

# **APPENDIX I**

## **DESIGN ENGINEERING ANALYSIS FOR TERMINAL GROIN LENGTH**

**(Prepared by Olsen Associates, Inc.)**

**An Evaluation of Varying  
Terminal Groin Lengths  
and the  
Feasibility of Phasing Construction**

Olsen Associates, Inc.  
2618 Herschel Street  
Jacksonville, FL 32204  
(904) 387-6114

September 23, 2013

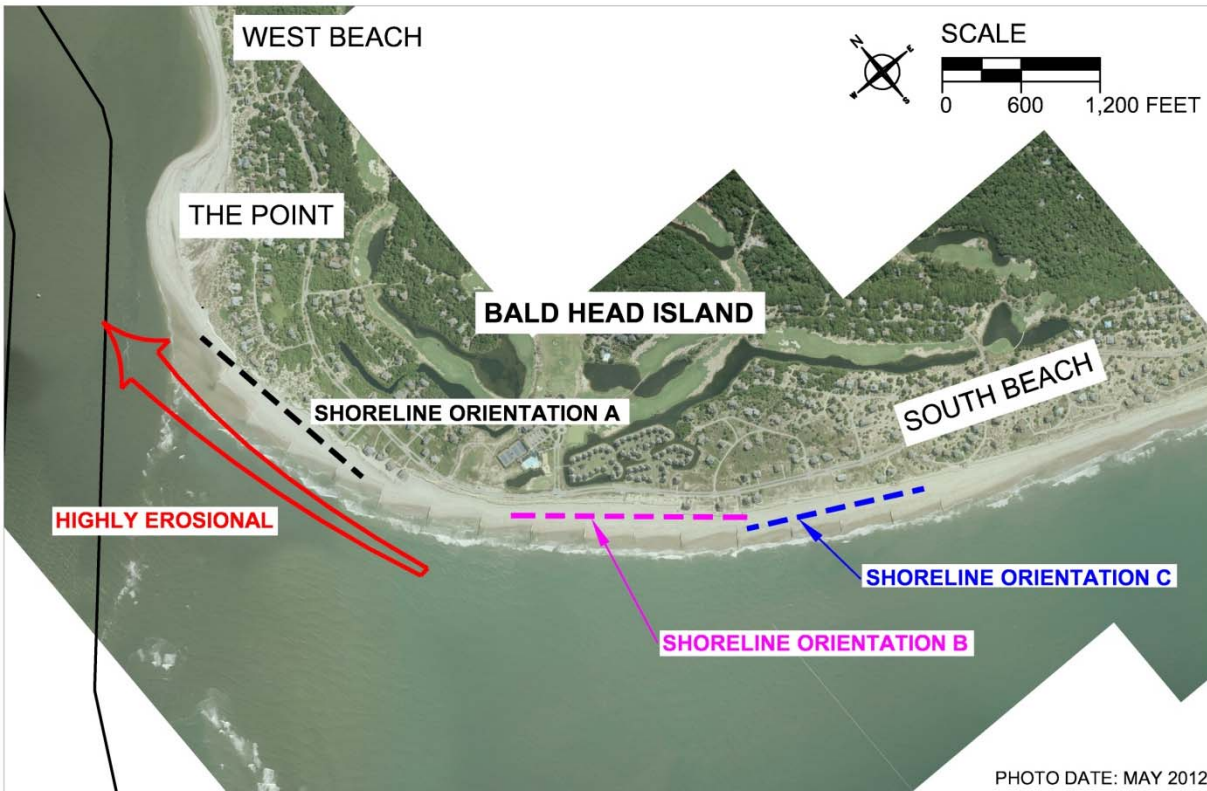
An initially preferred (maximum) design length for the proposed terminal groin on Bald Head Island was investigated through extrapolation of numerical model results and application of practical coastal engineering principles and experience. The resulting analysis focused on the potential ability of different terminal groin lengths to protect varying lengths of updrift shoreline along South Beach while minimizing negative impacts to the downdrift (west) beaches. For purposes of discussion, the predicted performance of three (3) conceptual terminal groin lengths were compared: a short groin (~1,100 feet total length), a mid-length groin (~1,900 feet total length), and a long groin (~2,900 feet total length). The landward point of attachment and general structural orientation of each groin alternative are self-similar. Each alternative was considered to be relatively permeable with respect to its ability to allow some level of sand transport over and through the structure. This is in contrast to conventional groin or jetty structures which are typically designed to be “sand-tight”. The spatial extent of updrift benefits associated with a “leaky” terminal groin will be essentially proportional to the length of the terminal structure. Conversely, it is expected that at some point, potentially negative downdrift impacts are also proportional to increasing structure length. A mid-length terminal groin therefore appears to offer an acceptable balance between maintaining the updrift objective of the structure while minimizing the probability of downdrift impacts.

The primary purpose of a terminal groin at Bald Head is to stabilize the westernmost segment of South Beach nearest the inlet channel and to protect both private and public upland structures and infrastructure from chronic coastal erosion occurring immediately eastward thereof. Sediment transport at this location is directed strongly towards the inlet, in the net. Numerical studies and physical monitoring both indicate that the rate of alongshore sediment transport accelerates with proximity to the inlet. Once beach sediments reach the inlet they are either transported into the navigation channel or deposited into various shoal formations. In either event these sediments are effectively lost from the littoral system on Bald Head resulting in beach profile erosion that is significant enough to warrant repeated application of erosion control

measures along the affected South Beach shoreline via beach fill, placement of sand filled tube groins, and sand bag revetments.

Over the last 12 years, the shoreline orientation at the west end of Bald Head has progressively rotated clockwise to an increasing north-to-south orientation thereby resulting in increased obliqueness between the island and incident breaking waves (see **Figure 1**). This relationship is currently a significant factor in the chronically *increasing* rate of sediment transport off the island at this location. The installation of a terminal groin and episodic beach fill are intended to strategically reorient the shoreline counter-clockwise to a more northwest-to-southeast orientation. This will decrease the effective angle between the shoreline and incident breaking waves -- thereby reducing sediment transport along the South Beach shoreline segment nearest the inlet. Simplistically, the resultant amount of shoreline reorientation can be considered to be directly dependent upon the effective length of any terminal groin constructed and its associated updrift impoundment fillet.

Along westernmost South Beach on Bald Head Island, three fundamental shoreline orientations are currently evident, A, B, and C, as presented in **Figure 1**. Shoreline orientation A, which trends north-to-south, is associated with the aforementioned highest present-day erosional segment of South Beach. Future terminal groin performance will be predicated on developing a stable westerly extension more typical of shoreline orientation B throughout the chronically eroded westernmost reach – thereby essentially reversing the significant negative effects that currently exist with orientation A. Establishing or approaching some variation of orientation B in the long-term, in order to decrease the strong erosional gradient existing along west Bald Head Island, requires large-scale structural stabilization – such as a terminal groin of suitable length.



**Figure 1:** Fundamental shoreline orientations, A, B, and C, observed along western Bald Head Island.

It can be readily seen that a very “short” groin alternative of 1,100 ft or less in length (see **Figure 2**) fails to achieve the most desirable shoreline orientation (i.e., B). Hence its expected updrift impoundment effect does not necessarily extend throughout the most critically eroded section of developed shorefront. Instead, the westerly extension of orientation B forms the basis for defining the requisite length of the “mid-length” terminal groin (see **Figure 3**), for which the updrift effects are predicted to extend through the critically eroded area. To emulate the westerly extension of orientation C would require a significantly longer terminal structure – approaching 2,900 feet (see **Figure 4**). Conversely, the updrift effects of a “long” terminal groin would likely extend eastward through most of the existing sand tube groinfield; however, it entails an exceptionally long structural footprint and presents much greater potential for adverse impacts to both of the inlet-facing shorelines located northward thereof (i.e., the Point and West Beach).

The calibrated Delft3D model was employed in order to predict the short- and long-term responses to construction of the proposed mid-length terminal groin. Delft3D model simulations are described by Olsen (2013). The results suggest that the mid-length terminal groin is capable of protecting currently threatened upland infrastructure and residential structures while reducing sediment transport along western Bald Head Island to rates consistent with those computed under historic shoreline conditions -- without significant or wide-spread downdrift impacts, relative to

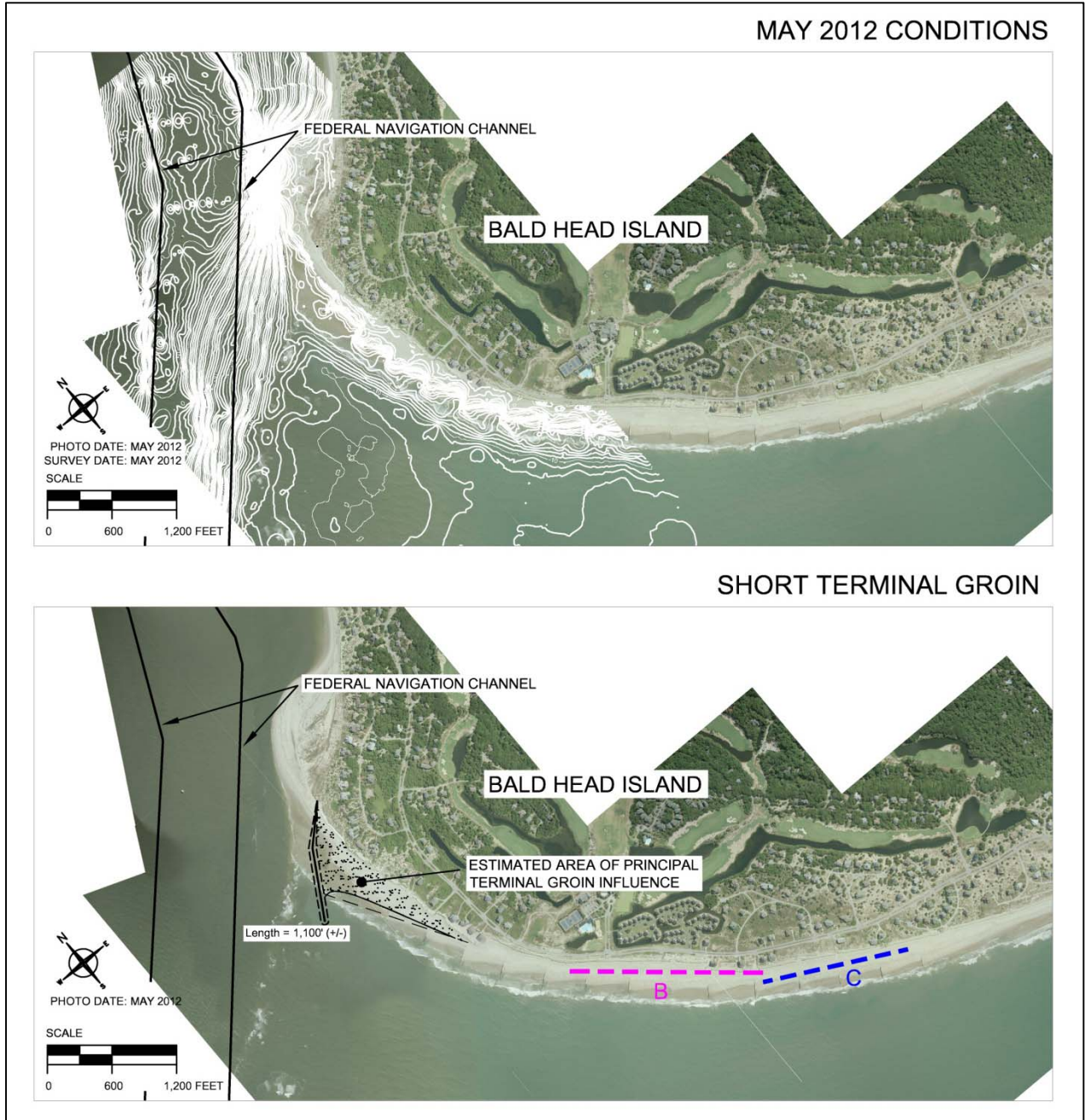
existing conditions. In order to ensure adequate post-construction sand bypassing such a structure would necessitate constructing a ~0.5 Mcy fillet of sand immediately updrift of the structure. Implementation would likewise need to be coincident with a federal beach disposal project that would function as a feeder beach.

