NEW BEACH DESIGNS AS URBAN ADAPTATION TO SEA LEVEL RISE

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1 ABSTRACT

Recreational beaches and beaches that protect against storms are regularly replenished with offshore sand. As rates of relative sea level rise increase, sandy beaches are likely to erode faster. Adaptation strategies that maintain these beaches will become increasingly critical in this context.

For this study, we reviewed recent design prototypes for urban beaches that use an innovative Dutch beach replenishment strategy known as "mega-nourishment," in which very large amounts of sand are placed every 20 years, rather than smaller amounts every 1-5 years. Waves and wind re-distribute the sand along the shore, with fewer bulldozers and pressurized slurry pipes. Mega-nourishment may also offer habitat benefits, creating large sandy beaches that lie relatively undisturbed for decades. These beaches also provide a different range of aesthetic and recreational experiences than the typical tourist beach.

Our approach was to examine present conditions and future trends at Virginia Beach, Virginia, a region of historic significance with one of the fastest rates of relative sea level rise in the U.S. We generated simple sand delta and spit forms at multiple scales and compared them according to specific performance criteria and the Coastal Evolution Model (CEM). Certain forms are more likely to perform well, but all of the prototypes involve some novel aesthetic experiences that are not common on linear beaches. We gathered local feedback about the desirability of this adaptation strategy, and found mixed reactions to the aesthetic implications but strong interest in the cost savings and ecological benefits. With greater involvement by designers, this adaptation strategy might find more rapid acceptance.

1.1 Keywords

urban design, beach nourishment, coastal ecology, community planning, aesthetic experience, climate change, urban adaptation, sea level rise

2 SANDY BEACHES

2.1 Coastal Erosion and Beach Nourishment

Sandy beaches play a critical role in protecting coastal communities from storm damage. Yet beaches are dynamic zones that often erode due to many factors, including changes in sea level, wave action and human alterations of the coastline (Charlier et al., 2005; USACOE, 2007). With the loss and alteration of natural sources of sand, coastal erosion on sandy beaches is occurring at a faster rate than accretion (Hapke et al., 2010). In order to retain their important functions, beach sands are periodically replenished, effectively building the beach berm seaward (USACOE, 2007). Sand is dredged from offshore sources and placed on the beach annually or semi-annually via dredge boats and pipelines, using trucks and bulldozers onshore (USACOE, 2007). Projections for increased erosion rates with global climate change (Hapke et al., 2010), as well as the reduced local and federal budgets for large public works projects such as beach nourishment, make it ever more important that coastal communities consider strategies that will maintain the ecological, recreational and storm protection benefits of sandy beaches in the future.

Coastal erosion also results in losses of coastal habitat. While most nourished beaches experience heavy recreational and seasonal use and often do not support unusual species, nourishment sands will eventually erode and be distributed through wave and wind action to other areas of the coast, including on-shore dunes. This can be a benefit for areas farther from the nourished beach resorts that receive sand. However, the standard process of nourishing a beach disrupts both the on-shore and off-shore habitats by using heavy machinery to add and distribute new layers of sand (Hayden and Dolan, 1974; Petersen and Bishop, 2005; Fenster et al., 2006). As a result, legal protection of certain endangered and threatened species often partially determines the permitted locations for dredge-sand sources and the schedule of beach nourishment, in order to protect nesting and migration areas.

Beach nourishment also maintains the aesthetic and recreational value of the coastal landscape (USACE, 2004). Sandy beaches play a central role in the tourist economies of coastal areas (City of Virginia Beach, 2002; Yochum and Agarwal, 2009). Additionally, coastal real estate has high value as a source of tax revenue (City of Virginia Beach, 2002). Both public and privately-owned structures are often affected by changes in sand movement. Sewer outfalls may require sand to be cleared if it interferes with discharge. Private boat docks, marinas and fishing piers may be made unusable if sand accumulates around them. While beaches with shoals of sand located below the low tide line may function as storm protection, they do not provide recreational space for water-oriented recreational events and sunbathing (Leonard et al., 1990).

Municipalities and US tax-payers already pay millions of dollars annually for these benefits. A formula is currently used that distributes the cost between local and federal governments, in which the federal government typically contributes 65% of the cost with a 35% local contribution, and beach nourishment projects are managed by the United States Army Corps of Engineers (USACE, 2007). In general, costs are reduced when the sand source is closer to the beach, dredged sand is placed in the near-shore zone with a so-called “rainbowing” or “side-casting” dredge boat, when a greater proportion of sand is placed in deeper water zones, and when the fleet of dredge boats on the East Coast is less busy (Philip Roehrs, pers. comm.).

