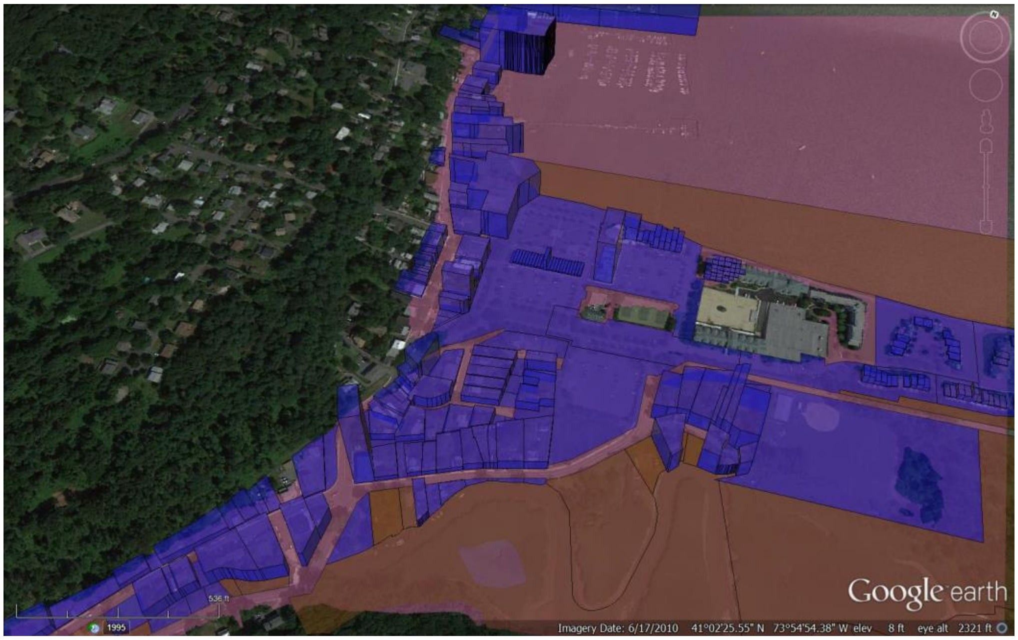
Benefit Cost Analysis for Adaptation to Sea Level Rise and Storm Surge in Piermont, NY:

Use of the COAST Approach™ to Evaluate Elevations, Flood Proofing, Flood Walls, and Strategic Relocations



COAST model scenario of buildings damaged in a 100 Year Storm arriving in the year 2025, with 10 inches of sea level rise and a total water elevation of by 10.83, if no action is taken, in the Village of Piermont.

- **Estimates One-Time Damage to Building Values from a 100-year Storm in the Years 2025, 2055, and 2100 if No Action is Taken.**
- **Indicates which Parcels are Predicted to be Permanently Inundated by Sea Level Rise on a Daily Basis, if No Action is Taken, by the Years 2025, 2055 and 2100.**
- **Utilizes Sea Level Rise Scenarios Provided by Scenic Hudson, and Flood Heights from FEMA Advisory Base Flood Elevations (2013).**
- **Includes Predictions for All Cumulative Expected Monetary Damage to Building Values from All Storms, up to the Years 2025, 2055, and 2100.**
- **Includes Cost Estimates and Benefit Cost Ratios for Three Proposed Adaptation Scenarios**

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Executive Summary

Catalysis Adaptation Partners of Freeport, Maine worked with Scenic Hudson and a task force of the Village of Piermont, to use the COAST modeling tool to:

- Conduct a vulnerability assessment for the Village from the threat of future storm surges, made worse by sea level rise over time.
- Calculate a prediction of cumulative damages to real estate over time if no action is taken.
- Calculate a prediction of one-time damages from 100-year storms that might occur in the future.
- Evaluate three sets of actions, or scenarios, that Village might pursue to mitigate future damages, with benefit-cost analysis.

The COAST Vulnerability Assessment predicts:

- By the year 2100, there will be $192.2 million in cumulative damages to buildings over time in Piermont, from all storms, as sea level increases by 6.00 feet above today's level.
- By the year 2100, that 178 parcels will be permanently inundated by the Hudson River, as sea level increases by 6 feet over today's level, with a total taxable assessed value of $105.5 million.
- During a 100-year storm in the year 2055, $35.7 million in damages will occur from this one-time event, significantly higher than from Superstorm Sandy, as it would arrive on top of a sea level increased by 2.42 feet over today's level.

The Piermont Flooding Task Force asked that COAST to be used to test three sets of adaptation strategies, to protect the waterfront area (cost estimates for each action developed in collaboration with Parsons Brinckerhoff).

- 1 – The "Piermont Protect" scenario, emphasized a fortification approach with a removable floodway along the entire Village waterfront, to maintain current land use and access patterns, and to protect against a 100-year storm until the year 2100.
- 2 - The "Raise Piermont" scenario, emphasized an accommodation approach, allowing floodwaters to move onto the waterfront, with elevations and floodproofing of buildings to minimize damages.
- 3 – The "Piermont Marshway" scenario, emphasized strategic relocation, reducing numbers of people and assets in the highest risk areas; fortification of selected densely developed areas; creation of green infrastructure to absorb floodwaters.

The COAST model was run again for each scenario to estimate avoided damage over time as if each adaptation action had been implemented. Benefit-cost relationships were then established to compare the relative fiscal efficiency of each adaptation option, where "benefits" are the cumulative avoided damages during each scenario. The highest benefit cost ratio was in Scenario 1, with positive ratios when looking at non-discounted dollar figures (Benefit:Cost Ratio = 2.47, by year 2100). However, the removable floodwall faces serious management challenges as it must be installed by a large crew starting two days before any large storm event, in order to function. A mistake in erecting the wall when it is not needed would be politically unpopular, but a mistake in not erecting the wall in time before a large storm would be catastrophic. The third scenario, featuring strategic relocation with voluntary property buyouts in the long term, compares relatively favorably (benefit-cost ratio = 1.48, by year 2100, with non-discounted dollars). In general, benefit-cost ratios in Piermont are low, because adaptations are relatively expensive for the amount and scale of the properties being protected. For instance, in the Kingston project also conducted by Scenic Hudson, benefit-cost ratios were higher because of protection provided to the multi-million dollar sewage treatment plant.

