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# Seasons, Storms and Seawalls: A Comparison of Constrained and Unconstrained Beaches in Groton, Connecticut

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# ABSTRACT

# SEASONS, STORMS AND SEAWALLS: A COMPARISON OF CONSTRAINED AND UNCONSTRAINED BEACHES IN GROTON, CONNECTICUT

by

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A study was done in order to evaluate the impact of a seawall on a beach in Groton, Connecticut. Literature predicts beaches containing seawalls will inhibit functioning as a normal beach and lead to increased erosion. Groton Long Point is developed and backed by a seawall while Bluff Point is located on a state park and receives much less human usage. Profiles were measured to study the affect of storms, seasonality and time on these two barrier beaches. Two transects at each beach were used to determine changes in profiles throughout the year. Profiles were then compared to previous research (Campbell, 2004) to analyze long-term change. The beach at Bluff Point reacted normally to the seasons and the storm and showed a trend of accretion over the four year period. On the other hand, Groton Long Point beach showed no change in beach features in regard to the seasons and storms and exhibited extreme variability in the long-term. While it cannot be proven the seawall at Groton Long Point is increasing erosion, there is strong evidence of erosion on the beach. The irregular system created makes it hard to predict how the beach will behave in the future.

*Keywords*: seawall; storms; beaches; Groton Long Point; Bluff Point; Connecticut

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## 1.0 Introduction

Millions of years of erosion have produced high sediment content on the east coast of the United States, making barrier beaches quite common along this shoreline. Barrier beaches are important because they protect the mainland from storm surge and waves (Davis and Fitzgerald, 2004). Beaches are highly dynamic, constantly shifting in response to the changing wave energy. These natural adjustments can be attributed to seasonal changes or strong storms like hurricanes or nor'easters. For example, during storms, when there is an increase in wave strength, excess wave energy is dissipated by a reduction in beach slope (Komar, 1998). Beaches are perhaps the most often developed fragile environment in the world. While they are often viewed as great vacation spots, residents, vacationers and developers are ultimately setting up either the beaches or the infrastructure for disaster. Coastal development leads to construction of hard stabilization structures, like seawalls, that inhibit sand transport. A study was conducted to evaluate the impact of a seawall on a beach. It is hypothesized beaches containing stabilization will show trends of erosion, while natural beaches will appear stable.

Barrier beach systems in Connecticut, like Groton Long Point and Bluff Point, have evolved to their present state in time since early in the present interglacial. Both beaches are extremely dynamic systems that respond to rising sea level by migrating inland, a process naturally occurring since the recession of the last known glaciers approximately 15,000 years ago (Stone et al., 2005). Barrier beaches respond by depositing sediment over the dunes in the landward margin to naturally move inland. Without human interaction, beaches can survive for millions of years. It is not known if barrier beaches can retreat at the same unprecedented rate of sea-level rise. Unfortunately

for the beaches, the sun, sand and ocean create a carefree atmosphere where most of America likes to vacation and live. With ocean front homes, resorts, and restaurants, the beach system is confined to its present location by the demands for protection of economic investments.

One response to chronic beach erosion along developed coastlines has been construction of hard stabilization structures like seawalls in order to reduce the effects of strong waves and protect homes from storms. Seawalls usually take the place of dunes, cutting off sediment supply from the backshore system. Seawalls can also increase offshore sand transport and erode the beach face faster (Komar, 1998). An alternative approach now widely used in the U.S., is beach nourishment, or replenishment, where sand from another location is placed on the beach. This approach may also be used in conjunction with hard structures. Different states chose different policies in how their coastlines are allowed to be altered. Maine, North Carolina, and South Carolina all prohibit the construction of hard stabilization structures on open-ocean shorelines (Pilkey and Dickson, 1996). States like Florida and New Jersey allow hard stabilization it is important to keep the coastlines healthy because beaches are not only important to protect the mainland from storms but also for the economy of many states. For example, North Carolina receives thousands of people yearly to the shoreline. Homeowners and vacationers want the beaches to be maintained. But at the same time allowed to exist in a dynamic state.

The beach at Groton Long Point faces the problem many developed beaches face. The beach is reshaped every summer to please a community reaching over 5,000 people. The seawall protects the ocean front homes from moderately severe wave conditions so

that the community can enjoy the beach sitting in front. In contrast, the beach at Bluff Point is located in a state park and receives much less human usage. Bluff Point used to be lined with cottages in the early 1900's. However, the hurricane of 1938 destroyed the development and Bluff Point has been allowed to naturally adapt to local conditions for the past eighty years.

Topographic measurements taken at Bluff Point and Groton Long Point were used to assess the affect of storms, seasonality, and long-term trends on the beach profiles. This study was done in order to evaluate the impact of the seawall on beach evolution at Groton Long Point. With the potential for storms to be stronger, it is important to know if there is a difference in response between constrained and unconstrained beaches. Natural beaches will move sediments in the classic "cut and fill" cycle, whereas stabilized beaches will have increased erosion after storms. It is important to understand how each beach responds to seasonal modification and storms to determine if Groton Long Point functions like a healthy beach or is in danger of disappearing.

## 2.0 Background

### *2.1 Barrier Beaches*

Barrier beaches make up about 15% of the world's coastline. These beaches are most common along coasts that have an abundant sediment supply, forming in a linear fashion to the coast due to an interaction of wave and wind energy (Davis & Fitzgerald, 2004). Therefore, North America's east coast provides a perfect environment for the formation of barrier beaches.

There are three types of barrier beaches that include islands, spits and welded barrier beaches. Barrier islands are isolated from the mainland and are surrounded by water on all sides. Barrier spits are attached to the mainland on one side and end in a bay or ocean. Spits are formed by lateral movement of water along the shoreline. Waves hit the coast at an angle causing the movement of water and sediment in one direction down the beach. This spit builds in the direction of the longshore sediment transport, resulting in deposition along the coastline (Davis & Fitzgerald, 2004). Welded barrier beaches are connected to the mainland at both ends. They are common on rocky and glaciated coasts and are generally backed by shallow bays or lagoons (Davis & Fitzgerald, 2004). Therefore, barrier beaches found on the east coast north of New Jersey are generally welded barrier beaches.

Depending on the influence of wave height and tidal energy on the system, there are three types of coast and associated beach morphology (Davis & Fitzgerald, 2004). The first class is a wave dominated coast. Wave dominated coasts usually have high longshore sediment transport and exhibit long, linear barrier islands. An example of this is the Outer Banks, of North Carolina. The second barrier beach morphology occurs on a

mixed energy coast. These coastlines have both wave and tidal influence. The barrier beaches are usually short and stubby, with large intertidal areas, occupied by marshes. The beaches of New England are good examples of mixed energy coastline. Finally, tide dominated coastlines are also short and stubby, but support large ebb-tidal deltas (Davis, 1994). Separated by stable inlets, Georgia's coastline is a good example of this type.

Barrier beaches consist of the beach, the barrier interior and the landward margin. The beach is the most dynamic area, where sediment is constantly moved by wind, storm and wave energy. The littoral zone is the entire beach environment (Figure 2.1), consisting of the zone extending from the dunes down into the water to the depth of closure, or the area where sediment is no longer in the barrier beach system and unable to be transported by waves (Komar, 1998)**.** The depth of closure is a function of wave energy. Wave energy can only reach to a certain depth in the ocean, so sediment cannot interact with waves beyond a certain distance from shore. The depth of closure is usually where the depth exceeds 20 m (Komar, 1998). The nearshore zone includes any longshore bars or troughs, the beach face, berms and dunes (Komar, 1998) (Figure 2.1). The backshore includes the beach profile extending from any vegetation or change in physiography seaward towards the beach face.

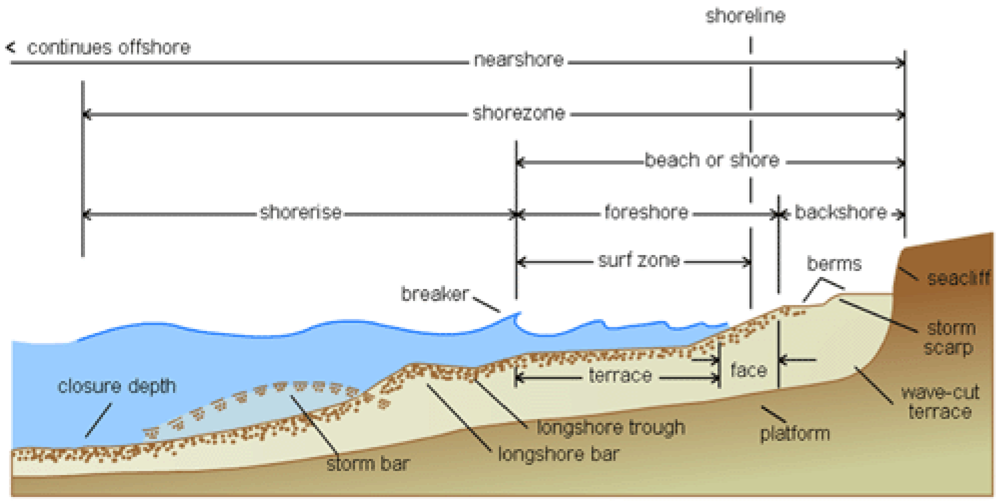


Figure 2.1: The terminology used to describe the beach profile. Here the term "shorezone" is supplemented for "littoral zone." (SCRIPPS, 2003)

A berm is a horizontal plateau on the backshore whereas a beach face is the sloping planar section of the beach (Komar, 1998). The berms and beach faces on beaches in the northeast consist of sand and gravel eroded away from a headland and deposited by the swash, which is the rush of water up a beach after the breaking of a wave (Boothroyd et al., 1989). The formation of the berm is controlled by wave run up onto the beach and sediment is brought to shore during low energy wave conditions (Komar, 1998). Waves run onto the shore, bring sand, lose energy and deposit the sand onto the beach. The beach face, the section of the beach that is normally exposed to the wave energy of the beach, assumes various gradients depending on the sediment size of the beach. Beach sediment is classified by its diameter (Table 2.1). When beaches are composed of gravel and larger sediment, the beach face's slope is greater due to the sediments permeability (Bird, 2000). For example, when the swash runs up the beach face, instead of carrying sediment back from the beach face, water percolates in between the sediment grains. This diminishes the effectiveness of the wave energy, leaving a steep beach face. Therefore, beach face slope increases with sediment size. In contrast,

with fine sediment, the beach face tends to occur in gentler slopes (Bird, 2000). The rate of percolation is also affected by the degree of sorting on the beach (Komar, 1998).

Table 2.1: Classification of sediment size by diameter (Komar, 1998).

| Size Nomenclature | Diameter (mm) | Phi Units |
|---|---|---|
| Boulders | >256 | > -8 |
| Cobbles | 64 to 256 | -6 to - 8 |
| Pebbles | 4 to 64 | -2 to -6 |
| Granule | 2 to 4 | -1 to -2 |
| Very Coarse Sand | 1 to 2 | 0 to -1 |
| Coarse Sand | 0.5 to 1 | 1 to 0 |
| Medium Sand | 0.25 to 0.5 | 2 to 1 |
| Fine Sand | 0.125 to 0.25 | 3 to 2 |
| Very Fine Sand | 0.0625 to 0.125 | 4 to 3 |
| Silt | 0.0039 to 0.0625 | 8 to 4 |

There are two common types of beaches, reflective and dissipative. A reflective beach is the result of long period waves that move sediment onto the foreshore. They contain steep beach faces and berms and indicate a fully accreted beach (Ritter et al., 2002). On the other hand, dissipative beaches usually have low-angle beach faces and wide, gently sloping surf zones. Beaches with different profiles form because of the different wave energies they receive. On reflective beaches, most wave energy is expended directly on the beach face, whereas on dissipative beaches, the wave energy is expended on offshore bars (Ritter et al., 2002). Beaches with a smaller fetch, or the length of unobstructed sea surface upon which wind can generate waves, will also receive less wave energy and most likely be dissipative.

The barrier interior consists of the frontal dune ridge and any secondary dunes. Dunes are generally formed by aeolian processes and act as natural barriers to ocean

storm surges and waves. Dunes also preserve the low lying landward margin areas like the marsh. The interior also includes areas of overwash depicting a landward progression of the beach system over the marsh. Overwash occurs when severe storm surge moves water back over the beach system. This results in a movement of sediments from the front to the back barrier (Boothroyd et al., 1989). The final part of the barrier beach system is the landward margin, which includes the backsides of the barriers, usually mud flats, salt marshes or open water like lagoons or bays (Davis & Fitzgerald, 2004). Salt marshes and lagoons provide not only important habitat for many wildlife species, they protect the mainland from inundation during strong storms. Their elevation is generally at sea level so they retain storm water before the upland is flooded.

*2.2 Storm Impact on Beaches*

Storms generally have a large impact on the beach profile. Shifts in beach profiles are due to differences in wave energies. Therefore, the larger the storm, the more the beach profile will change. Beach profiles shift naturally in response to the seasonal change in wind and wave energies. These two profiles are generalized as summer and winter profiles, while the fall and spring profiles are considered transitional periods. A summer profile is characterized by low energy waves, which develop a large, wide berm and a smooth offshore profile (Figure 2.2). In the winter, beach systems respond to high wave conditions: The berm is destroyed by the intensified swash and the sediment is shifted off shore into a bar and trough system (Komar, 1998). This roughly annual change is known as the “cut and fill” cycle, because the beach is not really losing sand, instead, it is relocated to different areas within the littoral zone. Sand is constantly moved

throughout the littoral zone between the depth of closure and the berm. As long as the sand stays above the depth of closure, given adequate time to recover, it will migrate landward after storms. Sometimes strong storms create overwash, which is a severe storm surge where water moves landward of the beach, breaching or flowing between dunes, and depositing sand from the beach in the interior and potentially even the landward margin (Boothroyd et al., 1989). When sand moves to the interior or landward margin, it is no longer part of the system and the beach has most likely been severely eroded. However, this removal of sand to the back barrier is an important long term natural "survival process" for the barriers as sea level rises. Barrier beach systems with sufficient sediment supply will naturally move upward and landward in response to storms and sea-level rise. So whereas the sand is lost to the nearshore system in the short-term, it is retained inland as part of the larger barrier system.

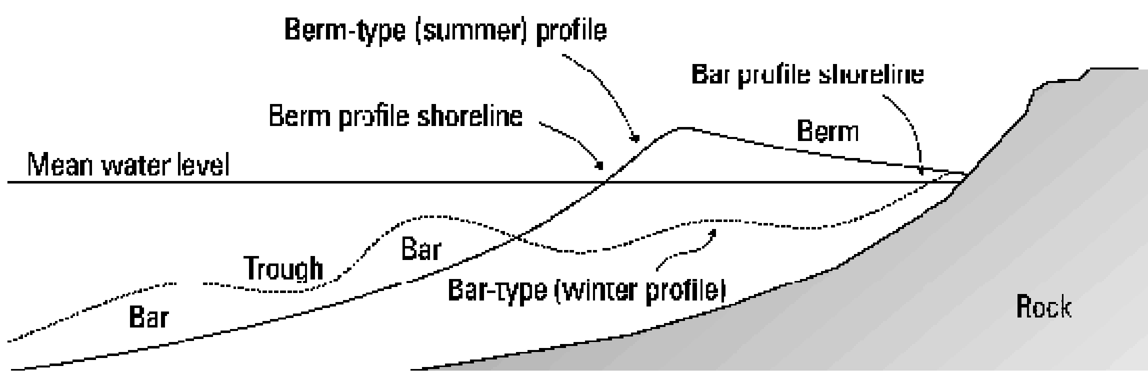



Figure 2.2: Seasonal response of a beach profile (Modified by Voigt, 1998 from Komar, 1998).

After a storm, once the waves have returned to normal, the beach system will begin to recover. The waves transport sand, which had moved offshore to sandbars during the storm, back onshore to the beach face. The four stages of beach recovery have been characterized as 1) rapid foreshore accretion following the storm, taking days to

weeks, 2) slower backshore aggradation, taking weeks to months, 3) dune formation, taking months to years, and 4) dune expansion and vegetation recolonization, taking years to decades (Morton et al., 1994). How much recovery the beach needs depends on the severity of the storm.

*2.3 Human Influence on Beaches*

Approximately 55% of Americans live within fifty miles of the coast (NOAA, 2007). Developed portions of coastline are a large economic resource for many states, as they bring in millions of vacationers yearly. Examples include Ocean City, Maryland, Atlantic City, New Jersey, and many of the Florida beaches. However the increased human usage of the coastlines is a danger to the beaches. Development does not allow the beaches to move naturally inland during a period of sea-level rise. Campbell (2003), Dolan (1973), Kraus (1988), Morton et al. (1994) and Pilkey and Wright (1988) have demonstrated how natural and stabilized beaches respond differently. The main conflict is that society wants the beaches to be maintained in place, but at the same time allowed to exist in a dynamic state.

Dr. Robert Dolan (1973) studied the difference in some natural and controlled barrier islands off the shore of North Carolina. The natural islands tend to be sparsely vegetated with a low elevation. Therefore, the beach is able to adjust to periodic storms; water can flow over the island and the energy will be dissipated. Natural beaches tend to be 125-200 m wide. The stabilized beaches have large dunes and vegetation. These beaches are only about 30 m wide, because wave energy is concentrated into one run up area, creating more erosion (Dolan, 1973). After a strong storm, severe erosion existed on

the stabilized beaches, whereas the natural beaches show an increase in the inland elevation. Stabilization through dune construction on the Outer Banks has now created a system that must be controlled in order to be habitable. This study showed the large impact control has on beaches. Unless landowners decide to retreat and relocate their development from the shoreline, the beaches cannot adjust naturally and must be altered somehow.

Engineers and scientists have come up with four reactions to coastal erosion which include: 1) no action; 2) retreat and relocate; 3) beach nourishment; and 4) stabilization structures (Komar, 1998). A policy of no action is rarely used on developed beaches. Beaches backed by development would ultimately recede towards homes, causing destruction of development if not the beaches. This action would be low cost and safe for the environment, as it is the natural reaction for the beach. However, this reaction would not be likely to be considered by homeowners or elected officials. The second policy of retreat and relocation means that when the beach erodes, homeowners would move their houses back. This policy benefits the beach because it allows the coast to develop naturally as homeowners retreat from sea level rise or increased erosion. Unfortunately for homeowners, while their homes would be intact, they would lose their property. Beach nourishment and stabilization structures are the most prevalent actions used to confront the beach erosion problems the United States faces today.

Beach nourishment, sometimes called soft stabilization, is the placement of large quantities of sand or gravel in the littoral zone to advance the shoreline seaward (Komar, 1998). Various design schemes are used, including adding all the sand as a dune, nourishment of the visible beach, scattering sand over the entire profile, or placing the

sand offshore as a bar. Most of this sand usually comes from dredged inlets, and has a short lifetime in the system. For example, in a period of forty years, Ocean City, New Jersey has been replenished at least forty times (Pilkey and Dixon, 1996). Soft stabilization is also extremely expensive. Miami Beach spent $60 million on 16 km of sand one year (Komar, 1998).

Hard stabilization structures come in many shapes and forms and are the traditional response to shoreline retreat. Hard stabilization, however, can be extremely detrimental to the shoreline. There are offshore breakwaters, groins, rip-rap revetments and seawalls, and all of them alter longshore sediment transport. Groins are built perpendicular to the shore and they trap sediment along their edges, building up the beach in front of the property, but essentially starving the other beaches down current (Dean, 1999). This then begins the "groin effect" where each homeowner down shore must also build a groin to trap his or her own sand. A seawall is a form of coastal defense built on the inland part of the beach to reduce the effects of strong waves. Seawalls and rip-rap revetments are built parallel to the shore and are designed to resist the full force of waves. They are built in order to reflect wave energy back into the ocean to protect development. When waves hit a seawall they reflect back with the same amount of energy, removing sand, and eroding the beach face faster (Komar, 1998). Seawalls also can cut off extra sediment accumulation in a dune area.

Seawalls can be destructive in many other ways (Pilkey and Wright, 1988). First, seawalls can be constructed between high and low tide lines. This immediately removes the beach, and leaves little to no beach during high tide. Next, seawalls can passively cause the beach to erode by cutting off sand supply to the system. Erosion continues and

there is no new source of sediment as an input to the beach. This occurs gradually over time until the shoreline eventually migrates landward of the seawall. Seawalls also actively cause a beach to erode through wave reflection and storm surf zone narrowing. This erosion is from direct contact with the wall and threatens the beach on a shorter time span. Seawalls also cut off the sand supply by inhibiting longshore sediment transport, which requires outside sand nourishment to maintain the beach. Finally, they inhibit storm response because there is no frontal dune as a reservoir of sand (Pilkey and Wright, 1988).

### *2.4 Sea Level Rise and Coastal Erosion*

Sea level rise is not a new process to our coastlines. Sea levels have been rising since the beginning of the Holocene Epoch 15,000 years ago (Stone et al., 2005). This rise in sea level is attributed to the melting of the Wisconsinan glaciers, the last ice sheets to advance through the United States. However, the rate at which sea level is rising now is unprecedented (IPCC, 2007). Industrialization has had many effects on climate, altering it unnaturally. The Intergovernmental Panel on Climate Change (IPCC), a program established by the United Nations Environmental Programme and the World Meteorological Organization in 1988, has completed three full reports assessing the scientific, technical and socio-economic information relevant to human induced climate change (IPCC, 2007). Climatic changes have occurred as a result of human induced accumulation of gases, such as carbon dioxide ($CO_2$), in the atmosphere. Most notably, the burning of fossil fuels has raised $CO_2$ exponentially from less than 280 +/-20 ppm

before 1750 to 379 ppm in 2005 (IPCC, 2007). This abundance of $CO_2$ in the atmosphere is linked to the abnormal warming and rising sea levels faced today.

Due to factors such as the melting of the Antarctic and Greenland ice sheets and thermal expansion of warmer seas, the most recent IPCC report claims sea level could rise 0.6 m or more by 2100 (IPCC, 2007). This report also claims sea surface temperature (SST) could increase by 3 ˚C. An increase in SST could lead to an intensification of hurricanes, storms and surges related to them (Trenberth, 2005). Globally, 1.2 billion people live within 100 km of the coast, which is around 23% of the world's population (Adger et al., 2005). By 2080, this number could rise to 1.8-5.2 billion (IPCC, 2007). Intense storms can drastically alter beaches, especially those backed by development, as most are. Besides destroying development, intense storms can cause flooding, rains and wind that create hazards for people living in houses near the shore.

Barrier beach systems are nature's way of protecting the mainland from strong storm systems. It is not known whether the east coast can recede naturally with the rate of sea level rise. Each coast has its own specific rate of erosion due to local factors such as fetch, aspect, storm frequency and intensity, coastal armoring, sediment supply and subsidence. Coasts subsiding due to natural or human induced causes will experience larger relative rises in sea level (Bird, 2000). As global warming influences rising sea levels, natural protectors such as beaches and wetlands will recess at faster rates, leaving property and population even more vulnerable. With natural defenses quickly disappearing, stronger storms pose even more of a risk to coastal areas. Higher levels of precipitation brought on by stronger hurricanes would increase flooding and storm

surges. Storm surges would reach further inland and projected damage is estimated to cost much more (Anthes et al., 2006). Humans have only added to the natural risks by the implementation of seawalls and groins on coasts, which ultimately erode beaches even faster.

With potentially stronger storms, it is important to know if there is a difference in response between natural and stabilized beaches. Does the sand in a stabilized beach shift in the same manner after storms as the sand on natural beaches, or do the beaches react differently? Literature from Campbell (2004), Dolan (1973), Kraus (1988), Morton et al. (1994) and Pilkey and Wright (1988) agree that stabilization can in fact change the way beaches react to various conditions such as storms. However, additional steps must be taken to understand beaches on the Long Island Sound containing seawalls. Stabilized beaches along the Long Island coastline have not been heavily researched because the area is fetch limited, which controls the height of waves in the area. However this coastline is still heavily developed and needs to be examined more completely. It is hypothesized that beaches containing stabilization will show trends of erosion, while natural beaches will appear stable. Natural beaches should move sediment in the seasonal "cut and fill" cycle and respond to storms by redistributing berms. On the other hand, an increase in erosion should be seen on stabilized beaches after storms. Stabilized beaches should also lack the natural defenses necessary in the beach recovery process.

## 3.0 Study Area

### *3.1 Geological History*

Southeastern Connecticut has a distinctive geologic history. Groton, Connecticut is located on the Avalonian terrane, which is made mostly of gneiss, a metamorphic rock (Marshak, 2005). Gneiss is generally comprised of pink and white feldspars, quartz and biotite. Because Groton is located on metamorphic rock, it must have undergone some compression to change the rock. Avalonia was originally an island off the coast of North America about 700 Ma ago (McHone, 2004). The Iapetos Ocean was in between North America and Avalonia, resembling today's Atlantic Ocean. As tectonic plates shifted, continents began to move and Avalonia and Africa collided into North America. This movement 300 Ma ago formed the supercontinent Pangaea. Following this collision was the break up of Pangaea, when Africa pulled away from North America, leaving parts of Avalonia connected to North America (McHone, 2004). The Avalonian terrane, on which Groton resides, therefore gets its name from the original island Avalonia.

The type of coastline depends on the kind of plate boundary the coast is located on. One type of plate boundary is a convergent boundary where two plates move toward each other so that one plate subducts beneath the other. The coastline in these areas can be classified as a leading edge coast. Leading edge coasts are distinguished by shorelines with cliffs and large waves (Davis, 1994). Although this type of coastline can be viewed on the west coast of the United States, the East coast evolved from a different boundary.

Another type of plate boundary is a divergent boundary where two plates move apart from each other at a mid-ocean ridge. Coasts here are extremely diverse. These coastlines are known as trailing edge coasts because the continental lithosphere is not at

the edge of a plate and has been stable for millions of years (Davis, 1994). Connecticut is found on a passive continental margin, so beaches had a long time to develop. However, Connecticut's recent glacial history created beaches composed of sediment from meltwater deposits.

Southeastern Connecticut has been altered by glacial advances in many periods of glacial history. The most recent glaciers, known as the Wisconsinian glaciers, reached their peak advance southward from the Hudson Bay area over Connecticut about 25,000 years ago (Stone et al., 2005). The ice sheet advanced as far as the middle of what is today known as Long Island before it began to retreat. It deposited a large amount of sediment, which formed Long Island. Long Island is a terminal moraine which shows the extent that the glacier traveled. A moraine is a large deposit of glacial till left to the sides, middle or end of the glacier (Ritter et al., 2002). This moraine once created the outer edge of a huge lake called Lake Connecticut that was created by glacial meltwater. Meltwater entering the lake through streams left deltaic deposits of gravels and sands on the lake bed. Eventually, Lake Connecticut drained through a low spot on the Orient Point-Fishers Island moraine (LISRC, 2004). About 500 years after the lake drained and scoured out a channel in the middle of it. Later, the present day Long Island Sound began to fill. As the channel in the sound filled, the seawater began to overtop the edges and wave action began to alter the previously buried marine deposits creating the beaches that exist today.

Glacial till is frequently reworked in fluvial systems. River systems transport sediment in its dissolved and solid state. Sand is one of the most common sizes of sediment carried by a river, and deposits are often denoted as alluvium (Ritter et al.,

2002). Alluvium is a pile of well-sorted sediment, with a fair amount of rounding, deposited by a river system. Most of this glacial till, transported from meltwater through the rivers, makes its way to oceans and collects on the beaches. Much of the sand is also from large glacial deltas formed in Lake Connecticut (LISRC, 2004). The low wave energy of the Connecticut shoreline on Long Island Sound preserves the sediment in valleys between rocky headlands.

Bluff Point and Groton Long Point, the two areas surveyed, are extremely close in proximity to each other (Figure 3.1). Long Island Sound acts as a wave barrier to the two beaches, limiting the fetch of the systems. Both beaches are oriented to the SSW, giving them comparable fetch, wind and wave energies. Bluff Point can be considered a welded barrier, with the Bluff as one headland and Bushy Point as the other. As the glaciers receded, large meltwater deposits formed and filled channels, shaping streams that led into a sediment-damned lake behind Bluff Point (Stone et al., 2005). Deltas in the glacially-fed lakes formed due to the heavy accumulation of sediment being released from the glaciers. The lake continued to fill until it breached the terminal moraine that damned it and spilled into the present day Long Island Sound. As a result, the beach at Bluff Point is composed of glacial meltwater deposits. Groton Long Point is more complicated due to the seawall, but can be classified as a welded barrier between two headlands. It is presumed that Groton Long Point is also composed of glacial meltwater deposits that were carried downstream along Fort Hill Brook.