Extrapolation of the numerical modeling results for the mid-length terminal groin was employed to initially infer the predicted physical performance of the shorter and longer terminal groin alternatives. For example, given the smaller post-construction impoundment fillet supported by the very short groin (**Figure 2**) this structure was predicted to offer benefits more akin to those afforded by the existing sand tube groins (with fill), albeit somewhat enhanced. That is, the area of direct updrift benefit is somewhat limited in scope and leaves several beachfront structures reliant upon the continued maintenance of the sand tube groins. Given that the Delft3D modeling of the mid-length groin suggests minimal short- and long-term downdrift impacts relative to existing conditions, it is reasonable to conclude that the increased sediment supply afforded by a shorter terminal structure would likewise achieve similar minimal downdrift impacts. However, relative to the mid-length structure a short terminal groin would over time allow a greater volume of sediment to pass onto the downdrift beaches. Moderation of this effect would be afforded by strategic beach disposal to the east on South Beach.

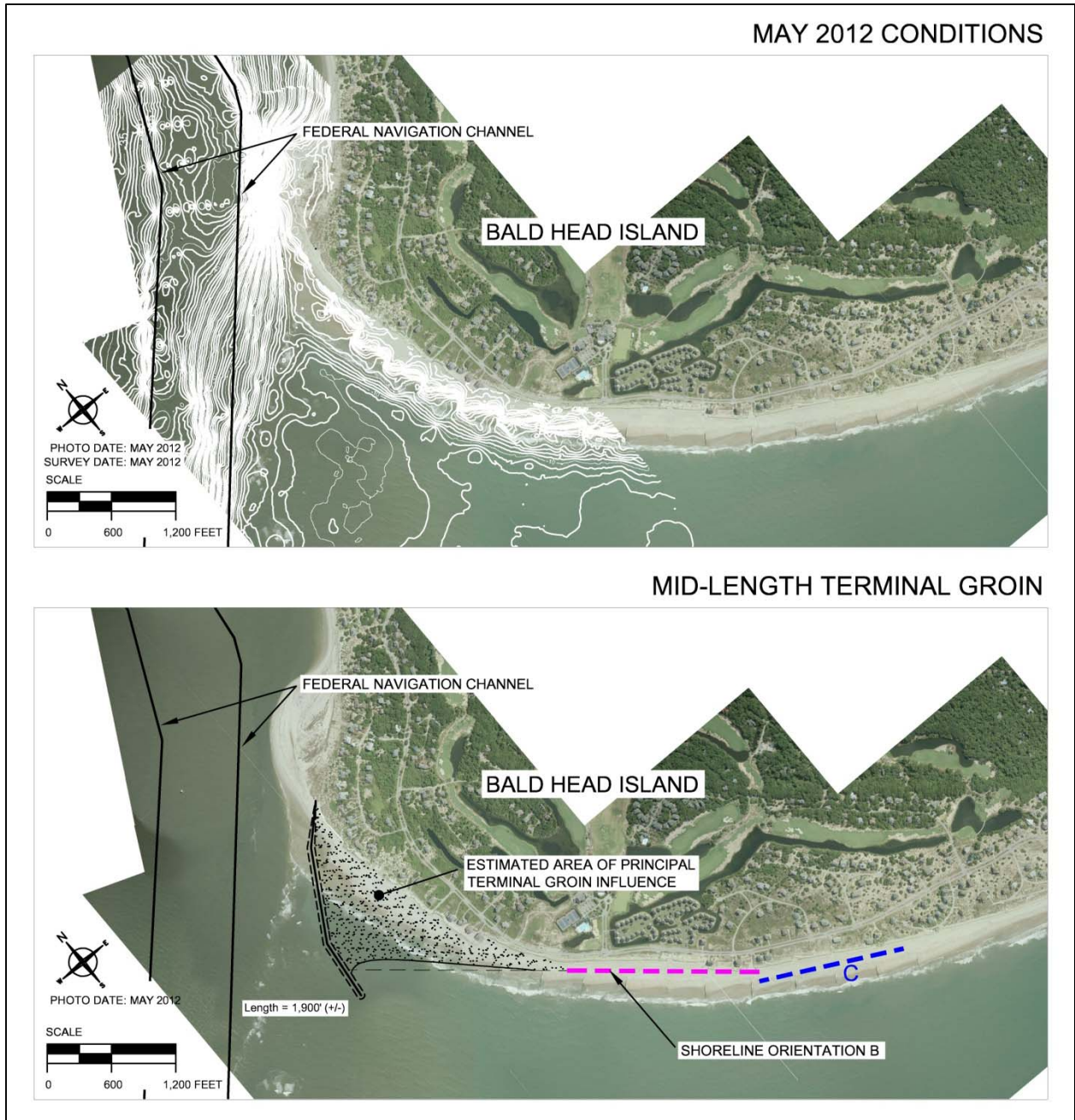
Conversely, extending the terminal groin a significant length beyond the mid-length shore normal dimension in order to maximize updrift impoundment potential (i.e., in general accordance with shoreline orientation C), would require a structure similar in length to that shown in **Figure 4**. The resulting fillet is defined by a shoreline that is nearly east-west in orientation and spans nearly the entire existing tube groin field. While theoretically possible, the resultant shoreline configuration would exceed that which would be expected at the terminal end of a barrier island at this location. In contrast to post-construction sediment transport rates predicted for the mid-length terminal groin, the very long terminal groin is likely to result in development of multiple updrift transport reversals including an increased potential for episodic crenulate bay formation immediately eastward of the structure. Additionally, the transport of sediment through and/or over the long terminal groin would likely occur predominantly near the structure's seaward terminus. This, combined with the overall length of the structure, suggests a decreased potential for sand to reach the downdrift shoreline, with sediment instead principally directed towards the navigation channel and/or onto Bald Head Shoal. Such a condition would be highly impactful to the Point and to West Beach.

From the preliminary investigation, it was concluded that the mid-length permeable terminal groin (on the order of 1,900 feet in total length, or less) is the longest length to reasonably and successfully achieve the objectives of decreasing erosion along the western end of South Beach and extending the easternmost limit of benefit. It is noted that this effective length was defined on the basis of the 2012 "eroded" shoreline location and includes a tie-back into both the existing

upland and the requirement of a 0.5 Mcy fillet to be constructed concurrently with structure implementation. Hence, much of the structure stem would be below grade thereby resulting in an effectively much shorter length relative to the new (post-construction) mean high water location.

