PORT/COASTAL INFRASTRUCTURE & CLIMATE CHANGE: AN ADAPTIVE MANAGEMENT APPROACH

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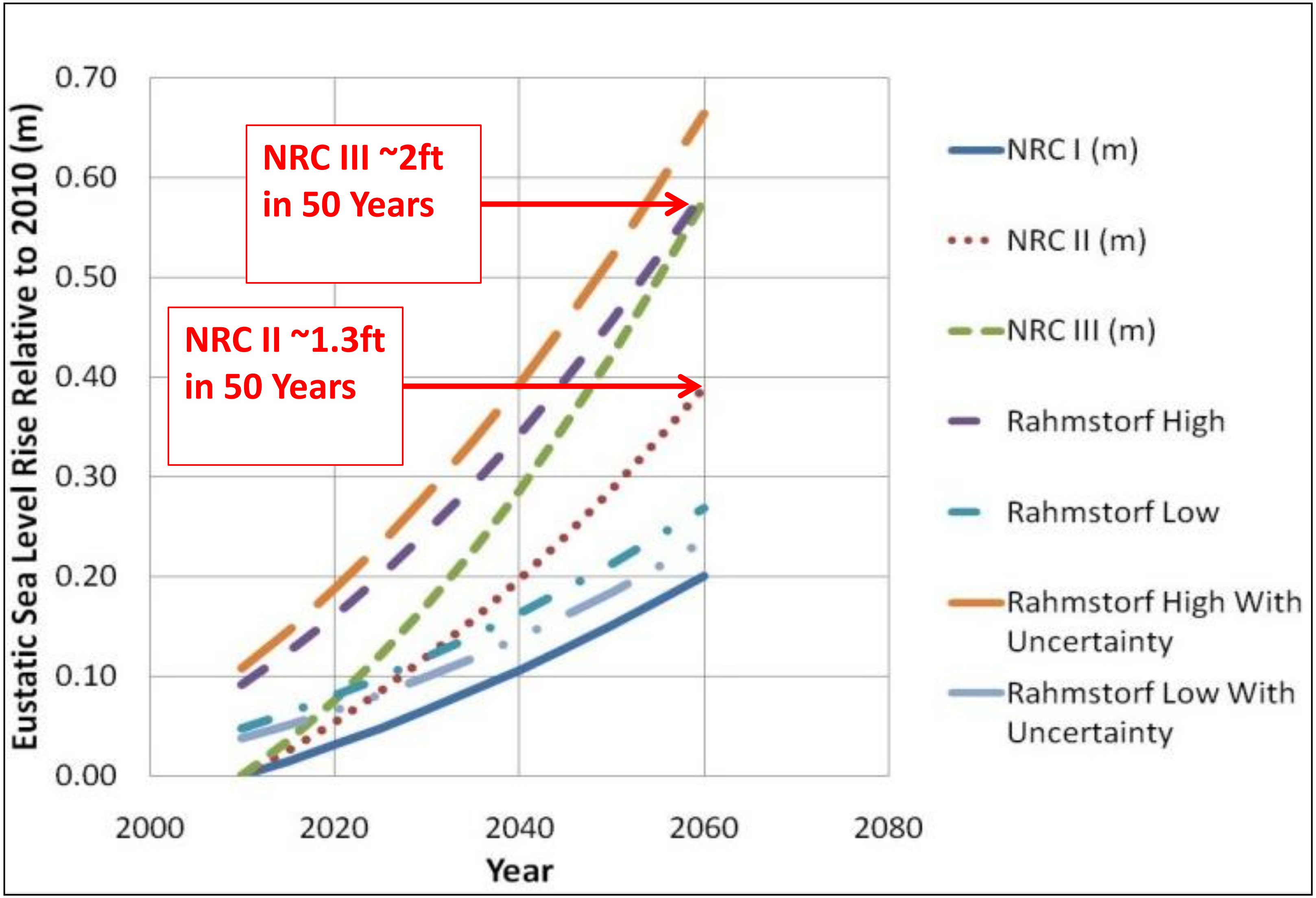
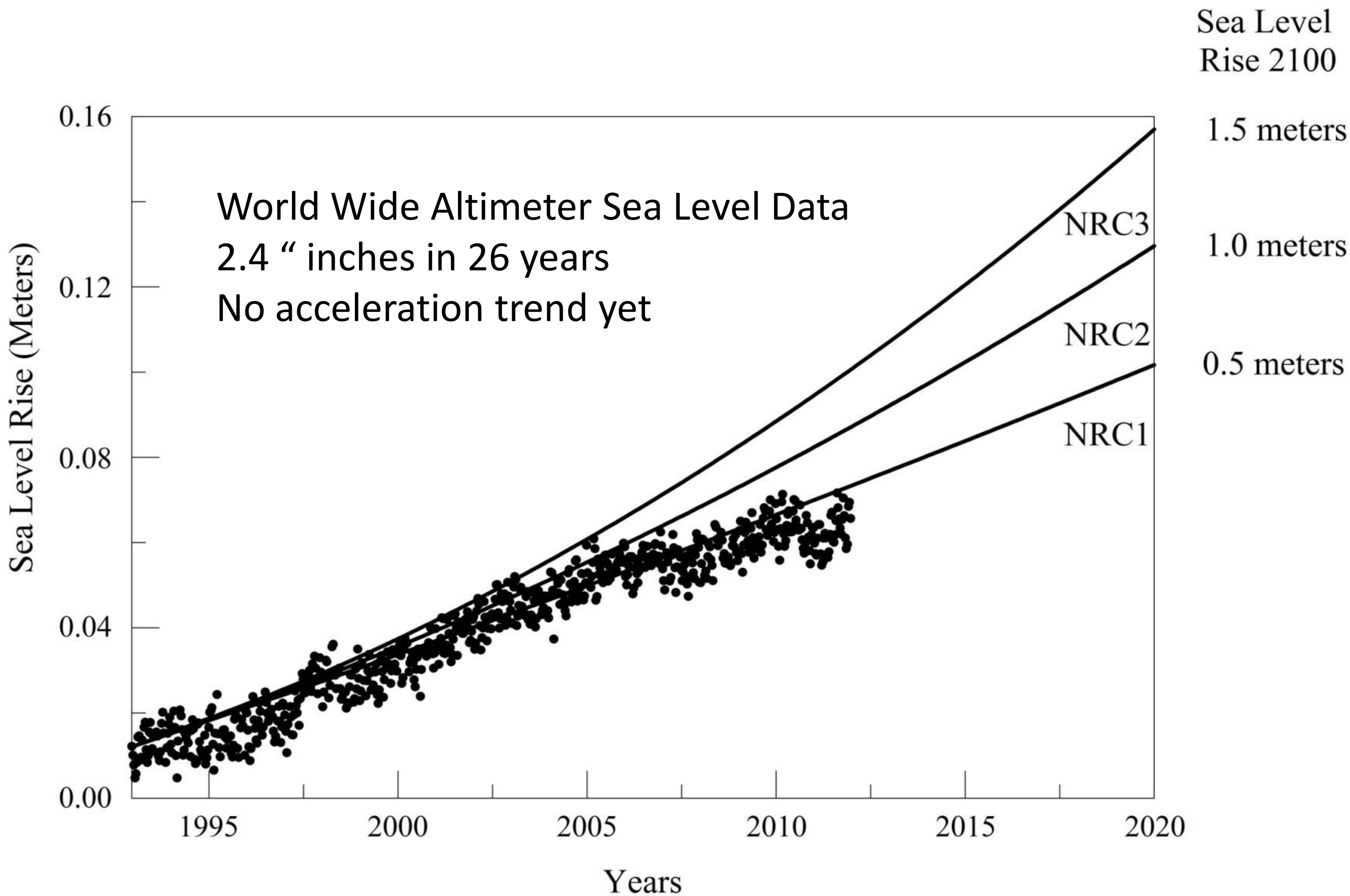
Moffatt & Nichol

AAPA American Association of Port Authorities
Alliance of the Ports of Canada, the Caribbean, Latin America and the United States

