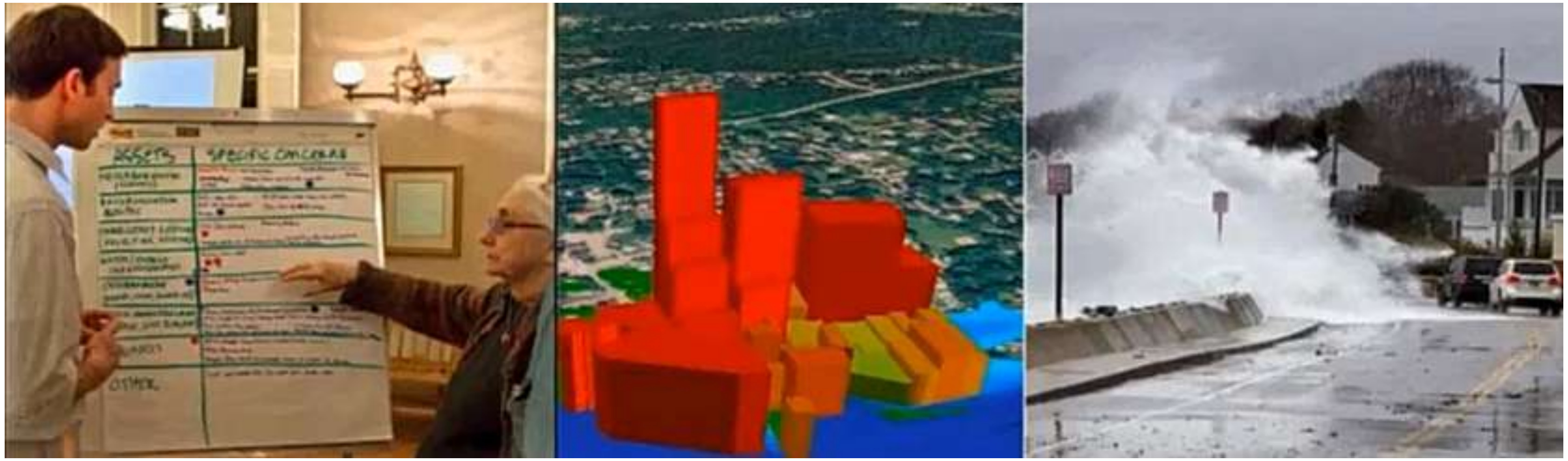
The COAST Approach™ to Adaptation Action for Sea Level Rise and Storm Surge



Catalysis Adaptation Partners, LLC

Samuel B. Merrill, PhD
May 20, 2014

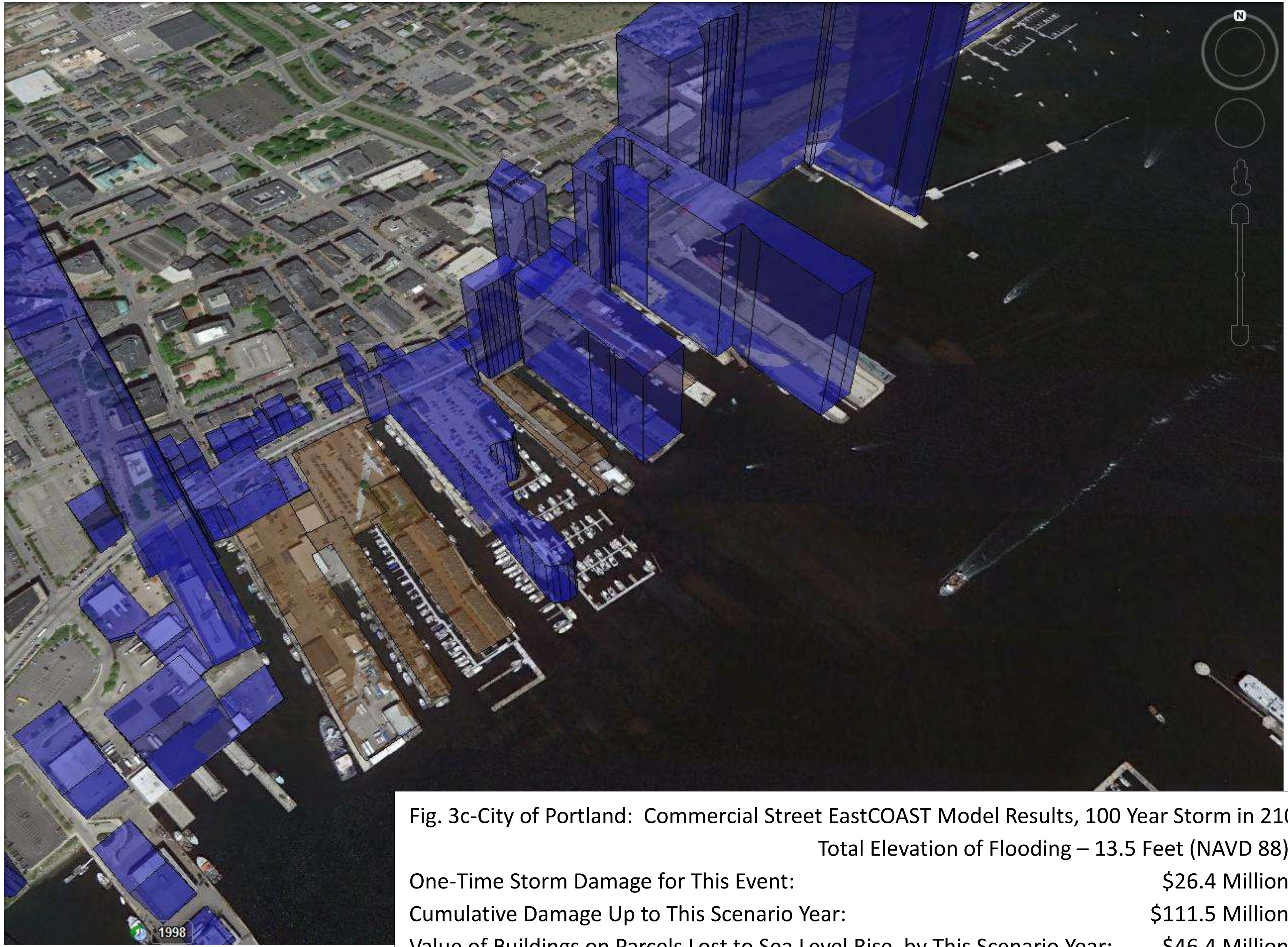


Fig. 3c-City of Portland: Commercial Street EastCOAST Model Results, 100 Year Storm in 2100

Total Elevation of Flooding – 13.5 Feet (NAVD 88)

One-Time Storm Damage for This Event:	$26.4 Million
Cumulative Damage Up to This Scenario Year:	$111.5 Million
Value of Buildings on Parcels Lost to Sea Level Rise, by This Scenario Year:	$46.4 Million