Figure 3.1: Top: Connecticut with the study section shown in the square. Bottom: Bluff Point and Groton Long Point beaches (Google Earth, 2007).

*3.2 Climate*

Connecticut has a moderate climate with average temperatures between 21 and 24 ˚C in the summer and –1 to –5 ˚C in the winter (Britannica, 2008). Water temperatures near Groton range from 3 ˚C in the winter and 22 ˚C in the summer (NODC, 2008). Connecticut receives 75 to 100 mm of precipitation per month. Coastal areas are known to have a more moderate climate, with cooler summers and warmer winters. Strong hurricanes are rare, however, Nor'easters are prevalent in the winter. These storms supply large wave energies which, in turn, cause more erosion on the beach.

*3.3 Bluff Point*

Bluff Point State Park and Coastal Reserve is located in Groton, Connecticut. It consists of a wooded peninsula containing over 800 acres, bordered by Mumford Cove, the Poquonock River and the Long Island Sound. Bluff Point Beach is west of the headland bluff known as Bluff Point. Bluff Point Beach extends one mile long, terminating at a small, rocky island known as Bushy Point (Figure 3.2).

Bluff Point can be considered a welded barrier, with the Bluff as one headland and Bushy Point as the other. Sediment is coarser towards the bluff but becomes finer moving out towards Bushy Point. Bluff Point used to be developed with cottages lining the beach. However, the 1938 hurricane destroyed these houses and the community was not rebuilt. The public can only access the beach by foot or nonmotorized vehicle. Because it is along Long Island Sound, it is fetch limited, with waves smaller than 1.0 m during calm conditions. The beach has a small dune system and is backed by a marsh and lagoon.


Figure 3.2: Map of Bluff Point State Park.
(http://www.ct.gov/dep/lib/dep/stateparks/maps/bluffpoint.pdf)

*3.4 Groton Long Point*

Groton Long Point is to the east of Bluff Point State Park and contains a beach system severely altered by human development. The beach is also a welded barrier surrounded by two rocky headlands. A seawall backs the beach in place of a dune, built to protect homeowners from devastating wave energies. The seawall was built in 1955 (Campbell, 2004). Prior to the seawall, there was a boardwalk, which was destroyed by Hurricane Carol. The beach was originally backed by dunes, then a boardwalk and finally a seawall, as the community grew (Campbell, 2004). The community now contains 602 houses, with a year round population of 1,762. In the summer, vacationers

flock to this 1.2 $km^2$ (0.4 $mi^2$) destination, and the population reaches 5,432. In the winter, sand builds up against the seawall so the beach is reshaped every May before the summer season begins (Bogdon, 2008). This means that no replenishment goes on, instead the existing sand is pulled down from the wall to make the beach flat and conducive for recreation. A surf rake also combs the sand to create an aesthetically pleasing beach and rid it of anything other than sand, like seaweed (Bogdon, 2008). The beach is backed by a lagoon with many docks used to moor boats in the summer. Groton Long Point also borders Long Island Sound and is fetch limited with small waves. Groton Long Point is slightly more sheltered than Bluff Point because of its location northward of Fisher's Island. Therefore, Groton Long Point has slightly less fetch than Bluff Point for southerly winds.

## 4.0 Methods

*4.1 Survey Measurements*

The two beaches were chosen for the study because one is constrained and the other is not. They are easy to compare due to their close proximity to each other. Benchmarks at each site were chosen to permit repeatability. Two cross sections perpendicular to the shore were measured at each beach, creating a total of four cross sections. Paired cross sections were taken in order to get the most accurate depiction of each beach's littoral zone. These transect lines were developed in an earlier study comparing the two beaches in 2003-2004 (Campbell, 2004). A resurvey of the benchmarks was done at the end of each survey for accuracy.

Surveys were taken from the spring to the fall of 2007, specifically on May 15, September 28, October 21, November 8, and November 25. The November 8$^{th}$ survey was completed after tropical storm Noel. Surveying was done by a two person team using an autolevel with tripod, stadia rod and a 100 m tape measure. One person held the stadia rod at one-meter intervals on the transect line, while the other recorded relative elevations from the autolevel. Measurements began at 0 m at the top of the transect and then continued into the water, going as far as the surveyor felt comfortable. Surveys had different lengths due to varying wave and tide conditions. Field notes were taken noting the berm, wrack line, and shoreline. The elevation of the benchmark was recorded at the beginning and end of each survey to ensure the tripod stayed level the entire time. A survey was considered of suitable precision if the elevation of the benchmark was within 0.5 cm.

The benchmark for Groton Long Point was measured at the concrete base of the railing on the westerly staircase (Figure 4.1). The first transect, called Picket Fence, stretched perpendicular from the seawall adjacent to the picket fence and between two houses to the water (Figure 4.2). The transect to the west is House 32, which extended perpendicular from the non-porch side of House #32 into the water (Figure 4.3). Both transects included the berm, beach face and any bar or trough. The autolevel was placed in front of the house called "The Big Dipper" to allow both surveys to have the same tripod location.

The benchmark for Bluff Point was taken on top of an orange and white stake on the upper dune of the beach, approximately 90 m from the bluff (Figure 4.4). Transects were located using the methods section from previous research (Campbell, 2004). Transect one, called Orange Stake, was laid perpendicular from the orange stake, over the dune and down to the water (Figure 4.5). This transect included the beach's dune, berm, beach face, and any bar and trough systems under water. The second transect, called Sand Fence, extended perpendicular from the end of the fallen sand fence into the water (Figure 4.6). This transect may not have been the original Sand Fence transect location because it looked as if the fence had been knocked over +/- 0.5 m. The Sand Fence transect included the berm, beach face, and any bar and or trough systems. Again, the autolevel was set in between the two transect locations.

Having transects with markers that are more or less permanent to the beach system creates a repeatable survey. The tape measure laid out from the marker to the water creates intervals the same distance from the marker each time. Therefore, the tape measure helps ensure repeatability of all specific spots each time the transect is surveyed. This permits easy comparison of transects from survey to survey and also to the previous research in 2003.

Figure 4.1: Benchmark location for Groton Long Point on the westerly staircase. Arrow indicates the location.

Figure 4.2: The Groton Long Point transect known as Picket Fence. The arrow depicts the transect line followed.

Figure 4.3: The second Groton Long Point transect known as House 32. The arrow depicts the transect line followed.

Figure 4.4: Benchmark location for Bluff Point. Arrow indicates the location of the orange stake.

Figure 4.5: The Bluff Point transect known as Orange Stake. The arrow depicts the transect line followed.

Figure 4.6: The Bluff Point transect known as Sand Fence. The arrow depicts the transect line followed.

*4.2 Profile Analysis*

Data was entered into an Excel spreadsheet for analysis. Bluff Point data was corrected by adding 150 cm to the benchmark elevation, whereas 200 cm was added to the Groton Long Point benchmark. These numbers designate approximately how high the benchmark is above sea level, because there was not a known elevation to reference to. Additions of 150 cm and 200 cm were used to stay consistent with previous profile analysis (Campbell, 2004). Next, each elevation measurement was subtracted from the corrected benchmark elevation to determine the elevation above sea level and get a depiction of the profile. In order to compare successive profiles, the difference was taken between the later of the two surveys. For example, the pre storm survey from October 21 (profile 3) is subtracted from the post storm survey on November 8 (profile 4) in order to compare the differences in the profile after the storm. In this analysis, negative numbers indicate erosion and positive numbers indicate accretion. Profiles from Campbell's 2004 surveys were used to assess long-term profile change. Here, profiles from Campbell's survey were subtracted from new profiles to measure the long-term beach change.

*4.3 Waves*

Wave information was recorded from the National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center. The buoy used is Station 44039 in Central Long Island Sound, located at 41.14 ˚N 72.66 ˚W. The University of Connecticut, Department of Marine Sciences owns and maintains this buoy. Data for the surveyed months including wind speed, wind direction and wave heights were used to estimate seasonal waves and impact of waves from storms. Excel was used to graph the

wave heights on days bordering profile measurements. Special attention was paid to any storms that impacted the area.

*4.4 Sediment Analysis*

Sediment samples were collected at each transect in order to analyze the particle size of sediment at each beach. Two samples were gathered at each profile line on the two beaches. The first sample was taken on the berm whereas the second sample was collected at the beach face. Dry sieve analysis was used to examine the particle size of all samples to the whole phi interval (φ). The phi interval is a type of unit calculated by taking the negative log to the base two of the sediment's diameter in millimeters.

After each sediment sample was dried for approximately one week, it was poured into a layer of sieves with large sized openings on the top and progressively smaller openings near the bottom. The sieve openings ranged in size from 32 mm (-5 ) to 0.0625 mm (4 ), allowing only the finest of sediment to pass through the smallest opening. The sieves were placed on a sieve shaker and agitated for thirty minutes. After agitation, each layer of sediment was weighed to produce a mass of material in each sieve and then divided by the cumulative mass. This value was then used to determine the percentage of sediment finer than a given phi size. Sorting indexes were also calculated to decipher how sorted a sediment is. In order to compute the sorting indexes, the formula,

$$\frac{1}{2} \times \left( \left( \frac{D84}{D50} \right) + \left( \frac{D50}{D16} \right) \right) \quad [1]$$

was used. Here, the value $D_{50}$ is found by reading across the graph at the 50% finer than line and then finding the corresponding value in millimeters. The $D_{84 \text{ and}}$ $D_{16}$ values are

also determined by finding their percent finer and the value attached in millimeters. A sorting index of one is completely sorted, because all sediments are in a single class size. The sorting index values increase with decreasing sorting of the sediment sample. These sediment size and sorting values were used to compare the beaches to see if sediment size played a role in profile change.

**5.0 Results**

*5.1 Surveying*

As explained in the Methods section, resurveying of all benchmarks was done after each survey. The resurveyed benchmarks were measured within +/- 0.5 cm for all transects on all dates. Therefore, it is assumed that all beach change viewed over 0.5 cm can be viewed as considerable, not as survey error. Areas that should have little change, like the dune system in Bluff Point, are consistent and line up on top of one another. The profile lines separate only in the lower beach area. Over the four months surveyed there was little or no change to areas not modified by waves (Figure 5.1a and 5.1b). The dunes are only impacted by wave energy when there is a large storm, so there is no more than a 3 cm change in elevation. Rates of aeolian processes are too small to have an impact. Throughout the survey, areas that deal with constant wave processes, like the lower beach, can be viewed as considerably altered.

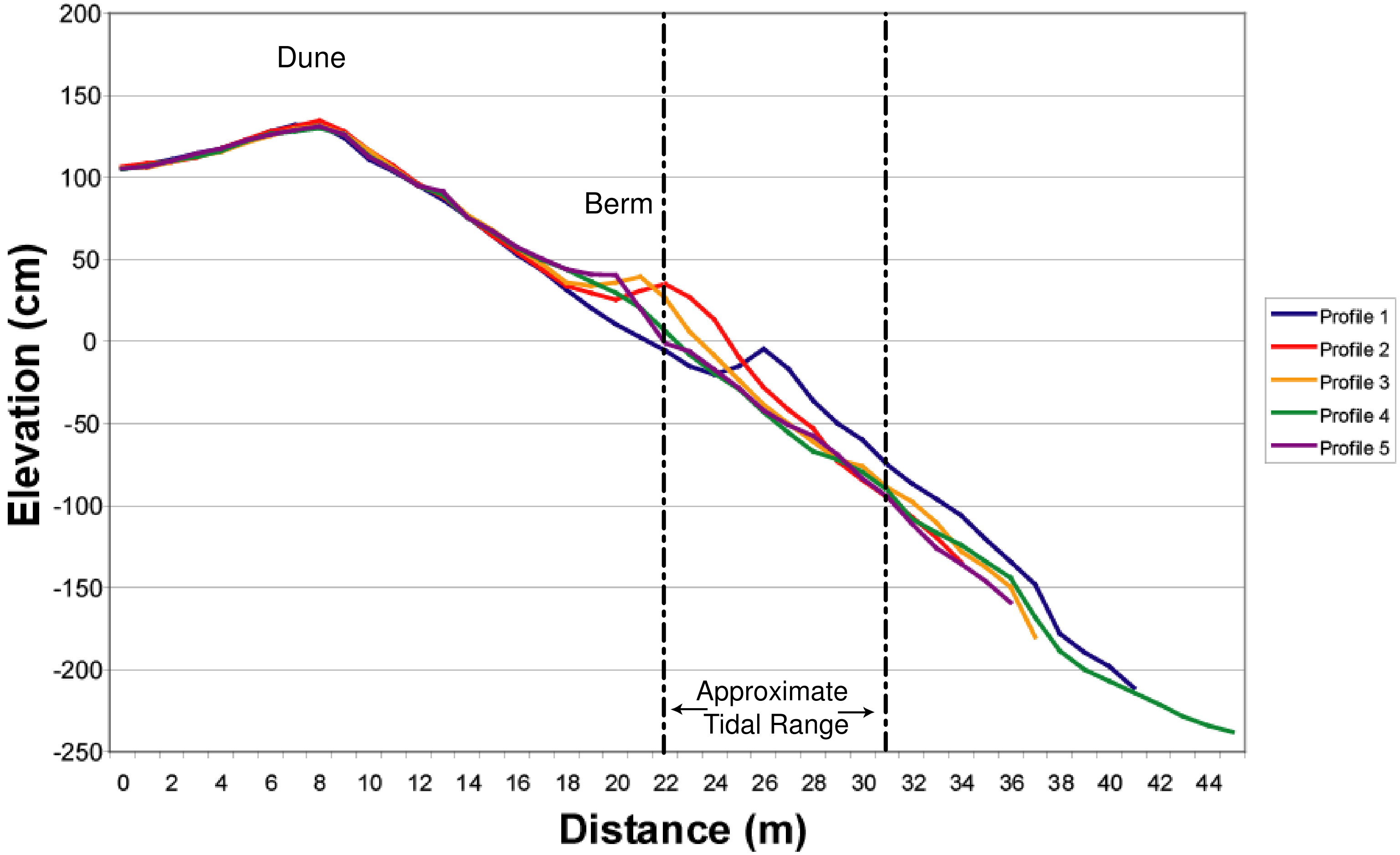



Figure 5.1a: Bluff Point's Orange Stake profiles. Each individual profile is marked in a different color as described in the legend. Note consistency of the dune area and the berms. Also notice the offshore bar on the winter profile (Profile 1) and depletion of a berm after the storm (Profile 4).

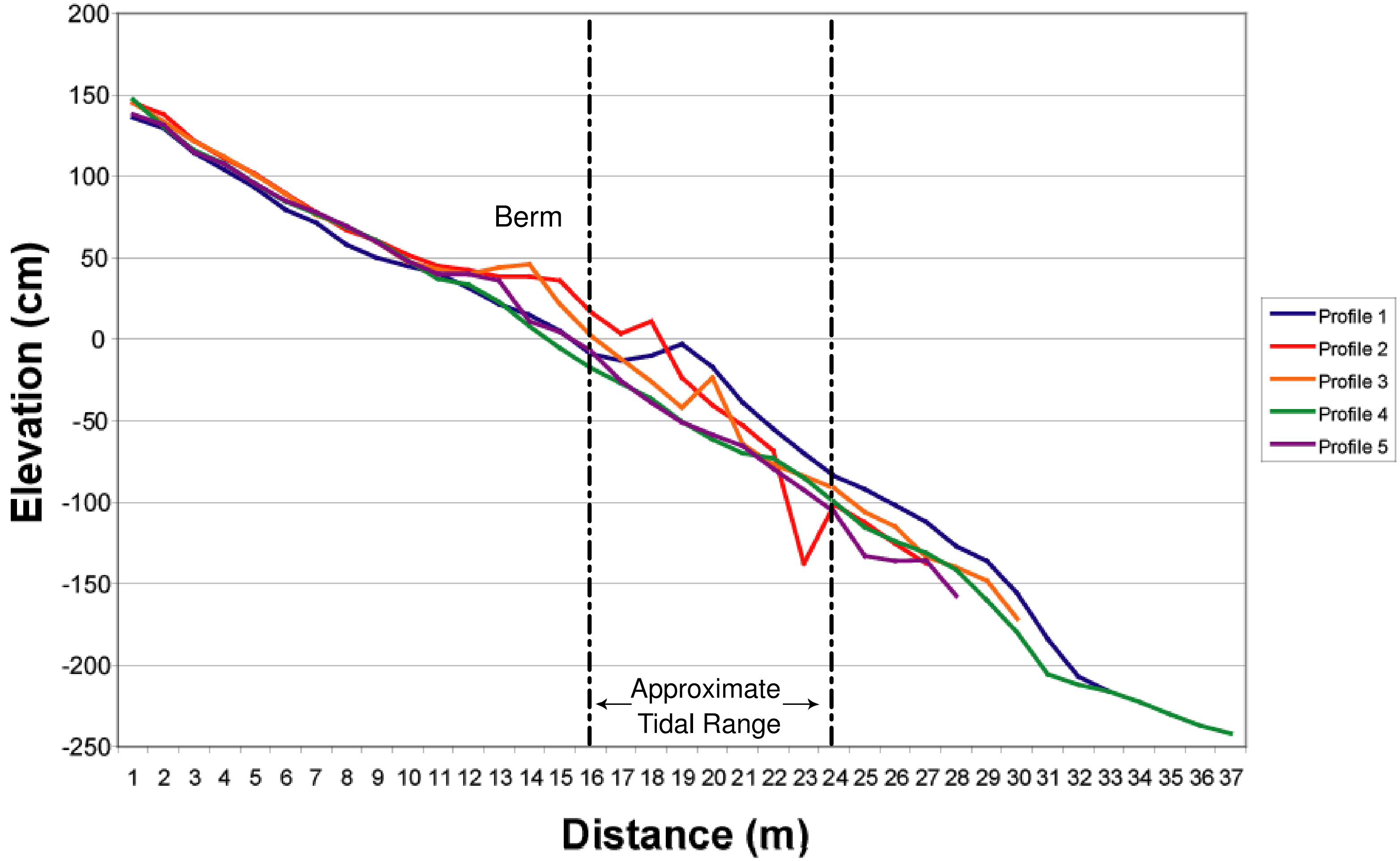



Figure 5.1b: Bluff Point's Sand Fence profiles. Each individual profile is marked in a different color as described in the legend. Notice development of berms on some profiles.

*5.2 Wave Conditions*

Wave conditions before May 15 were extremely mild, with a maximum of 0.90 m (Figure 5.2). August wave conditions were mild, staying under 1.00 m except for one summer storm. The storm on August 10 had a maximum wave height of 1.40 m (Figure 5.3). Wave conditions in September were relatively mild, only reaching over 1.00 m one day of the month (Figure 5.4). These conditions were similar to August's summer wave conditions. October was stormy around the 12th, and then had a week of wave conditions not reaching over 1.00 m prior to the survey (Figure 5.5). On November 3, 2007, tropical storm Noel passed through New England, creating wave conditions reaching 1.60 m at the height of the storm. Waves did not return to normal until the next day. Another storm, most likely a nor'easter, passed through on November 6th and 7th. This storm produced wave heights reaching 1.80 m (Figure 5.6). High waves were again noted on November 16th, reaching heights of 1.70 m.

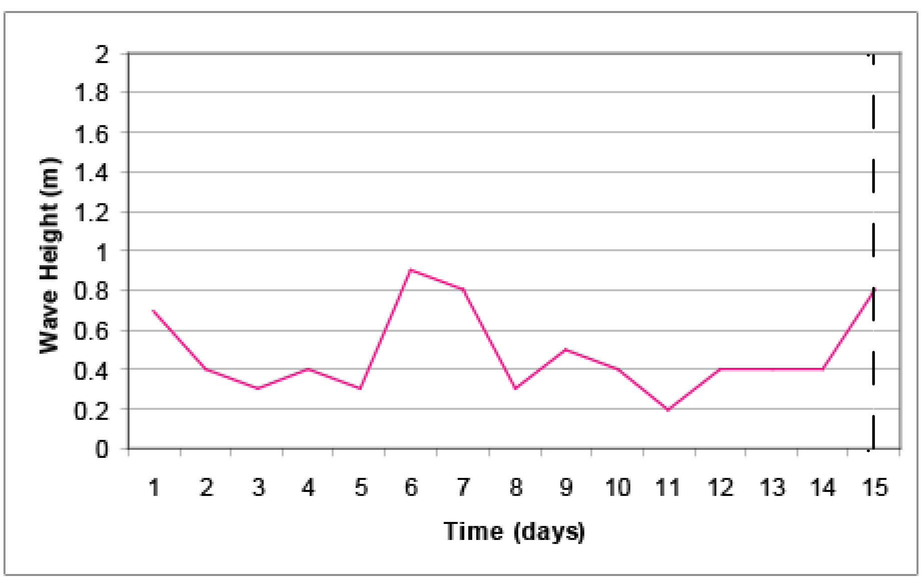
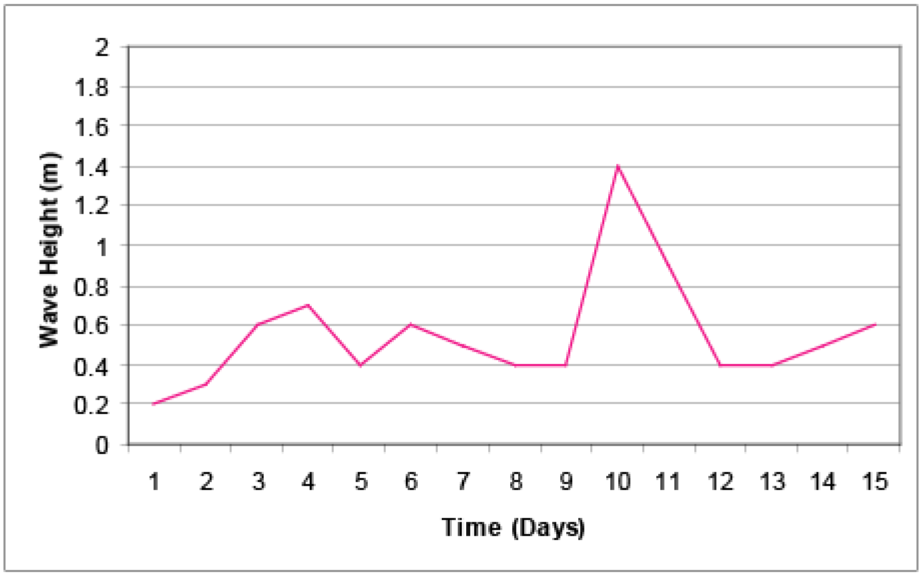
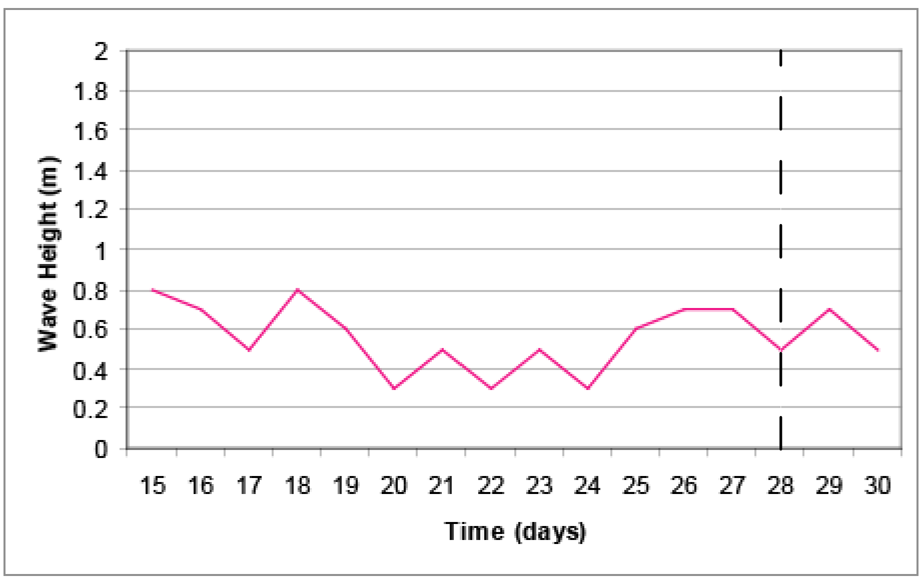


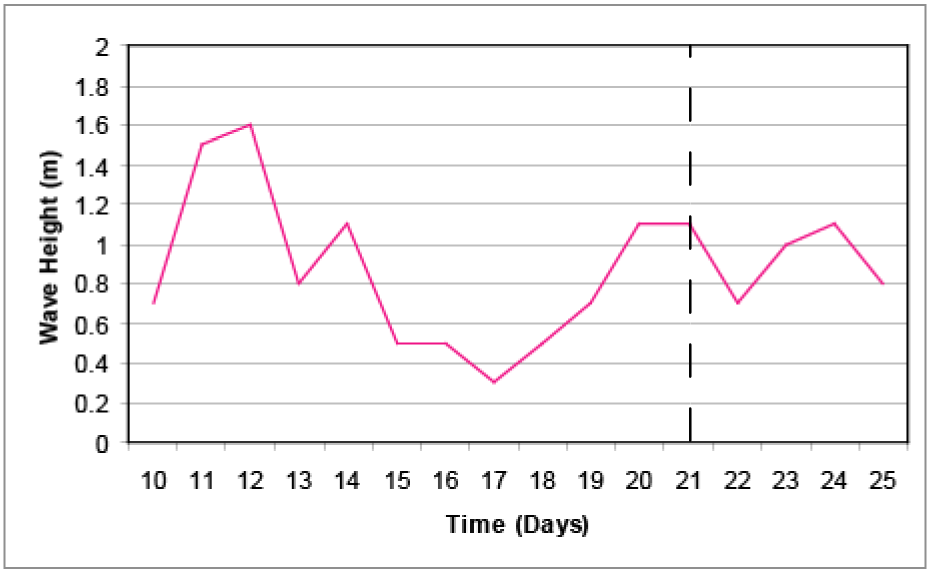

Figure 5.2: Wave conditions in the Long Island Sound preceding the May 2007 survey. The dashed line indicates date of survey.



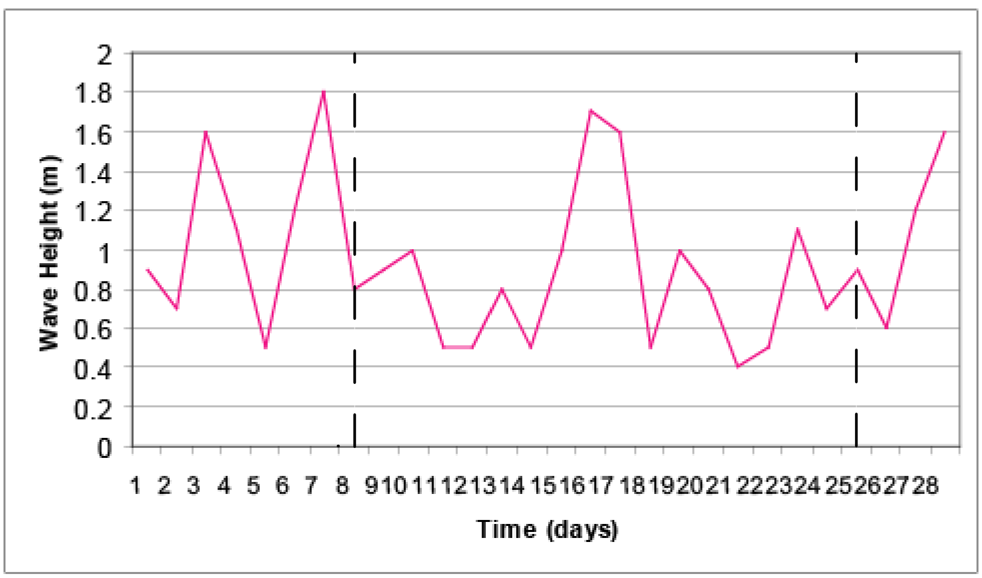

5.4: Wave conditions in the Long Island Sound occurring in the month of August 2007.