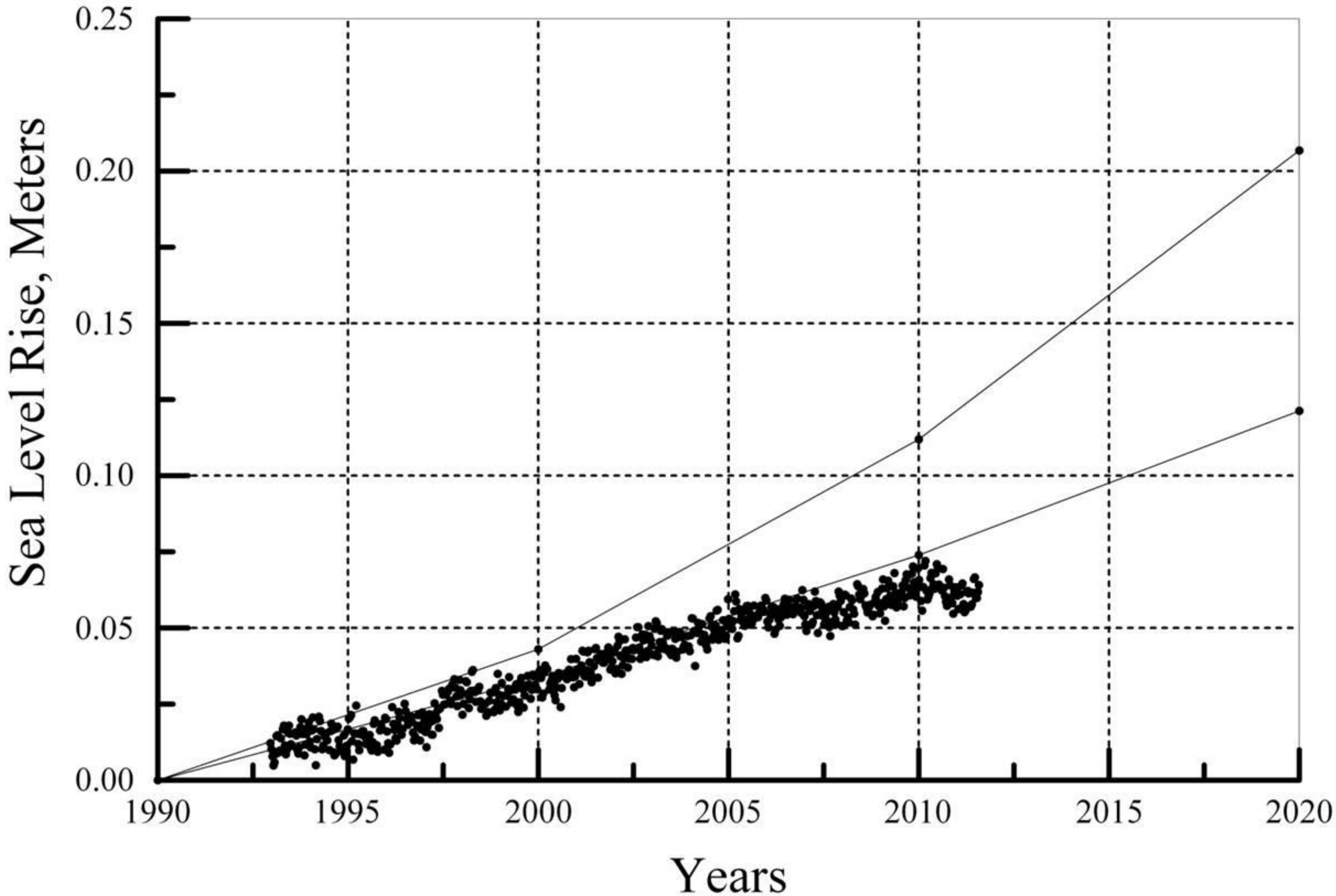
SLR SCENARIOS



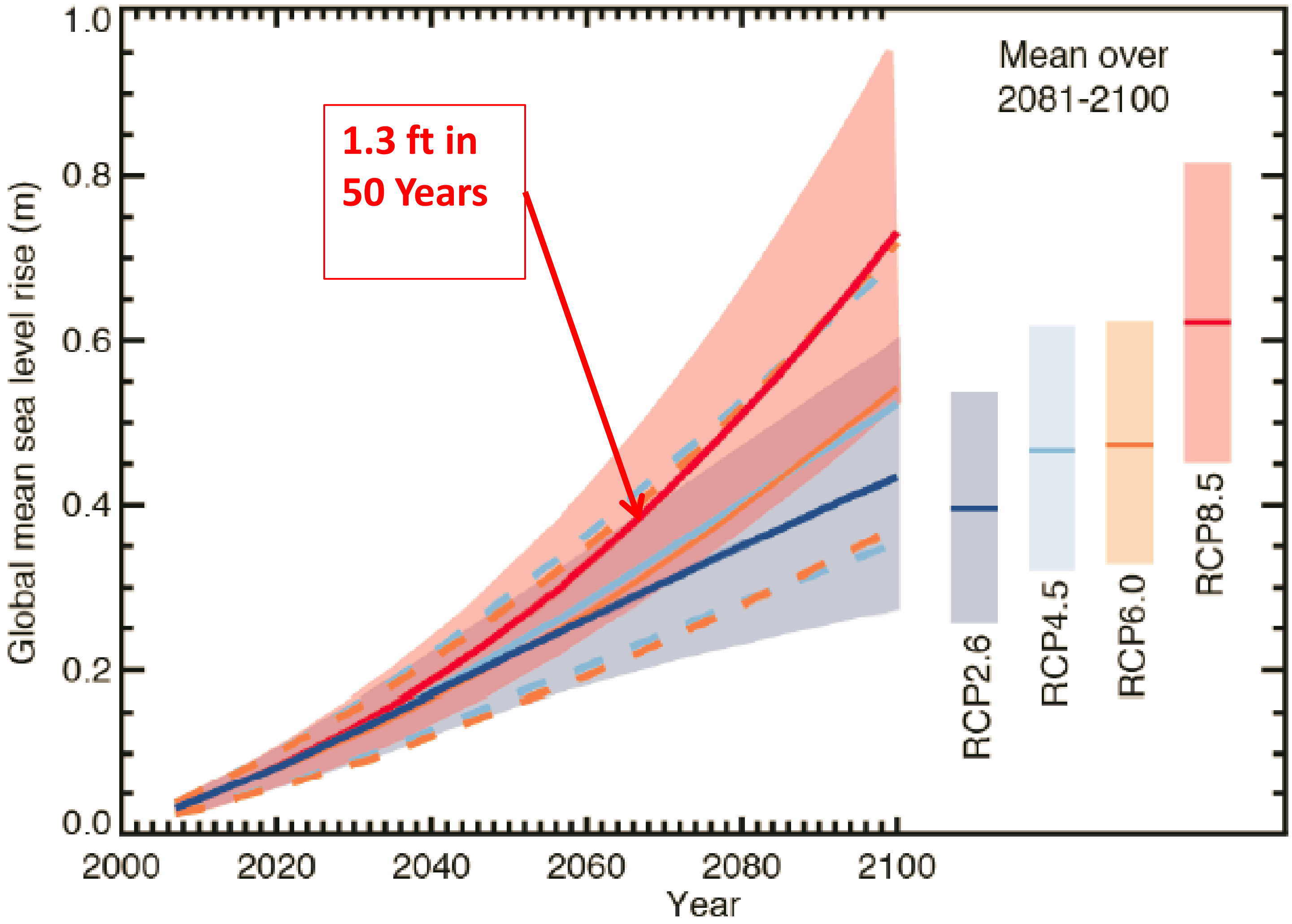
1987 NRC PROJECTIONS FROM 1992



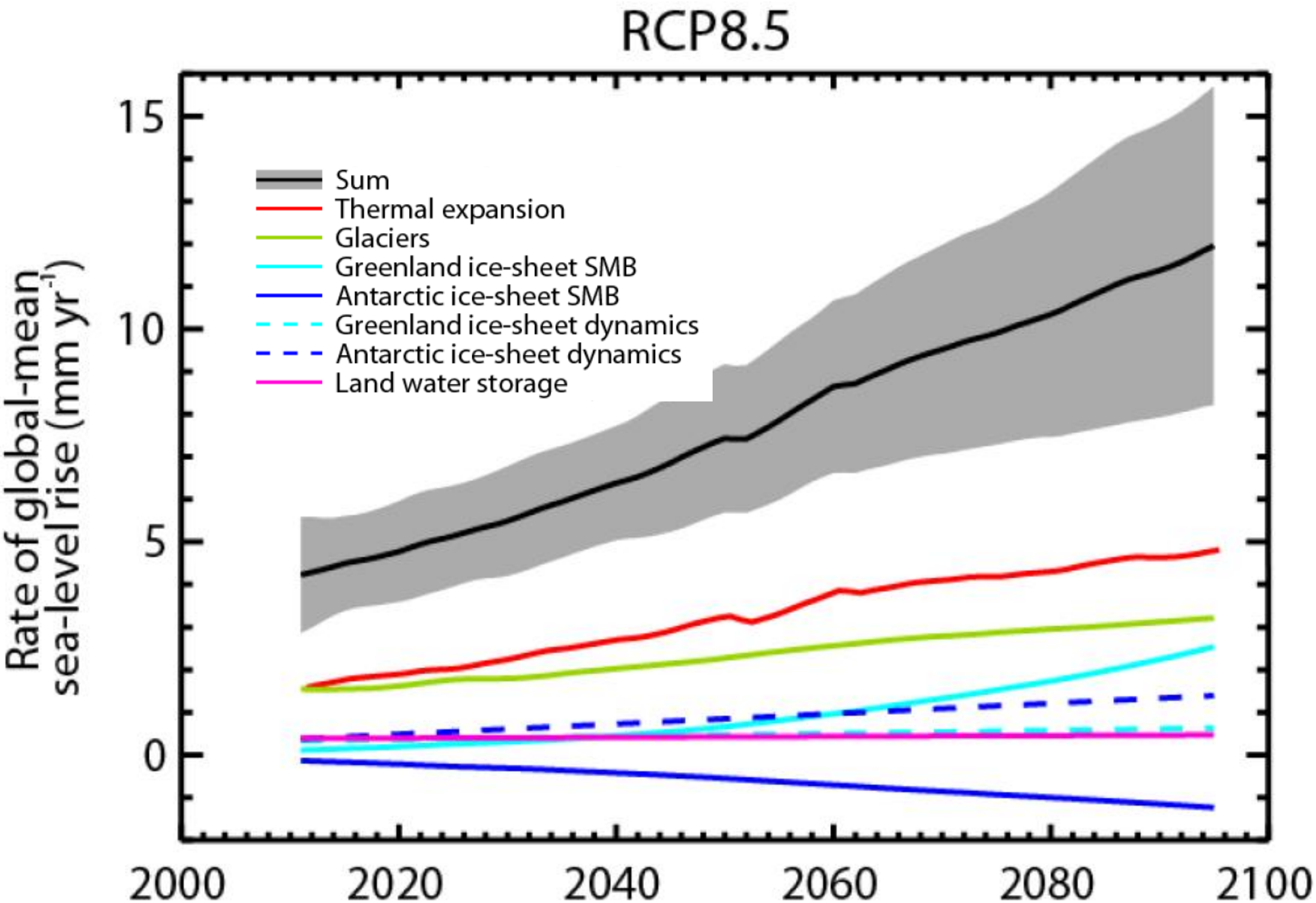
VERMEER & RAHMSTORF (2009) PROJECTIONS FROM 1990



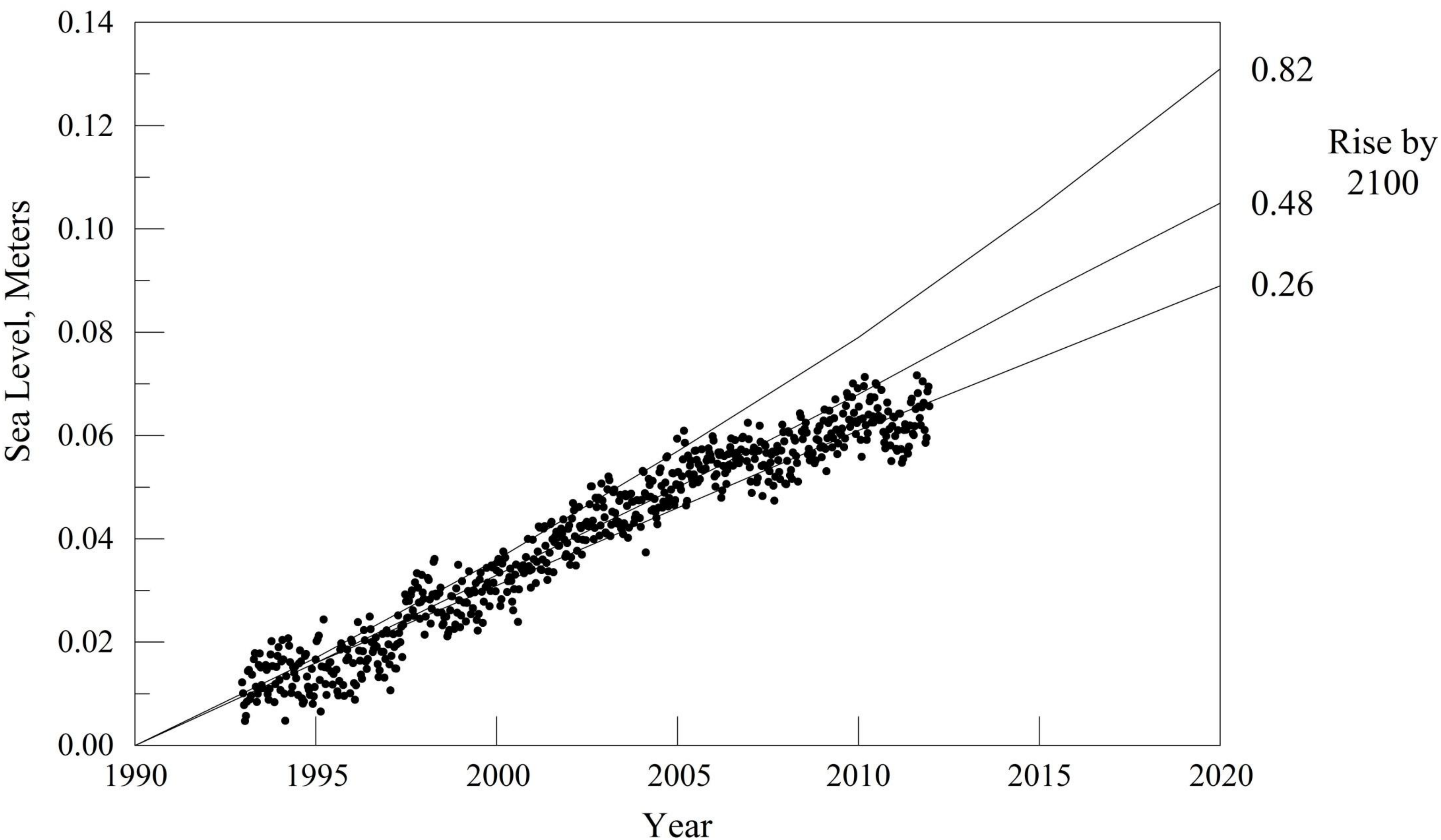
IPCC 5TH ASSESSMENT REPORT 2013



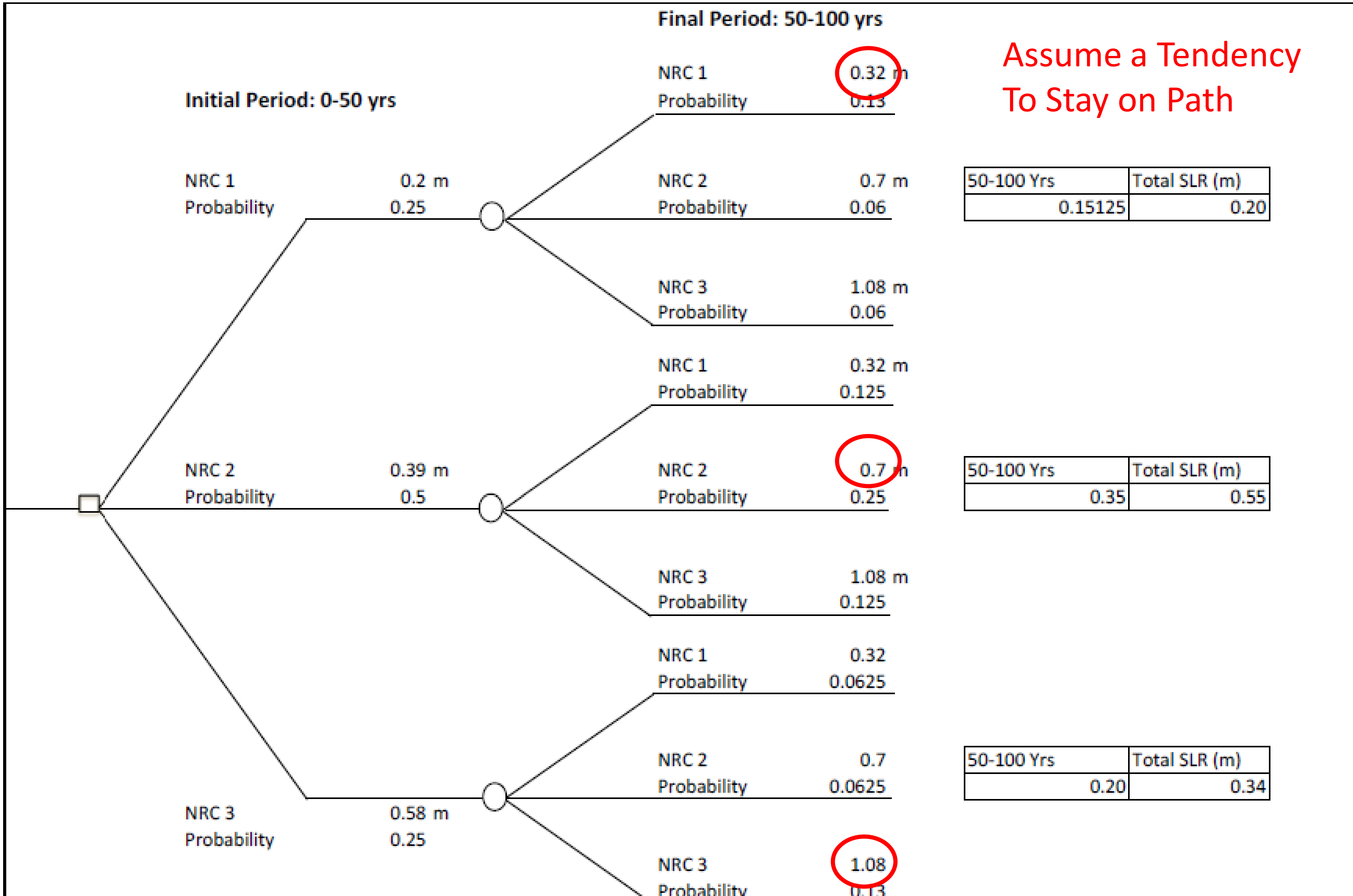
IPCC 5TH ASSESSMENT REPORT JUNE 2013



2013 IPPC PROJECTIONS FROM 1990



DECISION TREE ANALYSES

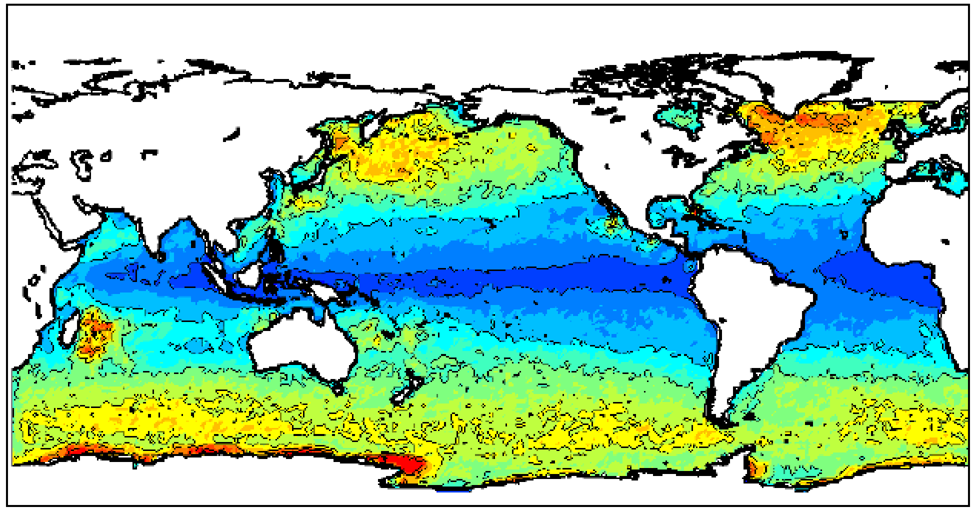


Assume a Tendency To Stay on Path

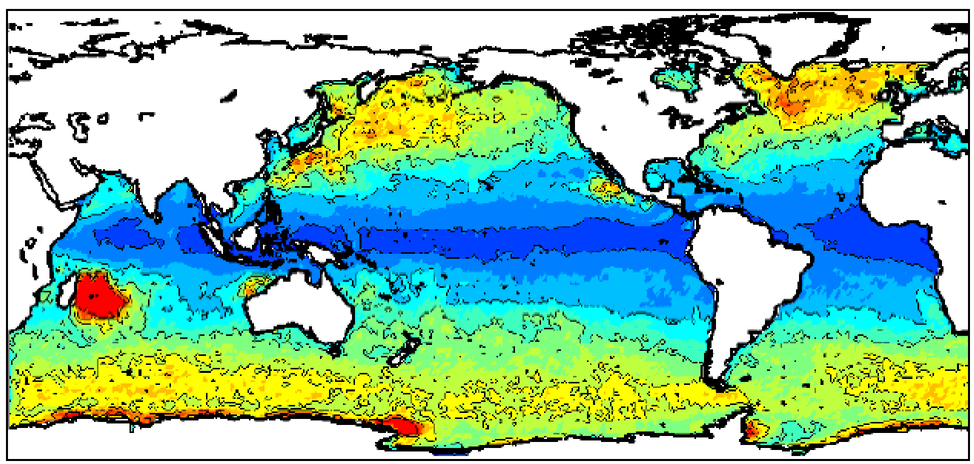
	0-50 Yrs (m)	50-100 Yrs (m)	Total SLR (m)
Initial Period Total	**0.39**		
Final Period Total		**0.70**	**1.09**