Muskie School of Public Service

University of Southern Maine
Portland, Maine

Partners

EPA United States Environmental Protection Agency

NSF

USF UNIVERSITY OF SOUTH FLORIDA

BLUE MARBLE GEOGRAPHICS
MIND THE GAP BETWEEN WORLD AND MAP

Maine Geological Survey
DEPARTMENT OF CONSERVATION

Casco Bay Estuary PARTNERSHIP

PREP
Piscataqua Region Estuaries Partnership

New England Environmental Finance Center

THE UNIVERSITY OF NEW HAMPSHIRE 1866

Maine Department of Agriculture, Conservation and Forestry

MaineDOT

Some Project Sites Completed or Underway

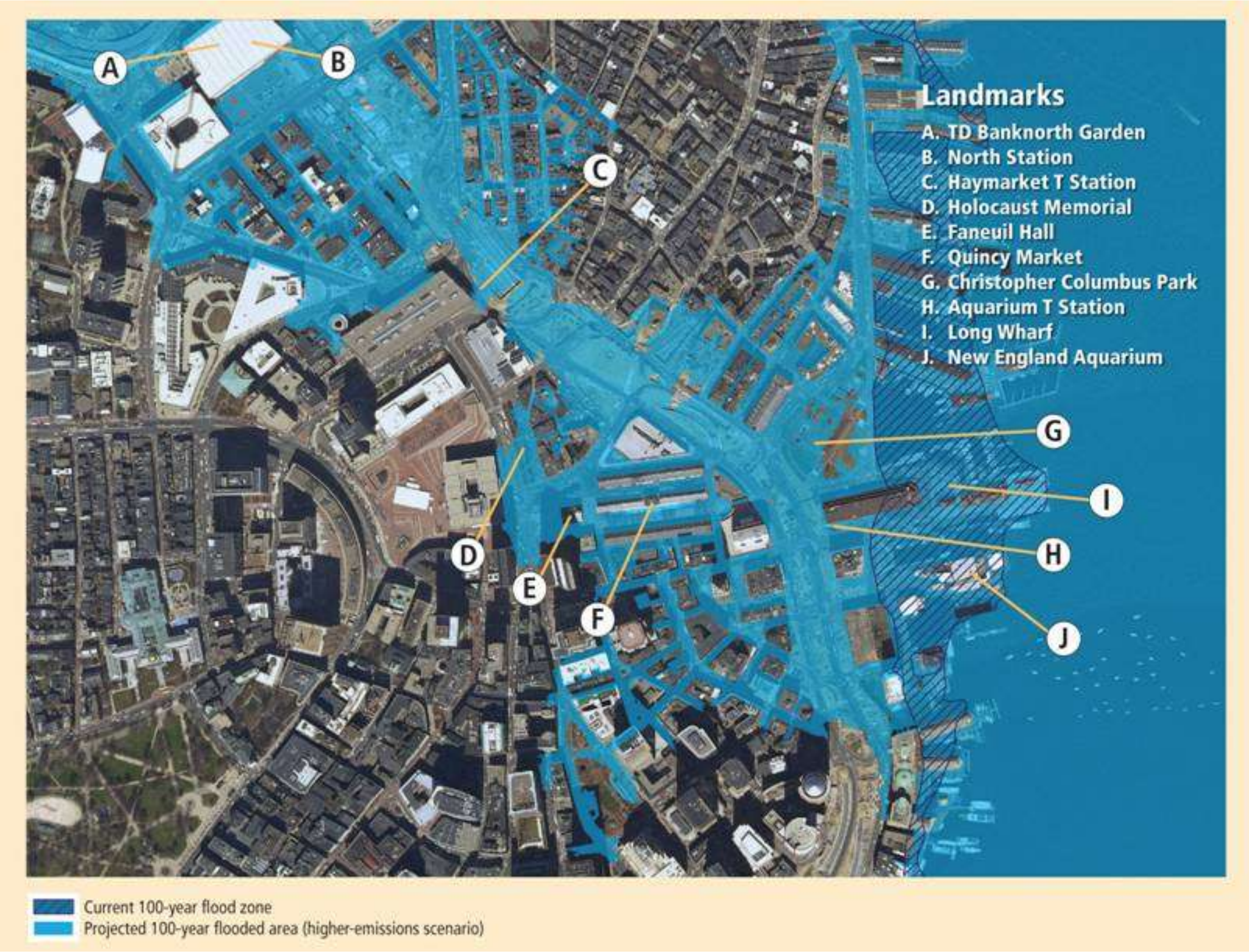
Kingston, New York
Piermont, New York
Catskill, New York
Groton/Mystic, Connecticut
Hampton, New Hampshire
Seabrook, New Hampshire
Hampton Falls, New Hampshire
East Machias, Maine
Falmouth, Maine
Portland, Maine
Old Orchard Beach, Maine

Scarborough, Maine
Bath, Maine
Duxbury, Massachusetts
Marshfield, Massachusetts
Scituate, Massachusetts
Duluth, Minnesota
Sarasota, Florida
Key Largo, Florida
Islamorada, Florida
Portsmouth, United Kingdom
Santos, Brazil

It is Difficult to Shift into Action Mode:

1) Consequences appear far off in time.
2) Cost-benefit relationships are ambiguous.
3) Possible actions are complex.
4) Doing nothing is far, far easier.

Coastal Flooding in Boston under Present and High Emission Sea Levels



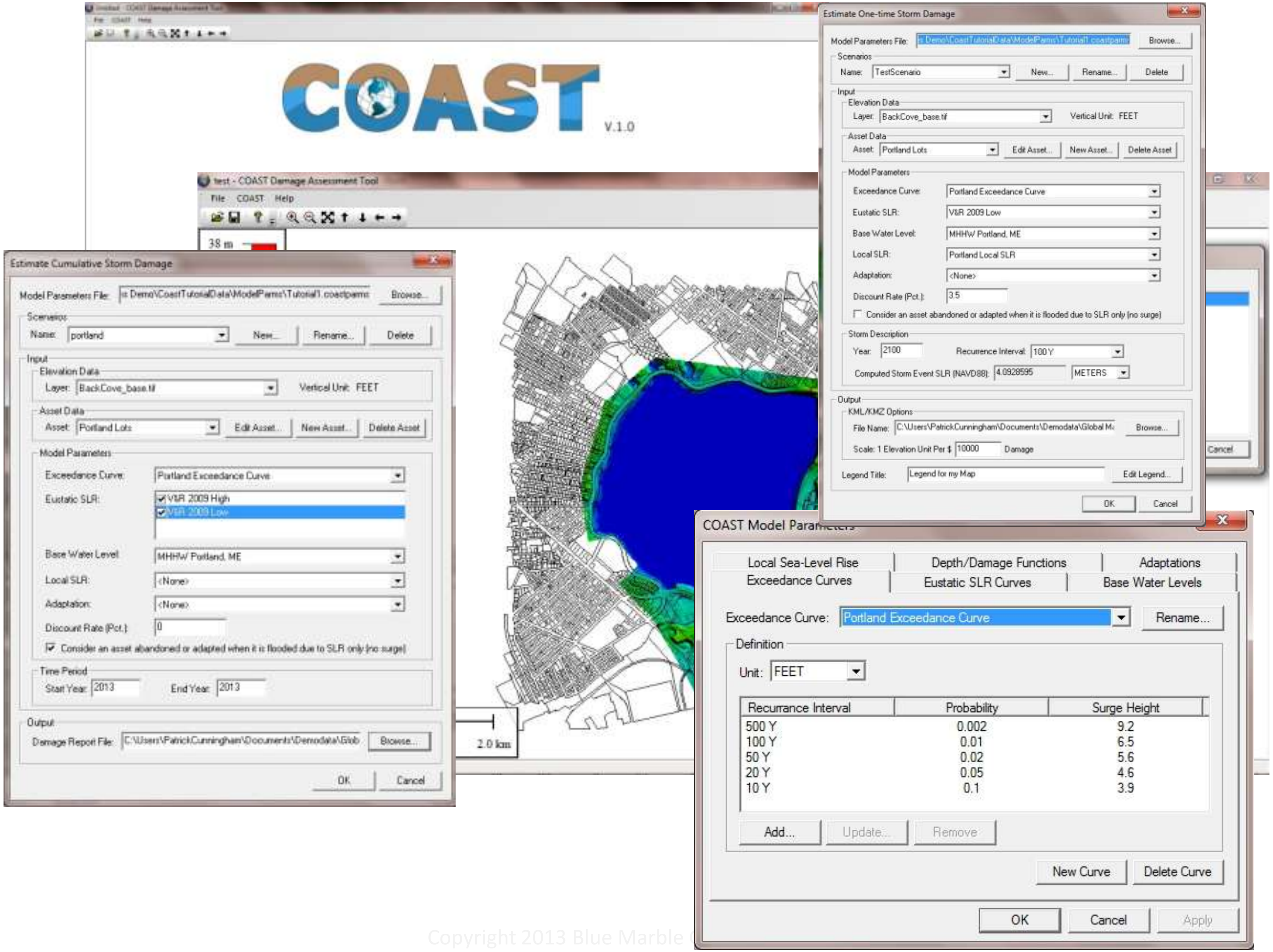
There are only four options:

1) Do nothing (usually = remain in denial)
2) Fortify assets
3) Accommodate higher water levels
4) Relocate assets

There are only four options:

1) Do nothing (usually = remain in denial)
2) Fortify assets
3) Accommodate higher water levels
4) Relocate assets

>> COAST is a tool and approach to help
1) evaluate costs and benefits of these options, and
2) move from risk perception > risk anticipation > action.