5.3: Wave conditions in the Long Island Sound preceding the September 2007 survey. The dashed line indicates date of survey.



5.5: Wave conditions in the Long Island Sound preceding the October 2007 survey. The dashed line indicates date of survey.



5.6: Wave conditions in the Long Island Sound preceding the November 2007 surveys. The dashed line indicates date of survey.

*5.3 Profile Changes*

Profile changes calculated for each survey were consistent within each beach. Bluff Point's Orange Stake and Sand Fence transects show similar trends. Beach profile 1 contained a possible bar accreted on the beach face. Profiles 2, 3 and 5 contained berms, while profile 4 was completely flattened out (Figure 5.1a and 5.1b).

Groton Long Point's transects also showed consistency with each other, but had different responses than the beach at Bluff Point. Profiles were relatively uniform with little or no berm and bar development. On the House 32 transect, profile 1 showed a flat terrace of sand near the seawall while profiles 3-5 displayed a possible small berm development (Figure 5.7a). The Picket Fence transect stayed mostly uniform (Figure 5.7b). Both transects depict a flat, offshore bar approximately 40 m from the beach.

The slope for each beach profile was calculated. At Bluff Point, the slopes were measured from 2 m above the berm to the shortest profile length. At Groton Long Point, the slope was measured from an estimation of where a berm would be to the shortest profile length. Bluff Point's profiles ranged from 9% to 11%. Groton Long Point's profiles ranged from 11% to 14% (Table 5.1).

Table 5.1: The slope of each transect for each profile. Abbreviations are for sites are as follows; BP is Bluff Point and GLP is Groton Long Point. Abbreviations for transects are; OS is Orange Stake, SF is Sand Fence, PF is Picket Fence, and H32 is House 32.

| | **15-May Profile 1** | | | **28-Sep Profile 2** | | | **21-Oct Profile 3** | | | **8-Nov Profile 4** | | | **25-Nov Profile 5** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BP | OS | 0.09 | BP | OS | 0.11 | BP | OS | 0.10 | BP | OS | 0.10 | BP | OS | 0.11 |
| | SF | 0.10 | | SF | 0.09 | | SF | 0.11 | | SF | 0.11 | | SF | 0.11 |
| GLP | PF | 0.13 | GLP | PF | 0.12 | GLP | PF | 0.11 | GLP | PF | 0.11 | GLP | PF | 0.13 |
| | H32 | 0.13 | | H32 | 0.14 | | H32 | 0.13 | | H32 | 0.13 | | H32 | 0.11 |

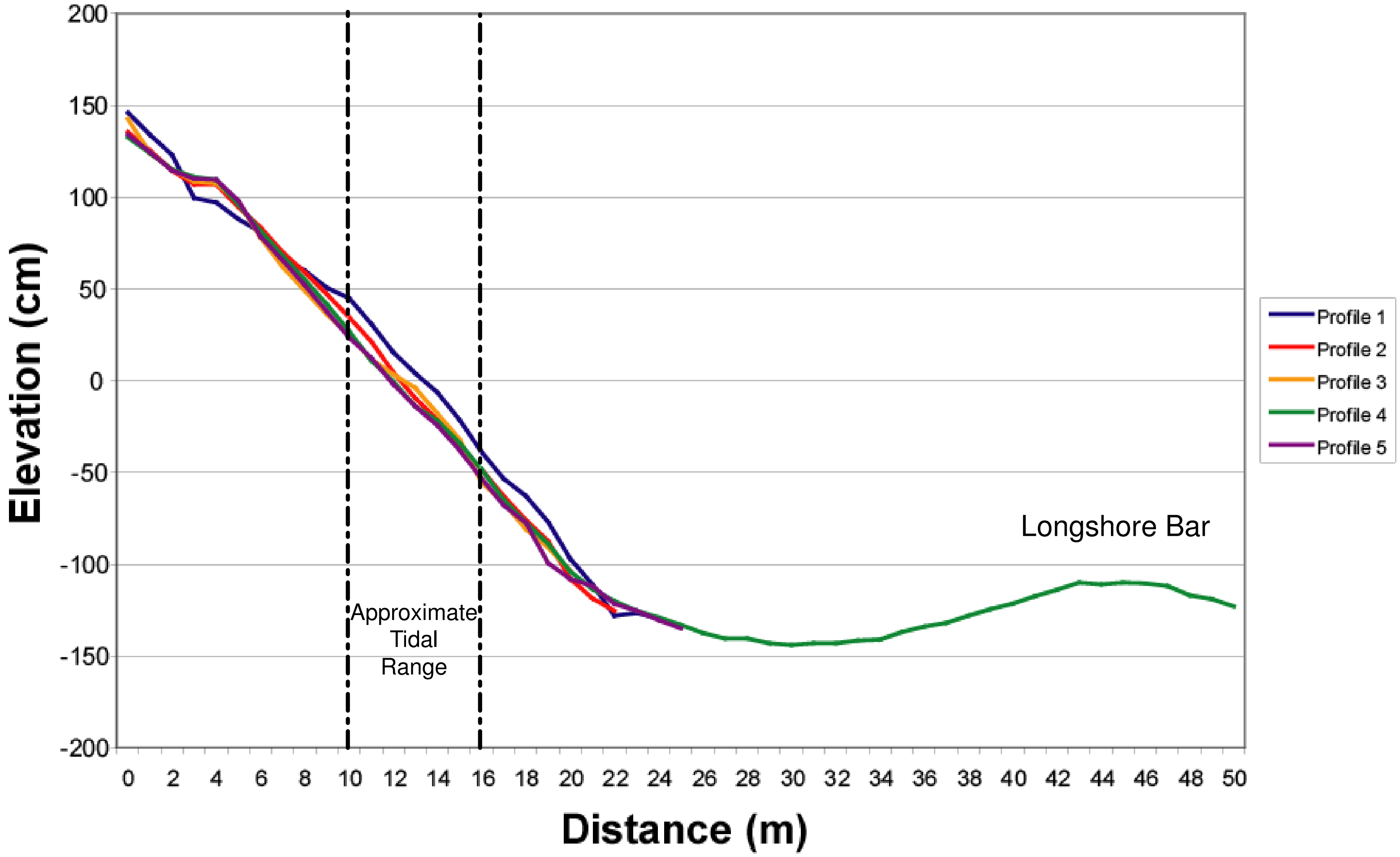



Figure 5.7a: Groton Long Point House 32 profiles. Each individual profile is marked in a different color as described in the legend. Notice the lack of beach features and the longshore bar measured 40 m from the seawall.

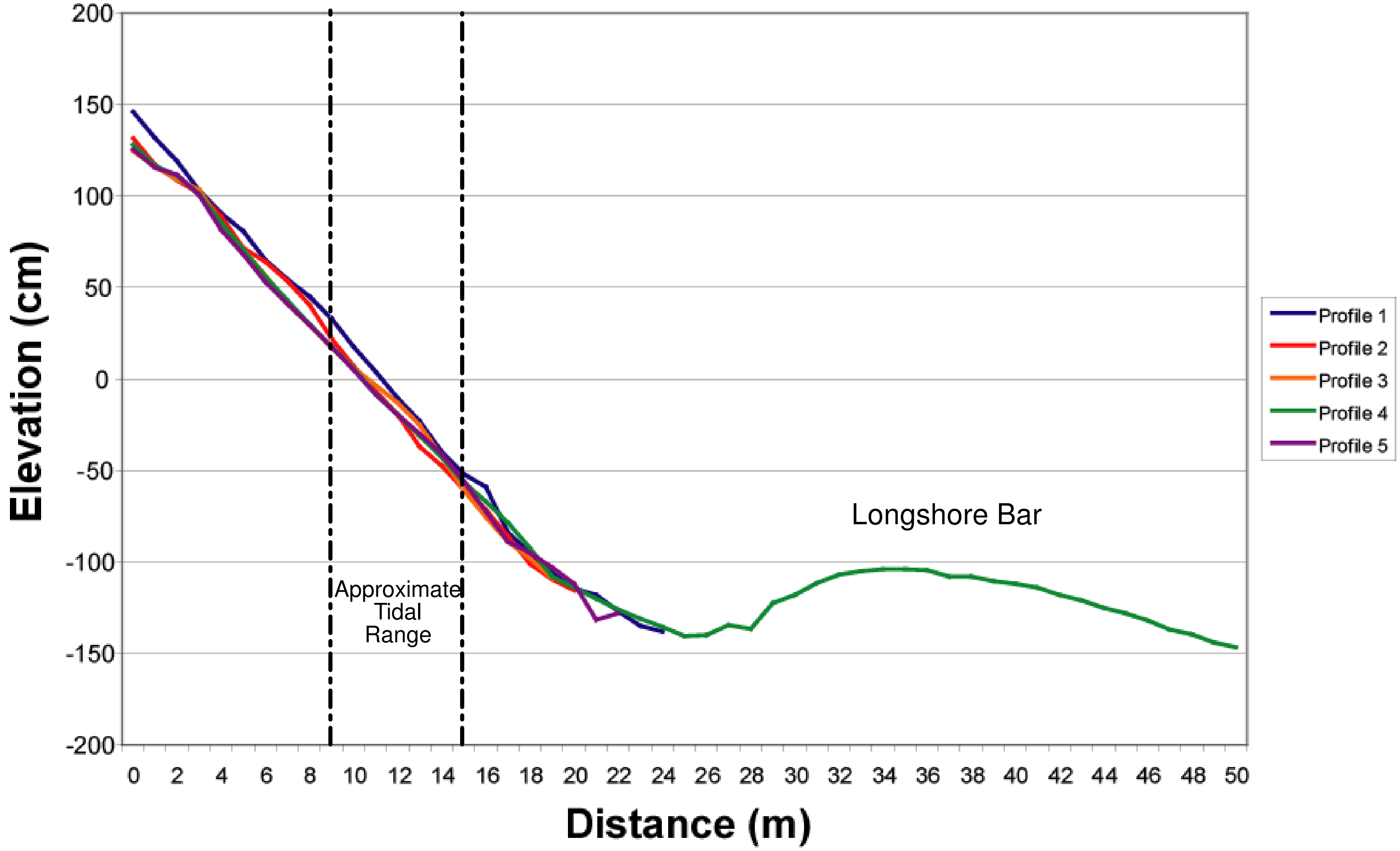



Figure 5.7b: Groton Long Point Picket Fence profiles. Each individual profile is marked in a different color as described in the legend. Notice the lack of beach features and the longshore bar measured 30 m from the seawall.

*5.4 Storm Response*

Profiles on each beach responded differently to Tropical Storm Noel and a subsequent nor'easter in November. After the storms, Bluff Point's Orange Stake transect had a trend of erosion on the beach face, losing a maximum -88.1 cm of sand (Figure 5.9). There was little change on the beach above water with a possible small berm build up. The beach was extremely cuspate after the storm with a high wrack line (Figure 5.8a and 5.8b). Three weeks later on November 25$^{th}$, the beach face seemed to have recovered most of the sand, with a net loss of only -4.9 cm (Figure 5.10). Again, the rest of the beach showed little change, except for possible trough development offshore.

Bluff Point's Sand Fence transect behaved similarly to the Orange Stake transect. Sand Fence had a net loss of -92.5 cm of sand on the lower beach. Again there was little change on the upper beach; however, Sand Fence's berm lost -38.0 cm of sand (Figure 5.11). After the storm, the beach was extremely cuspate and Sand Fence's upper beach measurement was taken on the ridge of the cusp. The lower beach recovered approximately 2/3 of the sand lost, which was about 60 cm of sediment, but still resulted in a net loss of -31.5 cm. (Figure 5.12). As the beach recovered, Sand Fence also accreted a berm.

Both transects at Bluff Point behaved comparably in response to the storm. Both transects had a net loss of sand on the lower beach after the storm. Each transect had a berm before the storm that was eroded after the storm (Figure 5.13a and 5.13b). After the storm, both transect's lower beaches began to recover the sand lost.

Figure 5.8a: Image of Bluff Point showing the wrack line in a post-storm survey on November 8, 2007.

Figure 5.8b: Image of Bluff Point showing cusp development in post-storm survey on November 8, 2007.

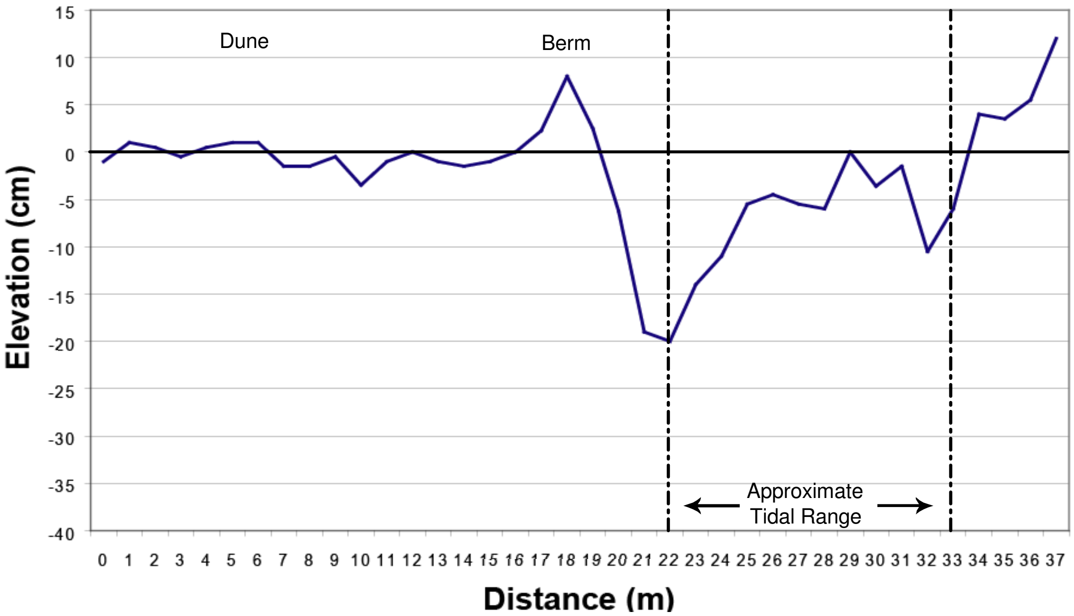



Figure 5.9: Bluff Point Orange Stake profile depicting the differences between a pre-storm survey (October 21, 2007) and a post-storm survey (November 8, 2007). The dashed lines represent the approximate tidal range. Note the dune and berm areas.

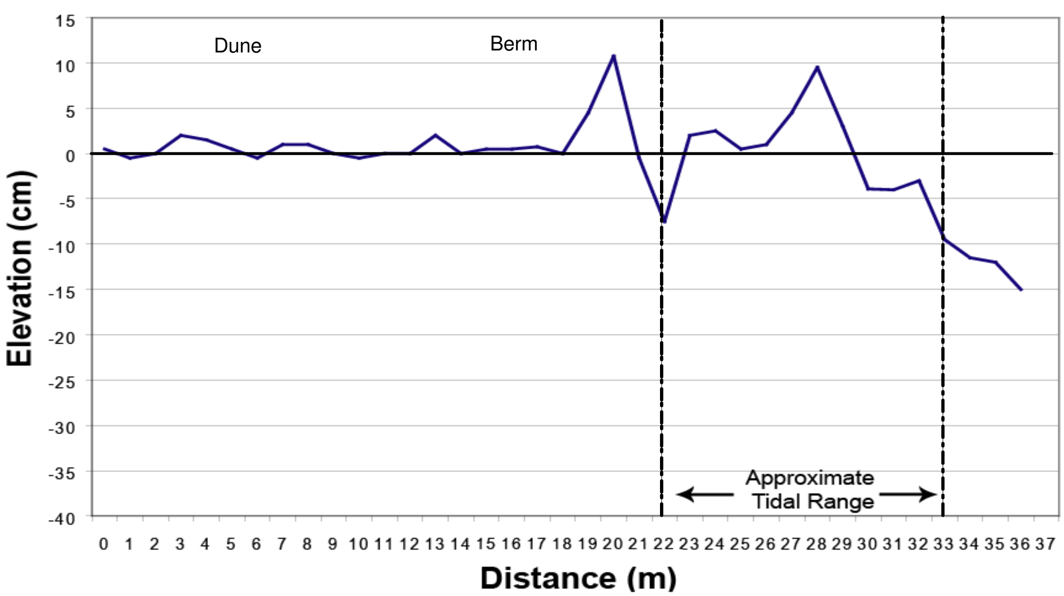



Figure 5.10: Bluff Point's Orange Stake profile depicting storm recovery. The differences are between a post-storm survey (November 8, 2007) and a storm recovery survey (November 25, 2007). Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Note the dune and berm areas.

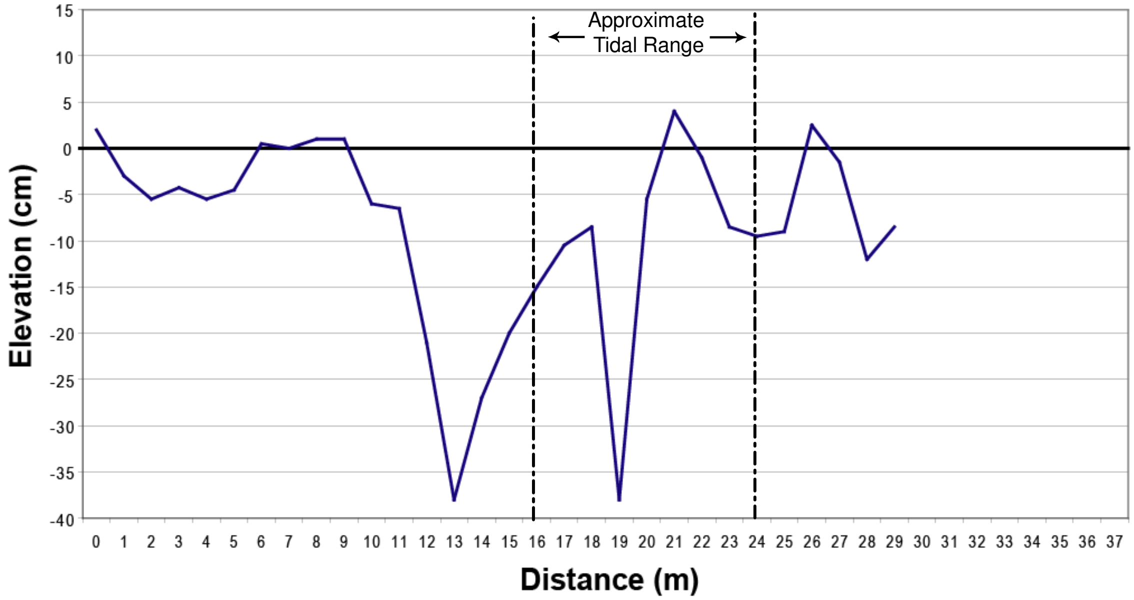



Figure 5.11: Bluff Point's Sand Fence profile depicting the differences between a pre-storm survey (October 21, 2007) and a post-storm survey (November 8, 2007). Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range.

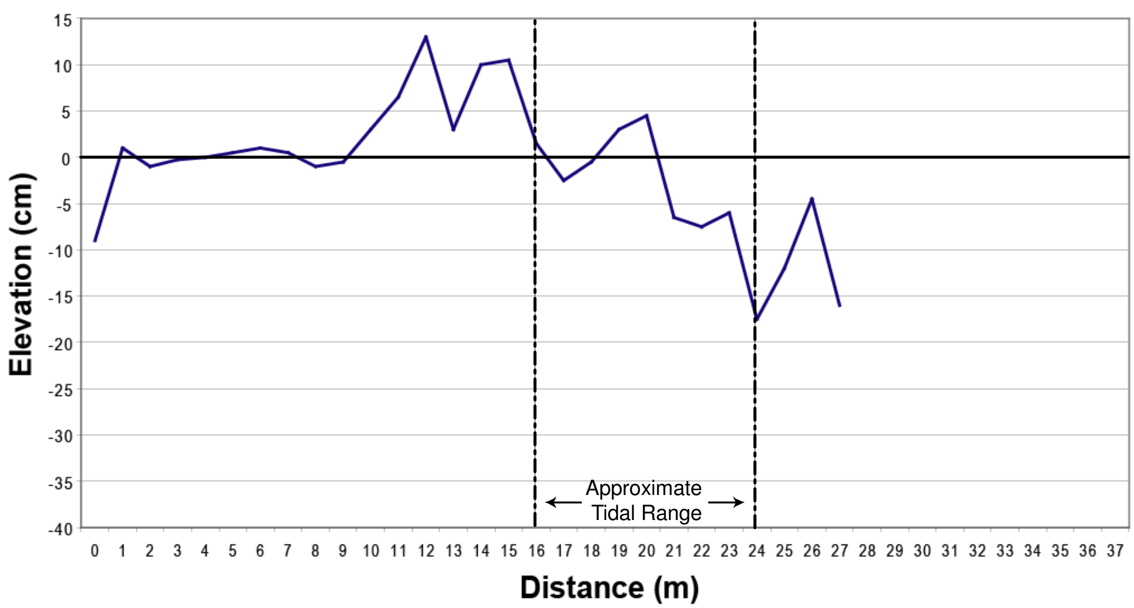



Figure 5.12: Bluff Point's Sand Fence profile depicting storm recovery. The differences are between a post-storm survey (November 8, 2007) and a storm recovery survey (November 25, 2007). Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range.

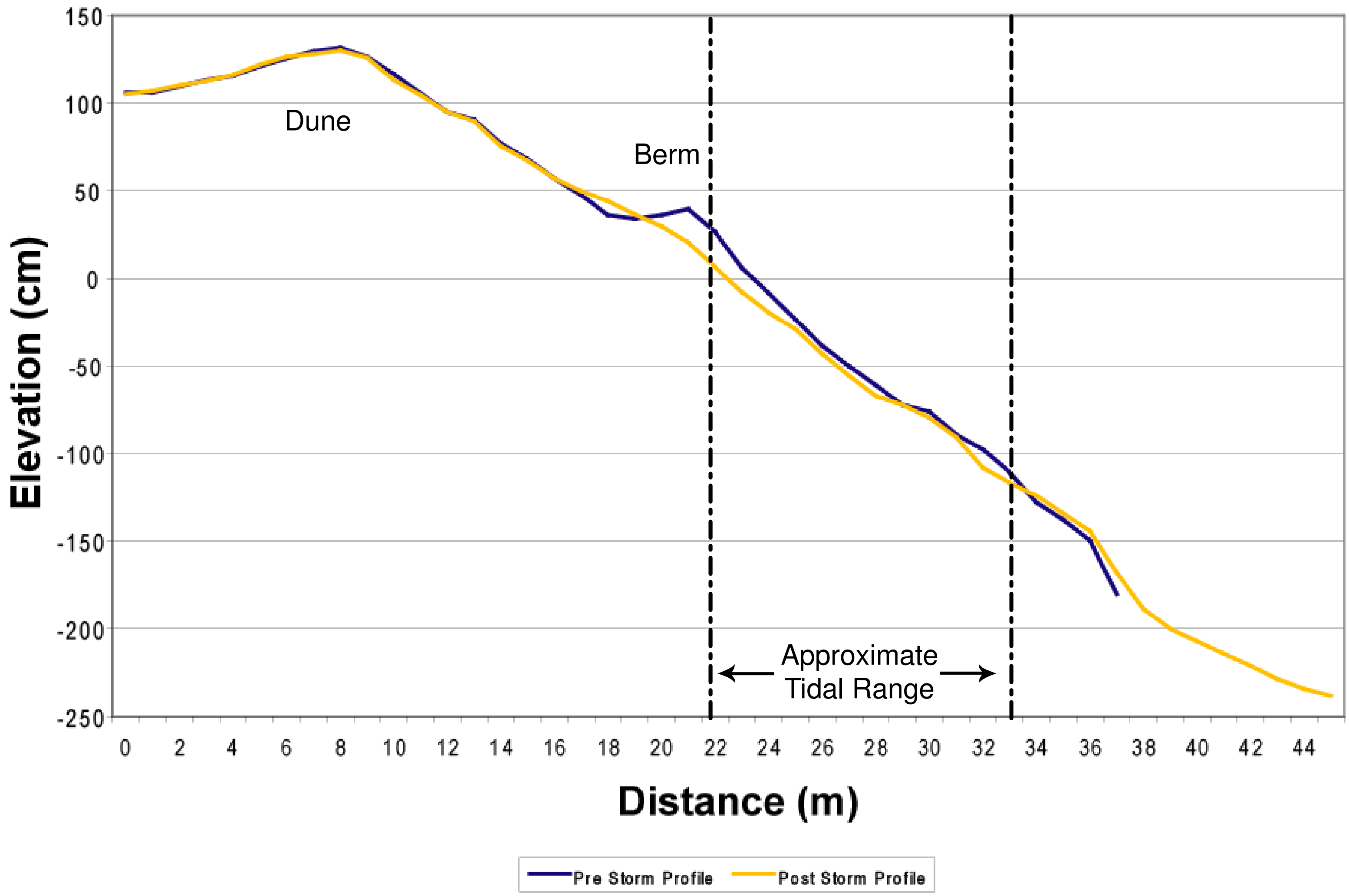



Figure 5.13a: Bluff Point's Orange Stake profile response pre storm (October 21, 2007) and post storm (November 8, 2007). Notice the consistency of the dune area and the development of a berm before the storm.

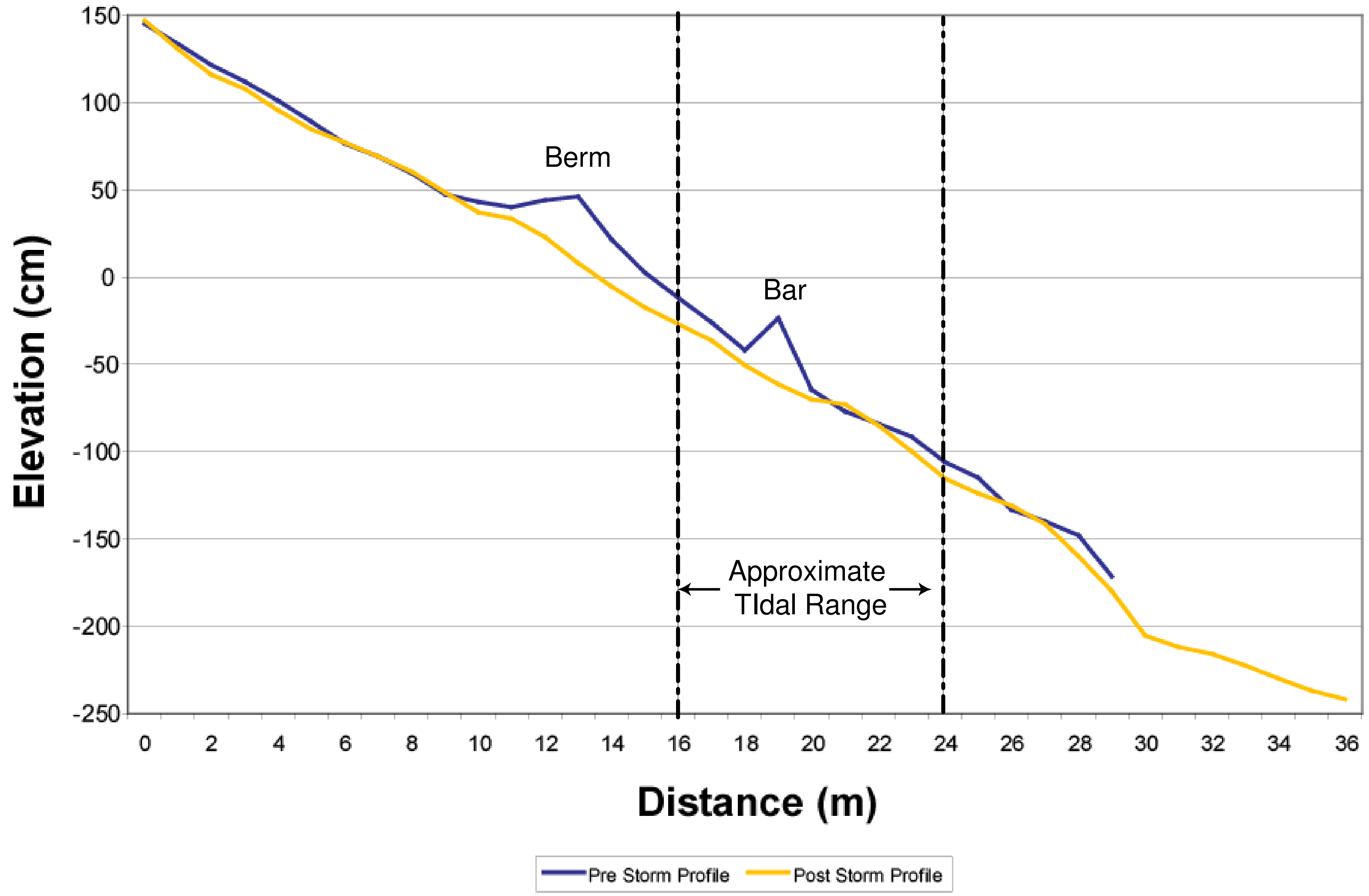



Figure 5.13b: Bluff Point's Sand Fence profile response pre storm (October 21, 2007) and post storm (November 8, 2007). Note the development of a berm and bar before the storm and the lack of features afterwards.