50 YEAR SIGNIFICANT WAVE HEIGHTS H_S (M)

Present

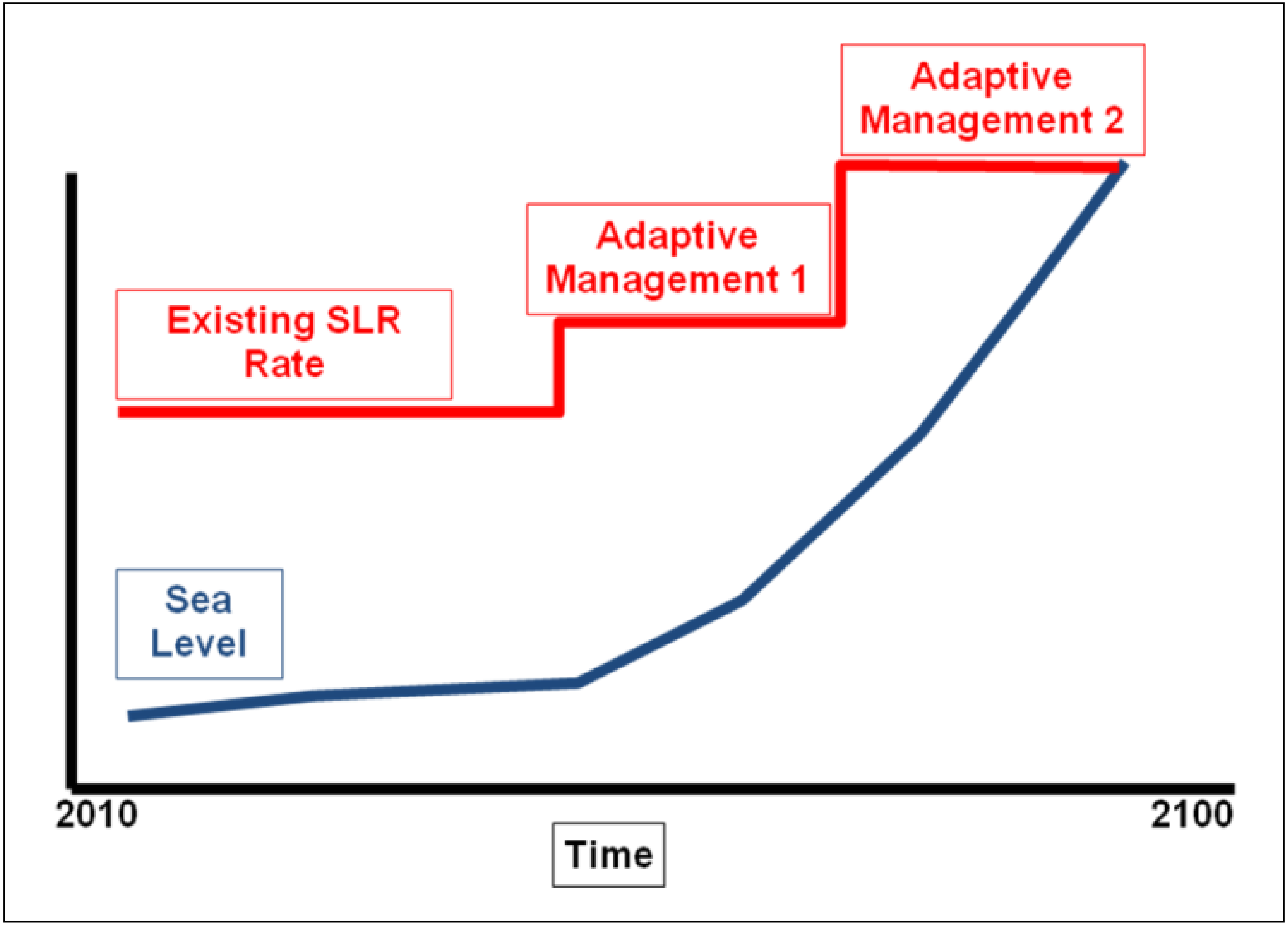


Future

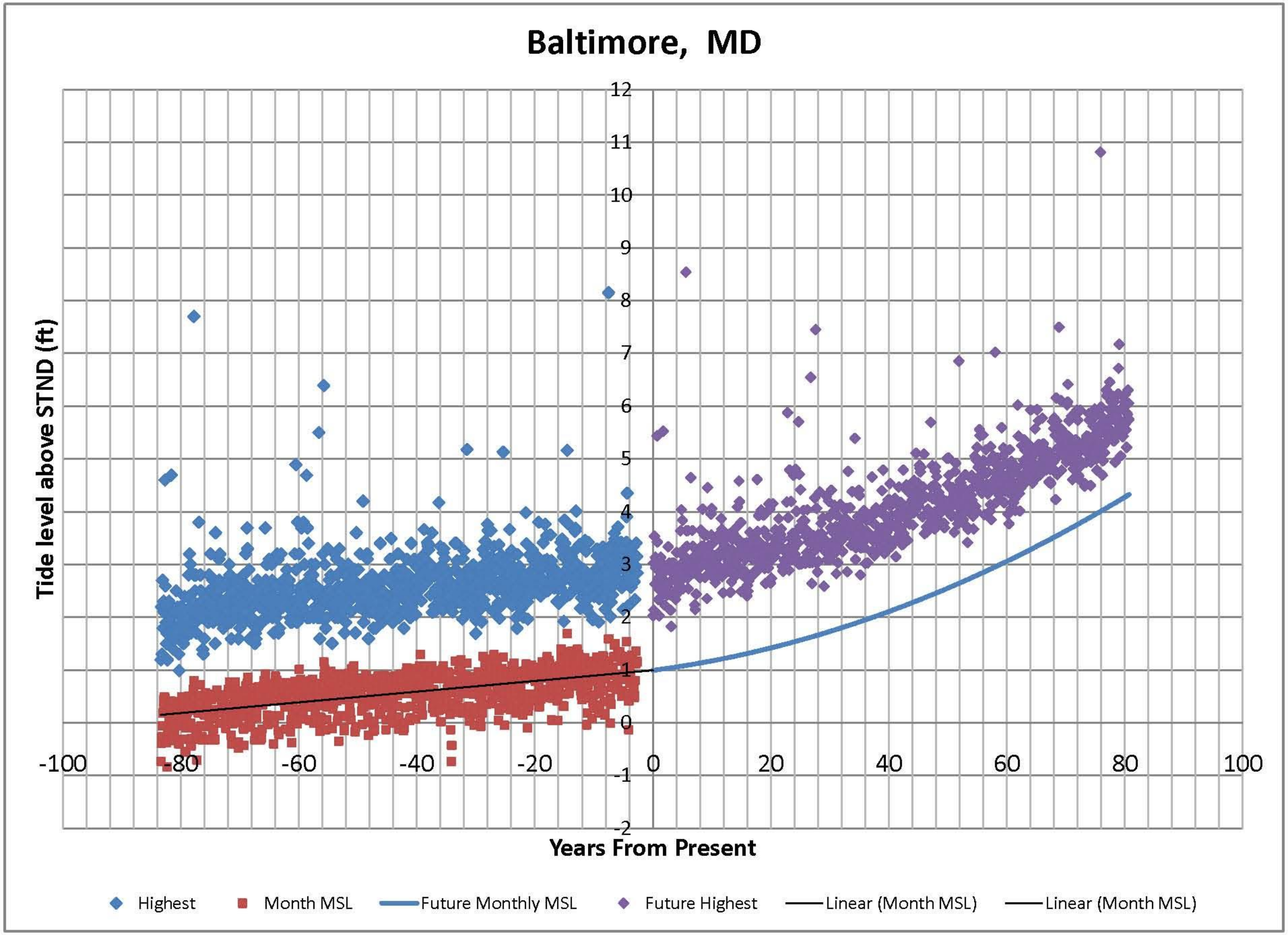


Mori Et al. “Projection of Future Wave Climate Change and Application of Coastal Structure Design”, ICE Coasts & Breakwaters, 2013

ADAPTIVE MANAGEMENT



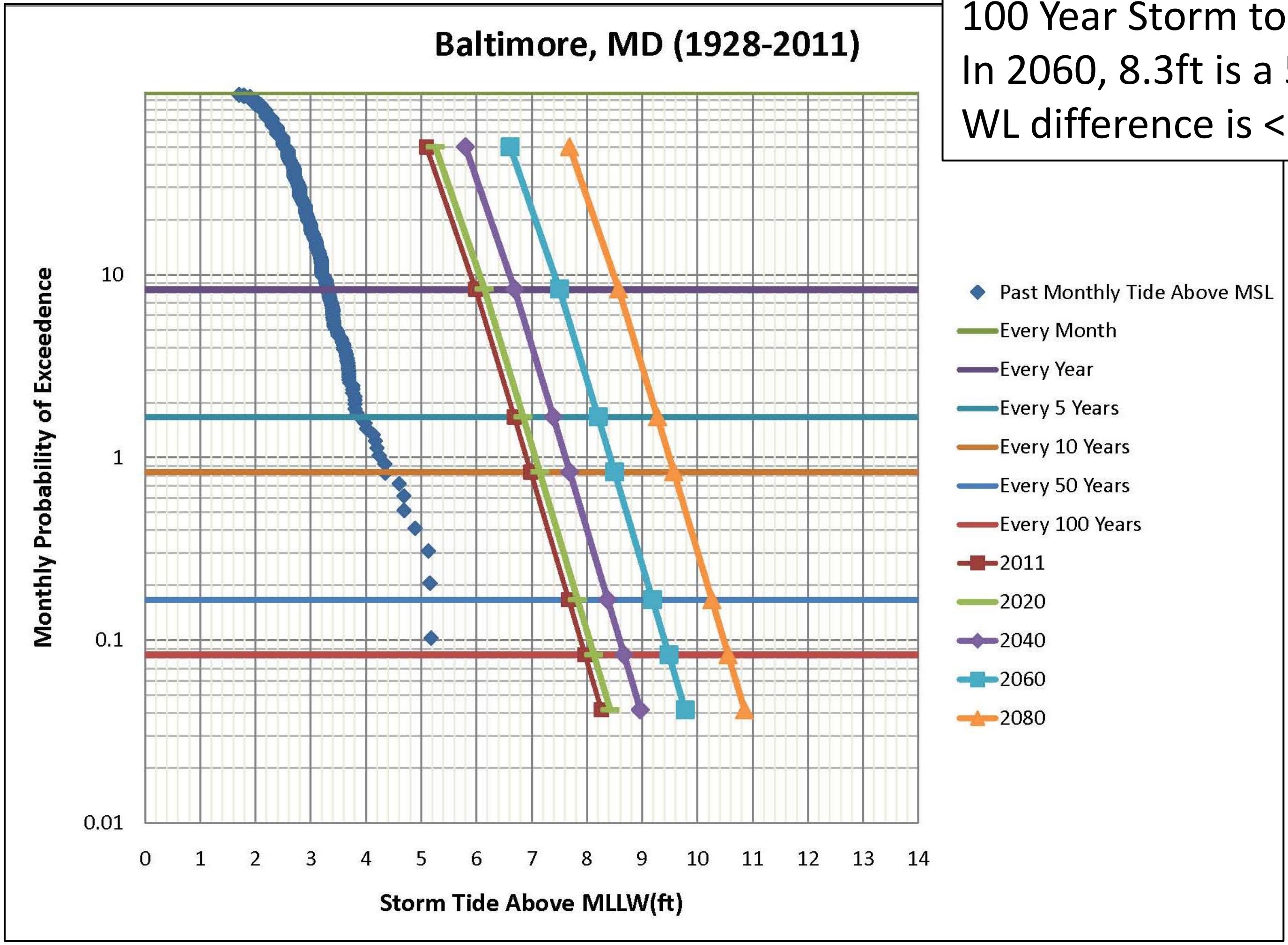
EAST COAST PORT EXAMPLE



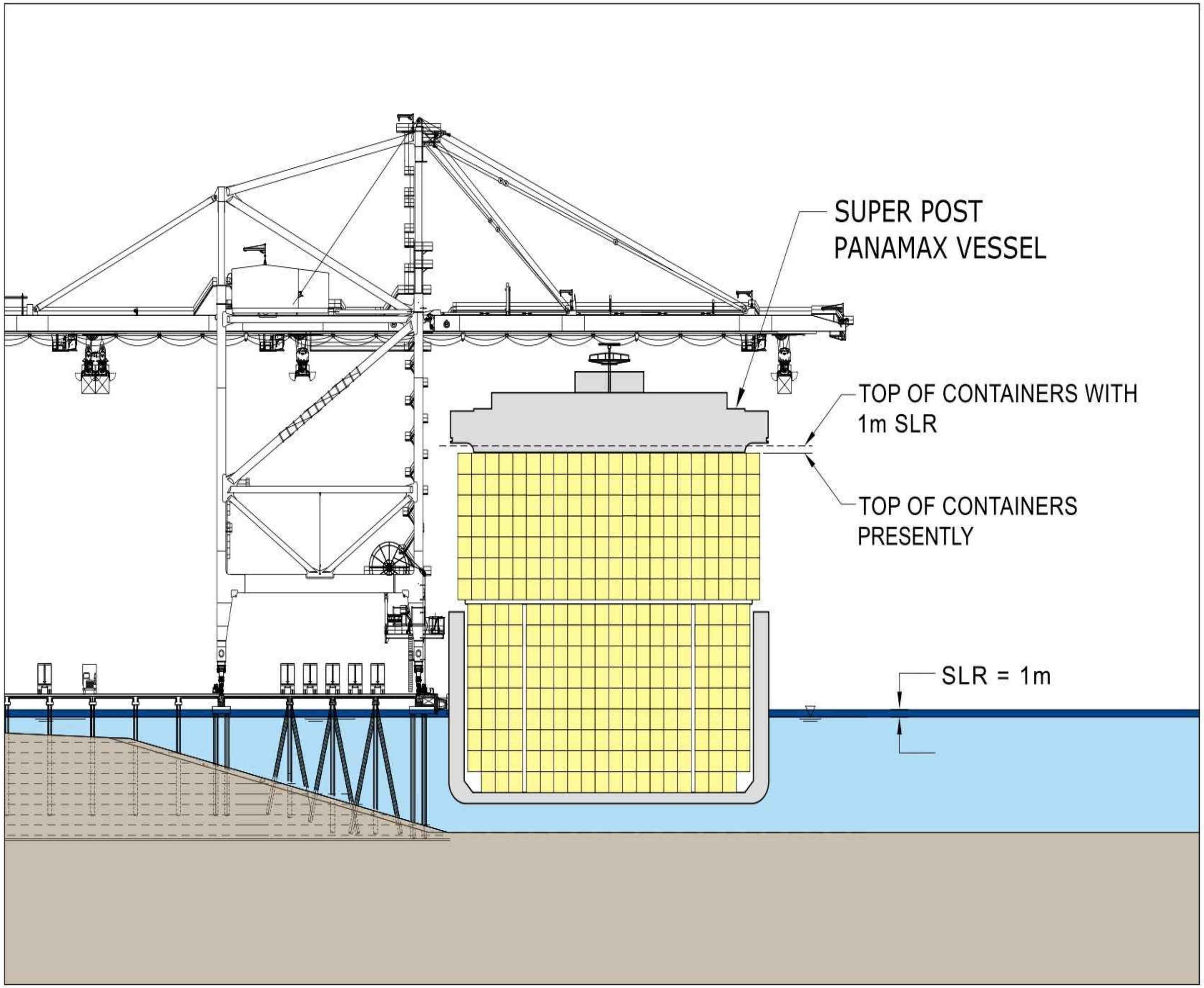
Baltimore, MD
Tide level above STND (ft)
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-100
-80
-60
-40
-20
0
20
40
60
80
100
Years From Present
Highest
Month MSL
Future Monthly MSL
Future Highest
Linear (Month MSL)
Linear (Month MSL)

FUTURE STORM TIDES

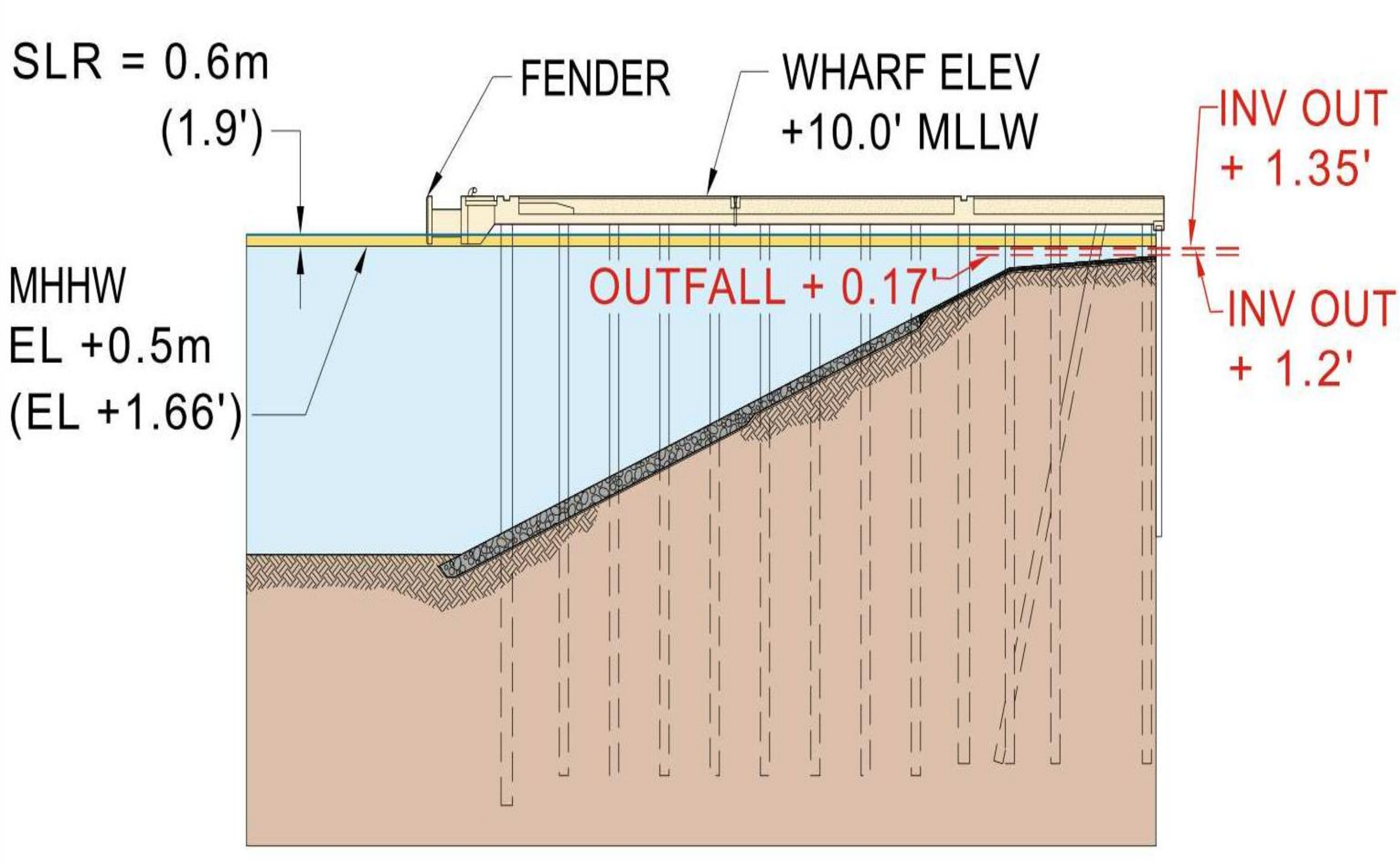
100 Year Storm today is 8.3 ft
In 2060, 8.3ft is a 5yr Storm
WL difference is <2'



