consulting engineers and scientists

Extreme Weather Events and Transportation Infrastructure:

A Framework for Benefit-Cost Analysis

Samuel B. Merrill, Ph.D.
Climate Prediction Applications Science Workshop, Burlington, VT
March 24 2016

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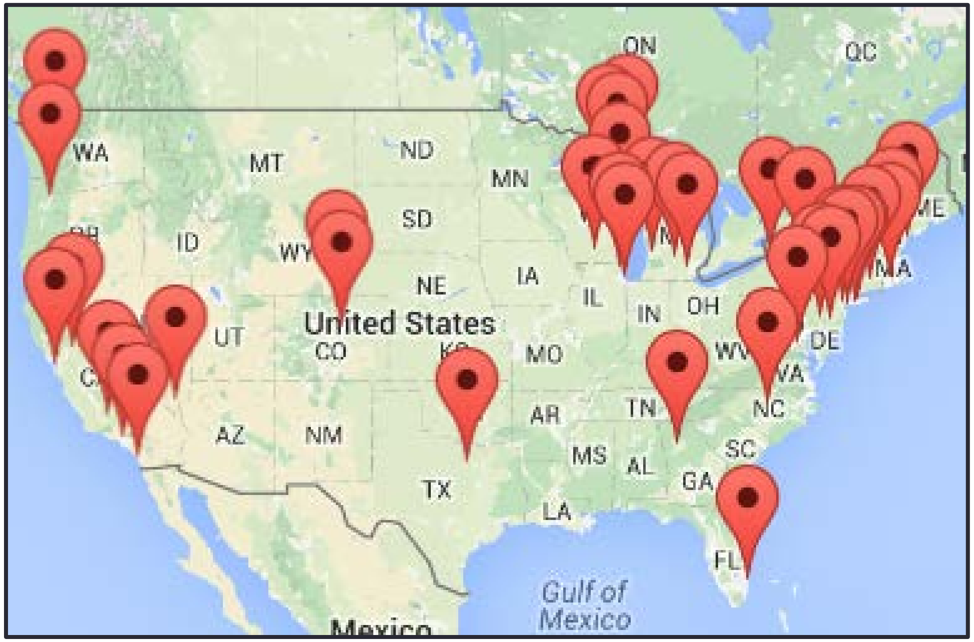
GEI Basics



- Founded in 1970
- 750+ Employees
- 37 Offices
- 35,000+ Projects in all 50 states and 25 countries

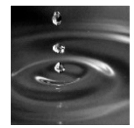
Technical Practice Areas

Environmental

- Compliance
- Permitting
- Due Diligence
- Characterization
- Remediation
- Risk Assessment
- Restoration
- Asbestos
- Demolition
- Brownfields
- In-Water & Uplands

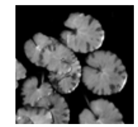
Geotechnical

- Coastal Engineering & Planning
- Foundations
- Excavation Support
- Construction
- Tunneling
- Dams
- Embankments
- Levees
- Failure Analysis
- Geotechnical Testing



Water Resources

- Conveyance
- Flood Control
- Water Management
- Water Supply and Storage
- Water Resources Support
- Hydropower



Ecological

- Ecotoxicology
- Monitoring
- Water Quality
- Aquatic Ecosystems
- Environmental Impact
- Laboratory Services
- Sensory Services
- Air Quality

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US Capitol Visitor Center, Washington DC

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Goldman Sachs Building, NY

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Brickell City Centre, Miami

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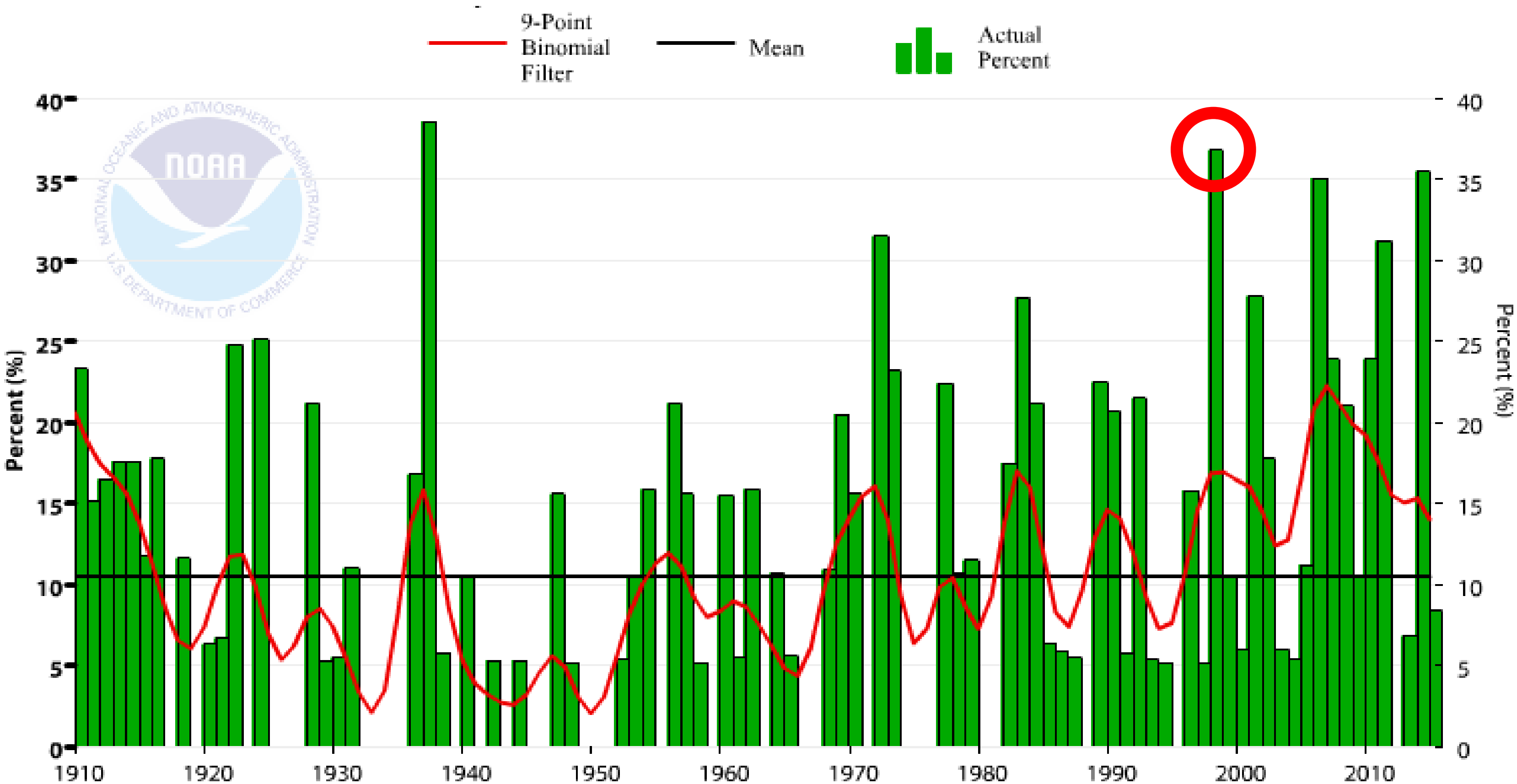
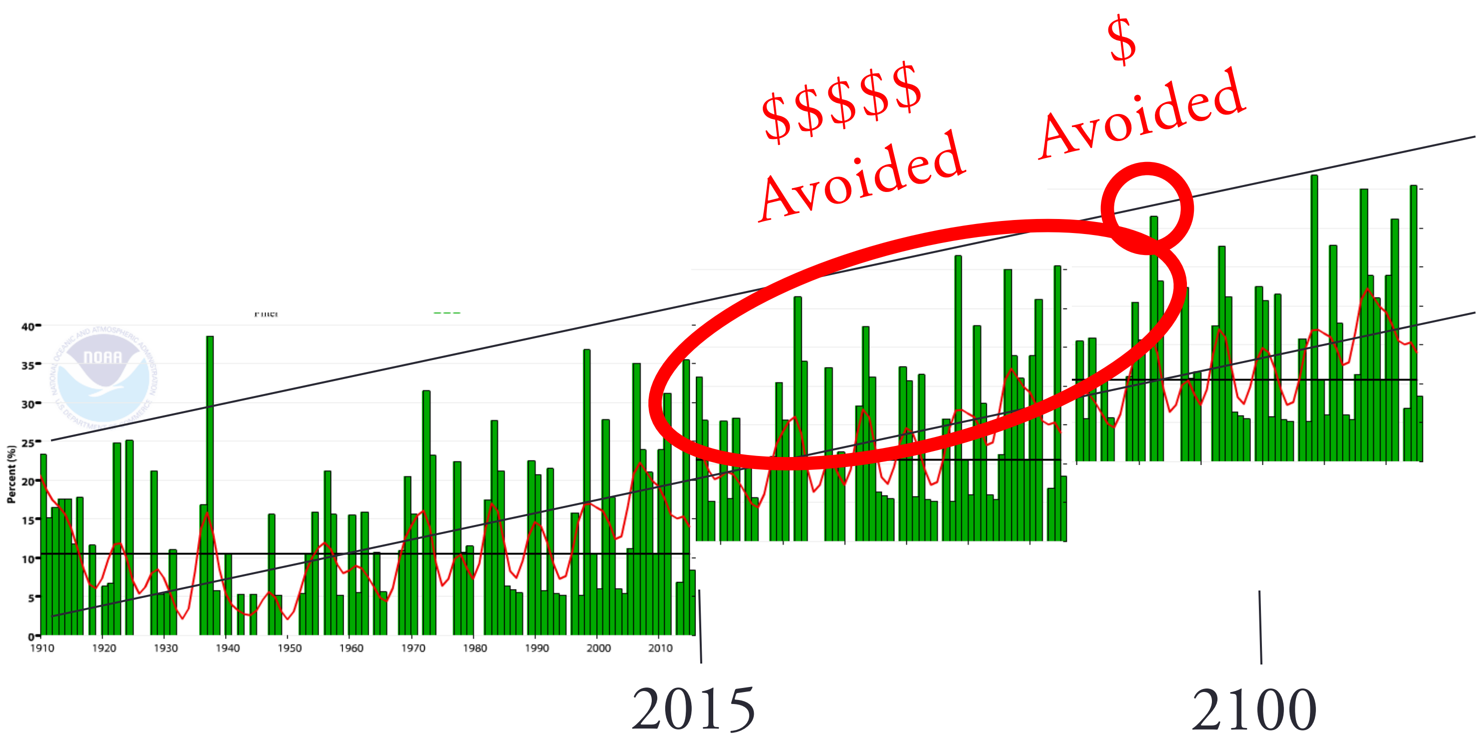
What storm do we currently consider in our design standards?



http://www.ncdc.noaa.gov/extremes/cei/graph/ne/4/01-12

So what do we design for?