3 EXAMINING ALTERNATIVE STRATEGIES

Recently, Dutch engineers and planners have begun to experiment with “mega-nourishment” as a new strategy for sustaining critical beaches and dunes. A very large quantity of sand is added to a sandy beach, and a longer time interval is established between nourishment events, in contrast to the typical practice of annual or semi-annual nourishments (Aarninkhof et al., 2010). The Zandmotor (“Sand Engine”) was built between the cities of The Hague and Rotterdam in 2011-2012, led by the coastal management authority (Rijkswaterstaat, 2013). A much larger quantity of sand (about 28 million CY) was used to nourish the beach with the understanding that additional nourishment would not be required for 10-15 years. The sand was placed in the shape of a hook that protrudes from the existing coastline and extends into the ocean. The key innovation was that cost is reduced by placing a much larger percentage of the sand in deeper water, allowing future accretion of sand on the coastline to occur via wave action and wind alone.

Several positive outcomes already observed from the Sand Engine suggest that this method can be applied successfully in places where large quantities of dredged sand are available, such as the Mid-Atlantic, the Southeastern coast of the United States, and the San Francisco Bay. The cost of the Dutch Sand Engine was approximately 25% the price of traditional beach nourishment for the same length of coastline (Nico Bootsma, Project Manager, Rijkswaterstaat. Pers. comm.). Dutch coastal managers have also observed plants and animals returning that were long absent from this area of the coast, and believe that the placement of sand by natural processes of wind and waves, as well as the longer time interval before re-nourishment, support the return and establishment of coastal organisms (Nico Bootsma, pers. comm.). Wind surfers, kite surfers and board surfers have all found that the Sand Engine produces exceptional conditions for their sports, in comparison to a linear beach. In short, the design of the Sand Engine imitates and makes use of natural processes to reduce the cost of achieving the multiple goals of storm protection, ecological diversity, recreational potential and varied aesthetic experience.

3.1 The Sand Engine and Virginia Beach: Comparison of Conditions

We identified Virginia Beach, Virginia as a city where the need for regular beach nourishment, presence of a strong recreational and tourism economy, and continued problems from coastal storm damage might warrant a new approach. Sand transport dynamics and coastal geomorphology set many of the parameters for construction in both standard beach nourishment projects and for mega-nourishment. We compared these variables to understand whether the Dutch model could be applied to this Virginia site and found the geological and climatic conditions to be reasonably similar. Typically, wave energy in the Dutch condition is higher, moving more than twice as much sand along the coast (Aarninkhof et al., 2010; Hapke et al., 2010). This means that sand would probably be transported more slowly in Virginia Beach unless a major storm occurs.

