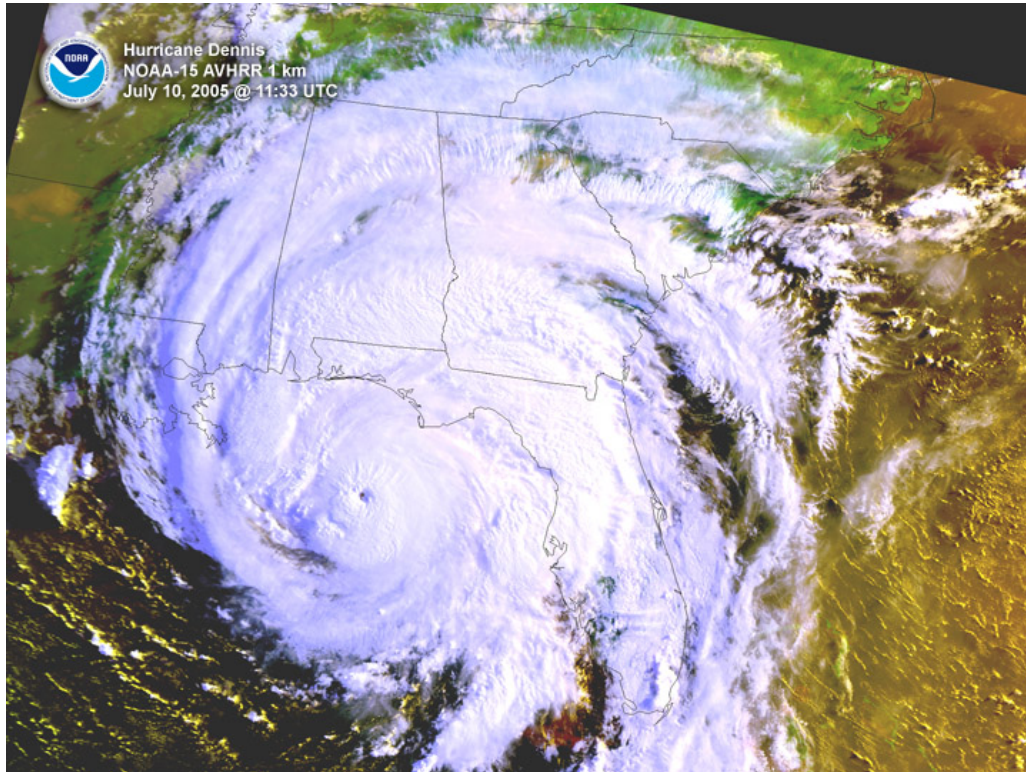


A Comparative Analysis of Hurricane Dennis and Other Recent Hurricanes on the Coastal Communities of Northwest Florida

By Ralph Clark and James LaGrone



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**Bureau of Beaches and Coastal Systems
Florida Department of Environmental Protection**

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Abstract

Northwest Florida has been directly impacted by nine hurricanes and sustained major fringe impacts from three other major hurricanes between 1972 and 2005, or roughly one hurricane every three years (Figure 1). The Bureau of Beaches and Coastal Systems of the Florida Department of Environmental Protection and predecessor agencies have monitored and assessed the impact of most of these hurricanes on northwest Florida's beaches and coastal construction during the past three decades. Much of the information on these hurricanes has been published in Bureau reports of post-storm beach conditions and coastal impact with recommendations for recovery. Post-storm reports are available for at least eight of these hurricanes. As this data base of storm damages continues to grow, comparisons can be made for different northwest Florida beach communities. There are both similarities and differences in each storm's impact on a coastal community from which we may learn and plan for the future.

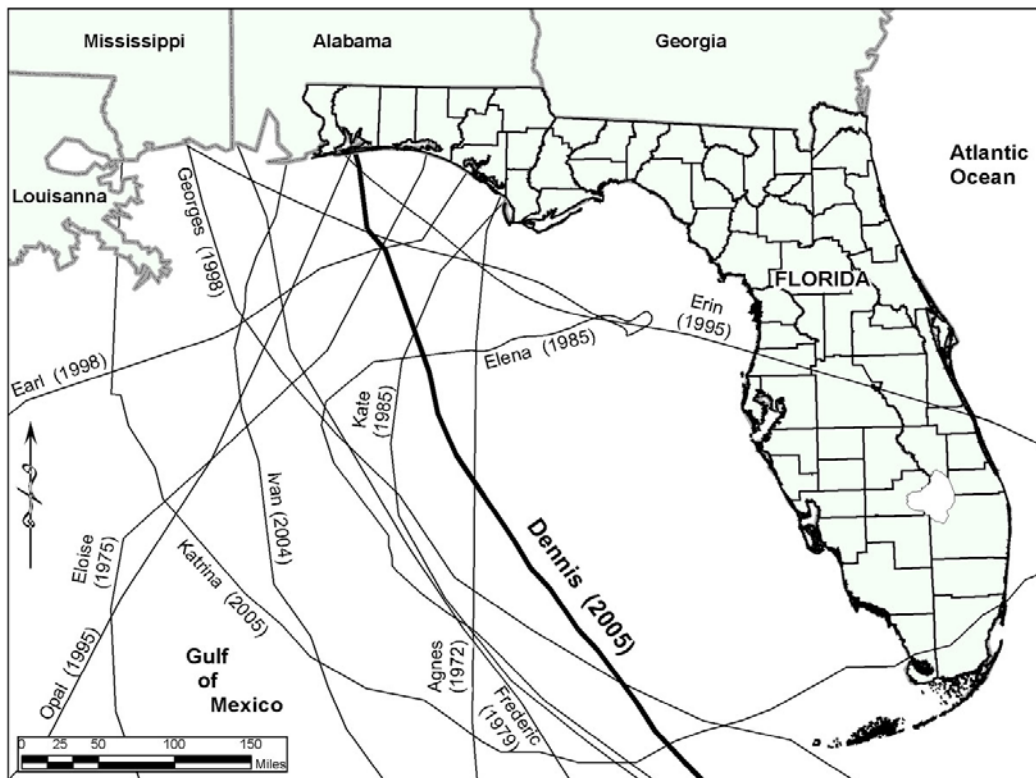


Figure 1. Northwest Florida hurricane tracks (1972-2005).

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Introduction

Hurricane Dennis, the first hurricane of the 2005 hurricane season for the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico, made landfall June 10th, on Santa Rosa Island, Florida, between the beach communities of Pensacola Beach and Navarre Beach. Dennis made landfall as a category three hurricane on the Saffir-Simpson hurricane intensity scale with winds of 115 to 120 mph. Major beach and dune erosion was sustained throughout northwest Florida between Pensacola Pass and the St. Marks River. In Navarre Beach, to the immediate east of the eye at landfall, a storm tide of +15 feet was measured. Dennis destroyed or substantially damaged 448 major structures within the Coastal Building Zone from Escambia through Wakulla County, including 209 major structures located seaward of established Coastal Construction Control Lines between Escambia and Franklin County.