COAST
V.1.0
test - COAST Damage Assessment Tool
File COAST Help
Estimate Cumulative Storm Damage
Model Parameters File:
Browse...
Scenarios
Name: portland
New... Rename... Delete
Input
Elevation Data
Layer: BackCove_base.tif
Vertical Unit: FEET
Asset Data
Asset: Portland Lots
Edit Asset... New Asset... Delete Asset
Model Parameters
Exceedance Curve: Portland Exceedance Curve
Eustatic SLR: V&R 2009 High
V&R 2009 Low
Base Water Level: MHHW Portland, ME
Local SLR: <None>
Adaptation: <None>
Discount Rate (Pct.): 0
Consider an asset abandoned or adapted when it is flooded due to SLR only (no surge)
Time Period
Start Year: 2013
End Year: 2013
Output
Damage Report File:
OK Cancel
Estimate One-time Storm Damage
Name: TestScenario
Exceedance Curve: Portland Exceedance Curve
Eustatic SLR: V&R 2009 Low
Base Water Level: MHHW Portland, ME
Local SLR: Portland Local SLR
Adaptation: <None>
Discount Rate (Pct.): 3.5
Storm Description
Year: 2100
Recurrence Interval: 100 Y
Computed Storm Event SLR (NAVD88): 4.0928595 METERS
KML/KMZ Options
Legend Title: Legend for my Map
Edit Legend...
OK Cancel
COAST Model Parameters
Local Sea-Level Rise
Depth/Damage Functions
Adaptations
Exceedance Curves
Eustatic SLR Curves
Base Water Levels
Exceedance Curve: Portland Exceedance Curve
Rename...
Definition
Unit: FEET
Recurrance Interval | Probability | Surge Height
500 Y | 0.002 | 9.2
100 Y | 0.01 | 6.5
50 Y | 0.02 | 5.6
20 Y | 0.05 | 4.6
10 Y | 0.1 | 3.9
Add... Update... Remove
New Curve Delete Curve
OK Cancel Apply
2.0 km

Climatic Change
DOI 10.1007/s10584-011-0379-z

Simplified method for scenario-based risk assessment adaptation planning in the coastal zone

Paul Kirshen · Samuel Merrill · Peter Slovinsky · Norman Richardson

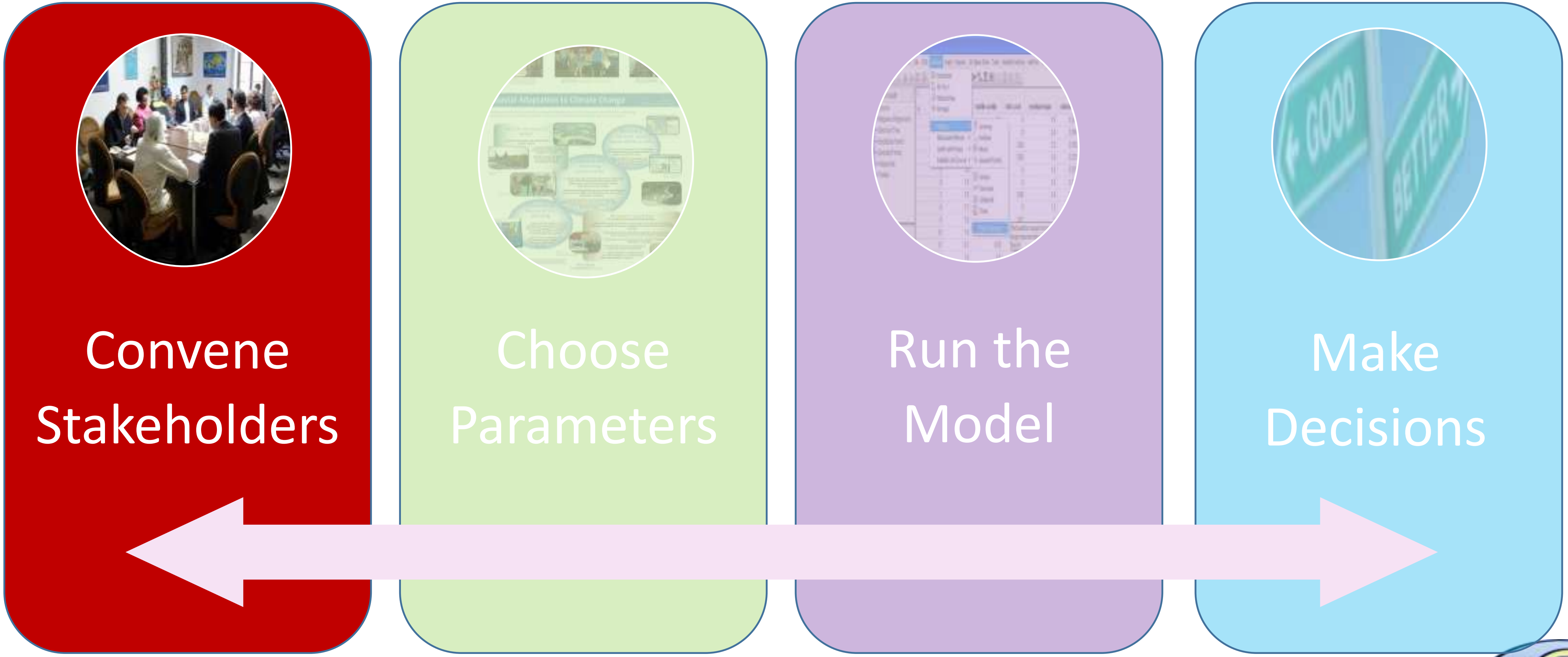
Received: 16 November 2009 / Accepted: 14 November 2011

Convene Stakeholders

Choose Parameters

Run the Model

Make Decisions


Convene Stakeholders
Choose Parameters
Run the Model
Make Decisions

The process is stakeholder-driven

Convene Stakeholders

Choose Parameters

Run the Model

Make Decisions

Stakeholders identify and select vulnerable assets

A Range of Vulnerable Assets:

- Real estate values
- Economic output
- Public health impacts
- Displaced persons, vulnerable demographics
- Natural resources values
- Cultural resources values
- Community impacts
- Infrastructure (transportation, energy, facilities, telecommunications)

Stakeholders select scenarios for sea level rise and storm surge

Steps in the COAST Process

Input Depth-Damage Function

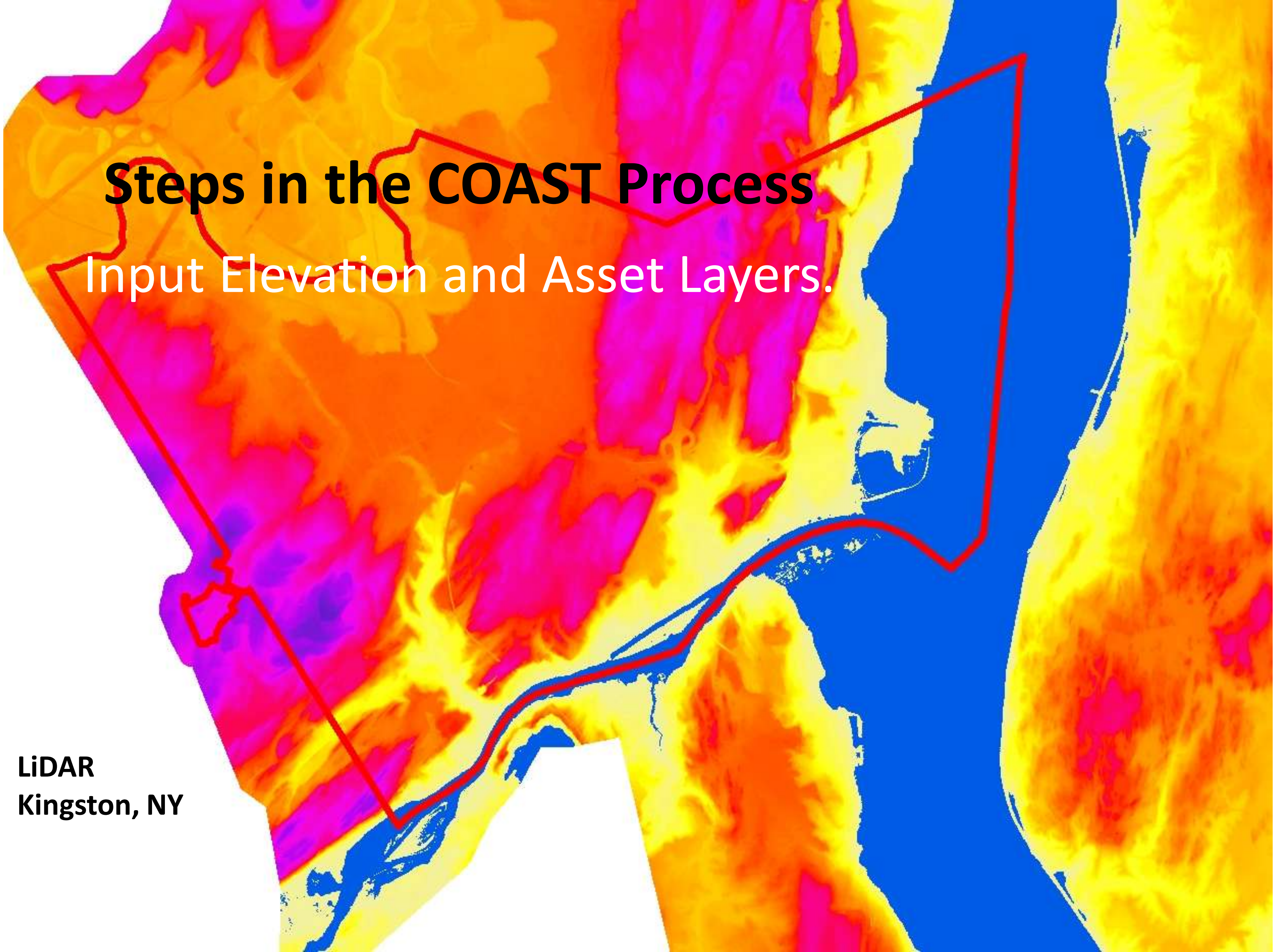
(can be customized with engineer input).