A key measure of the value of any adaptation design investment is **cumulative avoided damage**



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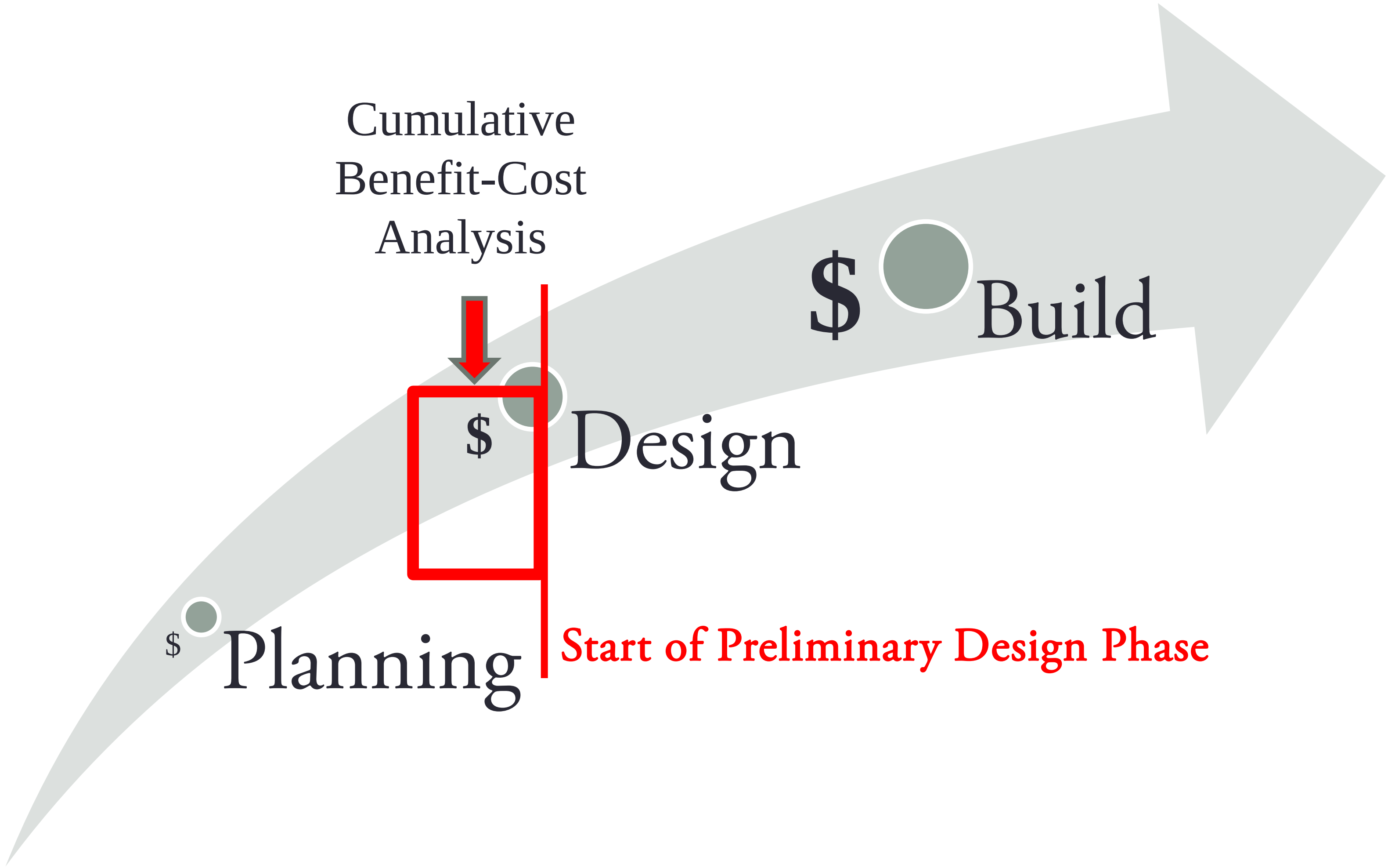
Engineering Project Timeline



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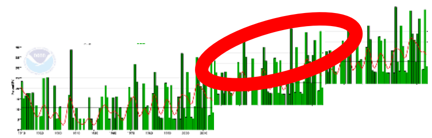
Cumulative BCA Summary



Cumulative
BCA Start

Design 1

Design 2

Design 3

Cumulative
Avoided
Damages

Construction
and
Cumulative
Repair Costs

BCRs

5:1

1:1

0.2:1

25x savings

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Lifecycle/Cumulative BCA Framework Concepts

Methods to calculate cumulative avoided damages should:

- Track impact of events over an entire time period, not just as snapshots.

The Old Port, 10/11 at high tide (M. Craig)

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Lifecycle/Cumulative BCA Framework Concepts

Methods to calculate cumulative avoided damages should:

- Track impact of events over an entire time period, not just as snapshots.
- Account for impacts of events with different intensities, frequencies, and rates of change.
  - *and their interactions.*

Rates of Sea Level Rise are Increasing

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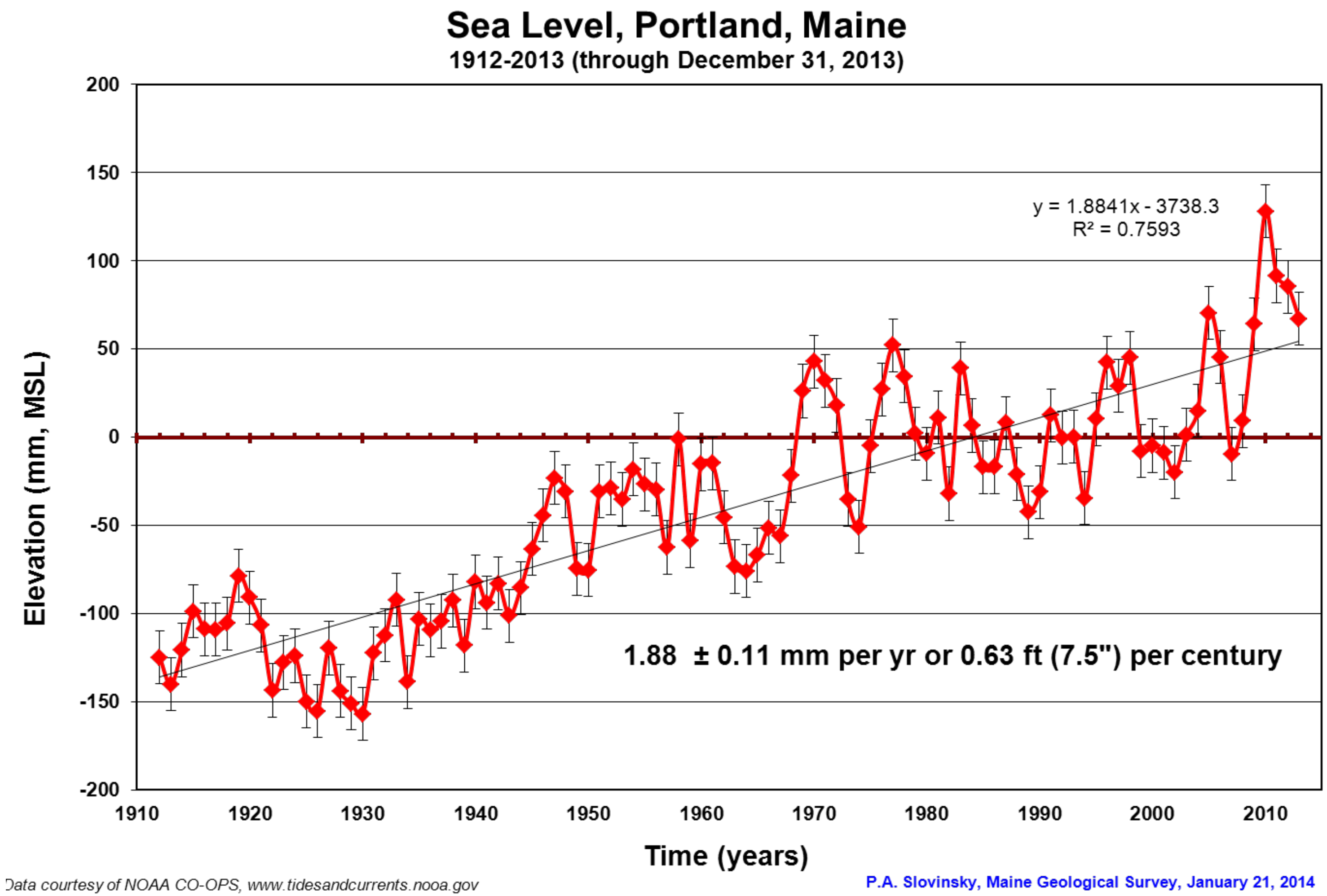
Rates of Sea Level Rise are Increasing

