coincidentally, greater trends in coastal construction and population growth occurred during the 1960's through the early 1990's. The North Carolina tropical cyclones included in this study are listed in Appendix A along with the date of landfall, intensity at landfall, area of landfall, unadjusted and normalized damage totals.

Figure 4b shows a comparison graphically of the normalized damage totals based on the housing vs. population factor. There is less divergence in damage totals of more recent tropical cyclones as compared to earlier tropical cyclones. The coastal construction boom of the 1960's and 1970's is a reason for the greater divergence between the housing and the population factor prior to 1961.

### **C. Interpretation of Damage Data**

Pielke and Landsea (1998) concluded that the majority of tropical cyclone damage (over 83%) in the United States was caused by major hurricanes (Saffir-Simpson categories-3,4, and 5). However, on a regional scale, the percentage attributed to major hurricanes can be different than the 83% for the U.S. in general. Table 3a summarizes

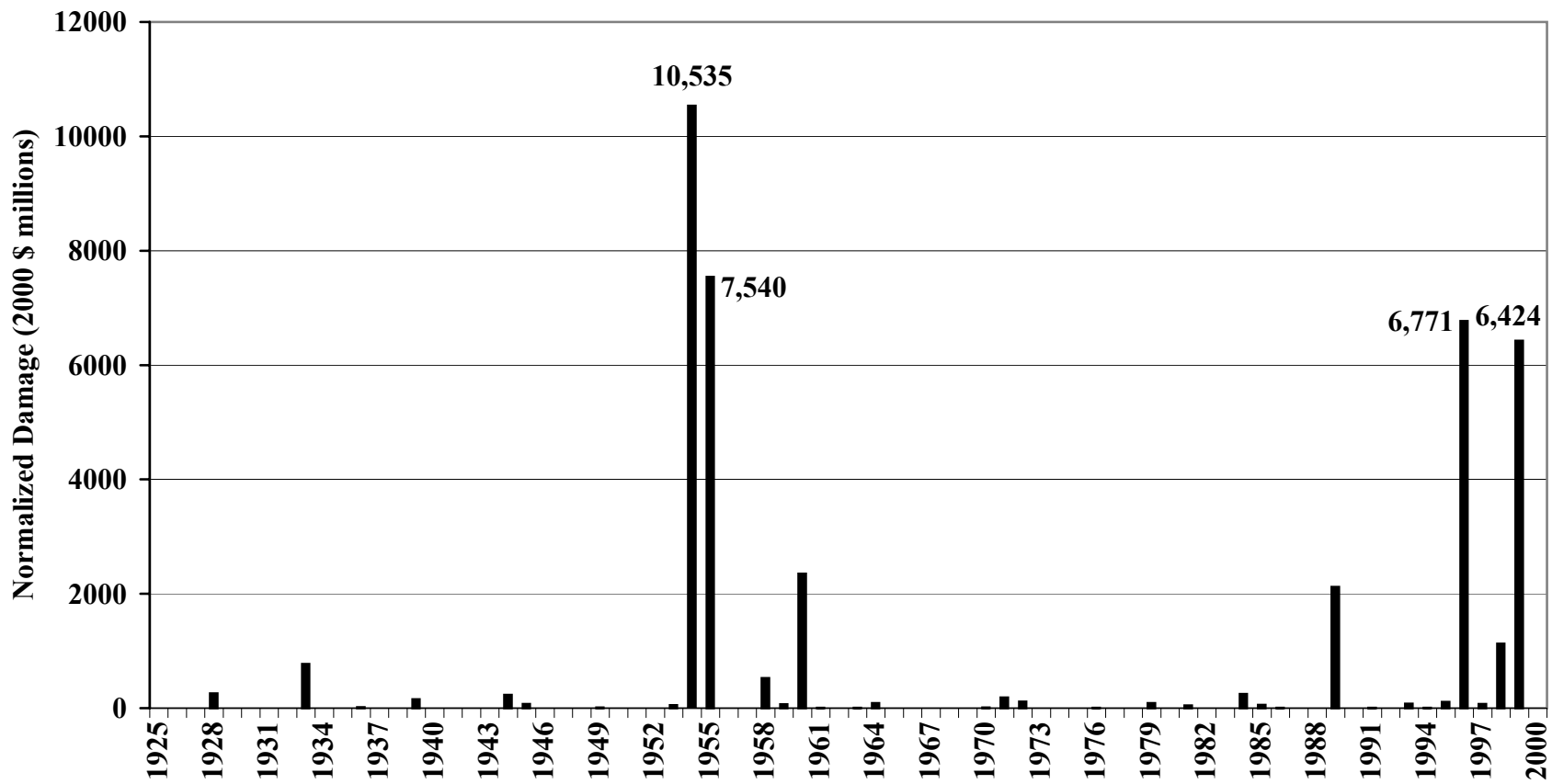


Figure 4a. Annual North Carolina tropical cyclone damage totals from 1925-2000 normalized to 2000 values. Normalization takes into account inflation, changes in wealth and housing trends.

