United States Department of the Interior

FISH AND WILDLIFE SERVICE
1875 Century Boulevard
Atlanta, Georgia 30345

RECEIVED
AUG 15 2012
NC DEPT. OF TRANSPORTATION
OFFICE OF THE SECRETARY

In Reply Refer To:
FWS/R4/RF/RE

AUG 09 2012

LA- North Carolina
Pea Island NWR
State of North Carolina
Department of Transportation
(M11)

FEDERAL EXPRESS
Secretary Eugene A Conti, Jr.
State of North Carolina
Department of Transportation
1501 Mail Service Center
Raleigh, North Carolina 27699-1501

Dear Secretary Conti:

Enclosed is the signed Right-of-Way Easement (executed in duplicate) between the U.S. Fish and Wildlife Service and the State of North Carolina Department of Transportation to authorize the retention of the existing terminal groin and connected revetments on the northern terminus of Pea Island National Wildlife Refuge. Please have the Easement recorded in Dare County, North Carolina and return an original recorded Easement to this office, to the attention of Barbara West.

If you have any questions, please contact me at 404-679-7204 or Barbara West, Senior Realty Specialist at (404) 679-7203.

Sincerely yours,

M. Craig Sasser
Acting Realty Chief

Enclosures

LA-North Carolina
Pea Island NWR
State of North Carolina
Department of Transportation
(M11)

CERTIFICATE OF COMPLETION OF CONSTRUCTION

This is to certify that all work in connection with the easement issued by the U.S. Fish and Wildlife Service for the purpose of authorizing the retention of the existing terminal groin and connected revetments on the northern terminus of Pea Island National Wildlife Refuge, was granted to the State of North Carolina Department of Transportation and work was completed on ____________, _______.

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

By: ________________________

Title: ________________________

Date: ____________________

Prepared By:
U. S. Fish and Wildlife
1875 Century Boulevard, Suite 420
Atlanta, Georgia 30345

LA – North Carolina
Pea Island NWR
State of North Carolina
Department of Transportation
(M11)

EASEMENT

For: THE RENEWAL OF THE PERMIT DATED JUNE 20, 1989 FOR THE NORTH CAROLINA DEPARTMENT OF TRANSPORTATION TO USE WILDLIFE REFUGE LANDS FOR THE RETENTION OF THE EXISTING TERMINAL GROIN AND CONNECTED REVETMENTS ON THE NORTHERN TERMINUS OF PEA ISLAND NATIONAL WILDLIFE REFUGE,

THE SECRETARY OF THE INTERIOR, through his authorized representative, the Regional Director, U.S. Fish and Wildlife Service (Service), whose address is 1875 Century Boulevard, Room 420, Atlanta, Georgia 30345, (GRANTOR), in accordance with applicable authorities and regulations published in 50 CFR 29.21, does hereby grant an easement to the North Carolina Department of Transportation (NCDOT), 1501 Mail Service Center, Raleigh, North Carolina 27699-1501, (GRANTEE), to use and occupy certain lands in Dare County, North Carolina, located within the boundary of the **PEA ISLAND NATIONAL WILDLIFE REFUGE** (Refuge) for so long as it is used for the purpose described herein.

The purpose of this easement is for the renewal of Permit dated June 20, 1989, and will be for the retention of the existing terminal groin and connected revetments (sometimes referred to herein as the "project") on the northern point and ocean front of the Pea Island National Wildlife Refuge, to protect the existing bridge and new bridge planned over Oregon Inlet. Consideration for this grant shall be the conservation, management, and where designated the enhancement of wildlife habitat affected by stabilization of dynamic inlet over-wash, dominated habitats along the north end of the Refuge, and partially restoring habitat lost to both avulsive and erosive action or degradation due to interference with the natural movement of sand and sediments through structural stabilization of the inlet shoreline. Upon signature by both parties, the terms and conditions of this easement shall replace all terms and conditions of the previous Permit, and its subsequent amendments. This Project is authorized under the National Wildlife Refuge System Administration Act (16 U.S.C. § 668dd(d)(1)(B)).

These lands are more particularly described as follows:

See Exhibit "A" and "B"

GENERAL STIPULATIONS

By accepting this easement the grantee agrees to the following terms and conditions, and to assume all financial responsibility for their implementation:

1. To comply with all Federal, State, and local laws applicable to the project, the easement area, or activities conducted thereon.

2. To clear and keep clear the lands within the easement area to the extent and in the manner directed by the Service; and to dispose of all vegetative and other material cut, uprooted, or otherwise accumulated during the construction and maintenance of the project in such a manner as to decrease the fire hazard and also in accordance with such instructions as the Service may specify.

3. To prevent the disturbance or removal of any public land survey monument or project boundary monument unless and until the grantee has requested and received from the Service approval of measures the grantee will take to perpetuate the location of those monuments.

4. To take such soil and resource conservation and protection measures, including weed control on the land covered by the easement as the Service may request.

5. To do everything reasonably within its power, both independently and on request of the Service, to prevent and suppress fires on or near, lands to be occupied under the easement, including making available such construction and maintenance forces as may be reasonably obtainable for the suppression of such fires.

6. To rebuild and repair infrastructure as may be destroyed or injured by construction work.

7. To pay the United States the full value for, or repair to the satisfaction of the Service, all damages to the lands or other property of the United States caused by grantee, or its employees, contractors, or employees of the contractors. In all contracts engaged in by grantee with private parties in connection with the construction, operation, and maintenance of the terminal groin and revetment, the private party shall be required to indemnify the United States and hold it harmless against any liability for personal injury or property damage arising from the occupancy or use of the lands under the easement.

8. All or any part of the easement granted may be suspended or terminated by the Regional Director, Fish and Wildlife Service, for failure to comply with any or all terms and conditions of the grant, or for abandonment. A rebuttable presumption of abandonment is raised by deliberate failure of the holder to use for any continuous 2-year period the easement for the purpose for which it was granted or renewed. In the event of noncompliance or abandonment, the Regional Director will notify the holder of the easement in writing of her intention to suspend or terminate such grant 60 days from the date of notice, stating the reasons, unless prior to that time the holder completes such corrective actions as are specified in the notice. The Regional Director may grant an extension of time within which to complete corrective actions when, in her judgment, extenuating circumstances not within the holder's control such as adverse weather conditions, disturbance to wildlife during breeding periods or periods of peak concentration, or other compelling reasons warrant. Failure to take corrective action within the 60-day period will result

in a determination by the Regional Director to suspend or terminate the easement. No administrative proceeding shall be required where the easement terminates under its terms.

9. To restore the land to its original condition to the satisfaction of the Regional Director so far as it is reasonably possible to do so upon revocation and/or termination of the easement, unless this requirement is waived in writing by the Regional Director. Termination also includes easements that terminate under the terms of the grant.

10. To keep the project manager informed at all times of its address, and in case of corporations, the address of its principal place of business and the names and addresses of its principal officers.

FOR THE GRANTEE:
State of North Carolina
Department of Transportation
Attn: Secretary of Transportation
1501 Mail Service Center
Raleigh, North Carolina 27699-1501
919-707-2900

FOR THE GRANTOR:
United States of America
Fish and Wildlife Service
Attn: Refuge Manager
Pea Island NWR
708 North Highway 64
Manteo, North Carolina 27954
252-473-1131 ext. 222

11. In the construction, operation, and maintenance of the project, grantee shall not discriminate against any employee or applicant for employment because of race, creed, color, or national origin and shall require an identical provision to be included in all subcontracts.

12. The grant of the easement shall be subject to the express condition that the exercise thereof will not unduly interfere with the management, administration, or disposal by the United States of the lands and waters affected thereby. The grantee agrees and consents to the occupancy and use by the United States, its grantees, permitees, or lessees or any part of the easement area not actually occupied for the purpose of the granted rights to the extent that it does not interfere with the full and safe utilization thereof by the holder. The holder of the easement also agrees that the authorized representative of the United States shall have the right of access to the easement area for the purpose of making inspections and monitoring the construction, operation and maintenance of facilities.

13. The easement herein granted shall be subject to the express covenant that any facility constructed thereon will be modified or adapted by the grantee, if such is found by the Service to be necessary, without liability or expense to the United States, so that such facility will not conflict with the use and occupancy of the land for any authorized works which may hereafter be constructed thereon under the authority of the United States.

14. The easement herein granted shall be for the specific use described and may not be construed to include the further right to authorize any other use within the easement area unless approved in writing by the Service.

15. To abstain from or perform, those activities as required by the Service in order to comply with the requirements of the National Historic Preservation Act of 1966 (16 U.S.C. 479 et seq.), the Archeological and Historic Preservation Act of 1974 (16 U.S.C. 469 et seq.) Executive Order 11593 "Protection and Enhancement of the Cultural Environment" of May 13, 9171 (36 FR 8921), and Procedures for the Protection of Historic and Cultural Properties" (36 FR. 800).

16. Upon completion of any construction authorized by this easement, the applicant will file a certificate of completion with the Service.

SPECIAL STIPULATIONS

SECTION I: GENERAL CONDITIONS

(1) The document *"Environmental Impacts of the Oregon Inlet/Pea Island Terminal Groin,"* (Terminal Groin Report) which is a part of the Bonner Bridge project administrative record is an accepted reference document, is attached to this easement as Appendix II and for reference purposes is made a part hereof.

(2) NCDOT is authorized to operate, maintain, and monitor a terminal groin not to exceed 2,750 feet and revetment of 625 feet on the north point of Pea Island National Wildlife Refuge as shown on Exhibits "A" and "B" attached hereto and made a part hereof. This easement does not authorize extension or expansion of the existing structure in any location.

(3) During the period covered by this easement if NCDOT should require the temporary use of additional lands outside the permitted area for purposes of maintaining the structure, such uses shall be considered on a case-by-case basis and may be authorized by Special Use Permit, Letter of Authorization, or other written instrument.

All temporary uses associated with the revetment and terminal groin shall occur in full compliance with the following provisions:

a. Use of the area will be planned to minimize disturbance, compaction, filling, excavation, vegetation destruction, or other reasonably foreseeable impacts on Refuge lands and waters.

b. All disturbed areas will be restored to pre-project condition as approved by the Refuge Manager, c/o Pea Island National Wildlife Refuge, P.O. Box 1969, Manteo, North Carolina 27954. NCDOT will mitigate the loss of or impact to any wetlands and for the use of Refuge lands in accordance with Federal law, regulation, and policy to achieve no net loss of wetlands and no reduction in habitat quantity or quality on Refuge land. This will be accomplished through a plan acceptable to the Refuge Manager, c/o Pea Island National Wildlife Refuge.

c. Temporary uses herein granted shall be for the specific use described and may not be construed to include the further right to authorize any other use within the Refuge boundaries unless approved in writing by the Service.

(4) The Service and NCDOT will develop monitoring and management programs, as defined in Section II and Section III of this easement, to monitor the Refuge habitat and shoreline changes, the function of the terminal groin and revetment, and beach nourishment if it occurs. Based on the monitoring reports and trigger points prescribed in this easement, if it is determined that the terminal groin and revetment are causing long-term adverse habitat impacts or shoreline erosion or migration by interrupting or otherwise affecting natural sand migration, or both, NCDOT will have the option to (a) remove the Terminal Groin and revetment structures; (b) provide funding for habitat management; or (c) perform habitat management actions as described by the Service in the referenced monitoring and management program sections to achieve no net loss of quantity and quality of habitat. All actions will be subject to the approval of the Service. All cost estimates set forth below are based on 2012 dollars.

(5) Proposed modification or extension of the terminal groin and revetment will require reevaluation and full compliance with applicable environmental review requirements, before issuance of a new or revised easement will be considered. Any reevaluation shall consider all direct, indirect, and cumulative impacts on the ecological integrity of Refuge land.

(6) NCDOT owns the revetment and groin and all appurtenant improvements for the term of this easement. Accordingly, it is the responsibility of NCDOT to construct, operate, and maintain the permitted features in a manner that will protect the public health and safety.

SECTION II: MONITORING CONDITIONS

NCDOT Monitoring Program:

NCDOT shall provide sufficient funding for the purpose of working with a mutually agreed-upon panel of coastal science experts from appropriate disciplines to develop the required contents of an Annual Terminal Groin Monitoring Report. NCDOT will develop and submitted this report to the panel and Service for review by October 31 of each calendar year. The area to be covered (monitored area) is on the Refuge and is to include the terminal groin to the new inlet approximately 6 miles south and from ocean to sound in the first mile south of the terminal groin and from the ocean to the west side of NC 12 ROW for miles 2-6. The Report shall include the following sections:

For Aerial Photography:
NCDOT shall conduct aerial photography four times per year covering the four seasons within the monitored area. NCDOT will provide the data to the Service in a format acceptable to the Service on a quarterly basis by providing the previous quarter before the following quarter ends. NCDOT shall include a base map with a shoreline change overlay in the annual report. The Service acknowledges that NCDOT has already begun taking the aerial photographs and coverage includes the whole Refuge.

For Habitat Monitoring:
A geo-spatial habitat analysis section shall be prepared once every five years starting before construction of the parallel bridge. The analysis shall characterize type, quality, and extent of habitats in the monitored area. The cost estimate is approximately $25,000 every five years.

A modeling section using computer software (e.g. STELLA) for detecting habitat change over time shall be prepared once every five years starting before construction of the parallel bridge. Model geo-spatial outputs should predict future changes in type and extent of habitats at time intervals not to exceed 15 years in the monitored area. Modeling data shall further be used to inform transportation corridor decisions related to Refuge lands. The cost estimate is approximately $25,000 every five years.

A one-time historic aerial photography section using photography from 1977, 1982, 1987, 1992, 1997, 2002, 2007 and 2012 shall be prepared. These are the recommended target years, but other representative dates selected by the panel of coastal experts based upon available photography with sufficient resolution to accomplish report objectives would be suitable. The purpose is to document historic habitat change on the Refuge as a baseline from a time prior to and during the term of the original terminal groin Permit. This information will help reduce variability in data used to monitor habitat change and forecast future conditions. The cost estimate is approximately $25,000.

NCDOT shall monitor physical and biological parameters along transects across the beach at approximately 0.2 mile intervals within the monitored area. Monitoring transects shall include, but are not limited to, dunes to lowest point of the swash zone. Physical data collection shall include, but is not limited to, dune width and height, beach width, beach slope, sand grain size as determined through one sample from the upper beach, and one sample each from the upper, mid- and lower swash zone, and mineral content of swash zone sand. Biological data collection shall include, but is not limited to beach invertebrates such as the ghost crab, swash zone invertebrates such as the mole crab, coquina, amphipods, and polychaete worms.

For Shoreline Monitoring:

The historic rate of erosion used for previous shoreline monitoring in the original terminal groin Permit shall be reconsidered and either verified or updated to more accurately reflect shoreline erosion rates in light of climate change and coastal processes. The historic rate of shoreline erosion shall be determined through analysis of tidal and sea level rise data compared to shoreline position over time starting in 1960 to present or other representative dates as selected by a mutually agreed upon panel of coastal experts based upon available data sufficient to accomplish the objectives of the analysis. The analysis of the historic rate of shoreline erosion and future shoreline prediction methodology shall be initiated within 30 days of signing this easement and shall be completed within 180 days of the date this easement is issued. Shoreline modeling shall be used as an assessment and forecasting tool to evaluate impacts to North Carolina Highway 12.

