IV. Engineering Construction Techniques

A. Overview of Approach

Several factors contribute to a terminal groin's performance, as well as its potential impacts on adjacent shorelines. Length, height, permeability, type of material, and groin configuration are all factors that affect a terminal groin's behavior. Groins that are too long, too high, or impermeable may overly impede the longshore drift. Groins that are too short, too low, or too permeable may be ineffective at impeding any longshore drift, rendering them effectively useless.

To complete this study on engineering techniques that may be used to limit potential impacts, an inventory of the five (5) study sites and their structural characteristics was completed. Summary results from each site were plotted using the calculations from Section II. These plots were then reviewed against the various groin heights, lengths, and porosities. Lastly, a literature review of engineering construction techniques used to limit terminal groin impacts was performed.

B. Characteristics of the Five Study Site Structures

The five study sites all consist of rubble mound (rock) groins. John's Pass and Captiva Island groins are short groins, with lengths less than 500 feet. Amelia Island and Fort Macon both have lengths over 1,500 feet. Amelia Island is also an example of a highly permeable groin. Oregon Inlet has the longest selected groin at over 3,000 feet long (including the wrap around portion).

1. Oregon Inlet

The erosion control measures at Oregon Inlet include a 3,125-foot long groin and a 625-foot long revetment. Nonetheless, it should be noted that a significant portion of the structure length is taken up by the wrap around feature of the structure and that the shore perpendicular portion of the structure is approximately 1500 feet. The elevation of the groin ranges between 8 and 9.5 feet (MSL), with the higher elevation at the head (seaward end) of the groin. The base of the groin ranges from 110 to 228 feet wide; and the crest width ranges from 15 to 39 feet wide. The groin has toe protection on both sides, with lengths varying from 10.5 to 43 feet. The rock sizes increase towards the head of the groin. Figure IV-1 shows the 2007 aerials, and Table IV-1 summarizes the structural information for the Oregon Inlet terminal groin.

Figure IV-1. Oregon Inlet Terminal Groin and Revetment

Table IV-1. Oregon Inlet Terminal Groin and Revetment Structural Information

Terminal Groin Parameter	**Value**
-Length	3,125 ft
-Elevation	8 – 9.5 ft MSL
-Width	Crest: 15 – 39 ft / Base: 110 – 228 ft
-Stone Size (Station: 6+25 – 17+25)	
Armor	Type 'A-II' Stone 2.5 – 4.5 Ton 50% > 3.5 Ton
Under layer	Type 'U-II' Stone 500 – 1000 lbs 75% > 750 lbs
Foundation	Type 'F-I' Stone 0.5 – 110 lbs
-Stone Size (Station:17+50 – 29+25)	
Armor	Type 'A-III' Stone 7 – 10 Ton 50% > 9.0 Ton
Under layer	Type 'U-III' Stone 1500 – 2000 lbs 75% > 2000 lbs
Foundation	Type 'F-I' Stone 0.5 – 110 lbs
Revetment Parameter	**Value**
- Length	625 ft

Construction for the groin began in 1989 and was completed in October 1991. The groin extends from the bulkhead at the US Coast Guard station in a northwest direction, curving 90 degrees towards the northeast, and straightening out to be perpendicular with the natural inlet shoreline. The groin was designed anticipating the channel moving towards the structure by adding a 40-ft wide scour apron along the inlet toe. The free-standing nature of the terminal groin in a position mimicking the 1985 shoreline relied on the natural coastal processes to deposit sediment along its landward (southern) side. Figure IV-2 shows a typical cross-section for the terminal groin (taken from Oregon Inlet Plan Drawings).

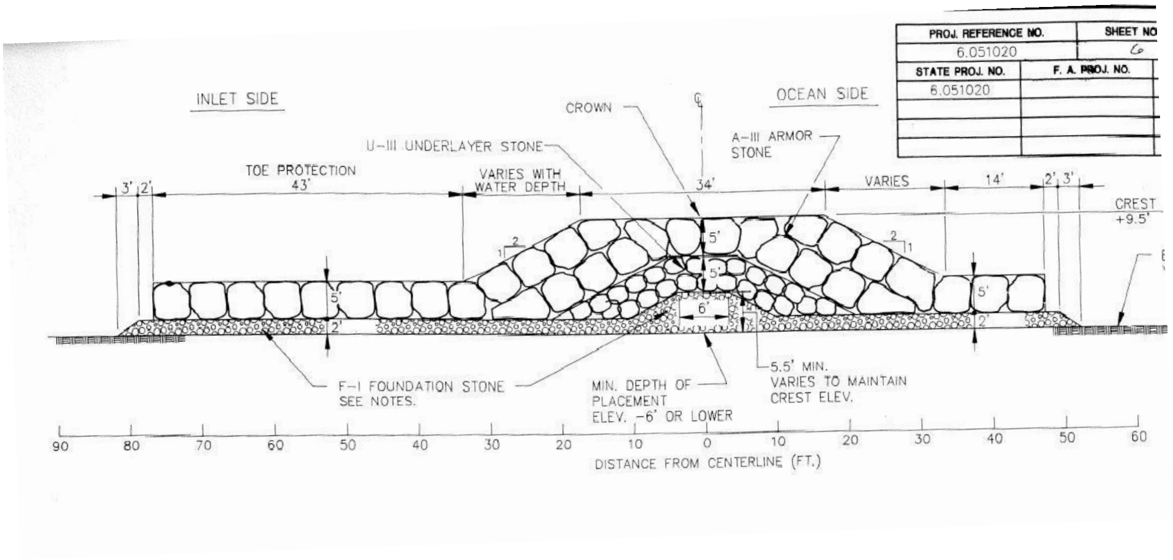


Figure IV-2. Oregon Inlet Terminal Groin Typical Cross-Section

2. Fort Macon

This terminal groin is constructed of rock with a total length of 1,530 feet and a crest elevation of 6 feet (MLW). The crest width is 10 feet, with a base width ranging from 58 to 66 feet. The foundation or bedding stone used ranged in size up to 12”, while the core consists of stone ranging in size from 12” – 24”. Over top of the core is the underlayer stone (2000 lb avg), while the armor layer used ranges in size from 7.5 – 12.5 tons. Table IV-2 summarizes the structural information for the Fort Macon terminal groin. Figure IV-3 illustrates the typical cross-section from the 1986 groin extension permit plans.

Table IV-2. Fort Macon Terminal Groin Structural Information

Terminal Groin Parameter	**Value**
Length	1,530 ft
Crest Elevation	6 ft MLW
Width	Crest: 10 ft / Base: 58 ft – 66 ft
Stone Size[1]	
Armor	Type 'A' Stone, 15 ton/LF (7.5-12.5 ton) 75% - 10 ton min
Under layer	Type 'C' Stone, 10 ton/LF (2000 lbs avg) 50% +-
Core	Type 'D' Stone, 11 Ton/LF (12" – 24'') 50% > 6''
Bed	Type 'E' Stone, 4 Ton/LF (<12'')

[1] Voids used for design computation: Type 'A' 40%, Type 'C' 35%, Type 'D' 30%, and Type 'E' 30%.

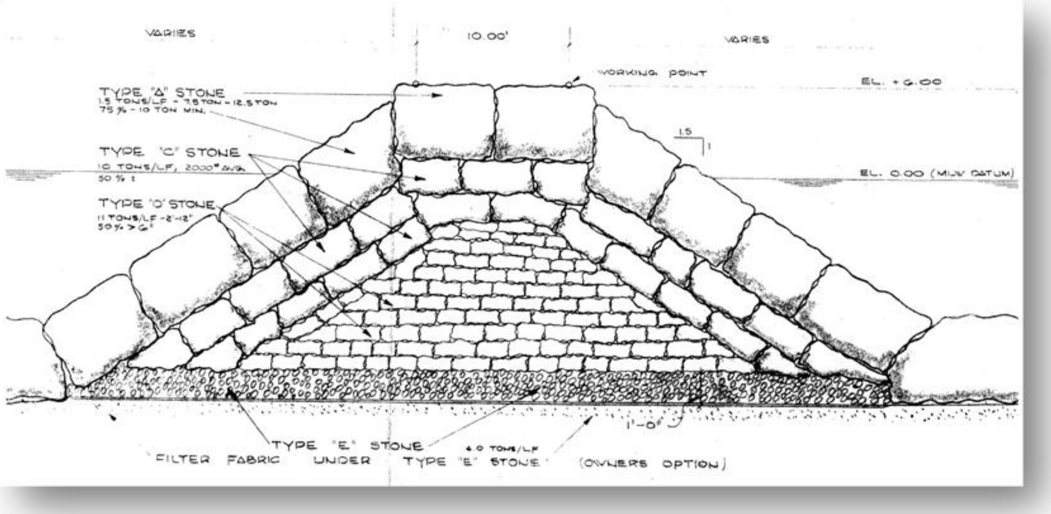


Figure IV-3. Fort Macon Terminal Groin Typical Cross-Section

Figure IV-4 shows the layout of the Fort Macon terminal groin, revetment, and seawall, where construction was completed in three phases. The first phase began in 1961 with the construction of the seawall, revetment, and a portion of the terminal groin that was built to a length of only 720 feet due to budget constraints. This portion of the groin was built to an elevation of 6 feet and excluded the structure's top armor layer. The revetment (250 feet) and seawall (530 feet) were constructed along the dune bank starting just north of the present-day Fort Macon parking lot in a southeastern direction.