Groton Long Point's beach showed different trends in response to the storm. Profiles lacked features pre- and post-storm with little berm development (Figure 5.14a and 5.14b). Whereas there was no cusp formation at either transect, bar build up offshore was noticeable. The transect at House 32 showed a decrease in sand of -11.5 cm at the beach face (Figure 5.15). Change was extremely variable on the exposed beach, which lost -10 cm of sand at distance 0 m against the seawall. After the storm, the wrack line was near the seawall, which means waves could have reflected off the wall (Figure 5.17). Unlike the beaches at Bluff Point, House 32 cross section's lower beach did not recover but instead lost an additional -3.5 cm of sand. This created a total loss of -15 cm (Figure 5.16).

Groton Long Point's Picket Fence transect behaved a little differently than the House 32 transect. After the storm, Picket Fence had a net loss of -12.8 cm of sand with little change on the rest of the beach (Figure 5.18). Again, after the storm, the wrack line almost reached the seawall. Like the House 32 transect, the beach face recovery showed a trend of erosion (Figure 5.19). Clumps of debris were stranded around the westerly staircase (Figure 20). Storm response within Groton Long Point was similar.

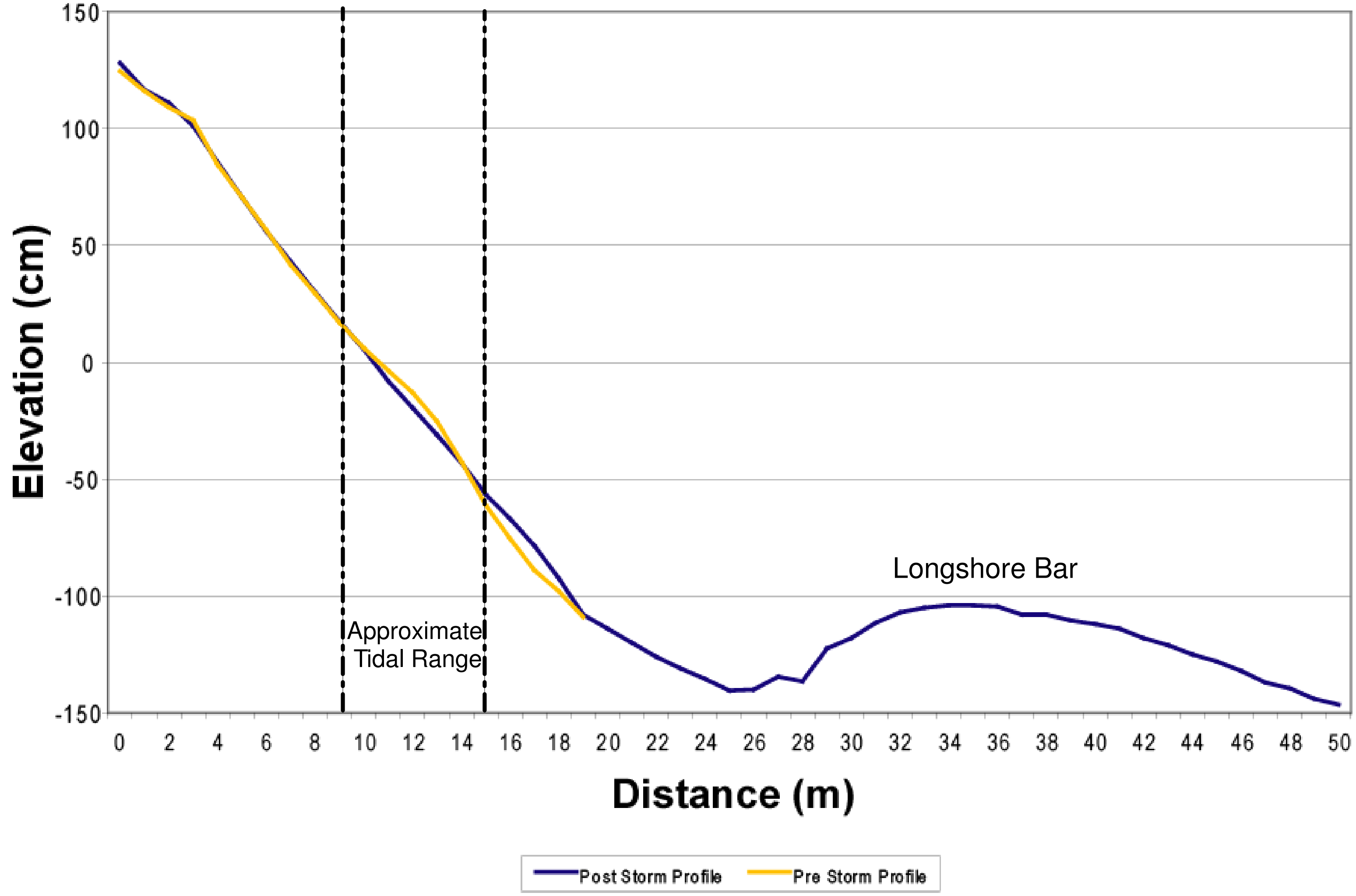



Figure 5.14a: Groton Long Point's Picket Fence profile response pre storm (October 21, 2007 and post storm November 8, 2007). Note the lack of features on both beaches.

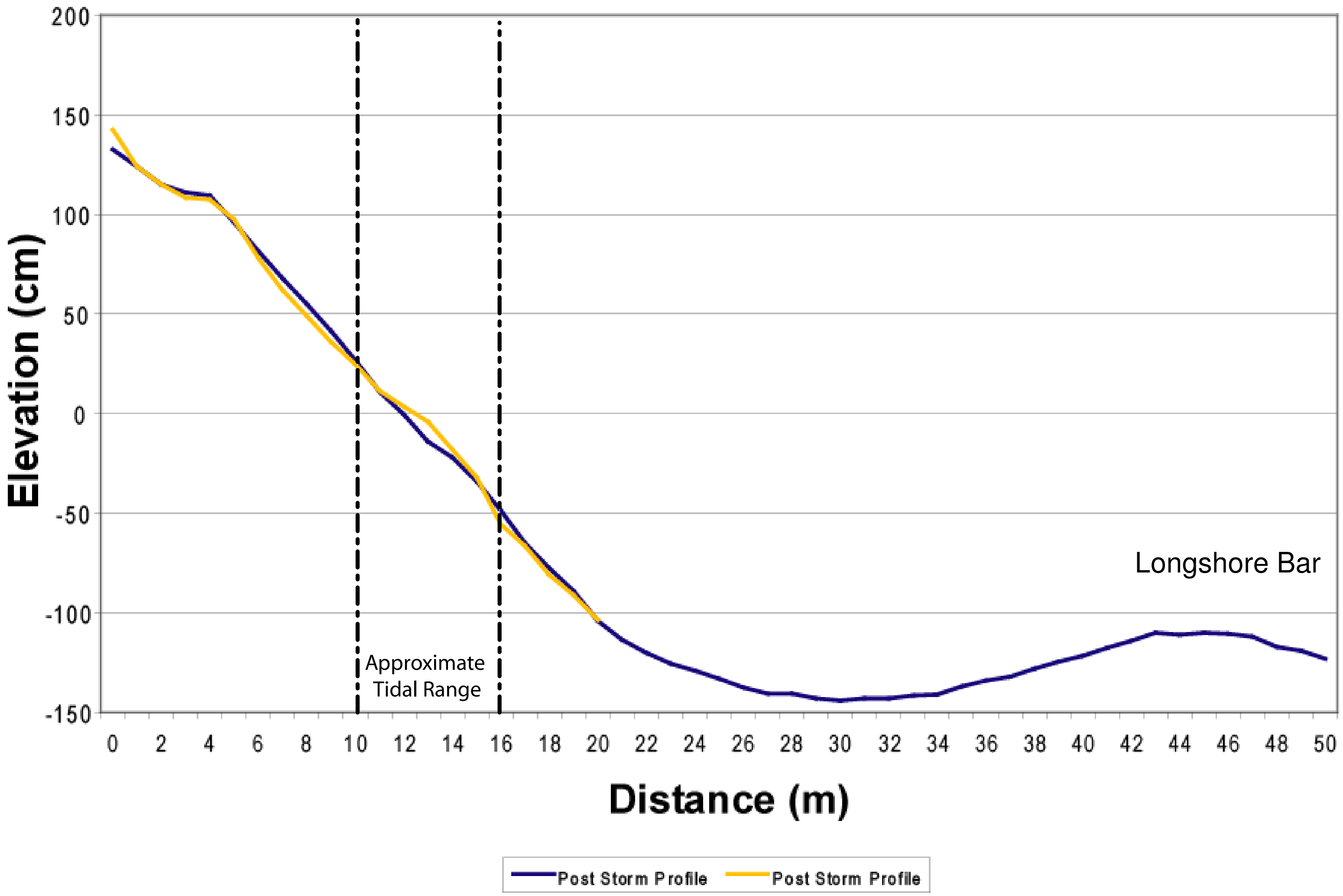



Figure 5.14b: Groton Long Point's House 32 profile response pre storm (October 21, 2007 and post storm November 8, 2007). Note the lack of features on the beach.

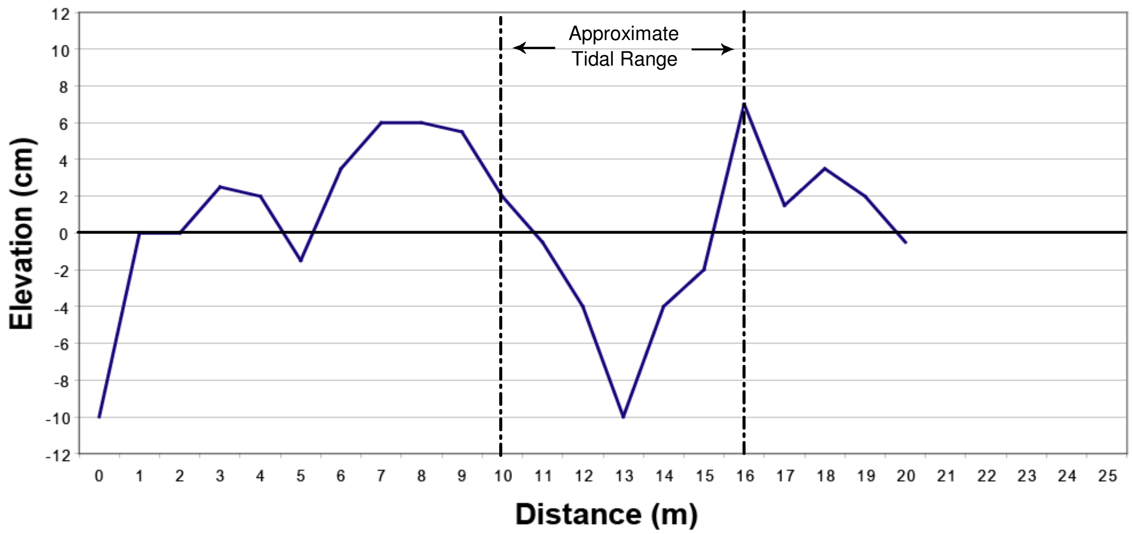



Figure 5.15: Groton Long Point's House 32 profile depicting the differences between a pre-storm survey (October 21, 2007) and a post-storm survey (November 8, 2007). Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range.

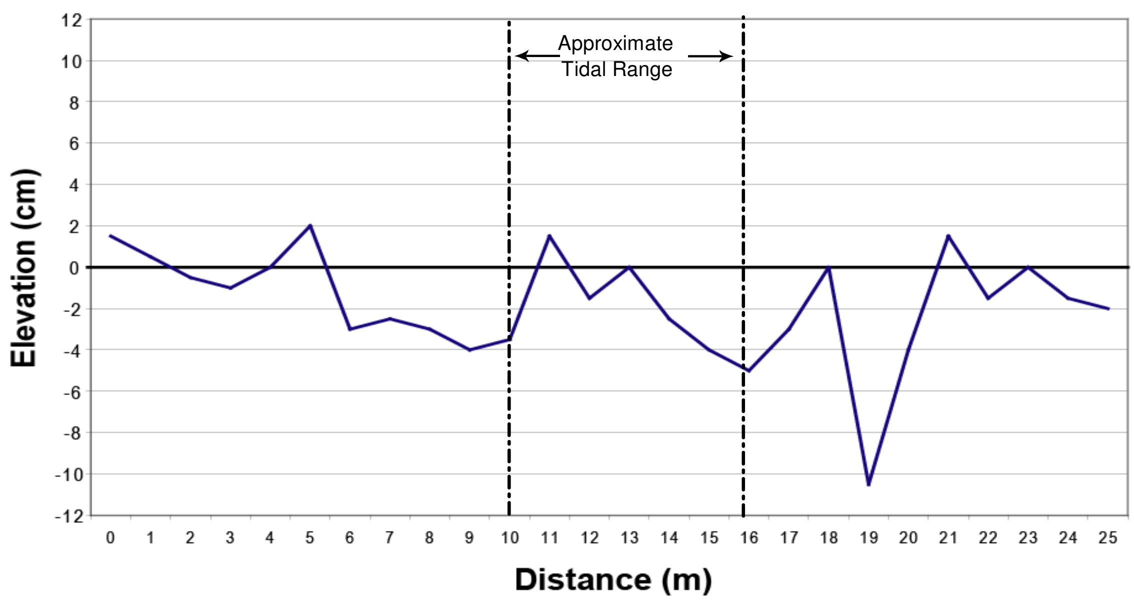



Figure 5.16: Groton Long Point's House 32 profile depicting storm recovery. The differences are between a post-storm survey (November 8, 2007) and a storm recovery survey (November 25, 2007). Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Notice the increased erosion.

Figure 5.17: Groton Long Point's accumulation of debris along the staircase after Tropical Storm Noel. The survey was taken on November 8, 2007.

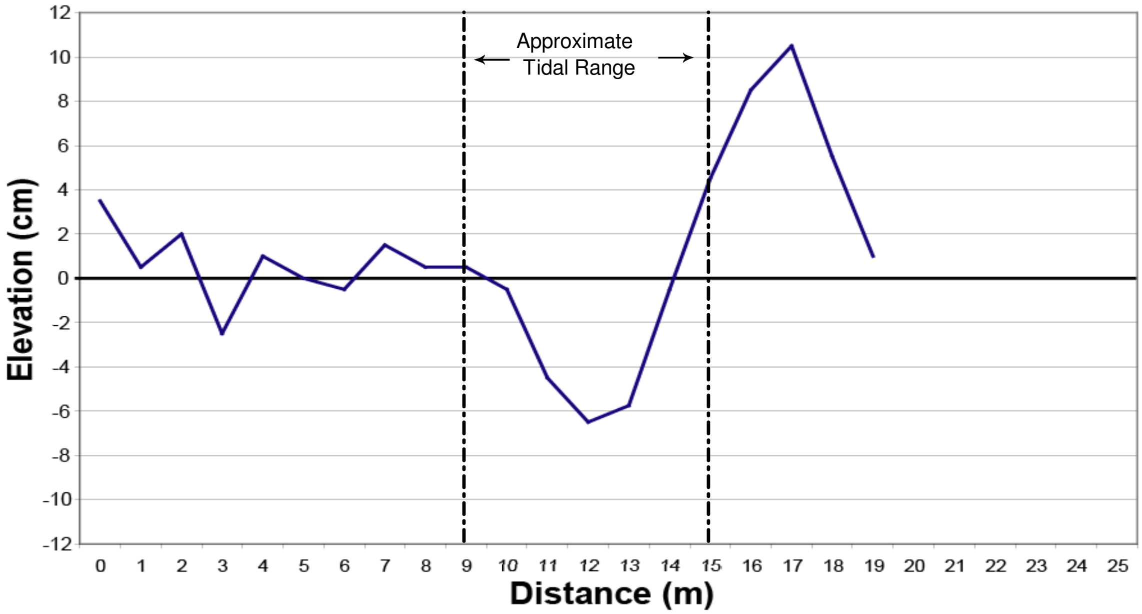



Figure 5.18: Groton Long Point's Picket Fence profile depicting the differences between a pre-storm survey (October 21, 2007) and a post-storm survey (November 8, 2007). Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range.

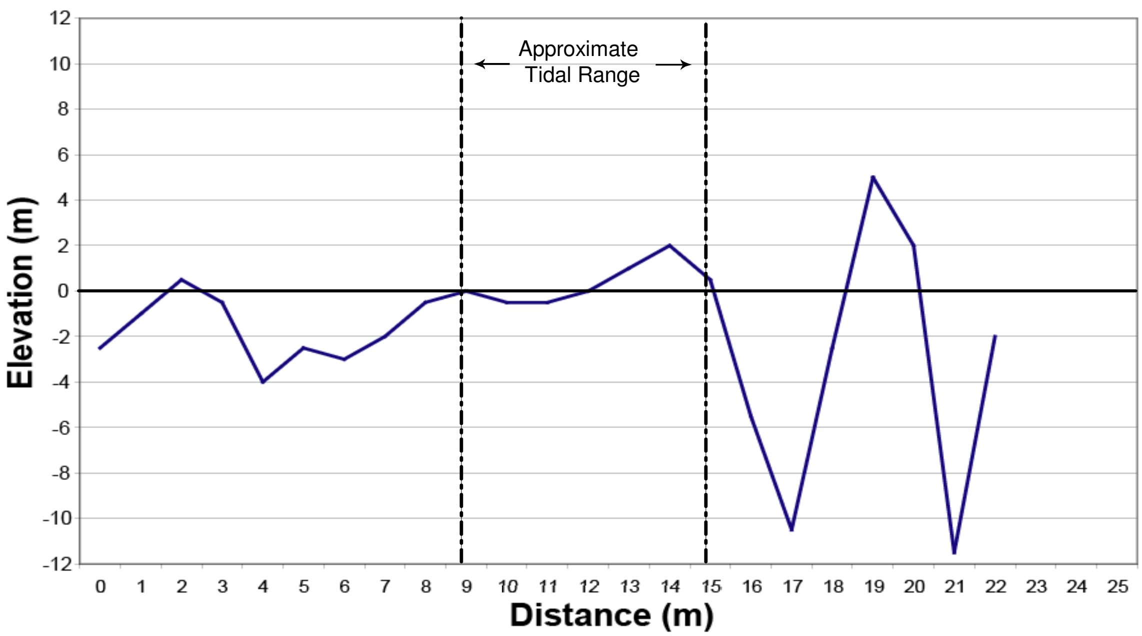



Figure 5.19: Groton Long Point's Picket Fence profile depicting storm recovery. The differences are between a post-storm survey (November 8, 2007) and a storm recovery survey (November 25, 2007). Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Notice the increased erosion.

Figure 5.20: Groton Long Point's wrack line after Tropical Storm Noel. The survey was taken on November 8, 2007.

*5.5 Long-Term Analysis*

Over the four year period, Bluff Point displayed little change. Comparisons from the last survey taken in December 2003 and the first survey taken in May 2007 show little to no change in the dune area of Orange Stake (Figure 5.21). There appears to be some berm and bar accretion over time. The net trend of the beach is positive with 81.5 cm of sediment accreted to the system. Sand Fence does not give as accurate a depiction of the system. The Sand Fence transect shows an unusually high amount of change at the dune area (Figure 5.22). Changes across the Sand Fence transect are extremely variable. To further observe the long-term change at Bluff Point, seasonal summer profiles were also compared. Again, measurements taken in the dune of Orange Stake showed little to no

change. (Figure 5.23). There also appeared to be berm and bar accretion. Data from the Sand Fence transect again was extremely uneven with accretion in the dune area (Figure 5.24).

Long-term change on Groton Long Point showed variability at the site. From December 2003 to May 2007 both transects depicted deposition to the upper beach. However, their lower beaches behaved differently. Picket Fence had an abundance of sand over the upper beach, although a drastic loss of sand directly near the seawall. The lower beach displayed a loss of sediment (Figure 5.25). House 32 also showed a loss of sand directly at the seawall, but then accreted sand over the upper and lower beaches (Figure 5.26). In comparing the September surveys, the beach face and offshore beach lost a tremendous amount of sand. House 32 ranged from a 20 cm of deposition to a -25 cm erosion. This transect experienced a net loss of -130.5 cm to the system (Figure 5.27). Picket Fence displayed erosion over the upper and lower beaches with a net loss of -289.5 cm (Figure 5.28).

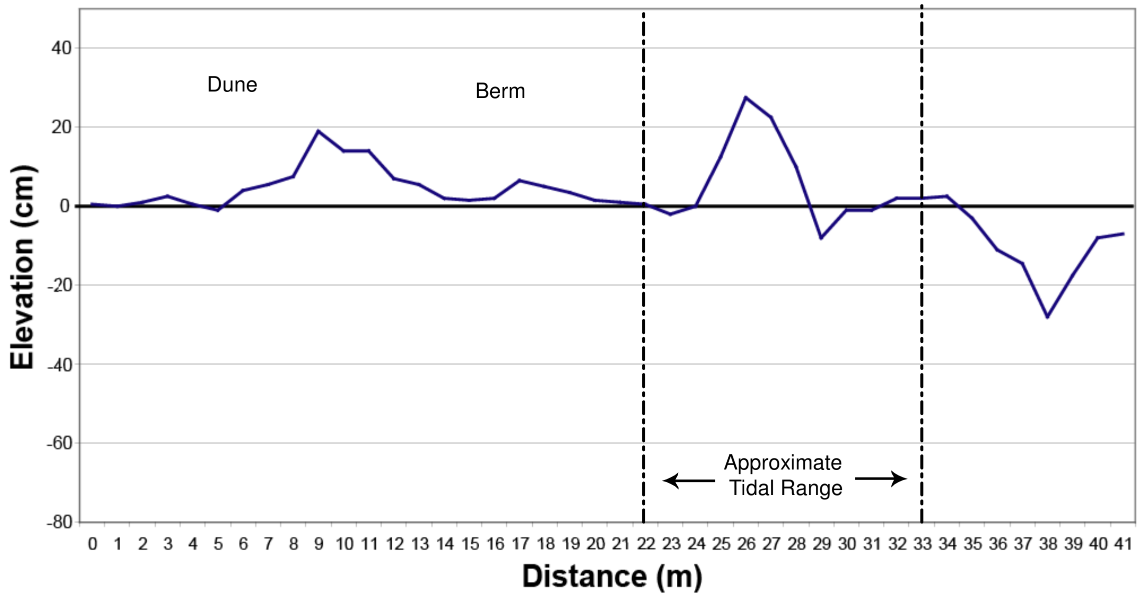



Figure 5.21. Bluff Point's Orange Stake long-term profiles change from December 2003 to May 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Note the consistency of the dune area and the accretion to the berm. Also notice the general trend of accretion.

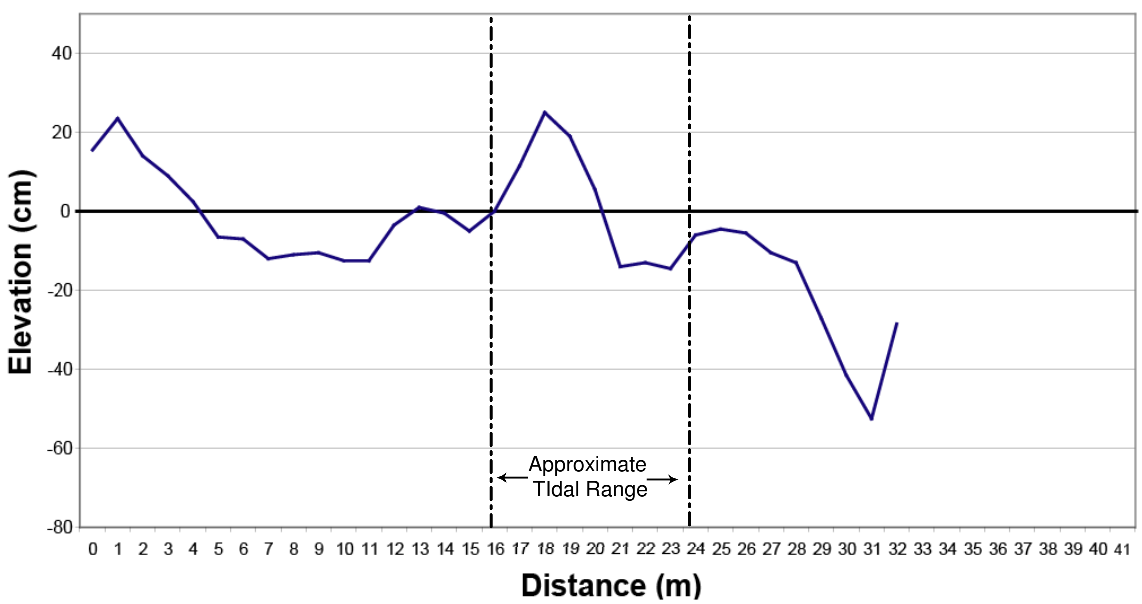



Figure 5.22: Bluff Point's Sand Fence long-term profile change from December 2003 to May 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Note deposition in the dune area.

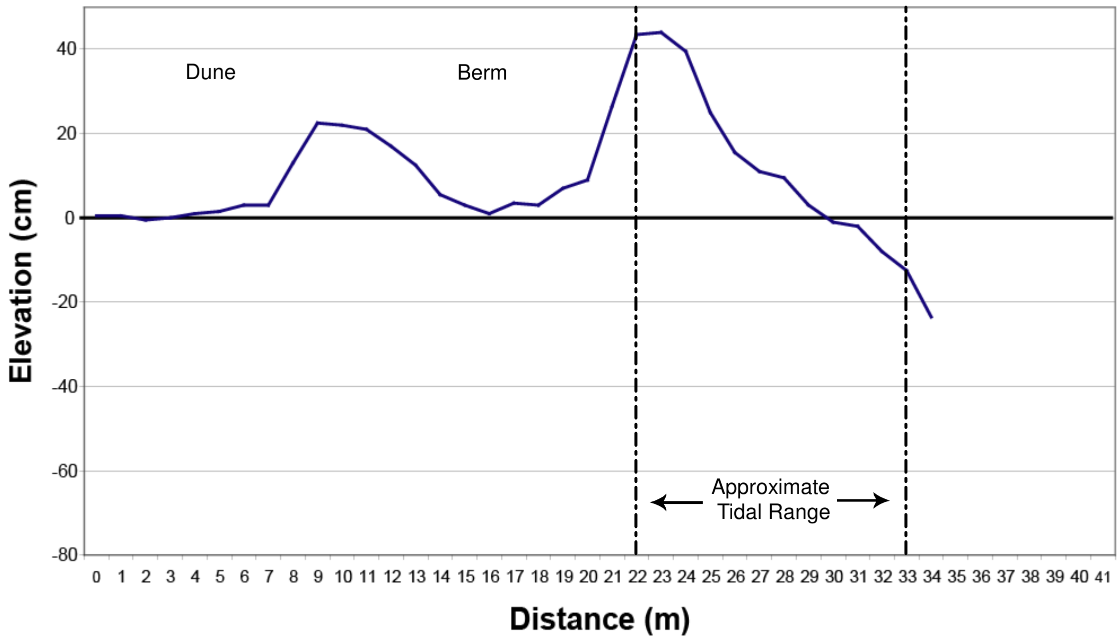



Figure 5.23: Bluff Point's Orange Stake long-term profile change from September 2003 to September 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Note the consistency of the dune area and the overall trend of accretion to the system.