During the past 35 years, the impacts of hurricanes on the beaches and coastal construction of northwest Florida have been observed, and a significant quantity of erosion and damage data have been collected. The effects of these hurricanes can be compared to the effects of Hurricane Dennis, and various conclusions may be drawn that should be considered when developing post-storm recovery strategies and future hazard mitigation planning.

Table 1 provides a summary of the major damage to major structures within the Coastal Building Zone of northwest Florida since the impact of Hurricane Agnes in 1972. Although substantial damage occurred during both Agnes and Hurricane Eloise (1975), direct comparative data is not available. Various post-storm reports published by the Department are available for storms since Hurricane Frederic (1979), and unpublished field data also exists for many of the storms, including storms of less than hurricane intensity.

Hurricane Dennis was unique among all recent hurricanes because all eight northwest Florida coastal counties sustained a significant impact to its beaches, dunes, and coastal development. The impact of Dennis is compared to prior recent hurricanes in each coastal community. While Dennis was typically not the worse storm event in any particular area, it was generally the third or fourth worse storm in every community over the past 30 years. In addition, after Opal and Ivan, the overall impact to the coast of northwest Florida was probably most severe due to Hurricane Dennis.

Table 1. Number of Major Structures with Major Damage within the Coastal Building Zone of Northwest Florida from Hurricanes between 1972 and 2005. Please note N.A. denotes that substantial damages occurred, but comparative data is not available.

County	Agnes (1972)	Eloise (1975)	Frederic (1979)	Elena (1985)	Kate (1985)	Erin (1995)	Opal (1995)	Earl (1998)	Georges (1998)	Ivan ² (2004)	Dennis (2005)	Katrina (2005)	Total Hurricanes ³ (1972- 2005)
Escambia	-	-	96	-	-	14	124	-	8	231	126	2	601
Santa Rosa	-	-	5	-	-	20	106	-	6	71	133	2	343
Okaloosa	-	-	-	-	-	-	229	-	2	194	47	2	474
Walton	-	N. A.	-	-	-	-	165	-	-	11	36	14	226
Bay	-	N. A.	-	-	6	-	471	-	17	12	8	-	514
Gulf	-	-	-	-	31	-	26	2	-	3	9	-	71
Franklin	N. A.	-	-	22	159	-	8	8	-	1	52	-	250
Wakulla	N. A.	-	-	1	46	-	-	-	-	-	37	-	84
Northwest Florida	N. A.	N. A.	101	23	242	34	1129	10	33	523 ⁺	448	20	2563 ⁺

² Please note that complete data records were not obtained for Hurricane Ivan in Escambia and Santa Rosa Counties.

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Storm Comparisons in Escambia, Santa Rosa, and Okaloosa Counties

The western barrier islands of Perdido Key (Escambia County) and Santa Rosa Island (Escambia, Santa Rosa, and Okaloosa Counties) sustained impacts from Hurricanes Frederic (1979), Erin (1995), Opal (1995), Georges (1998), Ivan (2004), Dennis (2005), and Katrina (2005) (Figure 2). The differences in storm strength, track, and location of landfall were important elements differentiating the level, type, and location of damages in each beach community. The nature and design adequacy of construction were also major factors.

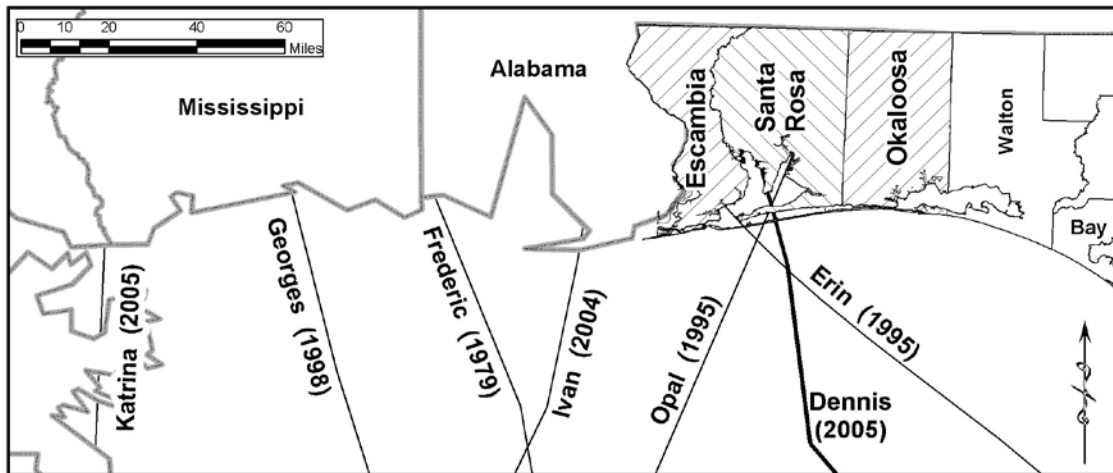


Figure 2. Hurricane landfall locations relative to Escambia, Santa Rosa and Okaloosa Counties.

Hurricane Frederic (1979)

Hurricane Frederic made landfall as a large category three hurricane to the west on the Alabama coast of Dauphin Island. Frederic destroyed the bridge crossing Mobile Bay to Dauphin Island as well as numerous beach houses along Dauphin Island and Gulf Shores, Alabama. In Florida, Escambia County sustained a significant impact by being to the east of the eye, and a well established dune system was damaged throughout western Santa Rosa Island. Most of Frederic's damage to development in Pensacola Beach was by storm surge flooding (+12 feet), erosion, and wave damage (Balsillie and Clark, 1979). Numerous grade level structures on soil bearing foundations were destroyed or substantially damaged along the beach front. In Navarre Beach, a new concrete pier was damaged along with a few single-family dwellings. Although the damage numbers shown in Table 1 are similar to those seen with Dennis in Pensacola Beach, the nature and location of damages differ. The directions of strongest winds were roughly opposite for these two storms, but their storm surges were comparable. The gulf front development exposed to Dennis was also of a different character, because most all existing structures were elevated on substantial pile foundations.

Hurricane Erin (1995)

Between 1979 and 1995, west Florida witnessed substantial growth in development. New beach front structures replacing those destroyed in Frederic had to meet the coastal construction regulatory standards to withstand the storm surge, waves, erosion, and wind loads of a 100-year frequency storm event. Hurricane Erin's impact in Pensacola Beach on August 3, 1995, was only a prelude to major impact when it made landfall as a small category two hurricane with a peak wind gust measured at the Pensacola Naval Station of 101 mph. Erin's track was to the west-northwest, which took the eastern eye wall over Gulf Breeze and northeast Pensacola where it inflicted its worst wind damage. More than 2000 homes were reported damaged primarily by Erin's wind in northwest Florida. Because Pensacola Beach received predominantly leeside winds during Erin, as during Dennis, only minor beach erosion was sustained and the worst flooding and wind damage was from the Santa Rosa Sound side and near the east end of the community. Even though Erin caused some flooding damage from the sound side, Dennis provided a greater impact from sound flooding, which substantially damaged or destroyed many old grade-level dwellings.