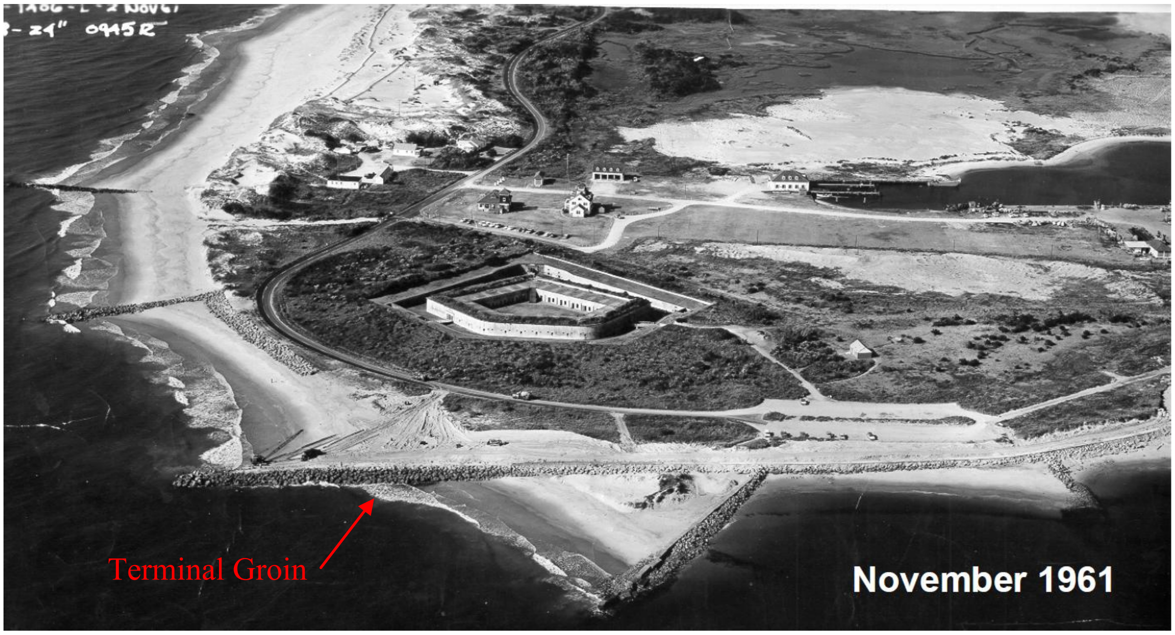


Figure IV-4. Fort Macon Terminal Groin Initial Construction (1961)

Phase two began in 1965 and extended the groin by an additional 410 feet oceanward. An additional groin was constructed west of the revetment due to extensive erosion on the sound side of the island, which was impacting the US Coast Guard station.

Phase three began in August 1970. It extended the terminal groin by an additional 400 feet to bring the total length to 1,530 feet. A 480-foot long stone groin was built near the bathhouse in an effort to stabilize beach fill placed in the area. The total erosion control measures include a revetment, seawall, a terminal groin, and seven more groins in the vicinity of Fort Macon.

3. Amelia Island

The terminal groin and detached breakwater located at Amelia Island were constructed between 2004 and 2005 on the southern end of Amelia Island. The groin length is approximately 1,500 feet long, with a crest elevation of 5.2 feet (NGVD). The crest width ranges from 6 to 15 feet. Due to environmental concerns, the groin used only armor stones to maximize permeability. The armor stone ranges from 0.4 to 7 tons. A Tensar rock-filled mattress was utilized as the foundation. Table IV-3 summarizes the structural information for the terminal groin. Figure IV-5 illustrates the typical cross-sections for Amelia Island terminal groin (taken from Olsen Permit Drawings).

Table IV-3. Amelia Island Terminal Groin Structural Information

Terminal Groin Parameter	Value
- Length	1,500 ft
- Elevation	5.2 ft (NGVD)
- Width	Crest: 6 – 15 ft / Base: 22 – 76 ft
- Stone Size Armor (Section C-C') Armor (Sections D-D' & E-E')	 Stone 2 – 3 Ft (0.4 – 1.5 Ton) Stone 3 – 5 Ft (1.4 – 7 Ton)

The structural stabilization on the southern end of Amelia Island consisted of the terminal groin described above and a 305-ft long detached breakwater. Both structures were designed to maximize permeability and allow passage of some sediment through the groin structure. The groin was designed to be long enough to stabilize the southern shore of the Amelia Island State Park; however due to environmental concerns downdrift, it was not designed long enough to benefit the shoreline further updrift. The breakwater was constructed near the northernmost boundary of the State Park, approximately 2,600-ft updrift of the groin, to help stabilize the updrift shoreline. Both structures were designed in accordance with the predicted elevations of high water that occur during the fall and winter months, and to be overtopped.

A unique design feature of the terminal groin was development of a sand spit on the downdrift side. The purpose of this spit is to maintain the natural littoral environment along the sound-side shoreline. The groin structure should ideally provide a template for land formation and updrift stability, while at the same time allow a large percentage of the local inlet-directed littoral transport to pass through the structure (Olsen, 2006). Recent aerial photography indicates that the terminal groin is completely inundated with sand and is essentially non-activated or allows sand to freely bypass the structure (Olsen, 2008). Figure IV-6 shows the Amelia Island terminal groin as of 2008.

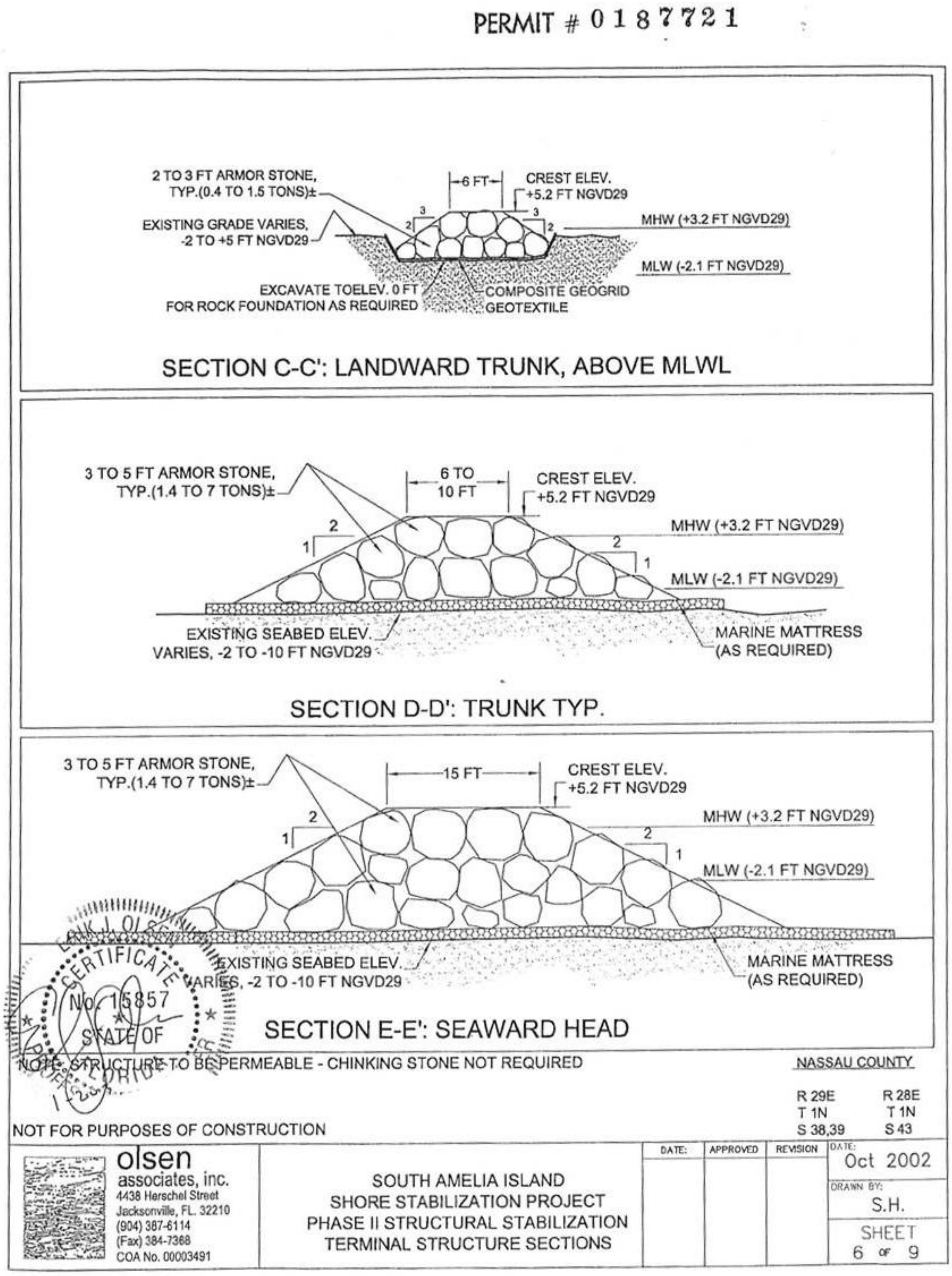


Figure IV-5. Amelia Island Terminal Groin Cross-Sections

Figure IV-6. Amelia Island Terminal Groin

4. Captiva Island

The rock groin was constructed between 1977 and 1981 at the north end of Captiva Island at Redfish Pass. The terminal groin is 350 feet long with a 1,500-foot revetment along the Gulf beach at the north end of Captiva Island.