For Assessment of Monitoring Protocols, i.e., Adaptive Management:

Once every five years the Monitoring Report will include a section with an analysis that evaluates the effectiveness of the established monitoring protocols with recommendations identifying protocols to continue and protocols to change or add. The purpose of this analysis is to evaluate the effectiveness of monitoring as it relates to transportation maintenance needs and the status of migratory bird and threatened and endangered species resources and their habitats on the monitored area. If recommendations are made to continue, modify, add, or change protocols and are mutually agreed to, then revisions to those requirements may be made.

SECTION III: MANAGEMENT CONDITIONS

Beach Nourishment:

If it is determined that the terminal groin and revetment are causing sand loss within the monitored area in excess of the historic rate of shoreline erosion, as determined by the analysis in Section II, NCDOT shall provide supplemental beach nourishment on the Refuge beach within the monitored area to restore such sand loss. Beach nourishment shall be required after a monitoring period that shows erosion has exceeded the historic rate of shoreline erosion, i.e., the trigger point, and shall be done during the appropriate time period. An exception to beach nourishment can be made only if the affected beach has accreted back to the pre-eroded condition prior to the period for dredging and nourishment. Beach nourishment shall be in conformance with then applicable Refuge regulation and policy. Full compliance with the terms and conditions of the reasonable and prudent measures to reduce the potential for incidental take of sea turtles as described in the Service's biological opinion last issued on May 26, 1989 is required.

Specifically: NCDOT shall provide advance written notification to the Refuge Manager no less than 60 days prior to proposed commencement of beach nourishment, outlining the time, method, equipment and routes of access, to conduct nourishment operations. The written notification shall include data acceptable to the Refuge Manager regarding sand quantity, suitability (grain size and mineral content), and placement location. Operations will not commence until the Refuge Manager has reviewed and approved the plans for nourishment and issued the necessary permits.

Habitat Management:

NCDOT shall provide equipment and personnel necessary to conduct habitat management actions when the Service determines that habitat conditions for migratory birds or other federal trust species within 0.5 miles of the terminal groin have become unsuitable due to the actions of wind or water. The Service shall determine when, where, and type of habitat management actions to be taken. Habitat management is anticipated to involve mostly moving sand to create moist sand and intertidal pool habitat with unvegetated shoreline and, nearby, at least 25 acre of contiguous, dry coarse sand and shell substrate. Moving the sand is likely to occur by: Mining the sand and using it elsewhere on the Refuge to create a berm for protecting NC 12 and/or moving the sand to the Refuge beach south of the point of attachment for the Oregon Inlet ocean bar. It is anticipated that habitat management will be necessary at approximately 5-year intervals plus or minus 2-years, depending upon storm frequency and intensity, and habitat monitoring results.

A single habitat management action would usually occur in one fall/winter period outside the migratory bird and sea turtle nesting season and involve moving up to 200,000 – 300,000 yd^3 of sand from within an area of approximately 25-30 acres in the vicinity of the terminal groin as determined by the Refuge Manager.

1. Trigger points for habitat management action are any of the following conditions:
    a. When low energy open water intertidal pool(s) with unvegetated moist sand in and along the shoreline is (are) less than one-acre in size on February 1 of each year and is not likely to persist through the upcoming beach nesting bird season.
    b. When low energy open water intertidal pool(s) have emergent marsh vegetation which prevents access to foraging by piping plover, American oystercatcher, and other shorebird species.
    c. When contiguous, dry coarse sand and shell substrate – that is within 0.5 mile of the low energy open water intertidal pool(s) with unvegetated moist substrate in and along the shoreline – is reduced to less than 25 acres by dune formation and plant succession.

2. NCDOT shall be responsible for obtaining all necessary permits. NCDOT shall estimate the cost of moving sand and move the sand. If NCDOT needs the moved sand for maintenance within

the NC 12 easement on the Refuge it would be permitted under a special use permit with conditions as usual.

IN WITNESS WHEREOF, I have hereunto set my hand this 19th day of July, 2012.

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

Witness

By:
Eugene A. Conti, Jr.
Secretary of Transportation

Notary Public
My Commission expires: 08-14-2015

TRACEY C. HUMPHRIES NOTARY PUBLIC JOHNSTON COUNTY, NC

ACKNOWLEDGEMENT

IN WITNESS WHEREOF, I have hereunto set my hand this 8th day of August 2012.

THE UNITED STATES OF AMERICA
Fish and Wildlife Service

Witness

By:
Cynthia K. Dohner,
Regional Director, Southeast Region

Notary Public
My Commission expires: January 17, 2016

EXHIBIT "A"

Terminal Groin Metes & Bounds Description
Prepared September 2011

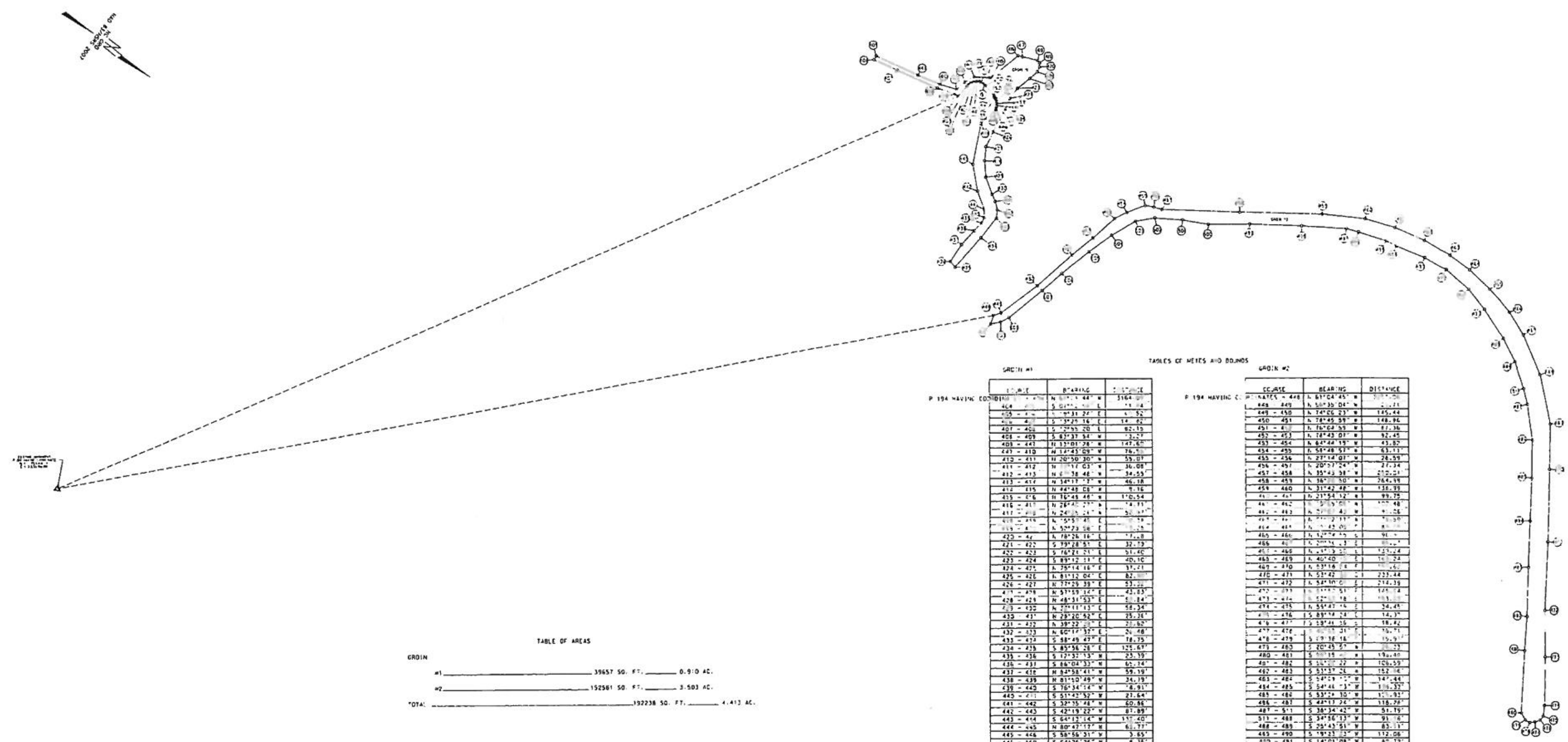
(Section under Bonner Bridge)
GROIN #1: Beginning at Point "404" being N 61^09'44" W and perpendicular to Monument P 194 HAVING COORDINATES OF Northing 750,431.03' Easting 3,032,912.86' 3,164.09 ft. Lt., thence S 07^52'54" E 11.44 ft. to point "405"; thence S 19^31'24" E 60.52 ft. to point "406"; thence S 13^25'16" E 140.82 ft. to point "407"; thence S 12^55'20" E 82.15 ft. to point "408"; thence S 83^37'54" W 13.27 ft. to point "409"; thence N 13^01'28" W 147.60 ft. to point "447"; thence N 14^43'09" W 76.95 ft. to point "410"; thence N 20^50'30" W 55.07 ft. to point "411"; thence N 77^17'03" W 36.08 ft. to point "412"; thence N 67^38'48" W 34.55 ft. to point "413"; thence N 34^17'17" W 46.18 ft. to point "414"; thence N 44^48'08" W 9.16 ft. to point "415"; thence N 76^48'48" W 110.54 ft. to point "416"; thence N 26^40'27" W 14.71 ft. to point "417"; thence N 24^25'26" W 50.57 ft. to point "418"; thence N 15^53'45" E 10.38 ft. to point "419"; thence N 52^23'56" E 13.25 ft. to point "420"; thence N 78^26'16" E 17.28 ft. to point "421"; thence S 79^28'51" E 32.39 ft. to point "422"; thence S 76^21'21" E 51.40 ft. to point "423"; thence S 89^12'11" E 40.10 ft. to point "424"; thence N 75^14'16" E 37.41 ft. to point "425"; thence N 81^12'04" E 82.90 ft. to point "426"; thence N 77^29'39" E 53.32 ft. to point "427"; thence N 57^59'14" E 43.83 ft. to point "428"; thence N 48^31'53" E 52.84 ft. to point "429"; thence N 32^11'13" E 58.34 ft. to point "430"; thence N 28^20'52" E 25.36 ft. to point "431"; thence N 39^22'39" E 28.62 ft. to point "432"; thence N 60^14'37" E 26.48 ft. to point "433"; thence S 88^49'47" E 78.75 ft. to point "434"; thence S 85^56'26" E 125.67 ft. to point "435"; thence S 12^37'13" W 23.39 ft. to point "436"; thence S 86^04'33" W 65.14 ft. to point "437"; thence N 84^58'41" W 59.19 ft. to point "438"; thence N 81^50'49" W 34.79 ft. to point "439"; thence S 76^34'14" W 18.91 ft. to point "440"; thence S 51^43'52" W 27.64 ft. to point "441"; thence S 32^35'48" W 60.86 ft. to point "442"; thence S 42^19'22" W 87.89 ft. to point "443"; thence S 64^13'14" W 132.40 ft. to point "444"; thence N 80^47'17" W 65.77 ft. to point "445"; thence S 58^56'31" W 3.65 ft. THENCE RUNNING WITH HEADWALL OF BONNER BRIDGE to point "446"; thence S 64^26'26" W 8.35 ft. to point "160"; thence S 58^03'04" W 7.99 ft. to point "158"; thence S 43^51'18" W 5.97 ft. to point "157"; thence S 36^18'12" W 6.88 ft. to point "156"; thence S 29^13'39" W 5.48 ft. to point "155"; thence S 15^24'38" W 4.60 ft. to point "154"; thence S 19^11'03" W 4.48 ft. to point "153"; AND CROSSING CENTER LINE STATION 3510+79.92 OF BONNER BRIDGE thence S 11^42'06" W 41.21 ft. to point "152"; thence S 09^45'34" W 6.50 ft. to point "151"; thence S 00^31'21" W 9.46 ft. to point "150"; thence S 16^48'32" E 6.09 ft. to point "149"; thence S 26^00'23" E 8.24 ft. to point "148"; thence S 37^30'16" E 6.16 ft. to point "400"; thence S 47^08'37" E 9.52 ft. to point "401"; thence S 65^10'53" E 10.27 ft. to point "402"; thence S 79^50'03" E 9.87 ft. to point "403"; thence S 86^53'18" E 45.28 ft. to point "404"; returning to the place of beginning. Area of Total Groin = 39,657 SQ. FT. _ 0.910 AC.

GROIN #2: Beginning at Point "448" being N 61^04'45" W and perpendicular to Monument P 194 HAVING COORDINATES OF Northing 750,431.03' Easting 3,032,912.86' 3,257.06 ft. Rt., thence N 56^35'04" W 25.71 ft. to point "449"; thence N 74^06'23" W 145.44 ft. to point "450"; thence N 78^45'59" W 148.96 ft. to point "451"; thence N 76^04'59" W 87.36 ft. to point "452"; thence N 78^43'07" W 92.45 ft. to point "453"; thence N 64^44'19" W 43.82 ft. to point "454"; thence N 58^48'57" W 63.11 ft. to point "455"; thence N 27^14'07" W 28.59 ft. to point "456"; thence N 20^57'24" W 27.34 ft. to point "457"; thence N 35^43'58" W 250.01 ft. to point "458"; thence N 36^20'50" W 264.99 ft. to point "459"; thence N 31^42'48" W 138.99 ft. to point "460"; thence N 21^54'12" W 99.75 ft. to point "461"; thence N 15^09'05" W 102.48 ft. to point "462"; thence N 07^07'43" W 95.06 ft. to point "463"; thence N 01^02'11" W 78.59 ft. to point "464"; thence N

05^43'05" E 89.09 ft. to point "465"; thence N 12^04'55" E 96.90 ft. to point "466"; thence N 20^36'23" E 85.07 ft. to point "467"; thence N 29^19'50" E 139.24 ft. to point "468"; thence N 40^40'10" E 163.24 ft. to point "469"; thence N 53^18'54" E 150.62 ft. to point "470"; thence N 53^42'30" E 233.44 ft. to point "471"; thence N 54^30'01" E 214.39 ft. to point "472"; thence N 51^50'51" E 145.54 ft. to point "473"; thence N 52^53'18" E 153.03 ft. to point "474"; thence N 59^47'19" E 34.45 ft. to point "475"; thence S 89^38'24" E 14.97 ft. to point "476"; thence S 58^46'56" E 18.42 ft. to point "477"; thence S 40^55'01" E 16.71 ft. to point "478"; thence S 09^38'16" E 15.97 ft. to point "479"; thence S 20^45'57" W 26.23 ft. to point "480"; thence S 55^15'42" W 196.48 ft. to point "481"; thence S 56^20'22" W 106.59 ft. to point "482"; thence S 53^37'26" W 152.96 ft. to point "483"; thence S 54^09'10" W 147.44 ft. to point "484"; thence S 54^46'03" W 138.33 ft. to point "485"; thence S 53^26'30" W 125.93 ft. to point "486"; thence S 44^17'24" W 118.28 ft. to point "487"; thence S 38^34'42" W 51.79 ft. to point "511"; thence S 34^56'13" W 91.76 ft. to point "488"; thence S 25^43'51" W 83.71 ft. to point "489"; thence S 19^23'23" W 112.06 ft. to point "490"; thence S 14^01'08" W 80.72 ft. to point "491"; thence S 03^08'00" W 95.07 ft. to point "492"; thence S 08^12'11" E 79.52 ft. to point "493"; thence S 15^27'19" E 97.76 ft. to point "494"; thence S 10^42'06" E 35.09 ft. to point "495"; thence S 20^46'22" E 94.73 ft. to point "496"; thence S 22^27'34" E 39.25 ft. to point "497"; thence S 34^26'51" E 145.01 ft. to point "498"; thence S 35^46'01" E 167.20 ft. to point "499"; thence S 38^15'30" E 133.51 ft. to point "500"; thence S 28^19'08" E 83.96 ft. to point "501"; thence S 33^28'12" E 88.81 ft. to point "502"; thence S 46^53'19" E 62.88 ft. to point "503"; thence S 67^31'00" E 88.58 ft. to point "504"; thence S 73^09'52" E 90.29 ft. to point "505"; thence S 75^44'03" E 111.97 ft. to point "506"; thence S 78^07'14" E 82.55 ft. to point "507"; thence S 76^40'23" E 138.77 ft. to point "508"; thence S 64^23'21" E 30.36 ft. to point "509"; thence S 48^59'33" E 32.72 ft. to point "510"; thence S 71^24'45" W 28.86 ft. to point "448"; returning to the place of beginning. Area of Total Groin = 152,581 SQ. FT. _ 3.503 AC.