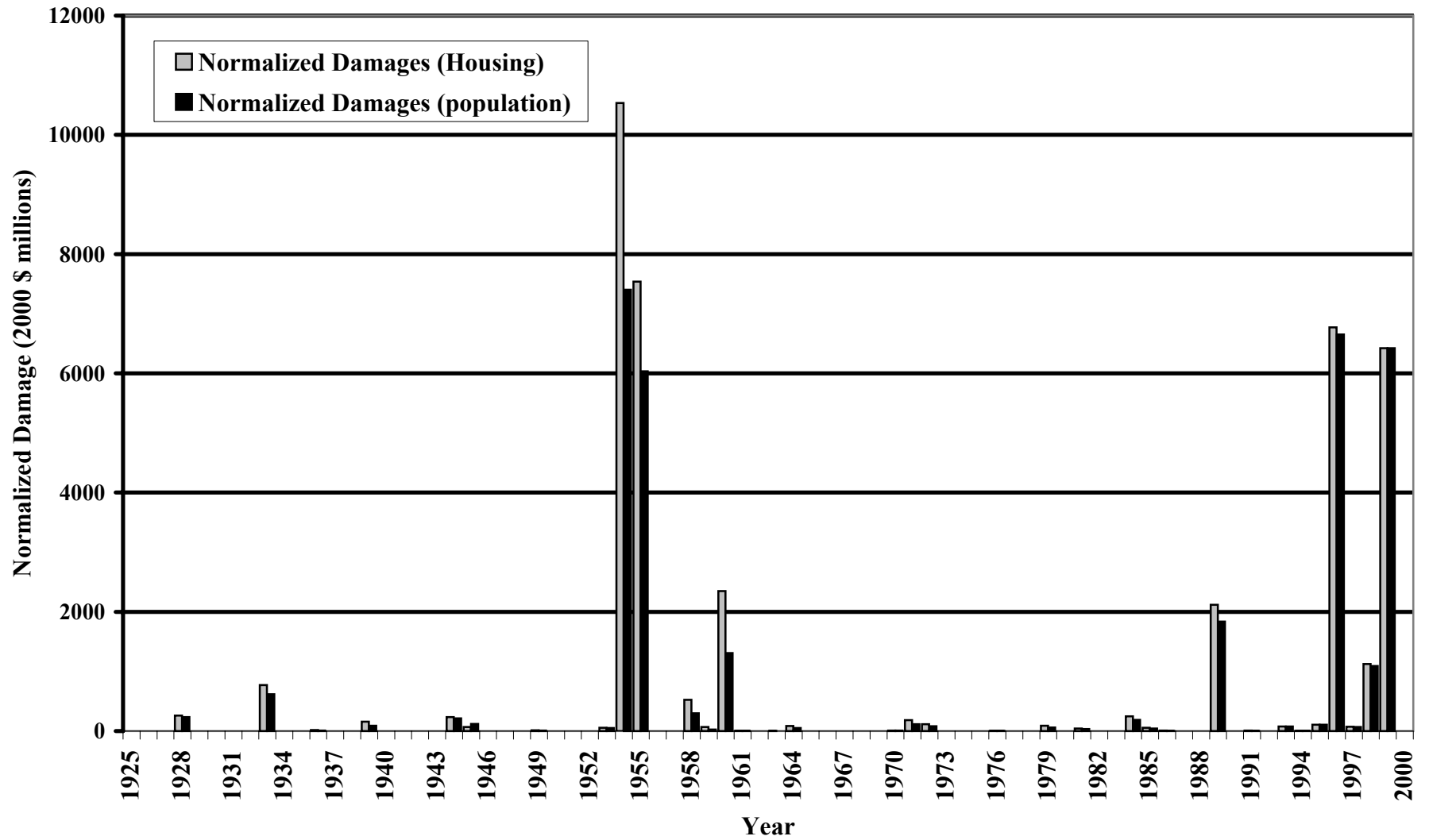


Figure 4b. Comparison of annual North Carolina tropical cyclone normalized damage totals from 1925-2000 based on housing vs. population factor. Damage totals are normalized to 2000 values.

the mean damage, total damage and percentage of total damage for each tropical cyclone category (normalized to 2000 values using the housing factor). For comparison, table 3b summarizes the same damage statistics but is based on the population factor instead of the housing factor. The tropical cyclones are separated into categories based on the intensity at landfall from tropical depression up to category-5 hurricane. The number of total storms per category is in parentheses. The mean damage for each category is just the total damage per storm. The percentage of total damage is the total damage for each category per the total amount of damage of all categories together. The major hurricane contribution of total damage in North Carolina is only 70%. This is lower than the 83% for the U.S. (Pielke and Landsea, 1998). Although category-3 hurricanes account for 41.7% of the total, the mean damage is relatively close for category-2 and 3 hurricanes. Category-2 hurricanes added a significant 21.4% to the total. A large part of North Carolina damages is due to coastal and inland flooding from weaker hurricanes and tropical storms, especially Hurricane Floyd (1999). Although the dataset is small (only 36 tropical cyclones included), it is an inherent problem in tropical cyclone studies that use a similar time frame. Just as Hurricane Floyd weighs heavily on category-2 storms, Hurricane Hazel was the only category-4 hurricane to hit North Carolina over the past 100 years. The risk