Contents

Methodology and Assumptions Used for COAST Model Analysis

Initial development of the COAST software tool was funded by the US Environmental Protection Agency. It is used to predict damages from varying amounts of sea level rise and storm surge under a range of candidate adaptation action scenarios that users construct. The software was run for Scenic Hudson and the Village of Piermont by Catalysis Adaptation Partners, LLC (Catalysis), whose principals designed the software, and who use it to help communities around the country. COAST is used to calculate the potential damage from one particular storm in the future, as well to calculate the cumulative potential damage from all storms that may occur over a period of years, from today until a point in the future.

Model Preparation for the Village of Piermont

Step 1 - Load accurate elevation data.

A LiDAR (Light Detection and Ranging) image of the area was used, which is a highly accurate map of land elevations made by taking laser measurements from an airplane. With this data layer the COAST model could identify the ground elevation of any point in the study area. LiDAR data for the Village consisted of a grid millions of squares, each 1 meter by 1 meter, with a single elevation value in feet for each square.

Step 2 – Load tax map parcels and assessed building values from the Village.

Property values were provided by the GIS Department of Rockland County. Care was taken to ensure the LiDAR images and tax map layers had the same coordinate system and units (feet) for both vertical and horizontal positions.

Step 3 – Determine water levels and probabilities.

As determined by Scenic Hudson, the starting value of the high tide level for Piermont at the Hudson River today, was 2.31 feet (NAVD 88 units), based on an adjusted tidal datum from NYHOPS. As set by Scenic Hudson, the "Rapid Ice Melt, Kingston and South" scenario was added to the model for sea level rise above today's level, as follows:

By the year 2025, an additional 0.83 feet.
By the year 2055, an additional 2.42 feet.
By the year 2100, an additional 6.00 feet.

An "exceedance curve" was also established that states the relationship between storms of different recurrence intervals, sizes, and probability of occurring in any given year. The following values were taken from the Advisory Base Flood Elevation data published by FEMA Region 2 after Hurricane Sandy, in the fall of 2013 (see http://www.region2coastal.com/sandytable).

Storm Event	Recurrence Interval	Probability in Any Given Year	Surge Height Above MHHW of 2.31 ft. (NAVD 88 units)		Overall Elevation of Flood Waters in Feet (NAVD 88 units)	
			A Zone	V Zone[3]	A Zone	V Zone[3]
500 Year Storm[1]	Once every 500 years	0.002	12.69	14.69	15.0	17.0
100 Year Storm[1]	Once every 100 years	0.01	7.69	9.69	10.0	12.0
50 Year Storm[2]	Once every 50 years	0.02	6.19	8.19	8.5	10.5
10 Year Storm[2]	Once every 10 years	0.10	3.99	5.99	6.3	8.3

[1]From the FEMA Region 2 Post-Sandy Advisory Base Flood Elevation Data, http://www.region2coastal.com/sandytable, 2013.

[2]Effective FIS Study water levels for these storms were not revised upwards in the 2013 ABFE data. Values from the existing FIS were increased from 5.1 and 6.1 for the 10 and 50 year storms, respectively, reading off a best fit 2nd order polynomial curve created from the new FEMA 100 and 500 year storm values.

[3]V zone values were set two feet higher than A zone values, for all probabilities of storms, as per the ABFE's published by FEMA.

These water levels were established for the creation of simulated storms, with identified sea level rise curves added over time.

Step 4 – Provide a depth-damage function

Finally, COAST needs a guide to calculate amounts of damage to be incurred by each asset, depending on flooding depth during each storm event. A "depth-damage function" was incorporated from the US Army Corps of Engineers, and was based on the Army's damage measurements from years of studying floods and the associated insurance claims. In the model parameters, it was assumed that once the daily high tide (mean higher high water) with no storm surge, reached a depth of one foot at the center of a parcel, the entire value of the building or buildings would be permanently lost due to sea level rise, if no action was taken.

Step 5 – Ensure asset data are appropriately structured

COAST creates flood scenarios over many years and measures flood depth at the center of each parcel polygon. In the case of multiple buildings on one lot, and with the version of the software being used at the time, there unfortunately was no way to apportion building value between separate buildings. The municipal tax parcel database aggregated "building value" for all buildings on a lot. Therefore, for the purposes of this model, the aggregate building value was assigned to the group of buildings on each multi-building lot. Implications of this are that if the model showed the centroid of the parcel as flooded, it calculated damage to all buildings on the parcel using the depth-damage function, as if it were one flooded building. This may have overestimated damage on some parcels.

Limitations of these COAST Model Results

- A uniform mean higher high water elevation for Piermont was entered in to the model. Variation in tidal surface elevations which might actually occur within the Village limits was not accounted for.
- On the open river coast, the effects of waves, wind, and erosion are not considered in the COAST model, as it calculates new high tide levels due to sea level rise, only using still water flood elevations on the existing terrain.
- Output of the model was not evaluated for the hydrologic connectivity of inundated areas. Certain low-lying areas not directly connected to tidal waters may appear flooded in some COAST results in Piemont, which may not necessarily be what occurs in actual flood events.
- Values for individual buildings were not available, as Town assessing records combined the values of all buildings on a particular lot into one number. Loss of building value for the lot was assumed to occur when flood waters reached the imaginary point centered in the parcel polygon, known in GIS terminology as the parcel "centroid."
- When the daily high tide level (MHHW) with sea level rise was projected to reach depths from zero to one foot, without any storm surge, permanent damage was assumed <u>not</u> to occur, to reflect and take into account uncertainty in the modeling. Only when daily MHHW depths reached 1 foot or more at the centroid were building values entirely removed.
- Assessing records did not reflect which buildings may have already been elevated on pilings or flow-through flood-proofed foundations. Sea level rise damage would be overestimated for these structures. However, it should be noted that an elevated structure protected from water damage at its base could still lose its value and utility after sea level rise, because street and utility accesses leading up to the building are lost to daily tidal flooding.