Over the past 100 years, sea level rise in Portland has generally followed globally averaged long-term trends



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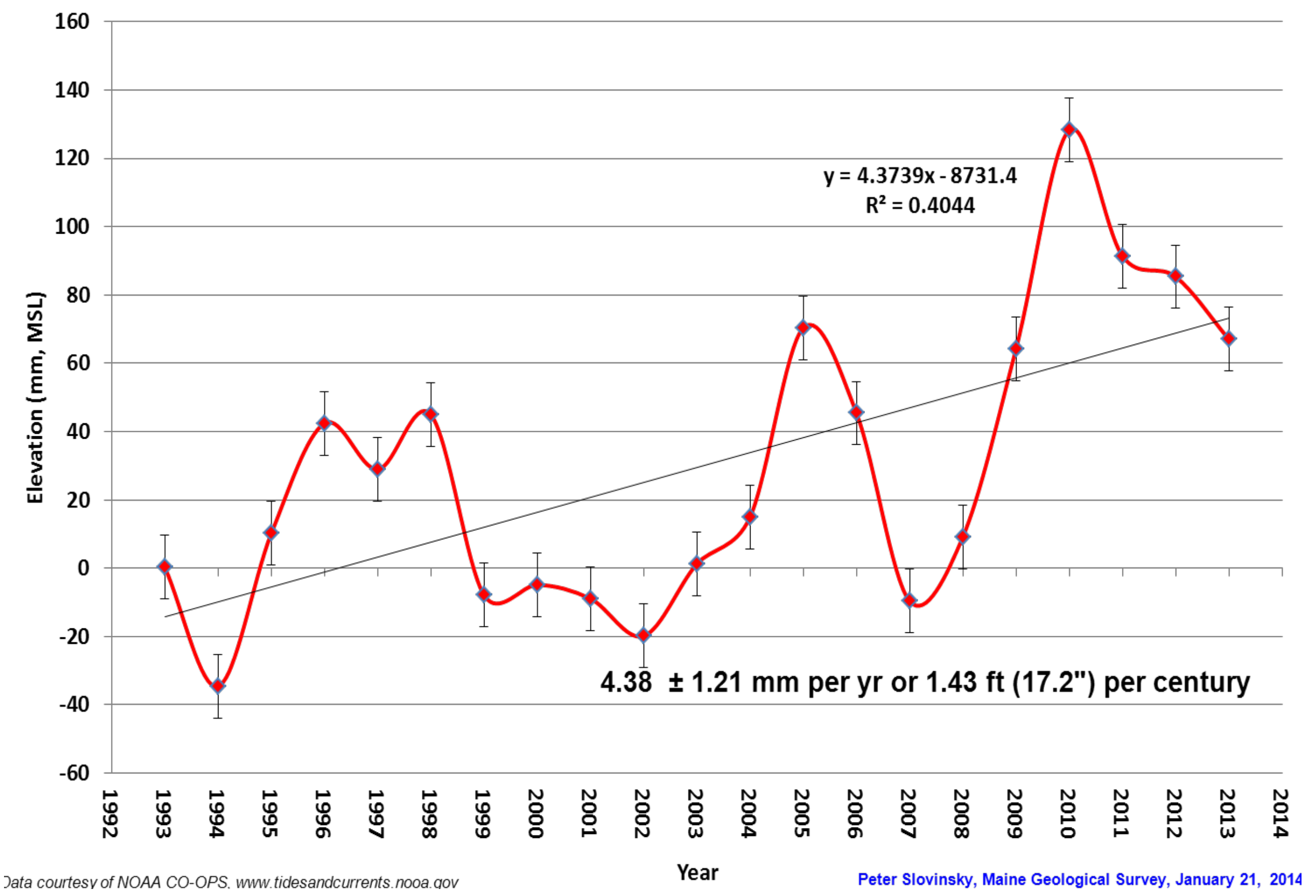
Rates of Sea Level Rise are Increasing

Over the past 20 years, sea levels in Portland have risen far faster than the long-term trend. This change in rate is also being seen in global measurements.

Sea Level, Portland, Maine

1993-2013 (through December 2013)



Surge Events are Increasing

The Old Port, 3/10 at high tide (D. Yakovleff)

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Surge Events are Increasing

The Old Port, 10/11 at high tide (M. Craig)

Surge Events are Increasing

East Bayside at High Tide 9/15 (Portland Press Herald 10/2/15)

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Flood Frequency is Influenced by Sea Level

Scenario	Flood Stage (ft, MLLW)	# times inundated	% of high tides	Duration, hrs
Existing Flood	12.0	8	1.1%	8.6
+1 ft SLR	11.0	87	12.4%	121.8
+2 ft SLR	10.0	312	44.4%	575.3
+3.3 ft SLR	8.7	616	87.6%	1748.5
+6 ft SLR	6.0	702	99.9%	3816.3

based on 2013 Portland tidal station data from the NOAA Inundation Analysis Tool

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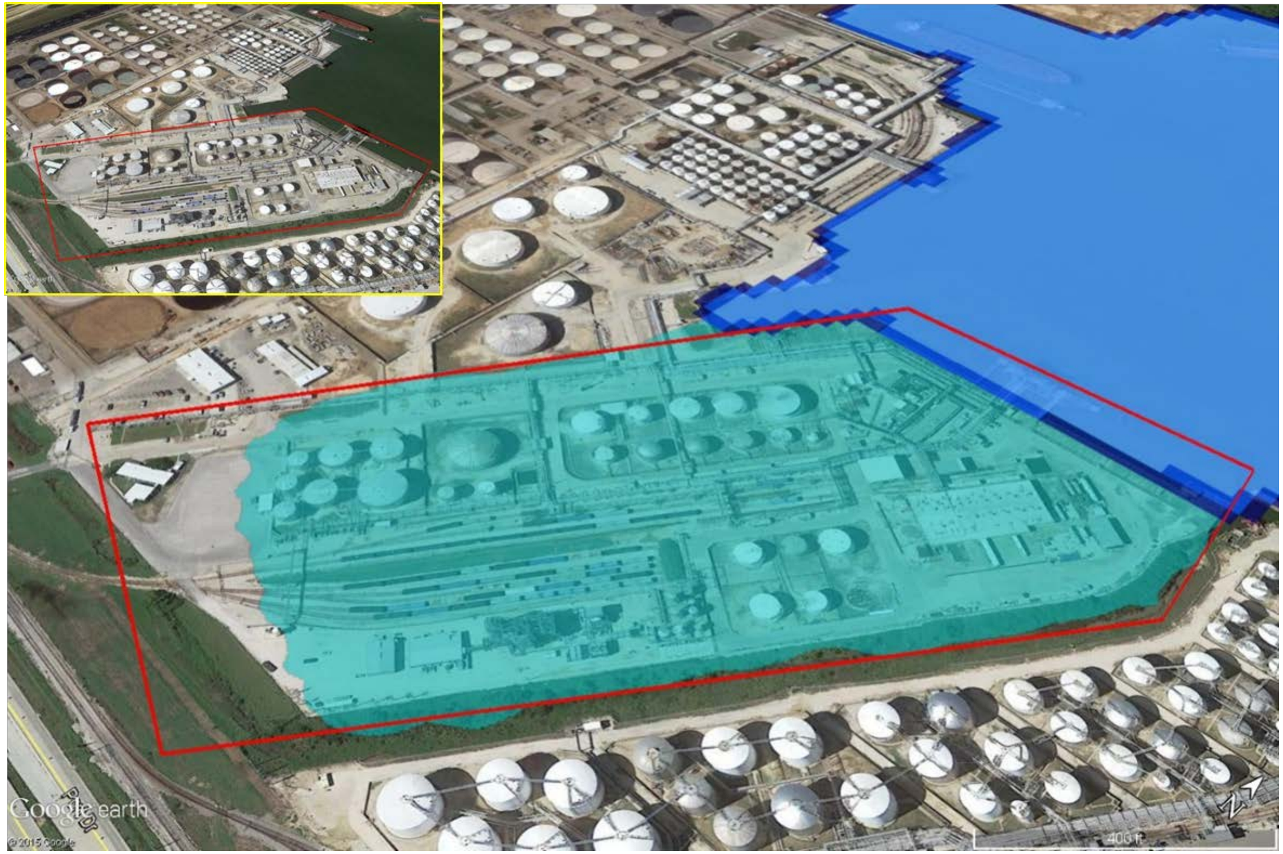
Oil Refineries Will Face Increasing Vulnerability from Sea Level Rise and Storm Surge

LEGEND

- 0 ft sea level rise
- 3 ft sea level rise
- 6 ft sea level rise
- 100-yr flood (no sea level rise)