assessment for North Carolina indicates a clear fact--North Carolina has a significant damage risk from category-2 hurricanes. This can be explained by the fact that category-2 hurricanes are destructive both by wind and flooding potential. It should be noted, however, that major hurricanes still cause the greatest damage per storm and should not be understated.

Table 3a. Damage statistics from direct landfalling North Carolina tropical cyclones (1925-2000) based on housing data.

<u>Category of Storm</u>	<u>Mean Damage*</u>	<u>Total Damage*</u>	<u>Total Damage (%)</u>
Tropical Depressions (2)	4.5	9	0.02
Tropical Storms (9)	14	125	0.34
Hurricane Cat. 1 (8)	383	3062	8.2
Hurricane Cat. 2 (6)	1327	7962	21.4
Hurricane Cat. 3 (10)	1549	15,487	41.7
Hurricane Cat. 4 (1)	10,520	10,520	28.3
Hurricane Cat. 5 (0)	0	0	0

Total Damage (36) \$37.165 billion

Percentage of damage due to major hurricanes: 70%.

Parentheses indicate the number of storms for each category.

\*Damage figures (in \$ millions) are normalized to 2000 values.

Housing factor was used in normalization of the data to 2000 dollar values.

Table 3b. Damage statistics from direct landfalling North Carolina tropical cyclones (1925-2000) based on population data.

<u>Category of Storm</u>	<u>Mean Damage*</u>	<u>Total Damage*</u>	<u>Total Damage (%)</u>
Tropical Depressions (2)	3.5	7	0.02
Tropical Storms (9)	12	108	0.35
Hurricane Cat. 1 (8)	330	2643	8.7
Hurricane Cat. 2 (6)	1317	7902	26
Hurricane Cat. 3 (10)	1235	12,348	40.6
Hurricane Cat. 4 (1)	7,390	7,390	24.3
Hurricane Cat. 5 (0)	0	0	0

Total Damage (36) \$30,398 billion

Percentage of damage due to major hurricanes: 64.9%.

Population factor was used in normalization of the data to 2000 dollar values.