Hurricane Charley, in 2004, severely damaged the groin. Between 2005 and 2006, beach nourishment and groin rehabilitation increased the stability of the beach. The groin reconstruction was completed in 2006 with 9,036 tons of limestone boulders and a total length of 340 feet. The new armor layer unit sizes ranged between 2 to 7 tons (Hagerup, 2006 & Coastal Planning & Engineering, Inc., 2008). Figure IV-7 shows the 2006 reconstructed groin. Figure IV-8 shows the Captiva Island terminal groin in 2008.

Figure IV-7. 2006 Terminal Groin at Captiva Island

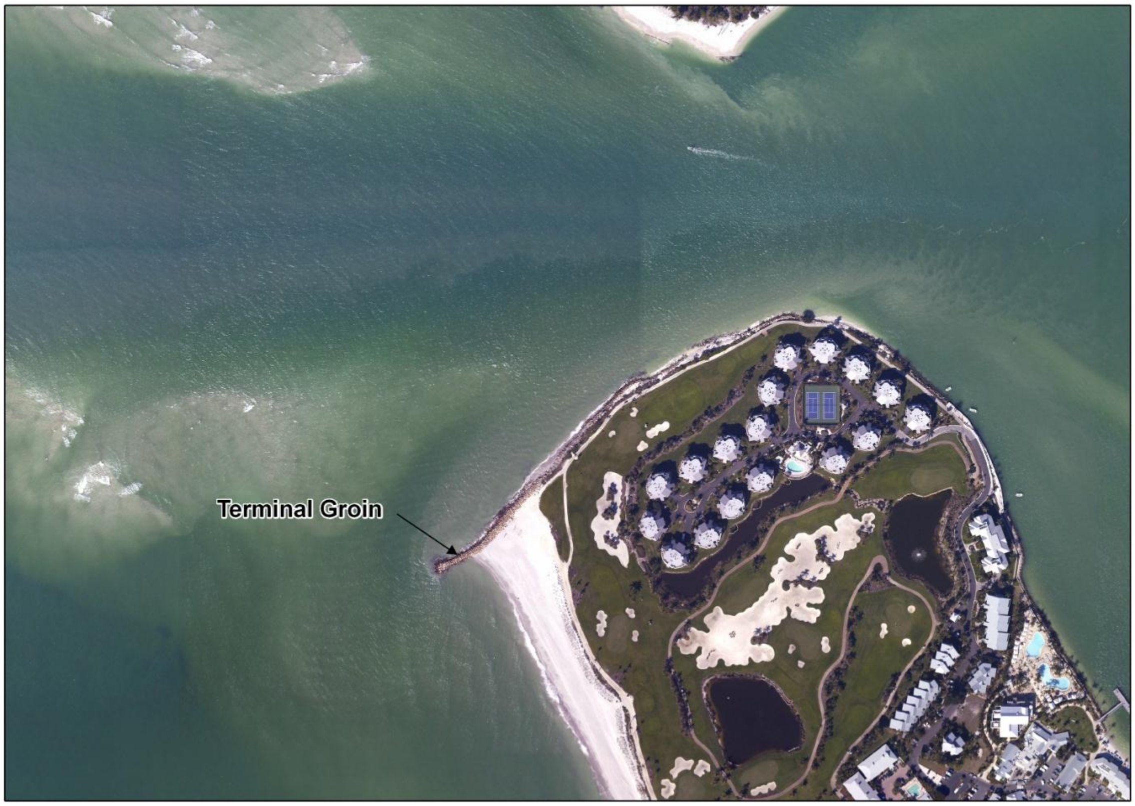


Figure IV-8. Captiva Island Terminal Groin

5. John's Pass

The terminal groin constructed at the south end of Madeira Beach at John's Pass is 460 feet long. The crest elevation ranges between 3.2 and 5.7 feet (NGVD). The crest width is between 12 to 22 feet. The groin utilizes three different types of stone for the bedding, core, and armor layers. Table IV-4 summarizes the structural information for the terminal groin. Figure IV-9 illustrates a typical cross-section for the terminal groin (taken from the 1986 groin extension permit).

Table IV-4. John's Pass Terminal Groin Structural Information

Terminal Groin Parameter	Value
- Length	460 ft
- Elevation	3.2 – 5.7 ft (NGVD)
- Width	Crest: 12 – 22 ft / Base: 72 – 162 ft
- Stone Size	
Armor	Stone: 1.0 Ton
Core	Stone: 0.1 Ton
Bedding	Stone: 15 – 50 lbs

A few years before the groin was constructed, the beach had thirty-seven 200-foot long groins that were originally designed to be adjustable; however, since they were made of concrete, this made the groins almost impossible to adjust. The southern portion of Madeira Beach (also known as Sand Key) continued to experience severe erosion; to the point where the beach ceased to exist in some areas.

The 460-foot curved terminal groin was constructed in 1961 on the north side of John's Pass. Its intended purpose was to block the swash channel along the southernmost part of the shore, force the longshore flow seaward, and cause some seaward movement of the shoreline in the immediate vicinity north of the groin (City of Madeira Beach, 1960).

In 2000, Pinellas County constructed a second terminal groin on the southern side. Figure IV-10 shows both terminal groins at John's Pass.