EXHIBIT "B"

METES AND BOUNDS DESCRIPTION
of B-2500
PROPOSED EASEMENT
ON
PEA ISLAND WILDLIFE REFUGE



TABLES OF METES AND BOUNDS

GROIN #1

COURSE	BEARING	DISTANCE
P 194 HAVING COORDINATES - 404	N [illegible]44" W	3164.[illegible]
404 - [illegible]	S 07°[illegible] E	[illegible]
405 - [illegible]	S 19°31'24" E	[illegible].52'
[illegible] - [illegible]	S 13°29'16" E	14[illegible].62'
407 - 408	S 12°55'20" E	82.15
408 - 409	S 83°37'54" W	[illegible]
409 - 447	N 12°01'28" W	147.6[illegible]
447 - 410	N 14°43'09" W	76.[illegible]
410 - 411	N 20°50'30" W	55.07
411 - 412	N [illegible]°17'03" W	36.08'
412 - 413	N [illegible]°38'48" W	34.55'
413 - 414	N 34°17'[illegible]" W	46.18
414 - 415	N 44°48'08" W	9.16
415 - 416	N 16°45'48" W	[illegible]0.54
416 - 417	N 26°[illegible] W	[illegible]4.71'
417 - [illegible]	N 24°[illegible] W	5[illegible]
[illegible] - [illegible]	N [illegible]5°5[illegible]'45" E	[illegible]
[illegible] - [illegible]	N 52°23'56" E	[illegible]
420 - [illegible]	N 78°26'16" E	[illegible]
421 - 422	S 79°28'51" E	32.[illegible]
422 - 423	S 76°21'21" E	51.40
423 - 424	S 89°12'11" E	40.10'
424 - 425	N 75°14'16" E	37.41
425 - 426	N 81°12'04" E	82.[illegible]
426 - 427	N 77°29'39" E	53.[illegible]
4[illegible] - 428	N 57°59'14" E	43.83'
428 - 429	N 48°31'53" E	[illegible].84'
[illegible] - 430	N [illegible]°11'13" E	58.34'
430 - 431	N 29°20'52" E	25.36'
431 - 432	N 39°22'[illegible]" E	[illegible].62'
432 - 433	N 60°1[illegible]'37" E	2[illegible].48'
433 - 434	S 58°49'47" E	18.75'
434 - 435	S 85°56'26" E	125.67'
435 - 436	S 12°37'13" W	23.39'
436 - 437	S 66°04'33" W	65.14'
437 - 438	N 84°58'41" W	59.19'
438 - 439	N 81°50'49" W	34.19'
439 - 440	S 76°34'14" W	18.91'
440 - [illegible]	S 51°42'52" W	27.64'
441 - 442	S 32°35'48" W	60.86'
442 - 443	S 42°19'22" W	87.89'
443 - 444	S 64°12'14" W	1[illegible].40'
444 - 445	N 80°47'17" W	6[illegible].77'
445 - 446	S 58°56'31" W	3.65'
446 - 160	S 64°26'26" W	8.35'
160 - 158	S 58°0[illegible]'04" W	7.99'
158 - 157	S 43°51'18" W	5.97'
157 - 156	S 36°18'17" W	6.88'
156 - 155	S 29°13'39" W	5.48'
155 - 154	S 15°24'38" W	4.60'
154 - 153	S 19°11'03" W	4.48'
153 - 152	S 11°42'06" W	41.21'
152 - 151	S 09°4[illegible]'34" W	6.50'
151 - 150	S 00°31'21" W	9.46'
150 - 149	S 16°48'32" E	6.09'
149 - 148	S 26°00'23" E	8.24'
148 - [illegible]	S 37°30'16" E	6.16'
400 - 401	S 47°08'37" E	9.5[illegible]'
401 - 402	S 65°10'53" E	10.27'
402 - 403	S 79°30'03" E	9.87'
403 - 404	S 86°53'18" E	45.28'

GROIN #2

COURSE	BEARING	DISTANCE
P 194 HAVING COORDINATES - 448	N 61°04'45" W	[illegible]
448 - 449	N 56°35'04" W	[illegible]
449 - 450	N 74°06'23" W	145.44
450 - 451	N 78°45'59" W	148.96
451 - 452	N 76°04'55" W	87.36
452 - 453	N 74°43'01" W	92.45
453 - 454	N 64°44'15" W	43.82
454 - 455	N 58°48'57" W	63.11
455 - 456	N 27°14'07" W	76.59
456 - 457	N 20°57'24" W	27.34
457 - 458	N 35°43'38" W	250.21
458 - 459	N 16°20'30" W	264.49
459 - 460	N 31°42'48" W	138.99
[illegible]	N 21°54'12" W	99.75
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
465 - 466	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
468 - 469	N 40°40'[illegible]	[illegible]
469 - 470	N 53°16'[illegible]	[illegible]
470 - 471	N 51°42'[illegible]	232.44
471 - 472	N 54°30'[illegible]	214.39
472 - 473	[illegible]	145.[illegible]
[illegible]	[illegible]	[illegible]
474 - 475	N 55°47'[illegible]	24.45
475 - 476	S 89°24'[illegible]	14.37
476 - 477	S 03°41'[illegible]	18.82
477 - 478	[illegible]	[illegible]
478 - 479	S 19°38'16" [illegible]	15.9[illegible]
479 - 480	S 20°45'[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
481 - 482	S 54°55'22" [illegible]	106.59
482 - 483	S 51°37'2[illegible]" [illegible]	152.1[illegible]
483 - 484	S 54°[illegible]	147.44
484 - 485	S 54°46'13" W	136.37
485 - 486	S 53°04'30" W	[illegible]
486 - 487	S 44°17'24" W	118.78
487 - 511	S 38°34'42" W	51.75
511 - 488	S 34°56'33" W	91.16
488 - 489	S 25°43'51" W	83.13
489 - 490	S 19°23'03" W	112.06
490 - 491	S 14°01'08" W	[illegible]
491 - 492	S 03°08'00" W	[illegible]
492 - 493	S 08°12'11" E	79.52
493 - 494	S 15°23'15" E	91.76
494 - 495	S 10°42'06" E	32.29
495 - 496	S 20°46'22" E	94.73
496 - 497	S 22°27'34" E	35.25
497 - 498	S 34°27'51" E	145.01
498 - 499	S 35°46'01" E	[illegible]
499 - 500	S 28°19'35" E	133.0[illegible]
500 - 501	S 28°19'05" E	[illegible]
501 - 502	S 33°28'12" E	68.61
502 - 503	S 46°53'19" E	62.86
503 - 504	S 67°31'03" E	88.58
504 - 505	S 73°09'52" E	90.29
505 - 506	S 75°44'03" E	111.97
506 - 507	S 78°07'14" E	82.55
507 - 508	S 16°40'23" E	138.77
508 - 509	S 64°23'21" E	30.36
509 - 510	S 48°59'33" E	32.32
510 - 448	S 71°24'45" W	29.86

TABLE OF AREAS

GROIN

#1 ____ 39657 SQ. FT. ____ 0.910 AC.

#2 ____ 152581 SQ. FT. ____ 3.503 AC.

TOTAL ____ 192238 SQ. FT. ____ 4.413 AC.

LEGEND

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
LOCATION AND SURVEYS UNIT
C. W. BROWN, PE, PLS
STATE LOCATION AND SURVEYS ENGINEER
ANTHONY G. PULP
PROPERTY SURVEY AND CADD MAPPING ENGINEER
MAP COMPILED 11/[illegible]/[illegible]
LOCATION ENGINEER
SURVEYOR
CADD OPERATOR

APPENDIX II

Environmental Impacts of the Oregon Inlet/Pea Island Terminal Groin

Coastal Research Associates (CRA)
Charlottesville, VA

November 2010

TABLE OF CONTENTS

BACKGROUND

With the planned construction of a new Bonner Bridge spanning Oregon Inlet, North Carolina (Fig 1), the US Fish and Wildlife Service (FWS) was asked by the Federal Highway Administration (FWHA) and the N.C. Department of Transportation (NCDOT) to provide an updated "Special Use Permit" for the continued use of refuge land on which the Oregon Inlet terminal groin was constructed. FWS requested a summary of the environmental impacts that the terminal groin has had on Pea Island and Oregon Inlet over the 20+ years, or since the structure was installed. NCDOT and FWHA declined to prepare an update of the impacts associated with the terminal groin that would satisfy their needs for scientific and engineering information which would assist in their management of the refuge. Therefore, FWS decided to carry out this study without the support of NCDOT and FWHA.

Coastal Research Associates (CRA) of Charlottesville, Virginia was commissioned to conduct a review of the physical and ecological elements of the inlet/barrier island system that have or might have been altered by the construction of a terminal groin (Fig 2). Our review of the groin impacts was based primarily on existing literature and professional experiences of the authors. The information will be used by FWS to assist them in their consideration of past and future refuge management options and the implications of issuing a new SMP. The review team consisted of:

Robert Dolan, Coastal geology and overall coordinator (UVA)
Robert Dean, Coastal engineering and inlet hydrodynamics (UFL)
Bruce Hayden, Coastal meteorologist and ecologist (UVA)
Heather McCafferty, US Coast Guard

Mike Erwin, Coastal ecologist (DOI-UVA)
David Richardson, GIS development (UVA)
Dennis Stewart, Coastal ecologist and representative of FWS

In addition to our literature review, we developed a regional-scale GIS program spanning changes over the period of 10-20 years from pre-groin through to the present. The analysis covers the geographic area from 3 miles north to a point 4 miles south. We classified the landscape into types or classes and interpreted changes in the physical and ecological elements of the beach/dune system identified by aerial photographs. Subject matter experts were queried regarding changes in the inlet, channels, beach, dunes, overwash, plant communities, and wildlife habitats. Existing scientific and engineering literature, and existing databases, were used to supplement the GIS work. The existing permit for the terminal groin was also evaluated in order to provide feedback to FWS on the strengths and weaknesses of the past and possibly future changes in the Oregon Inlet/Pea Island zone of the barrier island system.

More specifically, the focus of this review is on the effects of the Oregon Inlet Terminal groin on coastal processes and subsequent effects on wildlife habitat on the Pea Island National Wildlife Refuge, and how allowing the groin to remain in place over the next several decades will possibly continue to affect the barrier island habitats. A section of the report includes recommendations to offset these impacts through groin design modifications or through habitat management.

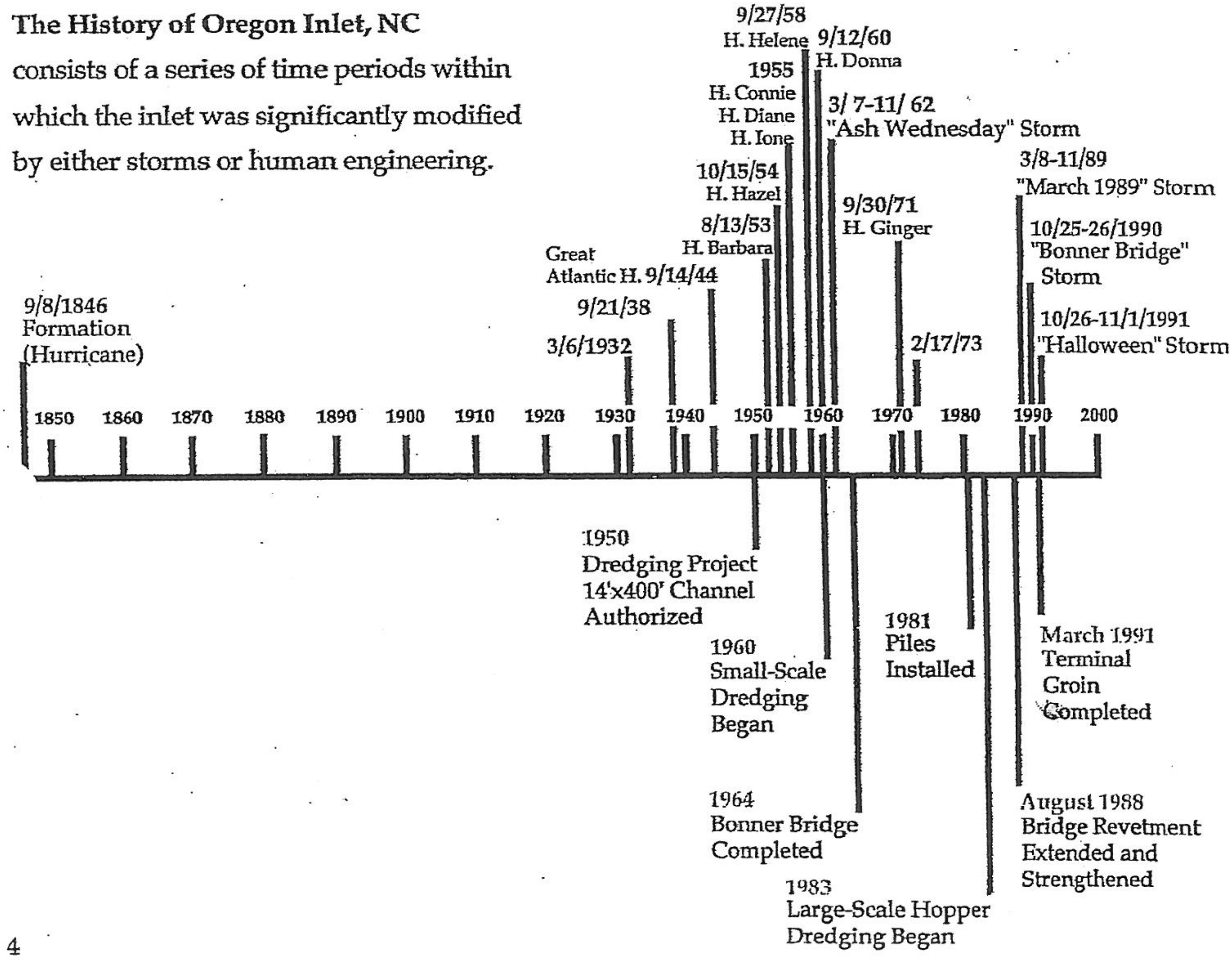
We also carried out a literature review and assimilated the best available scientifically valid databases with regard to natural inlet dynamics, terminal groins, and altered inlets.