Depth (feet)	Mean of Damage
0	25.5%
1	32.0%
2	38.7%
3	45.5%
4	52.2%
5	58.6%
6	64.5%

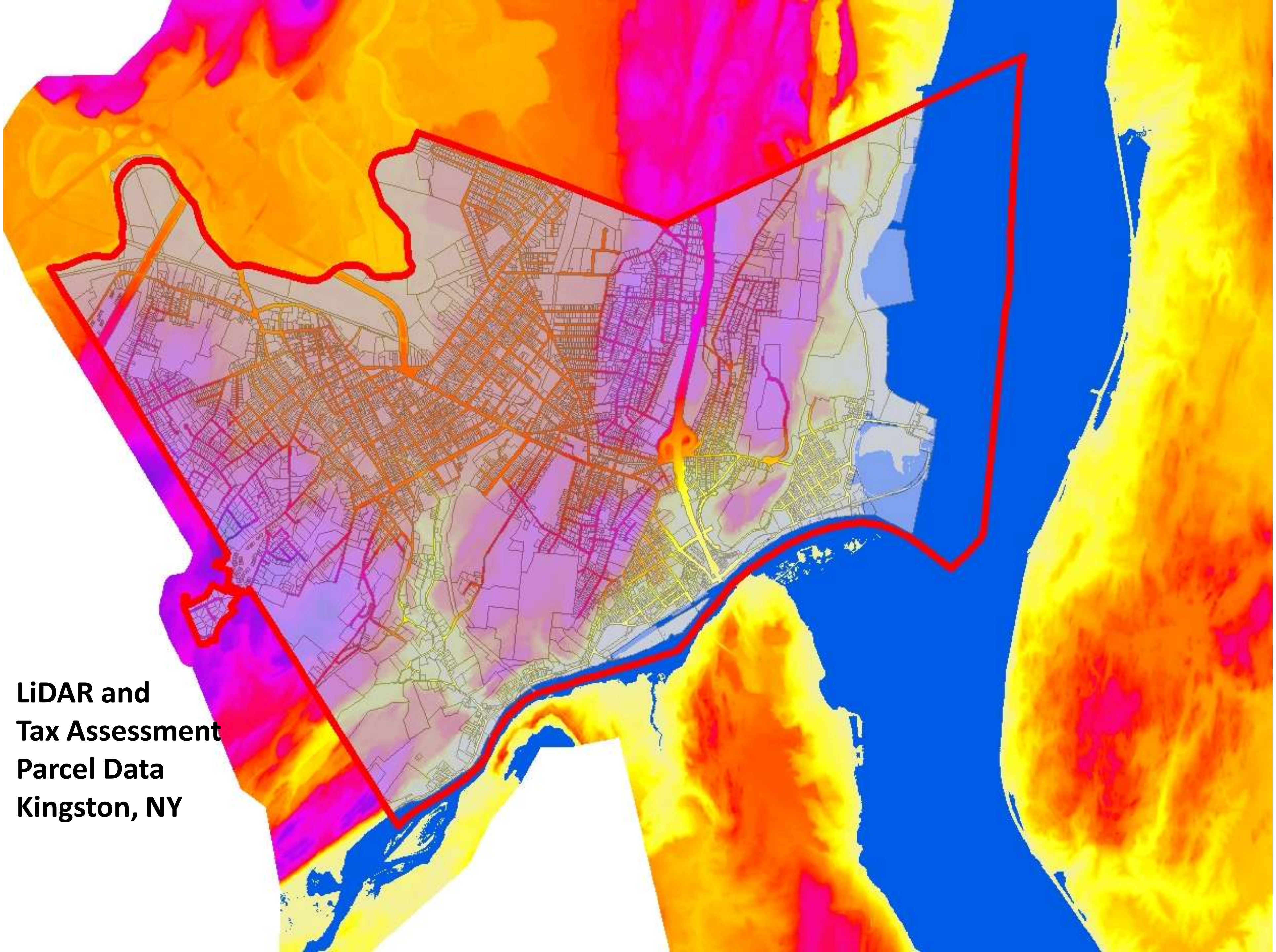
DDF, Single Family Residential Structures

Steps in the COAST Process

Input Elevation and Asset Layers.



LiDAR
Kingston, NY



LiDAR and
Tax Assessment
Parcel Data
Kingston, NY

Convene Stakeholders

Choose Parameters

Run the Model

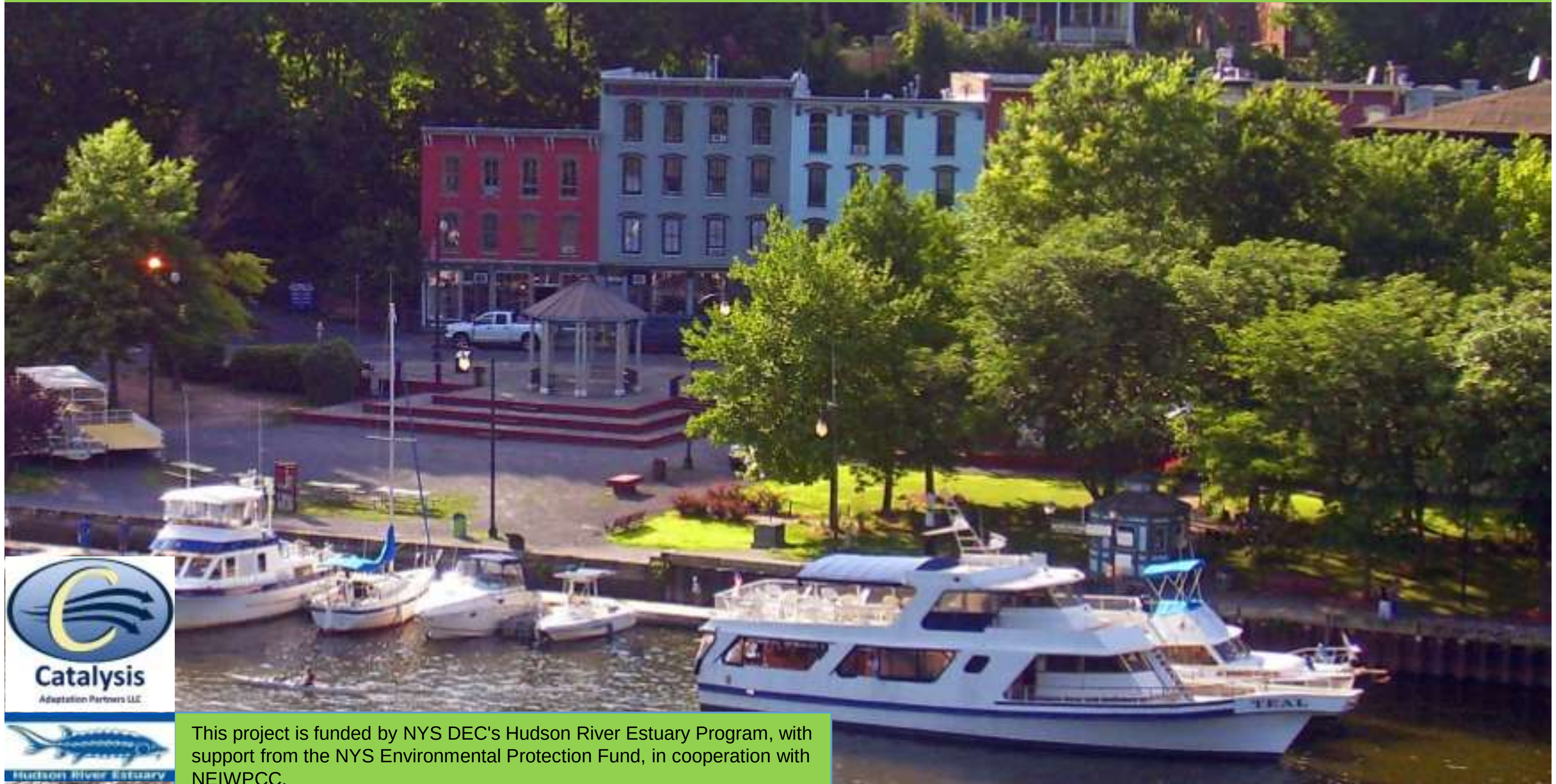
Make Decisions

Hit “Go” >> COAST will:

- Estimate dollar damage predicted for a particular-sized storm in a given year, and project results in 3D maps.

