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An Economic Analysis of Coastal Protection in Branford CT[1]

It is common knowledge that sea level rise and storms threaten communities along the coast with flooding risks. Branford, with its 20 miles of coastline, is particularly vulnerable to both increasing storm intensity and sea level rise. This study examines the cost and benefit of hardening the Branford coastline to protect low lying developed sections of town. The study begins by identifying all the low lying parcels in Branford. It then evaluates whether walls and storm gates would be effective at protecting each of these low lying areas. Specifically, the study examines whether the benefit of reduced flood damage exceeds the cost of each potential wall.

Although measuring the cost of storm surge protection is straightforward, measuring the benefit (the reduced damage) of flood protection is more difficult. The study relies on methodology that integrates available scientific evidence on flooding risks and sea level rise, with GIS information about each parcel, and an economic analysis of expected flood damage to generate expected flood damage and to estimate the benefit of alternative preventive actions. Comparing the cost to the benefit reveals whether protection is warranted at all. Examining the net benefit of walls and barriers at different heights reveals the optimal height of the wall.

The study begins with tidal data collected by NOAA (2018) at Bridgeport, one of many tidal stations along the American coastline. Using the highest observed tides each quarter, we

[1] This document was prepared by Alan Fairbank, Nicholas Fields, Emma Greenbaum, Jonathan Held, Jonathan Rigby, Andry Rajaoberison, and Mary Schoell as part of a class at the Yale School of Forestry and Environmental Studies taught by Professor Robert Mendelsohn.

first calculate a GEV regression that predicts the probability of storm surges of different heights along the south central Connecticut coast. For each potential storm surge, we use LIDAR data collected by the State of Connecticut and Geographic Information Systems (GIS) to calculate the area that would be flooded along the coastline in Branford CT. Using parcel maps, we determine which properties would be flooded by each storm surge. We calculate the depth of flooding at each parcel and predict the flood damage that would occur given the value of the building at each parcel. Multiplying this damage by the probability of the surge yields the expected damage to each building from each surge. Summing this damage across buildings yields the expected marginal benefit (the marginal damage avoided) of protection that stops this surge. By comparing the benefit to the cost of walls of different height, one can determine the wall height that leads to the highest net benefit.

The Branford coastline is a complex terrain with a variety of wetlands, coves, and low cliffs. This implies that there are effectively many separate low lying coastal segments, each of which could be defended independently. The coastline is also permeated with many coastal creeks and two major rivers, the Farm River on the western edge of town and the Branford River in the center of town. Coastal surges come up these rivers and creeks to reach far into Branford.

We examine two types of coastal protection: coastal walls built at Mean High High Water (MHHW) and storm gates along rivers and coastal streams. We examine coastal walls in each individual coastal segment separately. We also examine the use of storm gates along non-navigable coastal rivers and creeks. Note that the storm gates are assumed to be open during normal tides and are closed only when a major storm approaches.

The analysis reveals that although there are many properties in Branford that are subject to coastal flooding, coastal walls are justified in only a few places. Walls should be built to protect Stony Creek, Pawson Park, Blackstone Acres, and Branford town center west of the Branford River north of the railroad tracks. In the remaining coastal segments, there is not enough housing and flood damage behind the possible walls to warrant the cost of construction. A storm gate on the Branford River at the railroad crossing would be a highly effective strategy to hurricane proof Branford north of the railroad tracks. This storm gate would be cheaper and more effective than building walls along the Branford River north of the railroad tracks to protect the town center and Blackstone Acres. Another storm gate should be constructed at Sybil Creek where it crosses Rout 146 along with a short wall to protect the Limewood neighborhood. A third storm gate at Mill Creek where it cross under the Harbor Street Bridge may also be advisable if the cost is low enough. Finally, the underpass under the railroad tracks near Meadow Street should be permanently sealed also as part of hurricane proofing Branford north of the railroad tracks.

Methodology

The basic theory behind building a defensive coastal wall or storm gate is to maximize net benefits, Benefit, *B(H)*, minus cost, *C(H)*: .

$$\max_{H} B(H) - C(H)) \tag{1}$$

where *H* is height. This leads to a maximum valued action when the marginal benefit, *MB*, of a higher wall equals the marginal cost, *MC*:

$$MB(H) = MC(H) \tag{2}$$

The second order conditions for this to be a maximum is that $dMB/dH<0$ and $dMC/dH>0$. The wall should not be built at all if the cost exceeds the benefit.

Expanding this formula to take into account that storms are uncertain, the expected benefit of a wall of height H depends on the probability, $\pi(h)$, of a storm surge of height, h, and the aggregate damage in each segment. The probability of flooding is determined using tidal data from the Bridgeport station and estimating a Generalized Extreme Value (GEV) function:

$$F(x:\mu,\sigma,k) = \exp\left\{-\left[1 + k\frac{(x-\mu)}{\sigma}\right]^{-\frac{1}{k}}\right\} \tag{3}$$

where μ is the location parameter (mean height), σ is the scale parameter, and k is the shape parameter. The estimated parameters from this model for Bridgeport are: $\mu = 1.818$, $\sigma = 0.1337$, and $k = 0.1749$. Figure 1 presents the probability versus height of each potential storm surge from the estimated GEV function. MHHW in Branford is 1.06 m (3.5 ft). The probability of storm surge falls quickly from 100% at 1.9 m to 1% at 3.1 m. Tropical Storm Sandy caused a surge of 2.9m.

Making the calculations more complicated, we observe that there has been a certain degree of sea level rise (SLR) in the Northeastern United States since the Civil War (when measurement began at the Battery New York) of about 3 mm/year. Figure 2 shows how sea level has changed at both Bridgeport and New London. Although this SLR fluctuates up and down with oceanic changes, it has been rising linearly for the last 150 years (Zervas 2009). That is, observed sea level rise has been constant since 1850 (Zervas 2009). This analysis assumes that it will continue to rise at 3mm/year for the next 30 years. Oceanographers predict that climate change may increase this baseline rate to 4mm/yr over this century (Kopp et al. 2016).