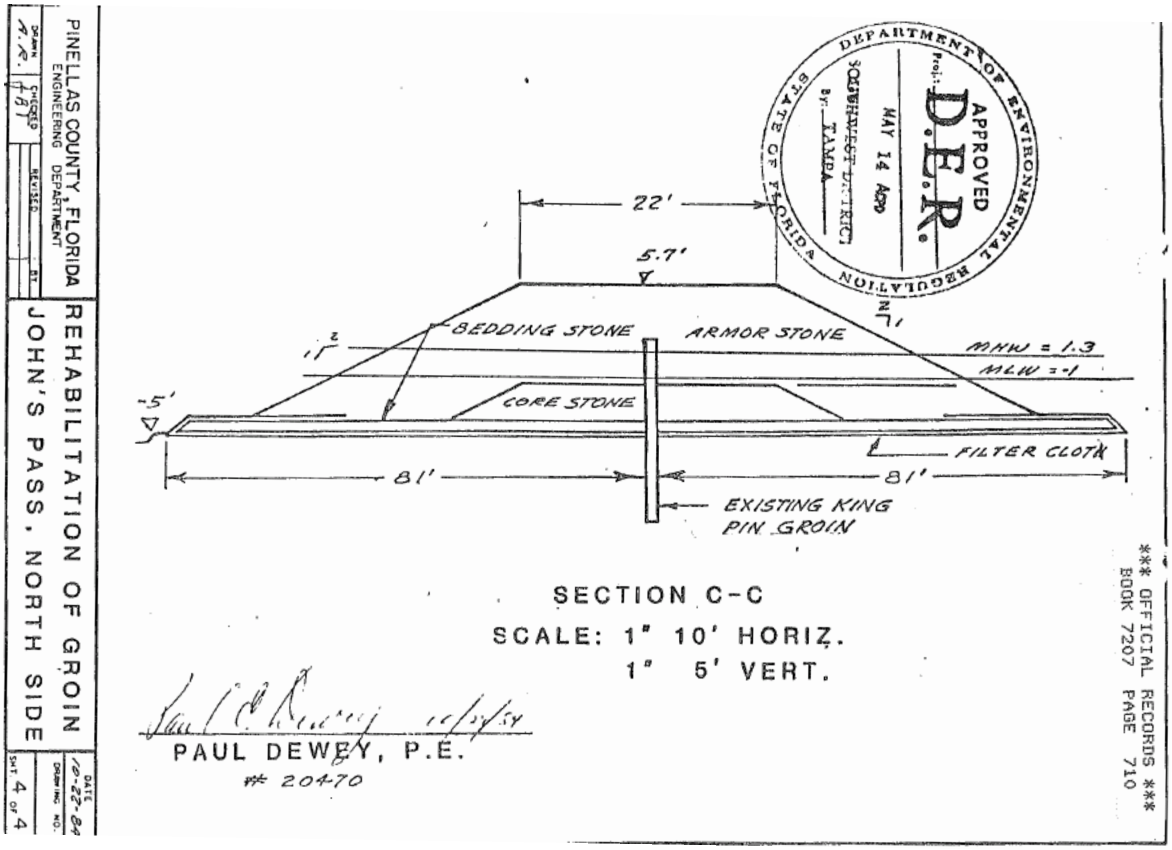


Figure IV-9. John's Pass Terminal Groin Typical Cross-Section

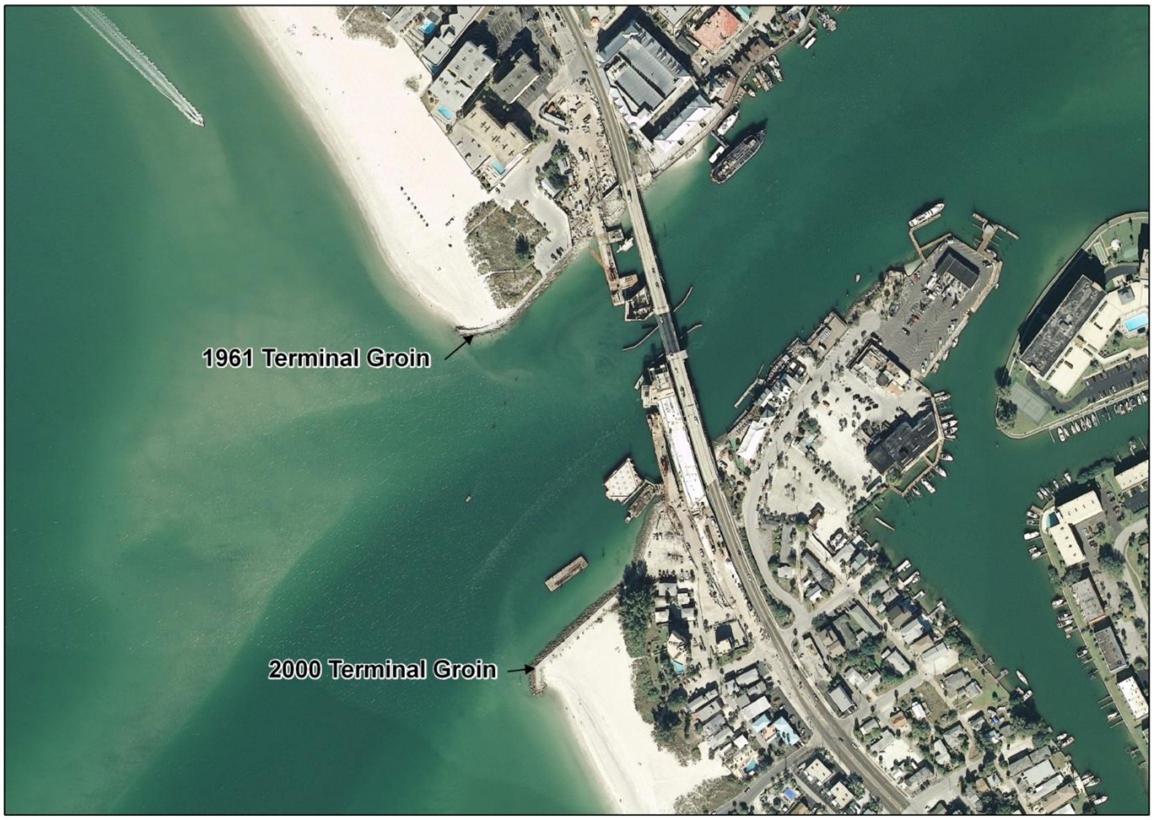


Figure IV-10. John's Pass Terminal Groins

6. Analysis of Existing Sites

In order to investigate the effects of groin length, elevation, and permeability on the adjacent shorelines, the results from the shoreline and volumetric analyses completed as part of the coastal engineering assessment were plotted for the five sites. Given the variability of the behaviors noted during the coastal engineering assessment, it was decided that the results would be plotted for both the cumulative and interval results over the 3 mile length for which calculations were completed.

a) Groin Length

The first factor investigated as part of the study was groin length. For each of the five sites, the difference between pre and post conditions were computed for the following over a distance of 3 miles: the shoreline change, overall volume change, and the volume change with nourishment removed. These factors were then plotted both as a cumulative total and individual intervals for both sides of the inlet. Note that the effective length (perpendicular to shoreline orientation) of the Oregon Inlet terminal groin was estimated to be approximately 1500 ft) and that the time periods of 1949-1980 (pre) and 1997-2007 (post) were used for this analysis of Oregon Inlet. Table IV-5 shows the individual groin lengths calculated. Figure IV-11 through Figure IV-13 show the results for the cumulative totals. Figure IV-14 through Figure IV-16 shows the results on an individual interval basis. Note that the results for the longer groins (~1500 ft) are shown in blue while the results for the shorter groins (~350-460 ft) are shown in red.

Table IV-5 Groin Lengths for Five Study Sites

Groin	Length (ft)
Oregon Inlet	1,500
Fort Macon	1,530
Captiva Island	350
John's Pass	460
Amelia Island	1,500

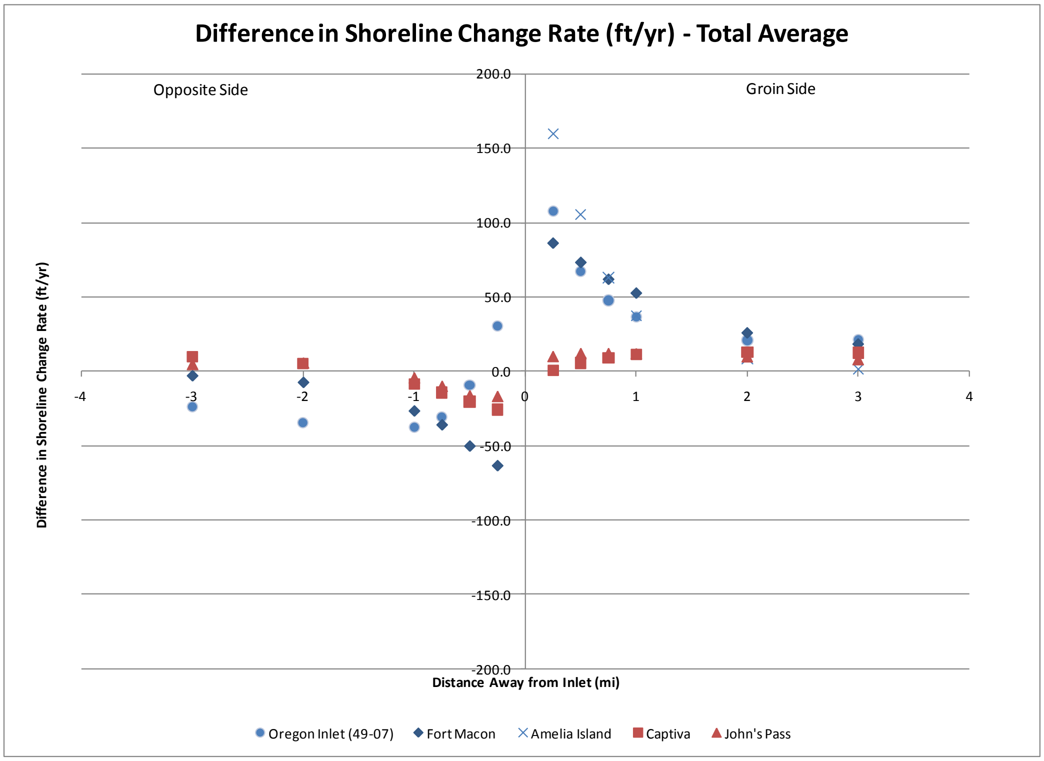


Figure IV-11. Difference in Total Average Shoreline Change Rate (ft/yr)

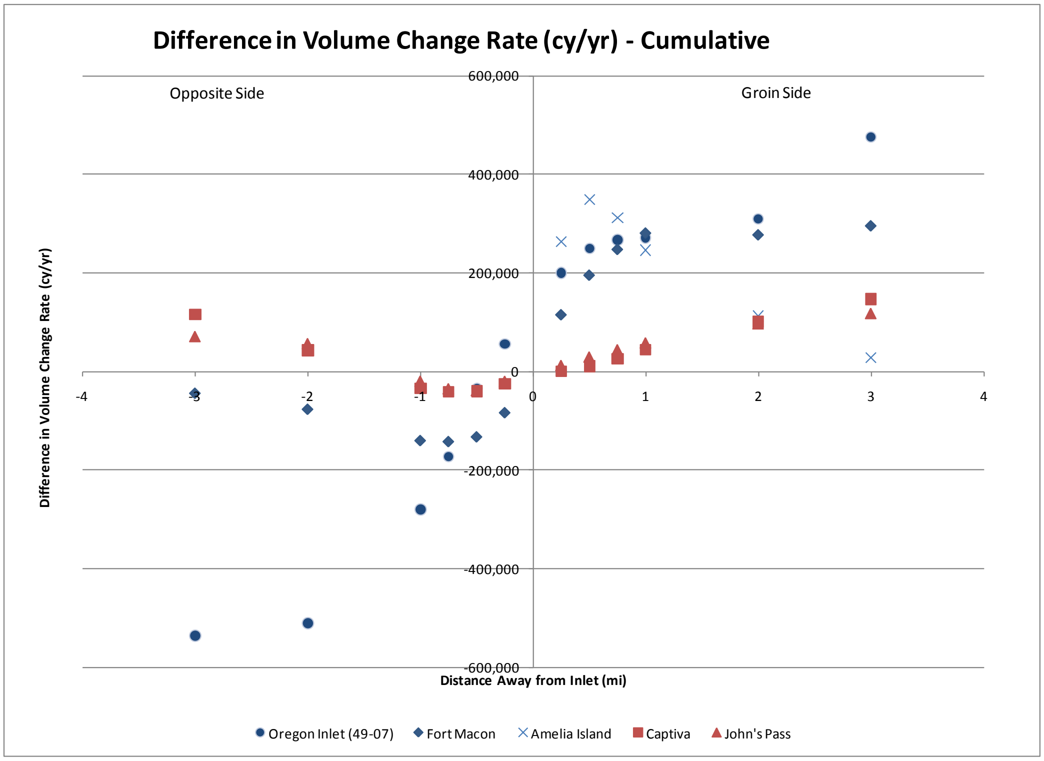


Figure IV-12. Cumulative Difference in Volume Change Rate (cy/yr) - With Nourishment