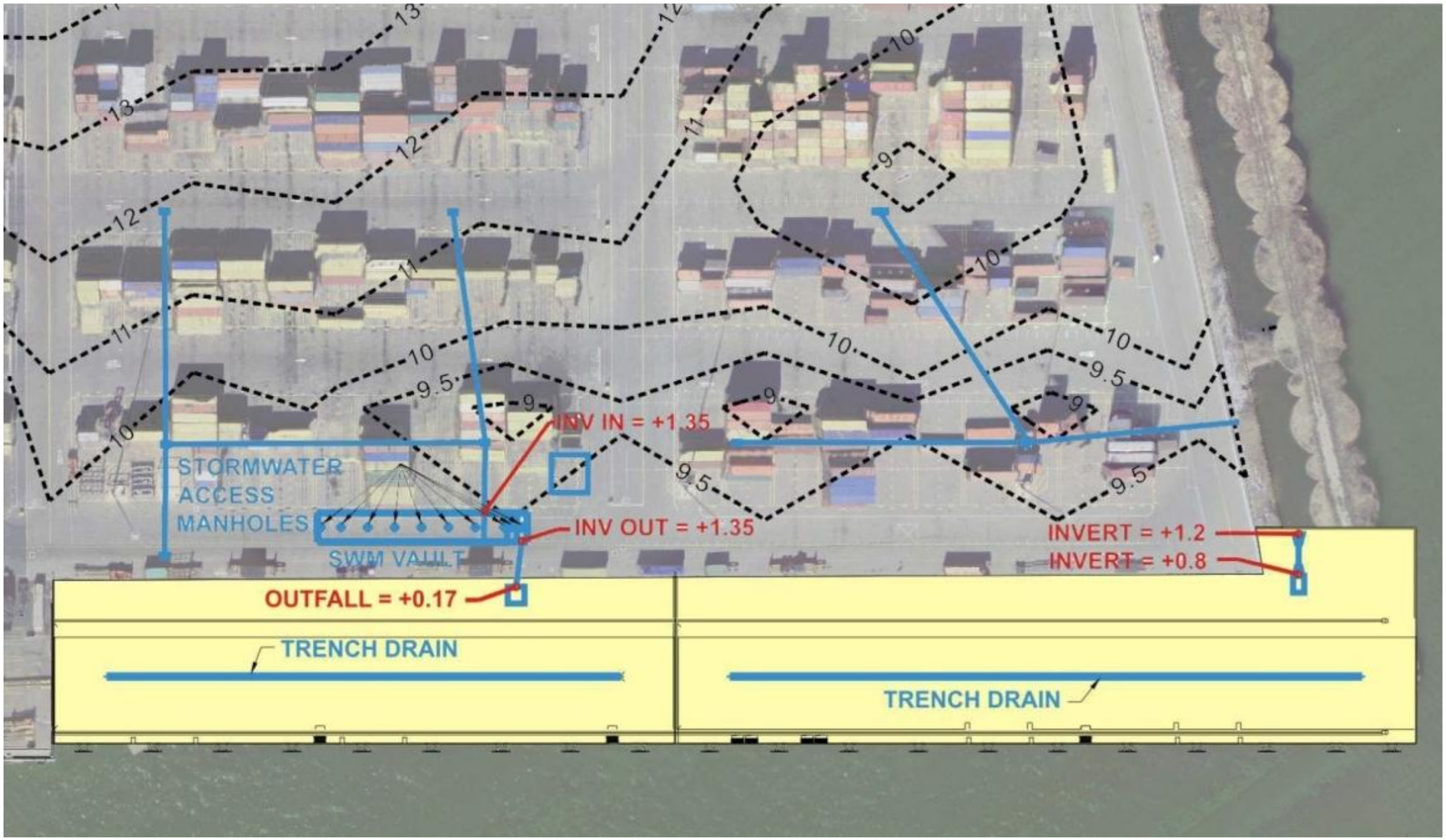
CONTAINER QUAY



POTENTIAL DRAINAGE SYSTEM IMPACTS



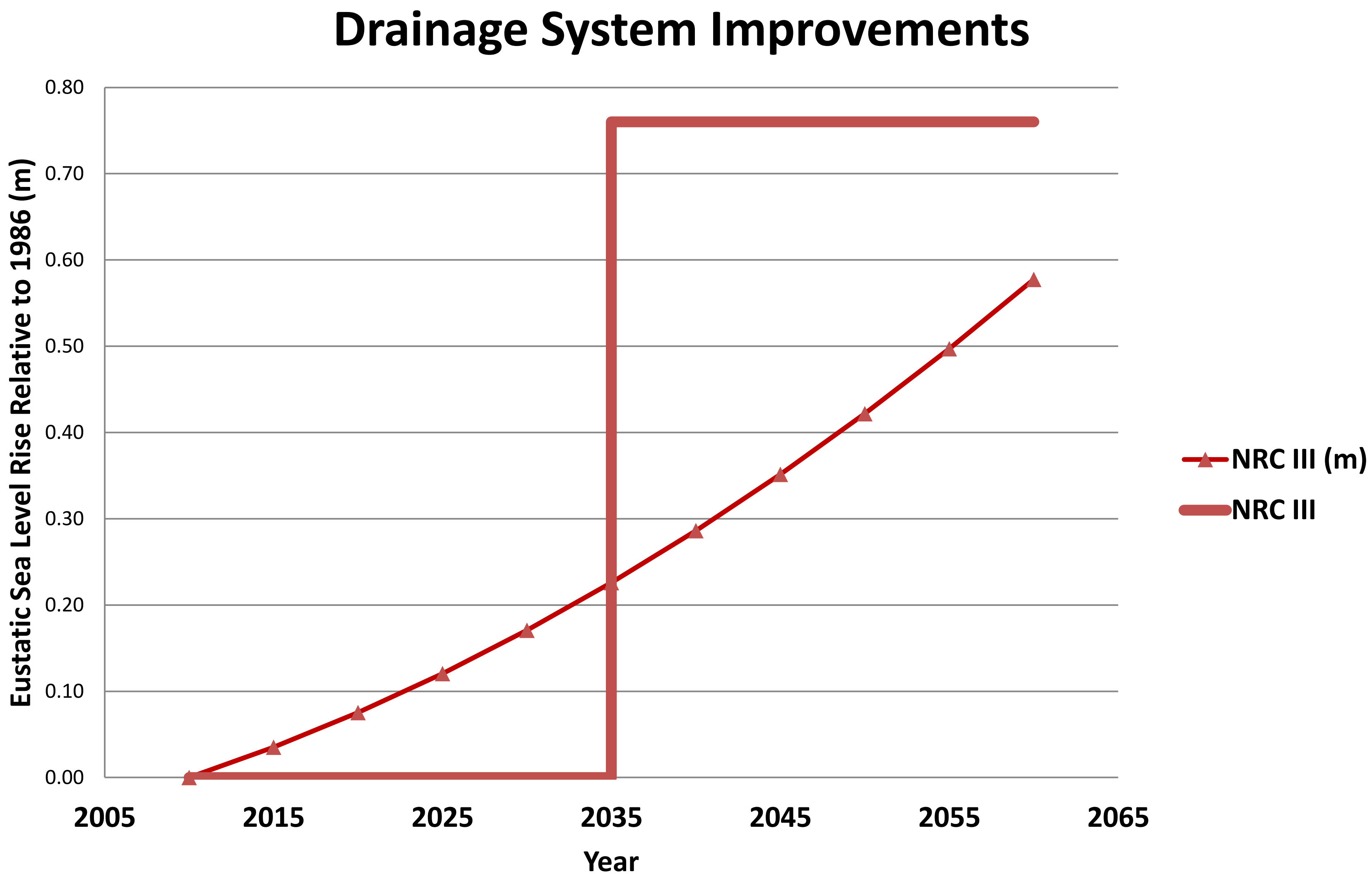
EXISTING DRAINAGE SYSTEM



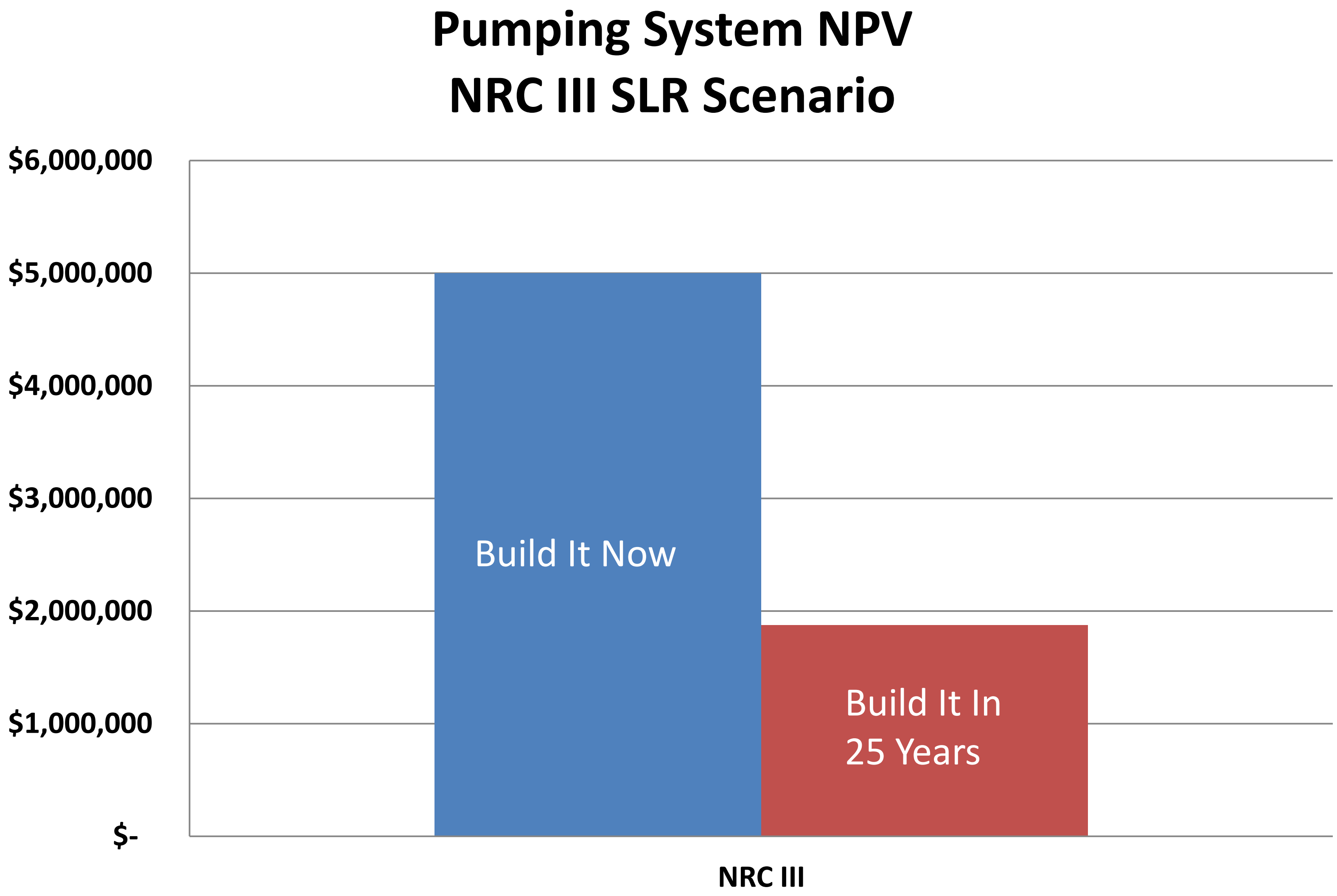
EXAMPLE APPROACH

- Drainage is the principle issue
- Drainage can be managed through re-grading the site and adding a pumping system
- For illustration purposes, an approximate cost of $5,000,000 is assigned to the a new pumping system

ADAPTIVE MANAGEMENT PLAN



SUMMARY ADAPTIVE MANAGEMENT



POTENTIAL IMPACT TO PORTS

- Increased flooding (related power loss)
- Weather changes effecting shipping and cargo movement operations
- Pressure on drainage systems
- Increased water demands
- Increased temperature (buildings, pavement, equipment)
- Changes in sedimentation
- Marine structures systems (fendering, air draft)

RISK QUANTIFICATION

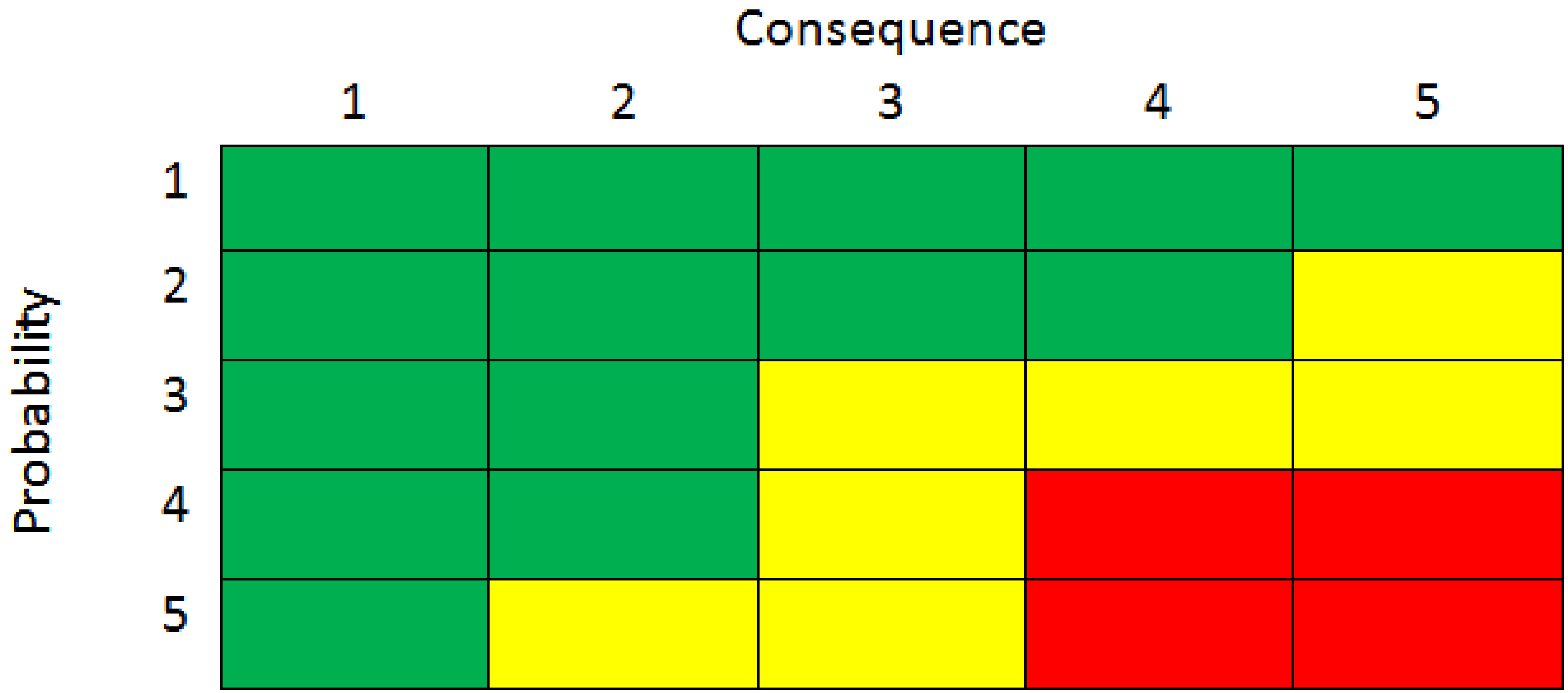


Figure 1: Risk Quantification Scale (1: Insignificant, 5: Extreme)