The terminal groin was constructed in 1989 primarily for the purpose of protecting the southern terminus of the Bonner Bridge. The permit to construct the groin was issued on June 23, 1989. The purpose stated was to protect the bridge and its southern approach that existed at the time the permit was issued. An important condition in the permit states that the groin must be removed within a 2-year period of when the project purpose no longer exists.

The NCDOT and the FWHA have determined that the terminal groin must remain in place to protect the new Bonner Bridge; however, a DOI solicitor has determined that leaving the terminal groin in place will require a new permit from the FWS. Upon receipt of a formal request from either NCDOT or FHWA, the FWS can issue a new permit after compliance with the Endangered Species Act (ESA), the National Environmental Policy Act (NEPA), and agency policies. The permit decision must be based upon sound professional judgment and the best available science.

The FWS determined that the best and most efficient approach for assembling the available science and engineering was to commission a team of experienced scientists and engineers with expertise in coastal processes, inlet dynamics, and coastal ecology to provide an objective assessment of past, present, and future effects of the terminal groin as well as develop and propose appropriate resource management actions for managing habitat types associated with the terminal groin to maximum conditions for wildlife resources of the dynamic inlet area.

The History of Oregon Inlet, NC consists of a series of time periods within which the inlet was significantly modified by either storms or human engineering.



continued following the construction of the Bonner Bridge, the channel narrowed and deepened undermining a large section of the supporting pilings. To aggregate the problem, the USACE began using large-scale hopper-dredgers to remove sand at a rate of approximately 700,000 yd^3 per year from the ocean bar and navigation channel. The dredging was designed to move the surplus sand from the inlet to the shallow-water zone along the beach of Pea Island. Unfortunately, it turned out that the larger capacity dredgers were incapable of operating in water depths of less than 25 ft so the sand was transported offshore for deeper water disposal contributing to a reduction of the inshore sand budget resulting in severe erosion along the north end of Pea Island.

With every severe storm, the loss of sand and deepening of the inlet resulted in significant losses of subaerial land on the north end of Pea Island, serious deepening of the inlet channels, and the pilings supporting the south approach road. One storm alone - the Halloween Storm of 1989 – caused erosion of approximately 1500 ft on the north end of Pea Island.

In order to protect the Bonner Bridge from further erosion caused by the loss of sand from the sand budget, a terminal groin was constructed in 1991. Prior to the groin, the width of the inlet increased and decreased during storms and storm-free time periods. The terminal groin fixed the southern shoulder (Pea Island) but the northern shoulder on Bodie Island has continued to extend southward, resulting in a significant decrease in width over the past six years; nevertheless the USACE remained convinced that the terminal groin has successfully stabilized the inlet and shoreline changes along Pea Island and that the hopper dredging had contributed little to the erosion problem along Pea Island.

The strong influence of the terminal groin has resulted in a narrowing of the inlet of over 1500 ft – from approximately 4500 ft wide to 3000 ft. With the decrease in width, there was a reduction in depth with little reduction in cross-section. Many questions have arisen relative to the implications of installing a large terminal groin have had in altering the pathways of sediment transport in and around Oregon Inlet. Included are questions of both physical and ecological changes due to alterations of the sand transport. A terminal groin is an engineering structure designed by coastal engineers to alter sediment transport processes so sand can be prevented from accumulating or eroding from an undesirable or desirable location. The purpose of this investigation is to report to the USFWS the impacts of the terminal groin installed on Pea Island that were required to stabilize the Bonner Bridge.

Three physical processes are responsible for the majority of changes in the configuration of Oregon Inlet and Pea Island. They are (1) changes in sea level, (2) frequency and magnitude of coastal storms, and (3) the sediment budget or supply and distribution of sand reaching the island beaches and channels within the inlet. Did the terminal groin have significant impact on the beaches and dunes of Pea Island? The answer is yes – terminal groins are designed to alter sediment transport processes leading to the redistribution of sand.

The volume of sand involved in the infilling of the void on Pea Island created by the groin amounted to a redistribution of approximately 2.5 million yds^3. The fillet began to fill with sand as the construction progressed. The sand in the fillet is measurably finer than the open exposed beach in the vicinity of the inlet and there is a higher heavy mineral content. This led to a reduction of the invertebrate filter feeders who are at the base of the food chain.

The purpose of this project was to summarize the existing scientific and engineering literature on the subject of impacts of terminal groins on tidal inlets and adjacent barrier islands. Coastal Research Associates was commissioned to carry out this review which will serve as background information for decisions the USFWS makes periodically before issuing special use permits for construction of a terminal groin on Pea Island.

The objective is to assess the importance of changes in the sediment transport mechanisms prior to the construction of the terminal groin including a summary of historic changes; to document the changes in inlet geometry that have occurred since the construction of the terminal groin at Oregon Inlet and to determine the degree to which storm frequency and magnitude data correlate with changes in the inlet geometry since terminal groin placement.

We also include a discussion and demonstration of a new Geographic Information System for these discussions and application of a statistical model ('Stella') for most of our quantitative analyses.

THE NORTH CAROLINA BEACHES
AND BARRIER ISLANDS

The Atlantic coastal plain is a relatively flat sedimentary formation that slopes gently seaward to wide continental shelves. The sand beaches and barrier islands that constitute the shore zones of these plains are the product of marine processes working and reworking the seaward margins of the coastal plains.

The processes that form barrier islands have been debated among earth scientists for many years. There is, however, evidence that most of the barrier islands along the Atlantic Coast formed 4,000-6,000 years ago. The islands have undergone change since then, and they continue to change. Peat and tree stumps – remnants of forests that once stood on the bay sides of the islands – are now being found on ocean beaches. The islands are moving toward the mainland (transgressing) in response to the current rise in sea level.

The North Carolina barrier islands and beaches consist mostly of quartz sand with small fractions of heavy minerals, rock fragments, and shell. A cross-section of Hatteras Island beach reveals sedimentary layers made up of particles of various sizes, but mostly larger than fine sand but finer than coarse sand that indicate their source and the processes responsible for depositing them. Embedded within the layers are units of well-sorted finer sands deposited by wind.

When the last period of continental glaciation (the Wisconsin) came to an end between 12,000 to 14,000 years ago, the sea level was approximately 350 ft lower than it is today, and the shore zones of the Atlantic Coast were from 50-75 miles seaward of their current position. With the change from glacial to interglacial conditions and the melting of the continental glaciers, the world's oceans began to rise. They continued to do so for 8,000 years, reaching within a few feet of the present level between 4,000 and 6,000 years ago. As the sea level rose and the shore zone progressed across the continental shelf, large masses of sand were moved with the migrating shore zone and deposited as beaches.

Once the sea level had become fairly stable, waves, currents, and winds reworked the exposed sand deposits to form beaches and barrier islands. As long as the inshore beach system contained a surplus of sediment, the beaches continued to build seaward until equilibrium was reached. Equilibrium in this case was a function of the balance between storms and waves, sea level, and the amount of sediment in the coastal sand transport system.

Evidence suggests that equilibrium was reached at about the time the sea approached its present level. At that time the barrier islands were probably much wider than they are now. As time passed, the complex landscape of the barrier islands evolved. In the narrow locations such as Pea Island, surging water from storms frequently breached the islands, creating new inlets. Long spits connected the wider, more stable stretches where sequences of beach and dune ridges developed. In this way, the long chains of the barrier islands evolved.

Table 2: Environmental Impacts of Terminal Groin – Open Coast (3-6 miles from inlet)

	LOW LEVEL POSITIVE IMPACTS	LOW LEVEL NEGATIVE IMPACTS	HIGH LEVEL POSITIVE IMPACTS	HIGH LEVEL NEGATIVE IMPACTS	FUTURE LOW LEVEL IMPACTS	FUTURE HIGH LEVEL IMPACTS
PHYSICAL IMPACTS						
Overwash Terraces						
Dunes						
Beaches						
Shoals and Channels						
Longshore Transport						
Shoreline Erosion						
Sediment Characteristics						
ECOLOGICAL IMPACTS						
Least Tern (nesting)						
Least Tern (feeding)						
Common Terns (nesting)						
Common Terns (feeding)						
Piping Plovers (nesting)						
Piping Plovers (feeding)						
Oystercatchers (nesting)						
Oystercatchers (feeding)						
Black Skimmers (nesting)						
Black Skimmers (feeding)						
Sea Turtles (nesting)						
Polycheats						
Invertebrates Filter						

COASTAL STORMS

The relative intensity of hurricanes was defined by the Saffir-Simpson scale using five categories based on the central pressure, maximum wind speed and storm surge elevation of the storm. Dolan and Davis defined a similar intensity scale for mid-Atlantic Coast northeasters. Five classes were defined by a cluster analysis of the peak significant wave height, duration and power of the 1,564 northeasters included in the 50-yr dataset (1942-1992). Data were obtained from wave hindcasting of extratropical cyclones generating northeasterly winds and at least 1.5 m significant wave heights. Northeast storms were defined by deepwater significant wave heights ≥1.5 m because they cause significant beach erosion along the Outer Banks. Bosserman and Dolan defined storm duration as the period of time in which waves of at least 1.5 m are generated. The relative storm power (P) was defined as a function of the peak significant wave height ($H_{1/3}$, m) and storm duration.

The Saffir-Simpson hurricane scale was compared quantitatively with the Dolan/Davis intensity scale by calculating the relative power index for three hurricanes which recently affected the Outer Banks. The duration within which the storms generated at least 1.5 m waves and the peak significant wave height were obtained from data recorded by an array of gauges positioned offshore from the USACE Field Research Facility at a depth of approximately 8 m.

Although Hurricane Felix ranked as a category 4 (very strong) hurricane and a class 4 on the Dolan/Davis scale, a direct correlation between the Saffir/Simpson category and the Dolan/Davis class was not determined because each scale defines storm intensity by different criteria. Hurricane Bob, a category 3 (strong) hurricane, generated storm waves ($H_{1/3} \geq 1.5$ m) for only 12 hrs and ranked as a class 2 on the Dolan/Davis scale. Hurricane Gordon, a category 1 hurricane, remained well offshore of the North Carolina coast but generated storm waves for 123 hrs. As a result, this 'weak' hurricane which caused considerable beach erosion ranked as a class 5 on the Dolan/Davis scale. Based upon the results of these case studies, a direct relationship between the meteorological and the hydrological parameters does not exist.

Severe Storms that have Impacted Oregon Inlet:

The most active coastal storm period (1953-62) recorded in North Carolina history included 12 hurricanes and the Ash Wednesday storm of 1962. In the vicinity of Oregon Inlet, Hurricanes Ione and Helene generated ocean tides (1.2-1.9 m) and sound tides (0.6-2.3 m) above mean sea level. The Ash Wednesday storm generated a 3 m ocean tide. As the eye of Hurricane Donna passed just west of Pamlico Sound, the storm generated 31-41 m/s winds from the south to southwest. These winds produced a setup on the sound side and a setdown on the ocean side yielding a 3 m head of water across the inlet. When such severe storms pass or dissipate, the sound or ocean tide is driven seaward or landward respectively, often scouring the main inlet channel.

The Ash Wednesday storm of March 1962 caused several storm surge breakthroughs along the barrier islands, reopened New Inlet, and significantly changed the morphology of Oregon Inlet. The severity of this infamous class 5 northeast storm can be attributed to its long duration, increased wind velocities, wave heights, storm surge and coincidence with perigean tides. The maximum deepwater wave heights (9 m) were generated by wind velocities which persisted across a maximum fetch (1207 m) for approximately 44 hrs. The storm surge (4 m) which persisted for four tidal cycles also coincided with spring tides. As a result, overwash extended 91-122 m inland and dunes receded by as much as 40 m. The estimated recurrence interval for a northeaster of this magnitude was 120 years. The breakthrough just north of the Oregon Inlet Fishing Center closed naturally within two weeks and the breakthrough at Buxton Inlet was artificially closed in 1963. New Inlet was reopened by the storm but shoaled and closed within two weeks due to the predominant tidal flow through Oregon Inlet. The storm generated 18-26 ms^{-1} winds from the north and northeast which produced a 2 m head of water across Oregon Inlet. The water setup on the ocean side and setdown on the sound side caused an extended period of flood flow through Oregon Inlet. Enormous volumes of sand, from beach erosion and dune recession, were transported southward by littoral drift and subsequently deposited in the inlet by the storm surge and prolonged flood tide. The shoals and relict barriers in post-storm aerial photos evidence the increased rates of sediment transport and the storm-induced overloaded in the littoral system. As a result of these increased sediment transport rates, Oregon Inlet attained its maximum width (2100 m) which was three times greater than its width at formation (640 m).

The class 4 northeast storm of March 1989 generated an 82 cm wave setup along the Outer Banks and deepwater wave heights in excess of 1.5 m (average 3 m) for 115 hrs. The estimated energy-flux of these waves was 11,500 kwH/m while the annual average wave energy-flux at Oregon Inlet was only 2 kw/m (17,500 kwH/m annually). The wave energy-flux and duration are directly proportional to the sand transport potential of a storm. Therefore, the March 1989 storm had a sand transport potential equal to 66% of the average sand transport potential for that year. In addition, the estimated storm-induced longshore transport of sand

($415,000\ m^3$) was comparable to the storm erosion ($360,000\ m^3$) measured from the north end of Pea Island. Based upon a hindcast analysis of wave data, Dolan ranked this storm as one of the three highest total energy storms of the mid-Atlantic from 1942-89.

The class 5 Halloween Storm of October 1991 was one of the most severe mid-Atlantic coastal storms in the past 50 years due to its duration of sustained wind speeds and significant wave heights which surpassed the Ash Wednesday storm of 1962 and the March 1989 storm. The durations of the Halloween Storm (114 hrs) and the March 1989 storm (115 hrs) are comparable but the March storm generated lower (3-5 m) significant wave heights.

On October 30, 1991, Hurricane Grace migrated north and joined the Halloween cyclone. The steep pressure gradient between this combined low pressure system (983 mb) and the blocking anticyclone generated the strongest winds (21 ms^{-1}) and most severe waves of the storm ($H_{1/3}$>10m). These waves persisted for over two days and affected the coastline from Newfoundland to south of Miami, Florida. Therefore, due to its long duration of significant wave heights and its enormous fetch, the All Hallow's Eve northeaster of 1991 was more intense than either the Ash Wednesday storm of 1962 or the March 1989 storm.