Damage assessment studies can also focus on the characteristics of individual storms and how hurricanes of different intensity, flooding potential, and coastal impacts can cause different types of damage. Figures 5a,b illustrate the damage to specific sectors for Hurricane Andrew in South Florida and Hurricane Floyd in eastern North Carolina. The statistics are the result of a compilation of sources including Pielke and Pielke (1997), *The Miami Herald, News & Observer*, National Climate Data Center, National Hurricane Center, and the Hurricane Floyd Economic Impact Report (FEMA, 1999). Both hurricanes caused record unadjusted damage to each region. However, two different aspects caused the damages-high winds and 500-year flood levels. The majority of the damages from both storms were to private property. However, there was a significant difference in the business/jobs and agriculture sectors. Andrew caused a devastating blow to Dade County businesses totaling almost \$6 billion (23%), but because Andrew was so localized, agricultural losses only contributed to 4% of the total losses. Contrarily, 17% of Floyd's impacts were to agriculture. Animal farms and crops over much of the eastern third of the state were flooded. By focusing on the mechanisms that cause damage, a better risk assessment can be made.

#### **D. Separation of damages**

Separating tropical cyclone damage totals into three categories based on the three most damaging aspects-wind, flooding, and storm surge was attempted. Wind damage includes the combination of the central circulation, straight-line winds from associated squall lines, and tornadoes directly related to the tropical cyclone. Flood damage, highly influenced by secondary factors such as previous rainfall and flood susceptibility, includes freshwater flooding unassociated with storm surge. This includes inland