Sea Level Rise

Variable	Cause	Effect	Probability	Consequence	Total Risk	Mitigation or adaptive measures to counter risk
Rising sea and storm surge levels	Flooding	Port Disruption Potential damage & maintenance	3	3		Adapt wharves, fender and drainage systems as necessary
Rising sea and storm surge levels	Utility flooding loss of power	Port Disruption	3	5		SOP for power outages or failures. Provide generators for sensitive cargo
Rising sea and storm surge levels	Loss of airdraft	Potential damage to vessels and port infrastructure. Port disruption	2	5		Evaluate required clearances for vessel traffic SLR. Adapt vessel calling drafts, port and/or regional infrastructure

Changes to Wind Climate and Patterns

Variable	Cause	Effect	Probability	Consequence	Total Risk	Mitigation or adaptive measures to counter risk
Increased winds and/or extreme weather	Loss of power	Port Disruption	2	4		SOP for power outages including generators
Increased winds and/or extreme weather	Loss of water supply	Port Disruption Potential health or safety impacts	1	4		SOP for power outages or failures
Increased winds and/or extreme weather	Staff cannot reach site	Port Inefficiency or Downtime	1	5		SOP for alternative access to port
Increased winds and/or extreme weather	Structure Damage; Stacked containers blowing over	Port Disruption Damage Costs	2	3		Consider for future port design and operations
Increased winds and/or extreme weather	Crane downtime	Port Disruption	3	3		Port automation
Increased winds and/or extreme weather	Reduction to visibility from wind blown dust or dry bulk cargo	Safety Risk Potential cargo loss.	1	2		Consider for future port design and operations

Changes in precipitation

Variable	Cause	Effect	Probability	Consequence	Total Risk	Mitigation or adaptive measures to counter risk
Increased & Intensified Rainfall	Utility flooding loss of power	Port Disruption	1	5		SOP for power outages including generators
Increased & Intensified Rainfall	Road/rail flooding	Port Disruption	1	5		SOP access alternatives
Increased & Intensified Rainfall	Port closure from rainfall flooding	Port Disruption	2	5		SOP for Flooding
Increased & Intensified Rainfall	Moisture sensitive cargo damage	Port Disruption	2	2		SOP for moisture sensitive cargo
Increased & Intensified Rainfall	Accidents from slippery surfaces	Port Disruption Health/safety issues	2	3		
Increased & Intensified Rainfall	Drainage/sewer systems overload	Port Disruption	5	1		Adapt drainage and sewage systems
Increased & Intensified Rainfall	Land subsidence from longer wet seasons	Possible structural damage	1	1		Monitor subsidence and adapt
Extended periods of less rainfall	Decreased river stages and water depths	Port Disruptions	1	4		Monitor

Increased Temperatures

Variable	Cause	Effect	Probability	Consequence	Total Risk	Mitigation or adaptive measures to counter risk
Elevated temperatures	Overheating of infrastructure, equipment , & refrigerated containers	Productivity loss damage to cargo and/or equipment	3	1		Monitor and regulate port temperatures
Elevated temperatures	Increased water demand/water shortages	Increased operational costs	3	2		Improve energy efficiency
Elevated temperatures	Increased power demand and disruption	Increased operational costs and possible downtime	3	5		SOP to respond to power outages & failures. Provide Emergency generators
Elevated temperatures	Damage to pavement from excessive temperature or drying	Port Disruption and increased pavement maintenance costs	2	1		Evaluate pavement and adapt as necessary
Elevated temperatures	Increased pest activity around organic cargos	Cargo Damage	2	2		SOP for pest control

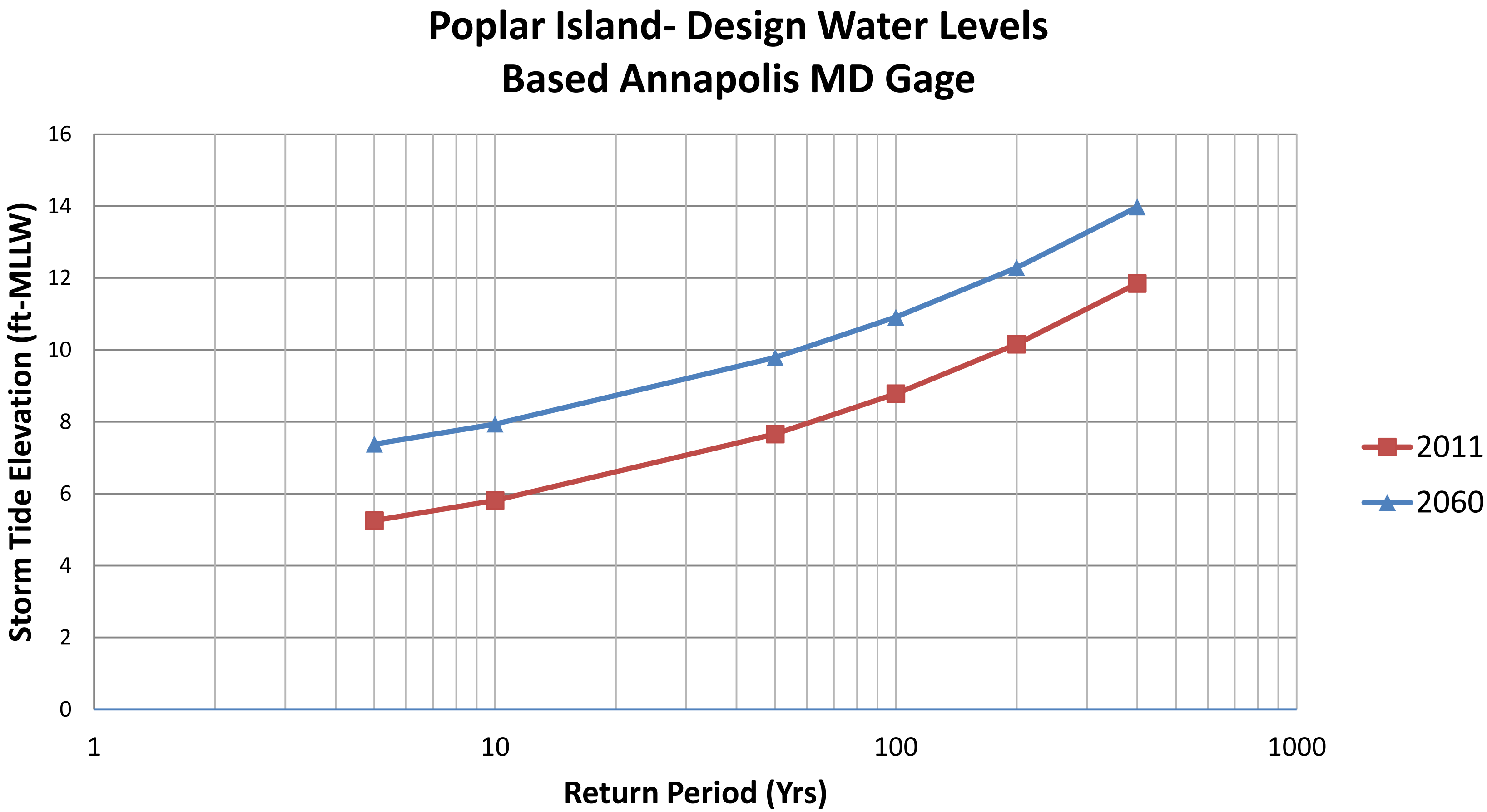
General changes

Variable	Cause	Effect	Probability	Consequence	Total Risk	Mitigation or adaptive measures to counter risk
General climate change	Potential Changes to existing supply chain logistics and cargo routes	Potential Changes in Cargo Volume	2	3		Monitor supply chain trends. Adapt where necessary/possible
General climate change	Potential rising costs of fossil fuels owing to emission allowances	Increase in operational costs	5	2		Phase in operations to reduce the use of fossil fuels.
General climate change	Changes in climate change regulations to curb green house gas emissions	Potential higher maintenance and operational costs	5	3		Take a pro-active management approach to climate change adaptation