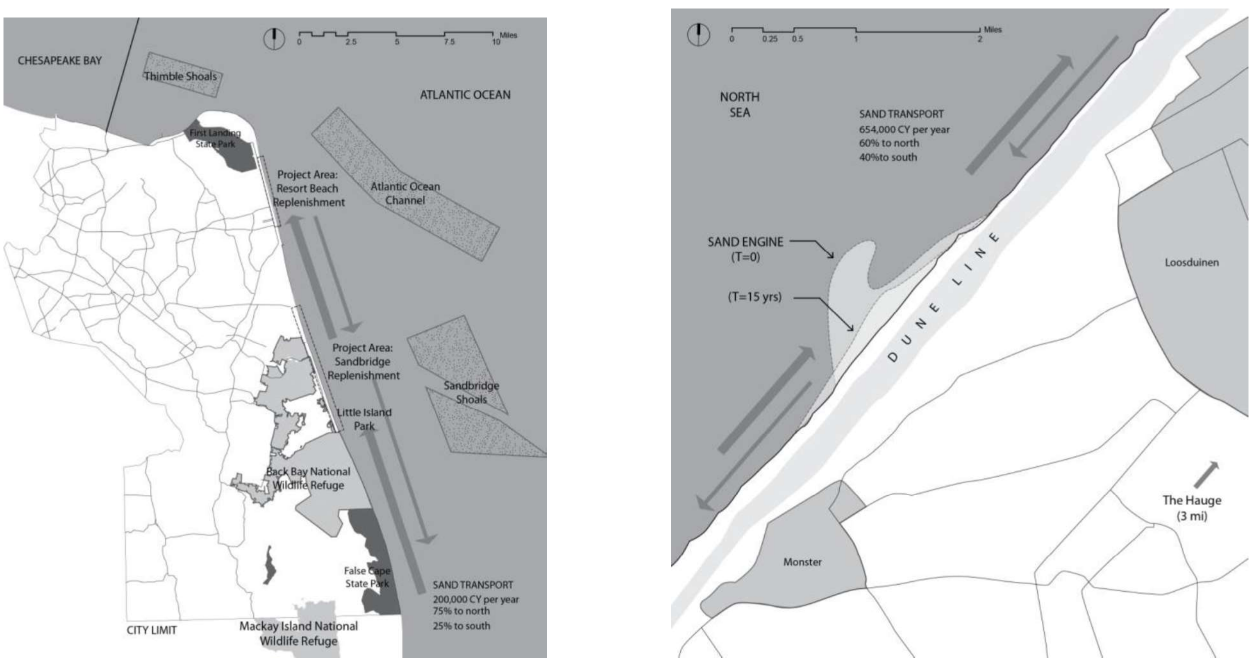


Figure 1. Context maps of Virginia Beach, VA (left) and Ter Heijde, Netherlands (right)

The development conditions are very different, however (see Figure 1). Virginia Beach has a highly urbanized shoreline with large hotels, businesses and private homes that face directly onto the Atlantic Ocean. In contrast, the coastline adjacent to the Dutch Sand Engine is largely undeveloped, with small towns located several kilometers inland. While both beaches are used for recreational purposes, the scale of the recreational and tourism industry in the Virginia Beach area is considerably greater. Infrastructure present at the sites also differs; Virginia Beach has a privately-owned fishing pier, a marina entrance that is dredged for boat access, several municipal storm water outfalls that extend up to 2000 ft. into the ocean, and a 13.5' tall concrete sea wall which has been incorporated into a concrete boardwalk (USACE, 2006). In contrast, the Sand Engine site has no piers, sewage outfalls, or seawalls, and is backed by a 35-foot high line of sand dunes rather than a seawall. A drinking water supply area lies beyond the dunes.

Since its construction in 2011, engineers have carefully mapped the surrounding currents and erosion of the Sand Engine, as well as accretion in adjacent locations. The only unexpected problem to arise has been an impact on the water table, which could have resulted in contamination of ground water by a nearby landfill. Recovery wells were installed to address the issue before contamination occurred (Nico Bootsma, pers. comm.). This is not expected to be an issue in Virginia Beach given the presence of a pumping system under the sea wall that can mitigate changes in ground water levels (USACE, 2006). The presence of a well-established dune line on the Dutch coast, rather than the sea wall present in the Virginia Beach area, is also significant since dunes constitute important buffers of wave energy in storms, and are also protected as part of coastal habitat. Elected officials and business leaders in Virginia Beach supported the use of a seawall instead of dunes because it allowed beachfront businesses to maintain valuable views of the water's edge, instead of having those views blocked by dunes (Philip Roehrs, pers. comm.).

3.2 Potential for a Sand Engine at Virginia Beach

We explored two primary forms for a feeder beach or Sand Engine in Virginia Beach: a sand spit or "groyne," and a sand delta (see Figure 2). We selected these basic forms because we believe they would be (1) relatively easy to construct, (2) would create zones of reduced wave energy with habitat and recreational benefits, and (3) could allow the placement of a relatively large proportion of sand in deeper water, reducing costs. We explored introducing different numbers of these forms as well as different sizes in order to examine their implications for cost, recreation, ecological value, and storm protection (see Table 1).

Table 1. Initial Conditions (comparison of forms in situ, using estimated values)

Criteria	SD1 L	SD3 M	SS1 L	SS3 M
Estimated area above MHW high tide (acres)	90	80	105	60
Estimated total sand volume (CY)	1,863,673.00	1,317,842.00	1,034,668.00	1,583,295.00
Est. CY in 0-10ft depth	376,003.00	57,033.00	114,066.00	28,516.00
Est. CY in 10-20ft depth	1,191,839.00	1,260,809.00	496,047.00	938,720.00
Est. CY in >20ft depth	295,830.00	0.00	424,555.00	616,058.00
Estimated cost (0-10ft $13/CY, 10-20ft $8/CY, >20ft $3/CY)	$15,310,254.00	$10,827,905.00	$6,724,904.00	$9,728,654.00
Estimated cost per CY	$8.22	$8.22	$6.50	$6.14
Ease of construction (= small number of pipe discharge locations, high % sand placed in deep water)	High	High	Medium	Medium
Evenness of storm mitigation on day 1	Low	High	Low	High
Evacuation route protection on day 1	Low	High	Low	High
Added shoreline day 1 (LF)	5550 LF	10200 LF	5580 LF	11800 LF

(SD=sand delta, SS=sand spit) (L=large, M=med.)