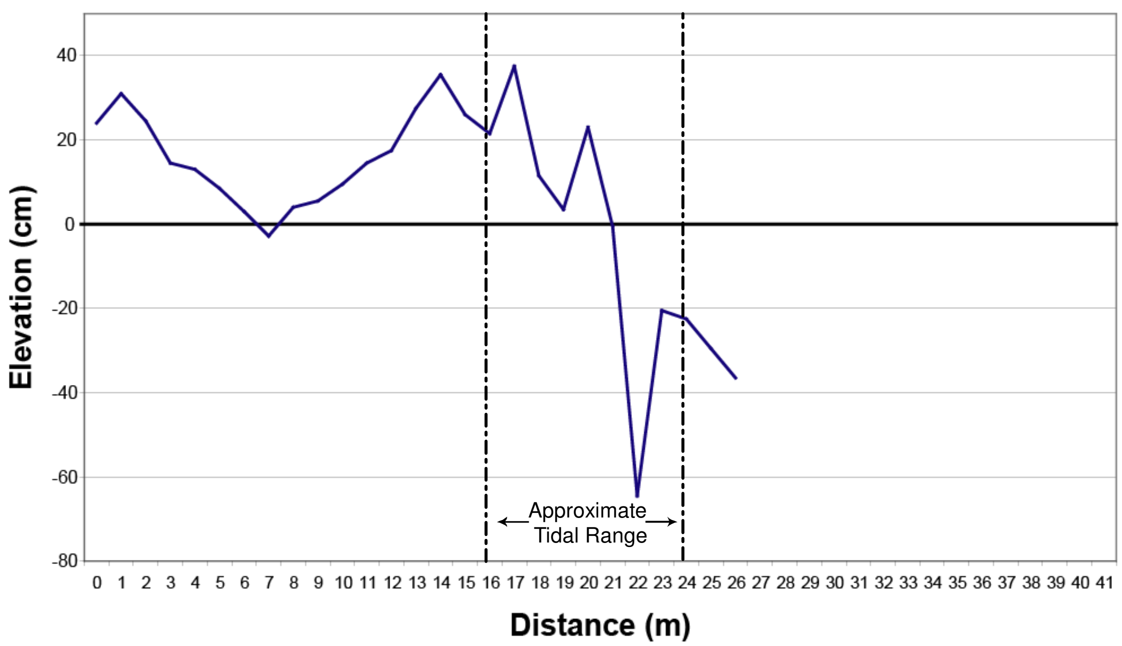



Figure 5.24: Bluff Point's Sand Fence long-term profile change from September 2003 to September 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Notice deposition to the dune area.

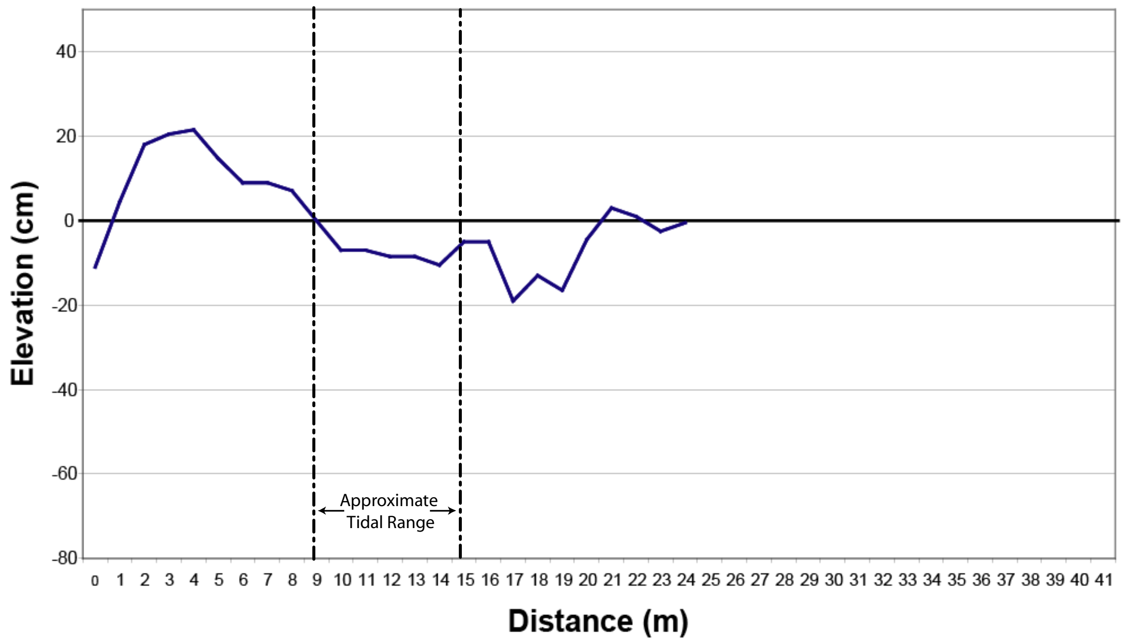



Figure 5.25: Groton Long Point's Picket Fence long-term profile change from December 2003 to May 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Note the offshore erosion.

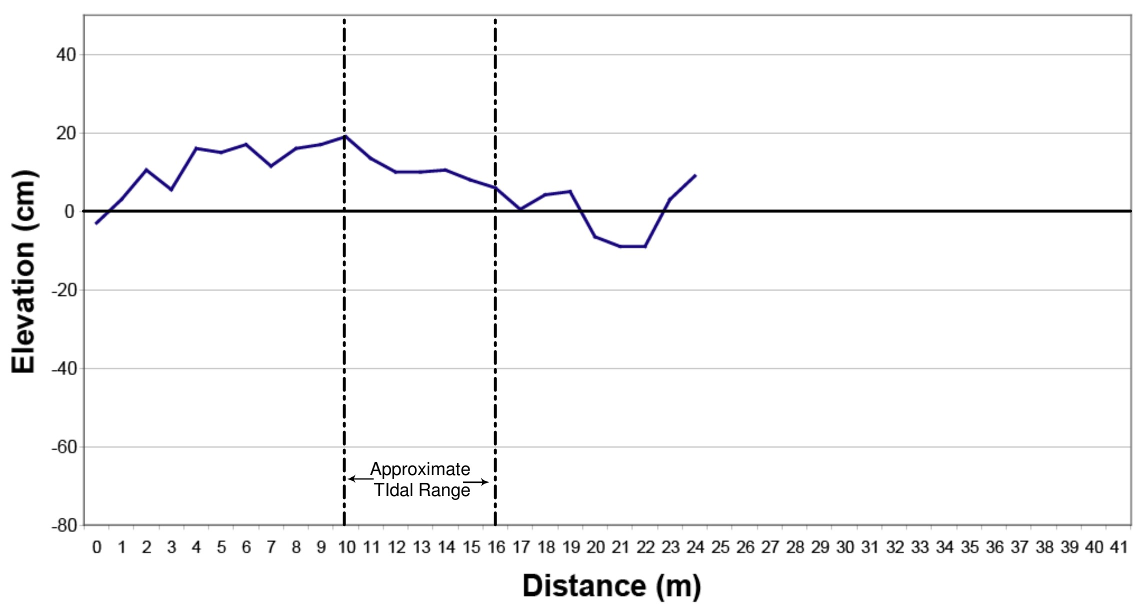



Figure 5.26: Groton Long Point's House 32 long-term profile change from December 2003 to May 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range. Notice the trend of accretion over the beach.

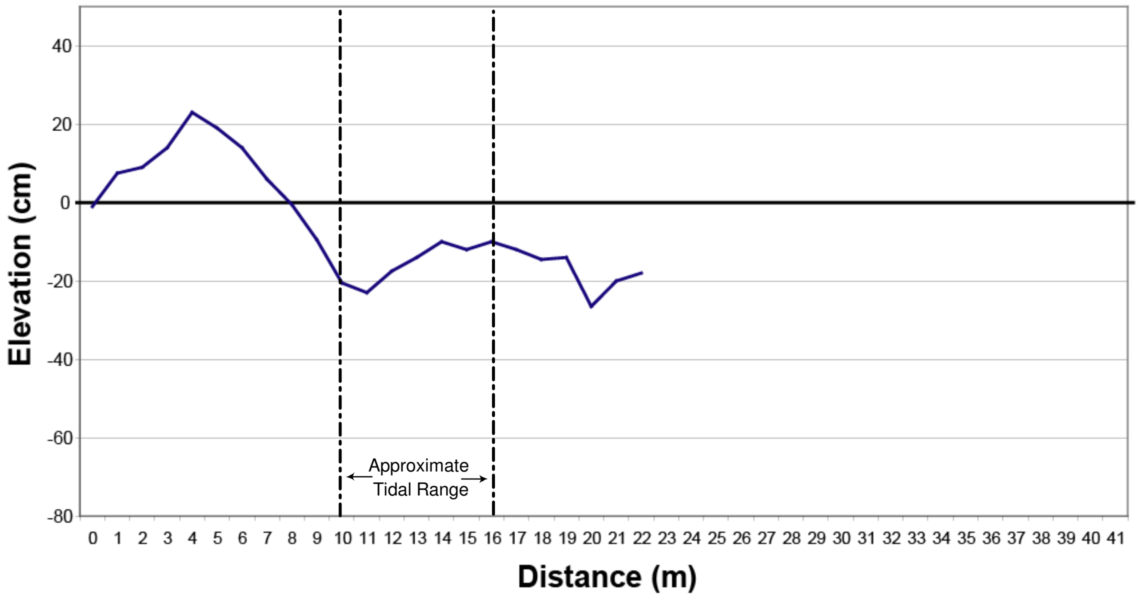



Figure 5.27: Groton Long Point's House 32 long-term profile change from September 2003 to September 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range.

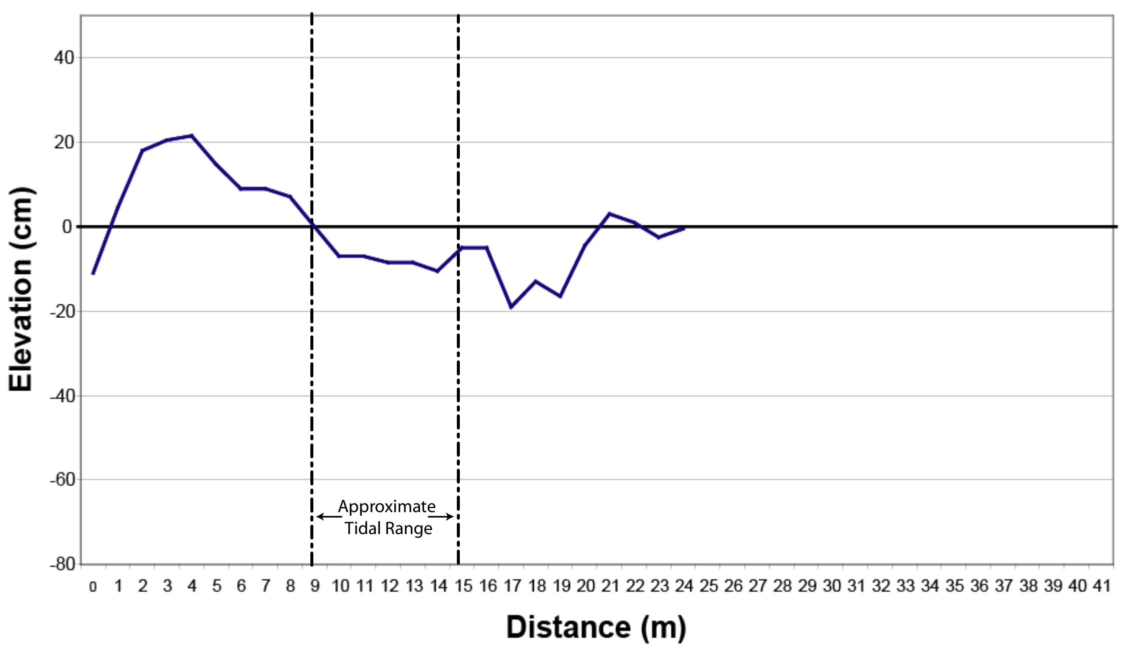



Figure 5.28: Groton Long Point's Picket Fence long-term profile change from September 2003 to September 2007. Everything below 0, depicted by the black horizontal line, is erosion, whereas everything above it is deposition. The dashed lines represent the approximate tidal range.

*5.6 Sediment Analysis*

Sediments at Bluff Point were noticeably coarser than those at Groton Long Point. Bluff Point contained sand, shells, and pebbles. The largest of these sediment, measured to be 38 mm, was much larger than the 16 mm sieve. A rock of this size was able to fit through the 32 mm sieve because the openings have a width and length of 32 mm but the diagonal is slightly larger. This rock's size is classified as a pebble, and is much larger than Groton Long Point's sediment which consisted of sand to very find sand. The upper beach at Bluff Point contained coarser sediment than their lower beaches. The beach at Groton Long Point consisted of much finer sediment but showed the same trend of coarser sand near the upper beach relative to the lower beach (Table 5.2).

Table 5.2: Calculated $D_{50}$, $D_{16}$, $D_{84}$ values for Bluff point and Groton Long Point. Abbreviations are for transects and are as follows; OS is Orange Stake, SF is Sand Fence, PF is Picket Fence, and H32 is House 32.

| | **Bluff Point** | | | | **Groton Long Point** | | | |
|---|---|---|---|---|---|---|---|---|
| | OS Upper Beach | OS Lower Beach | SF Upper Beach | SF Lower Beach | PF Upper Beach | PF Lower Beach | H32 Upper Beach | H32 Lower Beach |
| $D_{16}$ | 2.1 | 0.3 | 1.9 | 0.3 | 0.3 | 0.5 | 0.4 | 0.3 |
| $D_{50}$ | 4.9 | 2.5 | 2.8 | 0.4 | 0.3 | 0.7 | 0.5 | 0.7 |
| $D_{84}$ | 5.7 | 5.3 | 4.9 | 5.3 | 0.5 | 1 | 0.7 | 1 |

All Bluff Point samples had the least sorting, whereas the Orange Stake and Sand Fence transect samples were the least sorted of all sediment (Figure 5.29). Sand Fence's lower beach was bimodal, meaning there were two peaks instead of one. This is due to either two different processes or two different strengths of the same process taking place which indicates a mixed population of sediment and the bimodal distribution. In order to decipher how sorted the sediments are, the sorting indexes were calculated for all sites. The sorting index of sediment at Bluff Point's Sand Fence was the highest at 7.7, whereas sediment from Sand Fence upper beach was the lowest at 1.6 (Table 5.3). Groton Long Point again showed different trends.

The steepness of the graph of the sediment samples taken from Groton Long Point indicates strong sorting. There were no grains coarser than 8 mm (Figure 5.30). Sorting indexes of Groton Long Point were calculated to be less than Bluff Point's at similar positions along the beach, indicating Groton Long Point consisted of more well-sorted sediment. The sorting index of Groton Long Point's transects was all similar: House 32 lower beach was the highest at 1.8, whereas House 32 upper beach was the lowest at 1.4.

Table 5.3: Calculated sorting indexes for Bluff Point and Groton Long Point sediments. Abbreviations are for transects and are as follows; OS is Orange Stake, SF is Sand Fence, PF is Picket Fence, and H32 is House 32.

| Sample | Sorting Index |
|---|---|
| **Bluff Point** | |
| OS Upper Beach | 1.7 |
| OS Lower Beach | 5.9 |
| SF Upper Beach | 1.6 |
| SF Lower Beach | 7.7 |
| **Groton Long Point** | |
| PF Upper Beach | 1.5 |
| PF Lower Beach | 1.5 |
| H32 Upper Beach | 1.4 |
| H32 Lower Beach | 1.8 |

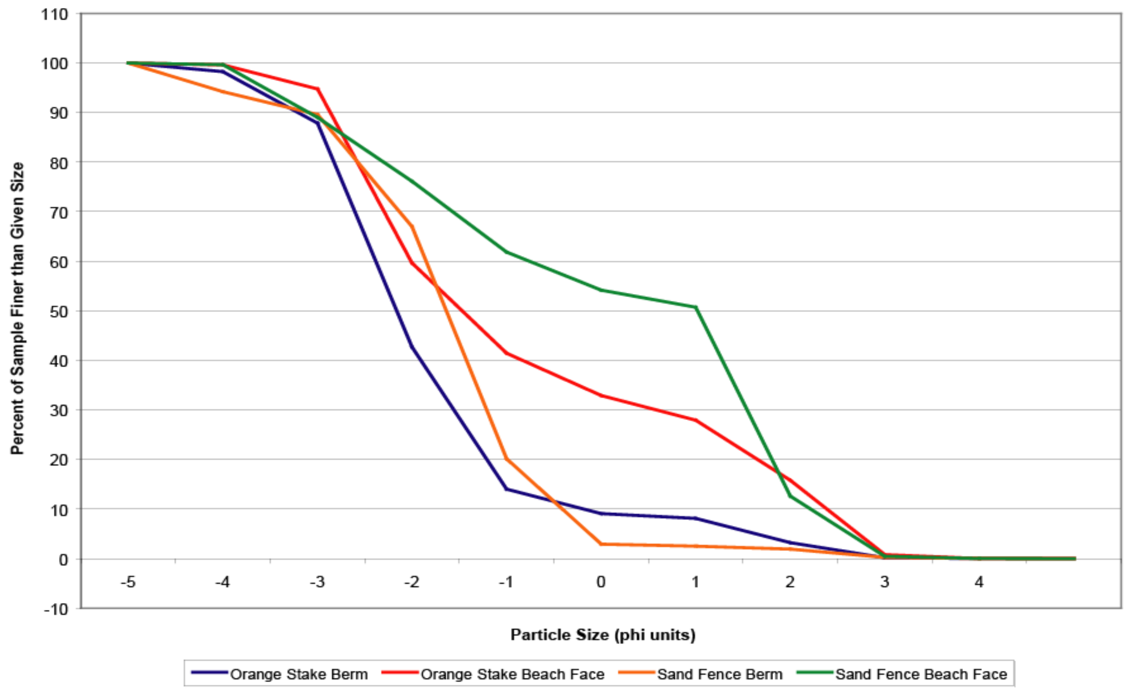



Figure 5.29: Bluff Point's sediment-size analysis. Note the coarse sediments and bimodal distribution of Sand Fence beach face.

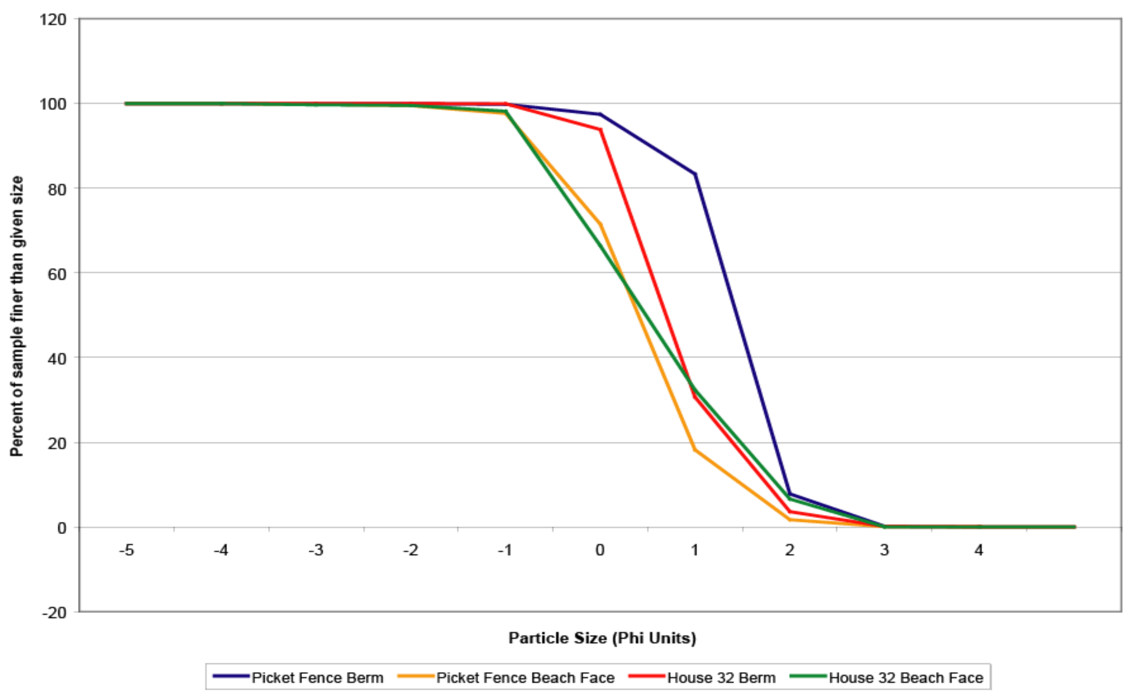



Figure 5.30: Groton Long Point's sediment-size analysis. Note the steep lines and the fine sediments.

## 6.0 Discussion

### *6.1 Seasonal Change*

Beaches at Bluff Point and Groton Long Point changed in response to various conditions from May to November 2007. The May 2007 profile (profile 1) for each transect was taken after the winter months, so it is considered representative of a winter profile, possibly transitional into a summer profile. Profile 2, measured in September 2007, can be considered a summer profile due to lower wave energy in the preceding months (Figures 5.3 and 5.4).

The Bluff Point beach system's seasonal response to wave energy closely resembles the classic "cut and fill" cycle (Komar, 1998). Summer profiles display a berm whereas winter profiles contain bar and trough systems. Bluff Point beaches respond to intensified wave energy in the winter by flattening out the beach profile by shifting sand offshore to create a bar. This winter profile serves to dissipate wave energy over a wide surf zone during storms. In the summer, lower wave energies deposit sediment on the beach creating a berm (Komar, 1998). This is also reflected in the slope of the beach, which stays relatively flat over the winter period and steepens during the summer.

In contrast, the beach at Groton Long Point did not respond to the seasonal change in wave climate in the same manner. Groton Long Point's lack of features, like a berm, shows that it does not behave naturally. Unlike Bluff Point, the two transects at Groton Long Point did not have the same response to the seasons. Both summer and winter profiles displayed a uniform slope. Neither transect showed any evidence of a "cut and fill" seasonal profile change. The beach slope at Groton Long Point was steeper in the winter than the one at Bluff Point, which is relatively flat. Groton Long Point's beach

did not flatten out like one would expect when responding to winter wave energy. The summer profile's steepness could be due to the human manipulation the beach endures before the summer season.

### *6.2 Storm Response*

As Boothyard et al. (1989) pointed out, modification of the shoreline oftentimes depends on storms. For Bluff Point and Groton Long Point, profile 3 was taken pre-storm and profile 4 was taken post-storm. Profile 5 can be considered representative of the beach system's recovery. The waves during tropical storm Noel and the subsequent nor'easter reached heights of 1.80 m in the Long Island Sound and had the potential to destroy the berm and shift the sediments offshore. The disappearance of Bluff Point's pre-storm berm, demonstrates the beach responds to a moderate storm normally (Boothyard et al., 1989). The zone the waves reached is also evident from the wrack line at Bluff Point. The location of the wrack line is a function of the swash uprush associated with wave breaking and water level elevation (Thornton and Jackson, 1998). Debris will then be left stranded on the beach as evidence of more intense waves than usual. Therefore, the position of the wrack line gives a good estimate of the strength of the waves, reaching over the berm almost to the dune area (Figure 5.9).

Erosion of sediment from a beach profile is a natural response to a storm (Dean, 1999). The erosion seen on the beach faces of the two transects at Bluff Point is a likely reaction to the storm. The lack of change above the wrack line verifies the consistency of this data. Analysis of post-storm and pre-storm profiles show offshore erosion and accretion. These are most likely bars and troughs, which are created when the berm is

destroyed and dispersed offshore (Boothyard et al., 1989). Beaches at Bluff Point also exhibited the first step to beach recovery after a storm, which is rapid forebeach accretion (Morton et al., 1994). The beach face here recovered more than 2/3 of the sediment that originally eroded. The formation of cusps on Bluff Point after the storm indicates that a dominate wave period was hitting the beach. Cusps are most likely to form when there are small longshore currents with monochromatic waves (Howd, 2008). Beach cusp formation is also favored on coarser grained, steep beaches (Werner and Fink, 1993).

In comparison to Bluff Point, Groton Long Point showed very little profile change in response to the storms. After the storm, Groton Long Point's featureless beaches remained uniform, with trends of erosion. Wrack lines on the beach were within 1 m of the seawall and reached its base in some places (Figure 5.20). Waves most likely did not uniformly reach the seawall due to the observation of footprints landward of the wrack line. Groton Long Point beach transects did not exhibit the same response to the storm, accentuating the variability along the beach here. The loss of -10 cm of sand at 0 m on the House 32 transect shows the unpredictability of the system. In contrast, Picket Fence displayed little change to the upper beach.

Storm recovery response was also unpredictable for Groton Long Point. Whereas one transect's beach face had continued accretion after the storm, the other actually lost more sand. Transects should differ less within a beach than between two beaches. The lack of a berm at Groton Long Point was also apparent. The flat zone on the House 32 transect was most likely a foot terrace due to human traffic along the beach. This terrace is not defined as a berm due to its elevation which is notably lower than the berms on Bluff Point. The erosion and accretion viewed across the whole exposed beach is similar

to beach processes occurring over the beach face. If waves crash close enough to the seawall during a storm, there is little room for berm development along the beach. Therefore, the entire beach at Groton Long Point functions like a beach face.

*6.3 Long-Term Trends*

Bluff Point displayed little long term change over the course of four years. Again, there was little to no change in the dune area of Orange Stake, further demonstrating the accuracy of the surveys taken and the certainty of the data. Sand Fence transect was more difficult to locate because the sand fence had been knocked down from its original location. The inconsistency of the 2007 transect compared with the 2003 transect displays the original transect was not located. The dune shows an amount of deposition over 20 cm. Because the wrack line rarely reaches this high, it can be assumed that the transect lines do not match up exactly. While aeolian processes do have an impact of dune formation, it is unlikely the wind would have created such a change in dune height in this one year over a four year period. Therefore the Sand Fence transect cannot be used to portray the long-term change of Bluff Point.

Berm accretion on Bluff Point could be due to the dates the surveys were measured. The 2003 survey was measured in December, whereas the 2007 survey was measured in May. Whereas the May survey represents a winter profile, it is transitional to a summer profile because of the low wave energies (<1.00 m) during the month. Therefore, a small berm may have been accreted. Bluff Point had a trend of deposition over the four year period. This is ultimately good for the beach because it is not losing sand. To further observe the long-term change at Bluff Point, summer profiles were also

compared. Again, measurements taken in the dune showed little to no change, which was expected. The accretion of the bar and berm further accentuates net deposition in the system. Despite meteorological factors like storms, Bluff Point continues to accrete sand because of the reservoirs of sand around the area. If sand is eroded from the system, the dune and headlands bordering the beach could potentially provide enough sediment to transfer to the beach.

Long term change on Groton Long Point was irregular. From December 2003 to May 2007, both transects showed accretion to the upper beach, but their lower beaches behaved differently. One transect exhibited deposition of sediments over the past four years, while the other transect showed erosion. Two transects were measured in order to get a better idea of how the entire beach system behaves. The fact that the two transects from Groton Long Point do not match up highlights the variability along the entire beach system here. In comparing the September surveys, the beach face and offshore beach lost a tremendous amount of sand. Whereas in some areas minimal accretion occurred, the beach has been losing sand over the past four years (Figures 5.27 and 5.28). Campbell (2004) discovered Groton Long Point constantly had the largest amount of scour to the beach. This research only compares the first 30 m of the beach. Surveys taken on especially low-tide days revealed a large bar offshore at about 40 m. This bar could be where the sand is accreting, so it may not be entirely out of the system. It seems that the effect the seawall is having is creating an unpredictable beach response to storms.