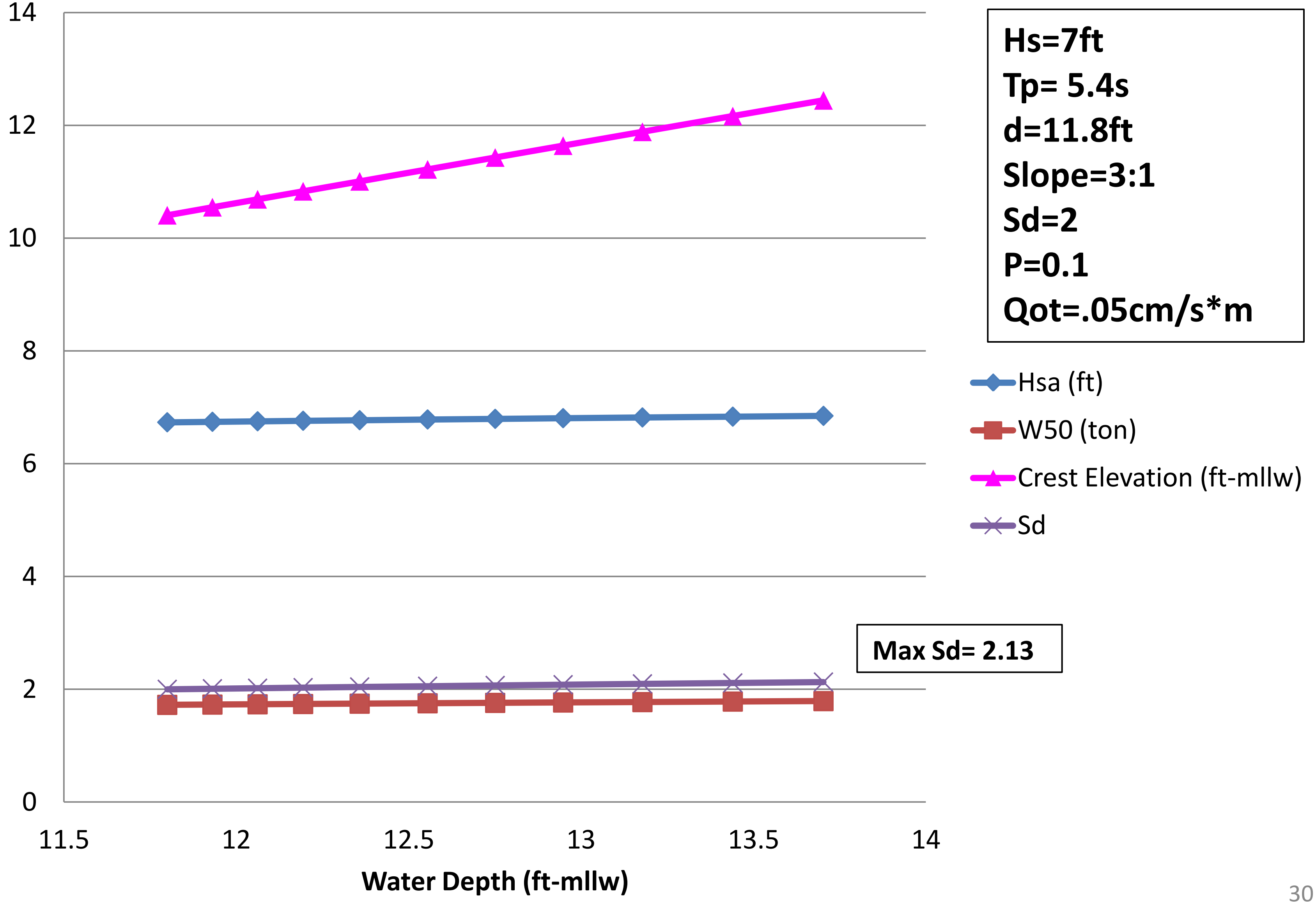
US EAST COAST
COASTAL STRUCTURE EXAMPLE

POPLAR ISLAND

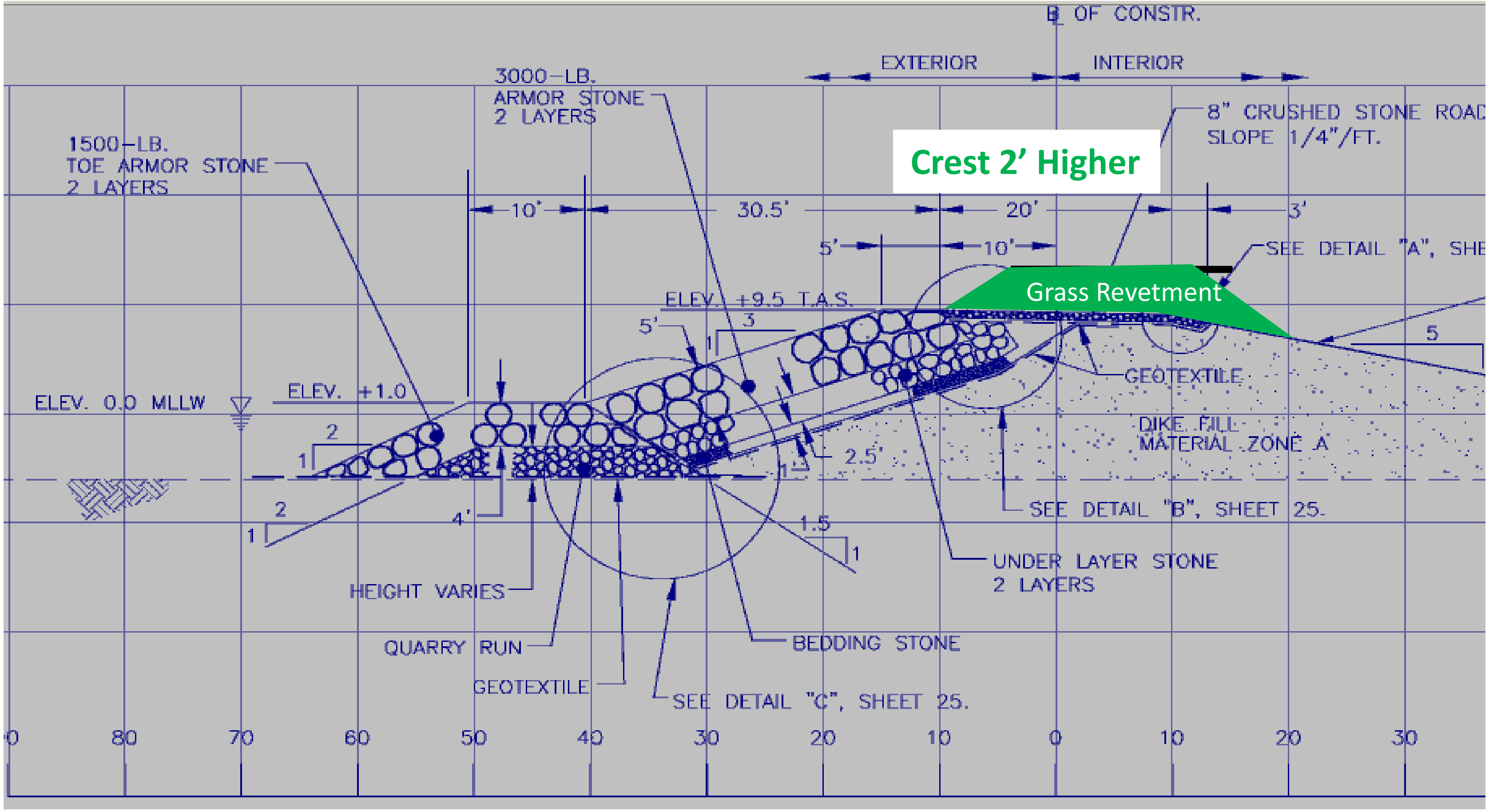
FUTURE STORM TIDES



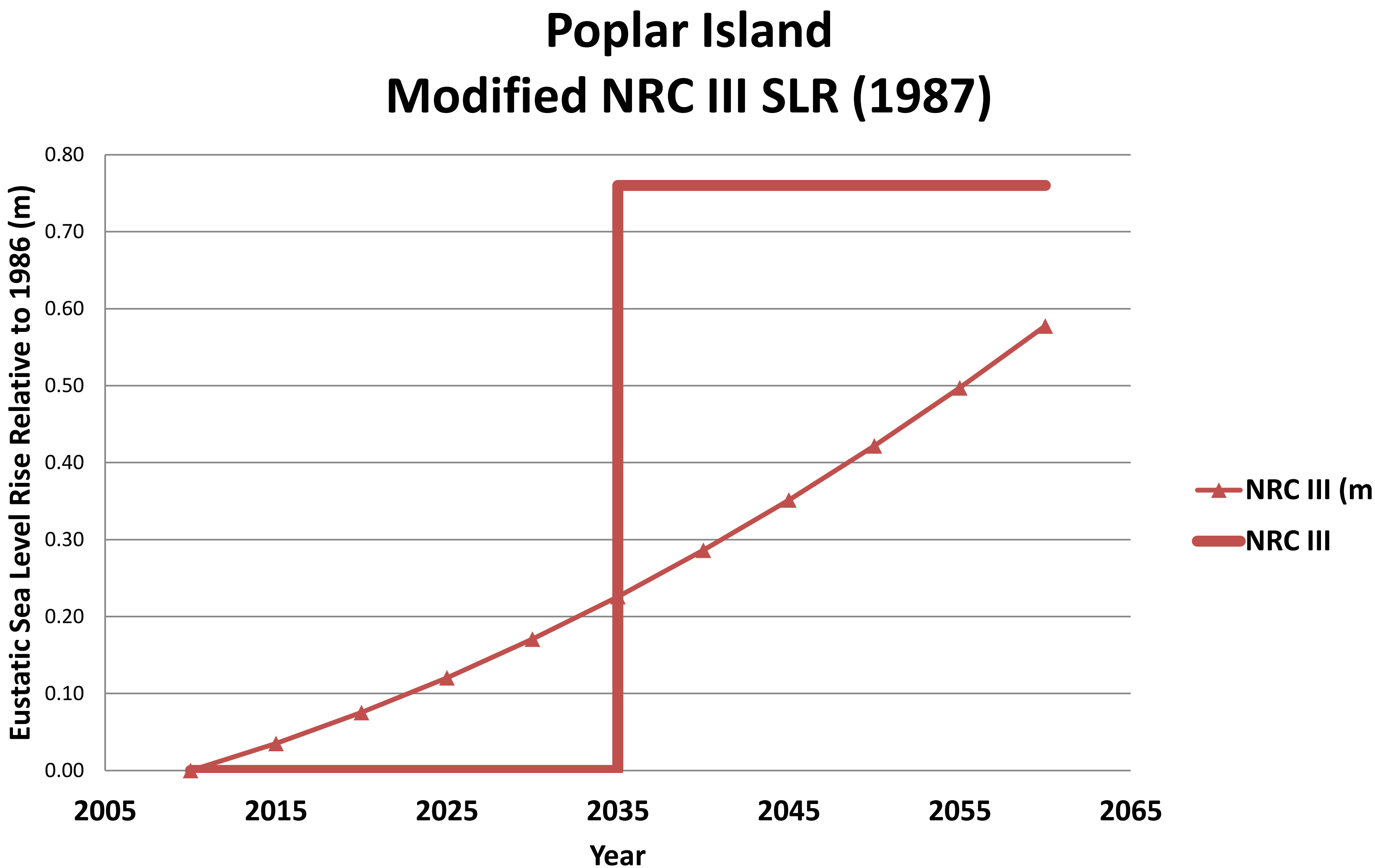
POPLAR ISLAND EXAMPLE



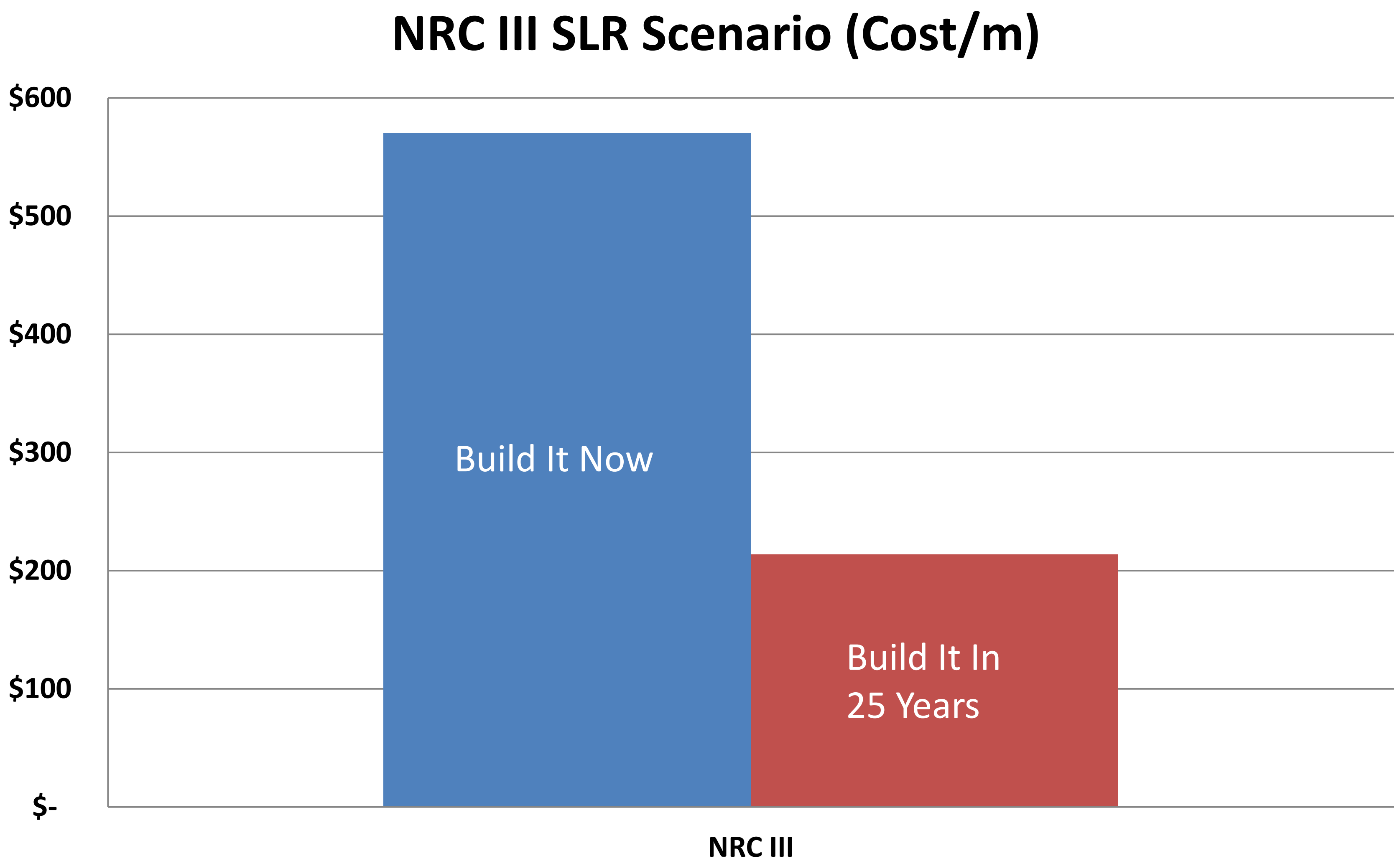
GRASS REVETMENT AT CREST



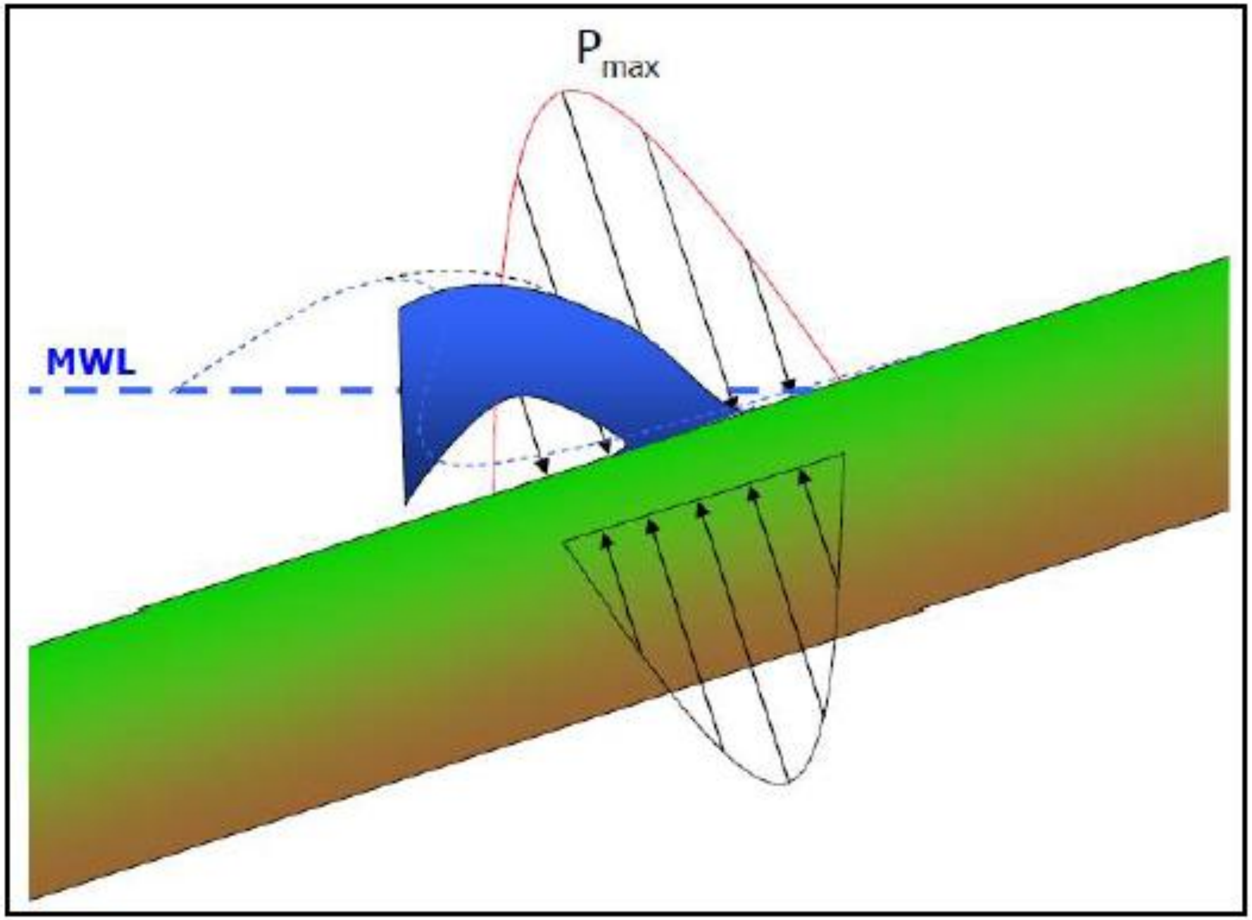
ADAPTIVE MANAGEMENT PLAN



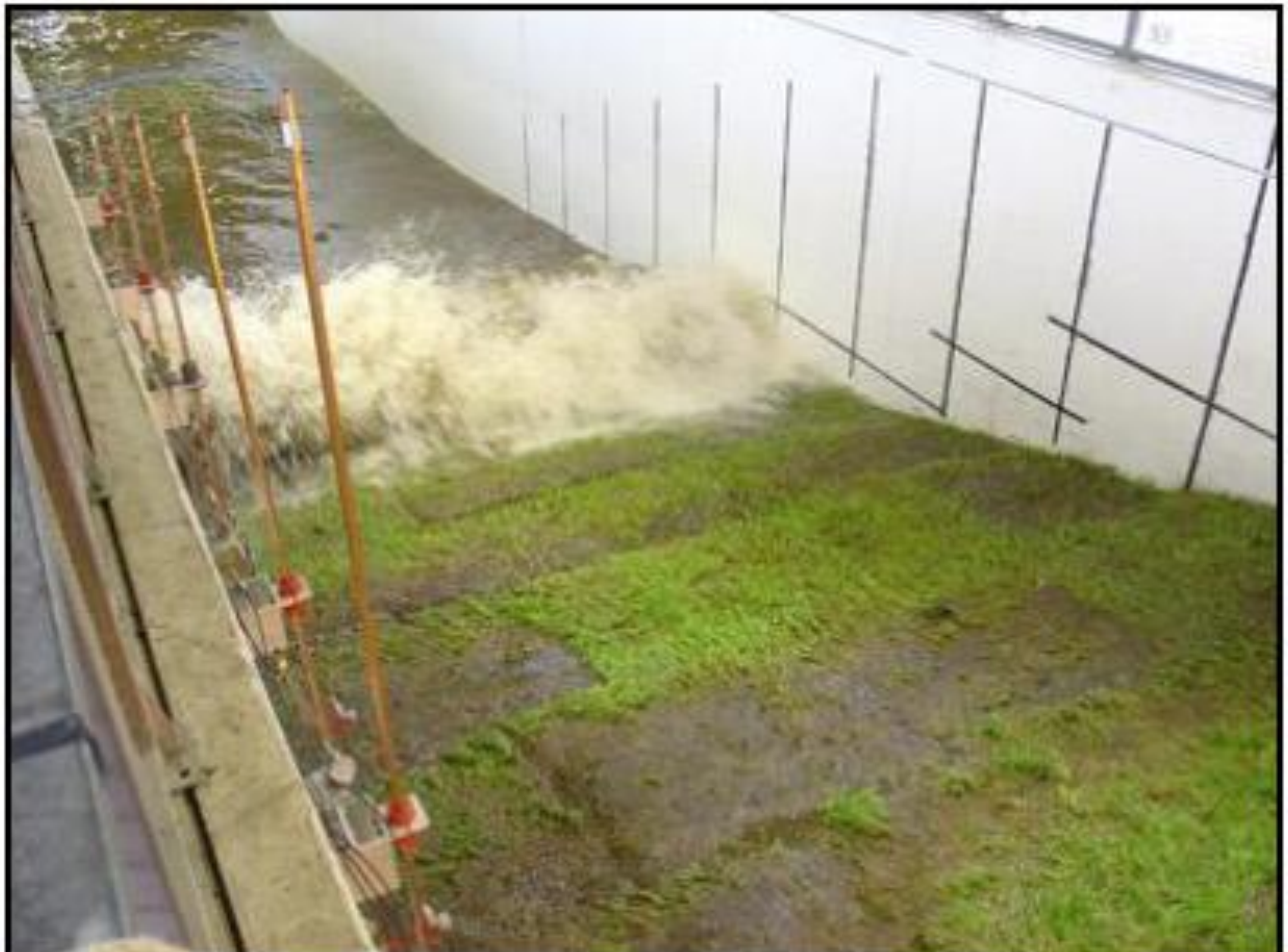
ADAPTIVE MANAGEMENT SUMMARY (NPV)