The Vulnerability Assessment

COAST was then run under a "no action" scenario for the Village of Piermont to calculate the losses of building value from sea level rise and storm surge, for the years 2025, 2055 and 2100 (11, 41 or 86 years from now). Results are summarized in tables on the following pages. A google earth map was also created for the Village, with the flooding depth and dollar damage estimate available for each individual parcel flooded by a 100 year probability storm surge with sea level rise, for each scenario. The google earth fil (*.kml format) are available and can be distributed to property owners or any other interested parties for use in personal or public planning for sea level rise and storm surge.

Key Findings of Vulnerability Assessment – If No Action is Taken

- By the year 2055, the COAST model predicts that there will be $70.8 million in cumulative damages to buildings over time in Piermont, from all storms, as sea level increases by 2.42 feet above today's level.
- By the year 2100, the COAST model predicts that there will be $192.2 million in cumulative damages to buildings over time in Piermont, from all storms, as sea level increases by 6.00 feet above today's level.
- By the year 2055, the COAST model predicts that 87 parcels will be permanently inundated by the Hudson River, as sea level increases by 2.42 feet over today's level, with a total taxable assessed value of $56.6 million.

- By the year 2100, the COAST model predicts that 178 parcels will be permanently inundated by the Hudson River, as sea level increases by 6 feet over today's level, with a total taxable assessed value of $105.5 million.
- During a 100-year storm that might occur in the year 2055, the COAST model predicts $35.7 million in damages from this one-time event, significantly higher than from Superstorm Sandy, as it would arrive on top of a sea level increased by 2.42 feet over today's level.
- During a 100-year storm that might occur in the latter half of the century, and with the specified increase in sea levels, the Piermont peninsula would be breached by Hudson floodwaters, creating a channel of water down Piermont Avenue in the Village center.

COAST Model for Piermont
Modeled Water Levels and Vulnerability Assessment Results
For the 100 Year Storm with Sea Level Rise in the Years
2025, 2055 and 2100

Year	Predicted Elevation of 100 Year Storm Flood Height from FEMA ABFE, 2013 NAVD88 (ft.)[1]		Model of Sea Level Rise Above MHHW in 2013 Selected by Scenic Hudson (ft)[2]	Model Total Flood Elevation for Each Scenario NAVD 88 (ft.)		COAST Model Expected Damage to the Value of All Buildings & Improvements From This Single Storm Incident in the Scenario Year ($ Million)[4]			COAST Model Cumulative Expected Value of All Buildings and Improvements Located on Properties Permanently Inundated by Sea Level Rise if No Action is Taken, by this Year ($ Million)[3]			COAST Model Cumulative Expected Damage to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million)[3]		
	A Zone	V Zone		A Zone	V Zone	A Zone	V Zone	Total Village	A Zone	V Zone	Total Village	A Zone	V Zone	Total Village
2025	10.0	12.0	0.83	10.83	12.83	17.8	8.9	**26.7**	2.1	0.5	**2.6**	11.4	7.5	**18.9**
2055	10.0	12.0	2.42	12.42	14.42	30.2	5.5	**35.7**	8.9	9.0	**17.9**	47.2	23.6	**70.8**
2100	10.0	12.0	6.00	16.00	18.00	54.7	2.0	**56.7**	42.7	17.7	**60.4**	156.1	36.1	**192.2**

[1] *Tidal state is included in FEMA FIS predicted flood elevations for the 10 year and 100 year storms.*

[2] *Elevation of Mean Higher High Water (MHHW) in year 2013 is 2.31 feet (NAVD 88).*

[3] *No Discount Rate applied.*

[4] *See kml files and spreadsheet for complete list predicted depths and damages to individual properties.*

Catalysis
Adaptation Partners LLC

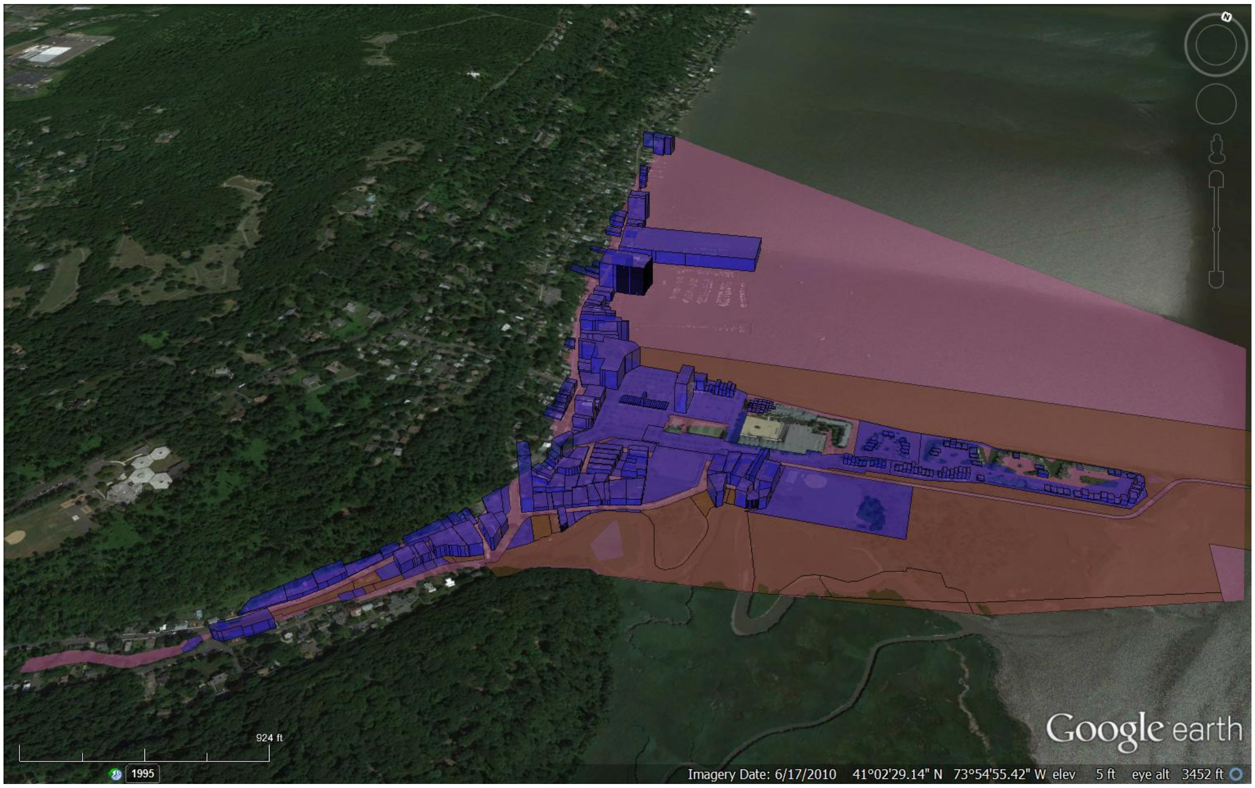
COAST Model for Piermont
Modeled Water Levels and Vulnerability Assessment Results
For Sea Level Rise Only, Without Any Storm Surge
in the Years 2025, 2055 and 2100