Figure 2. Visualization of a mega-nourishment in the Virginia Beach Resort area, used in stakeholder meetings to communicate research intent and implications (diagram by M. Geffel).

We used two methods to assess the potential of these forms. In the first, we estimated the predicted performance of these different design strategies across a set of evaluation criteria that we developed after a review of the literature (see Tables 1 and 2). In the second, we applied a known predictive model, the Coastal Evolution Model (CEM), to the proposed forms in order to more rigorously project the shoreline patterns that might develop over time, given the specific parameters of sand transport in the region (see Figure 3).

Table 2. Model Analysis (Comparison among outcomes, 1= most, 4=least)

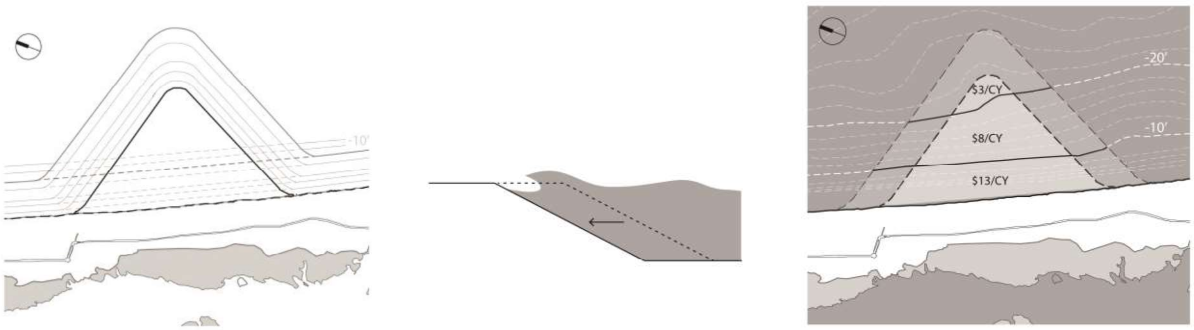
Criteria	SD1 L	SD3 M	SS1 L	SS3 M
A. Ecological productivity (LF shoreline with reduced wave energy, day 1)	2	4	1	3
B. Risk of shoaling	1	3	2	4
C. Speed with which the shoreline thickens by accretion	3	1	2	1

(SD = sand delta, SS = sand spit, 1 or 3 = number of features, L=large, M=med.)

3.3 Modeling Coastal Change Over Time

Predicting the change over time of mega-nourishment landscape interventions like the Sand Engine is a complex task that requires specialized knowledge from the sciences. Morphodynamic modeling has been used over the last five years to test the effect of human interventions on coastal morphology (Slott, 2010). One useful modeling approach for predicting both natural and anthropogenic morphodynamic change at large temporal and spatial scales is known as a "one-contour-line model." This approach assumes that the cross-shore beach profile remains constant over time. Since the Sand Engine is a large intervention intended to erode over many years, we used the Coastal Evolution Model (CEM)—a one-contour-line model—to explore potential changes in form of different Sand Engine plan-view shapes as waves and wind transport of sand alter these shapes.

CEM models gradients in the alongshore sediment transport flux, which are the primary driver of change in shoreline position. As waves approach the shore and move into shallow water, bottom influences begin to affect wave movement. Wave velocity decreases when the seabed begins to interfere with the wave motion. When waves approach the shore at oblique angles, the portion of the wave crest overlying shallow water moves slower than the portion over a greater depth. It is this refraction of the wave as it enters the shallow nearshore that causes energy to be transferred in the alongshore direction. This energy produces a current parallel to the shore that is responsible for the transport of sediment along a coast. Perturbations in the coastline generate gradients in the alongshore sediment flux, leading to changing patterns of erosion and accretion. The magnitude of this flux is predominantly determined by the size of the breaking waves and the wave approach angle. Angles of 45° or greater between the deep-water wave crest and the shoreline orientation maximize alongshore sediment transport.



(a) **(b)** **(c)**

Figure 3. (a) The Coastal Evolution Model (CEM) assumes effective shore-parallel contours over long timescales. (b) The shape of the cross-shore profile does not change in a one-contour-line model, it shifts landward with erosion or seaward with accretion. (c) The need for more dredge placement equipment drives up costs in shallower water.