In contrast to Pensacola Beach, Navarre Beach was in the stronger land falling wind field of both Erin and Dennis, and received the greatest damage in northwest Florida from both storms. The location of Erin's track at landfall was strikingly similar to Hurricane Dennis. However, Dennis contrasted to Erin by being a major hurricane and tracking more north-northwest bringing a higher storm surge from the gulf and inflicting higher winds from the northeast out of the leeside eye wall. Erin's surge was about three to four feet at Pensacola Beach, and six to seven feet in Navarre Beach where it was comparable to a 20-year storm event (Dean and Chiu, 1986).

Hurricane Opal (1995)

Two months after Erin's landfall, Hurricane Opal made landfall on October 4th, with the center of the eye passing over Pensacola Beach in the vicinity of the public beach, Casino Beach. Opal was basically a coastal regulatory program's design event, inflicting erosion, scour, overwash, storm surge, and wave forces on the level for which habitable major structures are required to be designed when located seaward of a coastal construction control line or within a coastal building zone (Leadon, Nguyen, and Clark, 1998). A good data base of damage information was obtained by the Bureau of Beaches and Coastal Systems to include aerial photography, aerial videography, ground videos, ground slides, and field notes of all major damage. This data remains available to compare with the damage from Dennis. Most gulf-front nonconforming structures were destroyed or substantially damaged by Opal. Infrastructure, including roads and utilities, were severely damaged and reconstruction of services took several months to return to normal. Opal inflicted a 10-foot storm surge in Pensacola Beach, a 12-foot storm surge in Navarre Beach (comparable to a 200-year event; Dean and Chiu, 1986), and a 12 to 14-foot storm surge in Okaloosa County (comparable to a 500-year storm event; Dean, Chiu, and Wang, 1991), and inflicted a significant impact on construction located two and three properties inland of the beach. While only the western 4.8 miles of Pensacola Beach was considered critically eroded before 1995, all 8.2 miles was designated critically eroded after 1995,

along with all Navarre Beach and the developed beaches of eastern Santa Rosa Island near Ft. Walton Beach (Clark, 1993).

Opal's erosion conditions and damage greatly exceeded the impact of Dennis, yet both storms made landfall as category three hurricanes. The primary difference in Pensacola Beach was landfall location, as the community received a direct impact from Opal, and was on the weaker lee side of Dennis. Opal caused major beach and dune erosion, and there were documented significant offshore and overwash losses of beach material. After Opal, beach restoration planning was initiated, and prior to Ivan (2004) and Dennis, the beach restoration project was completed. In Navarre Beach, the specific number of structures damaged by Dennis was similar to the number damaged by Opal; however, the level of damage to most of the damaged structures was considerably less during Dennis. Out of 108 gulf-fronting structures in 1995, Opal destroyed or substantially damaged 98 of them (over 90 percent). The structures that Opal destroyed did not meet the current coastal building requirements, and were impacted by the combined effects of severe erosion, storm surge flooding, and wave action. The impact of Opal's storm surge with wave action was severe, causing a number of structures to be carried 200 to 300 feet inland of their original location. Near the east end of Navarre Beach between R208 and R209 a major washover was experienced causing the seaward unit of a multifamily building to be destroyed even though it was located over 700 feet from the beach. Two other townhouse units on Santa Rosa Sound located about 1400 feet inland of the beach were also destroyed. Another single-family dwelling was swept completely off Santa Rosa Island and deposited well offshore into Santa Rosa Sound. The 15-foot storm surge from Dennis had much fewer nonconforming structures to impact, as most had previously been removed after Opal and Ivan. Dennis inflicted perhaps more wind damage to structures not destroyed by the storm surge and waves. The peak wind of Opal was estimated to have been about 115 mph at Navarre Beach, while the peak wind for Dennis was measured at 121 mph.

History finally caught up with Okaloosa County in 1995 with Opal's severe impact. Hurricanes Camille (1969), Frederic (1979), and Erin (1995) were far enough west, and Eloise (1975), Elena (1985) and Kate (1985) were far enough east so as only to leave minor to moderate beach and dune erosion along the county's coast with no major damage. Frederic did cause a breakthrough at Norriego Point between East Pass and Old Pass Lagoon. Though other prior storms spared the Okaloosa County coastline, Opal inflicted its maximum winds in combination with severe flooding and erosion. The storm tide of Opal was generally considered to be between 12 and 14 feet throughout Okaloosa County. At R8, inside a motel 400 feet from the beach, a mud line was measured to be +14.13 feet NGVD. Such a storm tide is well over a 500-year storm for the area (Dean, Chiu, and Wang, 1991). The winds of Opal were at their highest in western Okaloosa County, with a peak gust of 144 mph being measured at Hurlburt Field and another peak gust of 115 mph being measured at Eglin Air Force Base.

Most of Opal's damage was in the seaward tier of beach front development; however, on Santa Rosa Island near Ft. Walton Beach, 15 of the 70 damaged major structures were located between 600 and 800 feet inland from the beach, including three dwellings inland of Santa Rosa Boulevard that were destroyed (one by wind and two by storm tides). Another 28 of the 76 damaged major structures in the Holiday Isles section of Destin were

damaged inland of Gulf Shore Drive, including three dwellings destroyed over 1000 feet from the beach and seven dwellings destroyed between 500 and 700 feet from the beach. Clearly Opal, with its higher storm tides in Okaloosa County, inflicted far greater damage than did Dennis. Opal made landfall only a few miles further west than Dennis made landfall, but the storm surge was significantly greater in Okaloosa County and many more structures existed which were nonconforming to the current hurricane resistant building standards.

Hurricane Georges (1998)

1998 brought to northwest Florida the outer fringe impact of Hurricane Georges, which made landfall west of Florida near Biloxi, Mississippi. Wind gusts along Pensacola Beach approached hurricane force and the Pensacola Naval Station recorded a peak gust of 70 mph. Storm tides of about eight feet brought significant flooding, substantial overwash of sand, and major beach and dune erosion (Leadon, Clark, and Nguyen, 1999). The already eroded beach conditions following Opal were aggravated. Significant road damage was incurred along Ariola Drive and the beach throughout Pensacola Beach was severely eroded. Damages from Georges were substantially less than from Dennis, but the erosion conditions from Georges were much greater in Pensacola Beach. Georges hastened the planning and design of a beach restoration project, which was completed in 2003.

The fringe impact of Hurricane Georges to Navarre Beach was comparable to the fringe impacts of Frederic (1979) and Katrina (2005), and substantially less than the direct impacts of Dennis, Erin and Opal. Major beach and dune erosion was sustained during Georges and much of the island road was covered with sand as the storm surge overtopped the low island elevations. Storm tides of over 8 feet flooded across Navarre Beach from gulf to sound in numerous locations. These storm tides were comparable to a 35-year frequency event (Dean and Chiu, 1986). The only major damage to several Navarre Beach structures was due to winds. Georges had a minor fringe impact on Okaloosa County. Except for a couple local problem spots, the county sustained only minor beach and dune erosion, which was significantly less than Dennis, Opal, or Ivan. Damage was also minimal, as only two buildings on eastern Santa Rosa Island sustained major damage due to winds and 200 feet of bulkheads were destroyed on Norriego Point. The four to five-foot storm tides in Okaloosa County were between a five to 10-year frequency event (Dean, Chiu, and Wang, 1991) and generally half the amplitude experienced during Dennis.