IMPACTS OF THE OREGON INLET TERMINAL GROIN

Scientists and engineers have concluded, based on qualitative assessments, that the barrier islands adjacent to Oregon Inlet would be altered by the terminal groin significantly to a distance of 4.8 km (3 miles), that measurable and permanent changes would occur in a second zone of 4.8-9.6 km (3-6 miles) north and south of the stabilized inlet, and that subtle, but important, environmental changes would occur in a third zone to distances up to 16 km (10 miles) from the inlet.

In all cases, shoreline erosion rates had decreased with increasing distance from the inlet. In some localities, downdrift shoreline erosion had been severe, approaching -40 m/yr along some of the barriers such as Jupiter Island. In addition, this study discussed the complexity of processes and responses associated with tidal inlets and the limitations involved in determining cause and effect relationships in the vicinity of tidal inlets.

Along the Outer Banks, downdrift inlet accretion is present only on the northeast end of Ocracoke Island. This contrasts with downdrift inlet trends found along the majority of Virginia barrier islands. High erosion rates occur along the north end of Pea Island downdrift of Oregon Inlet. Maximum erosion occurs 0.5 km downdrift of Oregon Inlet and abrupt changes in the rate values cease 1.0-1.7 km. This change corresponds with a distinct change in shoreline orientation. Recent profiling by the US Army Corps of Engineers on Pea Island shows a transition in profile shape at a similar position (Miller, personal communication). The spatial standard deviation is minimized 6.7 km downdrift of the inlet and the maximum extent of inlet influence extends to 13 km. The updrift inlet shorelines are accretionary up to 0.4 km north of Hatteras Inlet on Hatteras Island and up to ≈2 km north of Oregon Inlet on Bodie Island. Along Hatteras Island, erosion and accretion trends alternate along-the-shore with accretion rates occurring ≈2.4 km north of Hatteras Inlet and erosion rates occurring ≈5.2 km to the north of Hatteras Inlet on Hatteras Island. Erosion becomes the predominant trend ≈2 km north of Oregon Inlet on Bodie Island.

The degree to which tidal inlets influence adjacent barrier island shorelines is a function of the sizes and number of inlets, and long- and short-term changes in the sediment budget. The number of inlets and their sizes are controlled by the tidal prism which, in turn, is controlled by the size of the backbarrier bay and the tidal range. Areas of high tidal energy relative to wave energy necessitate larger-sized or a greater number of tidal inlets to facilitate the larger volume of water flowing into and out of the backbarrier. In theory, as the tidal prism increases along a barrier coast, the ebb-tidal delta will increase in size (volume and geometry) and will, in turn, exert an increasingly greater influence on a barrier's sediment budget and shoreline behavior.

Additional processes that contribute to sediment losses and shoreline erosion in the vicinity of inlets include washover events during storms, shoreface retreat, inlet migration, and/or a net reduction in the longshore sediment flux due to sediment deposition in sinks such as tidal channels, tidal deltas, tidal creeks or the marsh surface. Sediment gains primarily result from spit growth and barrier extension on updrift inlet barriers, and/or sediment bypassing and bar welding processes on downdrift inlet barriers.

General patterns emerged from our analysis, however, the results demonstrate that the shorelines adjacent to inlets are characterized by unique temporal histories. Therefore, we compiled information on the attributes of the Oregon Inlet to compare the morphologic and hydrologic aspects to shoreline responses. The North Carolina inlets are shallower than those of the Virginia barriers but the cross-sectional profiles (widths) have changed substantially through time. The width of Hatteras Inlet, for example, has ranged from 2,300 in May 1990 to 550 m in November 1993. Virginia inlets have smaller width/depth ratios (the depths are greater relative to the depths of North Carolina inlets).

The spatial impact of tidal inlets on the patterns of shoreline change along the wave-dominated North Carolina coast extends to a maximum distance of 13 km and to 6.1 km along the mixed-energy, tide-dominated Virginia barrier islands. However, a significant degree of variability in the spatial range of inlet influence exists. Criterion one, the cessation of abrupt changes in the rates of change along-the-shore and the reduction in variability of along-the-shore rate values, revealed the greatest degree of inlet-related shoreline impact (≤6.1 km). Criterion two, a change in the sign of the rate value from erosion to accretion or vice versa, showed the next greatest degree of shoreline impact (except for two 'anomalous' locations along the north ends of Outer Banks barriers) (≤5.2 km). Criterion three, a change in the increasing or decreasing trends in rate change values provided the most conservative estimate of the spatial impact due to inlets (≤4.3 km). Therefore, we suggest that a barrier zone in which inlet-related processes *dominate* shoreline trends can extend to distances of up to 4-5 km from an inlet and a zone in which inlet-related processes *influence* shoreline trends can extend to distances of up 6-13 km.

The process-response patterns observed along the North Carolina barrier islands are expected to be similar to those found in other tide-dominated, mixed-energy environments such as northern Massachusetts, South Carolina, and Georgia. In addition, those patterns observed along the Outer Banks may be similar to those found in other microtidal, wave-dominated settings such as the east and west coasts of Florida.

The downdrift inlet shorelines (northern ends of barrier islands) show the greatest range in the spatial extent of along-the-shore rate-of-change values (influence) due to inlet processes. From a management perspective, the problem areas (erosional) appear to be associated with barriers which are located downdrift of actively migrating tidal inlets (e.g. Pea Island), inlets in which the throat is temporarily pinned adjacent to the downdrift barrier (e.g. Cedar Island), updrift of ephemeral inlets, or whether bypassing is poor to non-existent. Relatively 'safe' areas (accretionary) occur along barriers which are located downdrift of stable inlets, although high temporal variability can be expected. Areas located along updrift recurved spits may show accretionary trends but can be highly susceptible to storm washover due to their lower elevations.

Shorter islands, such as those commonly found in mixed-energy environments, experience a greater spatial impact of the shoreline due to inlet-related changes than longer islands. This is due primarily to the sizes of the tidal inlet and tidal deltas relative to the length of the island, the low inlet width/depth ratios, and the greater tidal ranges.

We have employed a variety of quantitative methods including non-linear robust regression analyses, principal component analysis, and stochastic process modeling to identify inlet-related shoreline changes. Results using the coefficient of determination as a spatial outlier detection technique show that, along the 66 km reach south of Oregon Inlet on Pea Island, the rate-of-change values greater than 1, 2, 3, and 4 standard deviations from the mean occur to distances of 6 km, 1.5 km, 0.7 km, and 0.4 km respectively. In addition, we examined the role of coastal storms on modifying inlet morphodynamics and adjacent barrier island shoreline changes.

Discussion:

The fundamental question underpinning the assessment is, *'has the Oregon Inlet/Pea Island terminal groin significantly impacted the inlet and adjacent barrier islands?'* The answer is 'yes.' The groin altered the alongshore coast sand transport processes in the vicinity of Oregon Inlet with sand accumulations downdrift of the groin occurring at approximately the same pace as the construction progress. The groin caused a significant reduction in the width and depth of the inlet and sand accumulated in the fillet area of the groin commenced almost immediately as construction progressed with a change from a large-area subaqueous environment overwashed frequently by storm surge and high tides to a low sub-aerial sand flat.

The infilling of the subaqueous area downdrift from the groin proceeded at a pace similar to the rate of construction and the placement of the rocks. In some cases, the impacts have been highly negative; with others, the impacts can be considered positive (see attached table). Any geological feature or indigenous organisms, located within the pathway of the high-energy sand transport zones was impacted. Construction of the terminal groin initiated changes on the north end of Pea Island almost immediately.

The north end of Pea Island transitioned from a natural landscape with open ocean exposure to a newly-formed stabilized element of the barrier island system.

Changes in conjunction with the installation of the rocks become apparent almost immediately; the most notable was the reduction in the width of the inlet from approximately 5000 ft to 2500 ft, the development of a large tidal fillet in the lee of the structure.

The length of the groin determined the size of the infilling and the size of the area transformed from subaqueous to sub-aerial. At the largest scale, there has been a distinct reduction in the subaqueous areas including the inlet width and alteration of the configuration of the fillet area to the lee of the groin on the northern section of Pea Island. In addition to the subaqueous to sub-aerial changes caused by the groin construction on Oregon Inlet, sand mining of the fillet area has contributed to considerable alterations of the landscape elements. However, if mining is stopped, overwash processes will drive the sand transport system back to a natural state.

The sand that has accumulated in the downdrift groin fillet area has had a negative impact on some species and a positive one due to expansion one way or another – that is when landscapes transmissions occur, results change from subaqueous to sub-aerial states – these changes were obvious and inevitable.

Other changes go hand in hand with the sand redistribution. For example, the sand that has and continues to accumulate in the fillet area downdrift from the groin is measurably finer than the open ocean beach exposures along Pea Island and Bodie

Island. The difference in sand sizes can be significant to the distribution and abundance of the filter feeders, especially *Emerita* and *Donax*. The changes from subaqueous to sub-aerial also have very significant impacts on the turtles and shorebirds; in some cases negative and in others positive.

STORMS AND SHORELINE EROSION

Coastal erosion and deposition are functions of three interrelated factors: the amount and type of sediment within a coastal area; the wave and tidal forces acting upon the sediment; and changes in sea level. The shoreline recedes when the forces of erosion exceed the amount of sediment supplied to the barrier island system. The greater the deficiency of sand, or the higher the wave forces, the more rapid the rate of erosion. Any of the three factors (wave, energy, sediment, or sea level) can vary through time and change the balance. Beach erosion is, however, a natural process and becomes a problem only when man's structures are placed in the path of beach recession.

The rate of North Carolina barrier island recession over the last 2000 years undoubtedly varied as the rate in the rise of sea level changed and as the supply of sand diminished. Some of the eroded material has been lost into large offshore sediment sinks, such as Diamond Shoals off Cape Hatteras. Much of it, however, has remained within the barrier island sediment budget and has contributed to spit growth, inlet filling, dune building, and storm overwash deposits.

Four types of sand movement are responsible for most changes occurring on barrier islands: movement of sediment along the shore zone occurs when waves approaching the coast at an angle set up sediment transporting processes called longshore currents. The direction and strength of longshore currents depends on the size and direction of the waves approaching the coast.

Over the course of the year, there is usually a net flow of water and sediment in one direction. Movement of sediment across the shore zone occurs during storms when very high waves and tides result in water levels so high that the beaches and barrier islands may be overwashed. Movement of fine-grained sand from the beach-face and sand flats occurs during periods of strong winds. And inlets such as Oregon Inlet also provide a means for sediment to be transported from the beach zone to the sounds and vice versa. Inlets are formed when storm surge and high waves drive water across the islands to the lower water levels of the sounds and bays. As the seawater moves across the island, usually into areas of progressively lower topography, channels form and may erode to depths that permit a reverse flow from sound to sea during ebb tide. Although most inlets that form during storms seal by natural processes within a relatively short time, some remain open for years, decades, and even centuries and thus become somewhat permanent features of the barrier islands. Inlet formation and closure are fundamental sediment transfer processes that move material from the ocean side to the sound side of the North Carolina barrier islands. The sand deposits that fill inlets represent a relatively large percentage of barrier island sediments, perhaps as much as 25%. The configuration of all North Carolina barrier islands respond, to a considerable degree, to the dominant processes – overwash and inlet formation.

Although hurricanes cause extensive damage and sometimes loss of life, it is the winter extratropical storms, or northeasters, that cause most of the damage along the North Carolina coast. Unlike hurricanes which form over the tropical waters of the Caribbean and the Atlantic, extratropical storms develop in the midlatitudes along weather fronts that separate cold, dry polar air from warm, moist tropical air. Each year between 20 and 30 such storms produce winds that generate waves of at least 5 ft (1.5 m). Dolan developed a ranking system for northeast storms based on the wave heights and durations of the winds. The Lincoln's Birthday northeaster of February 12-13 1973, one of the seven class 5 (most severe) northeasters to have occurred between 1942 and 1986, caused extensive erosion to the beaches from Long Island, New York, to Miami, Florida. The great Ash Wednesday storm of March 1962, also a class 5 storm, produced waves more than 30 ft high (10 m) that were coupled with very high astronomical tides. This resulted in damage and destruction of coastal property along the entire middle Atlantic Coast north of Cape Hatteras. More recently, millions of dollars in property damage occurred along the North Carolina coast due to a series of severe winter storms, including another class 5 northeaster, the Halloween storm of October 1991.

Measurement of Shoreline Change:

Marine scientists, managers, and engineers have long recognized the shoreline and beach face as elements of a highly dynamic physical system. What is needed for knowledgeable and competent planning is reliable information about the rates of shoreline change through time. Information of this type can be obtained from ground surveys, maps, charts, and aerial photographs. Ground survey methods, or direct measurements, provide data of the highest accuracy and reliability but opportunities for detailed historical comparisons are lacking for most coastal areas and the generation of new surveys is expensive and time-consuming. Therefore, with the exception of a few scattered sites, direct ground-level measurements are generally unavailable. On the other hand, maps and charts are available for most coastal locations and frequently date from the mid-1800s.

Aerial photographs are accessible for most coastal sites in the United States. The earliest photographs for the North Carolina coast date from the 1930s and images for subsequent decades are generally attainable. Aerial photographs have many advantages over other types of information in coastal mapping. In a matter of hours, hundreds of miles of coast can be photographed providing an 'instantaneous' record rather than a survey spanning months or years. Photographs include a measure of detail over extended areas unavailable with any other information base; furthermore, photographs are permanent and easily duplicated.

Overview of Rates of Shoreline Change for the Middle Atlantic Coast:

The attached diagrams summarize the shoreline erosion and accretion rates for the middle Atlantic states from North Carolina to New Jersey. Overall, 44% of the shoreline is eroding at rates greater than 2 ft/yr (0.6 m/yr) and 17% is accreting. 42% of the coast of North Carolina is eroding; 20.9% at a rate greater than 6 ft/yr (2 m/yr).

The development of North Carolina's Outer Banks typifies what has happened on many of the middle Atlantic Coast barrier islands. Even though the dynamic nature of the beaches and dunes has always been part of the aesthetic and recreational appeal of the Outer Banks, the islands remained remote and were seldom visited until the first bridges from the mainland were built in the 1930s. Soon thereafter, a plan was implemented to build a road running the length of the Outer Banks with barrier dunes to prevent storm surge and overwash.

The artificial dune stabilization has altered the ecology and geology of the Outer Banks. Viewed from the air, the most striking difference between the natural and altered barrier islands, other than the artificial barrier dune, is a marked difference in beach width. The unaltered islands have beaches from 350-600 ft (100-200 m) wide whereas on Hatteras Island the beach has been reduced to 100 ft (30 m) or less.

Coastal Engineering Measures:

There are four basic methods coastal engineers use to mitigate shoreline erosion. Structures designed to trap sediment in areas that are eroding (groins); structures that reduce the wave forces reaching the coast (breakwaters); structures that provide direct protection from wave action and storm surge (sea walls and revetments); and finally an approach that has become known as 'soft' engineering, the replacement of beach sands that are lost to erosion (beach nourishment).