CEM is an exploratory model intended to examine how wave climate and alongshore sediment transport instabilities influence shoreline evolution (see the example in Figure 4). The model assumes coasts are comprised of mobile and sandy sediments, and is designed for spatial scales on the order of hundreds of meters and temporal scales of years to centuries (Ashton, 2001; Ashton, 2006). The model is simplified to consider gradients in alongshore sediment flux and ignore smaller scale processes that may also influence the shoreline. The inputs for CEM include a digital representation of a shoreline and information about the magnitude and approach angle of waves relative to shore. In our modeling experiment, we used a 2010 Median High Water shoreline, generated by the NOAA National Coastal Data center, as an initial condition (NOAA).

This initial line was modified to represent four proposed plan-view form alternatives for a Sandbridge Sand Engine: one 356,900 m^2 delta, three 140,800 m^2 deltas, a 165,240 m^2 sand spit, and three 80,800 m^2 sand spits (see Figure 5). We used a wave climate generated from a series of wave roses developed from modeling studies and fieldwork (Maa and Hobbs, 1998; Komar and Allen, 2008; USACOE, 2012). The key wave parameters are an asymmetry value representing wave angle direction, and an angle parameter representing the proportion of high-angle waves influencing the shore.

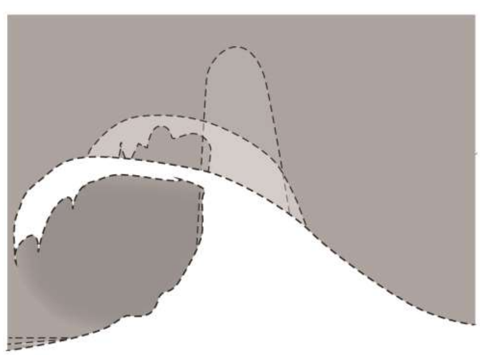


Figure 4. The incoming wave distribution creates a flying spit and embayment configuration. The simple sand spit was the initial shape, and a flying spit (curving spit) develops over time.

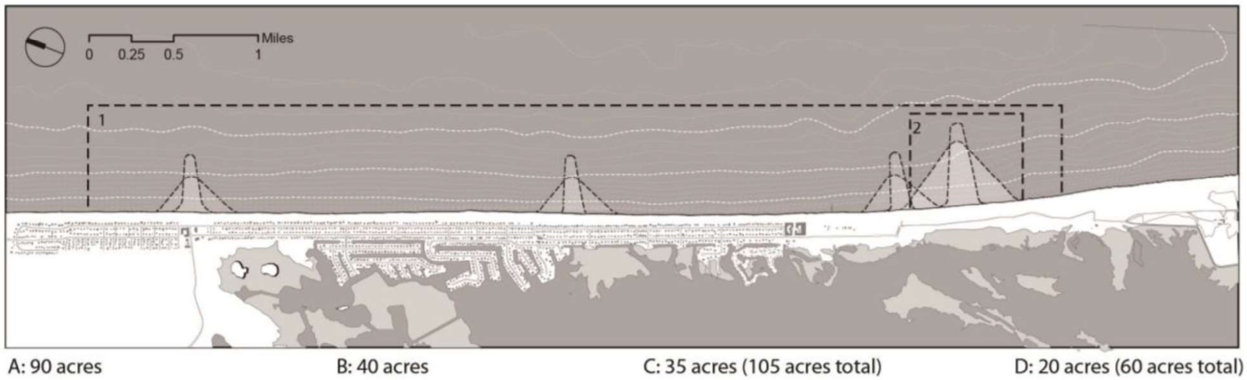


Figure 5. Sand spit and sand delta design alternatives in Sandbridge, VA, relative to existing structures and roads. Box 1 shows the placement of 3 smaller spits or deltas, and Box 2 shows the placement of a single large spit or delta. The City of Virginia Beach is to the north (left) in this map.