Flooding Vulnerability Assessment for the City of Kingston, NY
Benefit Cost Analysis of Three Adaptation Options for the Rondout/East Strand

- *For 10-year and 100- year Storm Events*
- *With High and Low Sea Level Rise Scenarios*
- *For the Years 2013, 2060 and 2100*
- *Including Predictions for All Cumulative Expected Monetary Damage to Buildings and Improvements using the COAST tool, and Predictions for Avoided Damages with Adaptations.*



Catalysis
Adaptation Partners LLC

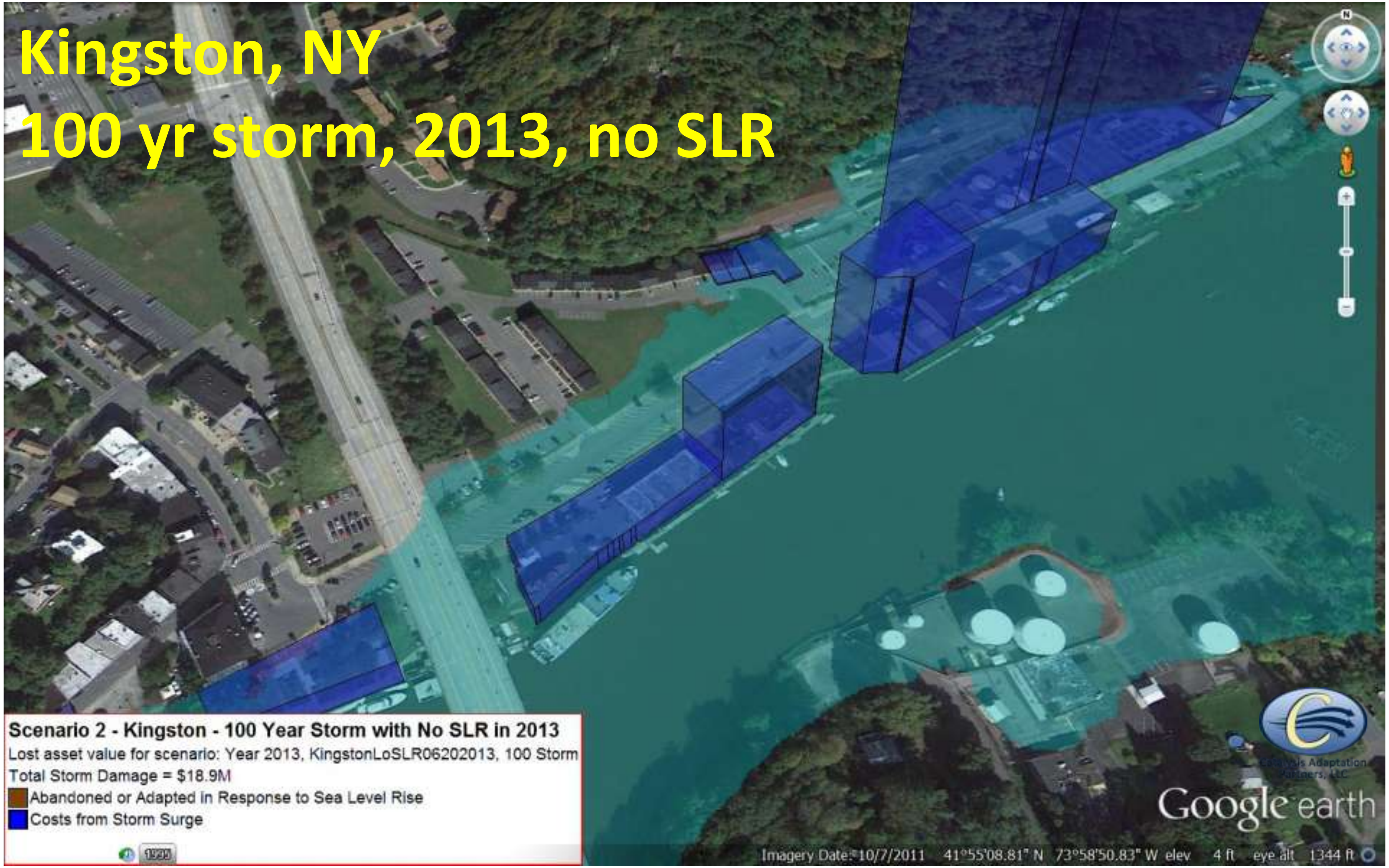
Hudson River Estuary

This project is funded by NYS DEC's Hudson River Estuary Program, with support from the NYS Environmental Protection Fund, in cooperation with NEIWPCC.


Kingston, NY
Google earth
1995
Imagery Date: 10/7/2011 41°55'08.81" N 73°58'50.83" W elev 4 ft eye alt 1344 ft