*6.4 The Seawall*

Groton Long Point's variability suggests that the entire beach behaves like a beach face. While Bluff Point is seeing a healthy trend of accretion, most of the sediment from Groton Long Point has been eroded. Seawalls are responsible for creating an obstruction between any rocky headlands but also prevent a dune from forming (Pilkey and Wright, 1998). Groton Long Point lacks a dune and, therefore, the seawall could have cut off any new sand supply to the system. If the waves hit the seawall during large storms, like tropical storm Noel, then there is little room for berm development.

The difference in slope between the two beaches further accentuates that Groton Long Point is an anomaly. Usually beaches containing coarser sediments retain a steeper slope than fine sanded beaches (Komar, 1998). Campbell's (2004) observance of sand accumulating at the base of the wall suggests that the seawall is creating an obstruction to berm or dune development. This sand is moved seasonally to reshape the beach to create a flat beach face conducive for recreation. However, even once the beach is flattened out it is still steeper than its neighbor, Bluff Point beach. This is an indication that while modification does have an impact on the area, it is less than the effect the seawall has.

Seawalls are built in order to protect homes (Dean, 1999). Groton Long Point has not been impacted by any severe storms for decades, but seawalls only work until they are undermined or fail. The beach can no longer recover from storms as a normal beach would, as dune formation is not allowed in this system (Morton et al., 1994).

The differences observed between Bluff Point and Groton Long Point show unpredictability to the man-made system. Not enough evidence exists to prove the beach is actually losing sand to the depth of closure. However, IPCC reports confirm

consistency in future continued sea-level rise. Whereas the Groton Long Point beach can continue being reshaped, the seawall is the landward limit to the system. Therefore, the beach cannot migrate inland as a natural beach would, putting the land as well as the homeowners in jeopardy.

More research must be done in order to better comprehend how these two beaches evolve. Understanding the evolution of the large flat bar off the coast of Groton Long Point would be helpful in determining whether the sediment accretes there year round. Profiles did not extend far enough offshore to evaluate the bar's evolution. This would help to explain whether Groton Long Point is actually losing sand or if it is being retained offshore in a possible sink. Groton Long Point also may receive slightly lower wave energy than Bluff Point. The large offshore bar may break waves further offshore. If this is the case, the finer sediments and the steep beach face could be due to lower wave energy. Given these facts, it is even more likely the seawall is impacting the area because the beach still lost more sand than Bluff Point. These areas are important to keep researching in the long-term to examine if Bluff Point responds to sea-level rise differently than Groton Long Point.

## 7.0 Conclusions

Beach profiles measured at Bluff Point and Groton Long Point both exhibited changes due to storms, seasons and a four year period. Bluff Point's response to the storm can be defined as a normal response (Boothyard et al., 1989). The high wave energy removed the berm and dispersed sand offshore in a bar. Bluff Point showed evidence of Komar's (1998) description of a "cut and fill" cycle through the seasons. The summer profiles were characterized by large wide berms, whereas the winter profiles lacked berms and contained bar and trough systems. Finally, Bluff Point displayed a trend of deposition over a four year period, with sediment most likely supplied by the dunes and headlands bordering the beach.

On the other hand, Groton Long Point exhibited much more variability. In response to the storm, the beach transects were different; where one beach eroded sand, the other displayed deposition. Also, the wrack line was close to the seawall, which indicates that there was little room for any berm development on the beach. Summer raking may have an impact on berm formation, however, more research must be done focusing on the berm area. Summer and winter profiles lacked features, displayed a uniform slope, and showed no evidence of seasonal profile change. In regards to long-term change, the two transects behaved differently, further highlighting the variability along this beach system. Therefore, is it hard to estimate how the beach will behave in the future.

Whereas the seawall protects homes from moderate surge, it presents a potential future hazard to the community of Groton Long Point. The seawall does not seem to be contributing to active erosion of the beach during the study period; however, a strong

storm surge and sea level rise could be threatening to this community. Seawalls prevent dunes from being formed, so the seawall is cutting off any new sand supply to the system. Removing the seawall is not an option because it provides a minimal buffer for current storms. However, a large storm surge could overtop the wall, and without any dune to diffuse the waves, homes in this community could be damaged or destroyed.

Sea level has been rising for the last 15,000 years and will continue to do so. Global warming has sped this rise to a historically unprecedented rate, and Groton Long Point's beach will slowly retreat to the seawall until it disappears. While the Groton Long Point community maintains the beach and makes it wider by pushing sand down from the seawall before the summer season, this will not always be an option. The manmade physical altering of this beach cannot be undone without creating further risk for the development in this area. In order to keep this a summer resort, residents will have to look into replenishment of the beach in the future. However, even this suggestion is short-term given the predicted magnitude of sea level rise.

Hard stabilization on beaches is a risky action to take. Even though it cannot be proved that the seawall is actively eroding the beach at Groton Long Point, Bluff Point beach's continued accretion make it the healthier beach overall. Therefore, it will be able to keep better pace with sea level rise in the future as the beach retreats inland. Hard stabilization methods may provide short-term benefits from storms, but overall they are destroying the beaches on our coastlines. Once sea level rises to the hard structures, beaches will be unable to retreat landward and cease to exist.

## 8.0 References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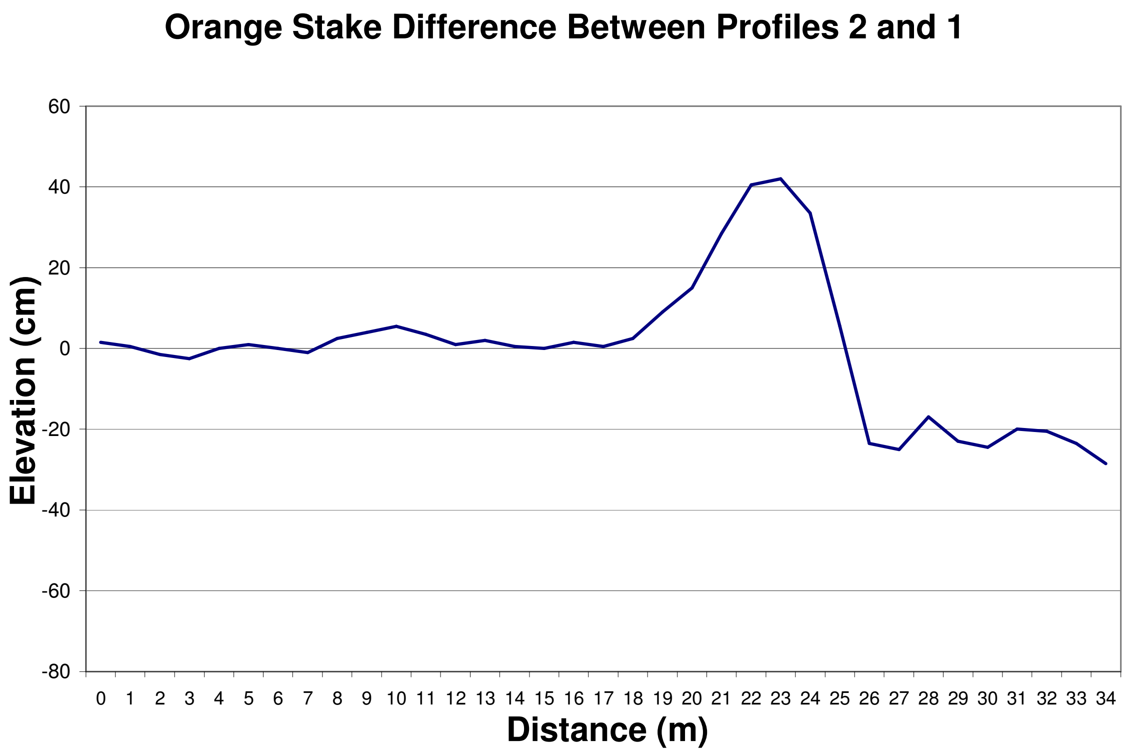
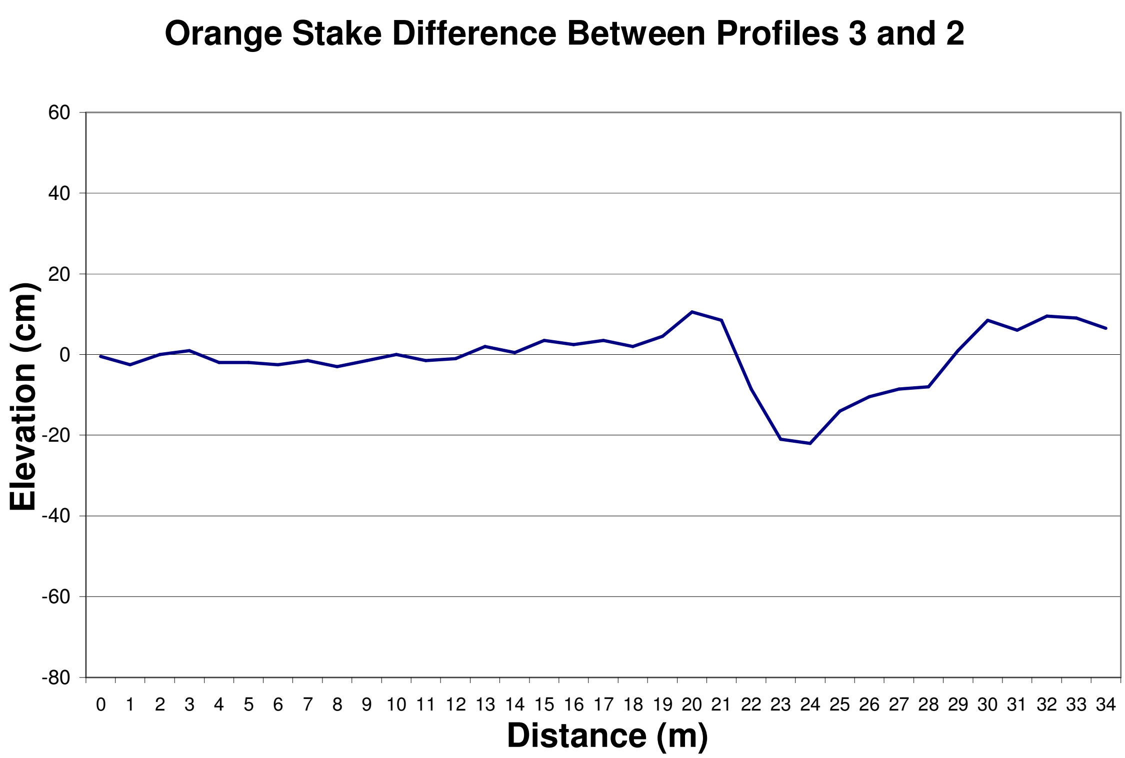
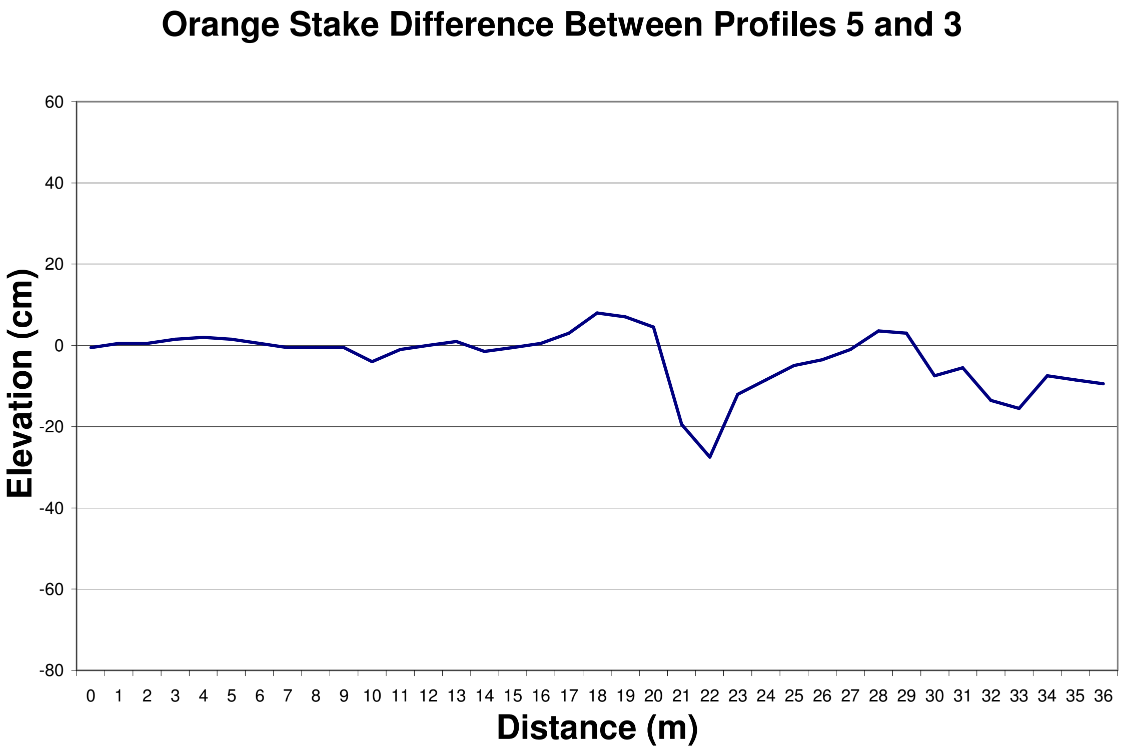
Appendix 1

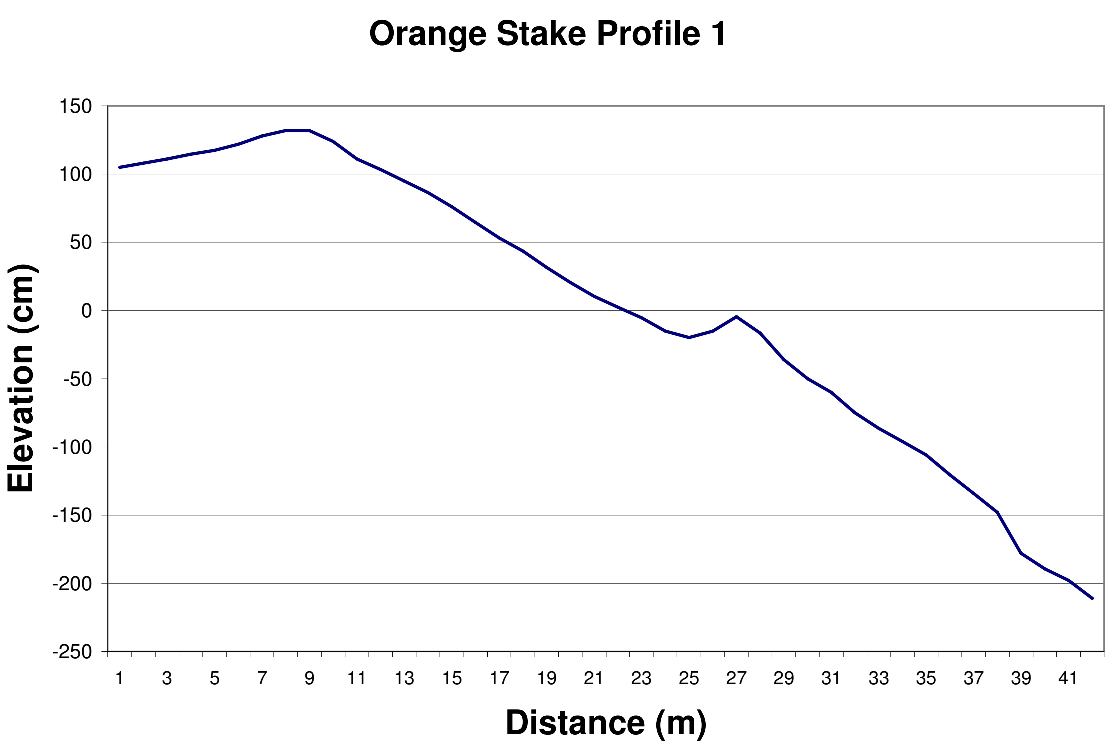
Figures showing erosion and accretion between profiles and individual profiles on each transect. Figures are separated by beach and transect.

Bluff Point Orange Stake

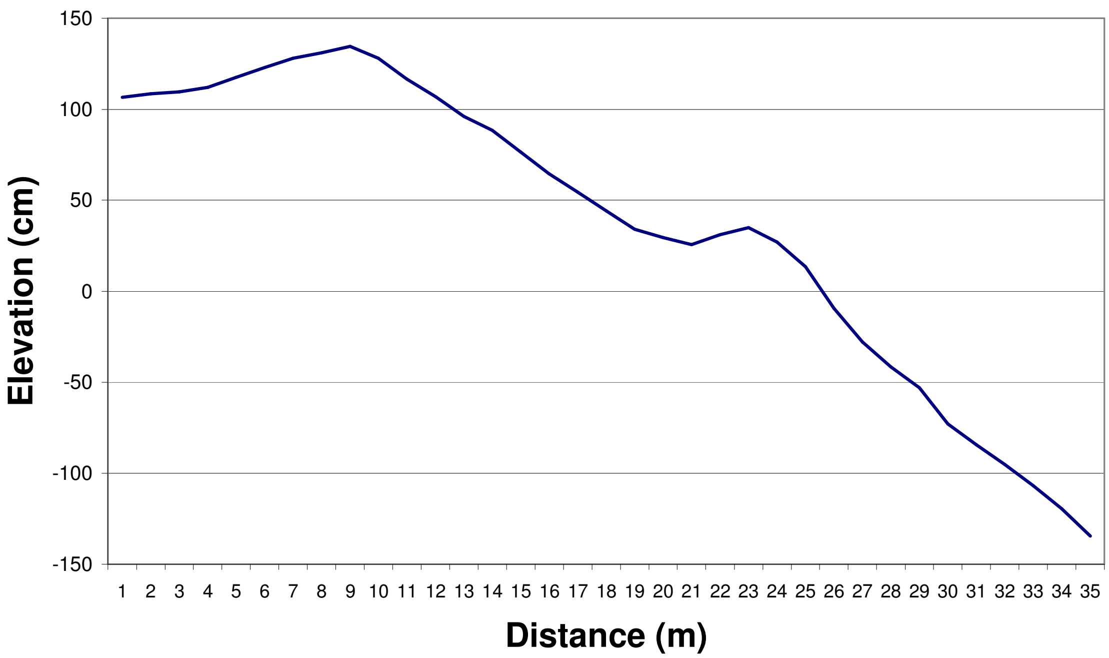


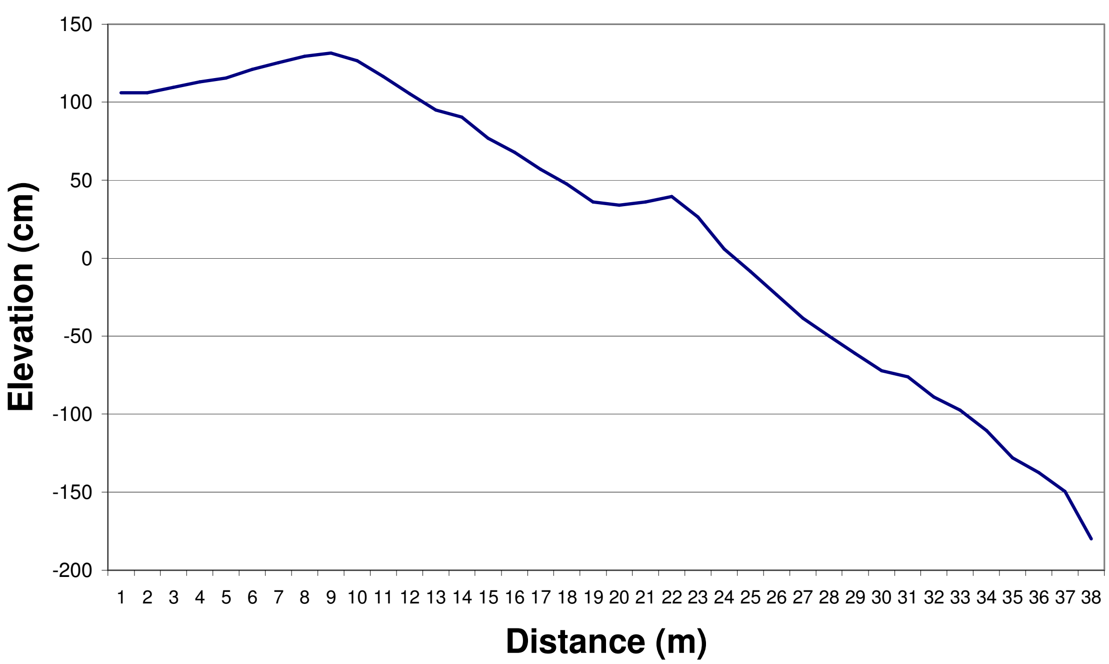

Orange Stake Difference Between Profiles 5 and 3
Elevation (cm)
60
40
20
0
-20
-40
-60
-80
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Distance (m)

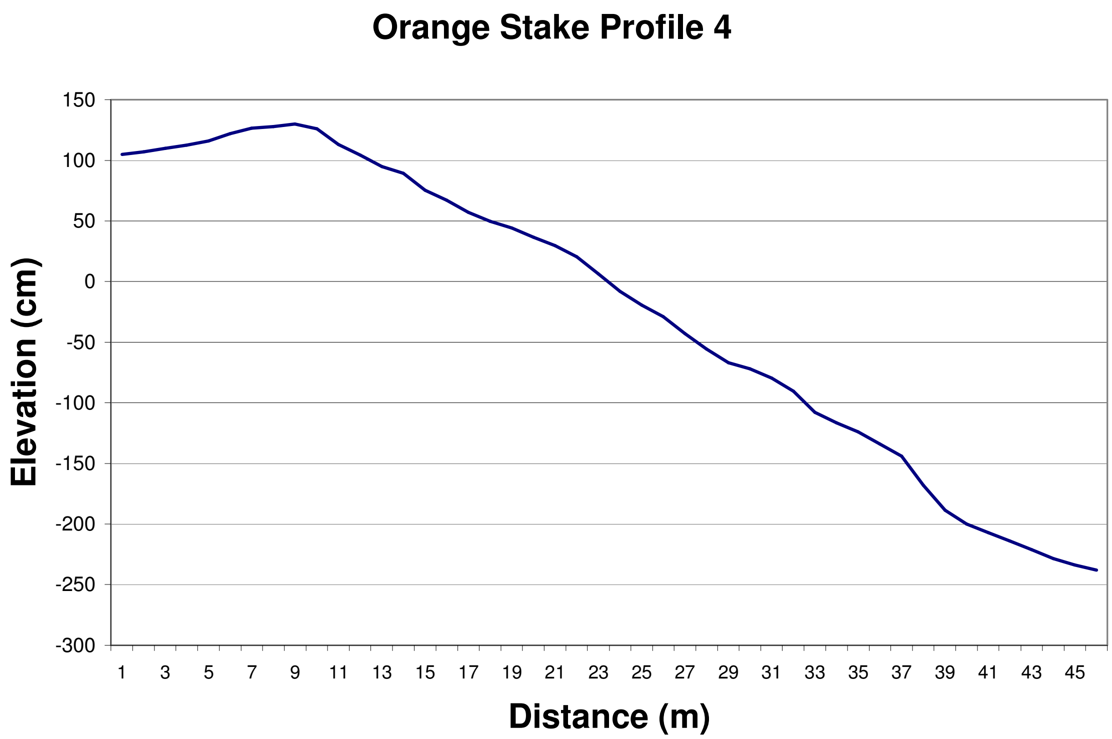

Orange Stake Profile 1
Elevation (cm)
150
100
50
0
-50
-100
-150
-200
-250
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
Distance (m)

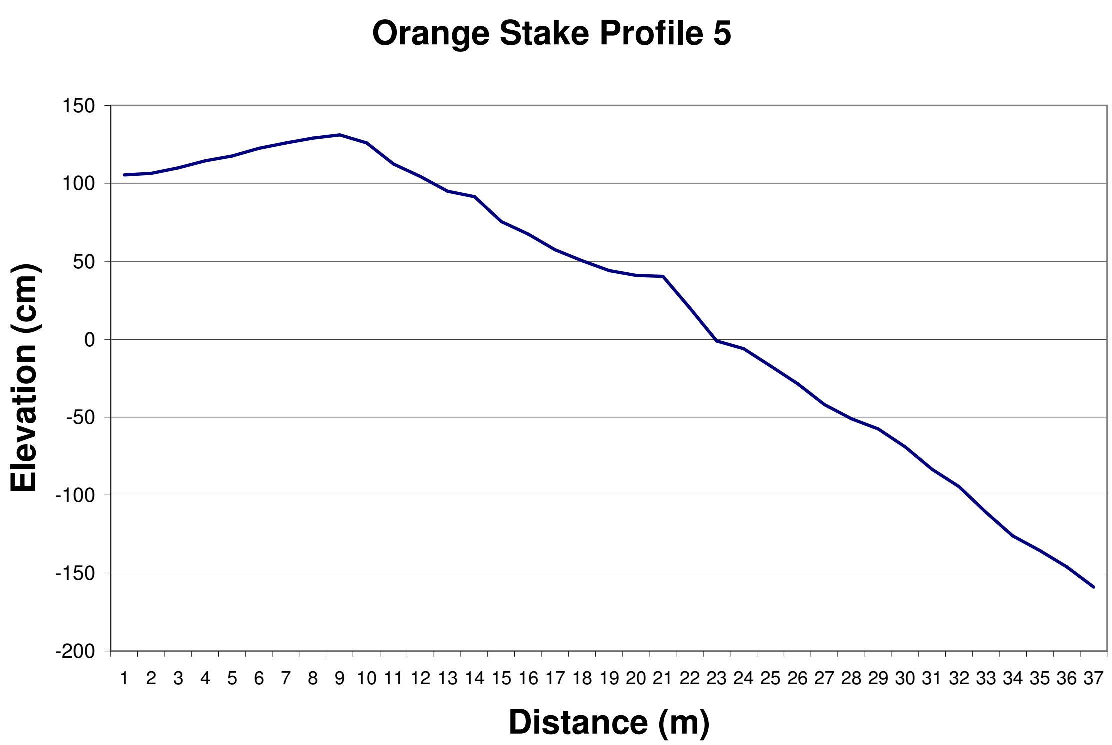
## Orange Stake Profile 2




## Orange Stake Profile 3

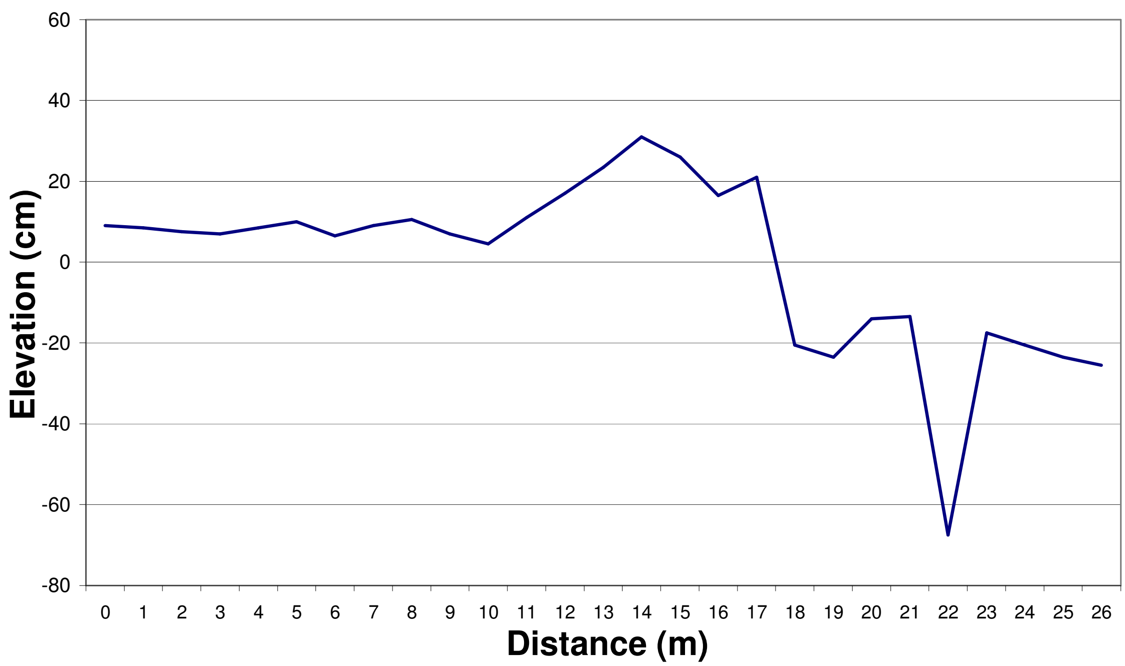



Orange Stake Profile 4
Elevation (cm)
150
100
50
0
-50
-100
-150
-200
-250
-300
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45
Distance (m)