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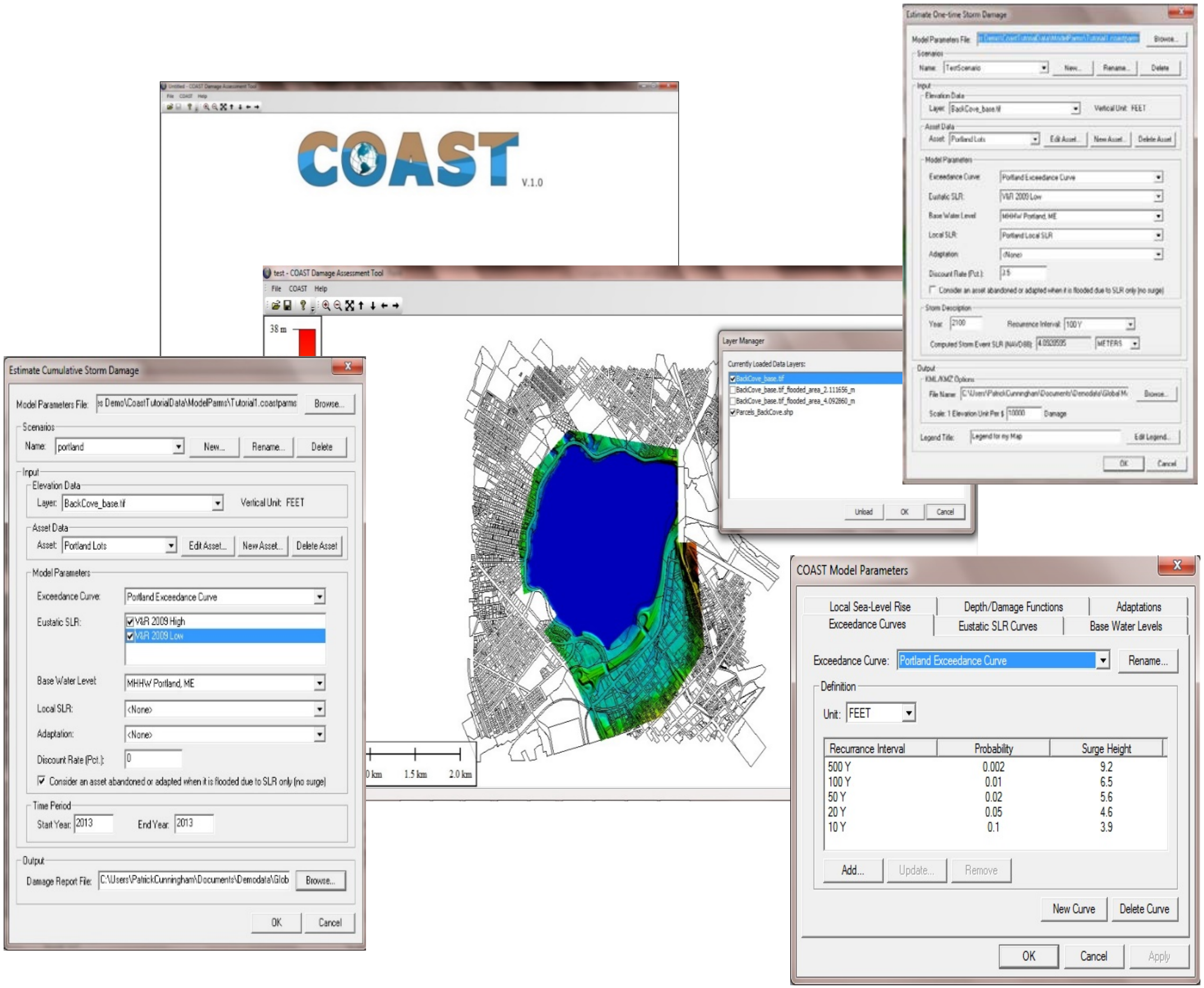
COAST Software (Initially US EPA)



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BCA for Infrastructure Upgrades

Muskie School of Public Service
University of Southern Maine

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Based on numerous peer-reviewed method papers

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

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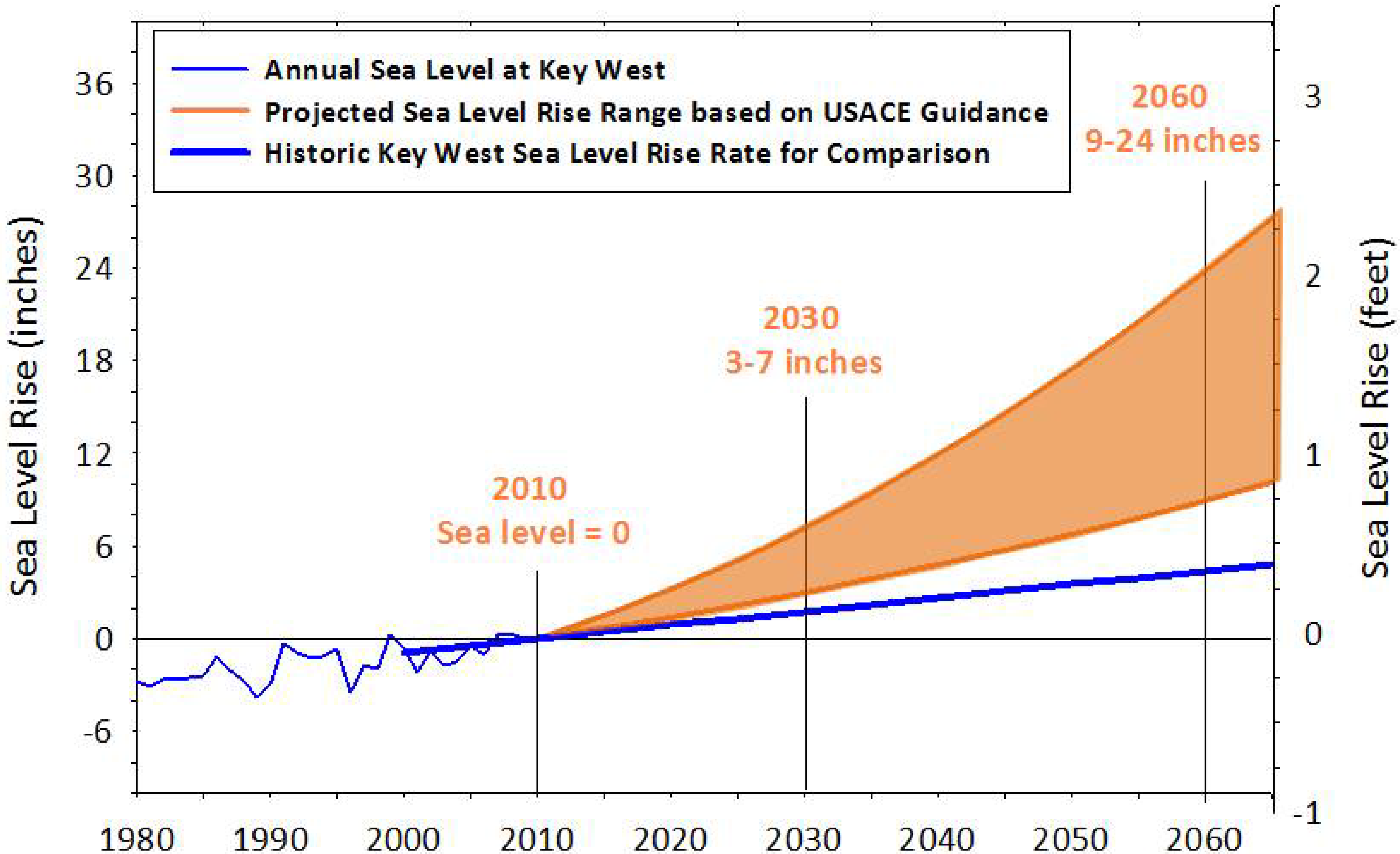
COAST is a means of

- Evaluating *cumulative* vulnerability to storm surge and/or sea level rise.
  - Tailored to specific engineered structures.
- Comparing costs and benefits of candidate adaptation actions or alternative designs.

Some Project Sites Completed or Underway

Selsey, United Kingdom
Santos, Brazil
Fort Lauderdale, Florida
Key Largo, Florida
Islamorada, Florida
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
Bowdoinham, Maine
Old Orchard Beach, Maine
Scarborough, Maine
Bath, Maine
Farmington, Maine
New Sharon, Maine
Marshfield, Massachusetts
Duluth, Minnesota
Rochester, Minnesota

Input Sea Level Rise Curves



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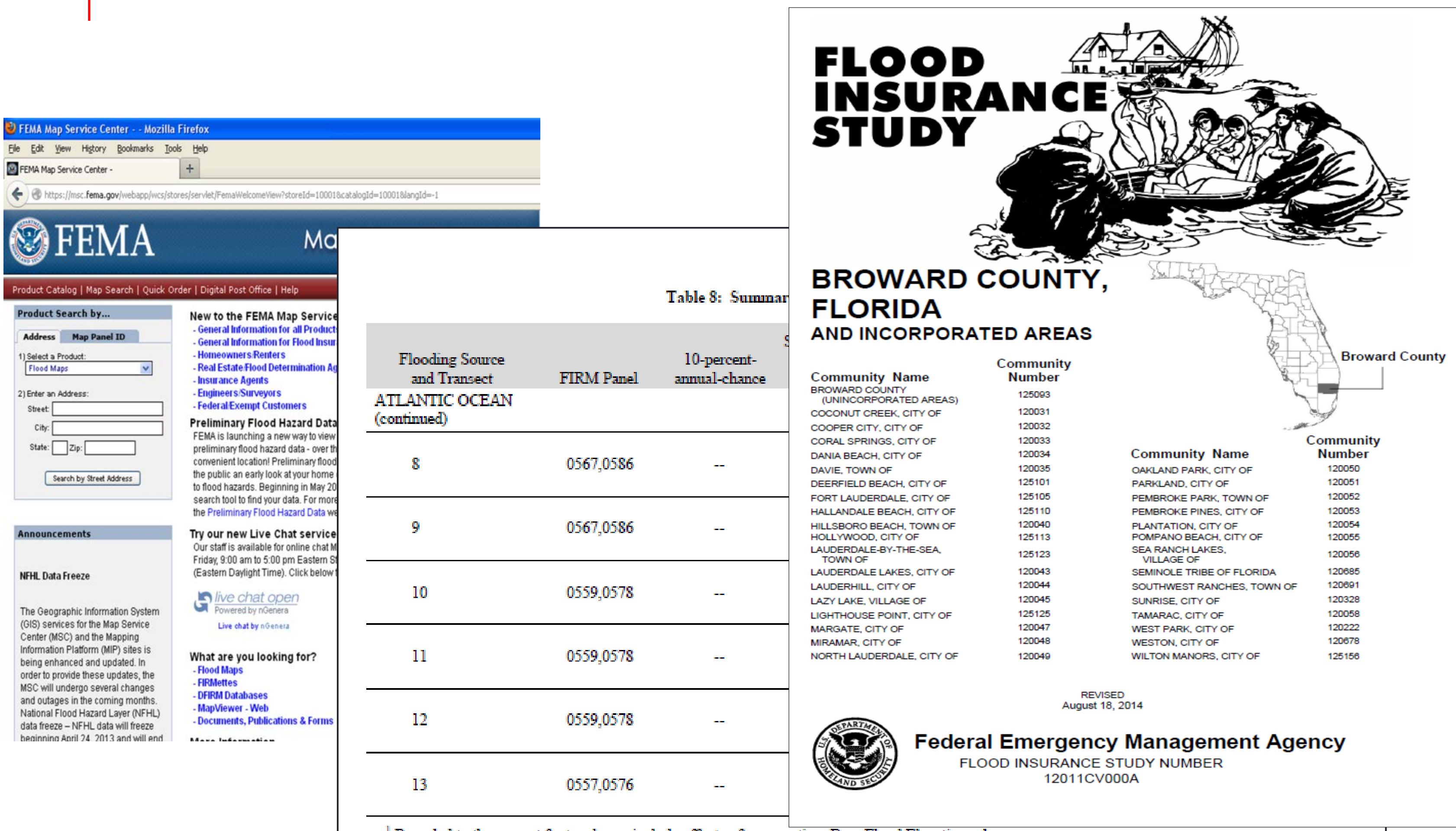
Input Flood Elevations and Recurrence Intervals