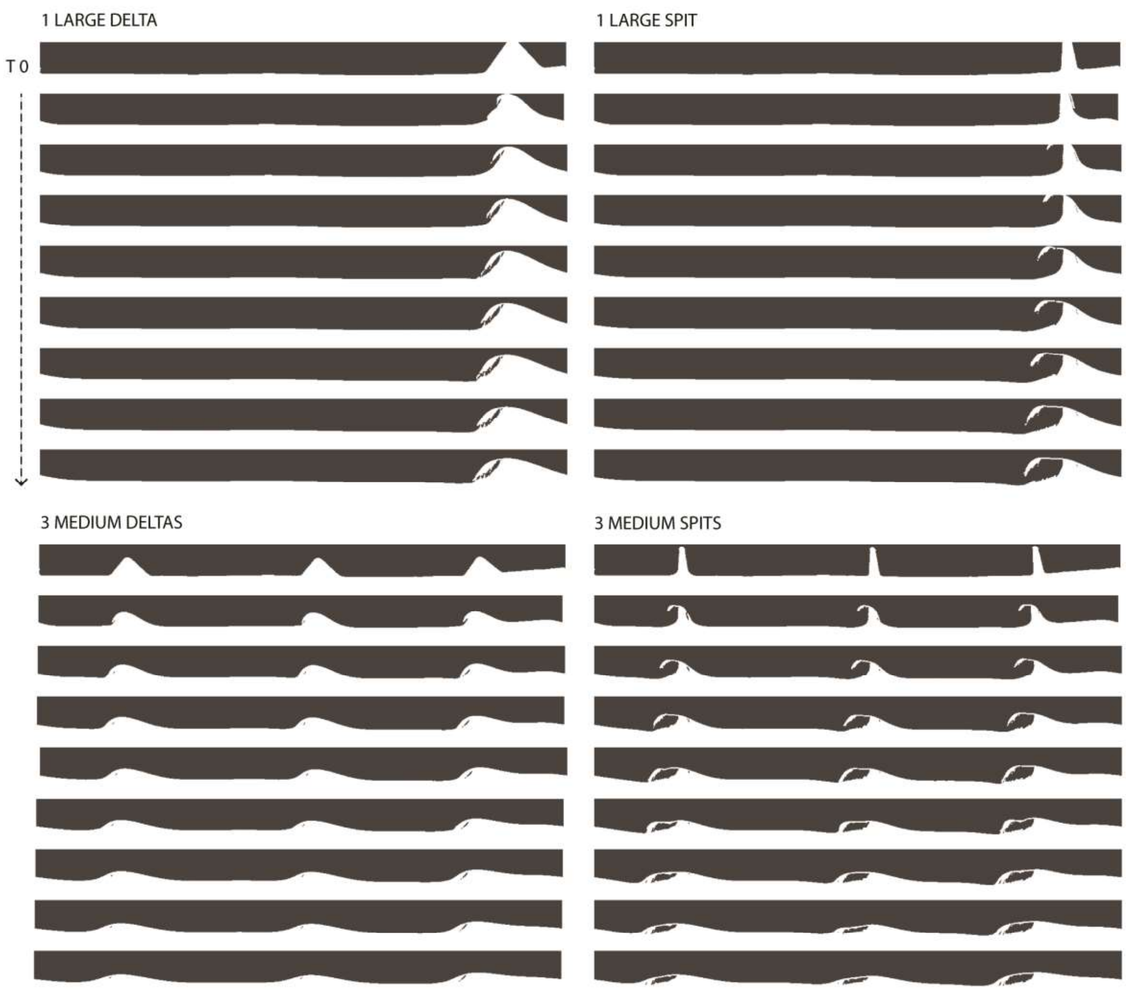


Figure 6. Model results for various geometries (1 sand delta or sand spit; 3 deltas or sand spits) are compared qualitatively between runs with similar wave distribution and wave intensity.

Map resolution was a challenge in using CEM. In order to differentiate among the geometries of our interventions, we needed to model these modified shorelines using a 10 m grid. The CEM was developed to model geometries using a 100 m or larger grid, and simulates deep-water waves assuming shore-parallel contours (Ashton, 2006). At a 10 m scale, nearshore bathymetric complexities would influence wave propagation. To achieve model stability with the higher resolution grid, we scaled-down the magnitude of the wave climate used in the model based on the historical wave data. Therefore, we chose to use a wave height of 0.1 m, an order of magnitude smaller than the mean significant wave height of 0.7-1.2 m typically noted in the area (USACOE, 2009; Fenster and Dolan, 1999; Basco, 1999; Dolan, 1988). CEM is not meant as a quantitative tool for shoreline engineering; model output is intended to display shifts in overall shoreline morphology. By comparing across our series of modeling experiments, the results provide some interesting clues as to how different plan-view Sand Engine geometries would change over time under our site's historical wave climate (see Figure 6).