Hurricane Ivan (2004)

The impact from Hurricane Ivan was unquestionably Pensacola Beach's worst storm impact in recent history. Fortunately, the beach restoration project was completed and much of the new beach front development was of an improved design, or damage, high as it was, would have even been greater. A substantial data set of the damage is available for comparison to other storms impacting Pensacola Beach. Local officials did report 869 of the 975 residential homes and businesses in Pensacola Beach were substantially damaged or destroyed. The Bureau of Beaches and Coastal Systems and the Beaches and Shores Resource Center (BSRC) obtained data on most of the significant damage (Leadon et al, 2004). Also, beach restoration project engineers, Olsen Associates, Inc., obtained post-

storm beach profiles throughout the project to calculate an erosion loss of approximately 3 million cubic yards above the -14-foot contour (Browder, 2004). This compares with an estimated loss of 450,000 cubic yards of sand from the project area during Hurricane Dennis, including an estimated loss of 125,000 cubic yards of sand derived from the post-Ivan FEMA emergency berm (Browder, 2005).

Pensacola Beach was positioned about 40 miles east of the eye's landfall at Gulf Shores, Alabama. Perdido Key and Santa Rosa Island sustained the worst of the open coast storm surge. A +12.2-foot storm tide measured after Ivan in Pensacola Beach (comparable to the +12 storm tide of Frederic) was equivalent to a 200-year frequency event (Wang and Manausa, 2005). In contrast, Dennis' maximum winds were pushing water against the sound side of Santa Rosa Island, and Pensacola Beach was spared the worst of the onshore winds at landfall. The storm tide of Dennis was likely between a 25 to 50-year frequency event for Pensacola Beach. Additionally, some of the beach losses sustained during Ivan were renourished prior to the impact of Dennis. Still, Dennis' damage figures seem relatively high for a leeside storm impact and due to the protection provided by the beach restoration project. Over half of the damage was due to the wind, and many structures could have been weakened by Ivan and prior storms. Additionally, the "boarding up" of structures often concentrates on the seaward side, whereas, Dennis impacted the structures from their "back side". The flood damage of Dennis was also severe from the sound side as opposed to the gulf side.

Hurricane Ivan brought storm tides measured between +10.4 and +11.6 feet along the beach front in Navarre Beach. Assuming an average storm tide of +11 feet, this was in excess of a 100-year frequency event. Ivan's highest measured wind near Navarre Beach was reported to be 81 mph at the Loop Tower on Eglin Air Force Base. The nature of Ivan's damage in Navarre Beach was similar to that sustained during Opal, which was predominantly due to the storm surge, erosion, and waves. With greater wind velocities during Dennis (121 mph at Navarre Beach and 110 mph at the Loop Tower), there were more wind damaged structures than during Ivan, yet less storm surge related damage than seen in Ivan notwithstanding the greater storm surge of +15 feet during Dennis. The less storm surge related damages during Dennis was substantially related to the fact that virtually all the gulf-front nonconforming structures had previously been destroyed or removed during or following Opal and Ivan. The continued severe erosion conditions from each storm have a cumulative effect on the adequacy of pile foundations of gulf-front structures, even though they were originally designed and authorized meeting the coastal building standards for a 100-year storm event. An adequately designed pile foundation for a 100-year frequency event built before August, 1995, in Navarre Beach would have now experienced three storm events equal to or greater than a 100-year event, plus one 35-year event and two 25-year events in a 10-year period.

Hurricane Ivan's impact was comparable to the impact of Opal in the Ft. Walton Beach area of Santa Rosa Island and substantially greater than the impact of Dennis. The 104 major structures with major damage from Ivan were somewhat larger in number than were damaged during Opal, yet the overall impact appeared equivalent. Although significant recovery had taken place following the impact of prior storms, the beach and dune system that Ivan impacted was narrower than that which existed prior to Opal. Dunes had

recovered significantly less between Ivan and Dennis, yet Dennis only inflicted a fraction of the impact of Ivan with only 11 major structures sustaining major damage. Storm tide measurements following Ivan are somewhat confusing with two measurements obtained near each other reflecting a storm tide of +8.5 feet and +13.8 feet. The BSRC storm tide model provided results consistent with the +8.5-foot measurement, which would be equivalent to about a 25-year frequency event (Dean, Chiu, and Wang, 1991). The +13.8-foot measurement (surveyed from a water line inside an enclosed building) would have been equivalent to a 500-year storm event. Based upon the storm surge flooding and overwash deposits observed throughout the community, it appeared that the storm tide was comparable to a 100-year frequency event which would be +11.4 feet. This storm tide height would also be about midway between the two measured elevations.

While comparing Ivan to Opal in the Ft. Walton Beach area is very difficult given the similar impacts, both storms' impacts were substantially greater than that of Dennis. An additional noticeable difference was seen along the northern Santa Rosa Sound shoreline behind the island where the storm surge of both Opal and Ivan caused severe flooding seaward of U.S. Highway 98 in Mary Esther and Ft. Walton Beach. At one location on U.S. 98, the storm tides of both Opal and Ivan carried large yachts completely across the highway and deposited them in the same outlet center parking lot. The storm tide of Dennis had only a minor impact on the Santa Rosa Sound shoreline and no significant flooding of the highway occurred. Further east, between Ft. Walton Beach and Destin, the storm tides of Opal and Ivan caused a major breach through U.S. Highway 98, while the storm tide of Dennis was substantially less impactful.

In Destin, Ivan inflicted much greater impact than Dennis. The 70 major structures sustaining major structural damage in Destin from Ivan is comparable to the 76 major structures substantially damaged by Opal, but twice the 35 major structures damaged by Dennis. The level of damage to the structures seen after Opal was greater than that which was apparent after Ivan, but both storms were significantly more impactful than Dennis was in this area. Near the tip of Norriego Point, Ivan caused a small breach. But Frederic (1979) and Opal created a major break-through across Norriego Point, which had to be closed by the U.S. Army Corps of Engineers during post-storm maintenance dredging projects in East Pass. The wave activity from Dennis prevailed from the southeast in this area and therefore the East Pass shoreline along Norriego Point was sheltered from the inlet's east jetty and no damage or breaching occurred. There was an additional setup of the storm tide to the east of the east jetty causing significant flooding in the Lands End Drive area, which was nearly comparable to the flooding seen during Ivan. This area, which is all located seaward of the Okaloosa County Coastal Construction Control Line, was not developed prior to Opal, or greater damage would have been sustained by the development that was subsequently constructed in a lagoonal depression.

Storm Comparisons in Walton and Bay Counties

Walton and Bay Counties were most affected by Hurricanes Eloise (1975), Opal (1995), Earl (1998), Georges (1998), Ivan (2004), and Dennis (2005) (Figure 3). The existence or lack of a beach restoration project played an important role in these counties when

comparing their hurricane impacts. In addition, the proximity of structures to the beach was also a major factor.