Groins are hard structures (wood, steel, or concrete), that are constructed perpendicular to the beach and extend out into the surf zone. The purpose is to impede the longshore transport of sand thus expanding the beach in the updrift side of the groin. However, groins commonly lead to erosion on the downdrift sides so there is an important trade-off that must be considered in using these structures.

Breakwaters are usually constructed in the pathways of approaching waves in order to impede or alter the shoaling and breaking process thus reducing the level of wave energy reaching the beach. The usual assumption in the design of these structures is that by reducing the level of wave energy reaching the beach, the forces responsible for erosion will also be reduced. As with groins, one of the most common problems with breakwaters is that sand gained behind the breakwater is sand lost at some adjacent site.

Sea walls and revetments are designed to protect coastal property by providing a structural barrier of wood, rocks, concrete, or steel that is strong enough to absorb and divert waves and storm surge. If severe erosion is the problem for a site under consideration for a sea wall, the design must include the eventual disappearance of the beach in front of the structure, leaving the sea wall exposed to the direct forces of waves and storms. From this standpoint, sea walls and revetments must be considered temporary solutions in areas of rapid erosion.

Beach nourishment, like sea walls, is not a permanent solution to beach erosion. This approach is simple; sand from an alternative location, preferably where it is not needed, is used to replace sand lost due to erosion. Sources for beach replenishment sands range from navigational channels in inlets to offshore shoals. The most limiting aspects associated with beach nourishment include the high costs per mile of beach, the lack of inexpensive sand sources, and the vulnerability of the soft engineering structure to several and unpredictable storms.

INLET PROCESSES

The two most important large-scale factors in landscape change of the barrier islands are overwash of seawater and sediment and the formation of inlets. During storms, the beach zone and nearby dunes are overtopped by high water levels and waves. Pea Island has many examples of these landforms. As sediment-charged masses of water spill across the beach and flow toward the bays and sounds on the inland margins of the barrier islands, a layer of sediment is removed from the beach and added to the island's interior. This process transforms the shapes and positions of the islands but conserves their total sediment mass.

Overwash and inlet formation and closure are common along the middle Atlantic 'microtidal coast'. Temporary inlets form during storms when the narrower reaches of islands are overwashed and breached, creating openings to the lagoons and bays behind the beaches. While the inlet is open sand moves through it and is deposited on the inside of the island as large, fan-shaped flood-tide shoals. Sand is also transported seaward during ebb tides, so that a similar delta may be created in the ocean. The inlet shoals are exposed at low tide and eventually become a new substrate for the formation of salt marshes and nesting areas for birds. Shoals below the low-tide level support underwater grass beds.

Soon thereafter a plan was developed to build a road running the length of the Outer Banks, with an artificial barrier dune to prevent storm surge and overwash. Until then the islands were overwashed several times a year which precluded a permanent road system. Beginning in 1936, the Civilian Conservation Corps and the Works Projects Administration, under the direction of the National Park Service, erected almost 3.3 million feet of sand fences (which act much like snow fences) to create a continuous barrier dune 70 miles long along Hatteras, Pea, and Bodie islands.

Most of the dune construction took place in the open sand flats behind the original low, irregular beach dunes--about 300-500 ft inland from the shore zone. The sand that collected along the fencing was stabilized further with some 1.4 million trees and shrubs and enough grass to protect more than 3,000 acres. The National Park Service dune construction in the late 1930s resulted in an almost continuous mass of dunes and vegetation within the Cape Hatteras National Seashore.

As discussed before, storm surge, overwash, and inlet formation are the most important processes driving the landward migration of the Atlantic Coast barrier islands. During severe storms, the beach zone and seaward dunes are periodically overtopped by high water levels and waves. As this sediment-charged mass of water spills across the beach and flows toward the bays and sounds on the inland margins of the islands, a layer of sediment is removed from the beach and added to the island's interior – a process that transforms the shape and position of the island but conserves its total sediment mass. Sand also moves inland through inlets into the bays and lagoons. Temporary inlets are formed during storms when the islands are overwashed and breached, creating openings to the lagoons and bays behind the beaches. Most of these inlets eventually close unless there is a major river discharge behind them. While the inlet is open, however, sand moves through it and is deposited on the inside of the barrier island as large, fan-shaped shoals. Sand is also carried out during ebb tide, and a similar delta may be created in the ocean. The inlet shoals are exposed at low tide and eventually become a new substrate for highly-productive salt marshes; shoals below the low tide support underwater grass beds. Sand overwash crossing the islands also creates a fringe of marsh substrate but inlet deposits lead to the most extensive marshes projecting into the sounds and bays behind the barrier islands.

In 1989, Michael Fenster, a coastal geologist on the faculty of Randolph-Mason College in Ashland, VA, and Robert Dolan, a University of Virginia faculty member, carried out a research project along the Atlantic Coast designed to answer this question: 'How far along the coast does the impact of a tidal inlet extend?' In their analyses, they used shoreline erosion data collected over many years by students and faculty at the University of Virginia, the Corps of Engineers, and staff members in the engineering division at North Caroline State University.

The basic assumption underpinning Fenster's and Dolan's research (which was published in a 1995 edition of the *Journal of Coastal Research* (see attachment), is that a large opening in the barrier islands (such as Oregon Inlet on the Outer Banks that allows water to be exchanged between Pamlico Sound and the Atlantic Ocean) would have measurable and significant impacts on the trends in beach erosion north and south of the Atlantic Coast inlets. That is, as the alongshore sand transport pathway along the beaches of the barrier islands approaches the inlet breach on the coast, to what degree is the sediment budget for the islands adjacent to the inlets altered.

The degree to which this alteration occurs is a function of the size of the inlet responsible for the impact on the alongshore transport and the size of the sand involved in the transfer.

This complex process with complex outcomes is directly related to the alongshore transport rates. If the sand transport volume is high (which is the case for the Outer Banks of North Carolina), sand transported into the inlet tends to 'choke' the flow water and transport of sediment on the updraft side of the inlet forming large geomorphic features called 'inlet marginal spits'. These spits migrate into the inlet, narrowing the overall cross-section while diverting erosion and alongshore transport from the adjacent barrier islands. This redistribution of sand in the inlet system results in an overall downdrift 'migration' of the inlet; that is deposition on the updrift side as the inlet marginal spits encroach on the inlet and erosion on the barrier island's downdrift side. With an increase in the alongshore transport volumes, this complex 'choking' process ends up forcing the inlet in the up- or downdrift direction. The rate is a function of sand volumes.

In the case of Oregon Inlet and Pea Island, over the 152 years of the inlet's history, the 'migration' of the inlet has been north to south at a rate of approximately 150 ft/yr; however, since the driving forces are currents in the inshore system, the frequency and magnitude of coastal storms determine the rates of sand redistribution.

The terminal groin at Oregon Inlet was designed to alter sand transport processes, leading to a more desirable distribution of the sand being transported along the coast into and out of tidal inlets. If a terminal groin does not perform in this manner, it would be considered a failure within the coastal engineering community. In the case of the Oregon Inlet/Pea Island terminal groin, the structure was designed to halt the southward migration of sand into the inlet, to provide protection to the Bonner Bridge, especially the southernmost section near the abandoned Coast Guard station on Pea Island.

HISTORY OF OREGON INLET DREDGING

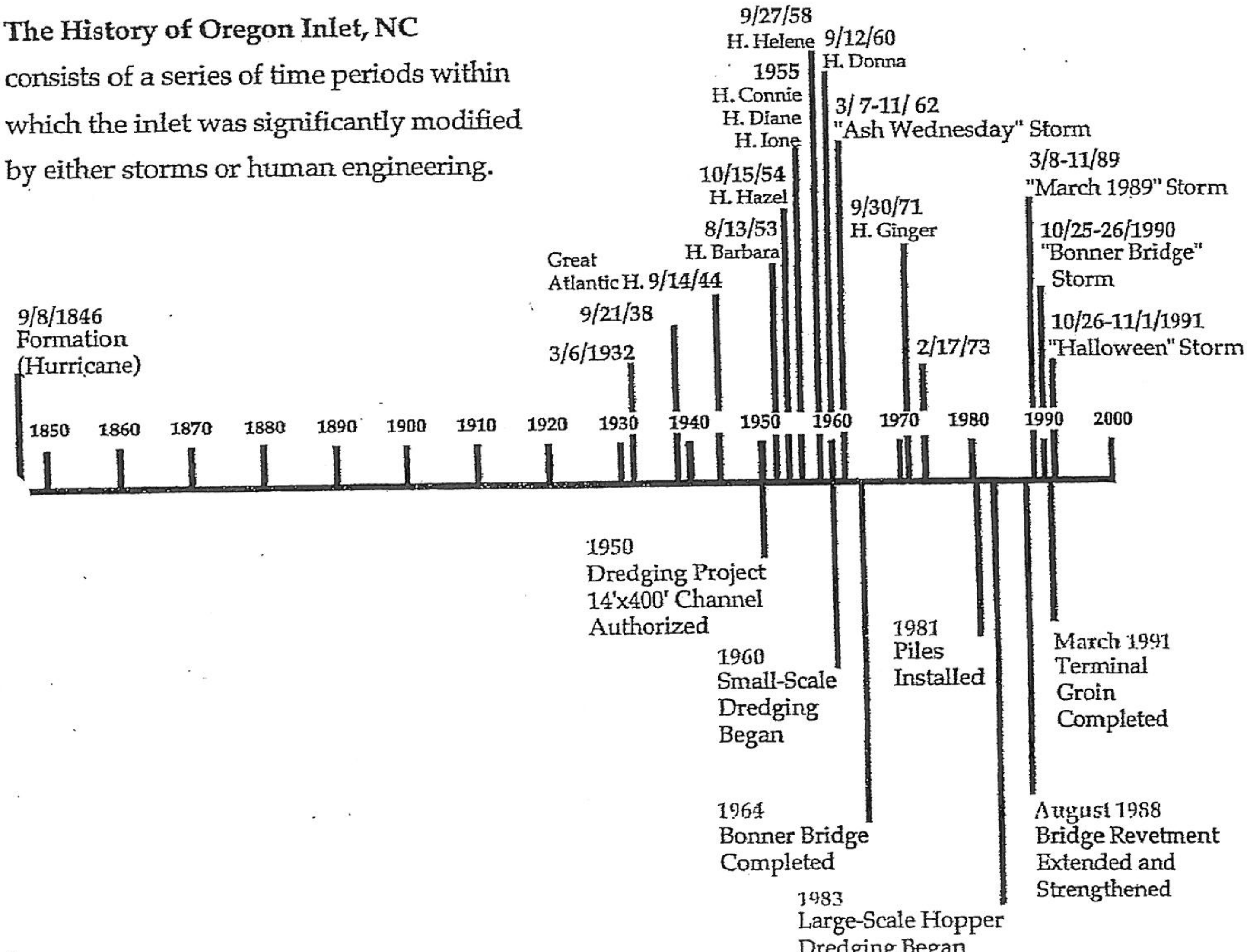
In 1950, Congress authorized the USACE to maintain a 122 m x 4.3 m navigation channel through the ocean bar of Oregon Inlet. In 1960 and 1961, a hopper dredge was used to excavate the initial channel and from 1962 to 1972 both a hopper and sidecasting dredge were used for channel maintenance. From 1962 to 1982, the channel was primarily maintained by sidecast dredges. In 1981, the ocean bar channel, adjacent to the south end of Bodie Island, shifted to a location near the center of the inlet. The USACE concentrated dredging efforts in the new channel which provided direct access to the navigation span.

To improve navigability of the inlet, the Corps intensified dredging efforts in 1983 by using large-capacity hopper dredges. Between 1983 and 1989, an average of 420, 530 m^3/yr was dredged from the channel and deposited offshore of Pea Island, approximately 2440 m south of the inlet. The hopper dredge material was deposited as close to shore as possible but seldom in depths less than six meters so the majority of this material was lost from the littoral sediment budget. The sand deficit caused by hopper dredging with nearshore disposal resulted in accelerated rates of erosion on Pea Island.

The intensified dredging after 1983 removed significantly greater volumes of sediment than sidecast dredging. For comparison, from 1960 to 1982 the mean volume dredged was 204,017 m^3 whereas the mean volume dredged after 1983 was 969,515 m^3.

Since 1989, the offshore disposal of dredge material has declined due to the restriction imposed by the National Marine Fisheries Service which permits

The History of Oregon Inlet, NC consists of a series of time periods within which the inlet was significantly modified by either storms or human engineering.



hopper dredging only from December to March. Consequently, from the fall of 1989 to 1992, approximately 1,146,900 m^3 has been deposited on Pea Island beaches by pipeline dredges. In that same period, 382,300 m^3 was deposited offshore by hopper dredges.

This change was attributed to the increased rates of spit extension to the decreased storm activity from 1965 to 1967 rather than from structural influences of the bridge.

In 1988, NCDOT commissioned a task force to assess the risks associated with the migration of Oregon Inlet to Bonner Bridge and NC 12 and evaluate several protective alternatives. The task force concluded that sporadic inlet migration, caused by rapid sediment transport during a single storm or year, threatened the southern abutment of the bridge and NC 12 5-8 km south of the inlet. Although not unanimous, a terminal groin was recommended as the best structural solution short of complete inlet stabilization. The task force maintained the groin would prevent future southward migration of the inlet, protect the southern bridge abutment and US Coast Guard Station and allow construction of a replacement bridge. The report acknowledged that maintenance dredging of the navigation channel would remain necessary and that the groin could be easily incorporated into a future jetty system.

Longshore transport rates in the vicinity of Oregon Inlet were obtained from the US Army Corps of Engineers and from the research of Inman and Dolan. The rates were calculated from wave hindcast data collected from the Wave Information Study (WIS) Phase III station 84 located north of Oregon Inlet and computed from wave data collected at the USACE.

In the past 150 years, natural processes and engineering have contributed to the highly variable migration rate of Oregon Inlet over different timescales. Sea level rise, sediment availability, and southern longshore transport are responsible for the long-term island recession and southward inlet migration. Coastal storms, tides, waves, and currents affect the inlet and adjacent shorelines over shorter time intervals. Deviations from these trends are caused by coastal engineering including dredging, beach nourishment and hard structures such as the Oregon Inlet terminal groin which alter the nearshore and tidal inlet sediment budgets and transport paths.

As the width of Oregon Inlet increased between 1862 and 1975, the cross-section increased but was highly variable. Since the construction of the terminal groin in 1989, the inlet width decreased at a rate of 78 m/yr. Despite this decrease, the inlet has maintained a comparatively constant cross-sectional area by an increase in depth to between 8 and 9 m.

The migratory history of Oregon Inlet is directly related to the frequency and magnitude of storms affecting the area. During periods of decreased storm frequency but increased storm magnitude, the midpoint of the inlet migrated to the north. It migrated south during subsequent periods of reduced storm frequency and the absence of severe storms.

The migratory trends of Bodie Island represent high frequency variations in erosion and accretion caused by storms. Between 1849 and 1988, Bodie Island migrated at rates ranging from 3 to 424 m/yr (Fig 9) northward in response to an intense storm or a period of high storm frequency; southward during periods of decreased storm frequency and reduced storm magnitude. Storms that breach

Bodie Island and spit accretion in the absence of storms are responsible for most of the changes in the width of Oregon Inlet.