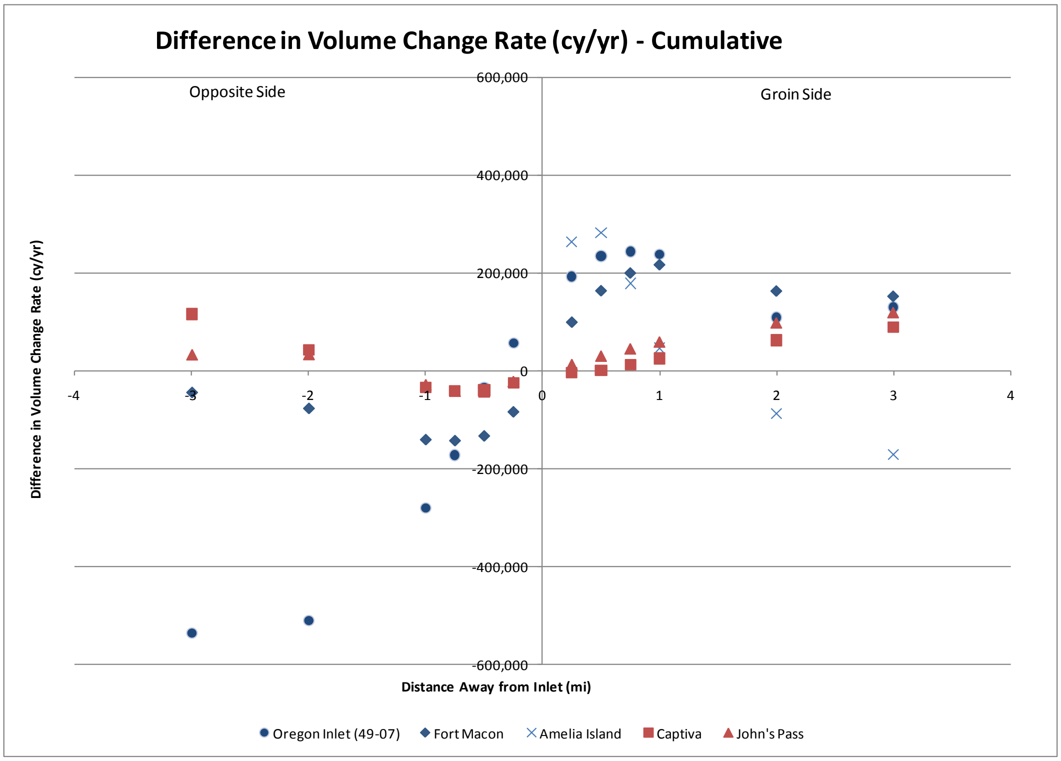


Figure IV-13. Cumulative Difference in Volume Change Rate (cy/yr) - Without Nourishment

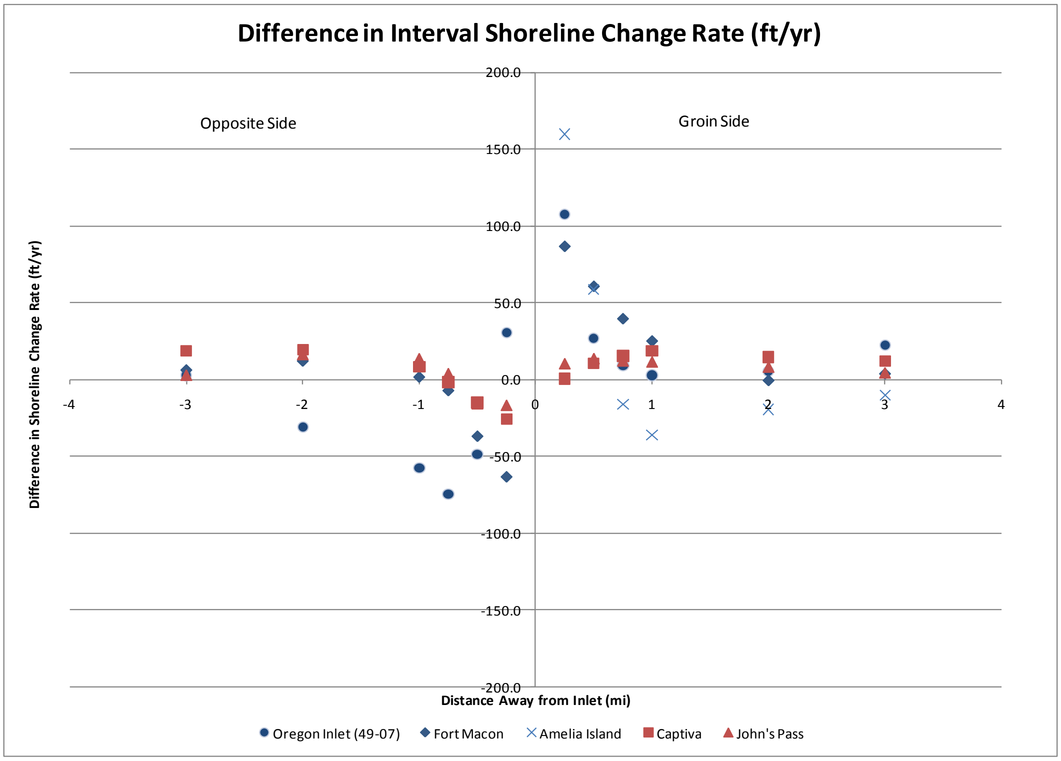


Figure IV-14. Interval Difference in Shoreline Change Rate (ft/yr)

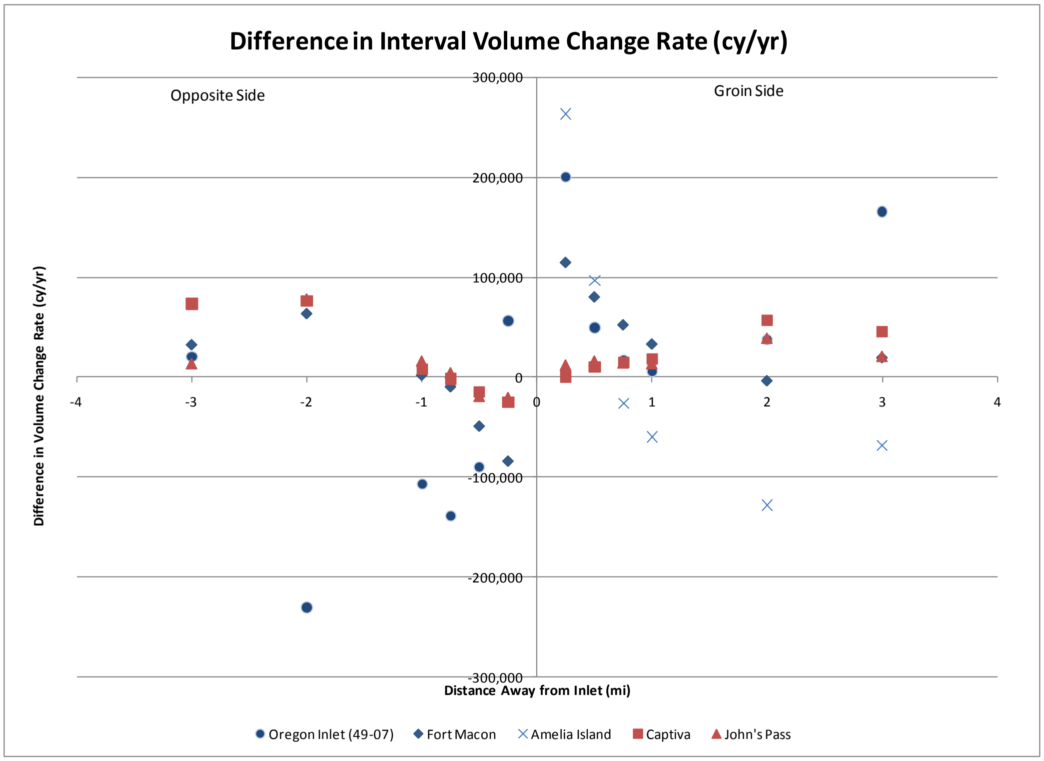


Figure IV-15. Interval Difference in Volume Change Rate (cy/yr) - With Nourishment

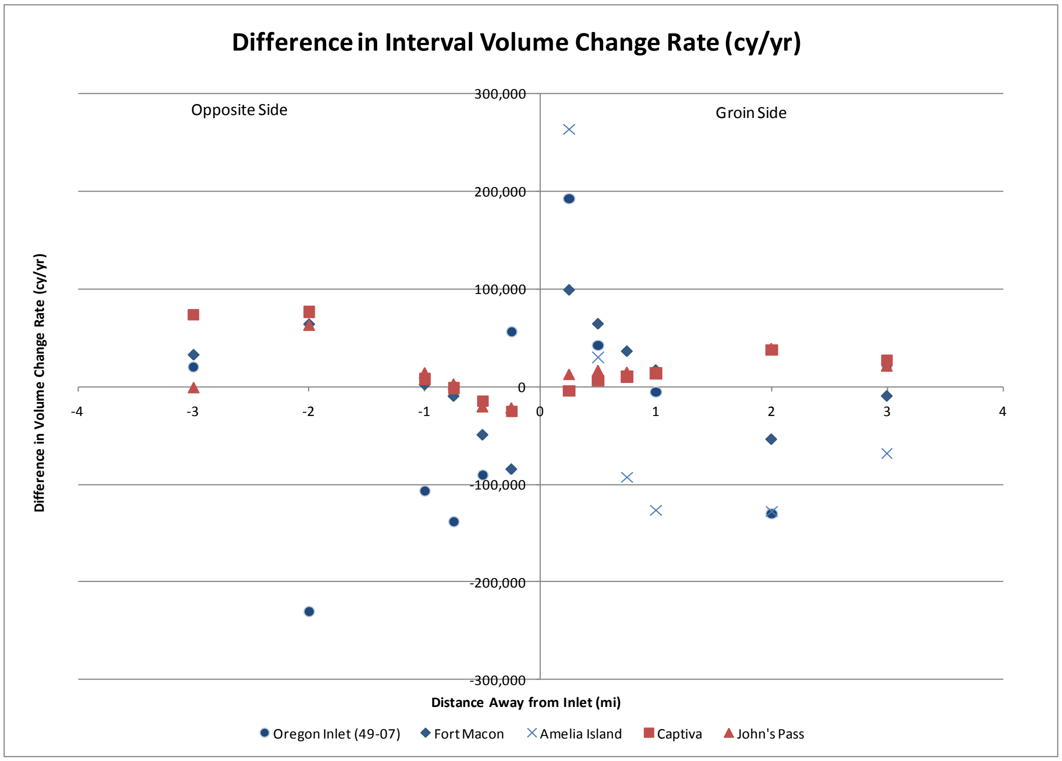


Figure IV-16. Interval Difference in Volume Change Rate (cy/yr) - Without Nourishment