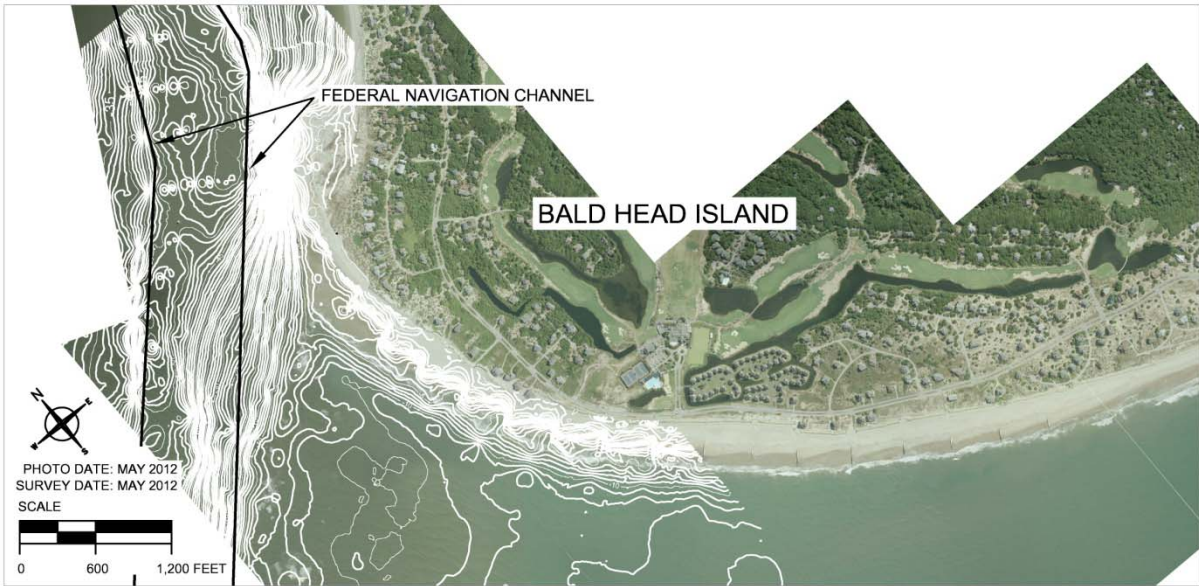


**Figure 2:** Conceptual illustration of updrift performance of a short terminal groin.

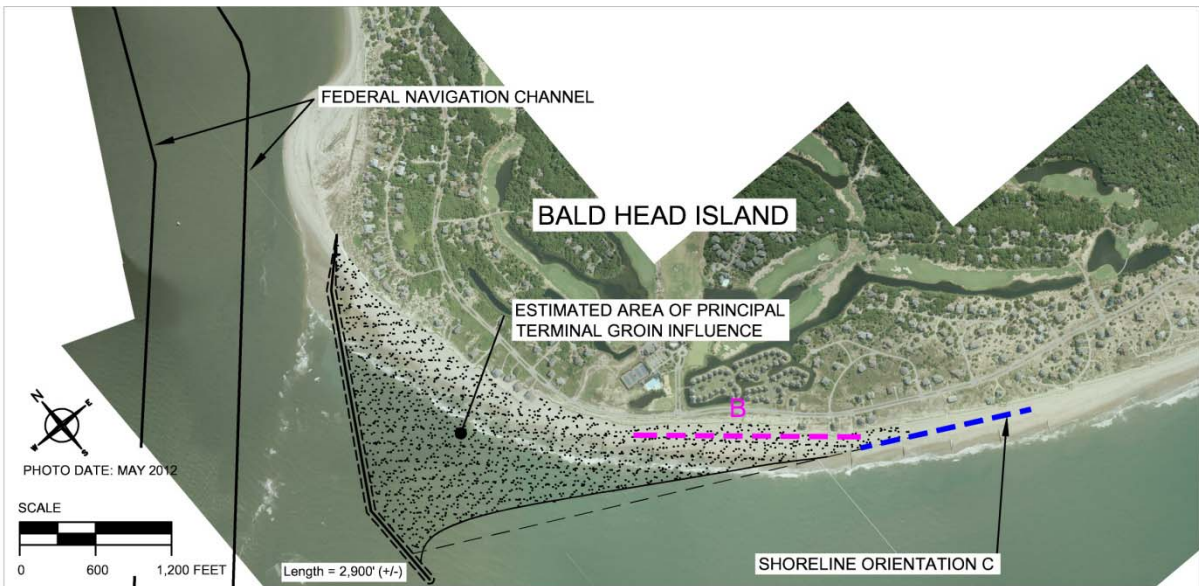


**Figure 3:** Conceptual illustration of updrift performance of a mid-length terminal groin.

MAY 2012 CONDITIONS



LONG TERMINAL GROIN



**Figure 4:** Conceptual illustration of updrift performance of a long terminal groin.

The Village of Bald Head Island intends to permit the construction of a terminal structure extending a maximum of 1,900 ft +/- in length seaward of the existing, seaward-most upland dune line. Such a project would be initiated in concert with a federal beach disposal project constructed eastward thereof in order to maximize benefits to the South Beach littoral system. Additional sand – beyond that placed by the federal maintenance dredging and disposal to the beach – would need to be placed updrift of an approximately 1,900 ft long terminal groin in order to facilitate rapid and complete infilling of the requisite sand fillet at the structure. A



supplementary sand (borrow) source located at Jay Bird Shoals would be required to dredge and place approximately 0.5 Mcy of sand needed for fillet creation.

In order to expedite beneficial post-groin shoreline equilibration conditions (both updrift and downdrift of the structure, and including formation of the sand fillet), the Village will permit the option to address construction of a terminal groin in Two phases. Phase I would first construct the landward two-thirds of the structure's overall length, more or less, coincident with the next beach disposal of dredged material from the navigation channel. Phase II would extend the seaward end of the structure to complete the structure's overall length, at an appropriately timed future date. A Phase I structure (currently estimated at 1,300 ft +/- in length) would be shorter than the terminal groin's overall design length, but is nonetheless deemed sufficient to initiate stabilization of the western limit of South Beach through beneficial shoreline realignment and associated reduction of sediment losses to the inlet. Moreover, the shorter Phase I structure is expected to be more conducive to the timely facilitation of sand bypassing to the downdrift shoreline. Supplementary sand source requirements for a Phase I structure would be substantially less. Fillet formation through entrapment of sand placed upon South Beach from the federal channel dredging may potentially obviate the immediate need for the use of a remote (additional) sand source. At the very least, supplementary sand placement if deemed necessary, would be substantially reduced over the 0.5 Mcy initially required for the full 1,900 ft structure.

Additional numerical modeling analyses for a 1,300 foot-long (Phase I) structure were specifically performed for purposes of comparison with existing model results for the full 1,900 ft (Phase II) terminal groin length. More specifically, the Delft3D model was used to simulate the near-term response of Bald Head Island to the construction of a Phase I permeable terminal groin along with periodic beach fill placement. Under this scenario, beach fill sand is derived from both the maintenance dredging of the federal navigation channel and non-federally sponsored beach disposal/nourishment projects. Disposal of maintenance material excavated from the federal project is assumed to be placed onto Bald Head Island in conjunction with two of every three maintenance events, in accordance with the tenets of the current WHSMP. The aforementioned non-federal beach nourishment efforts are intended to supplement the federal disposal during every third maintenance event. For the purposes of this analysis, sand was numerically placed onto Bald Head Island concurrent with channel dredging every three years throughout the nine year model run.

For the simulation, the initial modeled bathymetry was identical to that applied to all other long-term modeling efforts conducted in support of developing an EIS. The present bathymetry includes the addition of a semi-permeable terminal groin located at the western end of the Island's South Beach along with the existing sand-filled tube groin field. The modeled terminal groin was approximately 1,300 feet long and is designed to work in conjunction with a beach fill placement east of the structure -- the intent of which is to reorient the shoreline towards the

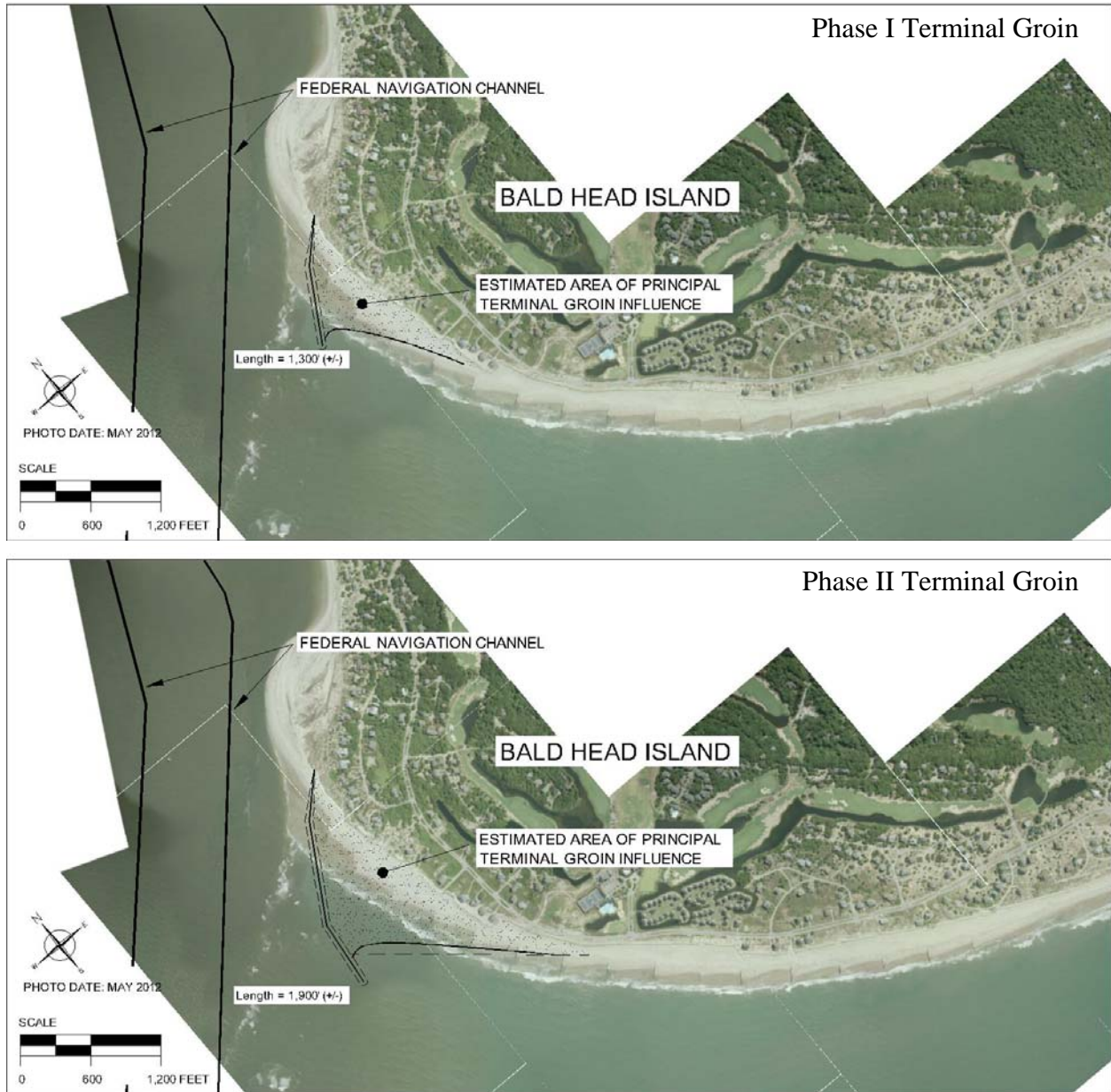
southwest, a more historically appropriate orientation. Initial structural conditions used for model input are shown in **Figure 5**. The figure graphically compares the Phase I “shortened” terminal groin to the previously simulated Phase II terminal structure. The Phase I structure therefore represents the partial construction of the originally proposed and modeled 1,900 foot-long terminal groin in the EIS documentation (ref: Alternatives 5 and 6). The Phase I terminal groin lies on the same footprint as the full Phase II terminal groin.

The Phase I terminal groin was likewise modeled as “leaky” using porous plates which are by definition infinitely high, semi-permeable numerical structures. The permeability of porous plates is numerically controlled by a friction term, roughly representing a level of permeability between about 10 and 30 percent, which is identical to the Phase II structure previously modeled. The existing tube groins are included in the model and are numerically described as thin dams, which act as impermeable, infinitely high barriers to sediment transport, which are mildly transmissive with respect to wave energy.