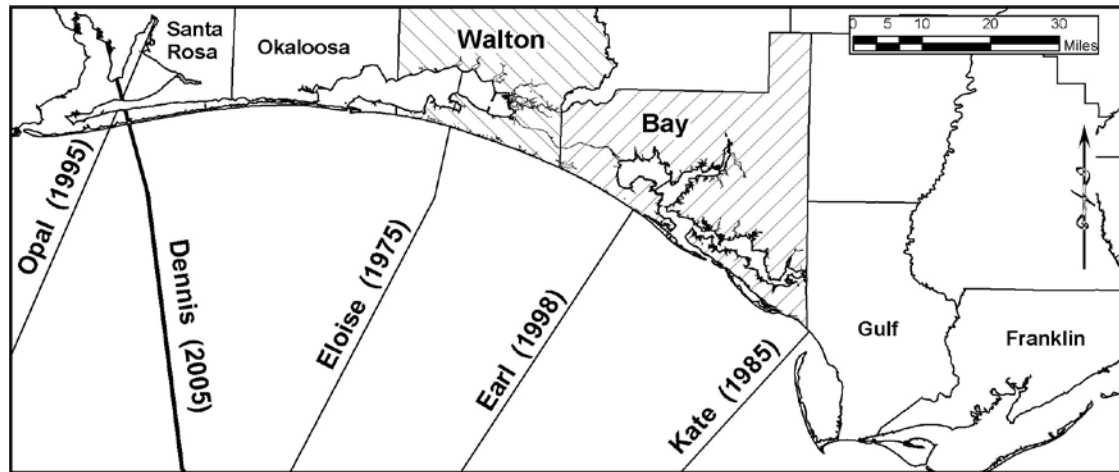


Figure 3. Hurricane landfall locations relative to Walton and Bay Counties.

Hurricane Eloise (1975)

In recent history, Eloise is the only hurricane to make landfall in Walton County. The center of the eye of Eloise made landfall at Dune Allen, about two miles west of Grayton Beach. The Bureau of Beaches and Coastal Systems' predecessor agency, the Bureau of Beaches and Shores, did not prepare a post-storm report describing damages for Eloise; therefore, definitive damage information remains unrecorded. It is important to note that the coast of Walton County was largely undeveloped in 1975, with the exception of the beach communities at Miramar, Dune Allen, Blue Mountain Beach, Grayton Beach, and Seagrove Beach, and even these areas existed as a small fraction of their current development. Only a few dwellings were damaged by the storm tide and erosion of Eloise, but a number were damaged by the winds. Although there were no wind measurements in Walton County, the National Hurricane Center (NHC) estimated the winds at 127 mph at landfall. A peak wind gust was measured offshore Panama City to be 155 mph. The NHC also reported a surveyed storm tide at Dune Allen Beach to be +13.8 feet NGVD. Chiu (1977) provided a definitive evaluation of the erosion conditions along Walton County from Eloise. The data from this study indicates that the dune system retreated a very rough average of 100 feet along the county's shoreline from the pre-storm vegetation line landward to the dune erosion escarpment. The +10-foot contour retreated an average of 38 feet to a maximum of 45 feet. County-wide, Eloise was estimated to have eroded 1,075,000 cubic yards of sand from above mean sea level.

Hurricanes Eloise (1975) and Opal (1995) were Bay County's two most impactful storms in recent history. Although the state did not prepare a post-storm report describing damages for Eloise, the Mobile District Corps of Engineers conducted a post-disaster study that provides useful data (USACOE, 1976). Given the storm predated the current Bay County Coastal Construction Control Line, a direct correlation of damages cannot be made. It is worthy to note that the measured storm tides exceeded a 500-year storm event (Dean,

Chiu, and Wang, 1992), with measured storm tides reported to be +14.9 feet at Panama City Beach and +16.2 feet at Sunnyside, located three miles east of Phillips Inlet. Wave heights to 20 feet as well as a peak wind of 155 mph were measured by the U.S. Navy on a platform located 14 miles offshore from Bay County. Structural damage along the Bay County coast was considerable as 215 single-family dwellings, 40 mobile homes, 15 motels and 5 commercial buildings were destroyed, while 3,500 single-family dwellings, 200 mobile homes, 150 motels, and 70 commercial buildings were damaged. Three of the four gulf fishing piers were substantially damaged and both jetties at St. Andrews Inlet were damaged.

Hurricane Kate (1985)

Ten years after Eloise, Bay County was impacted by Hurricane Kate, which made landfall on Crooked Island as a category one hurricane. Bay County escaped most of the storm's impact with Panama City being located on the leeward side of the eye and recording a maximum wind gust of 78 mph. Unlike Eloise's extensive damage, Kate only damaged two single-family dwellings, one motel, and one fishing pier in Panama City Beach, and two single-family dwellings in Mexico Beach (Clark, 1986b).

Hurricane Opal (1995)

Moore (1983) evaluated beach profiles obtained seven years after Eloise and determined that the areas unaffected by development had generally recovered to their pre-Eloise profiles. Beach conditions were at their most favorable 20 years later, prior to Opal. Although Walton County was located slightly farther away from the eye of Opal at landfall than Dennis, the storm tides and damage were the greatest ever recorded. Prior to Opal, there were no designated erosion areas in Walton County. After Opal, Miramar through Gulf Pines, Beach Highlands and Dune Allen, and Inlet Beach, were designated as critically eroded (9.2 miles). Walton County beach profiles were obtained and revealed the +10-foot contour retreated an average of 45 feet to a maximum of 155 feet (Leadon, Nguyen, and Clark, 1998). Throughout Walton County, Opal was estimated to have eroded 3.6 million cubic yards of sand from above mean sea level or roughly three times the amount eroded during Eloise.

Lacking a low barrier island in Walton County for the storm surge to overtop, there were some areas with very high wave uprush from Opal. Evidence of excessively high wave uprush limits was seen along the entire Walton County coast as measured from debris lines that reached elevations up to and exceeding +20 feet NGVD. Although there was some wind damage, most of Opal's damage was due to the storm surge, wave impacts, and erosion. The nature of Dennis' damage along Walton County's beaches was similar to the damage during Opal, although of a substantially lower magnitude.