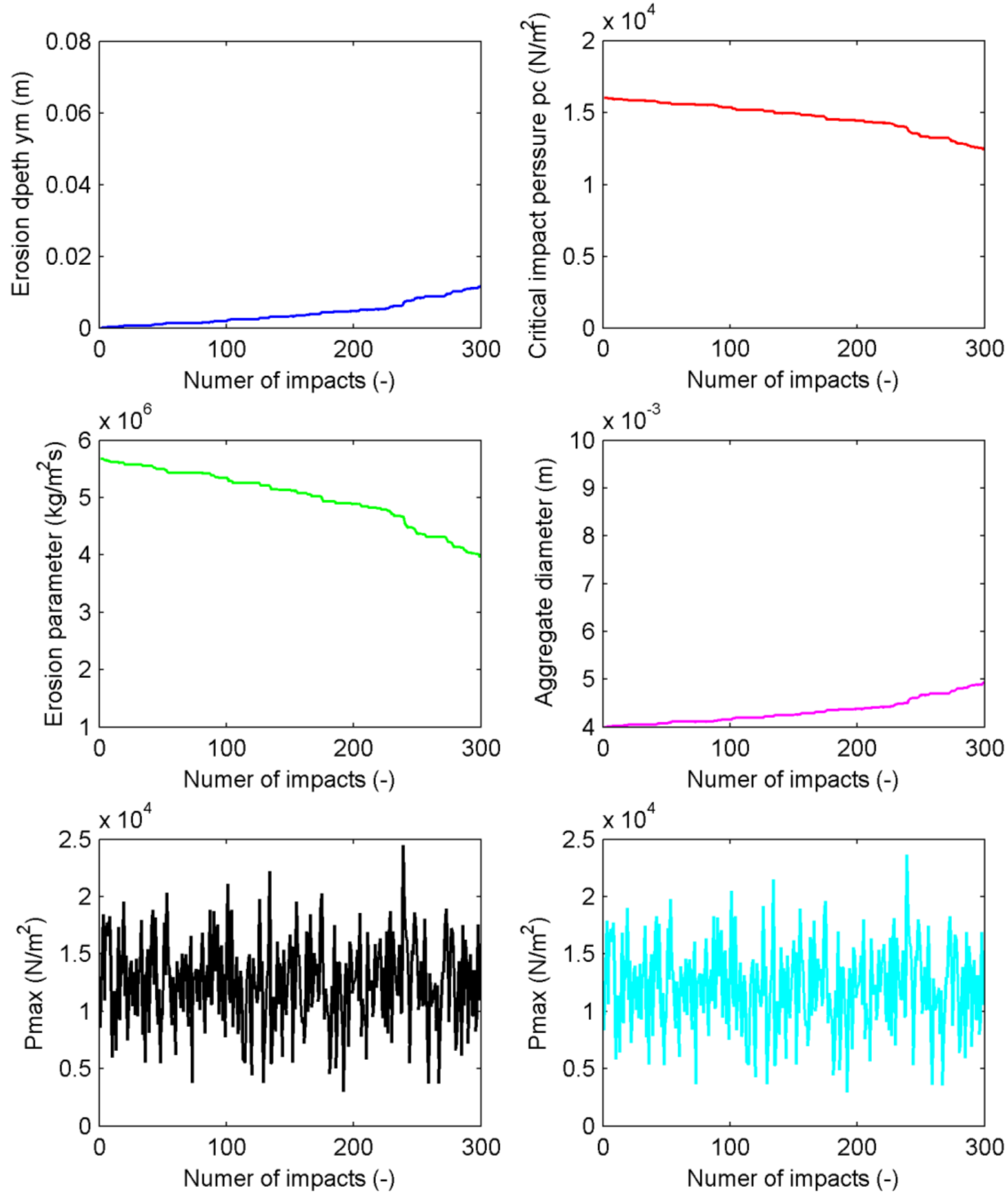
WAVE IMPACT PRESSURES



FULL SCALE TESTS

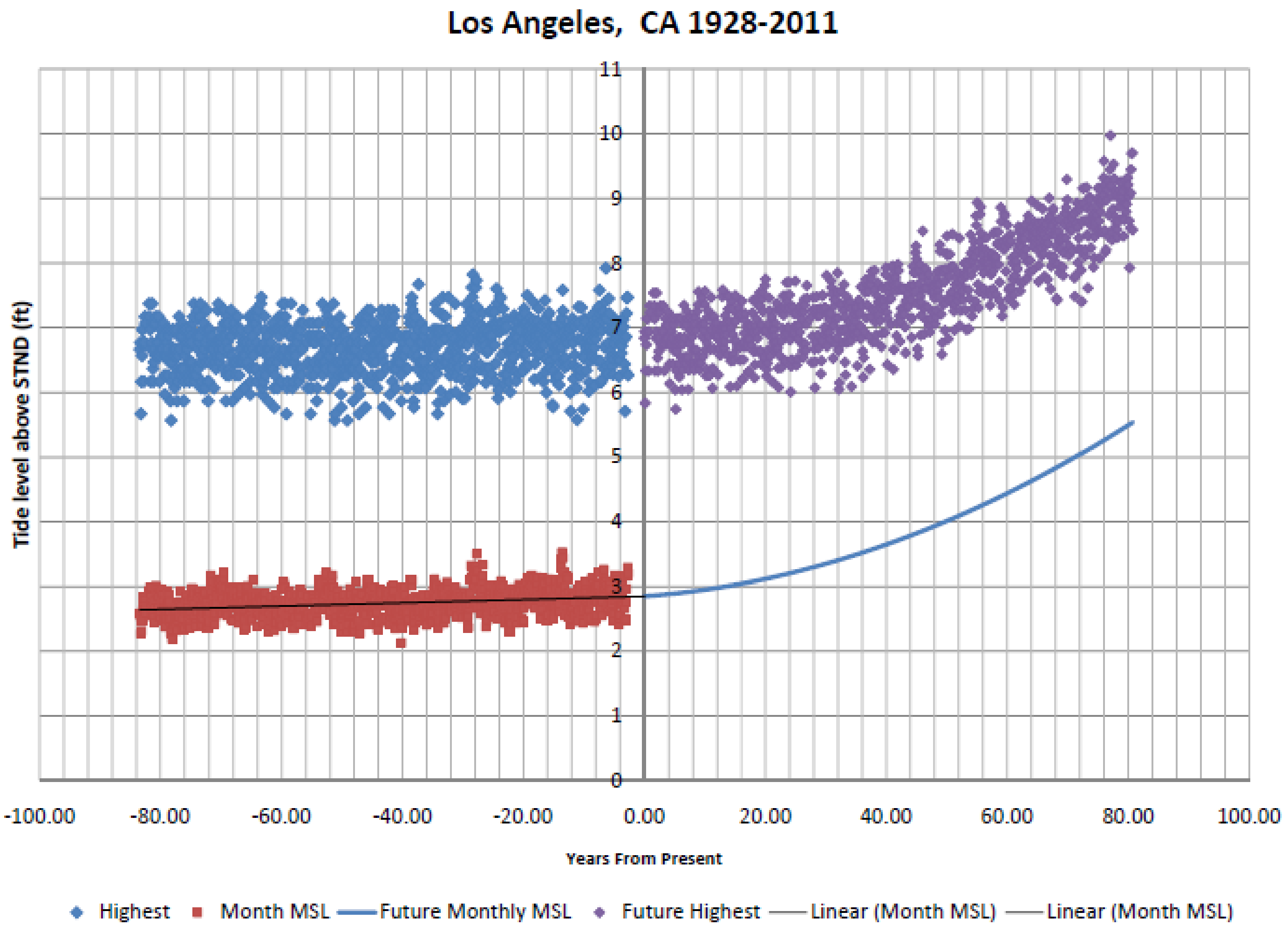


GRASS REVETMENT MODEL RESULTS



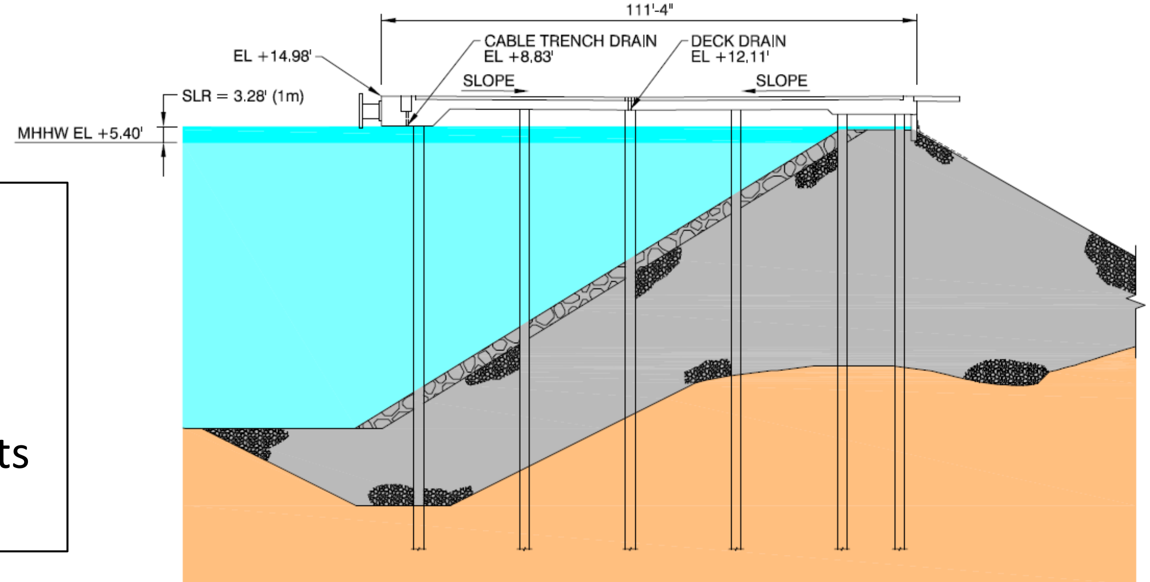
WEST COAST
PORT/COASTAL STRUCTURE EXAMPLE

LOS ANGELES FUTURE TIDES

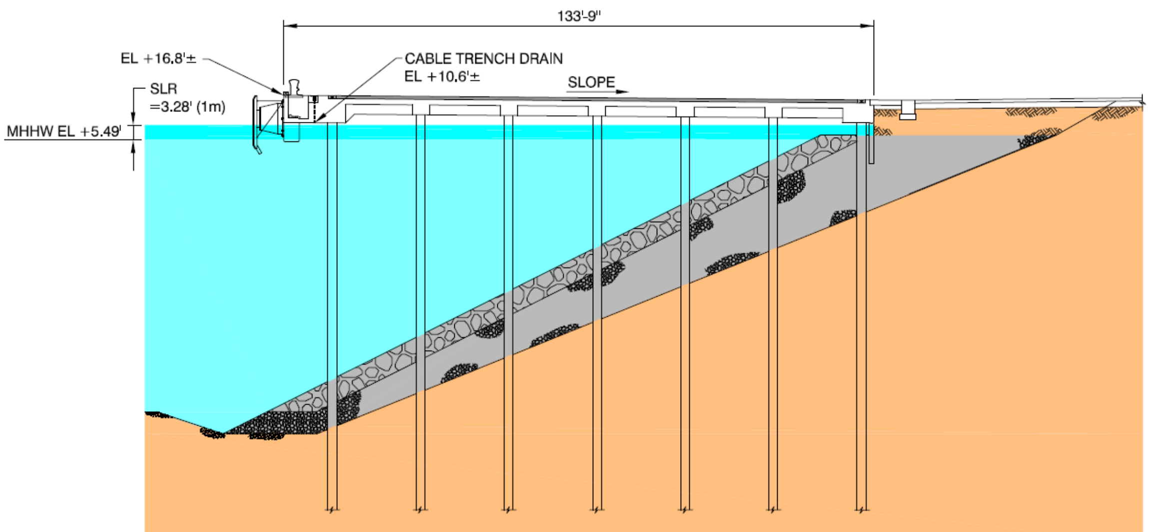


Southern California Container Wharves

These structures will likely be replaced in the next 50 years. If SLR accelerates Adaptation of fender systems and supporting structural elements would be necessary

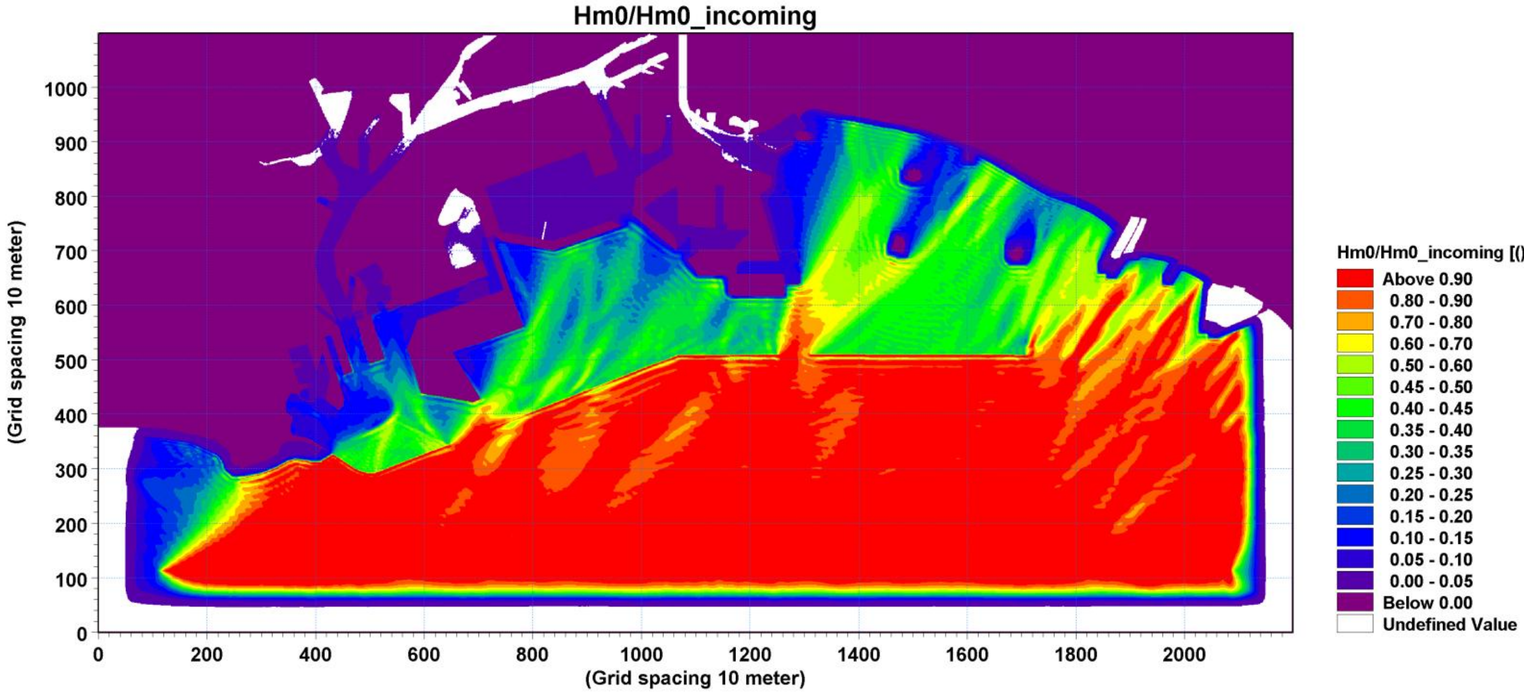


POLA WHARF SECTION
SCALE: 1/8"=1'-0"

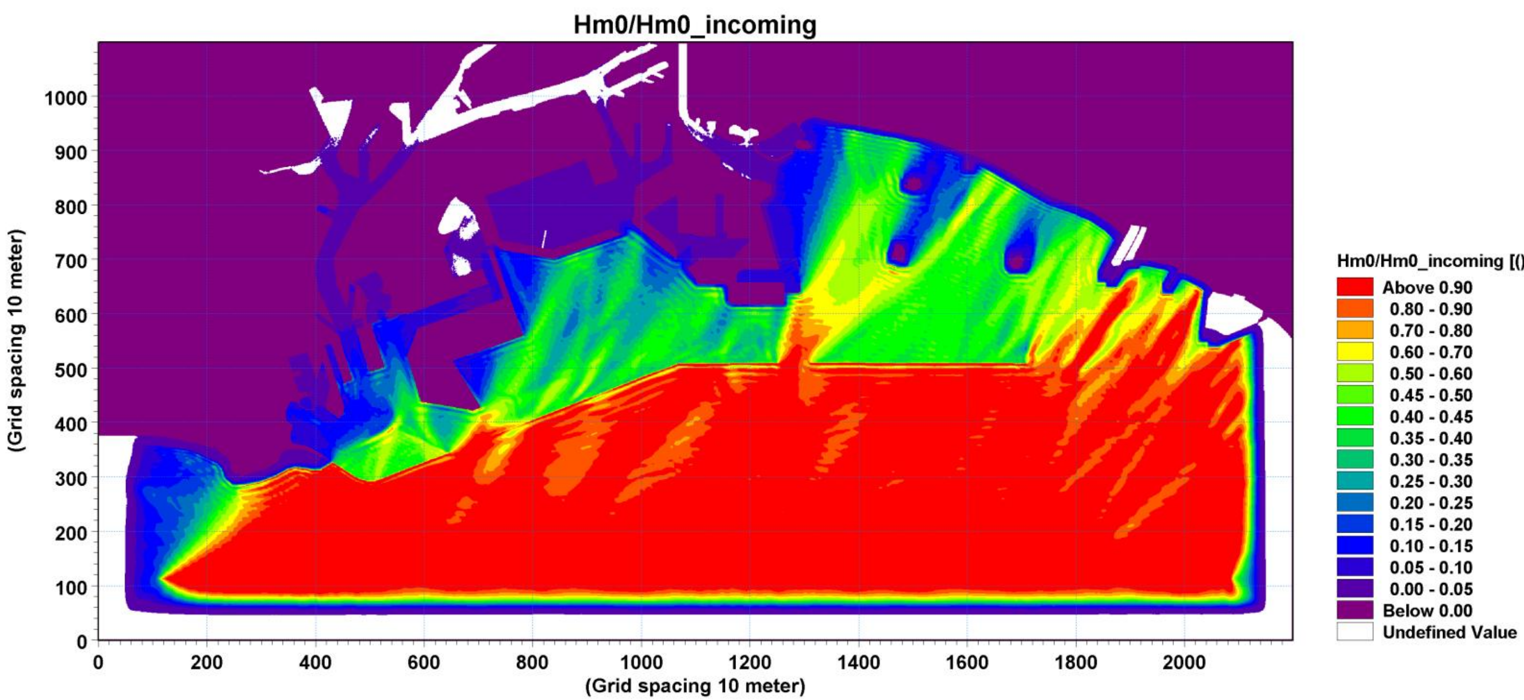


POLB WHARF SECTION
SCALE: 1/8"=1'-0"