HUDSON RIVER MARITIME MUSEUM

Kingston, NY
100 yr storm, 2013, no SLR



Kingston, NY
100 yr storm, 2013, no SLR

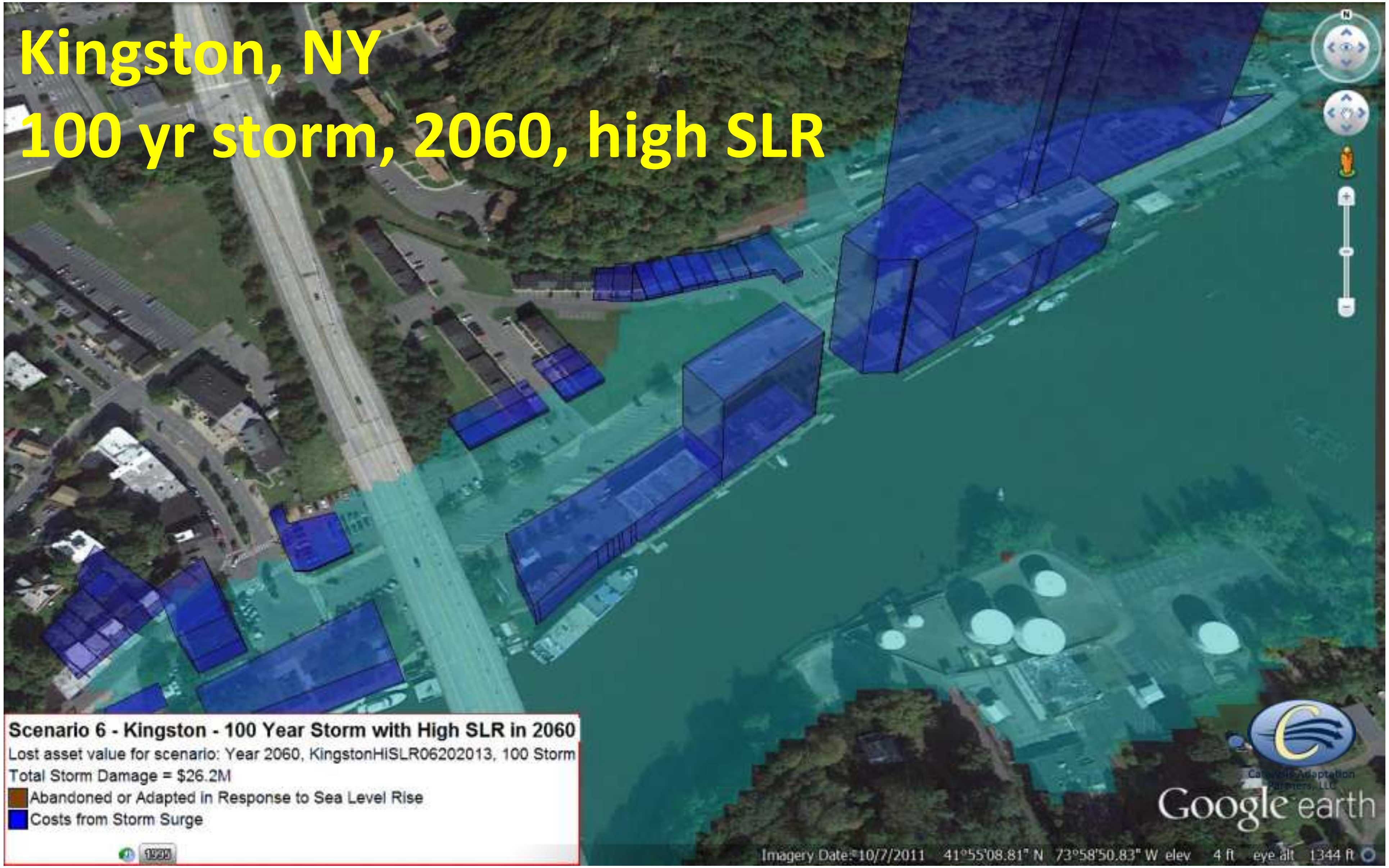
COAST ASSET DATA

Flood Depth = 8.2 ft

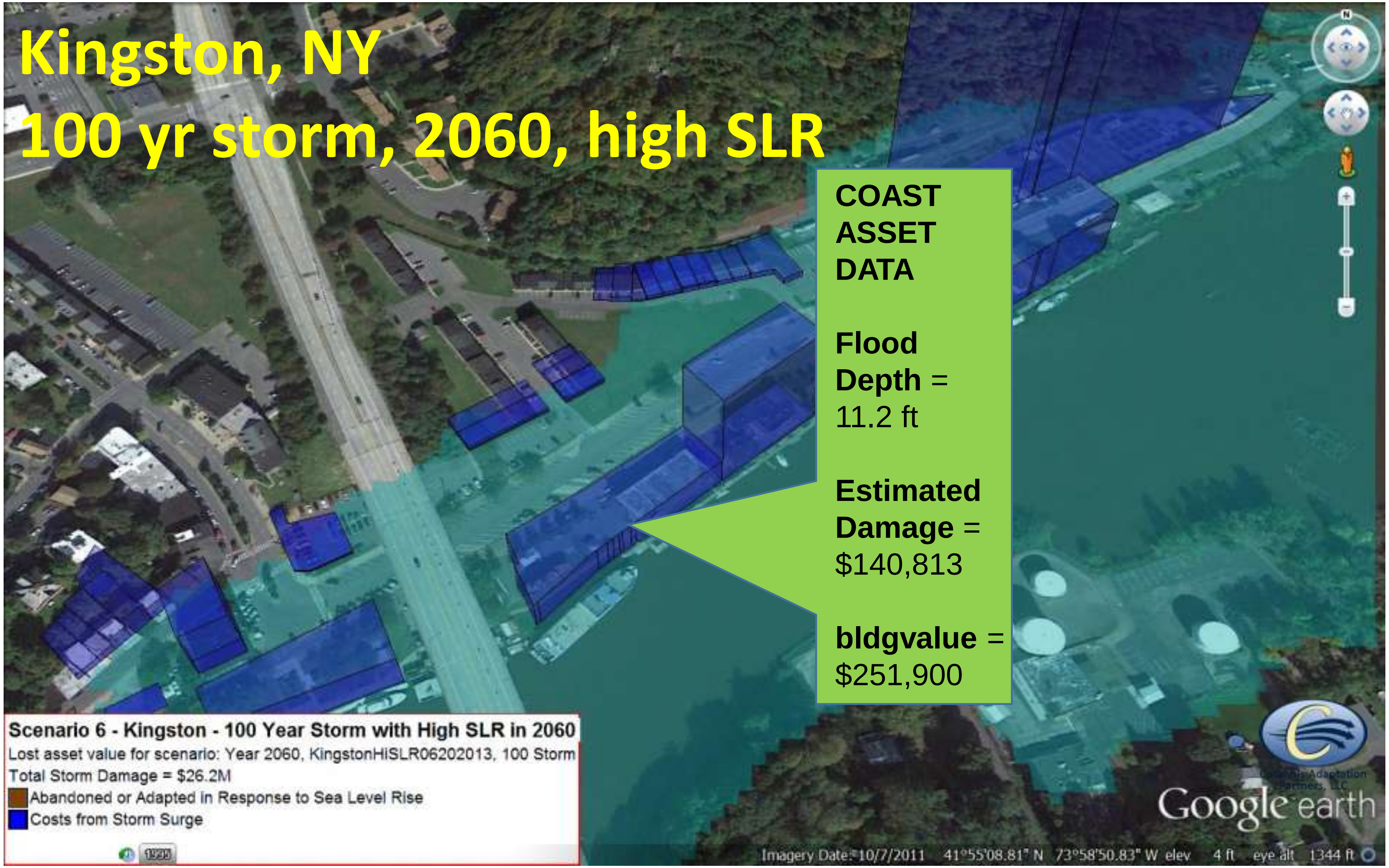
Estimated Damage = $120,912

bldgvalue = $251,900

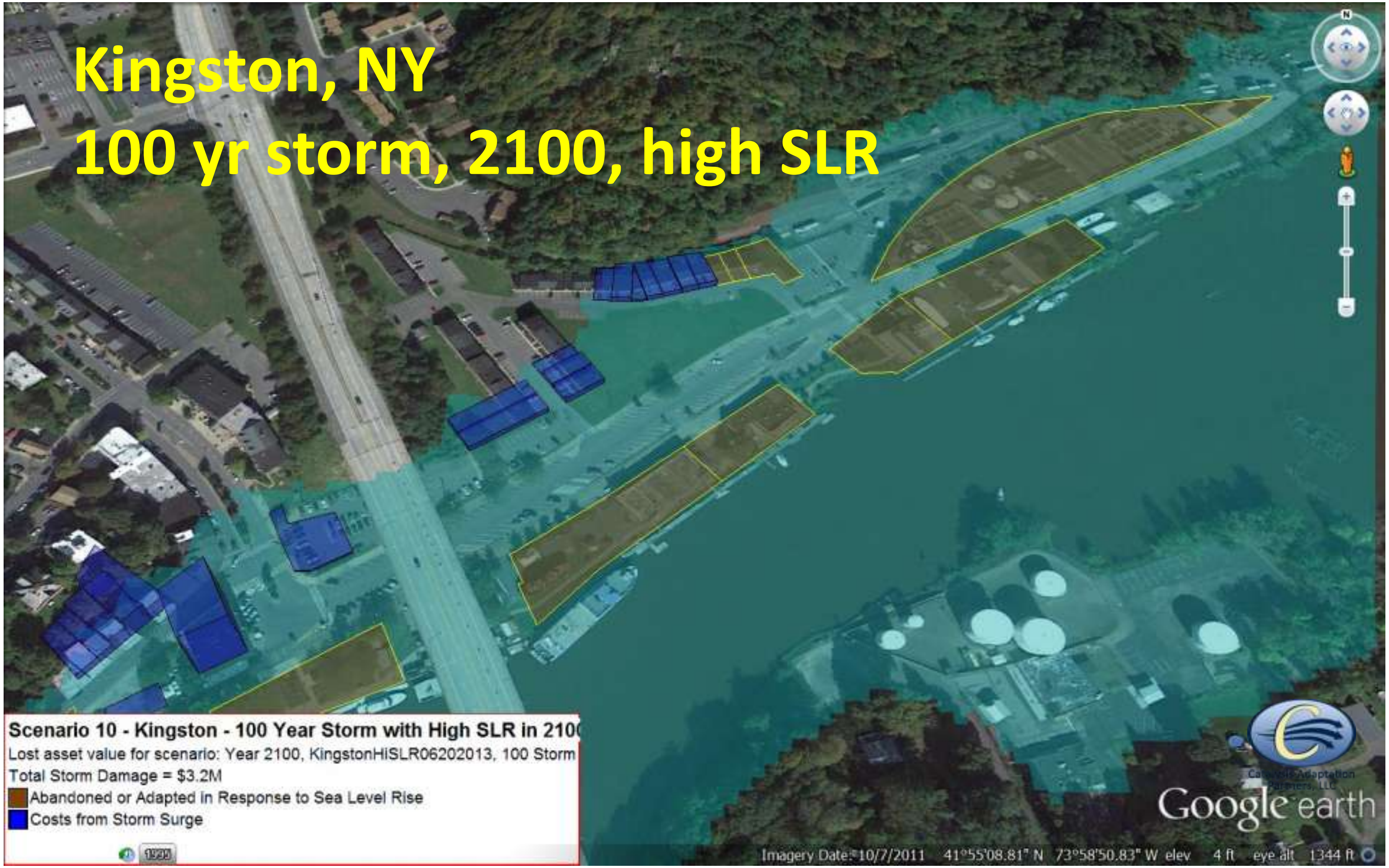
Kingston, NY
100 yr storm, 2060, high SLR



Kingston, NY
100 yr storm, 2060, high SLR



Kingston, NY
100 yr storm, 2100, high SLR



Kingston, NY
100 yr storm, 2100, high SLR

COAST ASSET DATA

Flood Depth=13.9 ft

Estimated Damage = $251,900

Year Abandoned Between 2060 and 2070

Hit “Go” >> COAST will:

- Estimate dollar damage predicted for a particular-sized storm in a given year, and project results in 3D maps.
- Calculate the cumulative expected damage from all predicted storms out to that year.