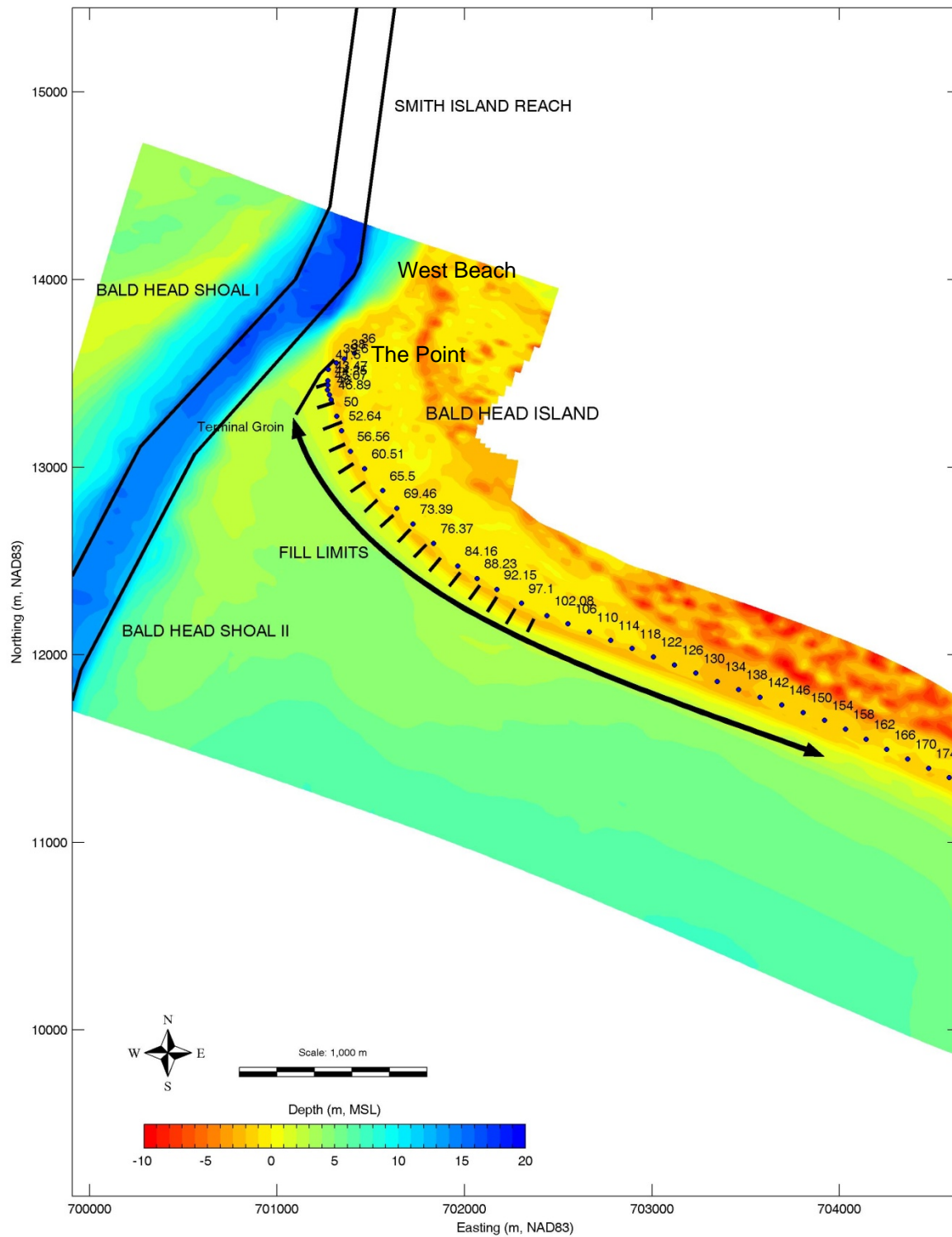
The depth-averaged Delft3D model of Bald Head Island and the Cape Fear River Entrance was previously calibrated in order to accurately simulate average annual alongshore sediment transport along Bald Head Island’s South Beach shoreline (Olsen, 2012). The initial modeled bathymetry comprising the nearshore zone and navigation channel were updated to reflect nearshore conditions existing in spring 2011. Nearshore bathymetry was described by survey data measured in May 2011 while upland topography away from the beach was described by LIDAR data collected in 2005/06. Conditions within the navigation channel were initially described by those measured in February 2011 in conjunction with the U.S. Army Corps of Engineers (USACE) condition survey. These conditions describe a generally eroded beach condition and a shoaled navigation channel, particularly in the Bald Head Shoal I and II reaches, as shown in **Figure 6**.

The numerical model was set up in order to simulate periodic channel dredging along with coincident placement of sand onto the Bald Head shoreline. Dredging and/or disposal/nourishment operations were initiated every three years during the simulation. Upon initiation of the dredge and fill operations, the entire navigation channel was numerically ‘dredged’ to a uniform depth of  $-(44+2)$  feet, the presently authorized channel depth. All dredge spoils were removed from the model. At the same time step, approximately 1,200,000 cubic yards (cy) of sand were placed onto South Beach within a fixed boundary extending from about Station 44+25 near the terminal groin to about Station 156+00 (see **Figure 6**). The offshore limits of sand placement remain the same as in previously analyzed simulations of the Phase II terminal groin (except in the immediate vicinity of the terminal groin). Relative to the Phase II terminal groin, the eastern limit of fill for the Phase I was adjusted westward in order to accommodate the reduced fill area required for the pre-construction of a fillet updrift of the Phase I groin, which is required by Statute. As such, the simulated western limit of fill includes

the entire length of the terminal groin. For purposes of direct comparison with previous analyses, an initial dredge and sand placement event was specified to occur immediately after the start of the simulation (time zero) with the subsequent events occurring at years 3 and 6. This simulation assumes sediment availability every three years and does not consider the effects of skipping fill placement/disposal on Bald Head Island.



**Figure 5:** Conceptual illustrations of the presently simulated Phase I terminal groin and the previously modeled Phase II terminal groin (beach disposal not shown). Note: the estimated area of principal terminal groin influence is hypothetical and not based on model results.



**Figure 6:** Approximate limits of periodic sand placement for simulation of a Phase I terminal groin. In the model simulations, beach placement occurs every three years and is coincident with channel dredging.

**Figure 7** plots the predicted bathymetry throughout the 9 year simulation for the Phase I terminal groin with sand-filled tube groin scenario. Each pane of the plot represents bathymetries predicted in the project area at years 3, 6, and 9 immediately prior to the next placement/dredge event. The approximate mean lower low water (MLLW) contour is shown in bold for reference in each plot. Areas shaded in green represent those which are expected to remain dry for at least a portion of the tidal cycle – typically areas above the MLLW elevation. The model results indicate that with the porous Phase I terminal groin and sand-filled tube groins in-place, the downdrift shoreline, “the Point”, is expected to remain accretional throughout the 9-year simulation. The majority of this accretion is predicted to occur on the downdrift (west) side of the terminal groin, just north of the structure’s landward end. This result is similar to that indicated for the Phase II terminal groin (see **Figure 8**) although the MLLW shoreline at Point tends to migrate into a broader tidally-influenced shoal feature relative to the Phase I structure. The subaqueous shoal at the seaward end of the Phase I terminal groin, however, is significantly smaller than that resulting from the Phase II groin, which is expected.

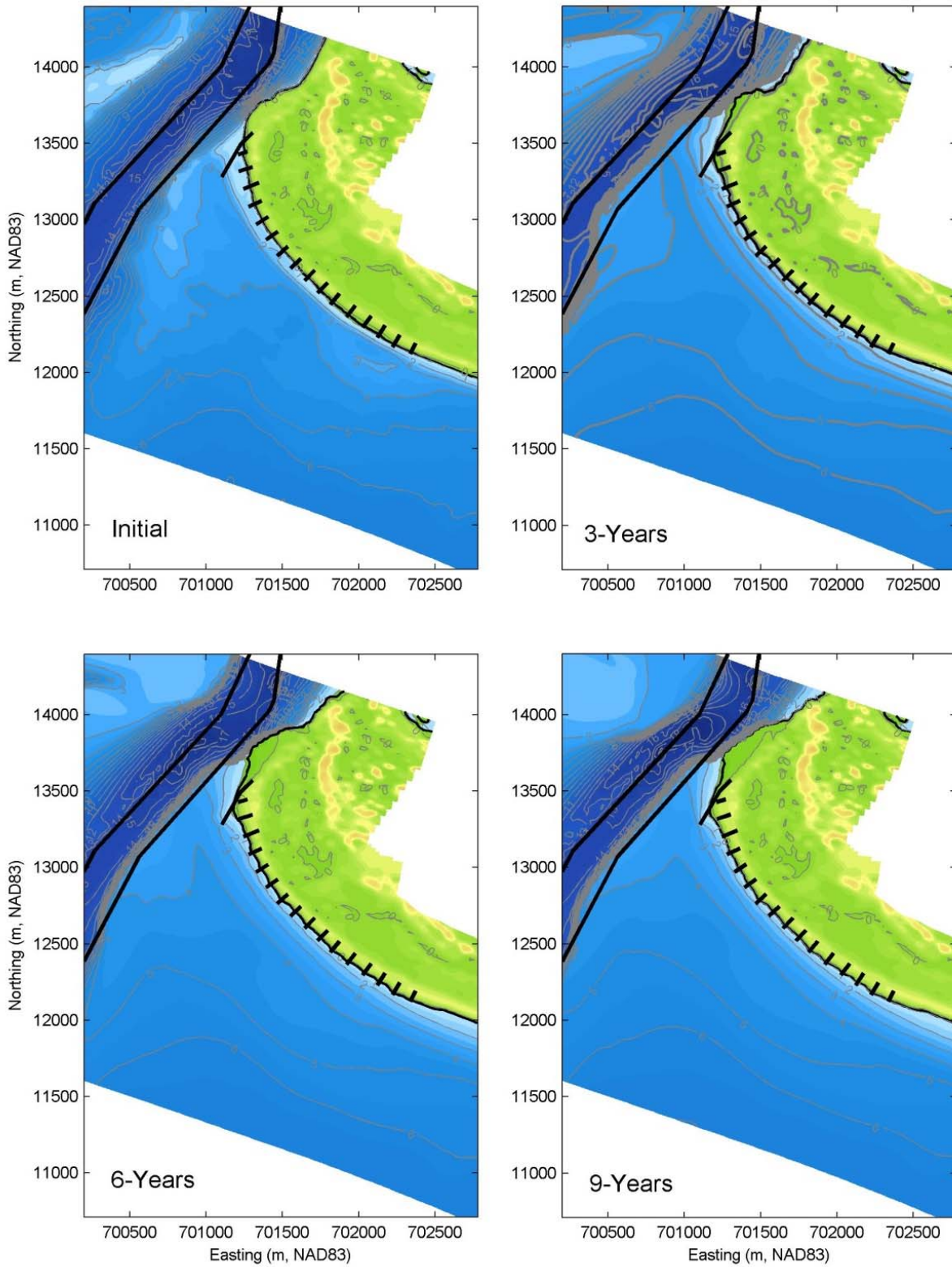
**Figure 9** plots the predicted MLLW contours at years 3, 6, and 9 for the Phase I terminal groin condition. For comparison, **Figure 10** plots the predicted MLLW contours at years 3, 6, and 9 following construction of the Phase II terminal groin. The results are similar for both structural lengths and highlight the aforementioned continued accretion of the Point throughout the simulation period under both terminal groin lengths. This is in comparison to a northward rolling back of the Point shoal under each non-terminal groin condition investigated for the EIS documentation (Olsen, 2013).