Year	Model of Sea Level Rise Above Today's MHHW, 2.31 NAVD 88 (ft)[1]	Total Height of Daily High Tide, Without Surge (MHHW – NAVD 88) (ft.)	Number of Tax Parcels Affected		COAST Model **Cumulative** Expected Value of **All Buildings and Improvements** Located on Properties **Permanently Inundated by Sea Level Rise** if No Action is Taken, by this Year ($ Million)[2]			COAST Model **Cumulative** Expected Value of **All Land** Located on Properties **Permanently Inundated by Sea Level Rise** if No Action is Taken, by this Year ($ Million)[2]			COAST Model **Cumulative** Expected Value of **All Land plus Buildings and Improvements (Total Assessed Value)** Located on Properties **Permanently Inundated by Sea Level Rise** if No Action is Taken, by this Year ($ Million)[2]		
			A Zone	V Zone	A Zone	V Zone	Total Village	A Zone	V Zone	Total Village	A Zone	V Zone	Total Village
2013	0	2.31	N/A	N/A	N/A	N/A	**N/A**	N/A	N/A	**N/A**	N/A	N/A	**N/A**
By 2025	0.83	3.14	20	4	2.1	0.5	**2.6**	13.7	0.7	**14.4**	15.8	1.2	**17.0**
By 2055	2.42	4.73	65	22	8.9	9.0	**17.9**	22.3	6.4	**28.7**	31.2	15.4	**56.6**
By 2100	6.00	8.31	144	34	42.7	17.7	**60.4**	35.3	9.8	**45.1**	78.0	27.5	**105.5**

[1] *Elevation of Mean Higher High Water (MHHW) in year 2013 is 2.31 feet (NAVD 88).*

[2] *No Discount Rate applied. Values taken from Rockland County/Village of Piermont Tax Assessment Database. See kml files for a complete list of permanently inundated properties with predicted depths.*

Illustrations of COAST Model Output for Sea Level Rise and One-Time Surge Impacts to Buildings

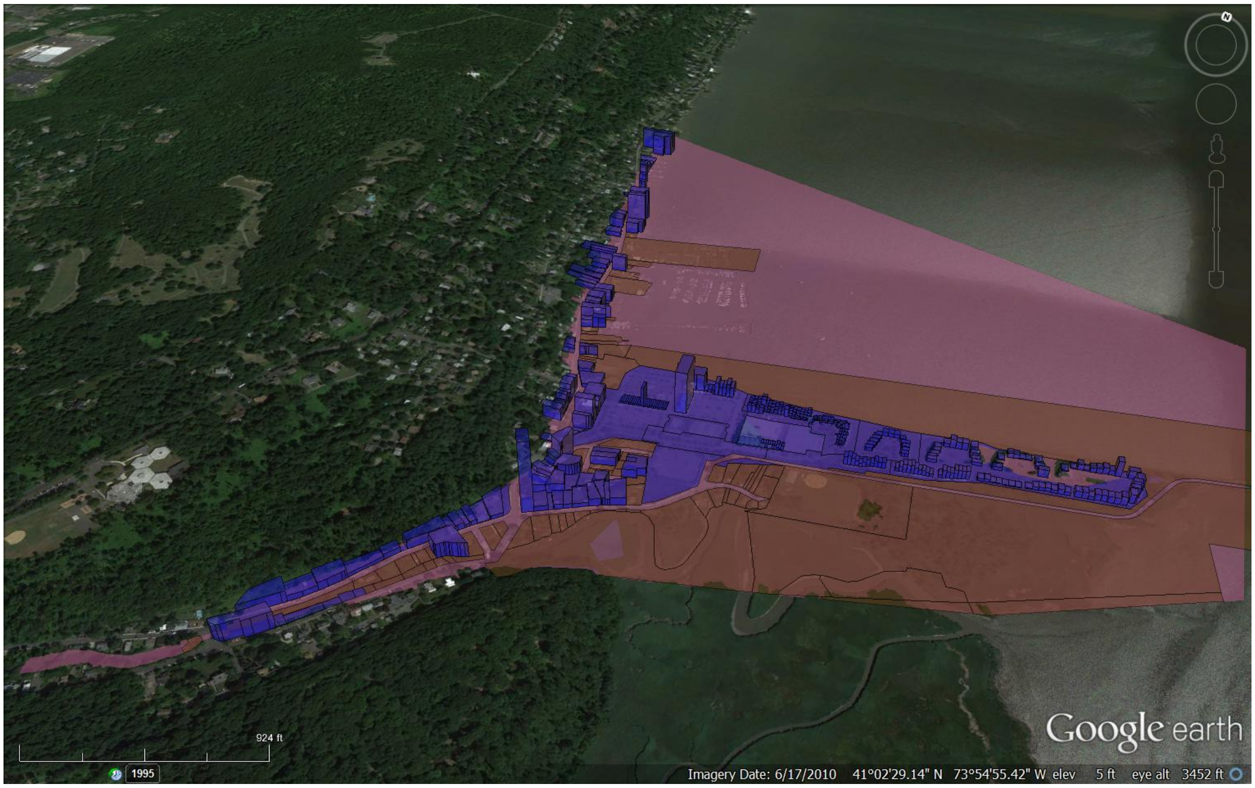


Village of Piermont

COAST Model Results, 100 Year Storm + Sea Level Rise in 2025
Total Elevation of A Zone Flooding –10.83 Feet (NAVD 88)