COAST Model for City of Kingston
Modeled Water Levels and Vulnerability Assessment Results

Year	Sea Level Rise Scenario	Storm Intensity (return period in years)	Predicted Elevation of Flood Height from FEMA Flood Insurance Study, 2007 NAVD88 (ft.)[1]	COAST Model of Sea Level Rise Above MHHW in 2013 Selected by Kingston (in./ft)[2]		COAST 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)	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)[4]	COAST Model Cumulative Expected Damage to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million)	COAST Model Cumulative Expected Damage to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million, with Discounting)[3]
2013	1-No SLR	10 yr	6.0	0	0	6.0	1.0	n/a	n/a	n/a
2013	2-No SLR	100 yr	8.2	0	0	8.2	18.9	n/a	n/a	n/a
2060	3-Lo SLR	10 yr	6.0	20	1.67	7.7	17.3	2.0	85.1	42.5
2060	4-Lo SLR	100 yr	8.2	20	1.67	9.9	23.7	2.0	85.1	42.5
2060	5-Hi SLR	10 yr	6.0	36	3	9.0	20.0	2.0	94.2	48.9
2060	6-Hi SLR	100 yr	8.2	36	3	11.2	26.2	2.0	94.2	48.9
2100	7-Lo SLR	10 yr	6.0	33	2.75	8.8	19.9	2.0	171.6	52.7
2100	8-Lo SLR	100 yr	8.2	33	2.75	11.0	26.0	2.0	171.6	52.7
2100	9-Hi SLR	10 yr	6.0	68	5.67	11.7	1.9	55.3	126.7	50.6
2100	10-Hi SLR	100 yr	8.2	68	5.67	13.9	3.2	55.3	126.7	50.6

[1]Tidal state is included in FEMA FIS predicted flood elevations for the 10-yr and 100-yr storms.
[2]Elevation of Mean Higher High Water (MHHW) in year 2013 is 3.0 feet (NAVD 88).
[3]Discount Rate of 3.3 percent applied.
[4]See spreadsheet for complete list of properties.

Dates Run: 06/25-30/2013

This project is funded by NYS DEC's Hudson River Estuary Program, with support from the NYS Environmental Protection Fund, in cooperation with NEIWPCC

COAST Model for City of Kingston
Modeled Water Levels and Vulnerability Assessment Results

Catalysis
Adaptation Partners LLC

Year	Sea Level Rise Scenario	Storm Intensity (return period in years)	Predicted Elevation of Flood Height from FEMA Flood Insurance Study, 2007 NAVD88 (ft.)[1]	COAST Model of Sea Level Rise Above MHHW in 2013 Selected by Kingston (in./ft)[2]		COAST Model Total Flood Elevation for Each Scenario NAVD88 (ft.)	COAST Model Expected Damage to the Value of All Buildings & Improvements From This Single Storm Incident in the Scenario Year ($ Million)	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)[4]	COAST Model Cumulative Expected Damage to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million)	COAST Model Cumulative Expected Damage to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million, with Discounting)[3]
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2060	3-Lo SLR	10 yr	6.0	20	1.67	7.7	17.3	2.0	85.1	42.5
2060	4-Lo SLR	100 yr	8.2	20	1.67	9.9	23.7	2.0	85.1	42.5
2060	5-Hi SLR	10 yr	6.0	36	3	9.0	20.0	2.0	94.2	48.9
2060	6-Hi SLR	100 yr	8.2	36	3	11.2	26.2	2.0	94.2	48.9
2100	7-Lo SLR	10 yr	6.0	33	2.75	8.8	19.9	2.0	171.6	52.7
2100	8-Lo SLR	100 yr	8.2	33	2.75	11.[illegible]	26.0	2.0	171.6	52.7
2100	9-Hi SLR	10 yr	6.0	68	5.67	[illegible].7	1.9	55.3	126.7	50.6
2100	10-Hi SLR	100 yr	8.2	68	5.[illegible]	13.9	3.2	55.3	126.7	50.6

[1]*Tidal state is included in [illegible]MA FIS predicted flood elevations for the 10-y[illegible] 100-yr storms.*
[2]*Elevation of Mean Higher Hi[illegible]ater (MHHW) in year 2013 is 3.0 f[illegible]VD 88).*
[3]*Discount Rate of 3.3 percent applie[illegible]*
[4]*See spreadsheet for complete list of properties.*

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COAST Model for City of Kingston
Modeled Water Levels and Vulnerability Assessment Results

Year	Sea Level Rise Scenario	Storm Intensity (return period in years)	Predicted Elevation of Flood Height from FEMA Flood Insurance Study, 2007 NAVD88 (ft.)[1]	COAST Model of Sea Level Rise Above MHHW in 20[illegible] Selected by Kingston (in./ft)[2]		COAST Model Total Flood Elevation for Each Scenario NAVD88 (ft.)	COAST Model Expected Damage to the Value of All Buildings & Improvements From this Single Storm in [illegible] Scenario Year ($ Million)	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)[4]	COAST Model Cumulative Expected Damage to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million)	COAST Model Cumulative Expected Damage to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million, with Discounting)[3]
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2060	3-Lo SLR	10 yr	6.0	20	1.67	7.7	17.3	2.0	85.1	42.5
2060	4-Lo SLR	100 yr	8.2	20	1.67	9.9	23.7	2.0	85.1	42.5
2060	5-Hi SLR	10 yr	6.0	36	3	9.0	20.0	2.0	94.2	48.9
2060	6-Hi SLR	100 yr	8.2	36	3	11.2	26.2	2.0	94.2	48.9
2100	7-Lo SLR	10 yr	6.0	33	2.75	8.8	19.9	2.0	171.6	52.7
2100	8-Lo SLR	100 yr	8.2	33	2.75	11.[illegible]	26.0	2.0	171.6	52.7
2100	9-Hi SLR	10 yr	6.0	68	5.67	[illegible].7	1.9	55.3	126.7	50.6
2100	10-Hi SLR	100 yr	8.2	68	5.[illegible]	13.9	3.2	55.3	126.7	50.6

[1] Tidal state is included in FEMA FIS predicted flood elevations for the 10-yr [illegible] 100-yr storms.
[2] Elevation of Mean Higher High Water (MHHW) in year 2013 is 3.0 f[illegible] NAVD 88).
[3] Discount Rate of 3.3 percent applie[illegible]
[4] See spreadsheet for complete list of properties.

Dates Run: 06/25-30/2013

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COAST Model for City of Kingston
Modeled Water Levels and Vulnerability Assessment Results

Ye[illegible]	Sea Level Rise Scenario	Storm Intensity (return period in years)	Predicted Elevation of Flood [illegible] from FEMA Flood Insurance Study, 2007 NAVD88 (ft.)[1]	COAST Model of Sea Level Rise Above [illegible]HHW in 20[illegible] Selected by Kingston (in./ft)[2]		COAST Model Total Flood Elevation [illegible]or Each Sc[illegible]ario NAV[illegible]88 (ft.)	COAST Model Expected Damage to the Value of All Buildings & Improvements [illegible]is Single Storm [illegible] Scenario Year ($ Million)	[illegible] Cumulative [illegible] All Buildings and Improvements Located on Properties Permanently Inundated by Sea Level Rise if No Action is Taken, by this Year ($ Million)[4]	[illegible] Cumulative [illegible] to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to Scenario Year ($ Million)	COAST [illegible]del Cumulative Ex[illegible]ected [illegible] to the Value of All Buildings & Improvements From Sea Level Rise and All Storms, 2013 to [illegible] ($ Million, with Discounting)[3]
[illegible]13	1-No SLR	10 yr	6.0	0	0	6.0	1.0	n/a	n/a	n/a
[illegible]013	2-No SLR	100 yr	8.2	0	0	8.2	18.9	n/a	n/a	n/a
2060	3-Lo SLR	10 yr	6.0	20	1.67	7.7	17.3	2.0	85.1	42.5
2060	4-Lo SLR	100 yr	8.2	20	1.67	9.9	23.7	2.0	85.1	42.5
2060	5-Hi SLR	10 yr	6.0	36	3	9.0	20.0	2.0	94.2	48.9
[illegible]060	6-Hi SLR	100 yr	8.2	36	3	11.2	26.2	2.0	94.2	48.9
2[illegible]00	7-Lo SLR	10 yr	6.0	33	2.75	8.8	19.9	2.0	171.6	52.7
21[illegible]	8-Lo SLR	100 yr	8.2	33	2.75	11.[illegible]	26.0	2.0	171.6	52.7
2100	9-Hi SLR	10 yr	6.0	68	5.67	[illegible].7	1.9	55.3	126.7	50.6
2100	10[illegible]i SLR	100 yr	8.2	68	5.[illegible]	13.9	3.2	55.3	126.7	50.6

[1]Tidal state is included i[illegible]A FIS predicted flood elevations for the 10-y[illegible]100-yr storms.
[2]Elevation of Mean Higher Hi[illegible]ater (MHHW) in year 2013 is 3.0 f[illegible]VD 88).
[3]Discount Rate of 3.3 percent applie[illegible]
[4]See spreadsheet for complete list of properties.

Dates Run: 06/25-30/2013

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Next Steps in the COAST Process

Select candidate adaptation actions to respond to sea level rise and storm surge, staged over time, and estimate costs of each action.