The model indicates continued erosion along portions of West Beach throughout both the Phase I and II terminal groin simulations, which is consistent with existing conditions as well as other non-terminal groin modeling results. The severity of the erosion signal indicated along West Beach (north of the Point) is similar between the Phase I and Phase II results but is likely overstated in both instances. That said, the model predicts that after 9 years the location of the shoreline coincides with the existing escarpment (bluff) along West Beach -- similar erosion patterns in the nearshore portions of West Beach are indicated in all simulations (structural and non-structural), away from areas affected by Point migration (Olsen, 2013).

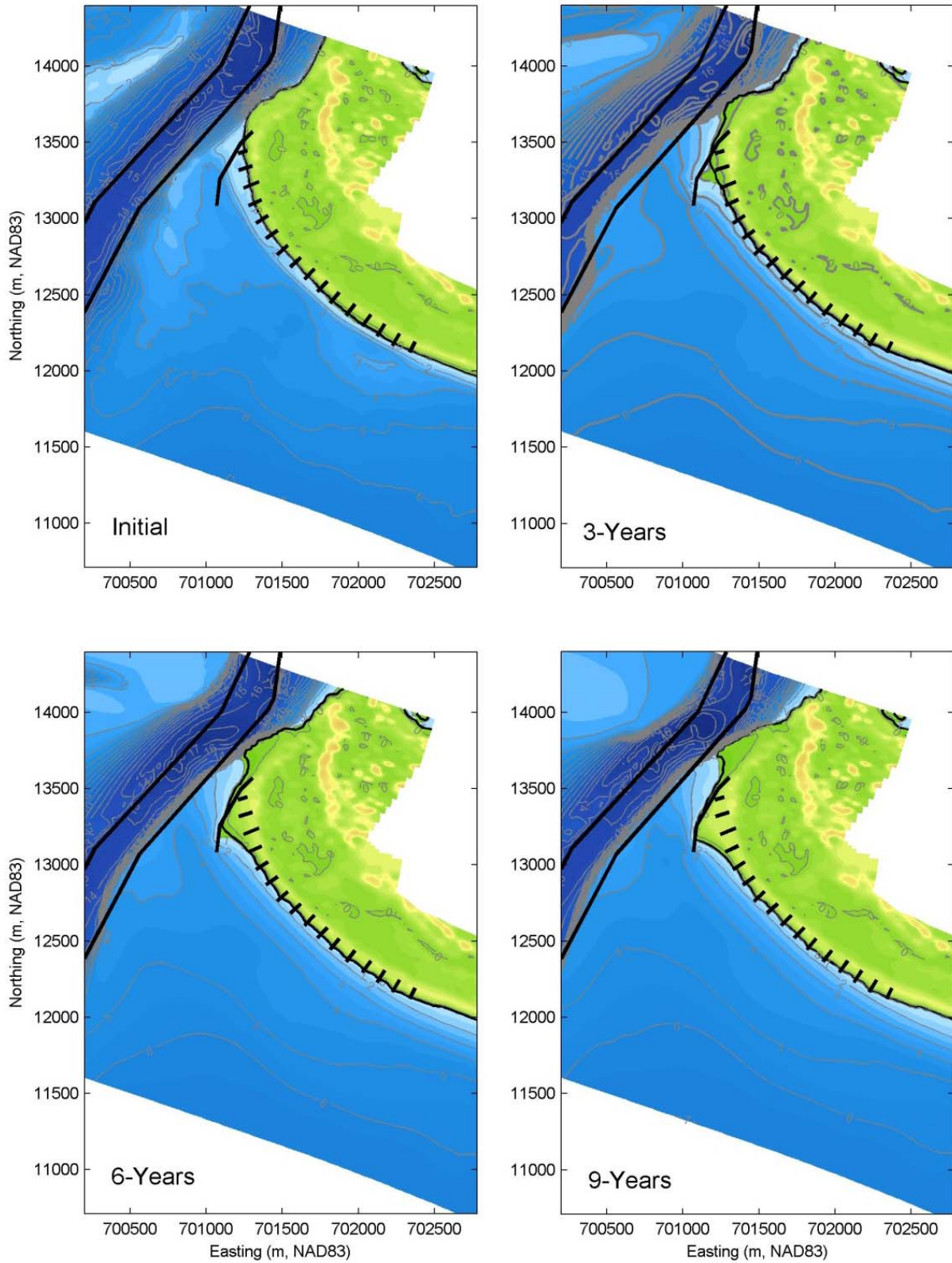
North of the Point, West Beach is generally protected from ocean waves and its location inside the entrance suggests that the principal physical mechanisms for morphological change along West Beach are not solely governed by normal open coast processes. It is likely that sediment transport here is dominated by local wind generated waves, river currents, ship wakes, etc., which, excepting typical currents, are not described in the model. The response along West Beach should therefore be estimated by relative comparison between similar model simulations and not as an absolute prediction of beach response. Such a comparison suggests few significant differences along West Beach as a result of phasing the construction of the terminal groin.

**Figure 11** compares the predicted MLLW shorelines for the Phase I and II scenarios at year 9 of the simulations. The resulting growth of an impoundment fillet on the east side of the terminal groin in time is clearly visible in both terminal groin scenarios. For the Phase I terminal groin the updrift fillet is predicted to extend through the westernmost three or four existing tube groins by year 9. The remainder of the South Beach shoreline presently within the groin field would continue to be dependent upon their maintenance and performance in order to avoid potential impacts from erosion. For the Phase II terminal groin, the fillet is predicted to extend through the westernmost six or seven tube groins, which should afford greater protection to habitable structures which have historically been at risk within the groin field (principally those which are seaward of the vegetation line).

For both terminal groin phases, seaward growth of the fillet slows over time in the model, likely as a result of the terminal groin approaching its capacity with respect to the volume of material it can impound. While the defined beach placement area extends to the seaward end of the terminal groin, the initial disposal event does not create an elevated berm along the eastern edge of the terminal groin due to the nature in which the model places sediment for beach placement. Rather than fully fill the terminal structure with a berm that extends near the groin's seaward end (which is what might be constructed), the Delft3D model inherently places the specified volume of sediment uniformly within the placement area up to a specified berm elevation. This process results in placement of material along the terminal groin at every event. Periodic sand placement along with the natural impoundment of sediment against the terminal groin, results in a more gradual formation of a full berm across the terminal groin. The process indicated herein is likely conservative with respect to the evolution of both the updrift and downdrift shorelines.

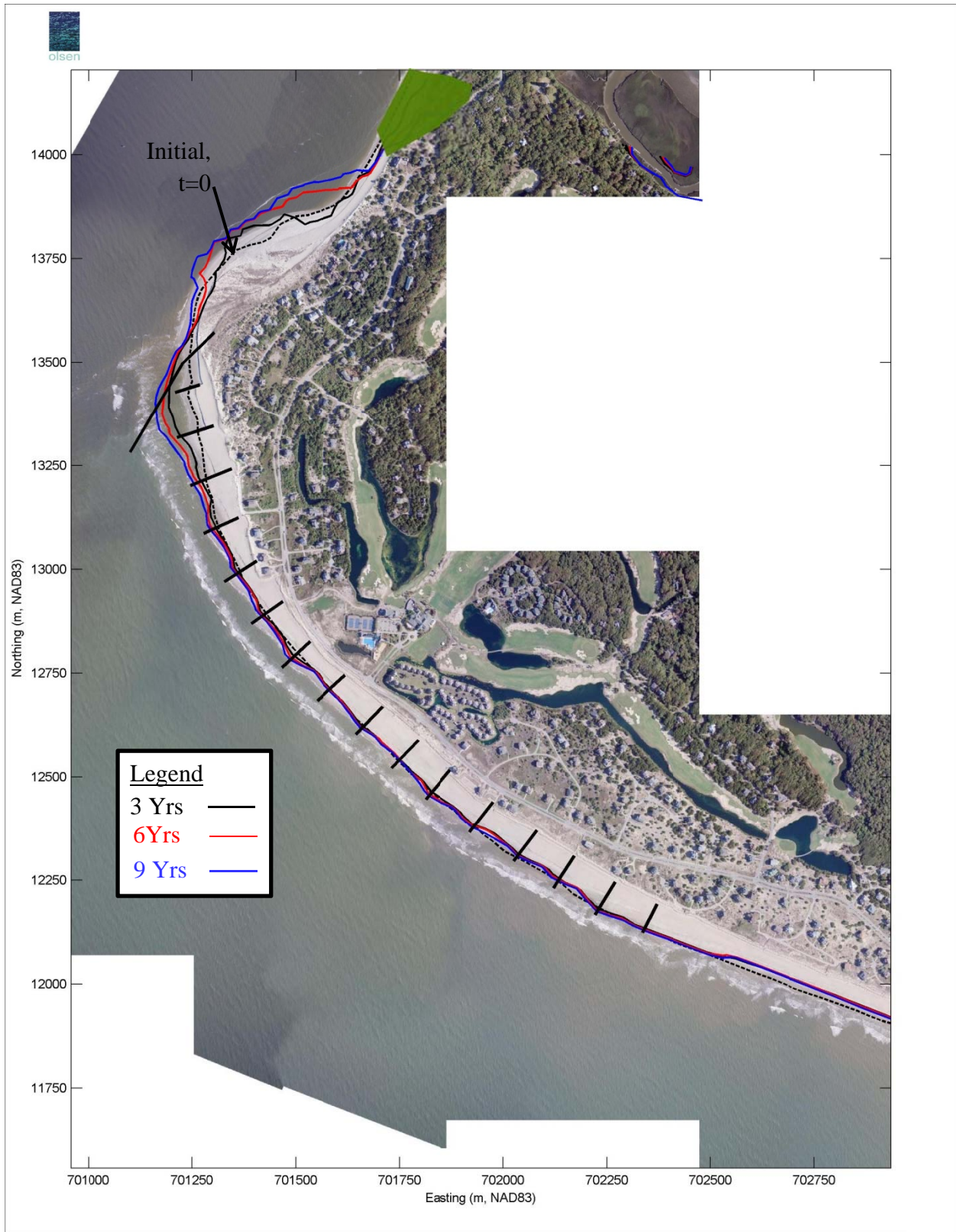


**Figure 7:** Bathymetry predicted throughout the simulation at years 3, 6, and 9 for a Phase I groin alternative. Each depicts conditions prior to the subsequent sand placement interval.