Can also use finer resolution data from ADCIRC and other models.

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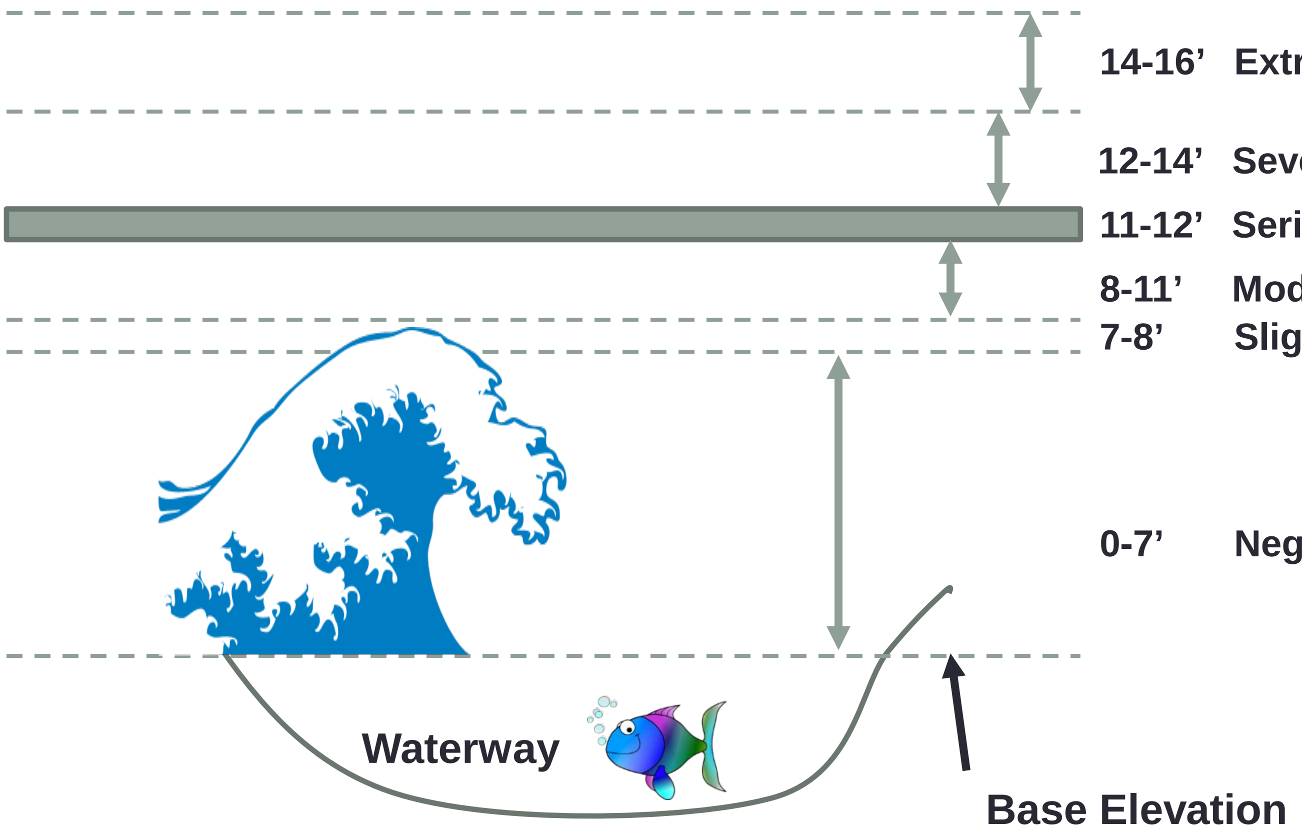
Depth Damage Functions Designed for Each Candidate Action/Structure



Elev.	Damage	Cost
14-16’	Extreme	= $$$$$$
12-14’	Severe	= $$$$$
11-12’	Serious	= $$$$
8-11’	Moderate	= $$$
7-8’	Slight	= $$
0-7’	Negligible	= $

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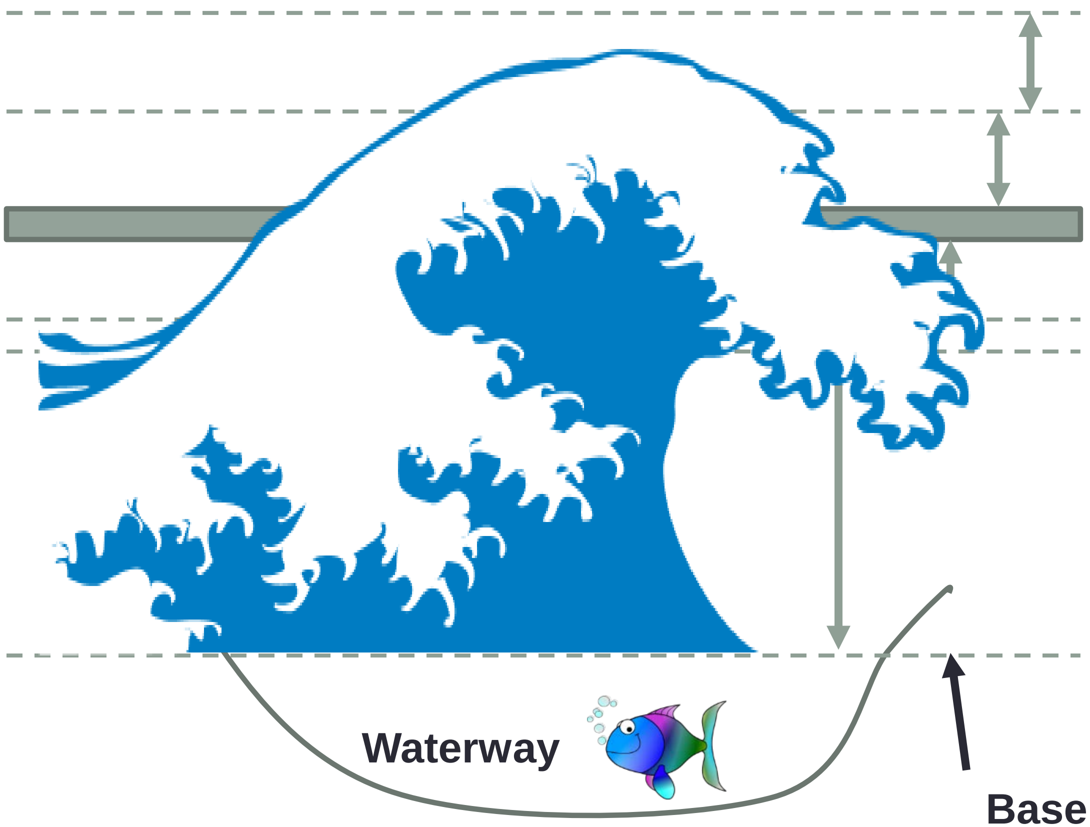
Depth Damage Functions Designed for Each Candidate Action/Structure



Elev.	Damage	Cost	
14-16’	Extreme	= $$$$$$	+ zero
12-14’	Severe	= $$$$$	+ $$
11-12’	Serious	= $$$$	+ $$
8-11’	Moderate	= $$$	+ zero
7-8’	Slight	= $$	+ zero
0-7’	Negligible	= $	+ zero