Nearly 10 years after Kate and 20 years after Eloise, Hurricane Opal caused extensive damage along the coast of Bay County. Like Dennis, Opal made landfall about 70 miles west of Bay County. Unlike during Dennis or Ivan (2004), the beach conditions prior to Opal were significantly eroded and the coastal development was not protected by a beach restoration project. The storm tides, including wave uprush, ranged from an average of

+12 feet at the west county line to +10 feet at the east county line (Leadon, Nguyen, and Clark, 1998). Along western Bay County, this was representative of a 100-year storm (Dean, Chiu, and Wang, 1992). Of particular note is that notwithstanding the different points of landfall for Hurricanes Opal, Ivan, and Dennis, to the west of Bay County, the storm tide elevations measured by the NOAA tide station at the Panama City Beach Pier were very similar. Yet there was an extreme difference in the level of impact to coastal development. Along the beach-front, Opal destroyed 115 single-family dwellings, 13 multifamily dwellings, and 23 motel/hotels. Opal caused major structural damage to another 30 single-family dwellings, 57 multifamily dwellings, and 107 motels/hotels. In addition, 49 other major structures were destroyed or sustained major damage. Of particular note was the 11,730 feet (2.22 miles) of seawalls, bulkheads, and retaining walls that were destroyed by Opal in Bay County. A lesson learned from seemingly every storm is the inadequacy of coastal protection structures at surviving and providing adequate upland protection.

Hurricanes Earl and Georges (1998)

The restoration of western Bay County beaches followed Hurricane Opal, commencing in 1998; however, Hurricane Earl made landfall east of Panama City on Shell Island as a category one hurricane in early September and Hurricane Georges inflicted a distant fringe impact in Bay County in late September. These storms caused additional erosion throughout Bay County including erosion of the limited segment of beach that had been restored prior to Earl (Leadon, Clark, and Nguyen, 1999). The structural damages due to Georges were largely wind damage. Although no storm tide data is available for Earl or Georges, it is assumed conditions were typical of relatively high frequency storm events falling between 10 to 15-year storms (i.e., a six to seven-foot storm tide).

Hurricane Ivan (2004)

Similar to the recovery processes after Eloise (1975) in Walton County, the post-Opal beach and dune conditions gradually recovered to the condition that existed prior to the impact by Ivan. Hurricane Georges (1998) had only a minor impact to the beaches, although Tropical Storm Isidore (2002) caused some major beach and dune erosion along generally the western two thirds of the county. In 2003, much of Inlet Beach was removed from the list of critically eroded areas due to recovery seen since Opal; however, the segment between Gulf Pines and Topsail Hill was added to the western critically eroded area due to continued erosion conditions. Ivan caused major beach and dune erosion throughout Walton County. A high water mark of over +10 feet was reported (Wang and Manausa, 2005), which represents a storm frequency of slightly greater than a 50-year event (Dean and Chiu, 1982).

It is important to note that Dennis impacted Walton County's beaches at a time when natural recovery had not been completed since the impact of Ivan. There had been substantial assisted recovery through the construction of back-shore berms and dune restoration activity as well as by beach scraping operations, which unlike dune restoration do not materially add sand to the beach system. These efforts probably reduced the overall impact of Dennis; however, the storm tide and erosion impact of Dennis was substantial

and further aggravated a cumulative impact of prior storm events placing much of the developed coast in danger from future storms.

In Bay County, Hurricane Ivan inflicted storm tide conditions similar to Opal (1995) and Dennis. The significant difference in damage was the existence of a protective beach restoration project that was completed in 1999. Ivan and Dennis inflicted only a small fraction of the coastal construction damage that had previously been so severe during Opal, even though storm tide conditions were essentially the same. The beach restoration simply provided adequate protection. Both Ivan and Dennis did inflict considerable erosion to the project area, and the erosion losses appear to have been comparable to the losses sustained during Opal. Leadon, Nguyen, and Clark (1998) reported an estimated 2.9 million cubic yards of erosion throughout Bay County above mean high water due to Opal, while Keehn and Armbruster (2005) reported 2.5 million cubic yards of erosion within the restoration project of western Bay County above the -20-foot contour due to Ivan. Post-2005 hurricane season surveys of the beach restoration project show erosion losses of 2.96 million cubic yards above the -18-foot contour. Most of this erosion loss is attributed to Dennis and some (possibly as much as 20 percent) may be attributed to Katrina (Keehn, 2006).

Figure 4 shows a comparison of the erosion to Panama City Beaches from Hurricanes Eloise, Opal, Ivan, and Dennis, as well as a comparison of the major structure damages from those storms. The red bars represent volumetric erosion to Panama City Beaches from the four hurricanes. Opal, Ivan, and Dennis were comparable erosion events. The graph's chronology moves in time without scale from left to right. The large green bar in the middle represents the volume of fill placed on the beach restoration project. The blue bars are only comparable to each other, but they represent the number of major structures destroyed or sustained major structural damage. Before the beach restoration, Hurricanes Eloise and Opal destroyed 746 major structures. After beach restoration, comparable Hurricanes Ivan and Dennis destroyed or substantially damaged only 20 major structures. This post-storm data is clear evidence for the storm damage protection benefits of restoring Florida's critically eroded beaches.

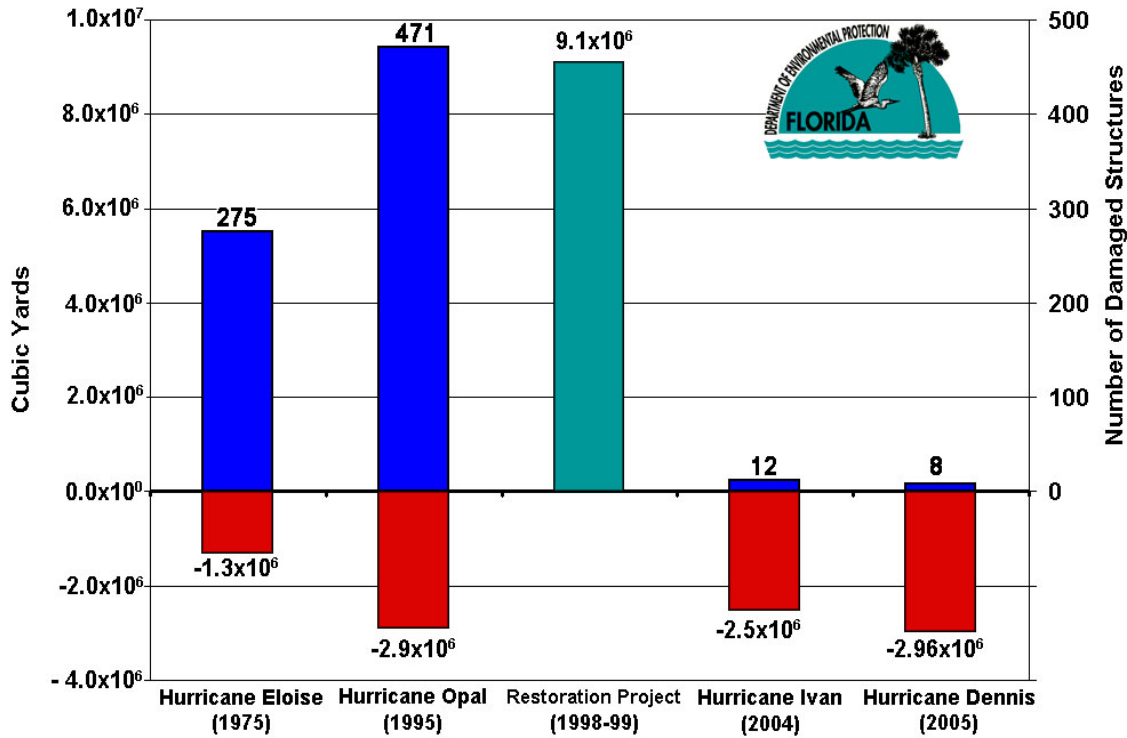


Figure 4. Storm erosion and damage comparisons for Panama City Beaches.