Figure 1: Probability of different storm surge heights

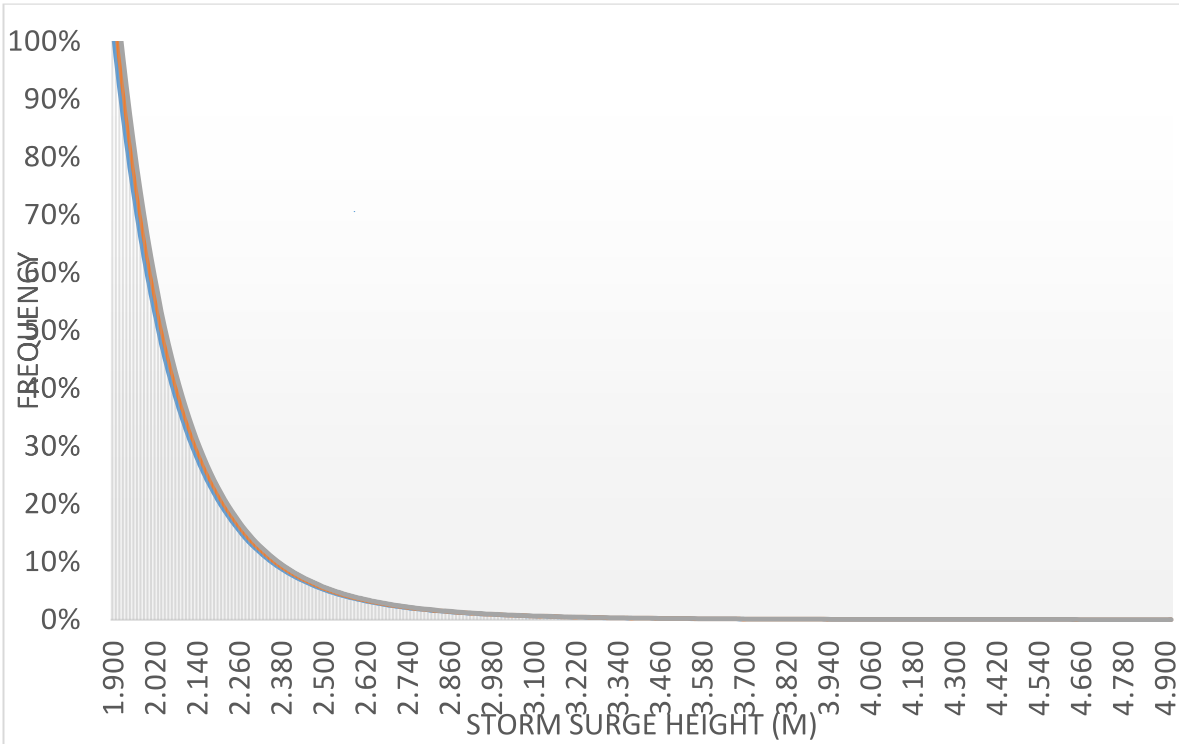
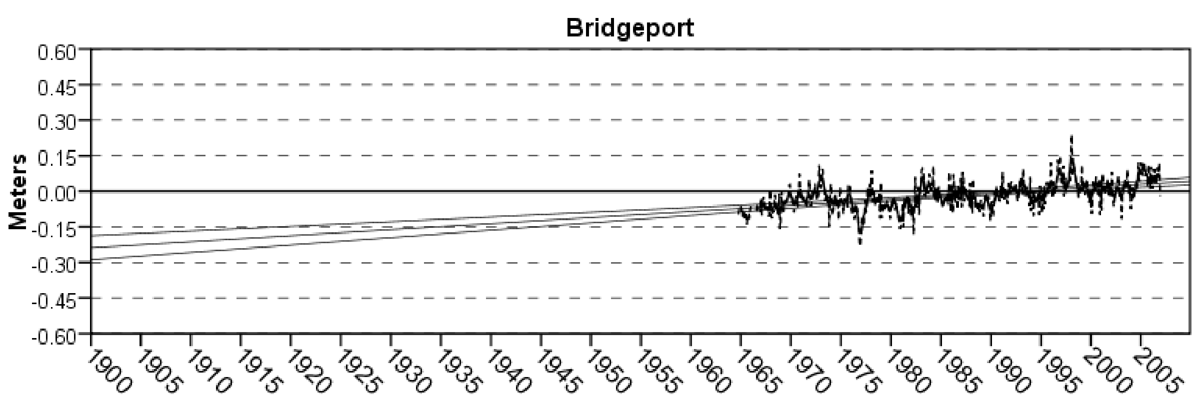
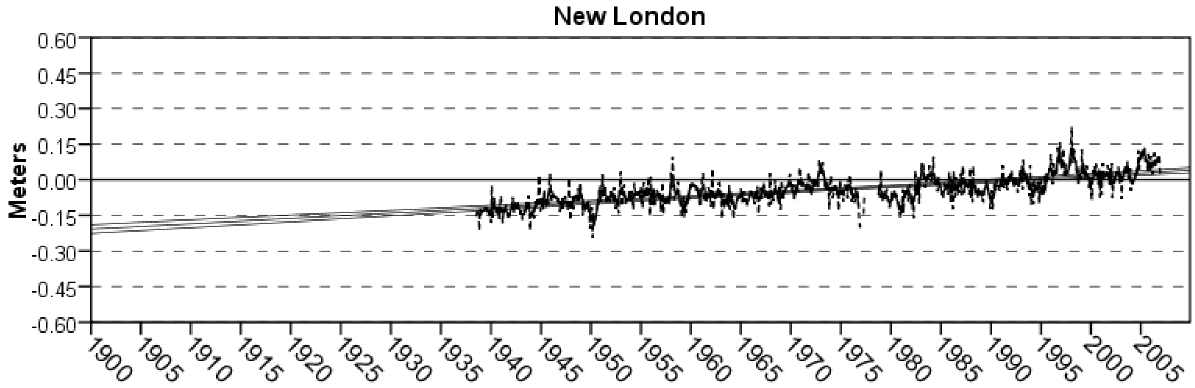


Figure 2: Sea Level at Bridgeport and New London





We take SLR into account by shifting the depth of flooding function in Figure 1 to the right by the amount of SLR each year. We include the baseline SLR rate (3mm/yr) in the initial calculation but we also explore the consequence of assuming higher rates (4 mm/yr) from climate change.

The aggregate damage in a coastal segment is the sum of the damages of all the buildings in that segment at each storm surge height. Buildings are damaged if they lie below the surge height. In order to determine which buildings were vulnerable to flood surges, we conducted an analysis of parcel elevations using the tile LIDAR data for Connecticut (http://cteco.uconn.edu/data/lidar/index.htm). We specifically used the tiles to calculate the average elevation of each parcel. For select regions of Branford, we compared these results with using tiles to measure the exact elevation of the main building in each parcel. We found that using building elevation was more accurate than using average parcel height because many buildings along the low lying coast are built on high ground in each parcel. We intend to redo the entire town using building elevation in the future.

The damage at each building depends upon the elevation of the parcel, *a*. Damage, D, is proportional to the depth of flooding (*h*-*a*) at each parcel times the value, *V*, of the buildings. HAZUS suggests that the damage to a property with a basement begins as low as -2 meters compared to the average elevation of the first floor of the property. Complete destruction of the property occurs when flood depth reaches 7 m. Low elevation homes have significantly more expected damage than high elevation homes partly because they are subject to more frequent floods but mostly because each flood is more harmful. We assume that the value of land is not affected by storm surge since the flooding is temporary. In the long run, with sea level rise, flooding may cause permanent land loss which would be an additional damage. However, no parcels are expected to be permanently flooded in the next 30 years in Branford.

We assume a wall of height H prevents the damage from all storms $H \geq h$.

$$E[B(H)] = \int_0^H \pi(h)(\sum D(h-a) * V)\, dh \qquad (4)$$

The expected benefit of a wall of height H is equal to the expected damage avoided by that wall. The expected damage is equal to the sum of the probabilities of prevented surges times the damage that would have happened when each surge occurs (without the wall). Note that the optimal wall does not prevent all flood damage. There will remain a low probability of a very high surge that will overtop the wall or storm gate.

In this analysis, we assume that the wall or storm gate would last 30 years, although this assumption can easily be varied. All costs and benefits are calculated as the present value of the total costs and benefits over the next 30 years. It is assumed that the structure will have to be replaced in 30 years. For example, a structure built in 2020, would have costs and benefits from now through 2050. In 2050, the town would have to evaluate whether to abandon or rebuild that structure. In 2050, this calculation can take into account the observed SLR in 2050 as well as what development has taken place in the interim.

The construction cost of the wall increases linearly with the length (L) of the wall. Because the wall is effectively a triangle with a wide base, the construction cost of the wall increases with the square of its height (H). This study relies on previous cost estimates that imply the cost of a 1 m high hardened wall that is 1 m in length is $3881 (Yohe et al. 1999).

$$C = 3881\, H^2 L \qquad (5)$$

Because the coastal walls will be built at MHHW, the wall will not be exposed to constant wave action so maintenance cost should be in the neighborhood of 2% of construction cost per year[2].