- (blue) Buildings & Land Damaged by Storm Surge from this Single Event (Height of Bar indicates relative damage amount)
- (brown) Buildings & Land Permanently Inundated due to Sea Level Rise by this Year, if No Action is Taken
- (pink) Extent of Flooding from this Amount of Storm Surge + Sea Level Rise

*Predicted flood depths and dollar damages for all individual affected parcels are available in Google Earth *.kml files.*

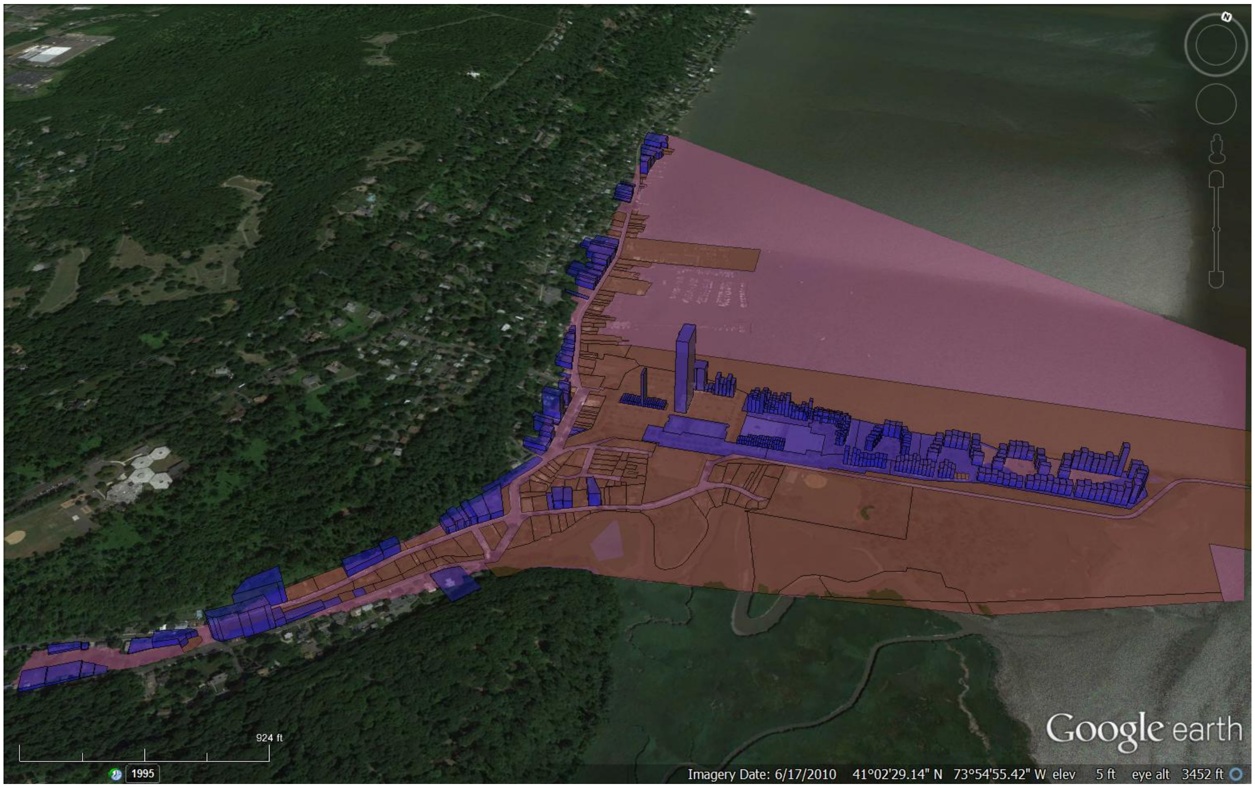


Village of Piermont

COAST Model Results, 100 Year Storm + Sea Level Rise in 2055
Total Elevation of A Zone Flooding –12.42 Feet (NAVD 88)

- Buildings and Land Damaged by Storm Surge from this Single Event (Height of Bar indicates relative damage amount)
- Buildings and Land Permanently Inundated due to Sea Level Rise by this Year, if No Action is Taken
- Extent of Flooding from this Amount of Storm Surge + Sea Level Rise

*Predicted flood depths and dollar damages for all individual affected parcels are available in Google Earth *.kml files.*



Village of Piermont

COAST Model Results, 100 Year Storm + Sea Level Rise in 2100
Total Elevation of A Zone Flooding –16.00 Feet (NAVD 88)

- Buildings and Land Damaged by Storm Surge from this Single Event (Height of Bar indicates relative damage amount)
- Buildings and Land Permanently Inundated due to Sea Level Rise by this Year, if No Action is Taken
- Extent of Flooding from this Amount of Storm Surge + Sea Level Rise

*Predicted flood depths and dollar damages for all individual affected parcels are available in Google Earth *.kml files.*

Adaptation Strategies and the COAST Tool

Do Nothing, Fortify, Accommodate, or Strategically Relocate

Options for responding to sea level rise and storm surge can be divided into four categories.

Doing nothing is the most common, as it simply involves waiting for a storm incident to happen, and responding afterwards.

Adaptation approaches that "*fortify*" use hard or soft structures to prevent flood waters from reaching community assets. Such armoring can be "hard," such as seawalls or bulkheads, or "soft" structures such as geotextile tubes, which are giant fabric sandbags designed to be replaced after storms. Unfortunately, wetlands and beaches in front of such structures can disappear as they are pinched out between the rising water levels and the fortifying structures behind them.

Adaptation approaches that "*accommodate*" modify community assets to reduce the impact of flood waters. Accommodation ackknowledges that structures will get wet, but action is taken to make it resilient, such as elevating a structure or its critical systems,.

Strategic relocation involves relocating existing structures, people, and land uses away from areas at high risk of flooding to a new location to eliminate the risk of flooding, and allowing wetlands, beaches and natural coastal habitats to migrate landward naturally.