Burden with other costs

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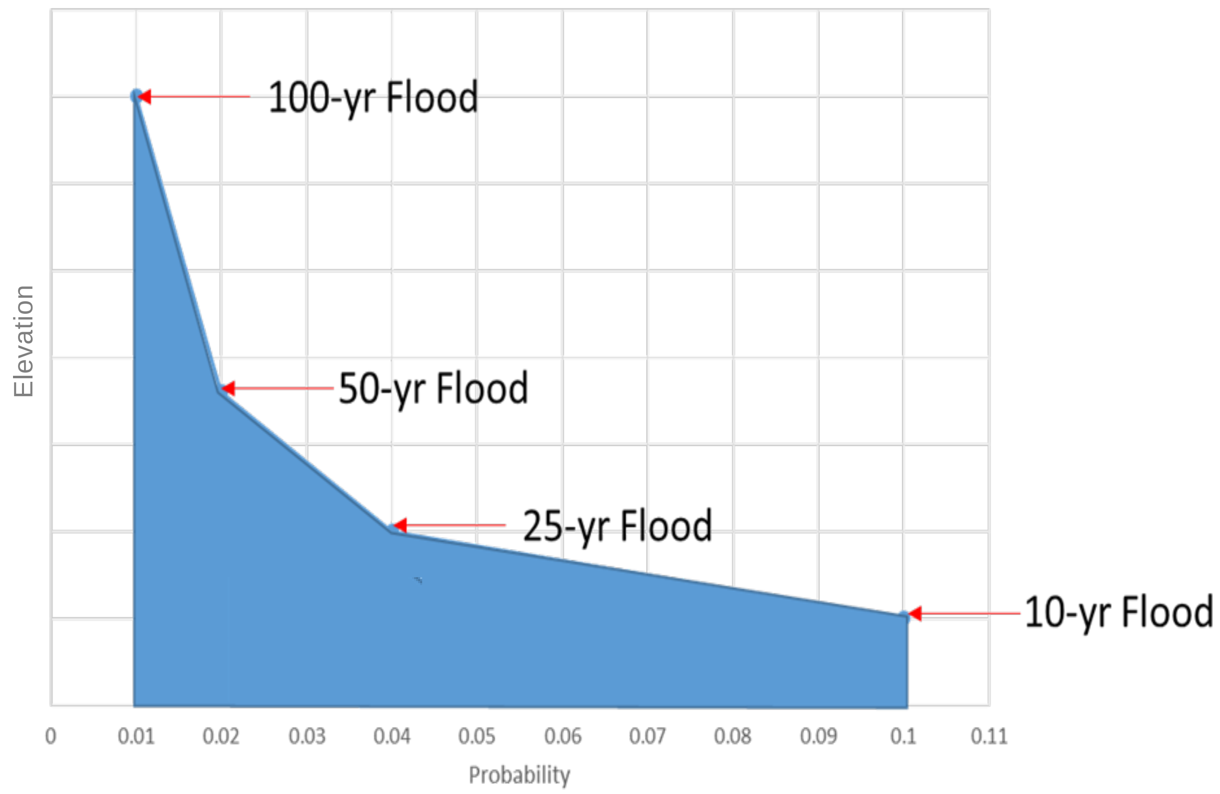
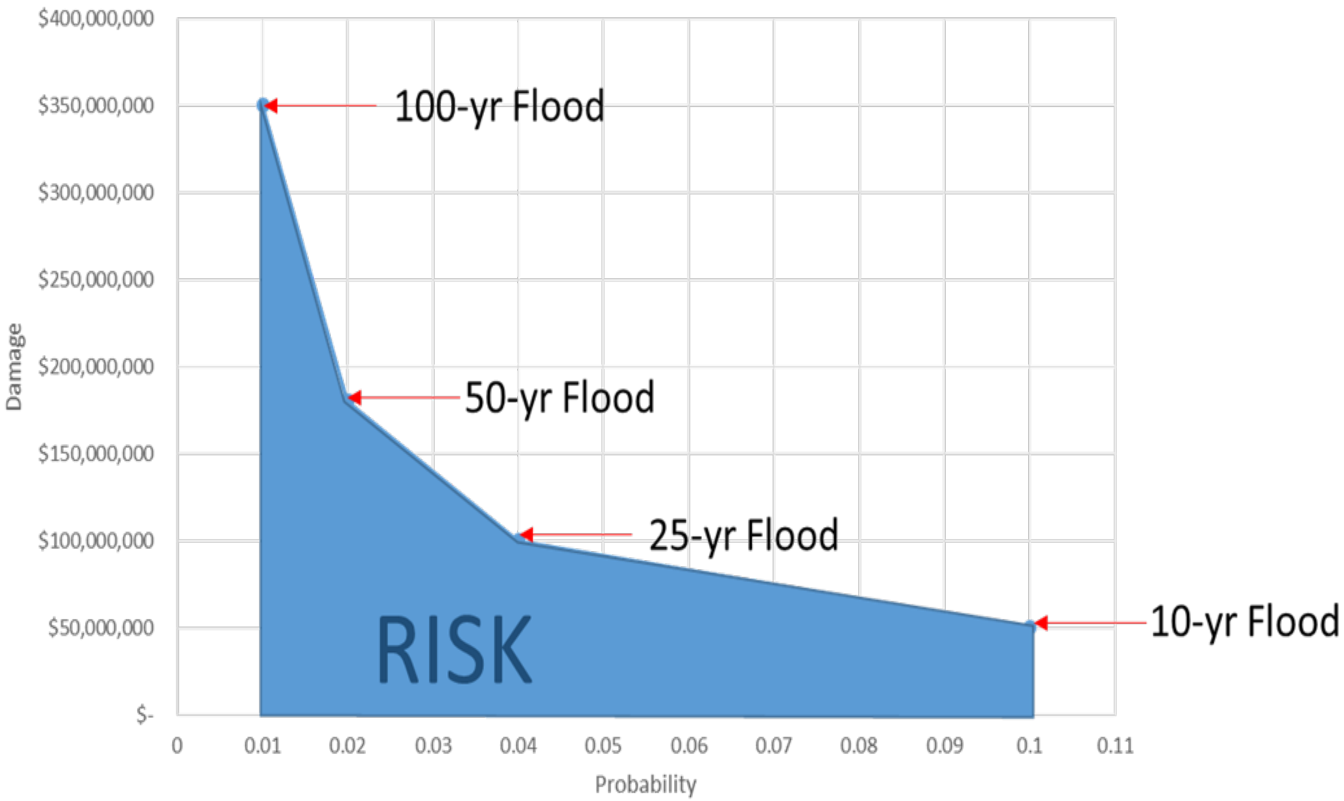
Exceedance Curves



How Vulnerable Are We If We Do Nothing?



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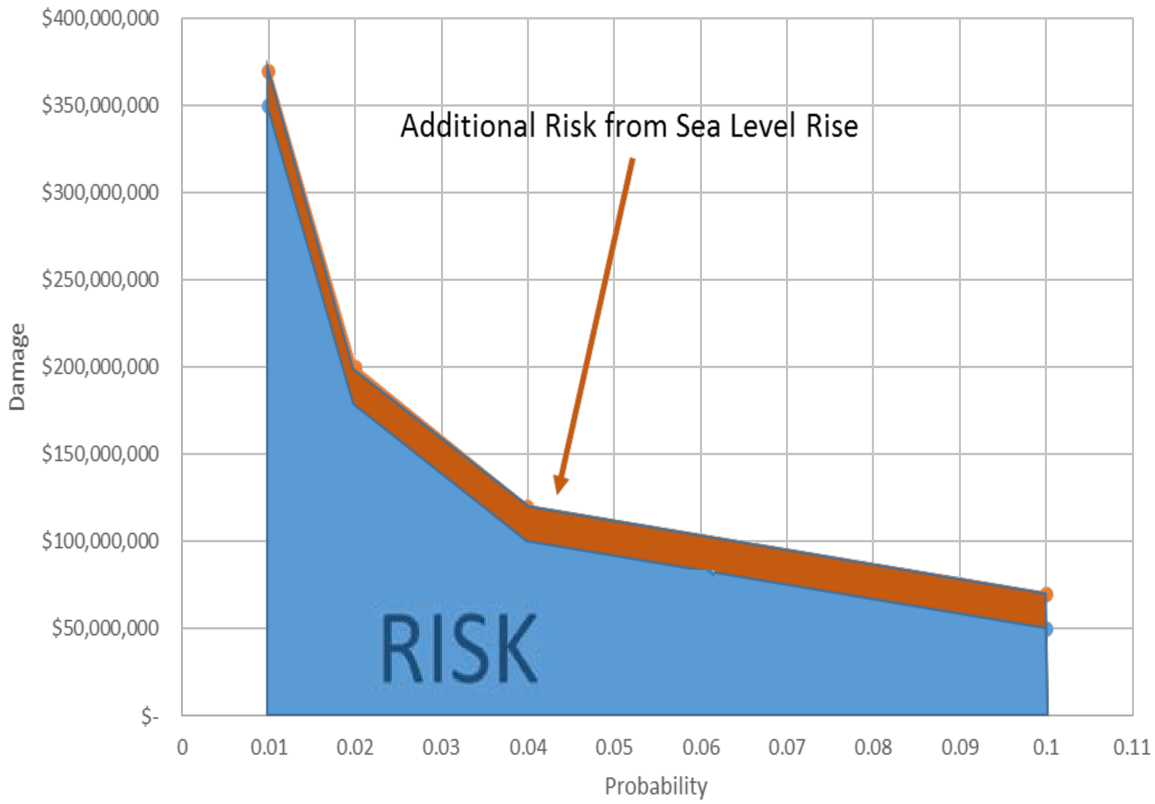

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Bridge Sensitivity to Elevated Water Levels

View of a bridge over the Sandy River on ME-41 in Farmington, an example of the types of structures that have been evaluated with the COAST software.