The results suggest that a weak seasonal trend in inlet width correlates with the seasonality of coastal storm frequency. The plots for 1990 and 1992-95 reveal a local maximum inlet width attained approximately 1-2 months after December, the peak of the winter storm season. The summer minimum in storm frequency is followed by a late summer to early minimum inlet width. For a few plots, a poor correlation ($r^2 < 0.7$) exists between the fitted curves and the storm frequency and inlet width data. However, these plots suggest a temporal lag exists between the seasonal minimums in coastal storm frequency and inlet width which ranges from 0.33 to 3.4 months.

The location of the main channel of Oregon Inlet has varied in response to storm frequency and magnitude. From 1931 to 1948, the location of the channel remained relatively stable due to the scour induced by severe storms. In the fall of 1955, three hurricanes resulted in the southward migration (823 m) of the main channel. During the most severe storm period (1957-65), the inlet was wider and shallower than during the period of reduced storm activity in the mid-1970s. Between 1990 and 1994, the main channel migrated southward adjacent to the terminal groin. The maximum depth of the inlet channel has remained between 8 and 9 m but the proportion of the channel width attaining this depth has increased from 1990 to 1994.

The most significant management concerns for Oregon Inlet and Pea Island are the protection of Bonner Bridge, maintenance of the navigation channel, and monitoring the physical and ecological habitat. The bridge provides vehicular, power, and telephone access vital to the residents and tourism industry of Dare County and a safe navigation channel through the inlet must be maintained for recreational and commercial fishing vessels. However, each of the engineering measures employed to preserve the integrity of the bridge and navigation channel have affected the migration and geometry of Oregon Inlet.

Construction of Bonner Bridge altered the sediment transport and introduced widespread shoaling. In response, the ocean bar and sections of the inner channels have been regularly dredged since 1960 to maintain safe navigation. From 1980 to 1989, severe scour around several supporting bents and the south approach necessitated additional armoring of the bridge: piles, a rip-rap revetment, and eventually the construction of the terminal groin (Fig 6). The piles and revetment diverted some of the ebb flow northward which contributed to increased erosion rates on Bodie Island. The effects of the terminal groin upon the migration and geometry of the inlet will be addressed later in this section.

As indicated earlier, the northern migration of the Bodie Island and rapid southern migration of Pea Island from 1981 to 1986 contradicts past trends in storm frequency and inlet migration; this can be attributed to the intensified dredging initiated in 1983. From 1983 to 1989, hopper dredging with nearshore disposal removed an average of 420/530 m^3/yr of sediment from the littoral system and accelerated erosion rates on Pea Island. Between 1985 and 1991, the midpoint of the inlet migrated northward (95 m/yr), the northern end of Pea Island eroded 1000 m southward (167 m/yr) and the inlet width steadily increased despite the decline in annual storm frequency from 1980 to 1985. The hopper dredging produced a sand deficit which caused these deviations from past migratory trends and increased erosion rates on Pea Island during the March 1989 storm.

IMPACTS OF TERMINAL GROINS ON BARRIER ISLANDS

Processes that contribute to sediment losses and beach erosion in the vicinity of inlets include storm surges, washover during storms, shoreface retreat, inlet migration, and/or a net reduction in the longshore sediment flux due to sediment deposition in sinks such as tidal channels, tidal deltas, tidal creeks or the marsh surface. Sediment gains primarily result from spit growth and barrier extension on updrift inlet barriers and/or sediment bypassing and bar welding processes on downdrift barriers.

The geological and ecological significance of tidal inlet formation and closure are considerable. These process results in the movement of great quantities of saline water and sediment from the ocean sides of the islands to the sounds. The water contains nutrients and organisms and the sediment forms shoals that provide new substrates for marsh grasses. Soon after the inlets close, shoal areas become incorporated into the island substrate. This is clearly illustrated on aerial photography. Inlet formation and closure is, therefore, one of the fundamental sediment-transfer processes that move material from the ocean sides of the barrier islands to the fringing sound sides.

This continuing process of wind and waves acting upon the barrier islands results in geomorphological responses which can be seen and measured over time and space. Measurements of process/response relationships allow predictions based on past occurrences which in turn allow for more environmentally sound management, especially when coupled with a GIS framework and statistical modeling.

Hurricanes and winter extratropical storms (northeasters) of the mid-latitudes have been the principal agents of change on the mid-Atlantic barrier islands since their formation 5,000 years ago. Change is brought about by the movement of sands from strong wind and wave activity. Hurricanes generate high storm surges in contrast to extratropical storms which generate small to modest surges.

Both hurricanes and northeasters generate waves by the action of winds moving across the surface of the sea. The height of the waves produced is a function of the speed of the wind, the distance over the water which the wind is blowing (fetch), and the duration of wind action on the sea surface (ref).

Hurricanes are especially destructive at the time of landfall on the coast. Elevations of the sea in excess of 20 ft (6.1 m) may occur over 50 miles (80 km) of coast zone.

Unlike hurricanes which are spawned over the tropical waters of the Caribbean and Gulf of Mexico, extratropical storms or winter northeasters develop along the weather fronts of the mid-latitudes which separate cold dry polar air from warm moist tropical air. Each year between 30 and 40 such storms generate significant surge and waves of at least 5 ft (1.5 m). The most damaging storms in recent history, the Ash Wednesday storm of March 1962, and the Halloween storm of 1998 was an extratropical storm.

During fair weather along the Outer Banks, especially in the summer, there is a slow persistent movement of sand to the north in response to prevailing southeast waves. During storms, predominantly in the winter months, northeast waves prevail and the longshore current along the Outer Banks is southward.

Thus on an annual basis, a quasi-equilibrium is established between northward drift and southward drift, with net movement to the south. Any engineering structure placed within the stream of the longshore currents will alter the sand transport processes.

Viewed from the perspective of averages in space and time, the barrier island landscape is a complex patchwork of rapidly and slowly changing elements. Spatial variations in these rates of change, organized along the coast, may be measured at the scale of hundreds-of-feet (meters) or more. Temporal variations across the barrier island are scaled in tens-of-feet (meters) or less.

Oregon Inlet:

There has been an inlet in the vicinity of the present-day Oregon Inlet since 1585. Between then and 2010, the number of inlets along this segment of the Outer Banks varied between two to as many as six. In 1775, an earlier inlet in the vicinity of Oregon Inlet closed and Currituck, Caffey's, Roanoke, and New Inlets were open in 1808. By 1833, New Inlet, located 13 km south of the present location of Oregon Inlet, was the only inlet open between Cape Henry and Cape Hatteras.

Between 1849 and 1944, tidal exchange through Oregon Inlet varied, as periodic hurricanes opened and closed New Inlet to the south. New Inlet, located on the southern boundary of the Pea Island wildlife refuge, attained its maximum width (792 m) in 1852 but its width steadily declined as tidal flow through Oregon Inlet increased. By 1909 New Inlet was only 213 m wide; the inlet closed in 1922. In March 1932, a storm reopened New Inlet then the Great Atlantic Hurricane of September 1944 passed almost directly over Oregon Inlet and reclosed New Inlet. Since that closure, Oregon Inlet has been the dominant inlet-outlet for tidal exchange between the Atlantic Ocean and Pamlico Sound and the only tidal inlet between Cape Henry and Cape Hatteras.

Processes and Events that have altered Oregon Inlet:

As stated previously, Oregon Inlet is the only inlet/outlet providing hydrological exchange between Pamlico Sound and the Atlantic Ocean between Cape Henry and Cape Hatteras. Approximately two-thirds of the flow through the inlet is freshwater riverine discharge from Coastal Plain river systems. The watershed is 63,478 km^2 and discharge freshwater into the five sounds of the Albemarle-Pamlico estuarine system.

Inman and Dolan's review of the sediment budget for Oregon Inlet indicated that before the terminal groin inlet migrated south at an average rate of 23 m/yr and west at a rate of 5 m/yr. In addition, approximately 0.5-1.5 million m^3/yr of sand is transported around the inlet predominantly in the southern direction. The three sediment transport paths responsible for this sediment bypassing around Oregon Inlet are longshore transport, flood tidal flow and ebb tidal flow. Each transport path contributes to the sediment size distribution, composition and depositional characteristics of the four distinct sedimentary features of Oregon Inlet: the accretionary spit, flood delta, ebb delta and main channel.

In the vicinity of Oregon Inlet, the direction of net littoral drift is southward from September to April and northward from May to August (USACE, 1977). However, the predominant southern longshore drift facilitates the accretion on the southern end of Bodie Island. The prograding spit is composed of fine sand to fine gravel-sized quartz and gravel-sized shell material, graded fining upward and nearly horizontal toward the beach but moderately to steeply dipped at the forward spit slope.

The flood tide flows landward predominantly through Middle Slough and transport sediment into Pamlico Sound. The maximum flood flow velocity recorded was 1.1 m/s. As the flood flow enters the shallow bay, transport velocities rapidly decrease and deposition occurs producing the flood tide delta. The flood delta is a lobate deposit consisting of very fine to fine grain quartz sand, silts, and clay with several intertidal flats, cross-cutting channels and one or two main channels. Some of the sediment from the flood delta remains in the sound and is incorporated into the barrier, and another portion of the flood delta deposit is transported by the ebb tide and reincorporated into longshore transport on the downdrift shoulder of the inlet.

The ebb tide flows predominantly through Davis Slough and redistributes flood and ebb delta deposits. The maximum ebb flow velocity recorded was 0.6 m/s. Seaward of the inlet, the ebb flow velocity and sediment transport capacity decrease due to resistance from ocean waves and the subsequent sediment deposition produces the ebb tidal delta. The morphology of the ebb delta complex depends upon the relative strength between the tidal flows and wave energy. Due to the combination of surface winds and freshwater flow, the ebb tidal prism exceeds the flood tidal prism by approximately 2.4×10^7 m^3. Despite this net seaward flow through the inlet, the ebb delta is small relative to ebb deltas in macrotidal environments. The ebb delta and platform are composed of several bars and channels located offshore and perpendicular to the inlet throat. This complex consists primarily of fine to coarse quartz sand and abraded shell material which is constantly redistributed by the shifting tides and the dominant wave energy, so graded bedding fining upward and cross-bedding are common. In response to the shifting tidal flows and waves, the offshore bars migrate in a zigzag fashion along the arcuate perimeter of the ebb delta and are eventually reincorporated with the downdrift barrier shoreline. In this manner, the ebb-tidal delta serves as a temporary sediment sink which facilitates sand bypassing around the inlet.

The main channel in the inlet varies in depth (1.5-7.6 m), width (640-2100 m) and orientation due to the rapid shoaling within the throat. The channel is eroded into a deposit composed primarily of fine to medium, light gray, quartz sand with coarser lag deposits in deeper sections. The channel floor has migrating sand waves which change with tide and storm conditions.

The previously-described hydrologic and sediment transport processes have contributed to the evolution of Oregon Inlet; the most significant geomorphic changes resulted from the alteration of these processes by coastal storms and human engineering. Fig 3 is a timeline of the most significant events in the history of Oregon Inlet, including severe storms and engineering procedures.

The impact of storms is also evidenced by the pre- and post-storm configurations of Oregon Inlet, including the shape and orientation of Bodie and Pea Islands, alignment of the ocean bar, alignment of the main channel, and the cross-sectional profile. During storm-free periods, the Bodie Island spit accretes southward, the inlet width decreases, and the ocean bar assumes a northerly alignment. The cross-sectional profile is narrow but deep with steep banks. A storm breaches the Bodie Island spit, rounds the northern and southern shoulders and increases the inlet width. The alignment of the ocean bar (N45ºE) is perpendicular to the adjacent beaches. The cross-sectional profile is shallow with wide overbanks on one or both sides of the inlet.

PEA ISLAND/OREGON INLET TERMINAL GROIN

A comparative analysis of the storm and migration data indicates the terminal groin has significantly altered the migration of Oregon Inlet. As previously discussed, the storm-induced variation in minimum width was greater (σ = 425 m) prior to the construction of the terminal groin. The majority of this variation resulted from the northward and southward migration of Bodie Island during active and calm storm periods respectively; the remainder can be attributed to the southward migration of Pea Island (23 m/yr).

The terminal groin was constructed to reduce the variability in inlet width by fixing the location of the northern end of Pea Island. As expected, Pea Island has remained fixed since 1990 and changes in inlet width have been caused exclusively by the migration of Bodie Island. From January 1990 to March 1994, Bodie Island has migrated southward (131 m/yr) despite the increased frequency and magnitude of coastal storms.

Since groin construction, the width of the inlet has decreased (σ = 161 m) because Bodie Island has not eroded as far northward during severe storms. As previously discussed, the Halloween storm of 1991 widened the inlet much less (+39 m) than a comparatively weaker class 5 storm, the Ash Wednesday storm of 1962 (+152 m). This reduced response to storms may be attributable to the post-groin locations of the inlet main channel and ebb shoal. Prior to the groin, the centrally-located channel facilitated the propagation of large, northeasterly storm waves through the inlet which contributed to the erosion of Bodie and Pea Islands. Since 1990, the main channel has migrated southward toward the groin which has changed the dimensions and orientation of the ebb shoal. As a result, Bodie and Pea Islands have been more sheltered from large, northeasterly, storm-induced waves which break over the ebb shoal. Due to the reduced northward migration and predominant southward migration of Bodie Island and the fixed location of Pea Island, the inlet has narrowed and the depth of the main channel has increased to maintain the relatively constant cross-sectional area.

Summary of Large-Scale Processes:

Our review of the literature shows that from 1983 to present, engineering measures have been responsible for major changes in the migration and geometry of Oregon Inlet and Pea Island. Neither the structure of the bridge or the small-scale dredging of the navigation channel before 1982 significantly altered the long- and short-term trends in inlet migration and width. Pea Island migrated predominantly southward in response to the longshore transport. Bodie Island migrated north and the inlet widened during periods of increased storm frequency and magnitude; the island migrated south and the inlet narrowed during subsequent periods of reduced storm activity. Hopper dredging initiated in 1983 produced a high sand deficit in the sediment budget which caused deviations from long- and short-term migratory trends of the inlet. The direct consequences of this sand deficit included increased erosion rates on Pea Island, the island migrated southward at a rate faster (167 m/yr) than the long-term average (23 m/yr) and the inlet width increased despite a decline in storm frequency and magnitude. The groin fixed the location of Pea Island and the Bonner Bridge and has caused the channel to deepen as Bodie Island migrates southward and the inlet narrows.

Hopper dredging of the inlet navigation channel which began in 1983 and the construction of the terminal groin in 1990 were intended to maintain the bridge and navigation channel but have caused significant deviations from the long- and short-term trends in inlet migration and geometry. From 1983 to 1989, hopper dredging with unsuccessful nearshore disposal resulted in removal of an average of 420,530 m^3/yr of sediment, produced a sand deficit in the littoral sediment budget and accelerated erosion rates on Pea Island. As a result of this deficit, the midpoint of the inlet migrated northward (95 m/yr) from 1985 to 1991, the northern end of Pea Island eroded 1000 m southward (167 m/yr) and the inlet width steadily increased despite the decline in annual storm frequency from 1980 to 1985. As expected, the terminal groin has altered the migration, width, and cross-section of Oregon Inlet. Despite the active storm period (1990-95) since groin construction, the inlet width has decreased at a rate of 78 m/yr, the cross-section has remained constant (σ = 143 m^2) and channel depth has increased to between 8 and 9 m.