The most important goal of mega-nourishment is that the sand ultimately thickens the shoreline. Both of the singular, large forms exhibited the formation of a sandbar-like flying spit near the seaward tip. This formation has the potential to isolate nourishment sand offshore, preventing the full amount of nourishment sand from thickening the beach. On the other hand, the complex shapes resulting from these flying spits create an intricate network of small-scale crescentic forms that suggest potential habitats for common species such as mole crabs that are a valuable food source for less-common shorebirds (Bowman and Dolan, 1985). The complexity and instability of these forms over time could also provide significant visual interest for beach tourists and residents. By contrast, when sand is distributed in multiple small forms, the sand is predicted to merge more quickly with the existing beach. Multiple small deltas did not develop a flying spit like the large delta. Multiple spits produced multiple smaller flying spits.

In this model output, the forms also produced changes in adjacent shorelines. For example, in timesteps 1-5 of the large delta and the spit, sediment is lost from the shoreline immediately north of the spit. This sediment loss reverses later as the sand mass ultimately begins to merge with the coast (Figure 6).

These plan-view diagrams provide a compelling way to frame ideas about change over time on coasts by linking the spatial patterns of proposed interventions directly to mathematical equations that represent significant shoreline processes. Iterative modification and testing of designs with CEM and/or other morphodynamic modeling packages will help designers achieve proposals that meet key spatial and programmatic criteria while working with natural coastal erosion and accretion processes.

3.4 Local responses

We discussed the proposal for a mega-nourishment project in the Virginia Beach area with a number of local stakeholders. A single meeting was held with most groups, except the City of Virginia Beach staff, with whom we met twice. Meetings were held with coastal engineers and public works officials for the city of Virginia Beach (8 stakeholders), hotel owners in the Virginia Beach resort district (2 hotel representatives active in local affairs), members of the Sandbridge VA Civic league and Beaches and Waterways commission (4 members of the League), and biologists at the USFWS Back Bay Wildlife Refuge (2 staff members). No tourists were included, but their needs were referred to by the hotel stakeholders. We chose this set of stakeholders because we were interested in the reactions of a group that we believe has historically had the greatest influence on beach management decisions in this region.

The concept of an alternative beach nourishment approach that could reduce costs and increase ecological and recreational value of the resort beaches was well-received by these stakeholders. The potential cost savings per cubic yard of sand, and longer interval of protection before new nourishment is required was of interest to city officials. However, they commented that they would most likely continue to support the existing practice of more regular, linear nourishment until there was stronger pressure from regulatory agencies or budget constraints to find other ways of replenishing the beach.

Hotel owners and city officials also expressed concern that visitors to the area would be put off by an unconventional shoreline, and that the politics of deciding where initial sand placement would create the benefits of beach nourishment soonest would be highly contested. Since the shoreline created by a wave-based mega-nourishment project would vary in width, local business owners also expressed skepticism that tourists would be willing to walk a greater distance to reach the water. However, the wider beach created with mega-nourishment, and the potential to extend the recreation season for surfing sports by creating a new point break with a spit or delta form, could expand the tourism economy in new ways.

The issue of equity was also noted by several local officials and business owners, since the properties located near the mega-nourishment would receive storm protection and recreational benefits as soon as it was in place, while several years would pass before other properties would experience the accretion of nourishment sands on their part of the shoreline. Some might even experience erosion before accretion.

Biologists at the USFWS Back Bay Wildlife Refuge expressed interest in a method of nourishment that might support vulnerable elements of the local coastal ecosystems. Species such as the sea turtle and piping plover are of interest to many coastal residents, and all parties we spoke with expressed strong support for beach nourishment that could more effectively support coastal habitat. Although the net movement of sand in the Virginia Beach area is to the north, 25% of the sand is understood to move south. Staff at the Back Bay Wildlife Refuge to the south have observed accretion on the refuge coastline following nourishment at the resort area. Beach nourishment to the north could therefore add to coastal habitat within the refuge, where direct beach nourishment is prohibited by federal policies.

The primary concern expressed by all stakeholders was that of cost. In the mega-nourishment approach, the initial cost of nourishment is greater because a larger quantity of sand is moved. However the cost per cubic yard of sand, based on both the Dutch example and on inquiries to American dredging companies, would be lower, and the time interval before the beach would be nourished again would be longer. Despite these longer term cost savings, persuading municipalities to make the investment in mega-nourishment would be a challenge. City officials and local business owners responded favorably to the suggestion of a smaller scale pilot project that could introduce the practice of mega-nourishment to the area, and which could be scaled to a size that would be effective for testing its storm protection value. Additionally, their position was that a smaller scale pilot would lay the administrative and logistical groundwork for a larger mega-nourishment project, addressing concerns over the environmental and other permitting that would need to be approved for a mega-nourishment project to be built.