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Transferable Examples

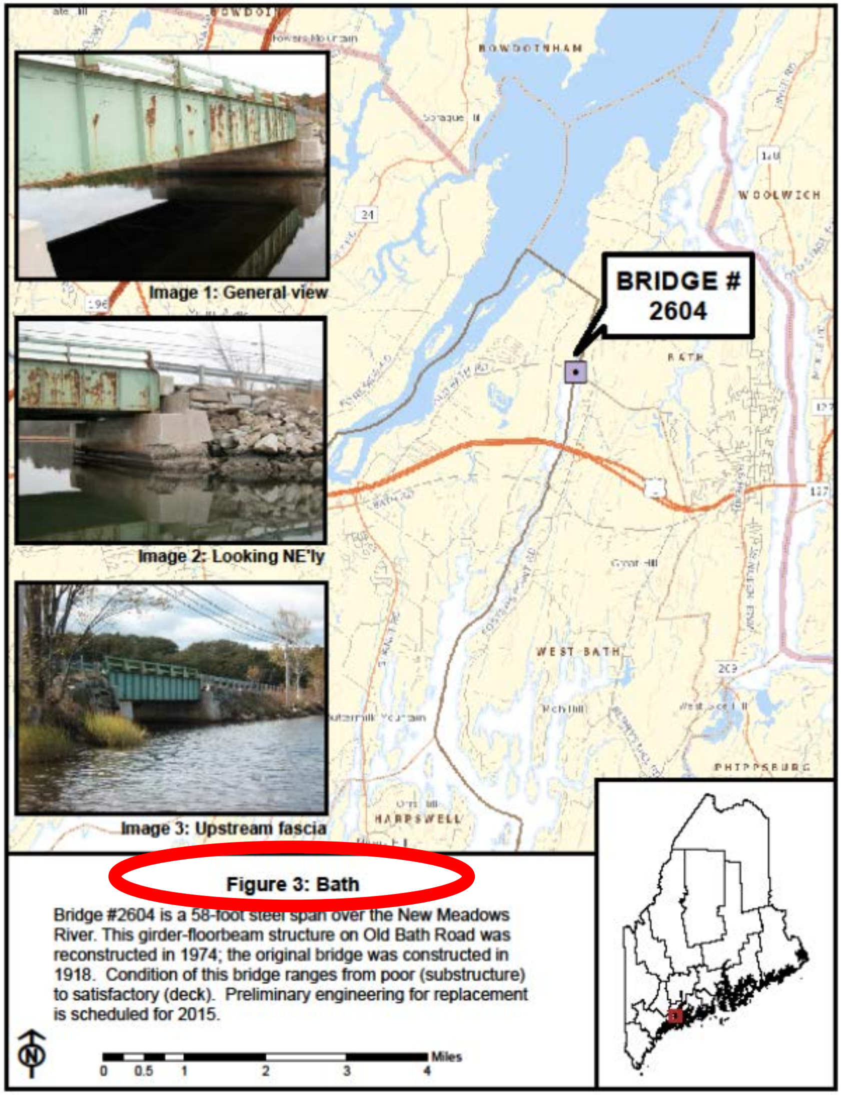

Figure 3: Bath

Bridge #2604 is a 58-foot steel span over the New Meadows River. This girder-floorbeam structure on Old Bath Road was reconstructed in 1974; the original bridge was constructed in 1918. Condition of this bridge ranges from poor (substructure) to satisfactory (deck). Preliminary engineering for replacement is scheduled for 2015.

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Transferable Examples

Bath

Low Sea Level Rise (3.3')

	Initial Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$400,000	$697,476	**$1,097,476**
Replace with 3.3' SLR design	$594,000	$697,476	$1,291,476
Replace with 6' SLR design	$1,000,000	$281,242	$1,281,242

High Sea Level Rise (6')

	Initial Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$400,000	$1,867,580	$2,267,580
Replace with 3.3' SLR design	$594,000	$1,867,580	$2,461,580
Replace with 6' SLR design	$1,000,000	$916,598	**$1,916,598**

Replace in Kind was the most cost effective choice for a Low sea level rise scenario, but **Replace with 6' SLR design** was the most cost effective choice for a High sea level rise scenario.

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Transferable Examples

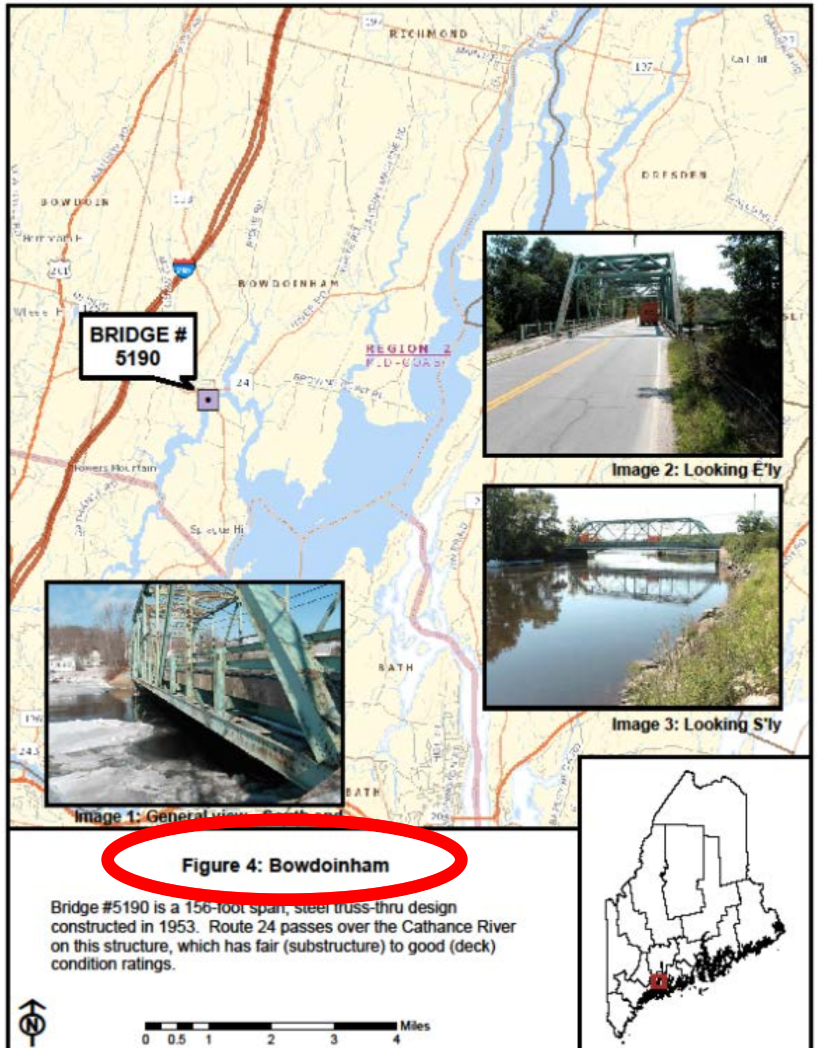

Figure 4: Bowdoinham

Bridge #5190 is a 156-foot span, steel truss-thru design constructed in 1953. Route 24 passes over the Cathance River on this structure, which has fair (substructure) to good (deck) condition ratings.

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Transferable Examples

Bowdoinham

Low Sea Level Rise (3.3')

	Initial Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$250,000	$1,656,830	$1,906,830
Replace with 3.3' SLR design	$394,000	$1,162,080	$1,556,080
Replace with 6' SLR design	$491,000	$205,159	**$696,159**

High Sea Level Rise (6')

	Initial Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$250,000	$2,163,283	$2,413,283
Replace with 3.3' SLR design	$394,000	$1,900,813	$2,294,813
Replace with 6' SLR design	$491,000	$908,565	**$1,399,565**

Replace with 6’ SLR design was the most cost effective choice for both Low and High sea level rise scenarios.

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Summary

- In terms of fiscal efficiency, there is no one right answer to the question “what design standard should we use?” Site-specific analysis is required.

Transportation Research Part D 33 (2014) 87–94

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

ELSEVIER

Economic analyses of sea-level rise adaptation strategies in transportation considering spatial autocorrelation

Qing-Chang Lu [a,*], Zhong-Ren Peng [a,b], Liye Zhang [c], Zhanyong Wang [a]

“…The construction costs of seawall and road elevation are different for different states or situations, so the economic analysis should be conducted based on the actual construction plan in proposed locations.”

But many futures are possible!

- How do we pick whether to build for a low or a high sea level rise scenario??

Bath

Low Sea Level Rise (3.3')