We calculate the present value of costs and benefits each year for the next 30 years. We discount these costs using a long term 4% interest rate:

[2] The maintenance costs of walls exposed to wave action is much higher - 5% per year. It is not clear that building a wall lower than MHHW is sensible.

$$Max \sum_0^{30}(E[B(H)] - C(H))e^{-rt} \qquad (6)$$

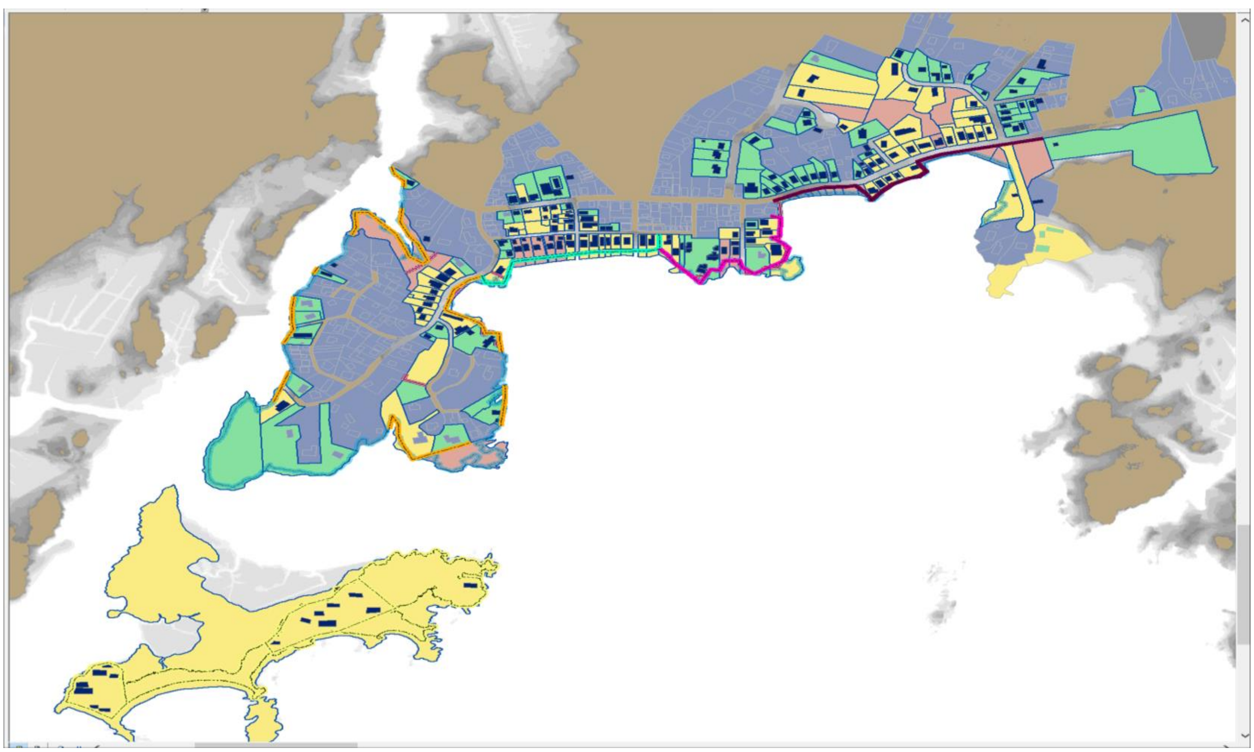
If Branford assumes a bond in order to pay for the project, the bond interest rate should be used as the discount rate.

Results

Short Beach to Pages Cove

There are many buildings that are vulnerable to flooding in Short Beach and Kelsey Island as shown in Figure 3. The parcels in yellow and light green are especially vulnerable. The analysis explores 5 potential sites for walls. There is a wall to protect most properties at Kelsey Island, a set of small walls to protect low lying properties along the peninsula of the Farm River, a wall along Clark Avenue to protect the cove, a wall along the beach near Beckett Avenue, a wall to protect Stanley Point, and a wall along Short Beach Road (Rt 142) to protect Pages Cove. None of these walls pass a benefit cost test. There is simply not enough damage to justify a wall in any of these locations.

Figure 3 Elevations along Short Beach and potential wall



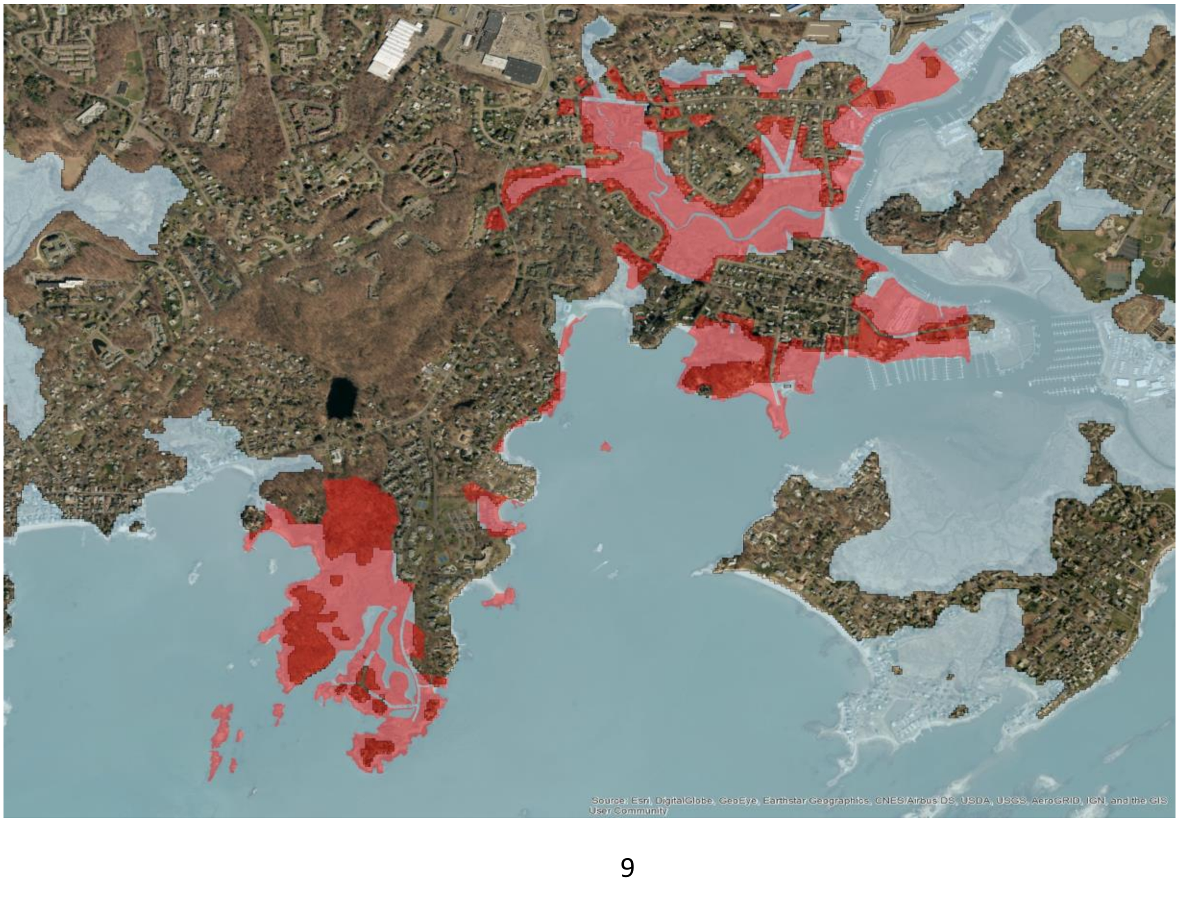
Northern Farm River

There is a creek that flows northeast off the Farm River that feeds wetlands north of Short Beach. There are several scattered parcels adjacent to these wetlands that are vulnerable to flooding. However, because the properties are scattered, they cannot be easily protected by a wall. Every potential wall explored in this region did not pass a benefit cost test.

Killams Point, Branford Cove, and Johnsons Point

As can be seen in Figure 4, there is a large amount of land along the edge of western edge of Killams Point that is low lying and vulnerable to flooding. In the northern section of the flooded area below, there is extensive wetland and few buildings so the expected flooding damage is low. But towards the south, there are 36 buildings along the coast and near the wetlands which flood. In order to protect this area, an extensive wall of approximately 3500 m has to be built along the coast and between the homes and the wetlands. Although there are about $500,000 worth of benefits to a wall with elevation of 2 m, the cost of the wall is about $15 million making this a poor investment.

Figure 4 Killams Point to Johnson Point



Double Beach

This section of Branford stretches from Johnson Point to Lindsey Cove along the Western edge of Branford Harbor. There are a few homes that are adjacent to the Branford Harbor that are vulnerable to flooding at Brockett's Point, Lamphier Cove, and Lindsey Cove. Walls are ineffective here because there are simply not enough homes in each place to warrant the cost of a wall.