Potential Sea Level and Storm Surge Adaptation Actions		
Fortify	Accommodate	Strategic Relocation
• Revetments • Seawalls • Jetties • Levees • Geotextile Tubes • Automatic Floodgates • Hurricane Barriers	• Dry Floodproofing – Sealing Out Water • Wet Floodproofing – Allowing structures to get wet safely, with minimal damage • Land elevation by fill • Structure Elevations • Dune Restorations • Tidal Marsh Restorations • Tunnel Plugs	• Property Buyouts • Rolling Easements • Relocation of Buildings • Relocation of Infrastructure and/or Facilities • Zoning or Other Regulations to Prevent Fortification, and/or limits on New Construction

Use of the COAST Tool to Perform a Benefit Cost- Analysis for a Proposed Strategies

Once an adaptation strategy, or set of strategies, has been identified for a community or portion of a shoreline, the COAST tool can be used to evaluate whether the strategy would be a good investment. The COAST model can be run with an adjustment to the depth damage function, to estimate how much cumulative damage might be avoided if the adaptation strategies were installed or put in place. The avoided cumulative damage can be compared to the cost of the potential strategies, creating a benefit/cost ratio. If this ratio is high, i.e., costs are low and benefits are high, then it indicates that the option may will be a good investment, and worthy of further study, and more detailed feasibility plans and construction designs and estimates can be prepared. The Piermont Flooding Task Force asked that COAST to be used to test three sets of adaptation strategies, to protect the waterfront area (see illustrations below). These sets of adaptation strategies were described as three scenarios, which were developed by a subcommittee of the Task Force, working extensively with Scenic Hudson and Catalysis staff.

Description of Three Adaptation Strategy Scenarios for Piermont

Scenario 1 was called "Piermont Protect." Its goal was to emphasize a fortification approach, to maintain current land use and access patterns, and to protect against a 100-year storm until the year 2100. Its adaptation elements were as follows:

Note: All units are in NAVD 88 elevation datum. High tide is Mean Higher High Water, 2.31 feet. 100-Year flood height was taken from the 2013 FEMA Post-Sandy advisory report.

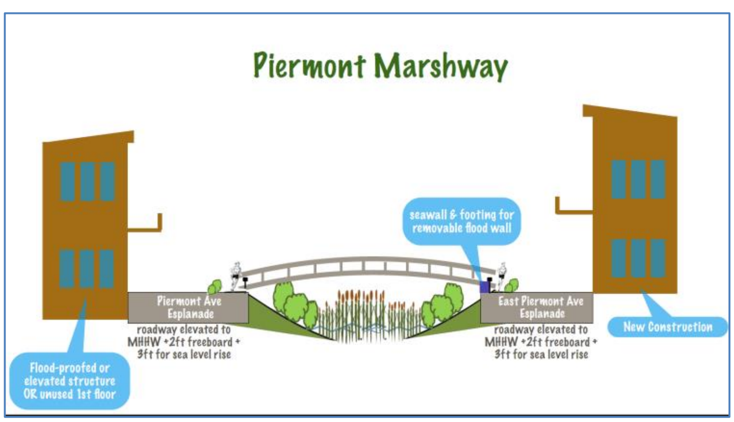
- Raise all sections of roads shown in red now, to a height of 6.75 feet, which is equal to today's high tide, plus 29 inches of sea level rise, plus 2 feet of freeboard.
- Raise all sections of roads shown in yellow and red in the year 2055, to a height of 10.3 feet (an additional 3.55 feet), which is equal to today's high tide, plus 72 inches of sea level rise, plus 2 feet of freeboard.
- Elevate all buildings on parcels shown in purple now, so that their base floor elevation is set at 14.5 feet, which is the current 100 year advisory flood height, with two feet of freeboard, and an additional 29 inches to account for sea level rise.
- Install a removable floodwall along the green line, the top of which will be set at 20 feet in elevation, which is today's high tide, plus the height of a 100 year flood with two feet of freeboard, and an additional 72 inches to account for sea level rise.

Scenario 2 was called "Raise Piermont." Its goal was to emphasize an accommodation approach, allowing floodwaters to move onto the waterfront, with building adaptations to minimize damages. Its adaptation elements were as follows:

- Raise all sections of roads shown in red now, to a height of 6.75 feet, which is equal to today's high tide, plus 29 inches of sea level rise, plus 2 feet of freeboard.
- Raise all sections of roads shown in yellow and red in the year 2055, to a height of 10.3 feet (an additional 3.55 feet), which is equal to today's high tide, plus 72 inches of sea level rise, plus 2 feet of freeboard.
- Elevate all buildings on parcels shown in purple now, so that their base floor elevation is set now at 14.5 feet. Elevate all buildings on parcels shown in purple an additional 3.5 feet to 18 feet, in the year 2055.
- Adapt all buildings on parcels shown in orange now, so that their first floors are modified either to:
  1. allow flood waters to flow through (wet-floodproofing) by removing habitable spaces; or
  2. equip all buildings to be able to seal their first floors, with water-tight doors, windows, vents, or other openings (dry-floodproofing).

Scenario 3 was called "Piermont Marshway." Its goal was to emphasize some strategic relocation, reducing people and assets in the highest risk areas, to fortify selected densely developed areas, and to create green infrastructure to absorb floodwaters. Its adaptation elements were as follows:

- Raise all sections of roads shown in black now, to a height of 6.75 feet, and in 2055 to 10.3 feet.
- Elevate all buildings on parcels shown in light purple now, so that their base floor elevation is set now at 14.5 feet.
- Adapt all buildings on parcels shown in purple now, so that their first floors are modified either to:
  1. allow flood waters to flow through (wet-floodproofing) by removing habitable spaces; or
  2. equip all buildings to be able to seal their first floors, with water-tight doors, windows, vents, or other openings (dry-floodproofing).
- Install a removable floodwall along the dashed black line, the top of which will be set at 20 feet in elevation, which is today's high tide, plus the height of a 100 year flood with two feet of freeboard, and an additional 72 inches to account for sea level rise.
- Install new bridges at locations shown in orange, to cross over areas allowed to transform into marsh as sea level rises.
- Buy out vulnerable properties shown in tan in 2025, in a voluntary program.
- Buy out vulnerable properties shown in pale green in 2055, in a voluntary program.
- Construct esplanades along new marsh, shown in yellow and black dashed lines, in 2055. Diagram of Proposed Piermont Marshway in cross-section, produced by Scenic Hudson:



Cost Estimates of Adaptations – The Costs that are put in the Benefit:Cost Ratio

Catalysis Adaptation Partners in consultation with Parsons Brinckerhoff engineers, developed rough cost estimates for the three scenarios described above. The cost estimates are summarized in tables in the following pages. Costs are shown both in today's dollars, and also with a discount rate applied to expenditures that would occur in the future. A discount rate is often used by economists when thinking about spending money many years from now, as opposed to spending money right away. When comparing two options for spending money to fix a problem, if you are required to spend $10,000 next year versus spending $10,000 immediately, choosing the option of paying next year is often preferred. To quantify the advantage of paying some time in the future, economists will apply a "discount rate" to the $10,000 payment next year. If a 3.3 percent discount rate is used, the $10,000 payment will be reduced to a "net present value" of $9,670 to reflect the advantage of being allowed to pay later.