In general, the business leaders, elected officials, and public agency staff of the City of Virginia Beach seemed to be well informed on the issues of sand transport, storm protection and coastal ecology. Among those interviewed in this research were those who deal directly with the condition of the beach every day, either as a city official, coastal property owner, or scientific researcher. Reactions might be considerably different among people in the broader public of the Virginia Beach community who are less familiar with these issues. Additionally, funding for annual beach nourishment in Virginia Beach was restored in summer 2012, and with the removal of that stress on the beach nourishment agenda, both city and local residents seem content to resume beach nourishment via the standard methods. There is no source of pressure to innovate or pilot new methods of beach nourishment at this time. We concluded that a small sand spit or delta at Sandbridge would be most likely to receive broad support as a pilot for potential future changes in management or nourishment strategies on the main resort beach.

4 LESSONS LEARNED

This research yielded a number of interesting insights, ranging from the predicted movement of sand to the priorities of local residents, business owners, officials and scientists. Initially, the Virginia Beach Resort area was targeted as a potential site of a mega-nourishment due to its character as an iconic landscape in the region and central location of tourism and real estate value/investment along the coast. However, a number of factors suggest that the smaller resort community to the south of Virginia Beach, Sandbridge, would be preferable for a pilot project that could introduce mega-nourishment as a beach-building technique in the United States. The factors that shifted interest from Virginia Beach to Sandbridge also highlight concerns that may be generalizable to coastal adaptation and design in other areas of the United States.

Areas with a continuous line of hotels rely for their business success on a linear beach with a consistent width. Without a consistent width, tourists might preferentially select hotels closest to the water's edge. If the edge of the water formed coves and lobes, resort properties would likely increase or decrease in value for the period of years it would likely take for the beach shape to be smoothed by wave action. Similarly, linear beach shorelines dominated by private residences might face inequities of beach access if the beach shape was altered. Changes in beach nourishment practices that produce "winners" and "losers" along the beach, even for only a few years, may be unacceptable to adjacent private landowners unless there is no other way they can afford to protect their property from storms and maintain a recreational beach.

Mega-nourishment may be an appropriate strategy in areas where land use is not uniform along the coast, and so beach nourishment can create a variety of physical conditions, such as the more urban coasts of New Jersey, Long Island, NY, and San Francisco Bay. In areas where funding for annual or semi-annual beach nourishment is uncertain, mega-nourishment may present a method for maximizing the benefits of beach nourishment over a longer time period, if an initial capital investment is possible. Areas with undeveloped land and few individual owners, similar to conditions at the Dutch Sand Engine, can also be an excellent fit for this adaptation strategy, as the complications of maintaining a status quo for multiple land-owners are reduced, and the potential ecological benefits of mega-nourishment can be realized.

While mega-nourishment may be a more cost-effective way to provide multiple benefits as a response to coastal erosion than methods currently being utilized in the United States, it is still not a permanent one. The expense of beach nourishment, even when it is less frequent, as well as projected storm frequencies and sea-level rise will have significant land use and urban design implications that beach nourishment may not ultimately solve. Additional fortifications, such as a strong dune line, may be needed in conjunction with beach nourishment to meet the environmental changes that are likely to exist after 2050.

The public experience of these coastal landscapes also requires attention. The way residents and visitors experience sandy beaches may have a direct role in shaping attitudes and cultivating interest in adaptive coastal designs and infrastructure that are different from the status quo. Designers can take the lead in developing the shoreline forms that will perform the functions discussed in this paper, communicating the implications of these designs, and shaping the experience of visitors to these places in ways that may lead to their implementation in additional locations. Furthermore, designs such as the sand engine can increase our awareness of wind and wave action as it affects the future of our coastlines, as opposed to annual nourishment that obscures the effects of coastal erosion. In this way, beach nourishment can be a tool not only for storm protection and coastal ecology but also for shaping our understanding of large-scale natural processes and informing our responses to changes in climate, including rates of sea level rise and storm patterns.

This research also highlights the need for designers to build partnerships that allow them to more rigorously predict the performance of alternative spatial proposals. Modeling programs such as Coastal Evolution Model can be applied as an initial design and communication tool, while adding rigor and scientific validity to forecasting design performance. As scientific theories and observations change, designers will be able to take advantage of scientific insights more quickly if our methods for testing our own spatial proposals make use of the same tools that scientists are using to refine their theories.

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