Branford Point and Goodsell Point

From Lindsey Cove to the Branford State Launch is a low lying peninsula to the west of the Branford River. This area contains Parker Memorial Park and 30 buildings that are vulnerable to flooding. A wall of 1380 m can be built along the Branford River to protect the buildings from flooding. But the cost of such a wall would exceed the flooding damage removed. For example, a wall with a top elevation of 2 m would eliminate about $100,000 of flood damage but would cost about $6 million.

Harbor Street Bridge to Dutch Wharf Boat Yard

This neighborhood is along the western edge of the Branford River, bordered from Driscoll Road to the south, and Dutch Wharf Boat Yard to the east, and the railroad tracks to the north. There are many homes that can be flooded from the Branford River. The properties could be protected by a wall of 500 m length along the Branford River. But the wall does not pass the benefit cost test. For example a wall with top elevation of 2m would cost $2.3 million and reduce storm damage by only $167,000.

Storm gate at Mill Creek- Harbor Street Bridge

The Mill Creek running west off the Branford River underneath the Harbor Street bridge currently feeds a wetland. The Mill Creek can also flood 61 properties on both sides of the wetlands all the way to the railroad tracks. In addition to the storm gate, one would want a wall for about 130 m along Harbor Road whose elevation at the top is 2.2 m. That would lead to a flooding benefit of $825,000 and a wall cost of $229,000. Assuming that the storm gate costs $500,000, the benefit to cost would be (825/729) which implies this project just pays for itself If the storm gate can be built for less than $500,000, the project would be more attractive.

Meadow Street Railroad Underpass

There is an underpass from Indian Neck Avenue to Meadow Street that allows water to flow north of the railroad tracks into the Meadow Street neighborhood as can be seen in Figure 5. Homes in this area are flooded from Rogers Street to the west to Church Street to the east and along Prospect Street to the north. There are 47 buildings affected. The flood damage to these properties is worth $650,000. This does not count future damage to a Senior Center planned for this neighborhood.

This flooding problem can be solved by blocking the water from getting through the underpass. The least expensive solution (under $10,000) is to permanently fill in this underpass and secure the railroad bed. A drawback of this solution is that some traffic would be diverted an extra half mile to the railroad bridge near the railroad station. An alternative that keep the underpass open to traffic is to build a gate at the underpass that can be closed during storms. An engineering study puts the cost of this alternative at $500,000. At least with the inexpensive solution, there is a very high benefit to cost ratio of blocking the underpass permanently. The underpass becomes part of the hurricane proofing of Branford north of the railroad tracks.

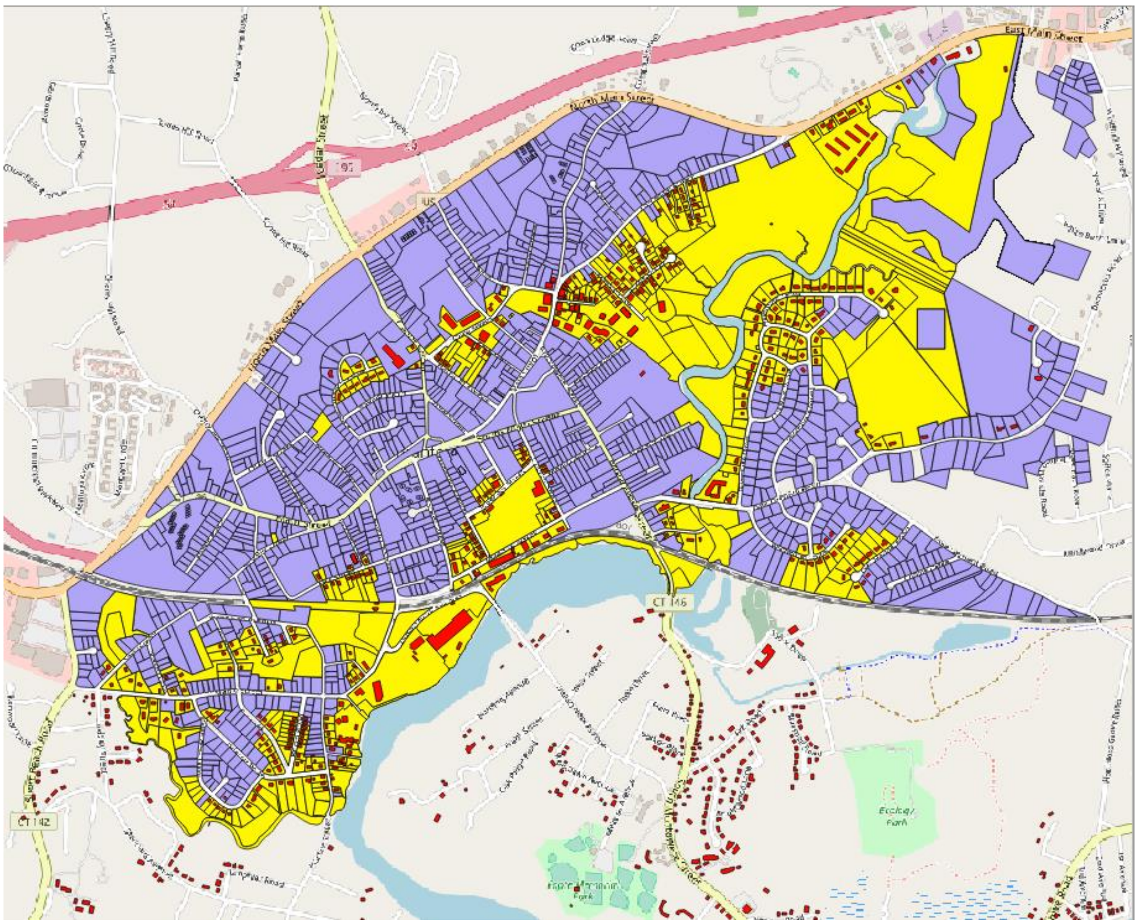
Branford Town Center

The town center of Branford is vulnerable to flooding from the Branford River north of the railroad tracks. The yellow area in Figure 5 shows the flooding west and north of the River to Rt 1 as seen in Figure 5. Walls along the western and northern edge of the wetlands would protect Branford town center up to the high school but would have to be 8000 m long. The optimal height for this wall would be 1 foot and it would cost about $1 million. This wall would protect against frequent nuisance flooding and lead to $2 million of flood protection. If nothing is done to control storm flow along the Branford River, this wall has a 2 to 1 benefit to cost ratio. However, the wall would not protect Branford town center from severe storms as pictured in Figure 5.

Blackstone Acres

Another neighborhood that is flooded north of the railroad tracks but to the east and south of Branford River is the Blackstone Acres neighborhood as seen in Figure 5. About 100 buildings in this development are subject to flooding. One could build a 1300 m wall between the wetlands and outer edge of this development from Pine Orchard Road to the last property along Riverside Drive. The model calculates the optimal elevation of the top of this wall would be 1.5 m. So it is a low lying wall that would only stop nuisance flooding. The cost of the wall would be $1 million and the flood benefit would be $2.7 million. The Benefit to Cost ratio is 2.7 to 1. However, the wall would not protect the neighborhood from more severe flooding.