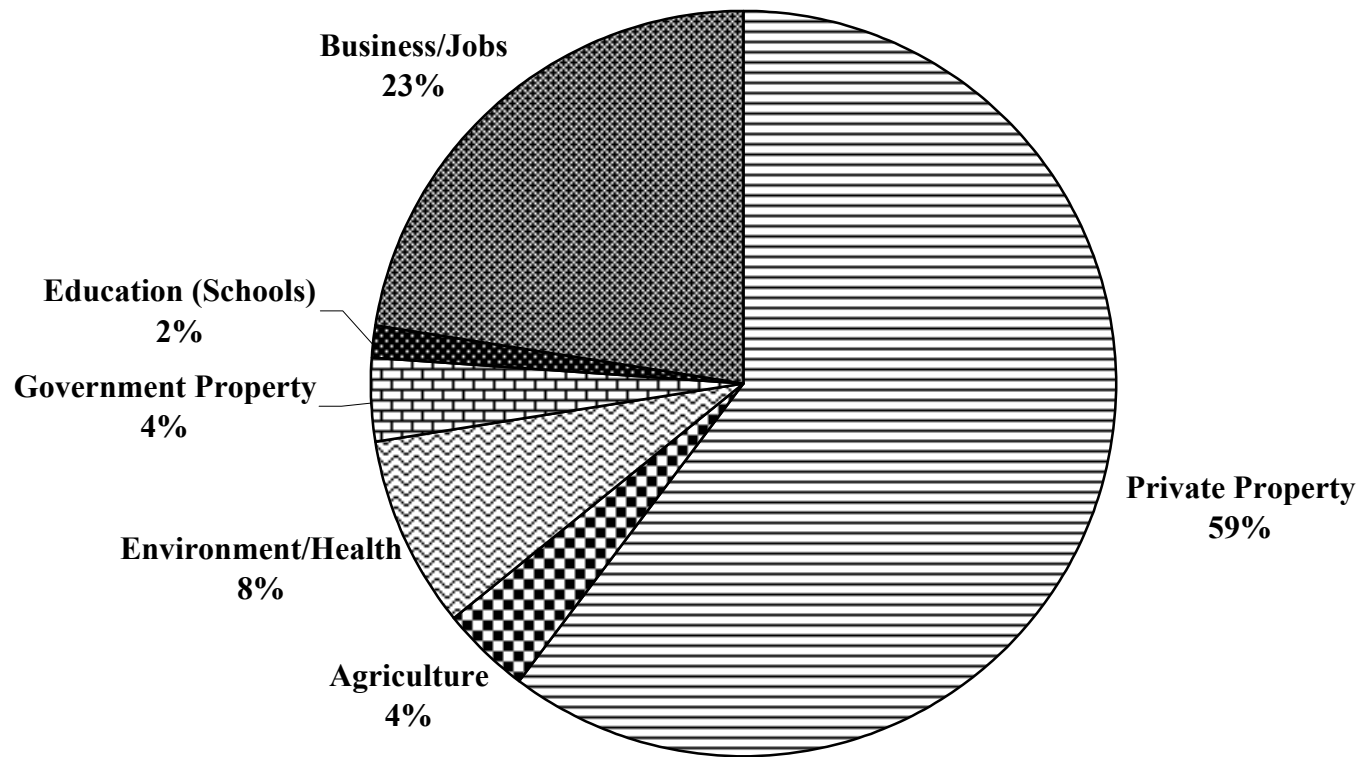


Figure 5a. Hurricane Andrew (1992) damage (%) distribution for individual sectors.

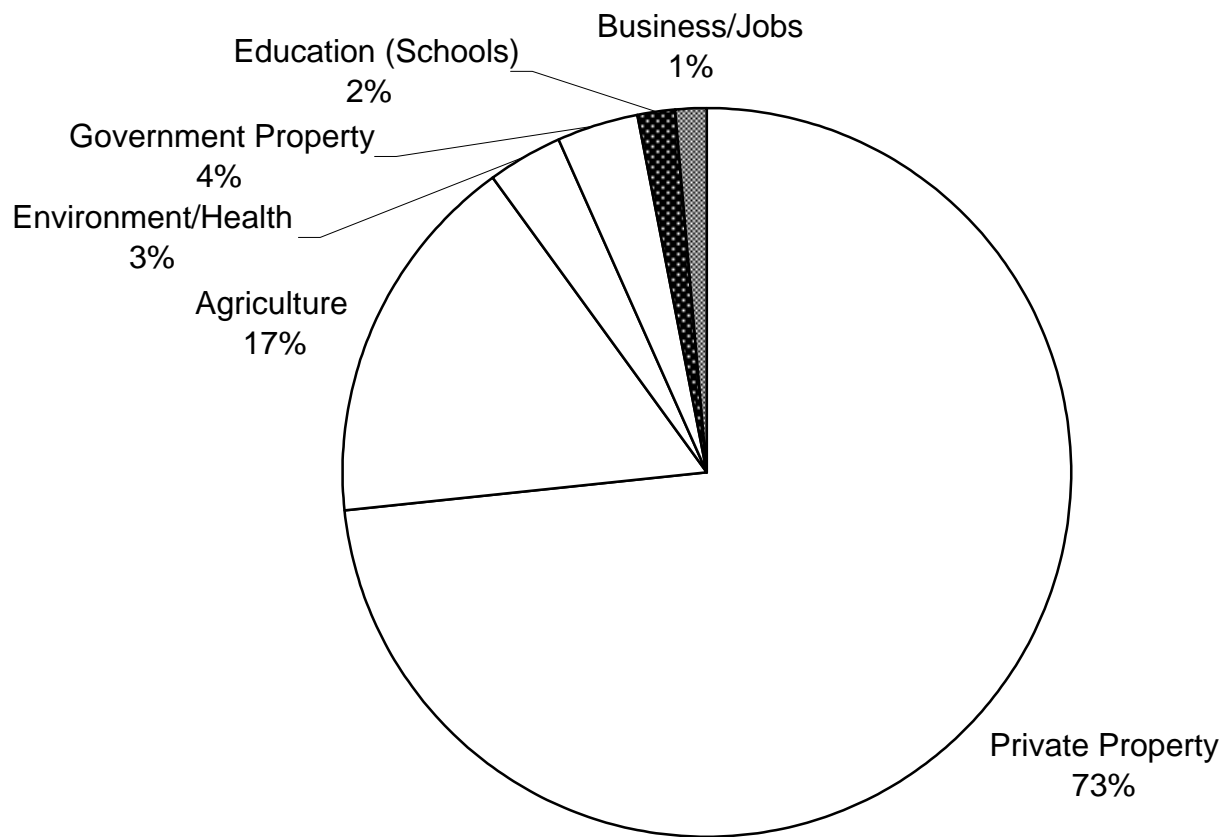


Figure 5b. Hurricane Floyd (1999) damage (%) distribution for individual sectors.