Storm Comparisons in Gulf, Franklin, and Wakulla Counties

Gulf, Franklin, and Wakulla Counties were most affected by Hurricanes Agnes (1972), Elena (1985), Kate (1985), Opal (1995), Earl (1998), Ivan (2004), and Dennis (2005) (Figure 5). Along with the factors discussed for the counties to the west, geomorphologic features in these eastern counties played an additional important role in the quantity and level of damages experienced. The unique geomorphologic alignment of the coast of St. Joseph Peninsula has played an important role in the damage experienced in Gulf County. Even though storm damages have not been extreme in Gulf County in comparison to counties to the west, storm impacts are experienced during nearly every gulf coast storm event due to the southward projection of Cape San Blas and the degree of exposure of St. Joseph Peninsula to the wave effects of every storm to the west. The coast of Franklin County, east of Cape St. George, and Wakulla County, is aligned southwest to northeast. Offshore contours are shallower and the shelf is wider for these eastern three counties than the western five counties. Franklin and Wakulla Counties are particularly susceptible to tide wave amplification due to their shoreline alignment with the Apalachee Bay shoreline to the east, and due to the shallow offshore depths. So pronounced is this amplification effect that the St. Marks River hosts the largest tide range in the entire Gulf of Mexico basin. Only two of the recent hurricanes affecting Gulf through Wakulla Counties made landfall in the region and neither were major hurricanes, yet damages were equally significant from distant landfalls of major hurricanes. Recent damage data would forewarn that catastrophic effects may be expected when a major hurricane makes landfall in this

area. Looking at past history, none of the recent storms were comparable to the hurricane of 1873. The “Great North Florida Storm” of 1873 was reported to have a storm surge of +20 feet at the St. Marks Lighthouse, and +18 feet up the river in the Town of St. Marks (*Tallahassee Weekly Floridian*, September 23, 1873).

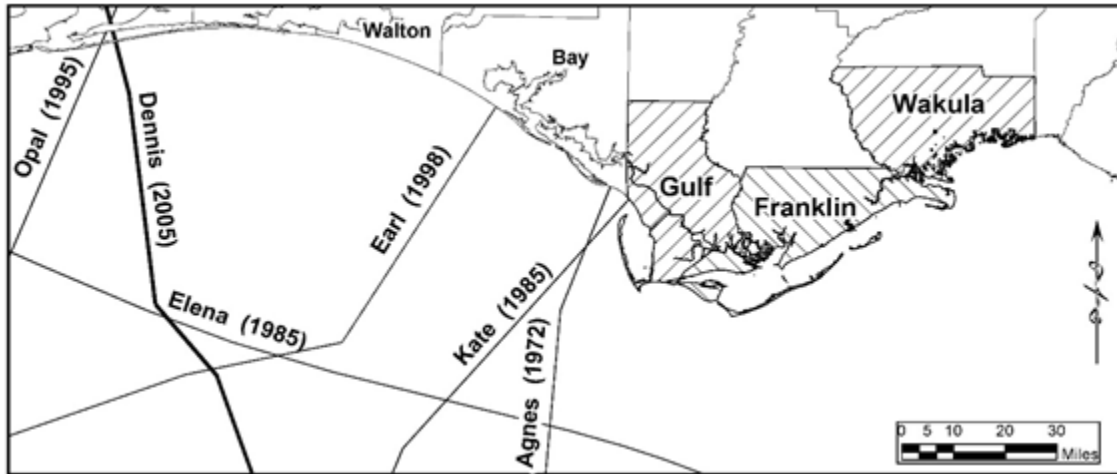


Figure 5. Hurricane landfall locations relative to Gulf, Franklin and Wakulla Counties.

Hurricane Agnes (1972)

In 1972, Hurricane Agnes made landfall west of Cape San Blas as a minimal category one hurricane producing a maximum wind gust measured at Apalachicola of 55 mph and measured storm tides of between six and seven feet between Apalachicola and Cedar Key. Storm tides, including waves, along St. George Island, Dog Island, and Alligator Point, were likely +10 feet, given the observed overwash deposits and road damage on St. George Island, and given the level of building damage along Alligator Point. The entire Franklin County coast sustained major beach and dune erosion and the historic inlet separating the two St. George Islands was breached near R39. The road on eastern St. George Island between R104 and R141 (over seven miles in length) was also totally destroyed by the storm surge of Agnes. Structural damage along Alligator Point was unprecedented. Agnes destroyed a few dwellings near the Southwest Cape and damaged several others, but along the length of Alligator Peninsula, nearly all the single-family dwellings were destroyed or sustained major damage (Clark, 1986b). Although sparsely developed at that time, Dog Island and St. George Island dwellings were also damaged. Numerous other dwellings were damaged along St. James Island and the remainder of the Franklin County coast. In total, 273 single-family dwellings were destroyed and another 821 dwellings sustained major damage (DeAngelis and Hodge, 1972). However, a direct comparison of the damages in Franklin County cannot be made between Agnes and later storms because the current Franklin County Coastal Construction Control Line did not exist in 1972.

Hurricane Elena (1985)

In 1985, the Gulf, Franklin and Wakulla County coast experienced the equivalent of three hurricanes in a 12-week span (Clark, 1986b). In early September, Hurricane Elena passed

offshore twice. On its initial pass from west to east before stalling near Cedar Key, Elena damaged three dwellings and destroyed 3,000 feet of road on Alligator Point (Clark, 1986a). Two days later Elena passed by offshore for the second time, traversing the northeastern gulf on a west-northwesterly track that brought an even greater impact. Approximately 1,500 feet of the exposed south tip of Cape San Blas disappeared. Elena's hurricane force winds brushed the coast causing only minor wind damage; however, an eight to nine-foot storm tide caused coastal flooding and damage. This storm tide was equivalent to a 30-year storm tide (Dean and Chiu, 1983). In total, Elena destroyed or substantially damaged 21 single-family dwellings in Franklin County. Elena also destroyed 2,930 feet of bulkheads and revetments fronting the gulf and destroyed a community center on Dog Island and a pier in Wakulla County (Clark, 1986a). Along with a few miles of U.S. Highway 98 damage along St. George Sound, 5,150 feet of road was destroyed on Alligator Point and St. George Island, and 20,650 feet of road sustained minor damage on St. George Island. In addition, the jetties at Sikes Cut were breached in a similar manner to the breaches caused by Dennis.