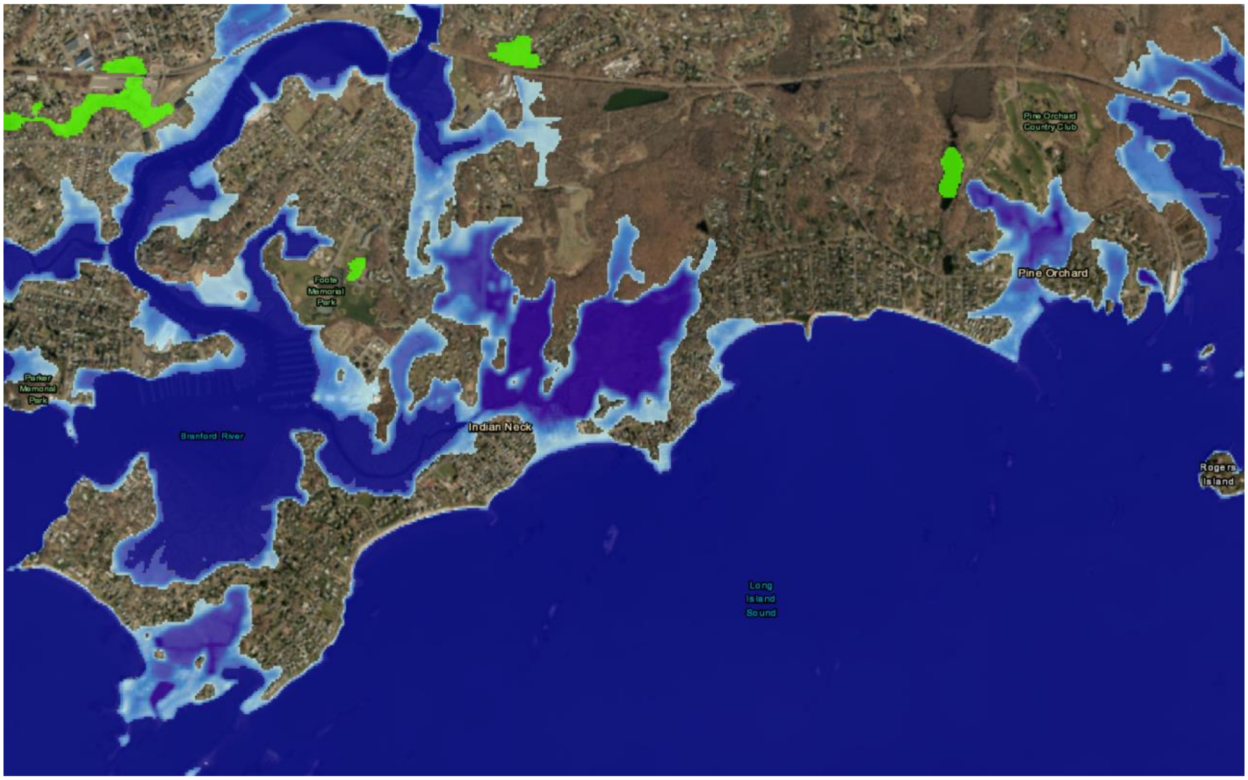
Figure 5: Flooding north of railroad tracks



Indian Neck

A flood map of Indian Neck is shown in Figure 6. Indian Neck is south and east of the Branford River, west of Ecology Park and Haycock Point, east of Pawson Park, and north of Long Island Sound. If flooding is no higher than 1.6 m, the flooding from the Branford River to the north and the flooding from Sybil Creek in the south are distinct. However, once the storm surge reaches 2 m, the floods completely surround Indian Neck turning it into an island as can be seen in Figure 6. Such a storm surge would inundate Indian Neck from three directions: from the Branford River to the north, from Sybil Creek to the west, and from the coast to the south.

Figure 6 Indian Neck Flood Surge of 2 m



A potential wall bordering the entire eastern edge of the Branford River from Sylvan Point to Tabor Drive, a length of about 6000m, failed a cost benefit test because it protected very few properties given its high cost.

Another potential wall was considered between the properties east of South Montowese from Tabor Drive and north of Ark Road and the adjacent wetland. The wall was 993 m in length. This wall would be intended to reduce flooding southeast from the Branford River above the Montowese Bridge as can be seen in Figure 6. Although 69 parcels would be protected by this wall, the flood benefits were less than the cost of this wall.

A wall was also considered along the wetland formed by Sybil Creek east of South Montowese Avenue (Route 146) (see Figure 6). With storm surge, the wetland floods and affects properties adjacent to the wetland. To protect this Indian Neck neighborhood from Sybil

Creek flooding would require a wall that is 600 m long. Although it would stop substantial flooding damage, the wall fails a Benefit Cost test.

Another wall was considered along the coast protecting Limewood Avenue (Rt 146). However, Figure 6 reveals that this coastal neighborhood is not flooded from the coast with surges up to 1.6 m. The flooding of this neighborhood is coming from Sybil Creek. As can be seen in Figure 7, it is not until flood surges reach 2m that the neighborhood becomes flooded from both the coast and the tributary. Because the coastal wall only protects from infrequent severe flooding, it fails a Benefit Cost test.

Sybil Creek Storm Gate

This analysis considers a storm gate at Sybil Creek where it crosses South Montowese Avenue (Rt 146) (near Lenny's restaurant and adjacent to Geronimo restaurant) as seen in Figures 6. The span of the creek at this point is about 3 m and the land is about 2 m in elevation. The storm gate may cost $1 million to install at the bridge. Walls would be needed on both sides of the bridge for about 100 m on both sides to raise the height of the barrier above 2 m. The model suggests the optimal elevation of the top of these walls is 2.9 m. The cost of the walls would be another $1 million. The model estimates that the benefit of the Sybil Creek storm gate and walls in reduced flooding would be $7.7 million. This is a net benefit to cost ratio of about 3.7 to 1.

Branford River Storm Gate

There are four possible locations to place a storm gate along the non-navigable portions of the Branford River. From south to north: these include the Indian Neck Avenue bridge, the Montowese Avenue Bridge, the Railroad bridge, and the extension of Old Pine Orchard Road. One technically could also locate a storm gate at Pine Orchard Road but this is likely to be more expensive than using Old Pine Orchard Road and it woud have the same benefit. The span of the river varies at each of these four points. The Indian Neck bridge has a span of 50 m, the Montowese bridge has a span of 25 m, the railroad bridge has a span of 18 m, and the extension of Old Pine Orchard Road has a span of 20 m. Each of these storm gates would have to be designed for the site and so it is diffcult to estimate the cost of these storm gates. We assume that the longer the span, the hgiher the cost of the storm gate. We estimate that the shorter span storm gates are likely to cost about $2 million and the storm gate for the wider Indian Neck location would cost about $4 million. Although narrow, we estimate that the railroad bridge storm gate is $3 million because it must be higher and it must be safely integrated with the railroad crossing. All of these storm gate costs should be reviewed.

If one wanted a storm barrier that is higher than the adjacent land (about 2 m), there would be an additional cost to building walls along the adjacent land for all but the railroad bridge location. The railroad bed is already at 4.6 m. The storm gate at the railroad bridge can be designed to protect to the height of the railroad bed, yielding a 4.6 m storm barrier. The land near the other three storm gate sites would need to be raised to increase the height of these potential barriers. To raise the height of the Indian Neck storm gate, one would need a 50 m wall north of the storm gate and a 200 m wall south of the storm gate built along Indian Neck Avernue to the railroad bed on the north side and to a slight hill on the south. To raise the Montowese storm gate, one would need a 100 m wall north of the storm gate to higher ground and a 100 m wall south of the storm gate to a slight hill. To raise the height of the storm gate at the extension of Old Pine Orchard Road, one would need a 140 m wall along the west side of the Branford River to the railroad bed and a 330 m wall on the east side of the Branford River again to the railroad bed.

When comparing the sites for the Branford River storm gate, the further down the river one blocks the storm surge, the more properties are protected by the storm gate. This implies more potential flood protection benefits. The difference between the Indian Neck bridge and the Montowese bridge location is the flooding damage to a few buildings along the river (1 north and 8 south of the river). This is a small additonal flood benefit. However, the Indian Neck wall to support the storm gate is longer and therefore more costly. This means that the Indian Neck barrier is lower which reduces the benefit of the Indian Neck bridge location. The difference between the Montowese bridge and the railroad bridge is over a 100 properties in Indian Neck to the east and south of the bridge. These properties would be protected by the Montowese location. However, the protection is effective only to 2 m because these same properties would also be flooded by a surge over 2 m from the south. There are no additonal properties at risk between the railroad bridge and the Old Pine Orchard Road locations. The primary difference between these two locations concerns the cost of building the extra walls to make the Old Pine

Orchard Road barrier higher. Because of the length of the wall needed to build the Old Pine Orchard bridge storm gate, theoverall wall heigh twoudl be low and nto as effective.