Scenario 1: Protect Piermont. The total estimate for implementing Scenario 1, "Protect Piermont," is summarized in the following table:

Project Elements – Scenario 1: Protect Piermont	**Estimated Cost**	
	In Today's Dollars ($ millions)	**With Discounting of 3.3% for Expenditures Made in the Future, if any ($ millions)**
Raise all sections of roads shown in red now, to a height of 6.75 feet, which is equal to today's high tide, plus 29 inches of sea level rise, plus 2 feet of freeboard.	17.89	17.89
Raise all sections of roads shown in black in the year 2055, to a height of 10.3 feet (an additional 3.55 feet), which is equal to today's high tide, plus 72 inches of sea level rise, plus 2 feet of freeboard.	19.56	5.17
Elevate all buildings on parcels shown in purple now (count = 61), so that their base floor elevation is set at 14.5 feet, which is the current 100 year advisory flood height, with two feet of freeboard, and an additional 29 inches to account for sea level rise.	6.10	6.10
Construct a permanent foundation, and purchase a removable floodwall along the green line (11,713 linear feet), the top of which will be set at 20 feet in elevation, which is today's high tide, plus the height of a 100 year flood with two feet of freeboard, and an additional 72 inches to account for sea level rise (initial purchase).	31.67	31.67
Erect and Disassemble Removable Floodwall 13 times by the year 2100 (labor)	1.26	0.54
Total Estimate, By 2100	**76.48**	**61.37**
By 2055	*56.92*	*56.21*
during 2056 to 2100	*19.56*	*5.16*

Scenario 2: Raise Piermont. The total estimate for implementing Scenario 2, "Raise Piermont," is summarized in the following table:

Project Elements – Scenario 2: Raise Piermont	**Estimated Cost**	
	In Today's Dollars ($ millions)	**With Discounting of 3.3% for Expenditures Made in the Future, if any ($ millions)**
Raise all sections of roads shown in red now, to a height of 6.75 feet, which is equal to today's high tide, plus 29 inches of sea level rise, plus 2 feet of freeboard.	13.4	13.4
Raise all sections of roads shown in yellow and red in the year 2055, to a height of 10.3 feet (an additional 3.55 feet), which is equal to today's high tide, plus 72 inches of sea level rise, plus 2 feet of freeboard.	44.24	11.69
Elevate all buildings on parcels shown in purple now (count = 459), so that their base floor elevation is set at 14.5 feet, which is the current 100 year advisory flood height, with two feet of freeboard, and an additional 29 inches to account for sea level rise.	45.9	45.9
Elevate all buildings on parcels shown in purple an additional 3.5 feet to 18 feet, in the year 2055.	45.9	12.13
Adapt all buildings on parcels shown in orange now, so that their first floors are modified either to: 1. allow flood waters to flow through (wet-floodproofing) by removing habitable spaces; or 2. equip all buildings to be able to seal their first floors, with water-tight doors, windows, vents, or other openings (dry-floodproofing).	22.87	22.87
Total Estimate, By 2100	**172.31**	**105.98**
By 2055	*82.17*	*82.17*
during 2056 to 2100	*90.14*	*23.81*

Scenario 3: Piermont Marshway. The total estimate for implementing Scenario 3, "Piermont Marshway," is summarized in the following table:

Project Elements – Scenario 3: Piermont Marshway	**Estimated Cost**	
	In Today's Dollars ($ millions)	**With Discounting of 3.3% for Expenditures Made in the Future, if any ($ millions)**
Raise all sections of roads shown in black now, to a height of 6.75 feet, which is equal to today's high tide, plus 29 inches of sea level rise, plus 2 feet of freeboard.	10.08	10.08
Raise all sections of roads shown in black in the year 2055, to a height of 10.3 feet (an additional 3.55 feet), which is equal to today's high tide, plus 72 inches of sea level rise, plus 2 feet of freeboard.	16.32	5.07
Elevate all buildings on parcels shown in light purple now (count =115), so that their base floor elevation is set at 14.5 feet, which is the current 100 year advisory flood height, with two feet of freeboard, and an additional 29 inches to account for sea level rise.	11.5	11.5
Construct a permanent foundation, and purchase a removable floodwall along the dashed black line (6,700 linear feet), the top of which will be set at 20 feet in elevation, which is today's high tide, plus the height of a 100 year flood with two feet of freeboard, and an additional 72 inches to account for sea level rise (initial purchase).	17.66	17.66
Erect and Disassemble Removable Floodwall 13 times by the year 2100 (labor)	0.76	0.43
Adapt all buildings on parcels shown in orange now, so that their first floors are modified either to: 1. allow flood waters to flow through (wet-floodproofing) by removing habitable spaces; or 2. equip all buildings to be able to seal their first floors, with water-tight doors, windows, vents, or other openings (dry-floodproofing).	1.62	1.62
Install new bridges at locations shown in orange, to cross over areas allowed to transform into marsh as sea level rises.	2.71	2.71
Buy out vulnerable properties shown in tan in 2025, in a voluntary program.	28.96	20.26
Buy out vulnerable properties shown in pale green in 2055, in a voluntary program.	21.77	5.75
Construct esplanades along new marsh, shown in yellow and black dashed lines, in 2055	5.64	1.49
Total Estimate, By 2100	**117.03**	**76.58**
By 2055	*89.31*	*69.29*
during 2056 to 2100	*27.72*	*7.29*