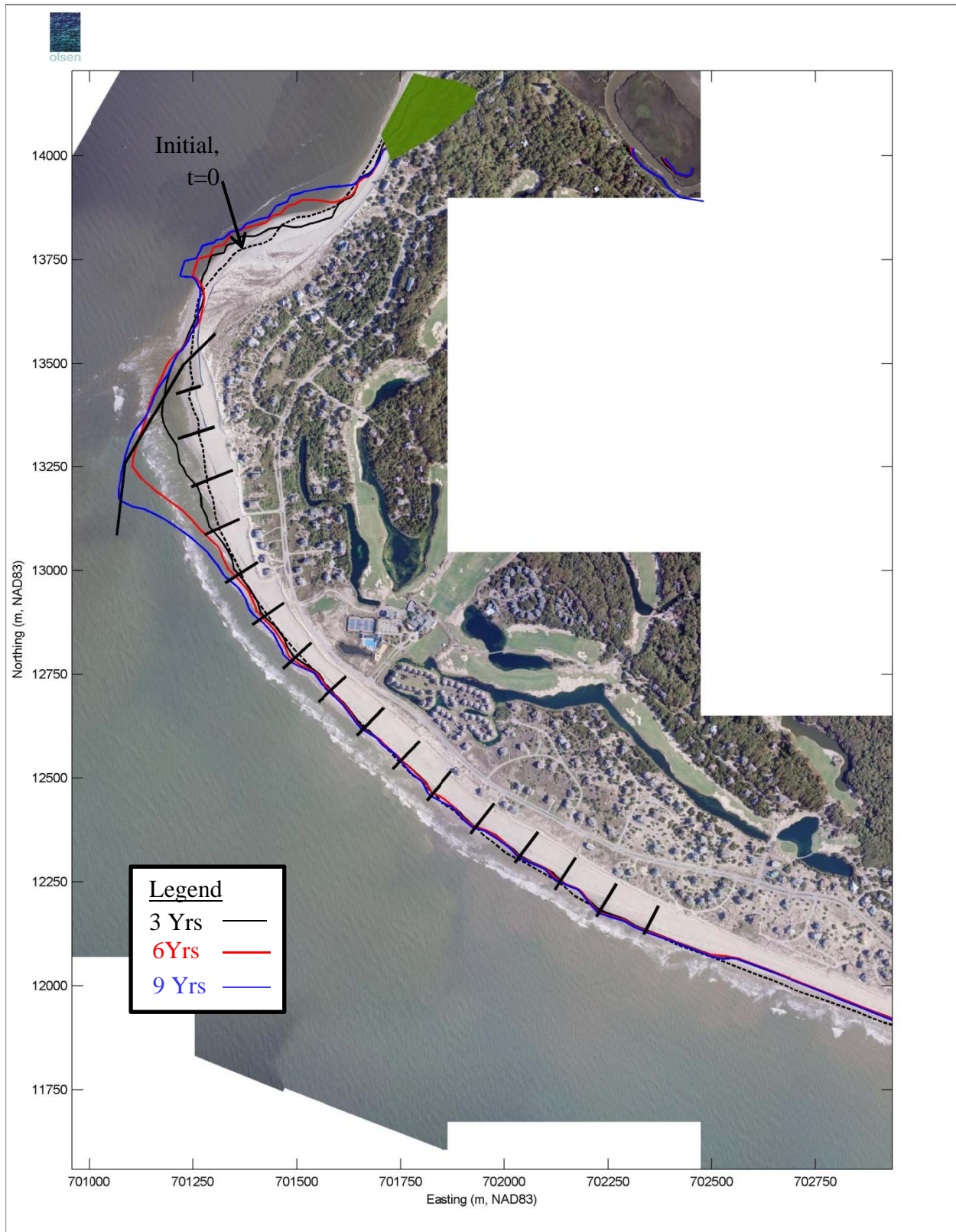


**Figure 8:** Bathymetry predicted throughout the simulation at years 3, 6, and 9 for a mid-length groin alternative. Each depicts conditions prior to the subsequent sand placement interval.





**Figure 9:** Approximate MLLW contour predicted at years 0, 3, 6, and 9 years for the Phase I groin scenario prior to the subsequent sand placement/dredge event.



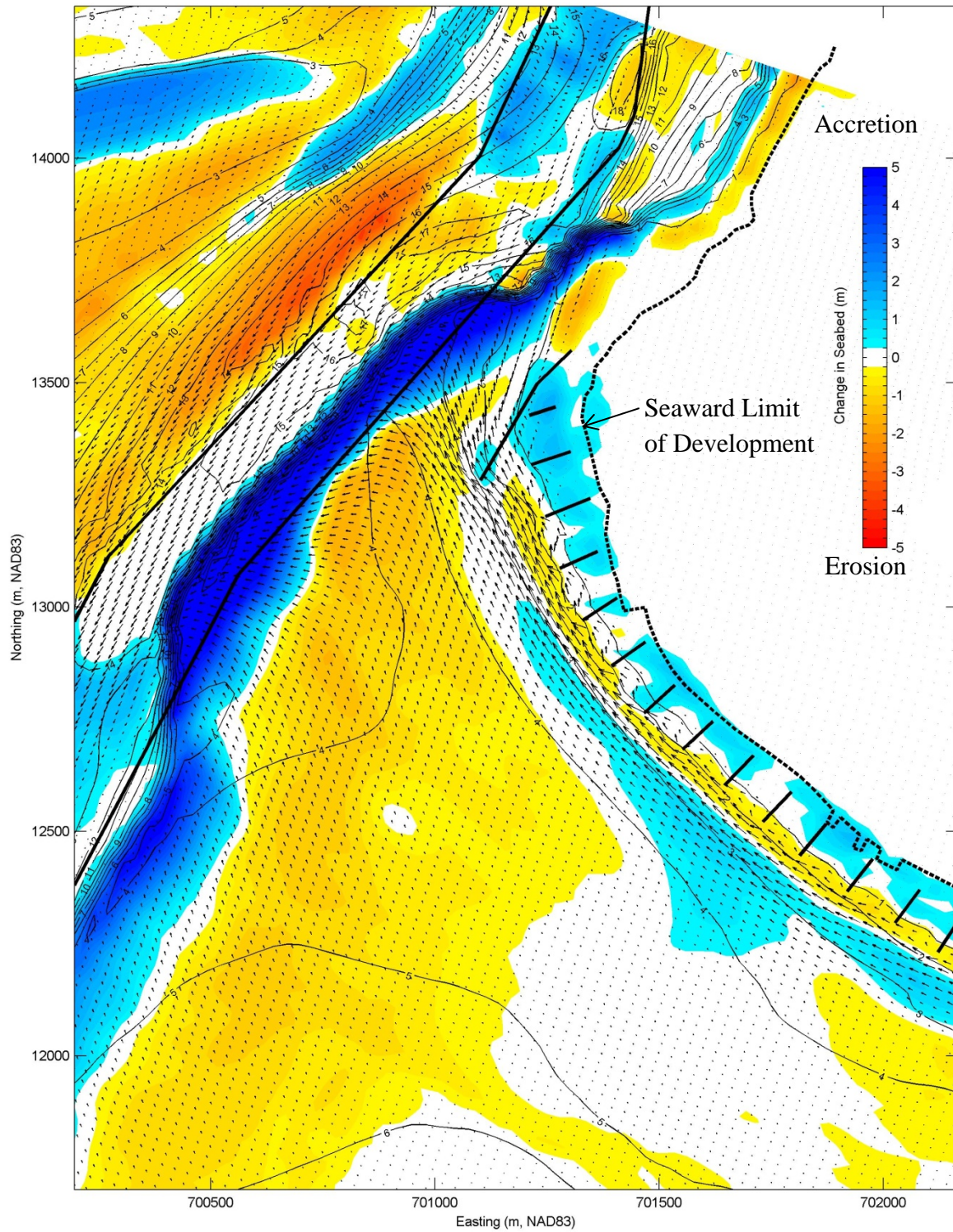
**Figure 10:** Approximate MLLW contour predicted at years 0, 3, 6, and 9 years for the Phase II groin scenario prior to the subsequent sand placement/dredge event.