The economic cacluations for each storm gate site are presented in Table 1. The storm gate is expected to cost $4 million for the Indian Neck bridge because of the wide span of the river. Given the length of the needed wall to raise the elevation about 2m, the cost of the wall is $5.3 million and the top elevation is reltively low at 2.9 m. The benefit of this Indian Neck bridge at 2.9 m is estimated to be $4.1 million. The Indian Neck bridge storm gate fails the Benefit Cost test.

Table 1: Alternative Branford River Storm Gates

Location	River span/ wall length	Height	Cost	Benefit	Net Benefit
Indian Neck	50 m/300 m	2.9 m	$5,300,000	$4,080,000	-$1,220,000
Montowese	25 m/225 m	3.1 m	$3,500,000	$4,630,000	$1,130,000
Railroad	18 m/0 m	4.6 m	$3,000,000	$18,500,000	$16,500,000
Old Pine Orchard	20 m/490 m	2.5 m	$2,400,000	$1,650,000	-$750,000

The cost of the storm gate at the Montowese bridge is expected to be $2 million given the span of the river. The optimal elevation of the wall around the storm gate is 3.1 m. The overall cost with the wall would be $3.5 million. The overall benefit of the Montowese brudge storm gate is estimated to be $4.6 million so the benefit of this storm gate exceeds the cost. One advantage of the Montowese bridge is that there is ample fresh water storage just upriver of the gate in the nearby wetlands. Closing the gate would stop the storm surge from the coast without creating a fresh water flooding problem.

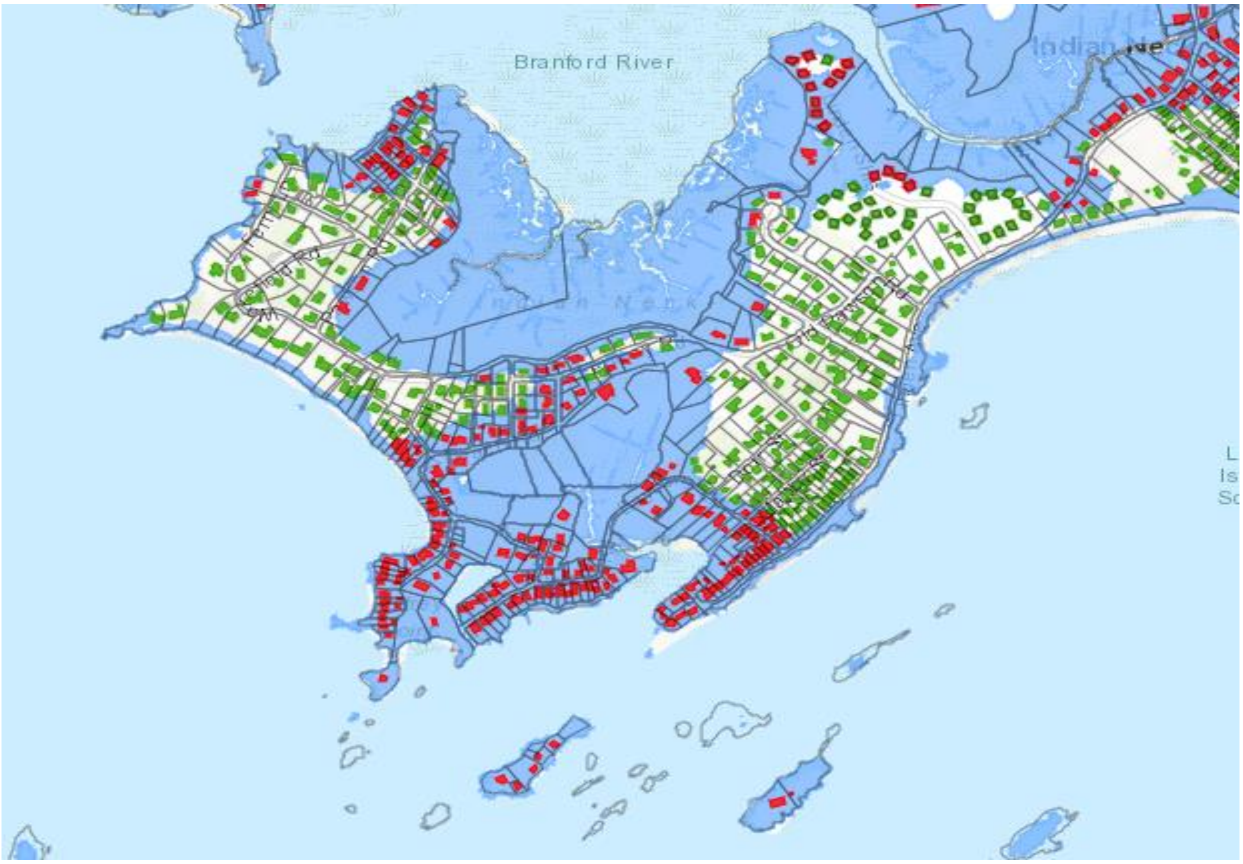
A Branford River stormgate gate just downriver from the railroad bridge has the advantage of a narrow river crossing but more importantly it takes full advantage of the railroad bed. The potential protection is up to 4 m. The railroad bidge storm gate effectively Hurricane proofs Branford north of the railroad tracks for the next century. It has very long term benefits for Branford. The walls needed to connecty the storm gate to the railroad bed are short. The likely cost of this storm gate is about $3 million. The flood portection benefits are about $18.5 million. The benefit to cost ratio is over 6 to 1.   The limitation of the storm gate at the railroad bridge is that it does not protect any of the properties in Indian Neck but another advantage of this storm gate is that it protects the railroad bridge as well.

The benefit of locating a storm gate at the Old Pine Orchard bridge location is estimated to be $1.7 million. It is much less effective than the railroad bridge because of its limited height. Given its overall cost of $2.4 million, it is not an atractive option.

Pawson Park

Pawson Park is a peninsula between the Branford River and Long Island Sound (see Figure 7). About half of the neighborhood is under 15 feet in elevation which makes it vulnerable to storm surge. The coastal defense analysis of this neighborhood considered 9 possible places to locate a wall to protect vulnerable homes (see Figure 9). Most of the potential walls would have protected only a few homes but at great cost and were rejected. However, a coastal wall along the entire low-lying coastline in the southwest corner of Pawson Park appears to be a worthwhile investment. The wall would have to be 4436 m long to protect this entire section. The ideal elevation of the top of the wall would be 1.8 m. The cost of the wall would be $12.7 million and the benefit would be $24 million leading to a benefit cost ratio of 2 to 1. A storm gate that could block the inlet under Summer Island Road and the inlet to the lagoon would increase benefits to $27 million.

Figure 7: Pawson Park Wall



Hotchkiss Grove

Walls were evaluated in two areas of Hotchkiss Grove: at Haycock Point (327 m) and Seaview (255 m). Both walls did not pass a cost benefit test.

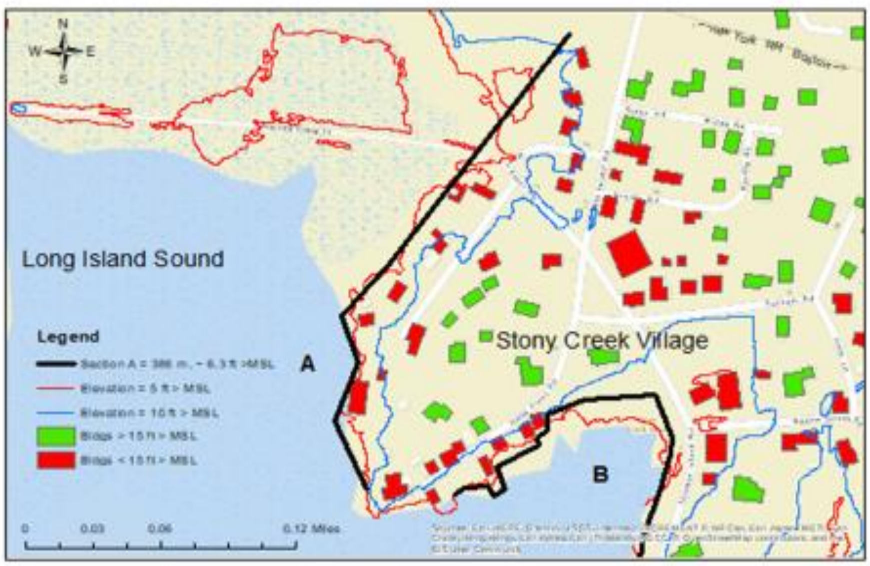
Pine Orchard

A wall was investigated stretching from the Pine Orchard Club south to Brown Point and then east along the coast near Island View Avenue. The cost of the wall exceeded the benefit of reduced damaged. There is simply not enough properties gaining protection from the wall.