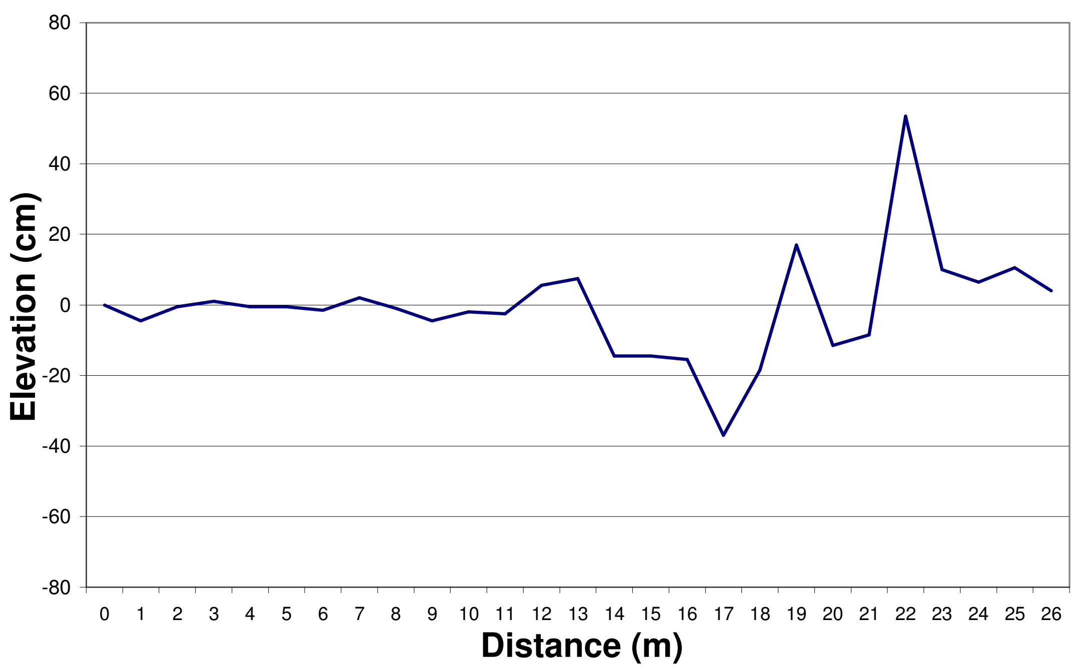

Orange Stake Profile 5
Elevation (cm)
150
100
50
0
-50
-100
-150
-200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
Distance (m)

Bluff Point Sand Fence

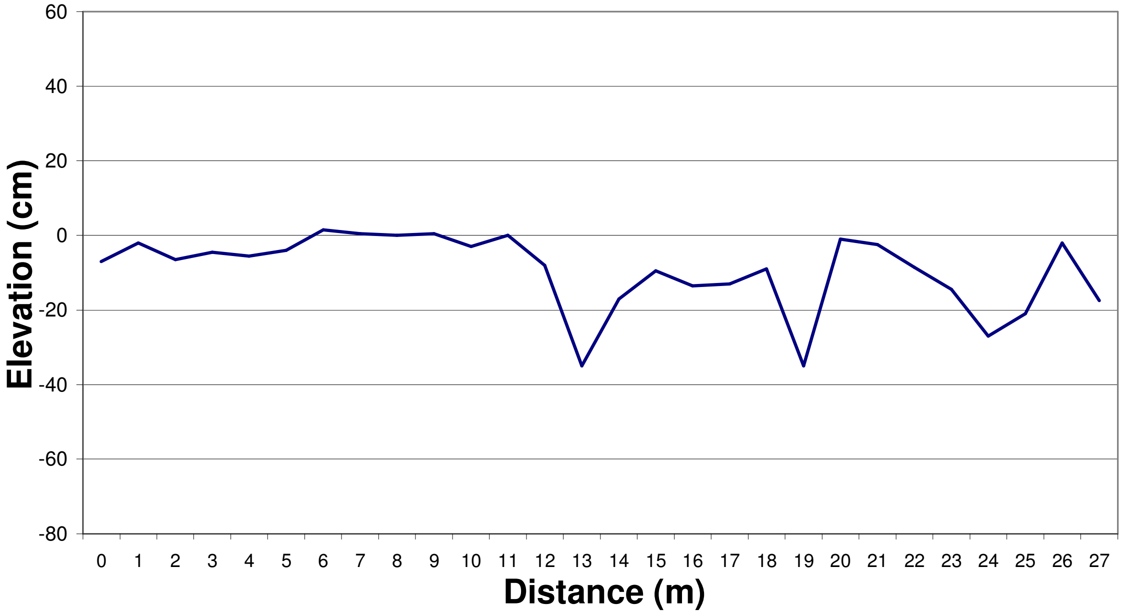
Sand Fence Difference Between Profiles 2 and 1



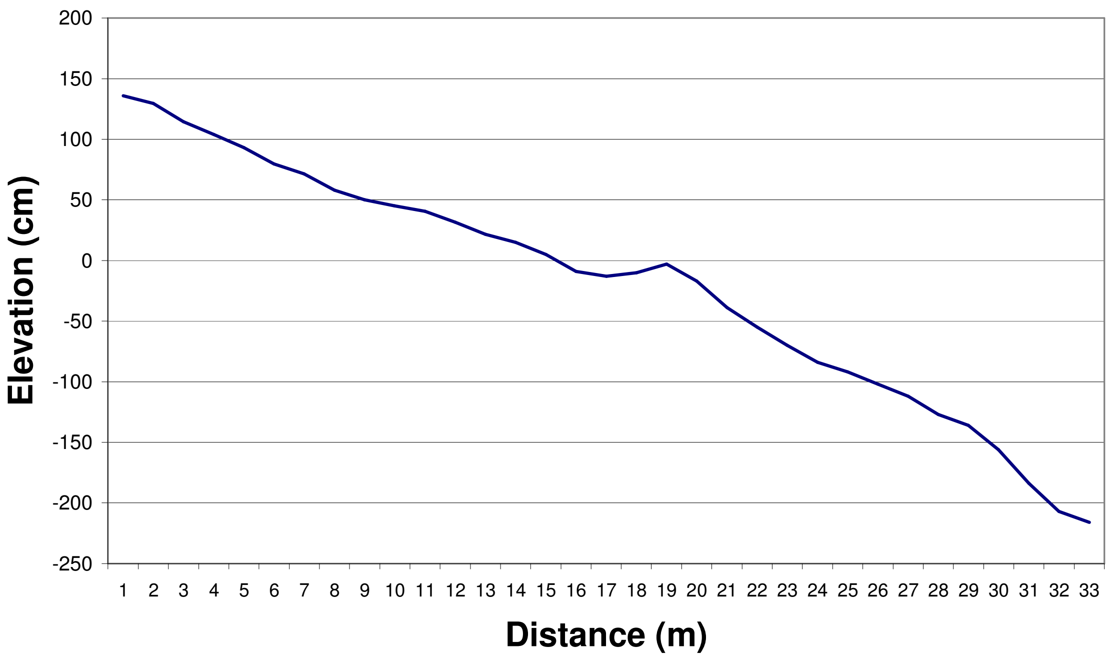

Sand Fence Difference Between Profiles 3 and 2

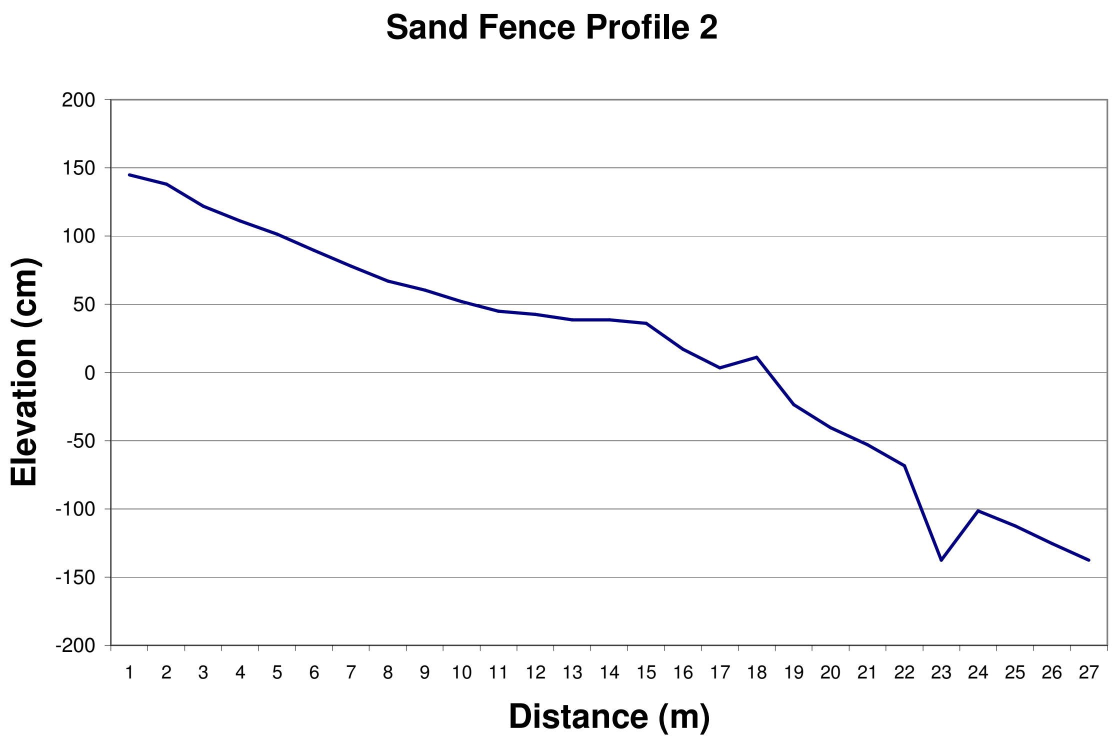


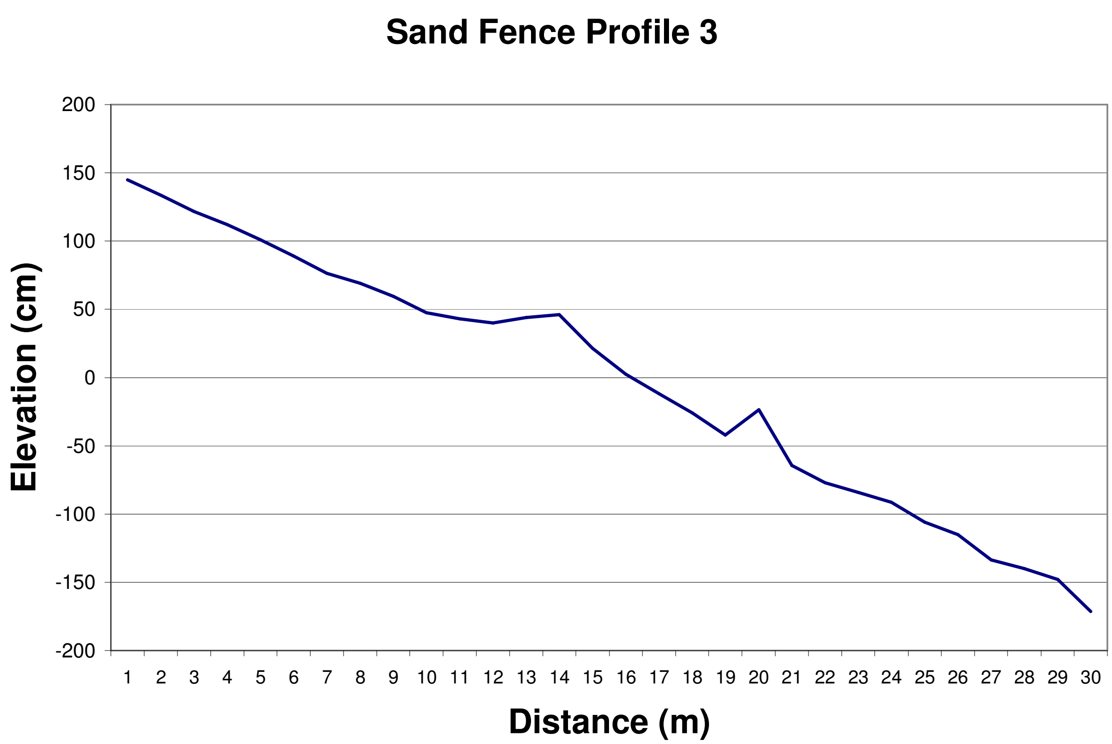
## Sand Fence Difference Between Profiles 5 and 3



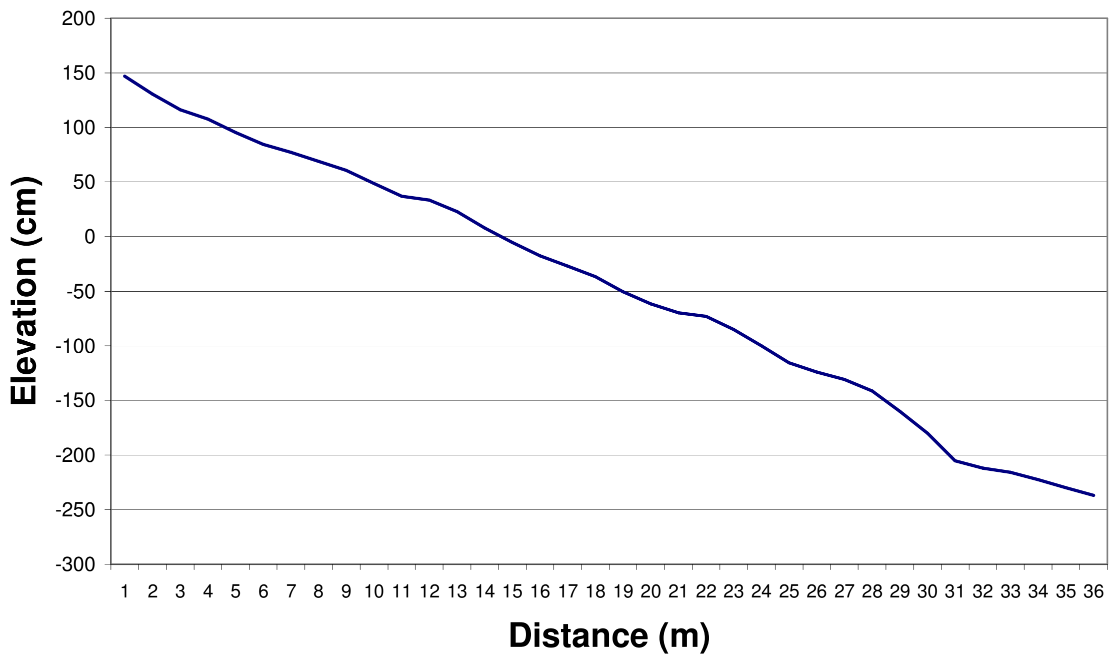

## Sand Fence Profile 1



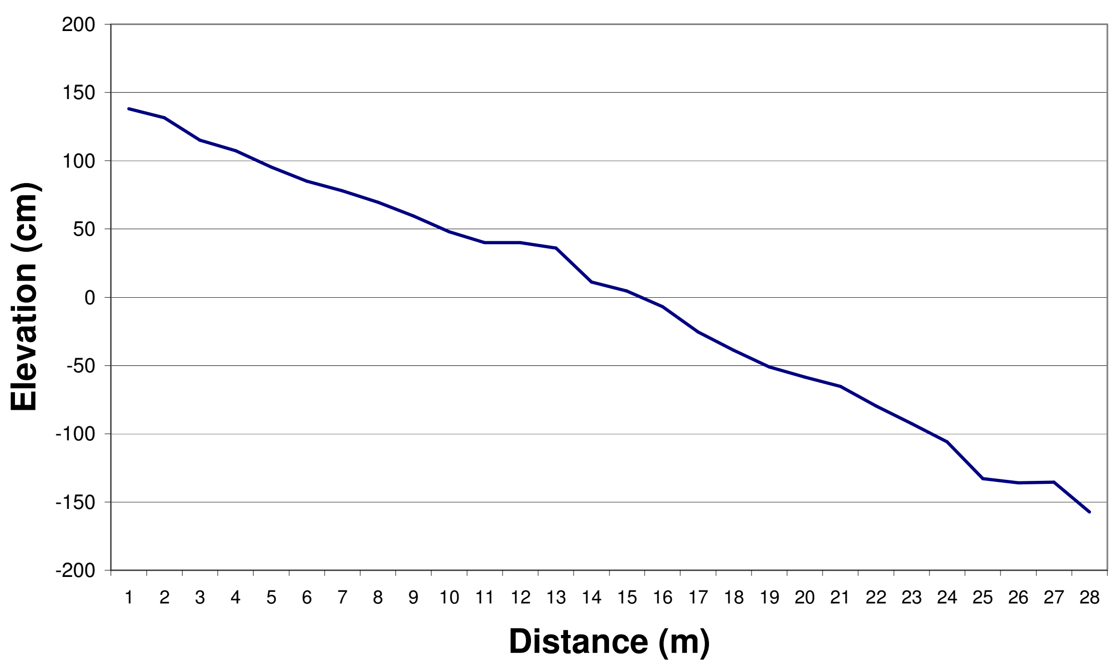

Sand Fence Profile 2
200
150
100
50
0
-50
-100
-150
-200
Elevation (cm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Distance (m)


Sand Fence Profile 3
200
150
100
50
0
-50
-100
-150
-200
Elevation (cm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Distance (m)