Hurricane Kate (1985)

Hurricanes Kate and Opal were Gulf County's two most impactful storms in recent history. Eloise (1975) caused major beach and dune erosion along St. Joseph Peninsula, but little damage was recorded. Gulf County, located to the east of the eye's landfall on Crooked Island, was substantially impacted by Kate. The NOAA weather station at Cape San Blas recorded maximum sustained winds of 74 mph and a peak gust of 108 mph. The NOAA buoy offshore measured wave heights to 33 feet. The University of Florida obtained high water elevations of +6.8 feet on the mainland coast of western Gulf County, +5.6 feet on St. Joseph Peninsula near the state park entrance, and +8.4 feet near Money Bayou in eastern Gulf County (Clark, 1986b). All these elevations were representative of a 20-year storm tide for their respective locations (Dean and Chiu, 1985). The 31 major structures damaged or destroyed by Kate represent the greatest documented damage of any storm in Gulf County.

Likewise the damage from Kate in Franklin County was the worst in recent history. The peak wind measured on the coast from Kate was 85 mph at the NOAA weather station in Apalachicola, and 68 mph at the Tallahassee airport inland of the coast. Storm tides from Kate ranged from eight feet on St. George Island to about nine feet at Bald Point (Clark, 1986b). As with Elena, this represented conditions equivalent to a 30-year storm tide (Dean and Chiu, 1983). Unlike the effects of Elena's offshore brush, the waves and wind from Kate's shore-incident landfall caused much greater damage to the area than did Elena. This situation might be compared to storms of Dennis' intensity. The moderate local winds of Dennis caused negligible damage to Franklin County structures, while the high storm tide caused considerable damages. If such a storm with its high storm tide as well as its high winds and waves made landfall near Cape San Blas to the west, the damage results could be expected to be catastrophic in Franklin County. Kate's intensity was only that of a category one hurricane in Franklin County, yet 31 single-family dwellings and four commercial buildings were destroyed, and 87 single-family dwellings and 40 commercial buildings sustained major damage. In addition, 5.4 miles of paved roads were damaged.

Prior to Dennis, Hurricane Kate provided the most extensive damage along the coast of Wakulla County. The NOAA tide gage located within a marina at Shell Point measured a storm tide of +8.44 feet NGVD and the Department of Natural Resources, Bureau of Beaches and Shores, measured a storm surge on the beach front of Shell Point to be +8.9 feet NGVD, which was essentially a 10-year frequency storm event (Clark, 1986b). Along with 46 major structures that were destroyed or sustained major structural damage due to Kate, over 150 dwellings were made uninhabitable due to flooding damage. This compares to 37 major structures substantially damaged by Dennis, with over 318 structures made uninhabitable due to flood damage. Kate caused wind damage to a few structures, whereas Dennis inflicted no significant wind damage. But the significant difference appears to be the slightly higher storm surge of Dennis and the increase in construction over the past 20 years. The continued accelerated coastal growth in this county coupled with a 100-year storm tide or greater will likely result in a cataclysmic event for Wakulla County.

Hurricane Opal (1995)

Ten years after Kate, Opal (1995) provided Gulf County's second worst impact of record, even though landfall was, like Dennis, over 100 miles to the west. No storm tide data was obtained for Opal in Gulf County; however, when compared to Bay County's measurements it is likely that the tide level was comparable to a 100-year storm on St. Joseph Peninsula (+8.8 feet; Dean and Chiu, 1985). Unlike other storm events in Gulf County, the mainland coast sustained a significant impact with six single-family dwellings being destroyed between R1 and R2. The coast east of Cape San Blas that was substantially impacted by Kate was not significantly affected by Opal. At Stump Hole, between St. Joseph Peninsula and Cape San Blas, Opal destroyed 2000 feet of County Road C30E. A granite rock revetment was subsequently constructed to protect the road. Numerous dwellings along St. Joseph Peninsula were also relocated inland after Opal. Opal only caused a distant fringe impact to the beaches of Franklin County and damaged several dwellings on Dog Island and Alligator Point. The Cape St. George lighthouse was also significantly impacted.

Hurricane Earl (1998)

Hurricane Earl made landfall west of Gulf County; however, only two major structures on Cape San Blas were substantially damaged. A good data set of pre-storm and post-storm beach profiles were obtained along St. Joseph Peninsula to reveal an average beach recession of the +2-foot contour to be -49 feet, and an average dune recession of the +10-foot contour to be -10 feet (Leadon, Nguyen, and Clark, 1999). Storm tide data was lacking for this category one hurricane. As during Opal, Ivan (2004), and Dennis, eastern Gulf County east of Cape San Blas was substantially sheltered from the winds and waves of Earl, and was not substantially eroded.

Earl was less intense than Opal, but was substantially closer to Franklin County, and inflicted comparable damage. Earl damaged four dwellings on St. George Island, one dwelling on Dog Island, one dwelling on Alligator Peninsula, and one dwelling on the Southwest Cape (Leadon, Clark, and Nguyen, 1999). The Cape St. George lighthouse was also pushed off its shallow pile foundation. Unfortunately, there is no storm tide data in

Franklin County for either Hurricane Opal or Earl; however, it is thought that the conditions were typical of a 15 to 20-year storm tide.

Hurricane Ivan (2004)

Ivan made landfall roughly 150 miles west of Gulf County, yet caused major beach and dune erosion along St. Joseph Peninsula. Post-storm comparative profiles reveal comparable erosion between Ivan and Dennis in some locations along southern St. Joseph Peninsula, and much greater erosion by Ivan in other locations. Only three major structures were damaged by Ivan; two single-family dwellings were destroyed and one dwelling was substantially damaged. The impact of Dennis, primarily to the foundation piles of several dwellings, is comparable to the general level of impact of Ivan.

In contrast to Dennis' major impact in Franklin County, Ivan's impact was minimal, as only one dwelling was damaged at Lighthouse Point and minor beach erosion was sustained county-wide (Leadon et al, 2004). Greater damage and erosion have been caused by high frequency storms in the past, most notably Tropical Storm Beryl (1994) and unnamed extratropical storms during 1983, 1992, and 1993.

Conclusions

During the past 35 years, coastal erosion and damage has been documented for 12 hurricanes and a number of lesser storms in northwest Florida. The impact of Hurricane Dennis in June, 2005, affected all eight coastal counties in northwest Florida. Dennis inflicted the third or fourth worst storm damage in each of these counties, and caused the most severe overall damage after Opal and Ivan. In the western three counties (Escambia, Santa Rosa, and Okaloosa), the differences in storm strength, storm track, and location of landfall, were important elements comparing Dennis with the impact of Hurricanes Frederic, Erin, Opal, Georges, and Ivan. The nature and design adequacy of construction were also major factors. In the central two counties (Walton and Bay), the existence or lack of a beach restoration project played an additional important role when comparing Dennis with the impact of Hurricanes Eloise, Kate, Opal, Earl, and Ivan. The proximity of structures to the beach was also a major factor. In the eastern three counties (Gulf, Franklin, and Wakulla), geomorphologic features played an additional important role in the quantity and level of damages experienced. When comparing the impact of Dennis in these counties to the impact of Hurricanes Agnes, Elena, Kate, Opal, Earl, and Ivan, damages were equally significant from distant landfalls of major hurricanes as near landfalls of minimal hurricanes. This forewarns catastrophic effects during a near landfall of a major hurricane.

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