As can be seen in the above graphs, on the structure side of the inlet, the shoreline change rate is lessened more over the entire 3 mile length with a longer groin than with a shorter one. It is also apparent that the greater reductions with longer groins are seen immediately adjacent to the structure and that the reductions appear to converge the further away from the structure. When looking at the volume changes, the same behavior can be seen. It is very interesting to note that there appears to be a point of diminishing returns with length especially once the nourishment effects are removed. It is also interesting to note how the "leaky" structure at Amelia Island appears to be allowing a significant portion of sediment to pass through the structure with the majority of the groin's impacts being felt within the first 0.5 mile from the structure. Also, while the cumulative behavior of the shorelines and volumes follows a distinct pattern, the interval plots do not show as clear of a trend. While still showing mostly positive impacts, there is one data point for Fort Macon and a few for Amelia Island that show a negative impact. However, it is believed that the impacts at Amelia are clouded by the equilibration of the recent large nourishment project that was completed recently. Lastly, it should be noted that the volume change rates listed above do not have the potential effects of dredging included.

Based on the above graphs, the longer structures appear to have a more pronounced effect on the opposite side of the inlet. However, it is important to note that these values were not adjusted for the dredging impacts which could be substantial and explain these apparent effects. The geologic considerations at these inlets could also explain these trends (especially Oregon Inlet). While only a few data points, they reveal the importance of the scale of these structures in relation to the other sediment transport drivers.

b) Groin Elevation

The next factor investigated was groin elevation. For each of the five sites, the shoreline change, overall volume change, and the volume change without nourishment from the above graphs could also be considered against groin elevation relative to local mean tide level. Table IV-6 shows the height relative to mean tide level for each site. Note that the results for the higher groins are shown in blue while the results for the lower groins are shown in red.

Table IV-6 Groin Height Relative to MTL for Five Study Sites

Groin	Height MTL (ft)
Oregon Inlet	8
Fort Macon	4.45
Captiva (estimated)	3.7
John's Pass	2.67
Amelia Island	4.67

As can be seen in the previous figures (Figure IV-11 through Figure IV-16), the trends are very similar on the structure side of the inlet with the shoreline change rate being lessened more over a 3 mile length with a higher groin than with a lower one which makes intuitive sense. When looking at the volume changes, it is very interesting to note that there appears to be a point of diminishing returns with height especially once the nourishment effects are removed.

When investigating the opposite side of the inlet, it appears that trends are again similar with higher groins having the potential for more effects than a lower one. However, it is again important to note that these values were not adjusted for the dredging impacts which are substantial at the higher groin sites (Oregon Inlet, Fort Macon-Beaufort Inlet).

c) Groin Permeability

The last factor investigated as part of the study was groin permeability. Since all of the terminal groins (except Amelia) were built with a dense core, the above graphs were also investigated by looking at the results for Amelia. Based on the above graphs, the results for Amelia show almost no effect on shorelines more than 1 mile updrift of the structure. In fact, the volume changes were negative (but likely due to the recent nourishment equilibration) past the 1 mile distance. Only by looking at the detailed results was it determined that the “leaky” structure showed shoreline and volume change benefits within the first 0.5 mile updrift of the terminal groin.

C. Literature Review and Discussion of Approaches to Minimize Impacts

As previously mentioned, a groin’s performance depends greatly on its dimensions and type of materials used. A great deal of consideration should be utilized when developing potential terminal groin designs, as each factor is site-specific. While much of the discussion below is taken from design guidance for groin structures, it is also relevant and germane to the design of terminal groins.

1. Length

The length of the groin needs to be sufficient to retain the required beach width, by reducing a proportion of the longshore transport under normal conditions. Since extending a groin across the entire surf zone is costly and a total reduction in longshore transport would deprive downdrift beaches, compromise in groin length is a necessary design consideration (Perdok, 2003).

The longshore sediment transport is dependent on groin length relative to the surf zone width. If the surf zone extends beyond the groin (i.e., a short groin), most of the transport bypasses the groin, carried in the accelerating flow near the groin head. Thus a shorter groin will lead to less erosion downdrift of the groin, but capture less sediment updrift. If the groin extends past the surf zone (i.e., longer groins), the groin blocks nearly all sediment transport. A longer groin will trap more sediment updrift of the groin; but starve the downdrift beaches of sediment, leading to more erosion (Johnson, 2004 & Aminti, 2007). Studies have shown that the impacts of the groin downdrift are dependent on the length of the groin; however, most impacts will be noticeable within 3 miles of the groin. Monitoring done at Oregon Inlet shows the impacts are noticeable for a maximum of 5 km (~3 miles) downdrift of the groin (Overton, 2004).

U. Perdok states, "*In practice, it is proven effective to construct groins beyond the breaker line of the summer wave climate at mean high tide, as this is the season when wave climate builds up the beaches. When a wider beach is desired, the groin should be constructed to a length related to the future breaker line*." To avoid outflanking at the upper end of the beach, the groin should be placed far enough back into the beach to allow for the occasional drop in beach levels (Perdok, 2003).

2. Height

Groin height is of great importance in reducing currents and sediment transport across the groin. However, excessive height can lead to a focusing of flow which can lead to scour at the head of the structure. Excessive height can also increase wave reflection. Groin height contributes to a reduction of wave energy along the shoreline, as it causes waves to break further offshore (Poff, 2001). In a series of models studying the effects of groins on the surrounding beach environment, H. Johnson states, "*Groin height should account for wave overtopping and the resultant sediment transport that occurs over or behind the structure.*" Results show that in storm conditions, low groins are unlikely to trap any significant amount of sediment (Johnson, 2004).

The top level of a groin will determine the maximum potential beach depth updrift of the groin. The structure should be designed for any combination of beach levels on either side of the groin between the local scour level and the desired maximum beach depth (Fleming, 1993).

In most situations, it is preferable for the groin to protrude just above the beach level, with adjustments that can be made as the beach level changes. This will allow for some sediment to be transported over the structure and will reduce wave reflections from the groin. Most of the sediment will be trapped, as the largest concentration of sediment travels along the bottom of the groin. Ideally, groin height will vary with beach level; however, in practice, it is not economically feasible to continuously adjust the height. Studies have found that seasonal adjustments restricting groin heights to a level approximately 0.5 – 0.75 meters above beach levels will improve groin function. An alternative to continuously adjusting groin height is periodic beach nourishment to maintain beach levels. A groin profile that matches the beach profile will reduce near-shore longshore currents, but minimize local increases in velocities along the groin (Perdok, 2003). A typical terminal groin profile is shown in Figure IV-17 (USACE, 2002).

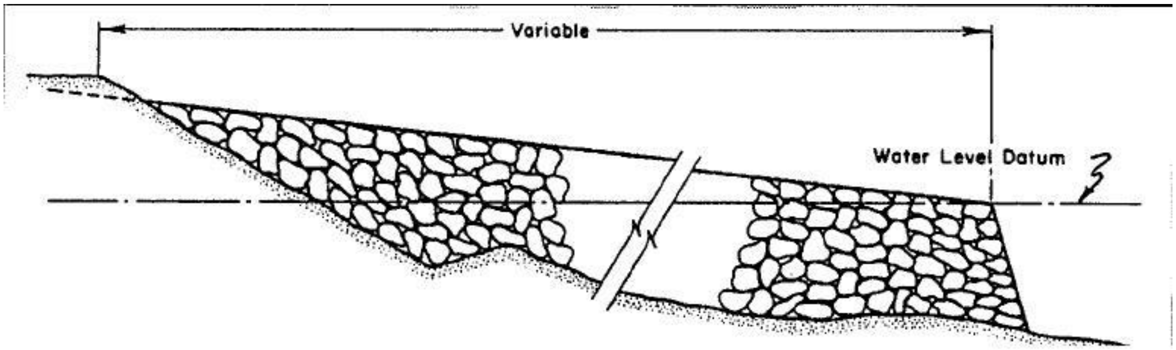


Figure IV-17. Typical Terminal Groin Profile

In some situations, a submerged groin is suitable to meet project goals. Not only are submerged groins about one-third of the cost of emerged groins, they can be just as effective as their emerged counterparts. As previously stated, most of the sediment transport occurs along the bottom of the groin, so submerged groins are capable of trapping sediment. A submerged groin also has the benefit of beach aesthetics, as the groin will generally follow the beach profile. Several examples of submerged groins have been utilized successfully along the coasts of Spain and Italy (Pena, 2007 & Aminti, 2007).