Possible Adaptation Actions: Hard or Soft

- Revetments
- Sea walls
- Jetties
- Levees
- Subway tunnel plugs
- Automatic floodgates
- Geotextile tubes
- Beach nourishment

- Dry flood-proofing
- Wet flood-proofing
- Increasing freeboard (now or later)
- Zoning changes
- Rolling easements
- Buyouts


TOWN HALL
MEETING
This way

Next Steps in the COAST Process

For each action, modify the DDF or the spatial distribution of the vulnerable asset to represent the effect of the action.

Next Steps in the COAST Process

Re-run the same scenarios to show benefits (avoided costs) of having taken action.


Legend
East Strand Adaptation Study Area
11 foot Contour Elevation
11 ft
East Strand Street Raised to 11 ft Elevation (NAVD88)
Bulkhead/Levee/Path Raised to 11 ft Elevation (NAVD88)
East Strand Study Area Parcels With Buildings Protected by Elevated Road
Parcels With Buildings Below Elevated Road
Catalysis
N
1:8,271

BENEFIT COST ANALYSIS OF ADAPTATION STRATEGIES – KINGSTON

	Scenario B: WITH ELEVATION OF EAST STRAND STREET TO 11 FEET (NAVD 88)		Scenario C: WITH ELEVATION OF BULKHEAD/WITH PATH TO 11 FEET (NAVD 88)		Scenario D: PURCHASES OF ROLLING EASEMENTS, WITH TRANSFER OF TITLE TO CITY AT 2060 OR WHEN MHHW REACHES 6.0 FEET (NAVD 88)	
	Low SLR	High SLR	Low SLR	High SLR	Low SLR	High SLR
Cumulative Damage to East Strand Study Area With No Action[1]	46,400,000	44,100,000	46,400,000	44,100,000	46,400,000	44,100,000
Cumulative Damage with Adaptation Strategy in Place[1]	4,900,000	4,700,000	241,000	466,900	36,900,000	39,576,000
Avoided Damage (Row 1 – Row 2) or BENEFIT	41,500,000	39,400,000	46,159,000	43,633,100	9,500,000	4,524,000
Estimated COST of Adaptation Strategy	9,800,000		6,200,000		[2]2,540,000	
BENEFIT/COST Ratio (The higher the number above 1, the more favorable the ratio.)	4.2	4.0	7.4	7.0	3.7	1.8

[1]Discount Rate of 3.3% applied.
[2]Does not include purchase of easements at five city-owned properties, and sewage treatment plant remains unprotected.

Scenario D:
PURCHASES OF ROLLING EASEMENTS, WITH TRANSFER OF TITLE TO CITY AT 2060 OR WHEN MHHW REACHES 6.0 FEET (NAVD 88)

- Purchase Easements from all property owners whose land is at less than 11 feet elevation.
- **City does not elevate road or bulkhead** or make any capital expenditures to mitigate damages over time.
- Owners receive a cash payment now, and can stay on their property until 2060 or when MHHW reaches 6 feet (3 feet higher than today). Title transfers to easement holder at that time.
- Cash payment can be used for flood mitigation for buildings or for any purpose, such as relocation, but **owner can not armor the shoreline**.
- Sewage Treatment Plant remains unprotected.
- **Total Estimate: $2.54 million**
- **B/C Ratio = 3.7 or 1.8 (Hi vs. Low SLR)**

Finally:

Use maps and tables in public process, modify and implement strategies.

Convene Stakeholders

Choose Parameters

Run the Model

Make Decisions

Some Social Lessons Learned through The COAST Approach™:

- Citizens want cities, towns and states to get beyond vulnerability studies and to start putting adaptation strategies in place!
- Appropriations for expensive strategies (e.g., elevating waterfronts or relocating WWTPs) will not occur until there is enough social, political, and economic consensus on a direction.
  - *The COAST Approach™ helps create this consensus*.

Thank You!

www.catalysisadaptation.com
Sam Merrill: 207-615-7523
smerrill@catalysisadaptation.com

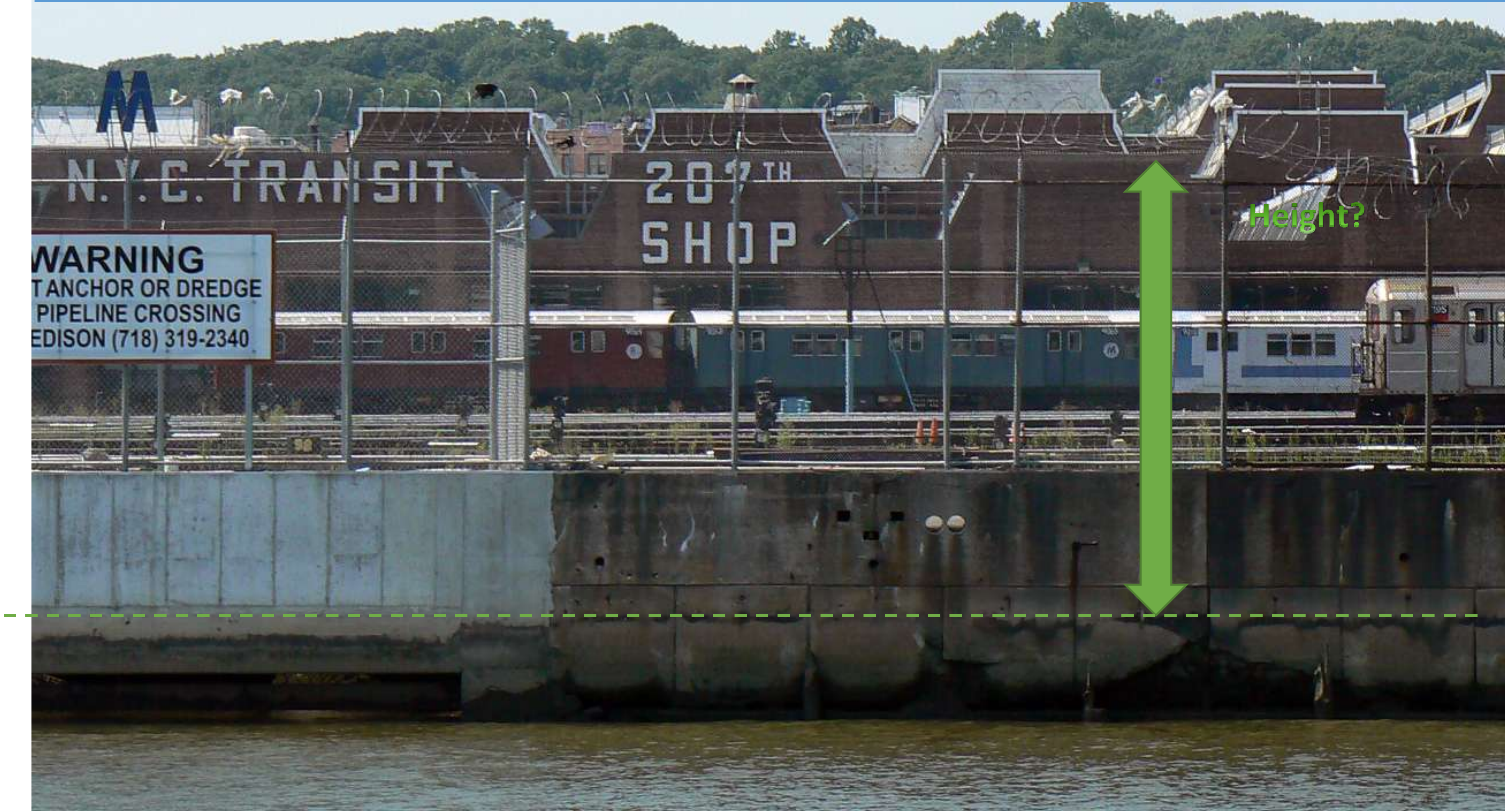
Joint Proposal: Catalysis Adaptation Partners with Parsons Brinkerhoff
Establishing the Proper Design Height of Protection Measures For the NYCT 207th Street Yard


A

Setting of Design Height must take into account:

- Probabilities of Tidal Stage when Surge Occurs during the Tidal Cycle (At high or low tide?)
- Probabilities of Surge Levels (How many feet should be added to the normal tide height?)
- Predictions of Sea Level Rise into the Future (2042, 2062 or 2100?)
- Design Life of the Protection Measure (30, 50 or 100 years?)
- Value of Protected Assets and Avoided Cumulative Expected Damages over Design Life

The COAST tool applied by Catalysis Adaptation Partners will insure that costs for various protection heights are weighed against probabilities of flood heights and costs of predicted damages, including each of these factors.



http://www.pattayadailynews.com/en/2011/12/19/don-mueang-airport-reopen-apr-1-after-flood/