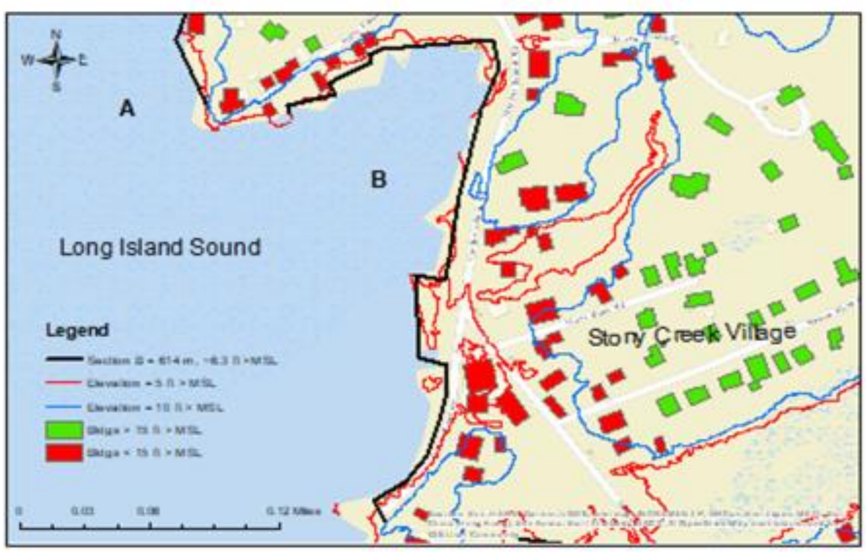
Stony Creek

A discontinuous wall of 1796 m should be built to protect the community of Stony Creek south of the railroad. The wall should be designed in 7 segments to block low points along the coast. Segment A is 386m, segment B is 614m, segment C is 298m, segment D-E is 266m, segment F is 70m, segment G is 90m long, and segment H is 72m. There is an alternative wall for F at F' that is 30m wide instead of 70m. The analysis is suggesting that the optimal elevation of the top of the wall is 2 m. The present value of the cost of the discontinuous wall in Stony Creek is $7 million and the present value of benefits is $21 million. The benefit to cost ratio of making these improvements is 3 to 1. Note that a great deal of this wall already exists. The proposal is to make it a little higher. This is especially true of a public boat launch which is currently a source of frequent nuisance flooding.

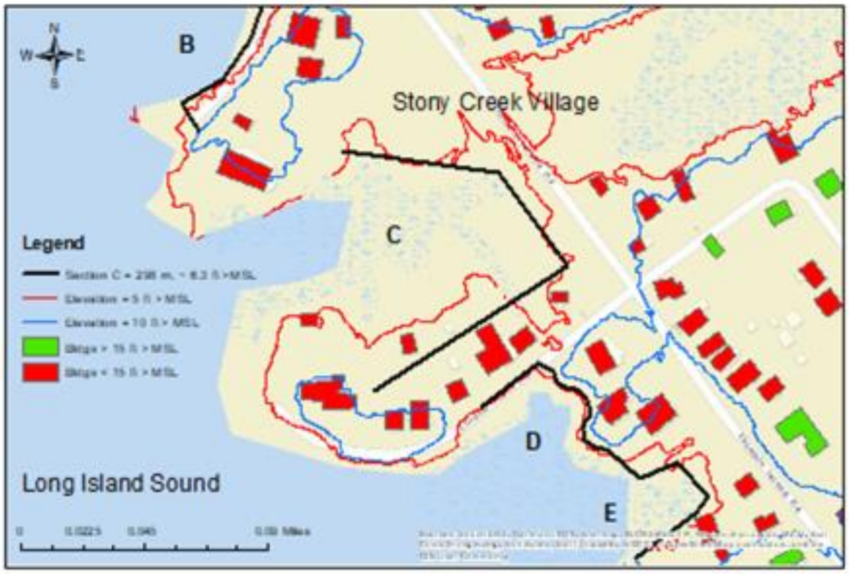
Stony Creek: Proposed Sea Wall, Section A



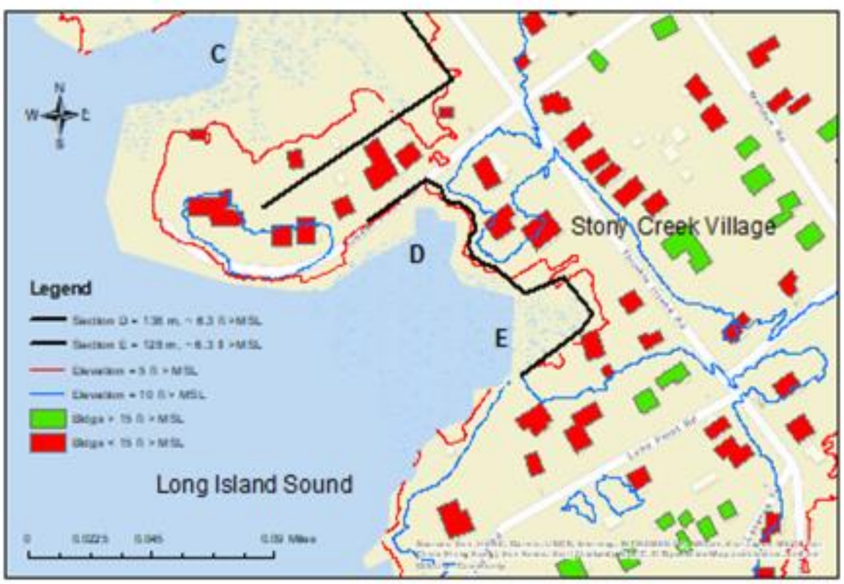
Stony Creek: Proposed Sea Wall, Section B



Stony Creek: Proposed Sea Wall, Section C

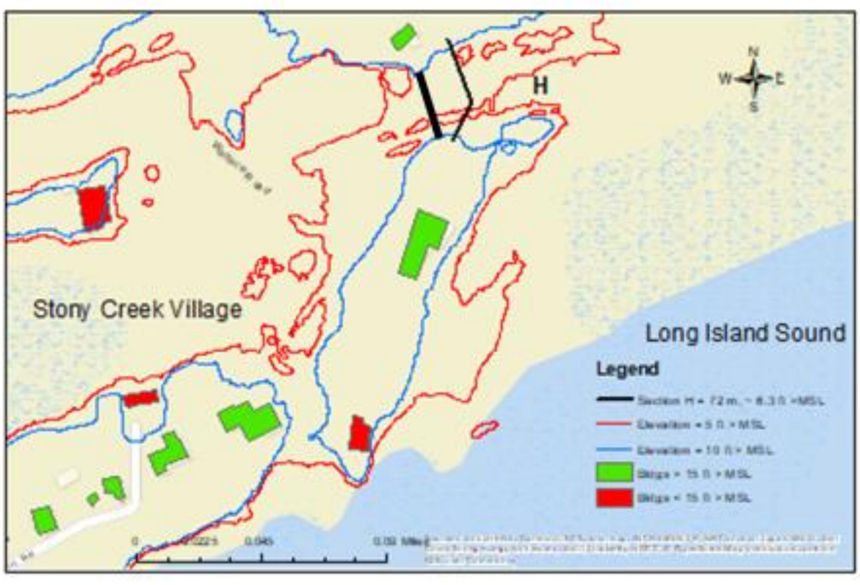


Stony Creek: Proposed Sea Wall, Sections D, E



Stony Creek: Proposed Sea Wall, Sections F, G

Stony Creek: Proposed Sea Wall, Section H



Conclusion

This paper evaluates all the coastal segments in Branford including all 20 miles (32000 m) of coastline. Simply examining the average elevation of all parcels south of Route 1 reveals that Branford has 252 properties that are 3 m or less in elevation. These properties are scattered across all of southern Branford. All of these properties are subject to flooding in a 1/100 year storm.