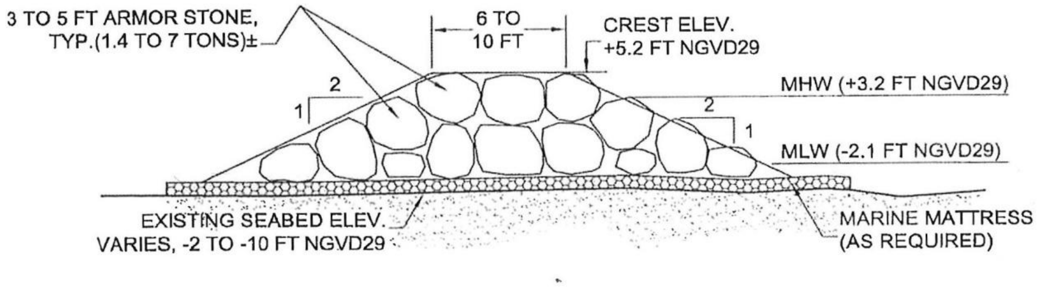
3. Permeability

Groins can be designed to be either permeable or impermeable depending on their intended purpose. Permeable groins do not impound sand directly, like impermeable groins. Permeable groins influence the water column's ability to retain and transport sediments by reducing the velocities through the groin.

Permeable groins can also affect wave energy by allowing waves to penetrate the groin. Permeable groins can behave as oblique breakwaters and can significantly alter the wave climate along the shore. A 10% groin permeability results in a 50% reduction of wave height when waves approach parallel to the groin (Poff, 2001 & USACE, 2002).

Permeable groins do allow sediment to be transported through the structure. They reduce longshore currents; however, they will trap less sediment than their impermeable counterparts. By trapping less sediment, they will cause less downdrift erosion problems.

The Amelia Island terminal groin is a functional example of a permeable groin. Due to environmental concerns downdrift, the groin at Amelia Island was intentionally designed to have a large degree of permeability. Post 2-year monitoring reports indicate that the groin and its detached breakwater are functioning properly and have exceeded expectations (Olsen, 2006 & 2008). It has retained enough sediment to help stabilize the shoreline updrift of the groin without causing harmful effects to important bird nesting habitats downdrift. Figure IV-18 illustrates the difference between Amelia Island (permeable groin) and a typical rubble mound groin.



Amelia Island Typical Cross-Section

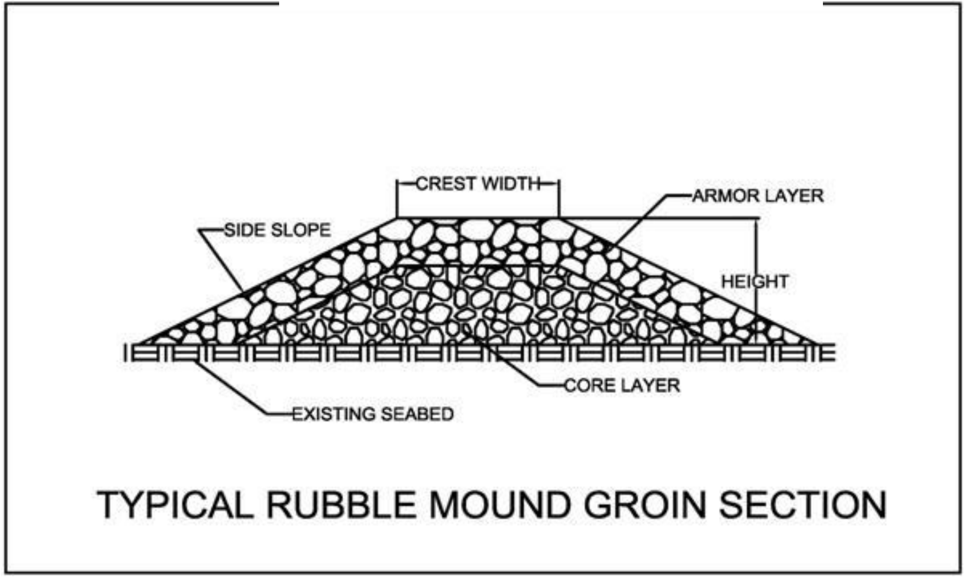


Figure IV-18. Permeable Groin vs. Typical Groin

A typical rubble mound configuration can be made more permeable by lowering the height of the core layer to below mean sea level. This will allow additional sediment transport through the larger, more porous, armor layer. The disadvantage of lowering the core layer is that the groin is unable to absorb excessive wave energy as effectively. Also, typically the cost will increase as the volume of armor stone increases (Ehrlich, 1982).

The major benefits of permeable groins include lower construction and maintenance costs, reduction in both tidal and wave induced currents, decreased longshore sediment

transport, decreased intensity of rip currents along the updrift side, more uniform shorelines, and reduced erosion on the leeward side of the groin (Poff, 2001).
Some disadvantages of permeable groins include increased channel shoaling from substantial sediment transport through the groin, possible higher dredging costs, and loss of beach material. Also, impermeable groins have predictable locations for abrasion, where permeable groin performance is generally less predictable (Perok, 2003 & USACE, 1986).

4. Configuration

Most groins are straight structures, perpendicular to the shoreline. However, other possible shapes include: T-, L-, and Y-shaped groins, inclined, dogleg, and tuned T-shaped. Some examples of these are shown in Figure IV-19. T-shaped groins are similar to near-shore breakwaters when the T end is above mean sea level. T-head and L-shaped groins include a shore-parallel head section that acts to diffract wave energy before it reaches the shoreline.

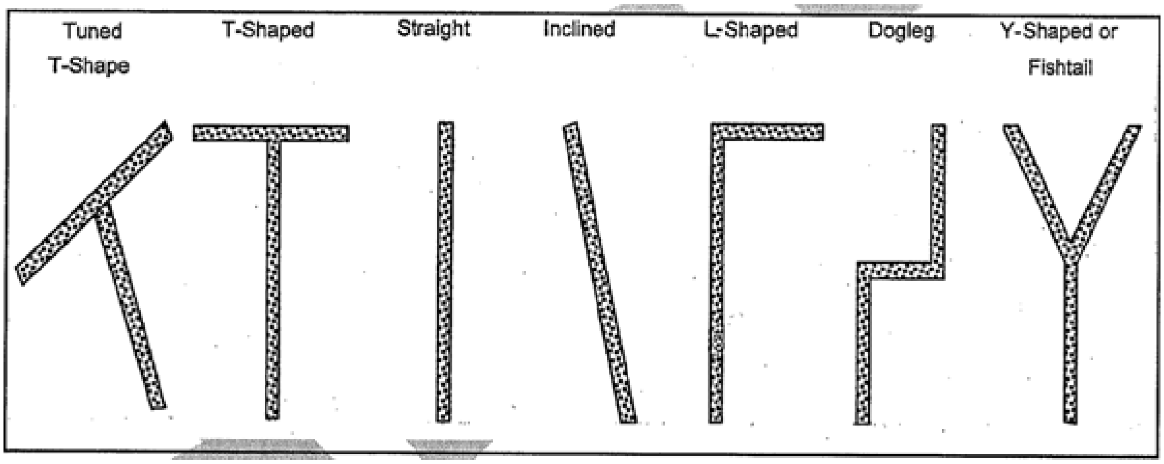


Figure IV-19. Possible Groin Configurations (taken from USACE Coastal Engineering Manual, 2002)

T-head groins can be an improvement over standard groins since they reduce the occurrence of rip currents adjacent to the groin and block the offshore movement of sand adjacent to the groin. The USACE Coastal Engineering Manual states, "*T-head and L-shaped groins are best suited for protecting limited coastal reaches where the mobilizing forces include tidal currents, as well as wave-generated currents and where the objectives are more focused on stabilization of the shoreline, rather than increasing beach width*" (USACE, 2002). Inclined groins may reduce rip currents along the updrift side when inclined in the direction of net sediment transport.

5. Material

The type of materials used in marine structures depends on the required lifespan and costs associated with the structure. Generally, due to the costs associated with these structures, the expected lifespan can be between 25 to 50 years. The design needs to determine the durability of a groin in the aggressive marine environment, while ensuring maintenance costs are kept to a minimum.

a) Rock

The most common material used in terminal groin construction is rock. Rock (or rubble mound) groins generally have a core of smaller, graded stone with an armor layer of larger stone overlaying the core. Generally rock groins have a trapezoidal cross section (either with or without toe protection) and are dependent on weight for their stability. Rock groins have degrees of permeability depending on the size stones used.

In most cases, rock must be hand-placed. The armor layer should have a degree of interlocking to protect the groin from loads associated with marine structures (Latham, 1993). Rock groins can also present a safety hazard if people climb on top of the groin. However, rock groins tend to be very durable when designed and built correctly.

b) Concrete Panels and Armor Units

Concrete groins may be constructed using precast blocks, fillable cells, interlocking shapes (concrete armor units), or sheet piles. Typically, concrete units reinforced with steel are used. Figure IV-20 illustrates an example of concrete sheet piles. Given the application environment and the need for a cantilever installation, it is expected that a terminal groin made of concrete panels would be limited to water depths of 10 ft or less.

Sea water, which is rich in chlorides and sulphates, can corrode the reinforcement. Deterioration can also occur from alkali aggregate reactivity. Admixtures should be added to the concrete to counteract these effects; however, care should be taken when selecting the admixtures so they do not adversely affect the performance of the concrete.