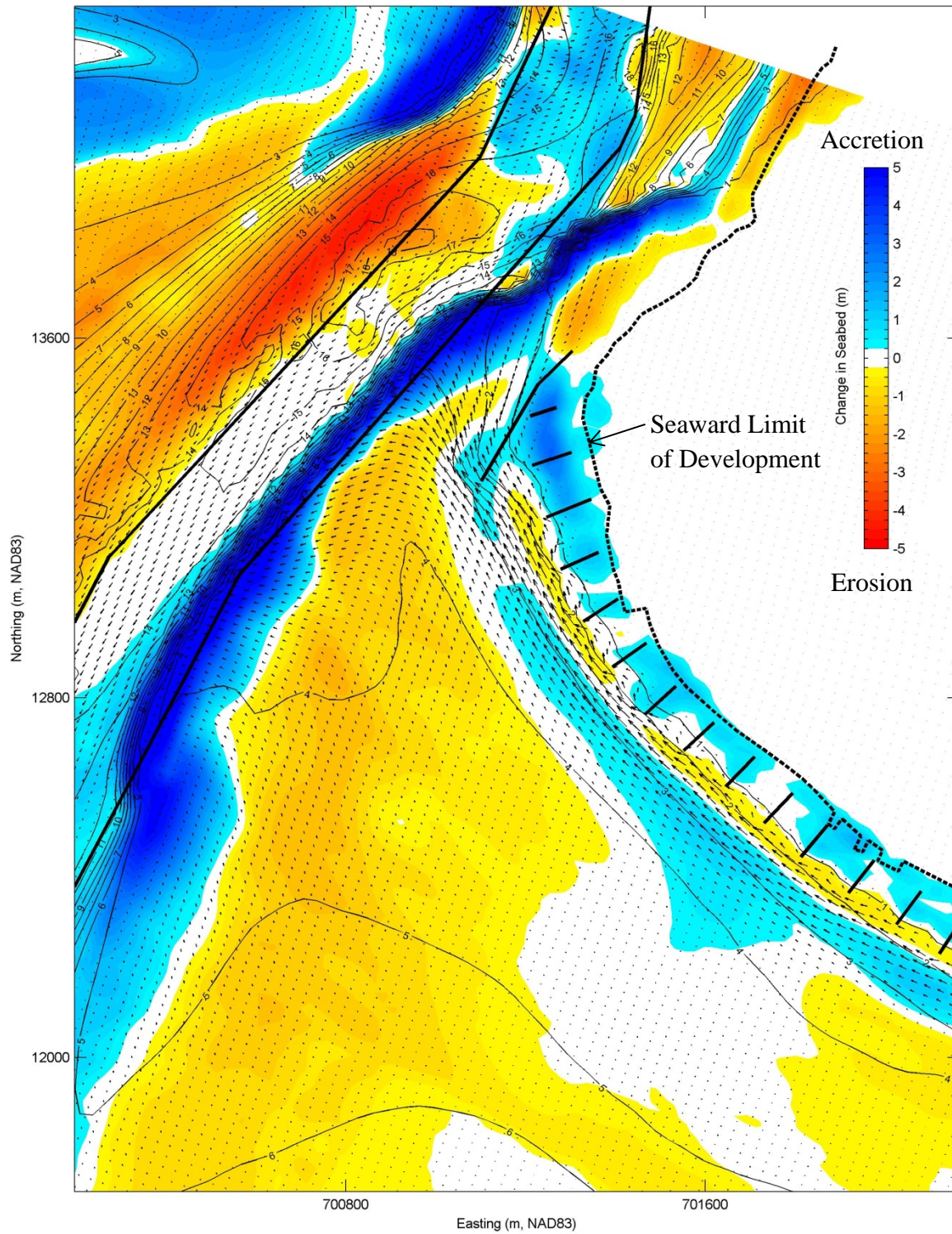
**Figure 11:** Comparison of MLLW predicted shoreline contours at year 9 for the Phase I and Phase II terminal groin scenarios.

**Figures 12** through **14** plot the predicted cumulative sedimentation and erosion patterns for the short terminal groin alternative after 3, 6, and 9 years, respectively. Red shading in the model indicates net erosion of the seabed while blue shading suggests net sedimentation. The approximate seaward limit of development is indicated by the black dashed line. The vectors represent the direction and scaled magnitude of mean total transport which is computed throughout the simulation. The effects of recurrent sand placement are included in these results.

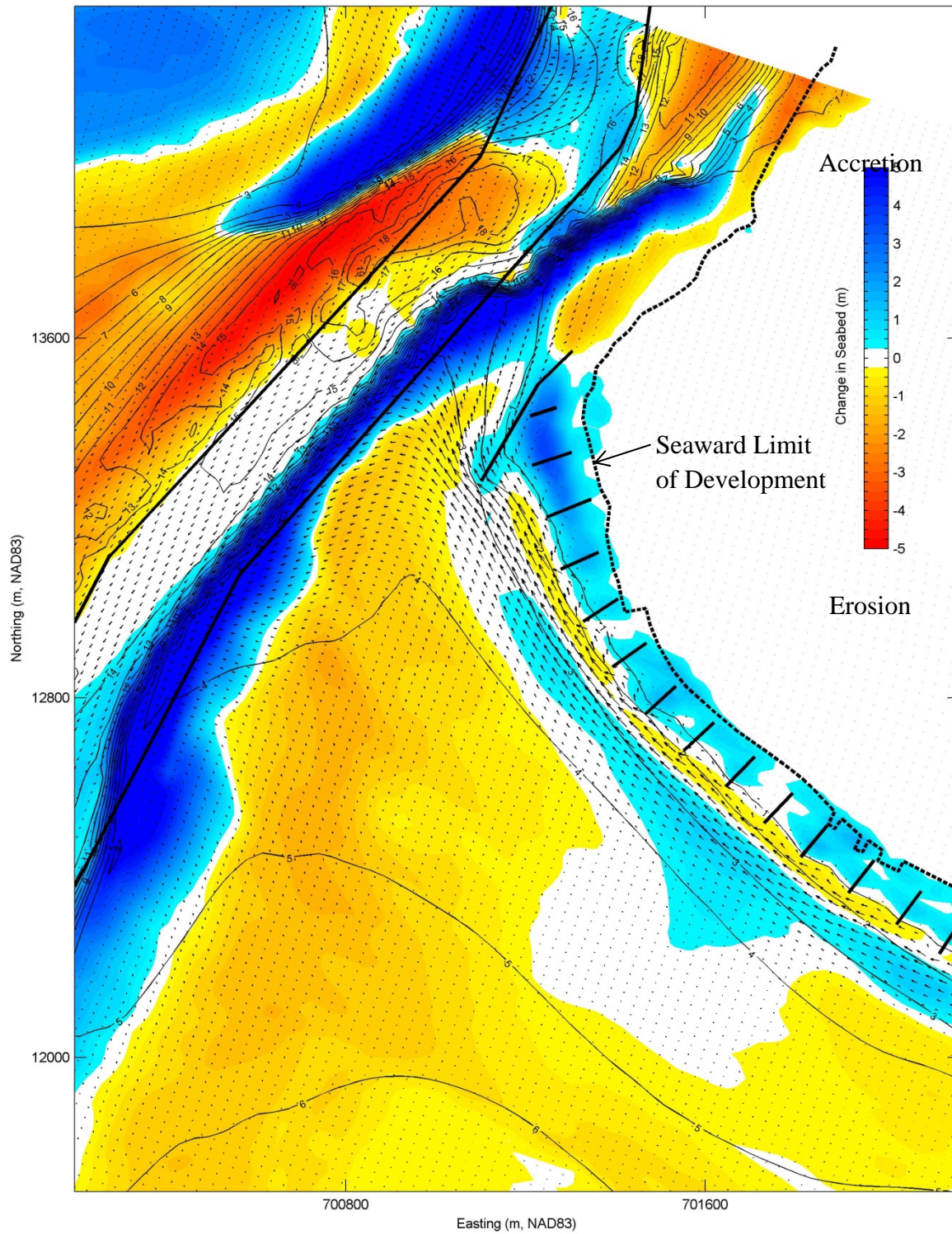
Similar to the predicted results for the Phase II terminal structure described under separate cover, the model suggests that the South Beach shoreline is effectively maintained by the combination of the Phase I terminal groin, existing tube groins, and periodic sand placement. North of the terminal groin, the model indicates the development of a largely submerged sand platform immediately adjacent to the Phase I terminal groin – owing to the transport of sand through, over, and around the structure. Net erosion along the Point and southern West Beach is indicated by the results and is manifest as a northward migration of the existing spit shoal. This erosion does not propagate into the limit of development after 9 years. Further north along West Beach (but away from the numerical boundary), the model predicts erosion which extends to the seaward limit of development after 9 years. This result is consistent with model predictions made for the simulation of existing conditions and does not appear to be induced by either the Phase I or Phase II terminal groins (Olsen, 2013). That said, the results predict a modest increase in erosion of the nearshore which is limited in scope resulting from the Phase I terminal groin. The northern model boundary behaves similarly to all other modeled conditions suggesting no causation between this alternative and the (likely grossly overestimated) erosion predicted there.



**Figure 12:** Cumulative sedimentation and erosion after 3 years for a short terminal groin alternative. The effects of repeated sand placement events are included in this result.



**Figure 13:** Cumulative sedimentation and erosion after 6 years for a short terminal groin alternative. The effects of repeated sand placement events are included in this result.



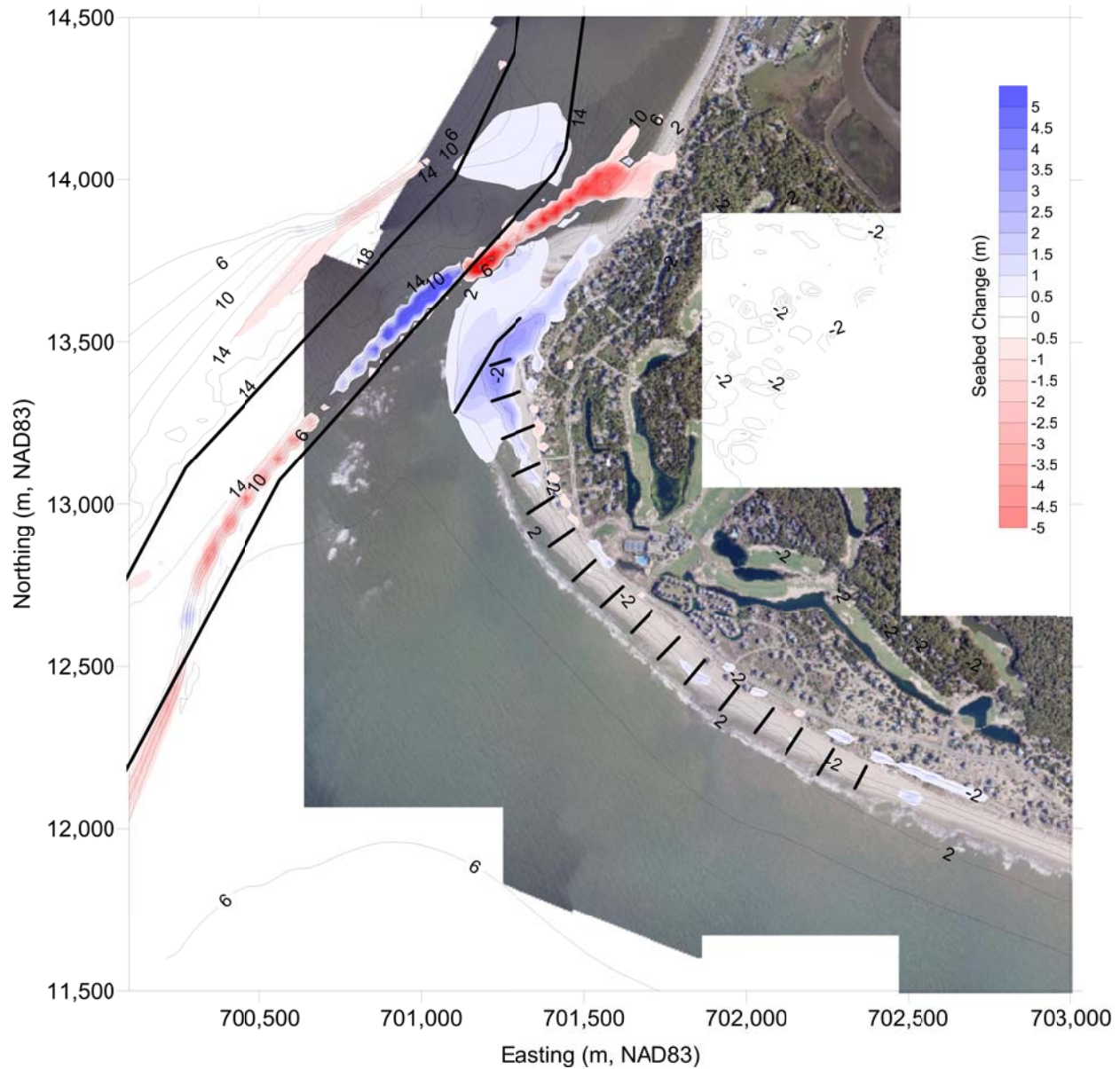
**Figure 14:** Cumulative sedimentation and erosion after 9 years for a short terminal groin alternative. The effects of repeated sand placement events are included in this result.