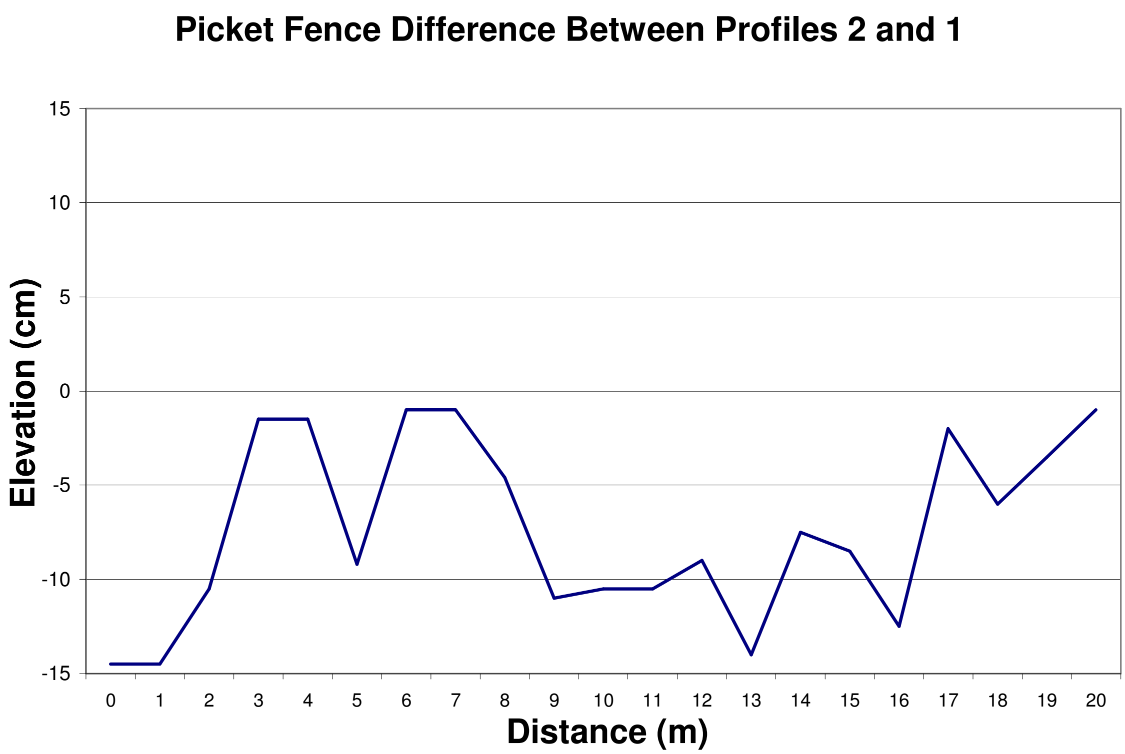
**Sand Fence Profile 4**

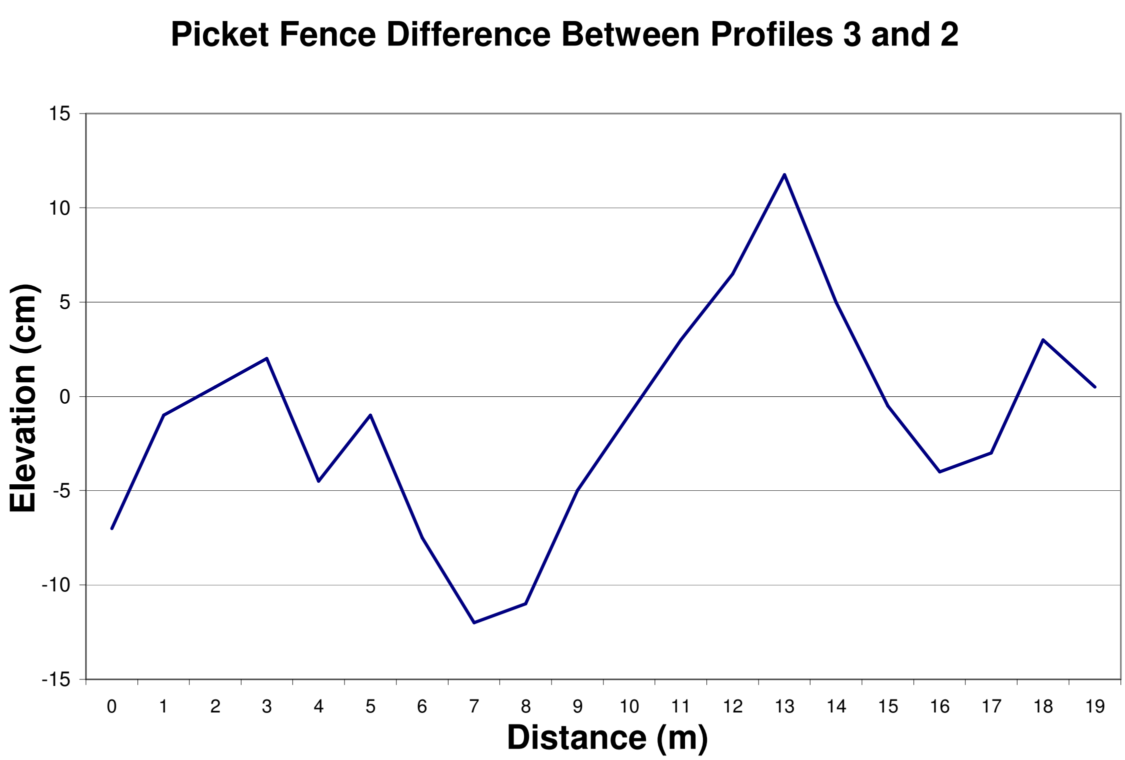


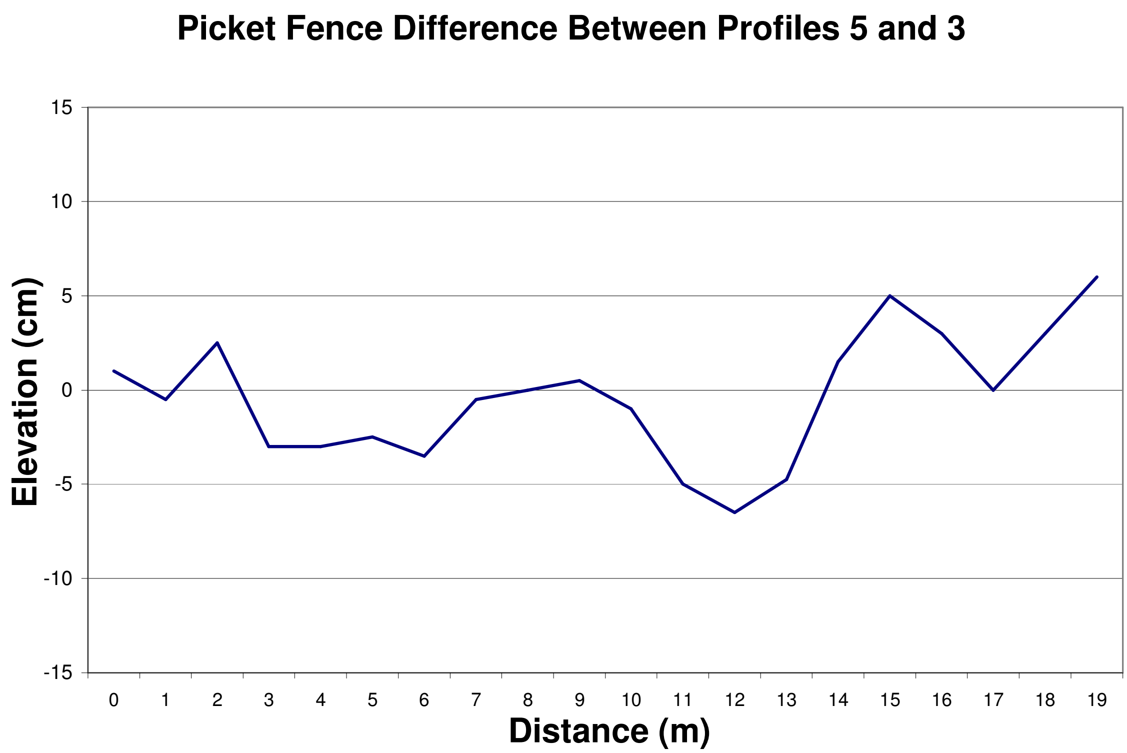

**Sand Fence Profile 5**



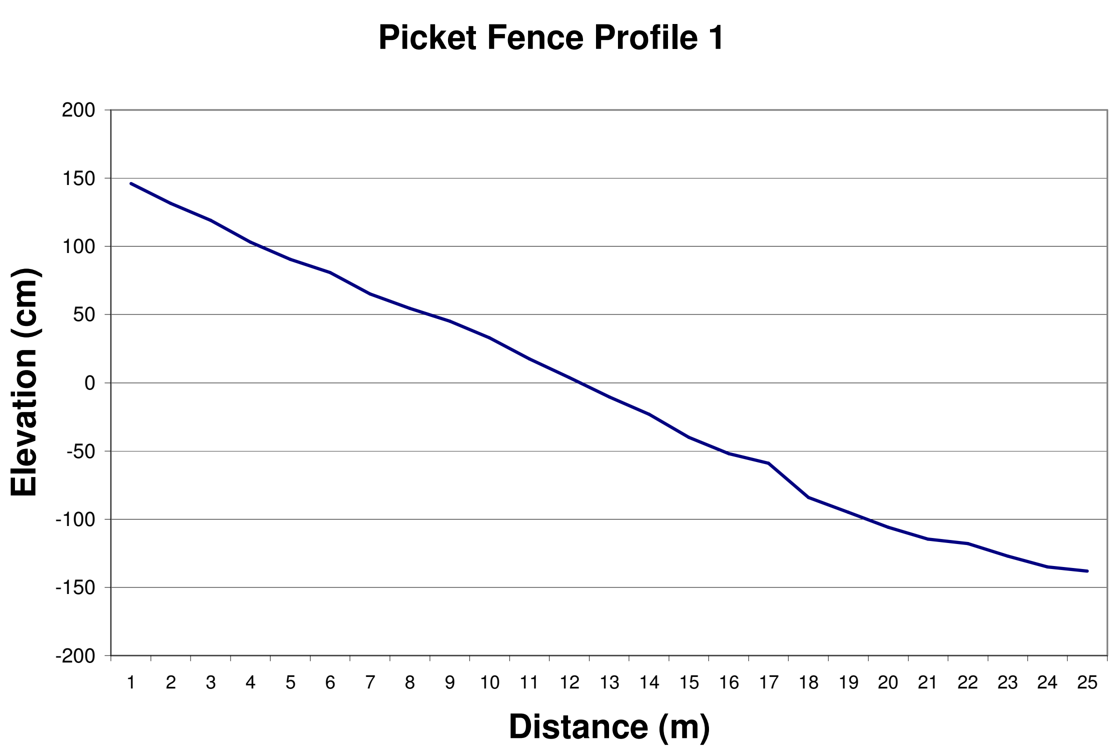
Groton Long Point Picket Fence



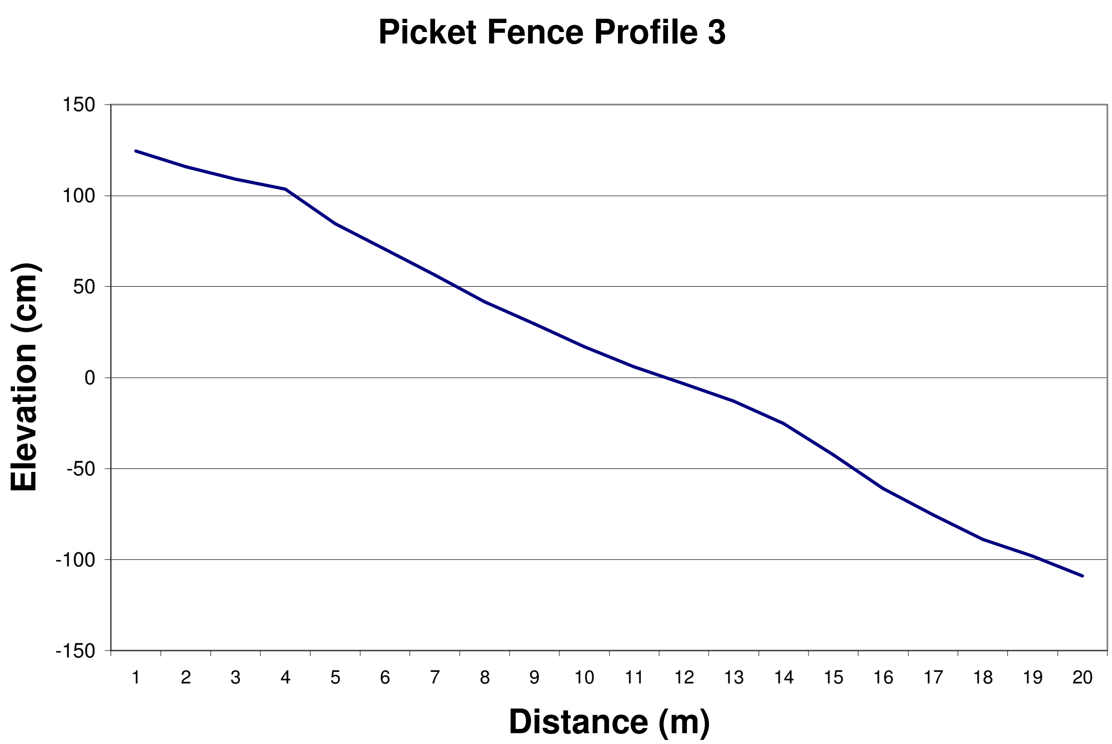


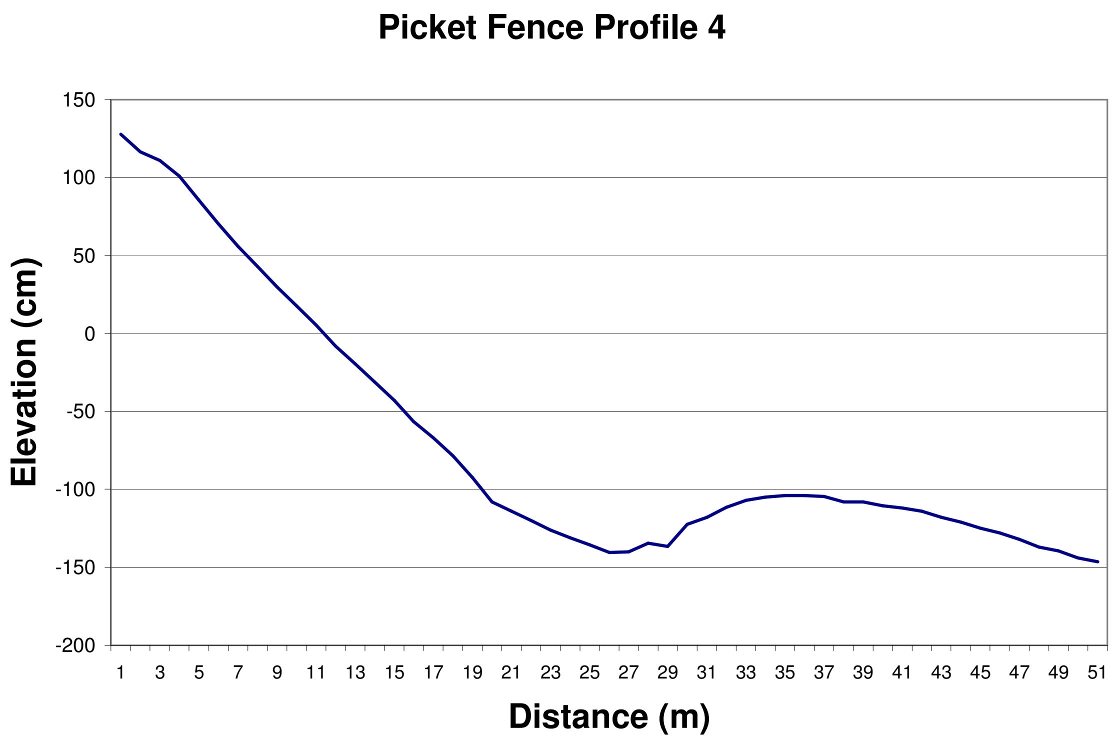
Picket Fence Difference Between Profiles 5 and 3
Elevation (cm)
15
10
5
0
-5
-10
-15
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Distance (m)

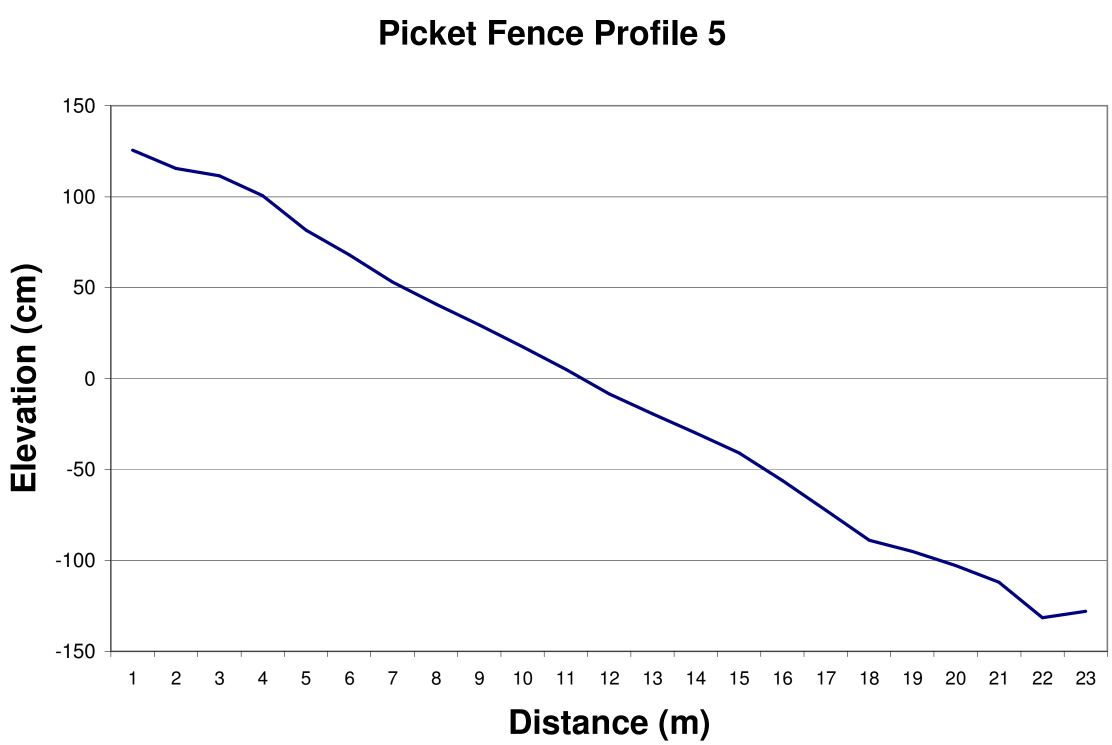



Picket Fence Profile 1
Elevation (cm)
200
150
100
50
0
-50
-100
-150
-200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Distance (m)

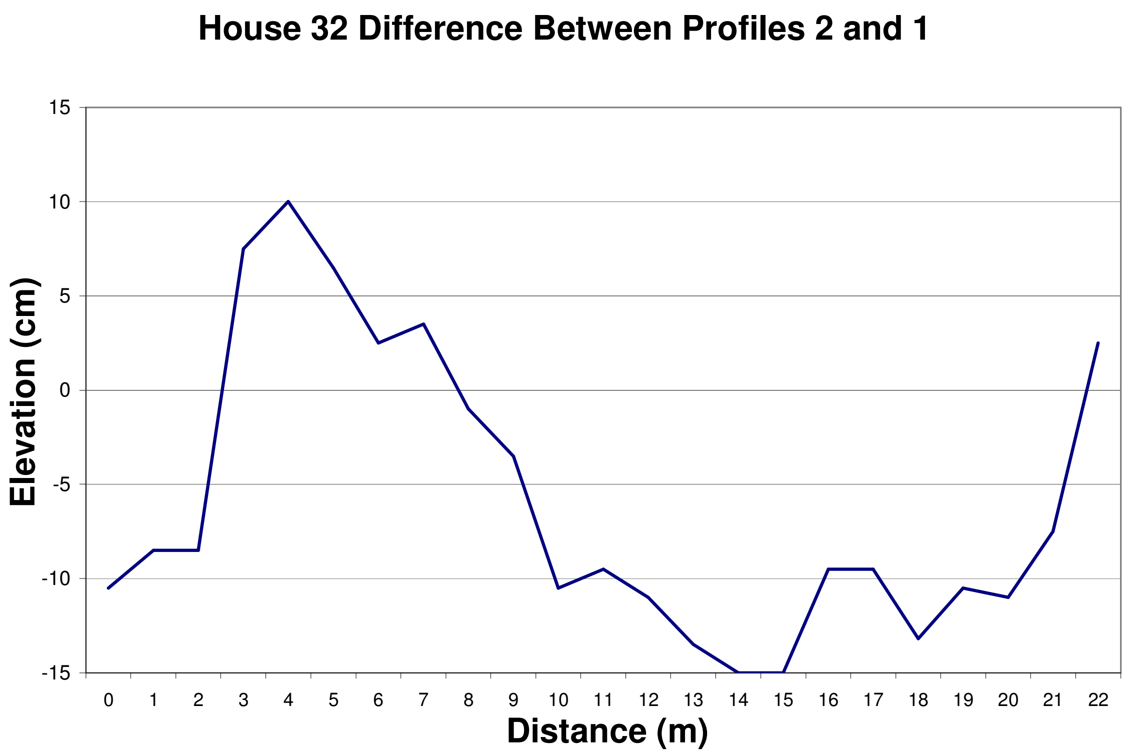

Picket Fence Profile 2
150
100
50
0
-50
-100
-150
Elevation (cm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Distance (m)

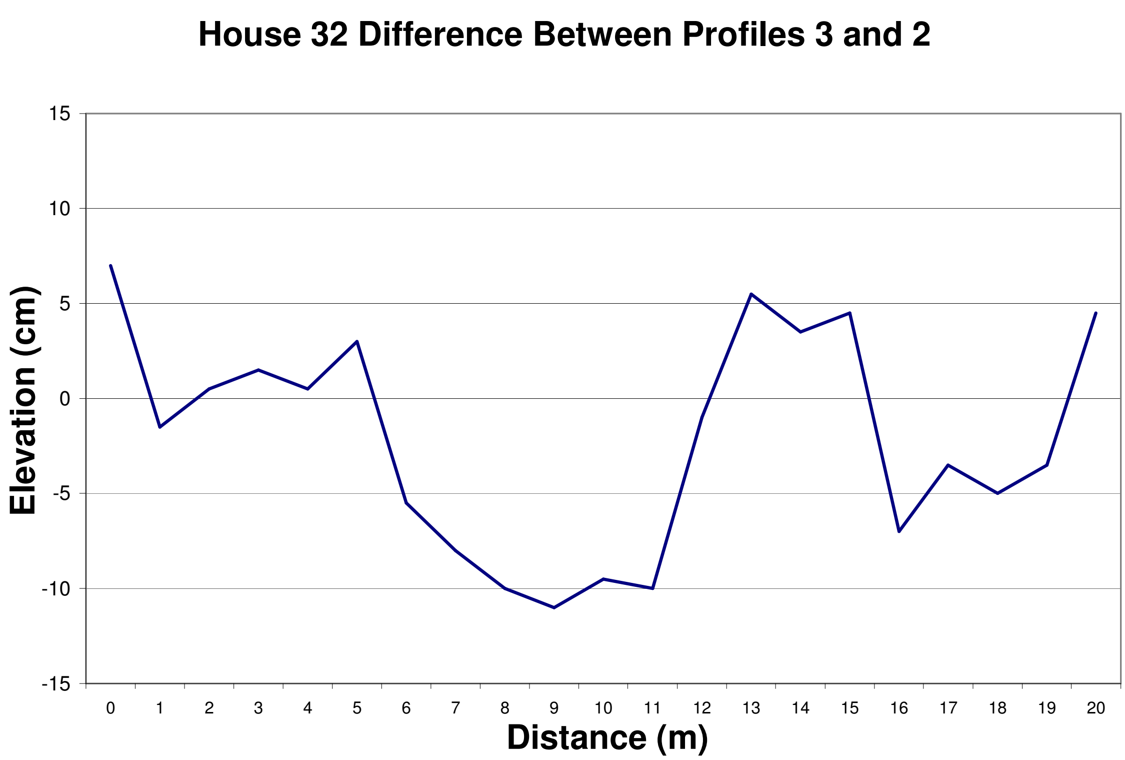

Picket Fence Profile 3
150
100
50
0
-50
-100
-150
Elevation (cm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Distance (m)

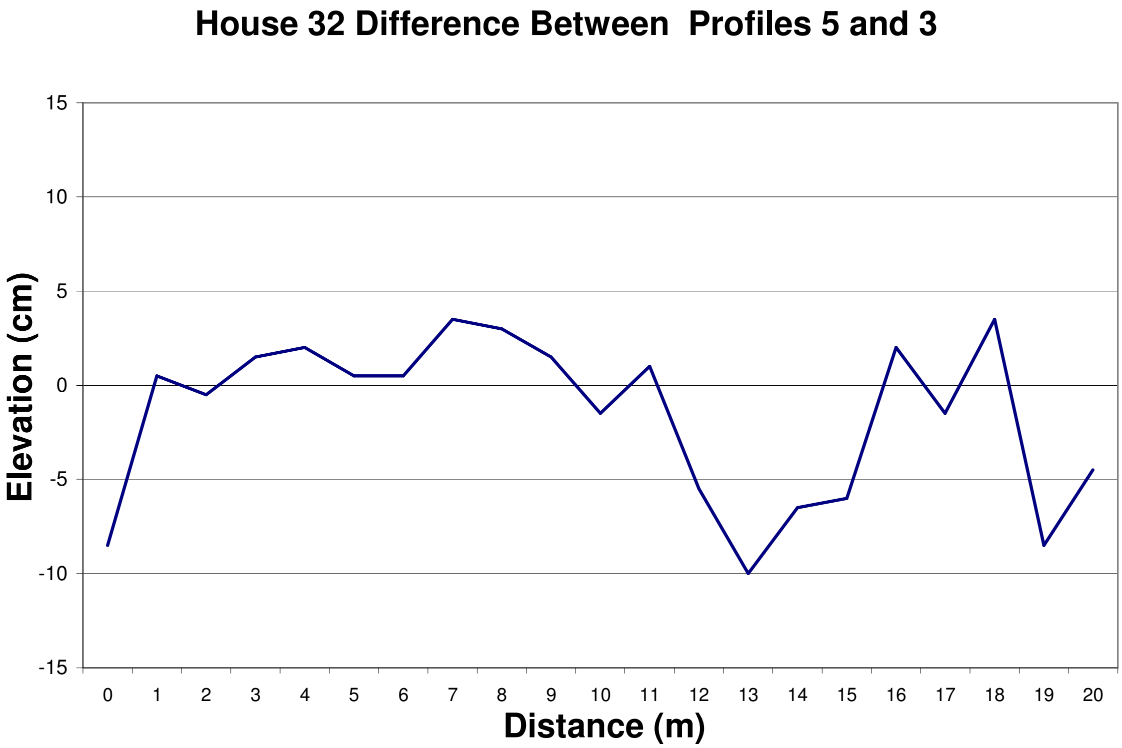

Picket Fence Profile 4
Elevation (cm)
150
100
50
0
-50
-100
-150
-200
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
Distance (m)

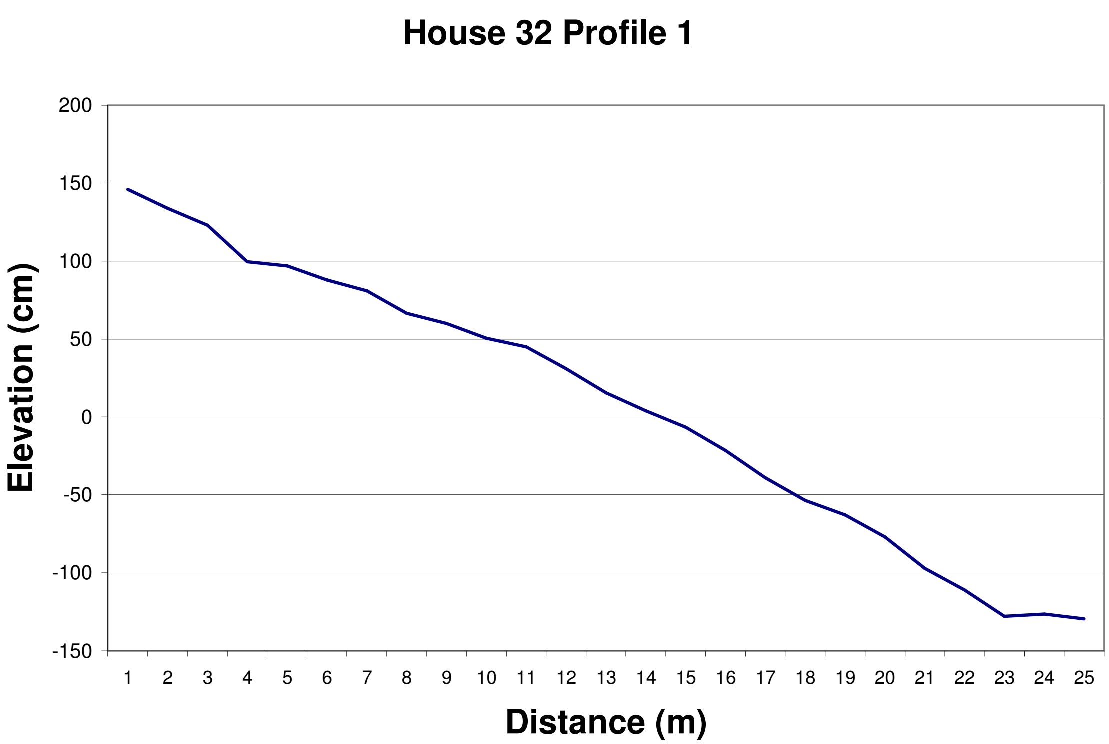

Picket Fence Profile 5
Elevation (cm)
150
100
50
0
-50
-100
-150
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Distance (m)

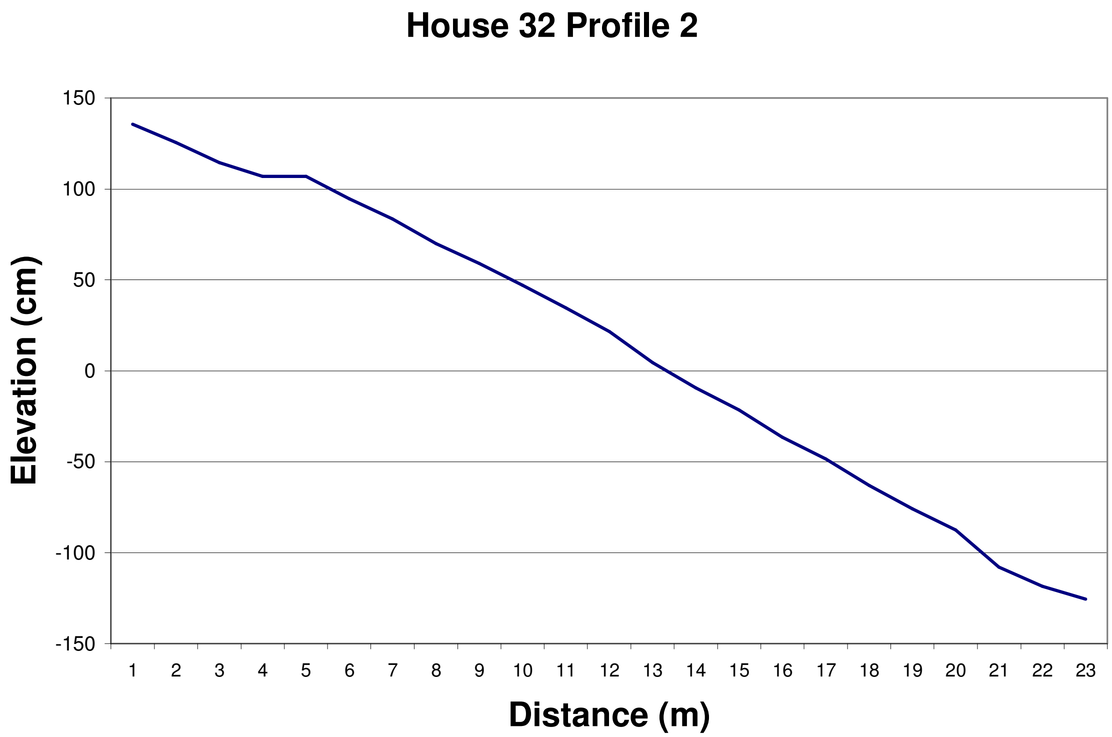
Groton Long Point House 32

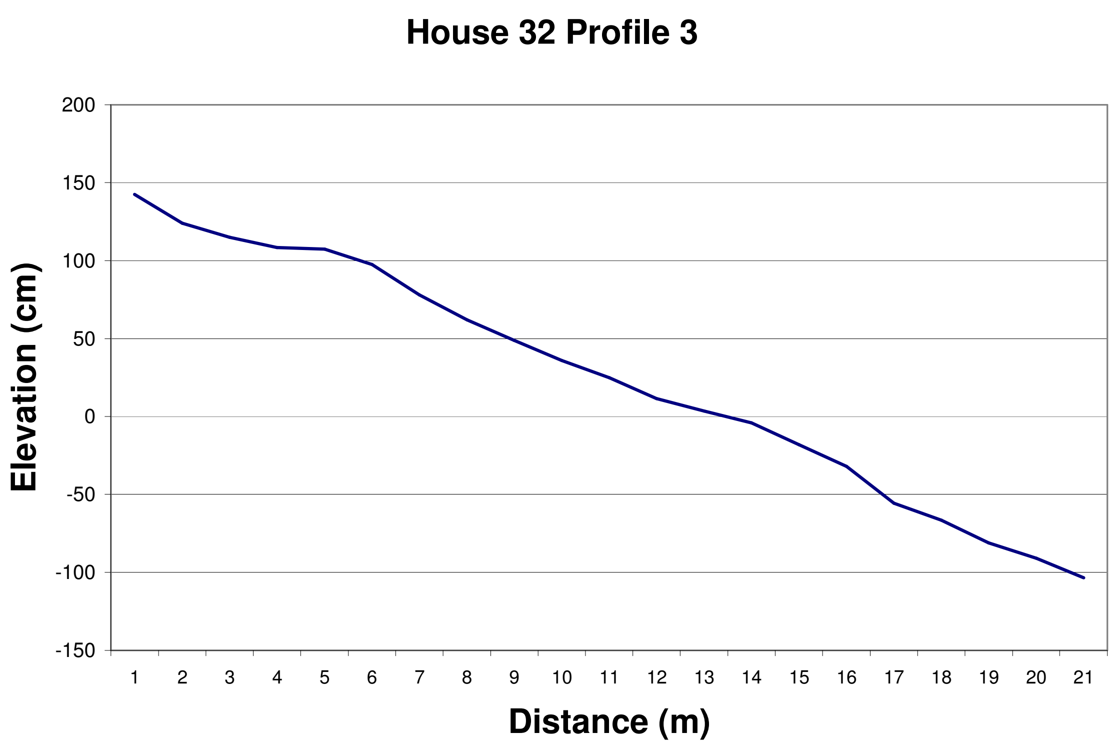


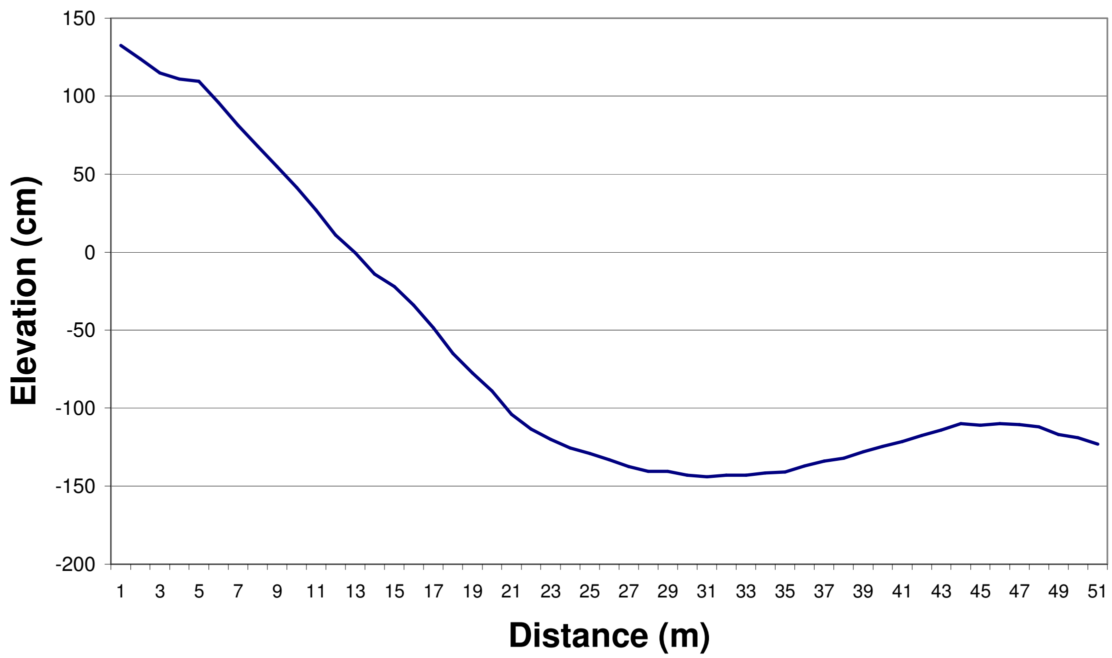

House 32 Difference Between Profiles 5 and 3
15
10
5
0
-5
-10
-15
Elevation (cm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Distance (m)


House 32 Profile 1
200
150
100
50
0
-50
-100
-150
Elevation (cm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Distance (m)


House 32 Profile 2
Elevation (cm)
150
100
50
0
-50
-100
-150
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Distance (m)


House 32 Profile 3
Elevation (cm)
200
150
100
50
0
-50
-100
-150
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Distance (m)

## House 32 Profile 4




## House 32 Profile 5