Concrete armor units are man-made concrete objects designed to resist the action of waves on coastal structures. The armor units are applied in a single layer. The performance of these units greatly depends on accurate positioning of the individual blocks to enable the full interlocking potential. Specific placing must be strictly maintained during construction to ensure stability of the armor layer. Breakage can occur if the units are not installed properly (Boorman, 1996; Bunker, 1996; & USACE, 2002). Figure IV-21 shows some examples of different concrete armor units.

Figure IV-20. Example of Concrete Sheet Piles

Figure IV-21. Examples of Concrete Armor Units

c) Steel

Steel groins may be comprised of sheet pilings, H-piling, waling, and sheeting; or a combination of all of the above. Steel sheeting, pilings, and sheeting are fairly quick and simple to install with pile drivers or vibratory equipment. Factory-produced materials can be delivered onsite with known properties, making quality control more reliable than other building materials. Steel has high strength and stiffness, with good ductility; however, it readily corrodes in a marine environment. Steel must be coated with an epoxy finish to keep it from corroding in saltwater. Steel groins can also have concrete fascias and caps to prevent corrosion (Spragg, 1993). Figure IV-22 illustrates an example of a steel sheet pile terminal groin. Given the application environment and the need for a cantilever installation, it is expected that a terminal groin made of steel sheet piling would be limited to water depths of 15 ft or less.

Figure IV-22. Example of Steel Sheet Pile Terminal Groin

d) Timber

A potential low-cost material available for construction is timber. Timber groin configurations can have single or multiple rows of pilings. Timber groins can also have planks between the pilings which can be removed easily to vary the height of the groin with the beach level, making the groin adjustable in different beach conditions without having to rebuild or remodel the groin. Timber groins are relatively easy to construct, have a smaller footprint, and are more aesthetically pleasing than some of their counterparts (Perdok, 2003).

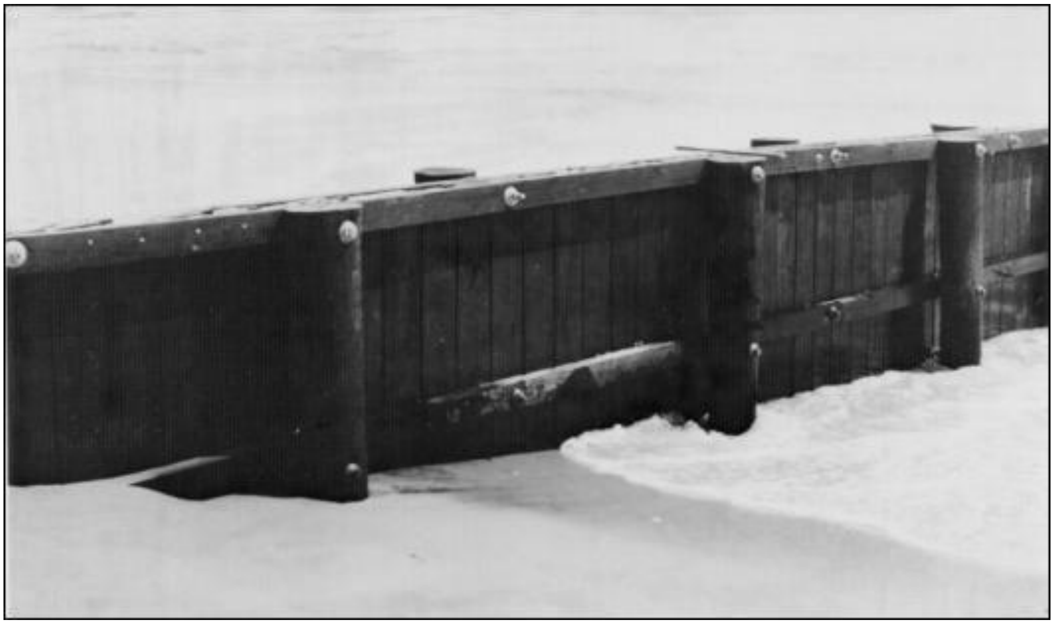


Figure IV-23. Example of a Timber Groin

Timber does have several disadvantages, including, attack from physical damage, fungal decay, rotting, and marine borers. Timber also has a very limited structural application; that is where applied loads are low. Timber cannot withstand the same forces that rock, steel, or concrete groins can, and should not be used for construction of deep water groins (Spragg, 1993). Given the application environment and the need for a cantilever installation, it is expected that a terminal groin made of timber would be limited to water depths of 6-8 ft or less.

e) Geotextile

Geotextile tubes are a relatively inexpensive alternative to other building materials. There are numerous types of tubes and bags that can be filled with sand and stacked on top of one another to construct the groin. Figure IV-24 shows an example of a geotextile tube.

Geotextiles made of polyester tend to perform better than polypropylene due to its better creep resistance and greater long-term strength. Polyester yarns are easier to sew, resulting in tighter seams. Also polyester fabrics tend to swell when wet, thereby decreasing the opening size and allowing for better sediment capture.

The major disadvantage to geotextiles is the ease of tearing or puncturing of the fabric during and after construction. Geotextiles also tend to degrade in UV light. Repairing damaged portions of geotextile tubes usually requires replacing or rebuilding the damaged sections. Patching geotextiles has proven ineffective in the past; however new technologies such as chemical seaming and HDPE covers may prove to be viable options to repair punctures and tears (Heilman, 2003). Another disadvantage to geotextile groins is, like timber, they cannot withstand larger loads and should not be used for deep water groins. Given the application environment, it is expected that a terminal groin made of geotextile tubing would be limited to water depths of 6 ft or less.

Figure IV-24. Example of a Geotextile Tube

6. Alternative Construction Techniques

When long groins have detrimental effects on the downdrift beaches, groin notching can be an alternative to removal of the groin. Groin notching, or removal and lowering of a portion of the groin just seaward of the beachfill design template, is designed to help maintain a straighter shoreline and provide the needed littoral transport downdrift of the groin. Another advantage to groin notching over removal is leaving existing marine habitats intact (Bocamazo, 2003).

Figure IV-25 Example of Notched Groins (New Jersey DEP Website)

Notched groins have recently undergone laboratory and field tests conducted by the US Army Corps of Engineers (USACE). Trial notched groins have been implemented by USACE along the southern New Jersey shore (Figure IV-25). Tentative conclusions show that notches in the swash zone are the most efficient. However, notching a groin in the swash zone may not be successful depending on how and at what rate sediment typically moves along the shore. Notches located in the surf zone are less efficient and can create strong rip currents which are hazardous to swimmers. Surf zone notches may actually move sediment further from shore (USACE, 2002).

In addition to groin notching, the selection of material type has a great deal to do with how adaptable the structure can be. For example, steel or concrete sheet piling would allow the opportunity to lower various sections by notching even after initial construction. These types of sheet pile structures would also allow for complete removal of the structure if unacceptable impacts were to occur. While rock structures can be removed, the marine environment and the weight of the armor units would likely cause 100% removal of the structure to be unattainable; especially in deeper water where the armor units may settle into the substrate.

Lastly, as stated previously, terminal groins made of rock are also now being constructed with only armor units to increase their permability. The lack of an impermeable core allows more wave energy and hence sediment to pass through the structure. Nonetheless, the elevation of the impermeable core within the structure could also be adjusted to change the overall permeability of the structure.

D. Overall Findings and Summary

Terminal groin design is very site-specific. The length, height, and permeability of the groin will determine how effective the groin is at trapping sediment updrift of the groin and the overall impact of the groin on sediment transport. Long groins that are built above the seasonal high water level or are completely impermeable will most effectively block sediment. However, short groins with high permeability may not block enough sediment to be effective. Terminal groins should be just long enough to retain the required beach width, without causing an undue reduction in sediment transport downdrift.

Ideally, the groin height should be limited to just above beach level. Adjustable heights to nourishment volumes and design berm heights are also beneficial. The design groin height should also account for wave overtopping and the desired amount of sediment transmission over the structure.

Rock is generally the most widely used building material since it is readily available and highly durable. Concrete and steel are suitable building materials for shorter, mid to shallow-water groins; however, these materials tend to be cost-prohibitive. Timber and geotextile groins are less expensive alternatives and can be adapted to a variety of beach conditions. Concrete, steel, and timber structures have the advantage of being adjustable with the beach profile without having to rebuild or remodel the groin. However, timber and geotextile structures cannot withstand the loads experienced with deep-water groins and should not be used in these applications.

Groin notching is an emerging technique that allows for adaptive management. Notching allows for sediment to bypass the groin where it would normally be trapped. This may prove to be a cost-effective alternative to groin removal.

These findings from the literature were confirmed when evaluating the five study sites. As reported in the analyses above, it appears that for shorter groins, the interruption to littoral transport is smaller compared to the overall magnitude of sediment transport and the muted impacts seen both updrift and downdrift of the inlet. There also seems to be a threshold that appears with both length and height to be crossed where adjacent impacts become more pronounced. While it is possible that dredging impacts may be responsible for this threshold crossing, it underlies the importance to considering the overall length of the structure in relation to the exterior man-made and natural processes that also drive sediment transport so that the structure's relative effects are minimized or eliminated.

Finally, the permeability of the structure has a significant impact on adjacent shorelines. Based on the results from Section II, one can see that the Amelia Island structure has allowed material to bypass the structure. However, the structure has also had a limited impact on the three mile updrift shoreline. In looking at the details, it appears that the updrift benefit of the Amelia Island terminal groin dies off after the first 0.5 mile. The other structures have impermeable cores and appear to hold more sand for a greater distance updrift of the structure.