The Phase I terminal groin model results indicate continued post-construction accretion at the Point, particularly within the subaqueous and tidally influenced portions of this feature. The model suggests continued mild erosion along West Beach under this scenario (see **Figure 14**). In order to assess the predicted magnitude of downdrift changes attributable to the Phase I terminal groin alternative, the final predicted bathymetries for the Phase I terminal groin and sand-filled tube groin only (existing condition) were directly compared (differenced) and the results are plotted in **Figure 15**. Red shading in the figure indicates areas where the seabed is lower with the Phase I terminal groin while blue shading indicates areas where the seabed is higher with the Phase I terminal groin, relative to the sand-filled tube groin alternative.

The results of this comparative analysis reflect the prediction of a much improved Point condition particularly at the landward base of the terminal groin 9 years after construction of a Phase I terminal groin (blue shading) relative to a tube groin only alternative. The results also suggest relative volume losses which are attributable to the terminal groin along more northerly portions of West Beach principally associated with a reduction in the size of the shoal near the navigation channel (denoted by red shading). These losses represent reduced accretion or increased erosion relative to the results predicted for the tube groin only scenario. It does not appear that the Phase I terminal groin induces large scale downdrift erosion along West Beach.

Relative differences in volumetric changes between the Phase I terminal structure and sand-filled tube groin *only* condition (i.e., Alternative No. 3) west and north of the Phase I terminal groin were computed based on the results shown in **Figure 15**. Under the Phase I terminal groin scenario, the nearshore area north of the terminal groin (from the landward terminus of the groin northward) is predicted to experience a total relative *net volume increase* of about +1,785 cy through 9 years. This nearshore net difference is comprised of a gross gain of about +33,842 cy and a gross loss of about -32,057 cy, over the 9 year period. On an average annual basis, the predicted gross losses attributable to the Phase I terminal groin are about -3,600 cy/yr. Gross nearshore gains induced by the Phase I structure tend to align with accretion of the nearshore immediately north of the terminal groin along the Point. Gross nearshore losses induced by the Phase I terminal groin are realized along a narrow reach of northern West Beach and tend to align with an existing escarpment visible in the aerial photography. This volume computation does not include the losses seaward of the -3 or -4m contour as such volume change, interpreted as reduced accretion which is attributable to the Phase I terminal groin's predicted ability to arrest, or slow, the northward migration of the Point which would otherwise occur. Quantification of the predicted volume changes attributable to the Phase I terminal groin along West Beach suggest either little to no direct impacts or those which are mild in scope and mitigated for via the ongoing management of erosion along West Beach, plus an estimated additional 3,600 cy per year to offset the predicted gross effects of the Phase I terminal groin. For reference, the additional sediment requirement along West Beach following construction of the Phase II terminal groin was estimated to be about 5,200 cy/yr, on average (Olsen, 2013).





**Figure 15:** Difference in seabed elevation after 9 years between the Phase I terminal groin and sand-tube groin only (existing condition) scenario. Red shading in the figure indicates areas where the seabed is lower with the Phase I terminal groin while blue shading indicates areas where the seabed is higher with the Phase I terminal groin, relative to the sand-filled tube groin alternative.

Along South Beach, the comparison of the with Phase I terminal groin and sand-filled tube groin results suggests that the spatial extent of the shortened terminal groin’s impact is limited to an area extending about 400 meters east of the terminal groin (see **Figure 15**). The net effect is induced deposition owing to both the direct placement of sand and the groin’s ability to impound sand naturally transported from the east. Over the 9 year simulation, the periodic addition of 1.2Mcy in combination with the Phase I terminal groin and the existing sand-filled tube groin

field is predicted to be sufficient to provide stabilization of the western end of Bald Head Island, albeit at a reduced scale than that predicted for the Phase II terminal structure. Similar results were identified by modeling of the Phase II terminal groin. Simulations which do not include a terminal groin do *not* achieve this goal as the model predicts impacts to upland infrastructure due to erosion at and immediately west of the existing westernmost tube groin. Accordingly, the sand-tube groin field with fill only scenario (existing condition) is expected to require implementation of emergency measures in addition to the periodic deposition of 1.2 Mcy of sand in order to avoid property damage – similar in nature to what was required between 2010 and 2013, prior to the most recent federal beach disposal event (Spring 2013).

A cyclic renourishment volume of 1.2Mcy every three years represents a conservatively likely volume of material available from the navigation channel under the current SMP – typically there is 1.5 to 1.8 Mcy available. However, the current SMP requires that Bald Head Island receive no sand every third renourishment. This requires the Village to supplement the entire volume with supplementary sediment from an alternate borrow source.

In summary, the Delft3D model was used to simulate 9 years of morphological change following construction of a semi-permeable Phase I terminal groin at the west end of Bald Head Island. The modeled Phase I terminal structure measures about 1,300 feet long and represents the potential initial construction phase of the Phase II terminal groin which is about 1,800 feet long in the model. Both structures are identical in location and model characteristics excepting overall length. The existing sand-filled tube groins were included in the model in their current locations. Periodic sand placement on South Beach was prescribed to occur at years 0, 3, and 6 concurrent with maintenance of the federal channel. Sand volume was held constant at 1.2 Mcy and placed between Station 44+25 near the terminal groin and Station 156+00. The initial beach and channel conditions were representative of those measured in the spring of 2011. The first dredge/disposal event is simulated to occur immediately after the model's initiation (at time zero).

The model results indicate the Phase I terminal groin in combination with the existing sand-filled tube groins and recurrent sand placement is sufficient to maintain the South Beach and Point shorelines through the 9 year simulation, thereby fulfilling its design objective in a manner similar to the Phase II structure. Upland development located more than 350-400 meters east of the terminal groin would continue to depend on the existing soft armoring for protection from erosion. Construction of the Phase II terminal groin is expected to provide a direct benefit which extends further east an additional 200 to 250 meters.

The present depth-averaged model suggests continued northward migration of material passing through the Phase I terminal groin which is deposited as a predominantly subaqueous platform immediately adjacent to, and slightly north of, the terminal groin. Further, a spit shoal north of

the terminal groin is expected to continue to provide a near-term, post-construction Point feature -- in contrast to comparative non-terminal groin scenarios which result in the predicted erosion of such a Point at the west end of the island. The model predicts continued erosion along West Beach which is generally consistent in spatial area to that indicated by simulation of scenarios containing only sand-filled tube groins (existing conditions). Erosion along West Beach is expected to continue as a maintenance issue rather than a significant project-related impact. Specifically, the Phase I terminal groin is expected to require a maintenance volume of about 3,600 cy per year in addition to that presently provided by episodic renourishment events.

It is anticipated that the post-construction performance of the Phase I terminal structure would be monitored with respect to its ability to (a) facilitate sand bypassing to the downdrift shoreline, (b) reduce the rate of sand loss from South Beach, and (c) maintain an updrift fillet, and to assess the alongshore extent of benefits derived therefrom. The timing and extent of the Phase II construction would benefit from the guidance provided by the Phase I monitoring program. It is reasonable to assume that the minimum time required to adequately assess the performance of the Phase I structure would be one to two channel-dredging and beach disposal cycles (approximately 2 to 4 years). Additionally, the implementation of a Phase I structure would reduce the amount of time that beachfront construction operations would extend beyond the typical 1 May Moratorium date. Depending upon shoreline conditions at the time, it is likely that any Phase II extension contract activities may potentially be scheduled to better coincide with construction outside of the Moratorium window.

Both the Phase I and Phase II terminal groin lengths continue to necessitate the maintenance of the existing sand tube groinfield located eastward of the new structure. Ultimately, however, any sand tube groins considered by the Village to be non-essential or counter-productive to terminal groin performance would be removed or modified. A decision in this regard would be based upon the results of shoreline monitoring.

A post-construction monitoring program for the Phase I structure would consist of biannual surveys intended to specifically quantify fillet volume, spit or platform formations associated with sand bypassing, and the condition of immediate updrift and downdrift shorelines. In order to facilitate the effort, only minor modifications to the Village's existing comprehensive shoreline monitoring program would be required. More specifically, these modifications would include additional survey lines in the vicinity of the groin structure, the fillet, and the downdrift shoreline. The existing biannual controlled aerial photography program would be continued; however, interim (quarterly) oblique photography would be acquired for purposes of high-frequency qualitative assessments of shoreline conditions.

Any decision as to when and how far to extend the Phase I structure would be closely coordinated with both State and Federal regulatory staff. In no event, however, would the groin

be extended beyond its full 1,900 ft permitted length. A Notice-to-Proceed (NTP) for a Phase II extension would be given by the Village for purposes of notification to all affected agencies, stakeholders and navigational interests.

*References Cited*

Olsen (2012). "Calibration of a Delft3D model for Bald Head Island and the Cape Fear River Entrance Phase I." Prepared for Village of Bald Head Island. Prepared by Olsen Associates, Inc. 2618 Hershel Street, Jacksonville, FL 32204. April 2012.

Olsen (2013). "Shoreline Stabilization Analysis. Bald Head Island, N.C." Prepared for Village of Bald Head Island. Prepared by Olsen Associates, Inc. 2618 Herschel Street. Jacksonville, FL 32204, July 2013.