	Initial Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$400,000	$697,476	**$1,097,476**
Replace with 3.3' SLR design	$594,000	$697,476	$1,291,476
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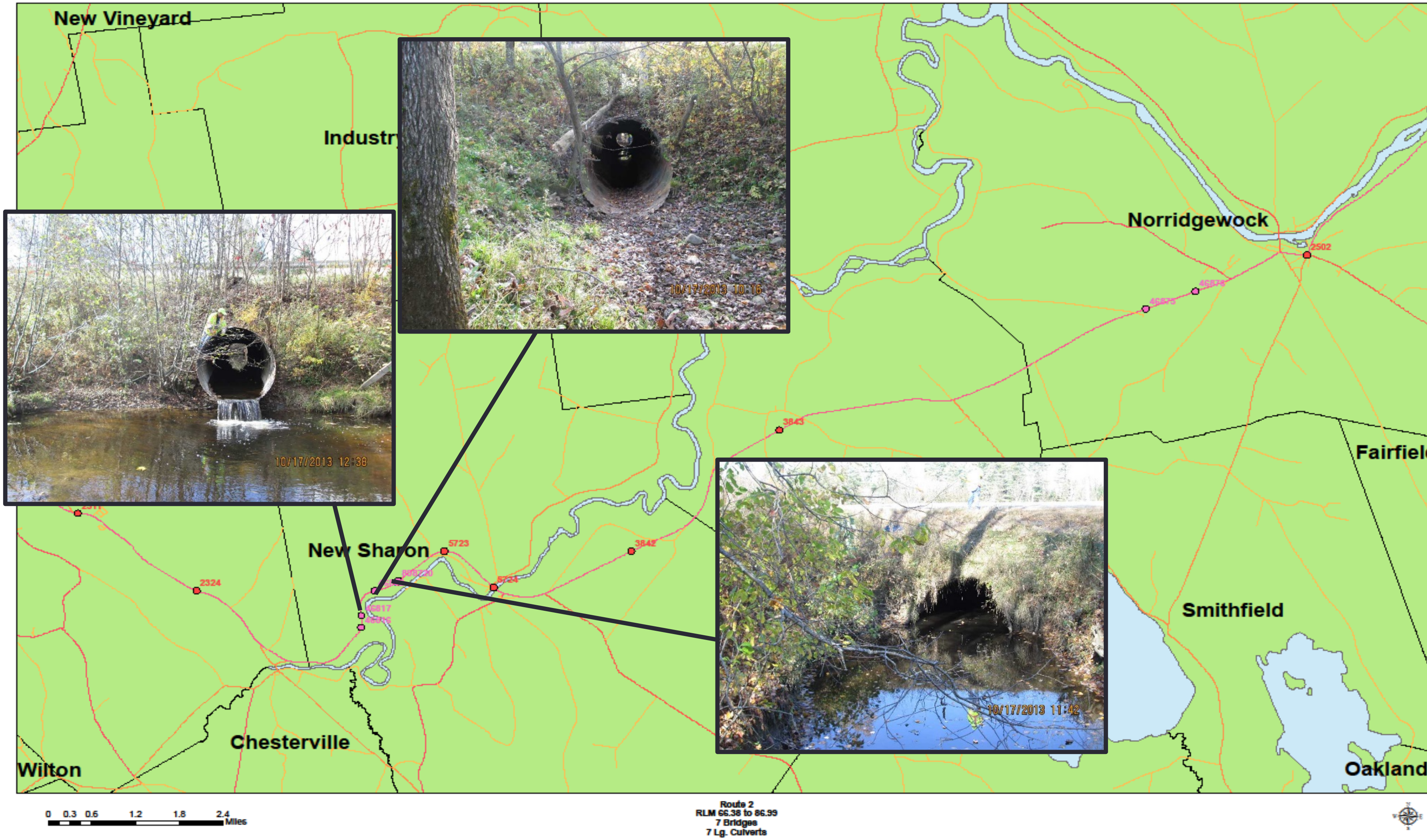
But many futures are possible!

- How do we pick whether to build for a low or a high sea level rise scenario??

- Still needed is a means of selecting from candidate designs in a way that minimizes risk across modeled future scenarios.

Transferable Example – Going Inland



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Transferable Example – Going Inland

Farmington_2311

New Sharon_989720

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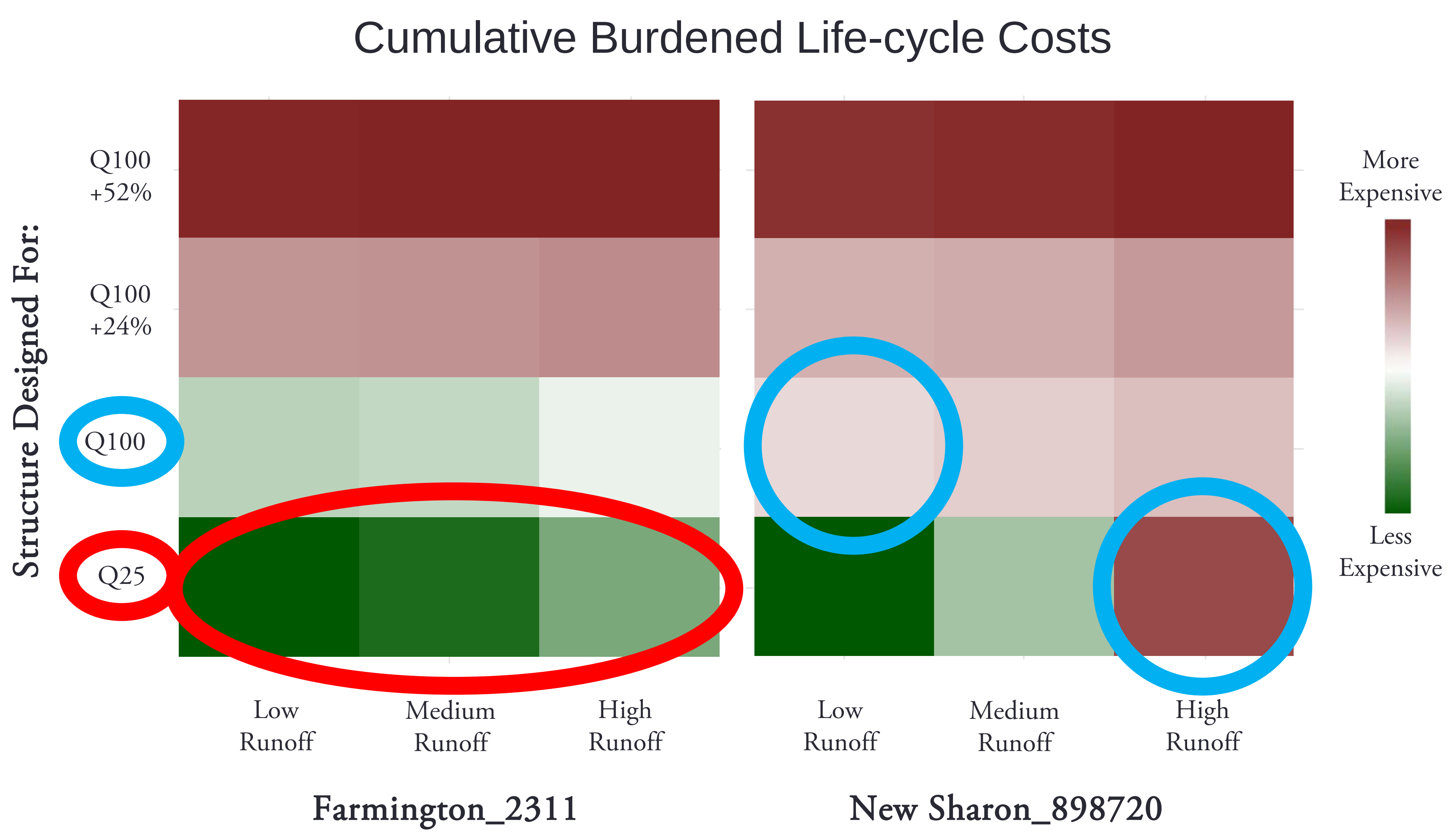
No-regrets Design Across Futures



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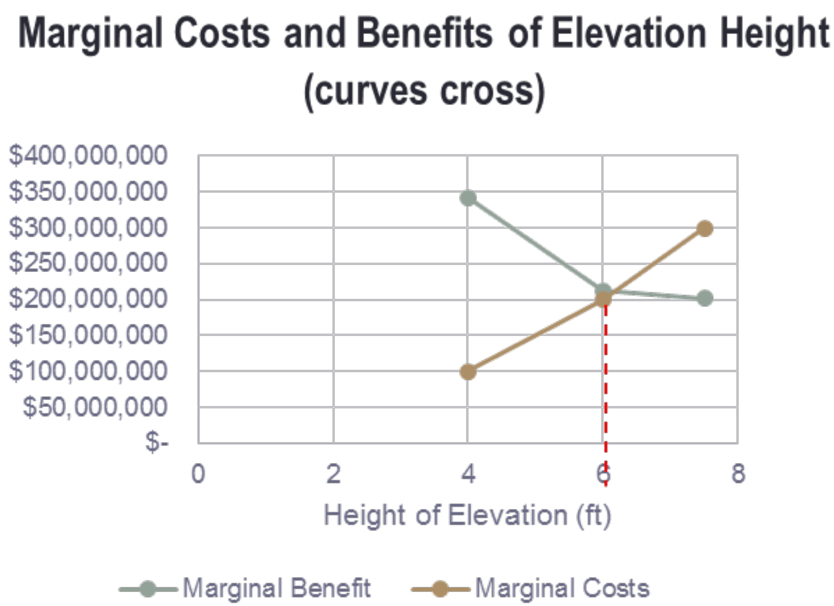
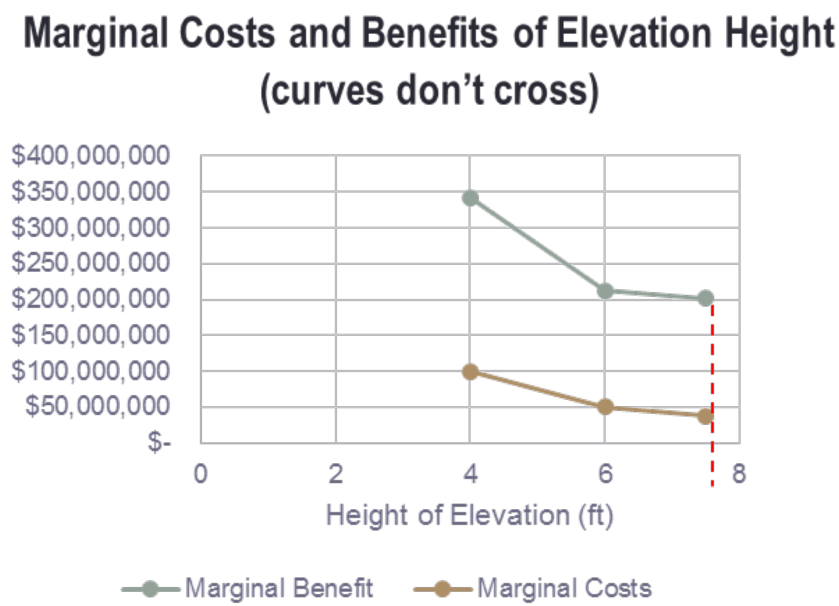
How High Should Road or Other Elevations Be?





- When curves cross, appropriate height is at the curve intersection.
- When curves don't cross, appropriate height is at the best ratio between them.

- If choosing to build to a standard other than ideal, you at least have an estimate of how efficient the investment will be.

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Thank You!

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