Calculation of Avoided Damages if Adaptation Actions are Taken – The Benefits

In the next step the COAST model was run three more times for the Village of Piermont, for each of the these three scenarios as developed by the subcommittee and approved by the Task Force. From the initial vulnerability assessment, we knew what the predicted amount of cumulative damage to the Village's real estate would be over time, if no action were taken. For the three scenarios, Catalysis adjusted the depth damage function inside the COAST model, to test how much less damage would occur if each scenario were implemented. The table below shows how much avoided damage could be achieved from each adaptation scenario, as predicted by the COAST model:

Scenario	COAST Model **Cumulative Expected Damages** to the Value of Buildings From Sea Level Rise and All Storms		**Avoided Damages** with Adaptation Scenario (No Action Losses Minus Losses with Adaptation in Place)	
	Discounted 3.3% ($ Millions)	Today's Dollars ($ Millions)	Discounted 3.3% ($ Millions)	Today's Dollars ($ Millions)
With No Action				
by 2055	$ 38.4	$ 70.80	$ -	$ -
by 2100	$ 53.8	$ 192.20	$ -	$ -
With Adaptation Scenario 1: Piermont Protect				
by 2055	$ 0.69	$ 1.35	$ 37.71	$ 69.45
by 2100	$ 0.95	$ 3.32	$ 52.85	$ 188.88
With Adaptation Scenario 2: Raise Piermont				
by 2055	$ 0.88	$ 2.24	$ 37.52	$ 68.56
by 2100	$ 1.96	$ 12.57	$ 51.84	$ 179.63
With Adaptation Scenario 3: Piermont Marshway				
by 2055	$ 8.35	$ 17.58	$ 30.05	$ 53.22
by 2100	$ 8.48	$ 18.63	$ 45.32	$ 173.57

These avoided damages can be considered as the benefit of each adaptation scenario, when creating the benefit:cost ratio.

Key Findings from Cumulative Damage Predictions from Different Adaptation Scenarios

- The prediction of the amount of damage avoided over time by the suite of actions in Scenarios 1 and 2 are remarkably similar.
- The prediction of the amount of damage avoided over time from Scenario 3 is a little lower, as some of the buyouts and other protective actions are delayed. However, by 2100 if you look at the discounted damage amounts, this effect is lessened.

Benefit:Cost Ratios for Different Adaptation Scenarios

The prediction of cumulative damage avoided over time by employing an adaptation strategy is considered a benefit. The cost estimate for constructing, maintaining, and/or employing the adaptation strategy is the cost. To compare a series of adaptation strategies, economists and policymakers create a benefit:cost (b/c) ratio for each. If the benefits outweigh the costs, the project will have a b/c ratio greater than one. The more cost effective options will have a higher number for the b/c ratio. The b/c ratios for the three adaptation options as calculated by the COAST model, appear in the table below:

	Scenario Cost		Benefit/Cost Ratio	
With No Action	Discounted 3.3%	Today's Dollars	Discounted 3.3%	**Today's Dollars**
by 2055	$ -	$ -	0.00	**0.00**
by 2100	$ -	$ -	0.00	**0.00**
With Adaptation Scenario 1: Piermont Protect	Discounted 3.3%	Today's Dollars	Discounted 3.3%	**Today's Dollars**
by 2055	$ 56.92	$ 56.92	0.66	**1.22**
by 2100	$ 61.37	$ 76.48	0.86	**2.47**
With Adaptation Scenario 2: Raise Piermont	Discounted 3.3%	Today's Dollars	Discounted 3.3%	**Today's Dollars**
by 2055	$ 82.17	$ 82.17	0.46	**0.83**
by 2100	$ 105.98	$ 172.31	0.49	**1.04**
With Adaptation Scenario 3: Piermont Marshway	Discounted 3.3%	Today's Dollars	Discounted 3.3%	**Today's Dollars**
by 2055	$ 69.29	$ 89.31	0.43	**0.60**
by 2100	$ 76.58	$ 117.03	0.59	**1.48**

Key Results of Benefit:Cost Analysis

- The best looking benefit:cost ratio is found in Scenario 1, with positive ratios when looking at today's dollar figures. However, the removable floodwall has serious management challenges that are not covered by this analysis.
- A removable floodwall must be installed starting two days before an event, and a mistake in erecting the wall when it is not needed would be politically unpopular, but a mistake in not erecting the wall in time would be catastrophic.
- A large crew would need to be instantly mobilized two days prior to a storm. Storage of the wall parts between storms would be challenging.
- The strategic relocation option in the long term compares relatively favorably.
- In general, the ratios in Piermont are low as adaptations are relatively expensive for the amount and scale of the properties being protected. For instance, in the Kingston project also conducted by Scenic Hudson, b/c ratios came out higher because of protection provided to the multi-million dollar sewage treatment plant.

General Observations

- The COAST tool and approach are designed to help communities evaluate the merits of various options, and to show which ideas might merit further study.
- More rigorous evaluation of potential costs conducted by an engineering firm will be needed before any designs are prepared or actions are taken.
- Numbers coming from a run of the COAST model provide powerful motivation to seek funding and to develop political leadership to obtain funding to design adaptation strategies to protect the community – whether the solution will be fortification, accommodation, or strategic relocation – or a suite of strategies with all three elements.
- The COAST process is not just about the numbers. The COAST approach is to build a model of the future jointly with a committee of stakeholders. Once the problems of sea level rise and storm surge are discussed with probabilities and damage numbers attached, the vulnerabilities begin to seem real and candidate adaptation actions are evaluated – leading to political momentum.
- Development of this type of model promotes discussions of factors outside of the model, leading to diverse co-benefits and planning outcomes.
- In cases like Piermont, the COAST tool and approach are designed to help evaluate the merits of various options, and to show which ideas warrant further study. It is not an approach that makes firm recommendations for funding a particular design approach. However, "shopping" for which particular engineered design to construct or planning avenue to pursue *is* an appropriate additional use of the COAST approach – it simply requires clarity of goals and expectations at the project outset, and appropriate resourcing on the engineering detail and costing inputs to be secured, at the beginning of the process.
- The experience of Catalysis is that when considering adaptations to sea level and storm surge, the most cost-effective option is not always the one chosen. Upon seeing results of a COAST iteration, communities sometimes determine that fiscal efficiency is less important than other values such as maintaining ocean views or protecting natural resources. Importantly, benefit-cost ratios resulting from this work tend to open these tricky conversations about exactly what is most important to a community.