Implications:

There are several implications associated with the results of this study. During a period of increased storm frequency and intensity (1990-95), the width of Oregon Inlet has decreased at an estimated rate of 78 m/yr. The continued narrowing and deepening of the inlet could compromise the integrity of the groin and/or the Bonner Bridge and necessitate additional 'stabilization' efforts. The bridge is scheduled to be replaced in 2015 but the design for a replacement with a projected 50-yr lifespan must account for a projected rate of channel narrowing and deepening. A future period of reduced storm frequency and intensity could result in increased shoaling within the inlet and a faster rate of inlet narrowing. The narrowing or closure of Oregon Inlet would increase the probability of a breach of either Bodie Island or Pea Island and subsequent formation of a new inlet. The location of a new inlet can only be speculated but conditions are ideal in several areas along Pea Island.

Summary of Findings and FWS Positions:

The data and analysis presented in this report have led the FWS to a number of important findings and conclusions.

The FWS believes that neither the short- nor long-term environmental consequences of the Oregon Inlet terminal groin can be predicted with acceptable accuracy. The groin has required two locations on Pea Island to serve as an anchor to be locked in place forever. The ocean, sound, and barrier islands are dynamic and ever-changing features of the project area. Landscape changes are driven by the powerful forces of wind and water through intricate mechanisms not completely understood. Within historic times natural forces have combined to move the barrier islands landward, move inlets, close some old inlets, and open new ones. Other environmental factors such as the gradual rise of sea level are recognized but difficult to predict. The FWS contends the natural features of the project area must be free to react to these ever-changing and unpredictable forces of nature. In a sense the barrier islands must move in order to survive.

While the precise environmental consequences of the terminal groin cannot be predicted, the FWS maintains that the stabilization and other alterations of this dynamic ecosystem are most likely to lead to a significant deterioration of fish and wildlife habitat values provided by the area. The terminal groin has eliminated some of the natural, continuous movement of sand which maintains area beaches and eliminate natural sediment flow into the sound which supports habitats as diverse as (1) sandy shoals, (2) tidal marshes, (3) mudflats, and (4) seagrass meadows, or SAV. The groin hinders the movement of estuarine-dependent fish from the ocean to estuarine nursery areas. While the USACE asserts that these natural functions can be maintained by engineering manipulations of the area, the success of such artificial efforts to substitute for complex natural processes cannot be assumed.

Unanticipated Impacts:

Among proponents of the groin project, there was optimism that all significant environmental consequences could be mitigated through the application of additional technology. The FWS does not subscribe to the optimistic viewpoint that technology will find a way to overcome any unanticipated environmental consequences. This position is based on a conviction that there may not be an engineering 'fix' for some unanticipated, adverse, environmental conditions such as a more rapid rise in sea level, or perhaps an increase in storm magnitude and frequency, and thus some impacts may be unmitigatable; even if adverse environmental consequences which arise in the future can be mitigated, there can never be an assurance that funds for corrective measures will be appropriated in a consistent and timely manner; and if future corrective measures are developed and funded, these measures may themselves lead to adverse alterations in the barrier island ecosystem which require additional interventions and thus establish a cascading pattern of artificial controls and manipulations within the area

This area represents a unique and irreplaceable habitat for fish and wildlife resources which face dwindling alternatives as the cumulative adverse impacts of coastal development mount. In addition to the vital support which the area provides to wildlife, the Outer Banks are a national treasure for the American people. The proposed project area is part of the American legacy which includes the Florida Everglades and Yellowstone National Park. The aesthetic, recreational, and educational values of the terminal groin area constitute incalculable benefits.

Therefore, the FWS finds that the overall outcome of both currently proposed mitigation measures and those that may be developed and implemented in the future is most likely to be a significant degradation of the existing ecological and recreational benefits which the project area now provides.

If the SMP should fail for any reason, the lands currently managed by the DOI, particularly the PINWR, would be severely degraded. If the SMP succeeds other areas of the ecosystem, such as habitats in Pamlico Sound starved for sand, are likely to be degraded. In short, if there is even a small possibility of the worst-case scenario occurring, a consideration of the resources at risk must lead to the search for a less harmful alternative.

Table 1: Environmental Impacts of Terminal Groin – Vicinity of Inlet (within 3 miles)

	LOW LEVEL POSITIVE IMPACTS	LOW LEVEL NEGATIVE IMPACTS	HIGH LEVEL POSITIVE IMPACTS	HIGH LEVEL NEGATIVE IMPACTS	FUTURE LOW LEVEL IMPACTS	FUTURE HIGH LEVEL IMPACTS
PHYSICAL IMPACTS						
Overwash Terraces	Yes		Yes	Yes	Yes	Yes
Dunes		Yes	No	Yes		Yes
Beaches	Yes	Yes	No	Yes	Yes	Yes
Shoals and Channels	Yes	Yes	Yes	Yes	Yes	Yes
Longshore Transport	Yes	No	No	No	Yes	yes
Shoreline Erosion	Yes	Yes	No			
Sediment Characteristics	No	Yes	Yes	Yes	Yes	No
ECOLOGICAL IMPACTS						
Least Tern (nesting)	Yes					
Least Tern (feeding)	Yes					
Common Terns (nesting)			Yes			
Common Terns (feeding)		Yes				
Piping Plovers (nesting)	Yes					
Piping Plovers (feeding)		Yes		Yes		
Oystercatchers (nesting)	yes					
Oystercatchers (feeding)		Yes				
Black Skimmers (nesting)			Yes			
Black Skimmers (feeding)		Yes				
Sea Turtles (nesting)	Yes					
Polycheats						
Invertebrates Filter Feeders		Yes		Yes	Yes	

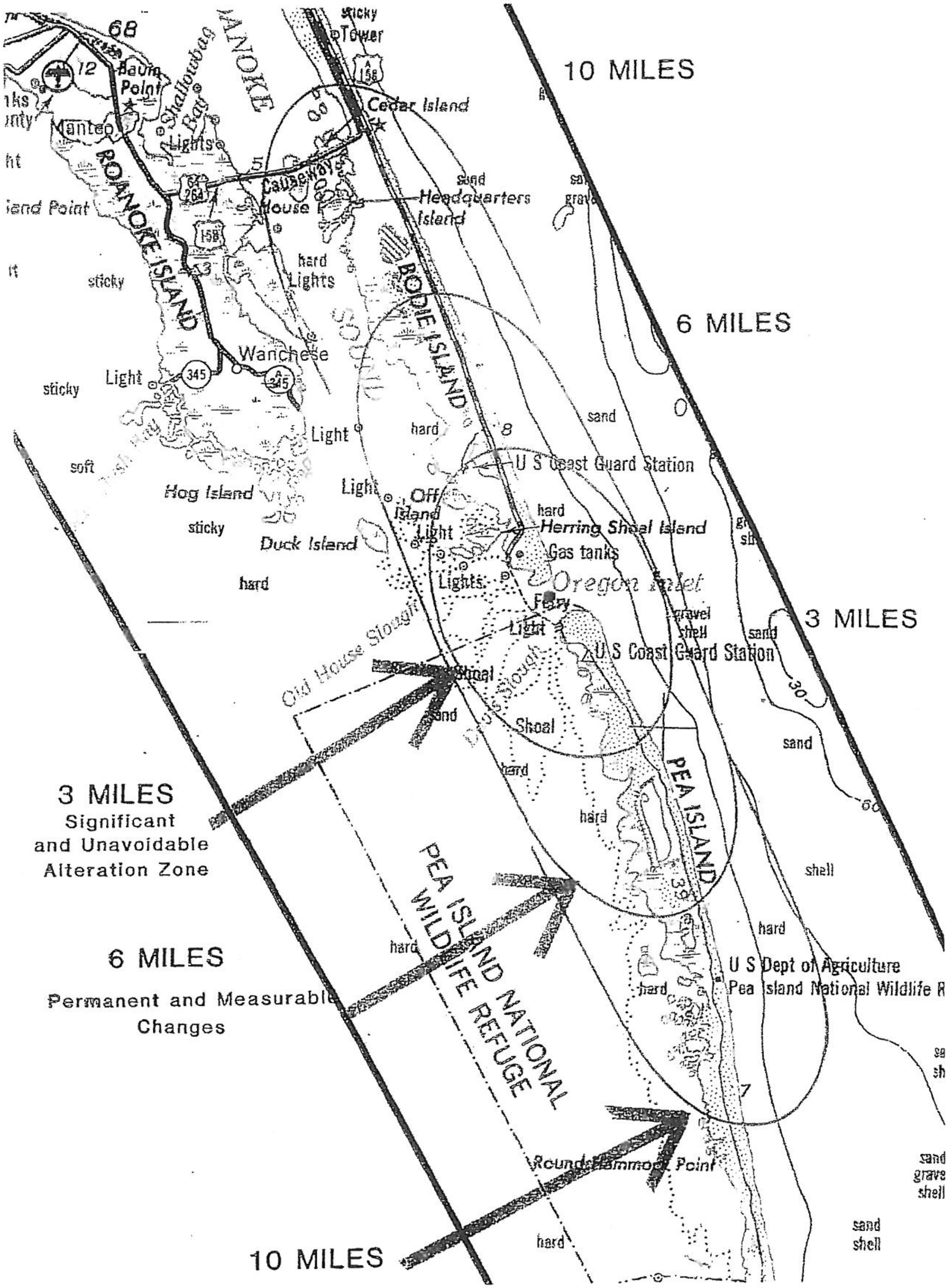


Figure 2. The COE jetty impact zones: 3, 6, and 10 miles.

SUMMARY OF ISSUES

The major question concerns description and quantification of how the groin installation has modified the physical and biological components of the Refuge and whether the forcings that have occurred as a result of the structure have had a net positive or negative effect on the key natural resources of concern to the Refuge. Further, DOI management needs to know not only what habitat changes have occurred from the pre-groin period to the present but also to what extent we can predict changes in the future (15-30 years ahead) if the groin is to be re-permitted.

Much data already exist on the physical aspects of shoreline change at Pea and Bodie Islands. In addition, a good deal of data exist on how the sand grain size distribution has changed near the groin and along the north end of Pea Island but much of this was related to the Corps inlet dredging sand bypass operations that began in the mid 1990s. On the biological component, data on mole crab and *Donax* clam abundance and distribution related to the shoreline bypass operations has been collected since the 1990s. The field data on nesting birds have been sporadic with little data earlier than about 1990 but data are more consistent over the past decade. Of most interest to the Refuge are the following nesting species: the federally-threatened piping plover, American oystercatcher, common, least and gull-billed terns, and black skimmer. Sea turtles (all federally listed) are also a priority, both green and loggerhead turtles. Mammals have been included in the listing but are of lower priority including red fox, raccoon, white-tailed deer, cotton rat, rice rat, Norway rat, cottontail rabbit, meadow vole, and house mouse.

The GIS analyses produced by Dave Richardson and Bruce Hayden includes details of the imagery used, how it was rectified, how habitat/cover types were broken down, where the geographic zones were established (emphasis on the northern 3.5-4.0 km of Pea I, southern 3.5 km of Bodie I), the uncertainties (fuzziness) associated with some of the classifications (vegetated dunes, shrub areas), and what level of effort it would take to extend the detailed analyses to the entire Refuge (12 miles of beach).

We used STELLA, a software modeling program developed at Dartmouth College to model this project. Since many of the 'habitat stocks' such as Active Beach could convert to Upper Beach with sand filling (or with succession upper beach could become dune-shrubs over time), it is important to have a program which can determine changes using a transition matrix model incorporating how 'stock values' change at two points in time with designated 'flow rates' (transition probabilities) from one to another type of 'stock'. This then allows us to determine net gains and/or losses of habitats deemed to be important for each species of guild. Using the habitat stock changes from 1978 to 92 was graphed and then extrapolated out the next 15 years in a predictive format. This was done for the period 1992 to 2007 then 15 or 30 years in the future.

The 'habitat stock' values for the nesting waterbird species/groups (piping plover/oystercatcher, least tern, gull-billed tern, common tern/black skimmer) and their changes for the northern 3.5 km of Pea Island and southern 3.5 km of Bodie Island summarized their net gains, losses, or no change in habitat both for nesting and feeding. In general, it appears that changes induced by the groin have resulted in either a net gain (or no change) to the species of interest.

However, we did not evaluate the full impacts on the invertebrates in the region of Oregon Inlet.

The recommendations or modifications that have been suggested include: first, for this internal project for FWS additional work might entail extending the habitat analyses to the entire 12-mile refuge boundary to the south; (2) using STELLA to extend the model from 1992-2007 out to the next (predictive) 15 years; and (3) add in more time periods for the imagery, eg 1988-89 to get a better measure of when most of the habitat changes occurred over the current 15-year intervals.

Second, on the issue of the special use permit relicensing to the DOT, we raised three points: we recognized the assumption of the 'erosion rate threshold' used by Margery Overton at NC State University needs to be revisited, preferably by an expert outside the immediate area (Outer Banks experience); revisit the idea of some modification of the existing groin such as removal of some of the rocks at a location along the western portion of the groin to permit more flow through the system to simulate more natural processes; require as mitigation for the new bridge that funding be made available for periodic (3-5 years) habitat management using combinations of heavy equipment, fire, and/or chemical control of vegetation to achieve habitat goals for the key refuge resources at Pea Island.

Table 1: Environmental Impacts of Terminal Groin – Vicinity of Inlet (within 3 miles)

	LOW LEVEL POSITIVE IMPACTS	LOW LEVEL NEGATIVE IMPACTS	HIGH LEVEL POSITIVE IMPACTS	HIGH LEVEL NEGATIVE IMPACTS	FUTURE LOW LEVEL IMPACTS	FUTURE HIGH LEVEL IMPACTS
PHYSICAL IMPACTS						
Overwash Terraces	Yes		Yes	Yes	Yes	Yes
Dunes		Yes	No	Yes		Yes
Beaches	Yes	Yes	No	Yes	Yes	Yes
Shoals and Channels	Yes	Yes	Yes	Yes	Yes	Yes
Longshore Transport	Yes	No	No	No	Yes	yes
Shoreline Erosion	Yes	Yes	No			
Sediment Characteristics	No	Yes	Yes	Yes	Yes	No
ECOLOGICAL IMPACTS						
Least Tern (nesting)	Yes					
Least Tern (feeding)	Yes					
Common Terns (nesting)			Yes			
Common Terns (feeding)		Yes				
Piping Plovers (nesting)	Yes					
Piping Plovers (feeding)		Yes		Yes		
Oystercatchers (nesting)	yes					
Oystercatchers (feeding)		Yes				
Black Skimmers (nesting)			Yes			
Black Skimmers (feeding)		Yes				
Sea Turtles (nesting)	Yes					
Polycheats						
Invertebrates Filter		Yes		Yes	Yes	