The paper calculates the probability of different storm surge depths for Branford using data from the NOAA tidal station at Bridgeport. Future tides are predicted using this model of storms from the long term record and the historical rate of sea level rise in Connecticut (3 mm/yr).

The paper examines whether one can protect the properties along the Branford Coast by building fortified walls or storm gates. The analysis takes into account the project costs and benefits over the next 30 years which is the expected lifetime of these protective actions. The study does not separately value wetlands but all of the defensive measures considered in this report have been designed to have minimal impacts on coastal wetlands. For example, the walls would all be built on upland sites above the wetland. The creek and river barriers are all storm gates that would only be closed during impending storm surges.

The study calculates the cost of walls to protect each segment of the coast as well as looking as the cost of storm gates for creeks and rivers. The study calculates the benefit of each protective action by determining the properties that would be inundated by each storm surge, the depth of the inundation, and the resulting expected damage. The analysis reveals that almost every coastal and riverine segment in Branford has at least one vulnerable property so that there are nonzero benefits to protection throughout the coast. However, there are only a few places where the benefit of protection outweighs the cost. We review the promising sites for building walls and storm gates below.

All of the desired protective walls are relatively low structures whose major purpose is to prevent frequent nuisance flooding. They would not protect properties from more severe events such as severe hurricanes. We rank the walls in terms of the benefit to cost of each site as shown in Table 2. Raising the wall at Stony Creek to an elevation of 2 m has the highest benefit to cost ratio. Note that this wall would be about 3 feet above ground level. Building a wall to an elevation of 1.5 m (about 2 feet above ground level) between Blackstone Acres and the surrounding wetland is the next most attractive choice. A 2 foot wall between developed sites and the western wetlands of the Branford River north of the railroad is another attractive choice. Finally, a 3 feet wall along the southwest coast of Pawson Park is also an attractive option. None of the other potential sites for walls along Branford currently are worth building.

Table 2: Attractive wall sites

Site	Cost	Benefit	Benefit/cost
Stony Creek	$7,000,000	$21,000,000	3
Blackstone Acres	$1,000,000	$2,700,000	2.7
Branford Center	$1,000,000	$2,000,000	2
Pawson Park	$13,000,000	$24,000,000	1.8

The analysis suggests that there are several specific storm gates that are promising. Where storm gates are beneficial, they are more effective than walls along the upriver creek. The storm gates can protect these properties from more severe flooding events and at lower cost. Several storm gates were considered to reduce flooding up rivers and creeks in Branford.

The most attractive storm gate blocks the Branford River as it crosses underneath the railroad tracks near Pine Orchard Road. The storm gate can be built just south (downriver) of the railroad bridge and then just have an abutting wall back to the railroad bed. The existing railroad bed would then form an effective barrier that is 4.3 m high. This is the single most beneficial coastal protection action that can be taken in Branford. It eliminates the need for walls along the Branford River north of the railroad tracks (the Blackstone Acres and Branford Center walls in Table 2). The storm gate at the railroad bridge effectively protects both the Branford town center and Blackstone Acres from hurricanes for the rest of the century. It is effective both in the short run and the long run with sea level rise and the increasing power of storms.

An alternative Branford River location for a storm gate is further down river along the Montowese Avenue bridge. The advantage of this alternative location is that it would also provide some protection for many homes in Indian Neck. But the Montowese bridge location is more expensive than the railroad bridge choice. The optimal height of this barrier is 3.1m which means it is less effective at stopping severe flooding. Because it requires a long wall on both sides of the bridge, it is noticeably more expensive than the railroad bridge. So the Montowese Avenue bridge location is not as attractive as the railroad bridge location for a storm gate. If the barrier at the railroad bridge is built, the benefit of the Montowese barrier falls dramatically because the properties north of the railroad would already be protected. So the town would not want to build both storm gates.

Another valuable storm gate should be located at Sybil Creek at the South Montowese Avenue crossing. By building a short wall along South Montowese Avenue, this storm gate can provide large flooding benefits to the Indian Neck/Limewood Avenue neighborhood along Sybil Creek.

A third possible storm gate site is where the Mill Creek crosses Harbor Street. Depending upon how much the storm gate costs, the benefits may exceed the cost at this site. Whether or not this storm gate is attractive will depend on its final cost.

Table 3 Storm gate sites

Site	Cost	Benefit	Benefit/ Cost
Branford River Railroad Crossing	$3,000,000	$18,500,000	6.1
Branford River Montowese Avenue	$3,500,000	$4,600,000	1.3
Sybil Creek S. Montowese Ave.	$2,500,000	$7,700,000	3
Mill Creek Harbor Street	$729,000	$825,000	1.1

Many of the vulnerable low-lying properties in Branford cannot be effectively protected by walls or storm gates. There is simply not enough property behind the wall to justify the cost. Alternative approaches such as raising homes or eventually retreating away from the coast are the only effective measures that can be taken in these cases.

Branford should evaluate whether or not to establish consistent rules for raising vulnerable homes. Quite often a home that has to be raised would subsequently violate current total building height regulations. Neighborhoods that have a few raised homes and a few homes that are low tend to look disjointed and unattractive. There are options to raise an entire block together that leads to much more attractive outcomes. Branford should consider such small development zoning options as a mechanism to encourage attractive flood proof outcomes.

Buying out homes is one way to facilitate retreat from hazard prone areas. However, it is very expensive and it gives the impression that it is the town forcing people to leave and not the natural hazard. The report recommends that the town establish rules concerning where people can build and where they can rebuild after a storm that discourages people from investing in risky locations. Building sites that are less than 9 feet in elevation are currently risky and will only get more risky in the future. Unless the home is going to be elevated to 12 feet, it is inadvisable for the town to permit rebuilding or building to take place.

Alternative strategies that are commonly mentioned as part of coastal defense include beach nourishment and living shorelines. These methods can be effective at controlling erosion. However, they are likely to be ineffective at preventing storm surge damage. They should not be encouraged as flood protection measures.

This analysis assesses actions that make sense for Branford to do immediately. With the steady progression of sea level rise of 3 mm/year, flooding risks will increase over time. Development may change what is at risk. The analysis done in this study should be reassessed every decade or two to see if conditions have changed enough to warrant new projects.

This analysis does not address how to finance the desired projects. There are many alternative financing mechanisms including raising taxes, bonds, and government grants. In principle, flood insurance rates should fall once a neighborhood is protected. However, it is not yet clear that the Federal Flood Insurance system is sophisticated enough to alter rates in proportion to the reduction in expected storm damage.

There are several factors that this analysis does not yet take into account. The analysis does not yet explore what actions should be taken 30 years from now (in 2050) for the 30 years following (from 2050 through 2080). The analysis does not consider whether wetlands should expand into developed areas in the future. The analysis has not completed a detailed engineering plan of each site which would be the next step if Branford proceeds with any of these projects. Finally, the model does not consider the design details of each project. Sometimes walls can be stand-alone structures and sometimes they can be integrated with other structures. A wall along a bridge, for example, can be part of the bridge design. Sometimes that wall can have multiple purposes. For example, many coastal walls are also boardwalks- people can walk on the walls. Design details can also affect the aesthetic appearance of a wall. For example, Stony Creek may well want to build their walls using Stony Creek granite because it is a local stone and because many existing walls in Stony Creek are already made of this stone. Such details may well determine the public acceptance of any proposed wall.

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