Hs=3m
Tp=18 s



1m SLR



PIER 400 ROCK DIKE

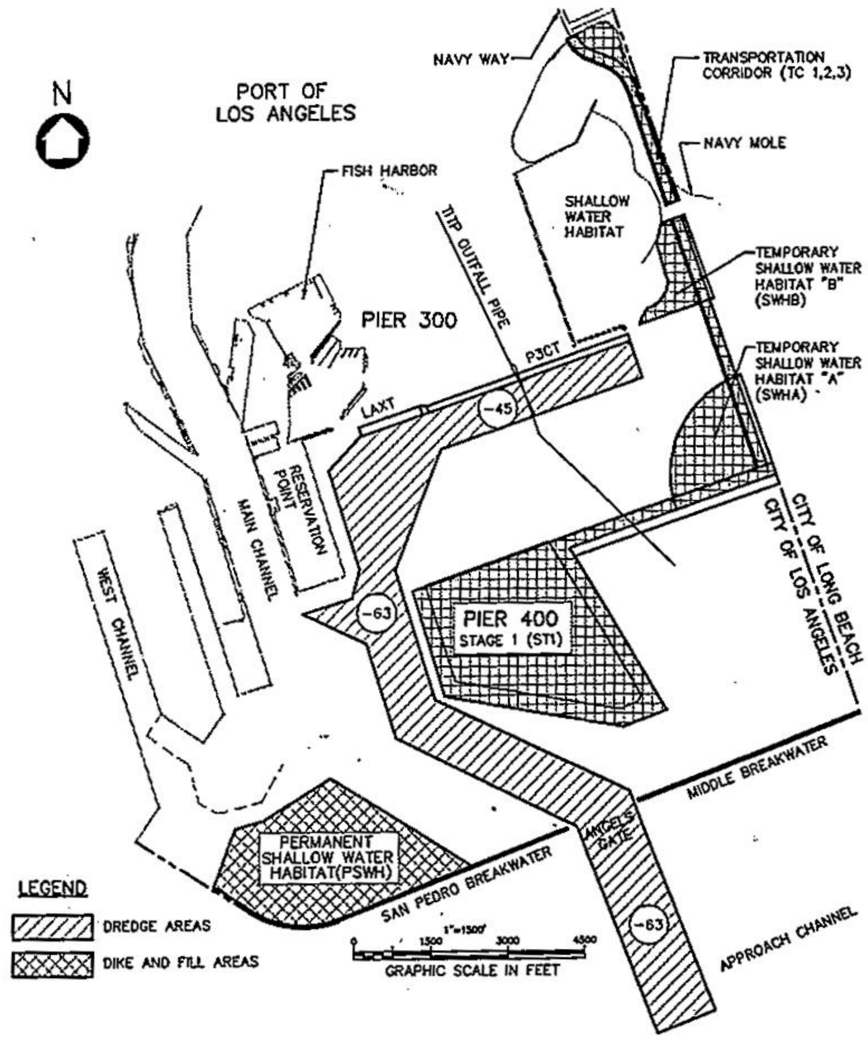


FIGURE 1. PIER 400 PROJECT PLAN

WAVES AT PIER 400

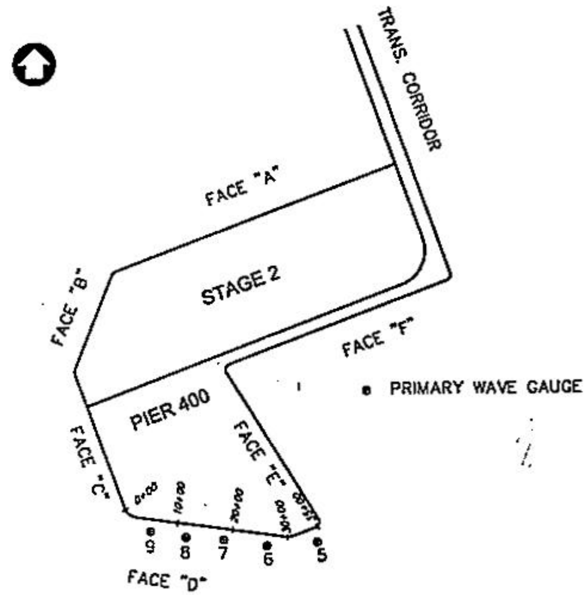


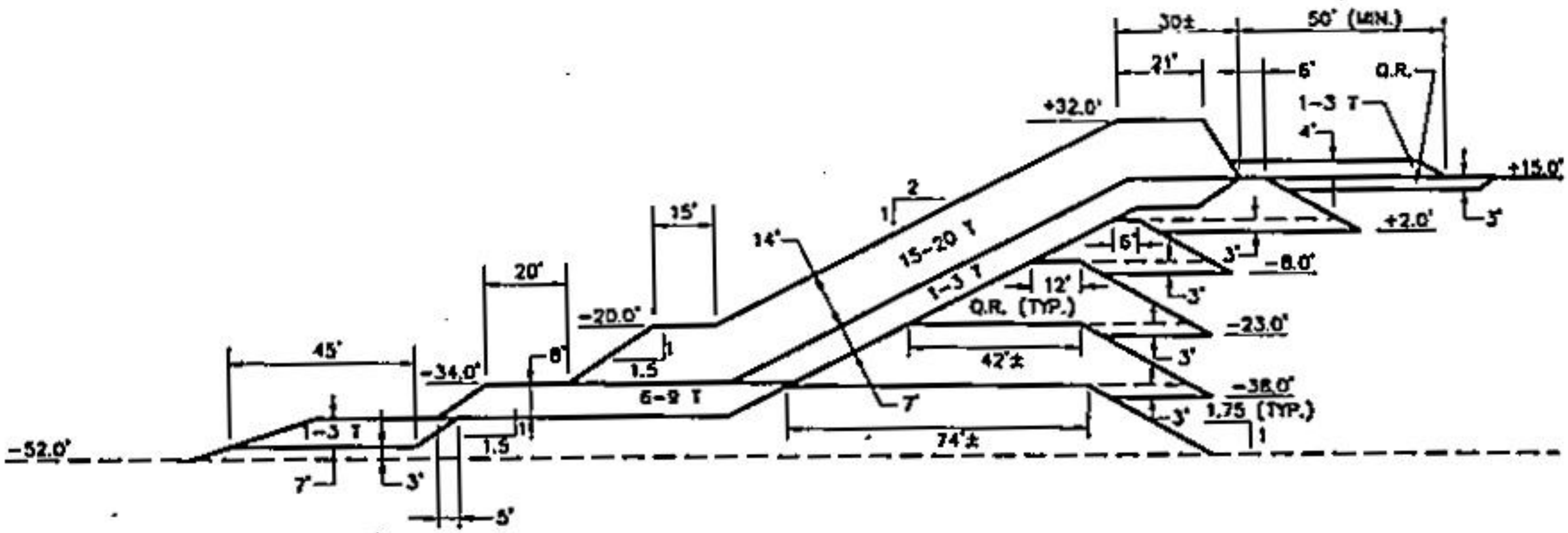
FIGURE 4. KEY PLAN

Table 2. Face D Stage 1 Design Wave Conditions

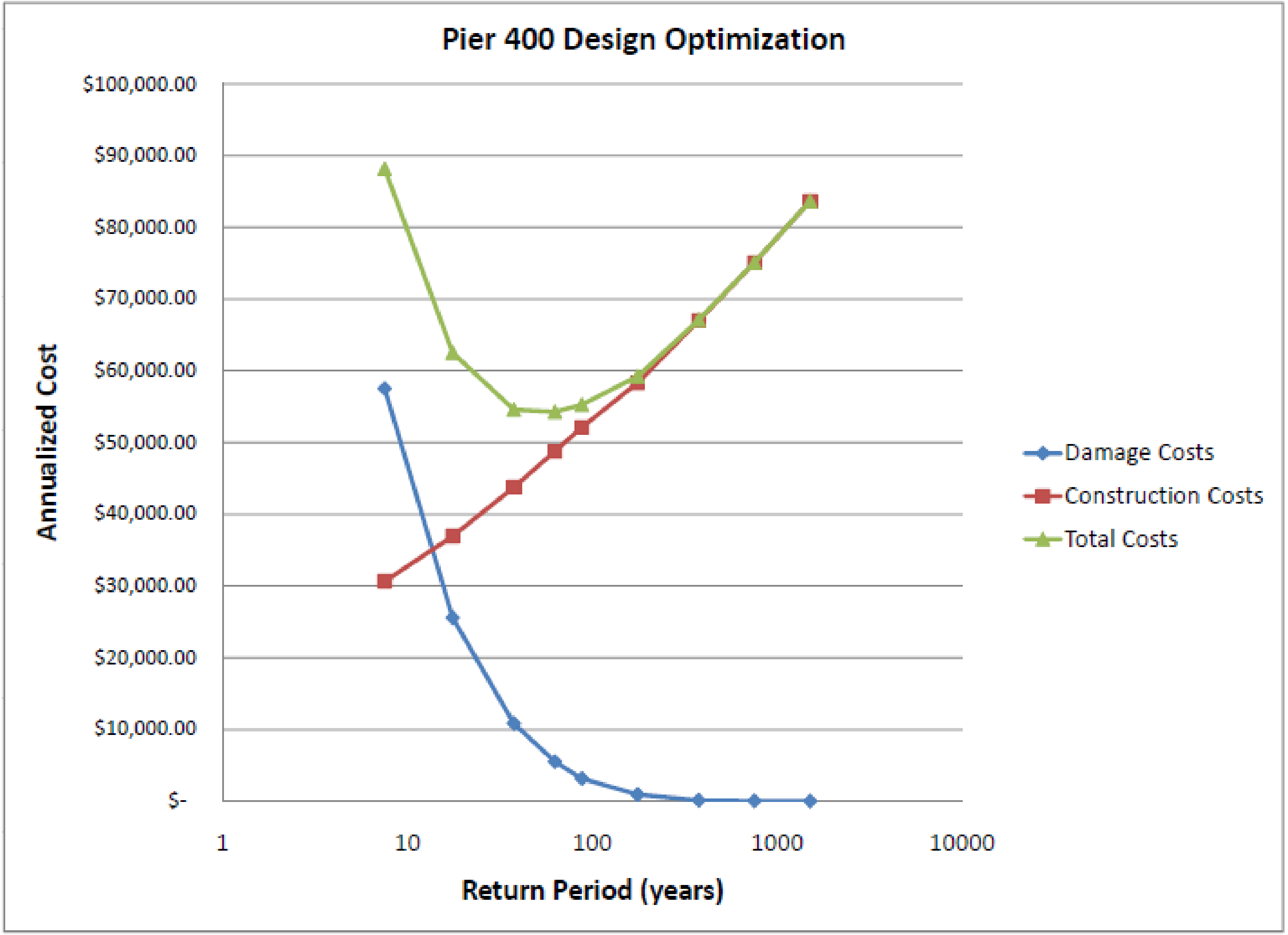
Wave Gage No.	Station Location (feet)	Significant Wave Height (ft) per Recurrence Interval (yrs)		
		25	50	100
5	3360	15.2	18.0	20.6
6	2460	8.9	10.9	12.8
7	1710	4.1	5.0	5.7
8	960	4.4	5.2	5.9
9	160	4.3	5.4	6.5

PIER 400 DIKE

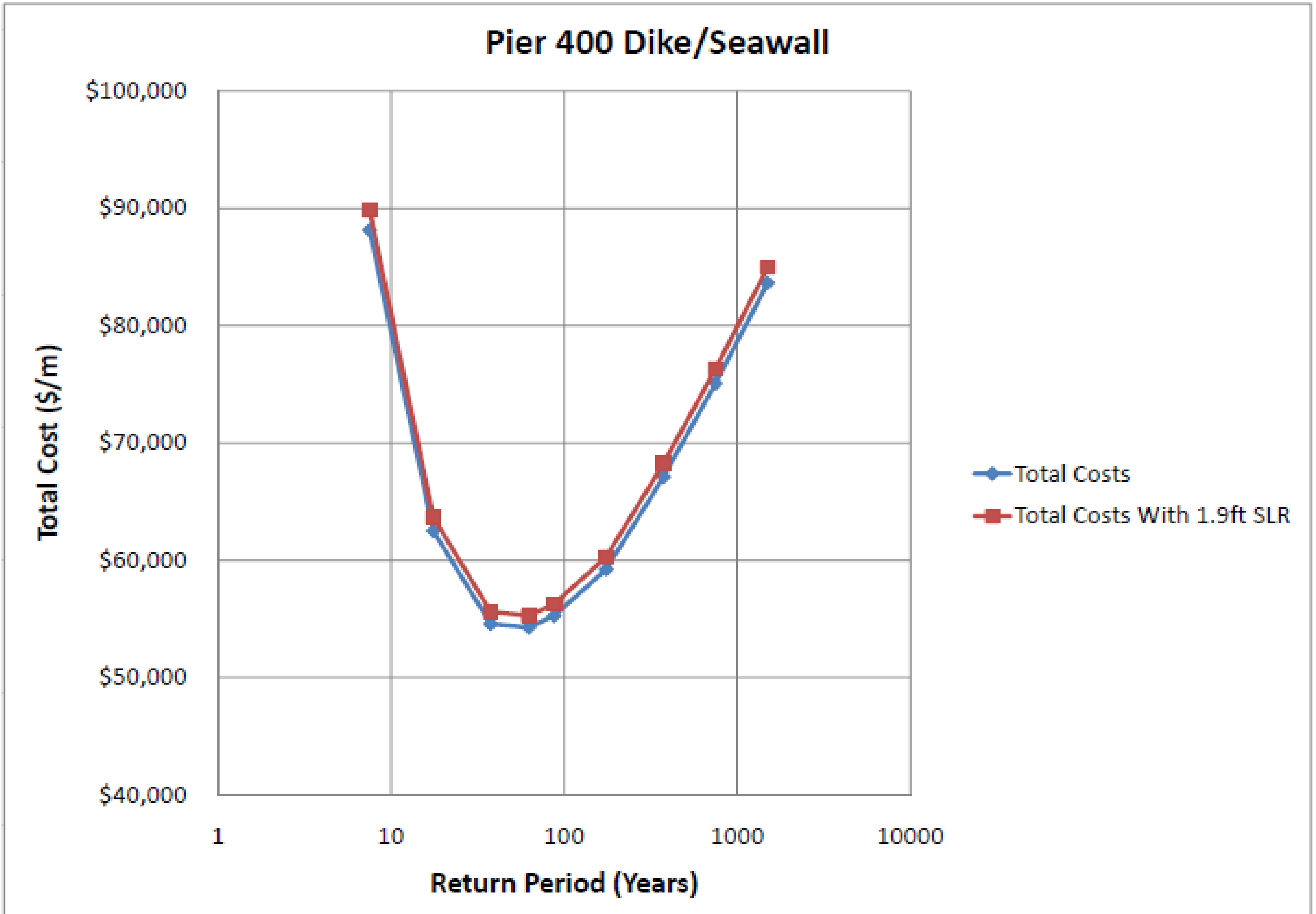
FIGURE 5. TYPICAL DIKE SECTION - FACE D - EAST REACH



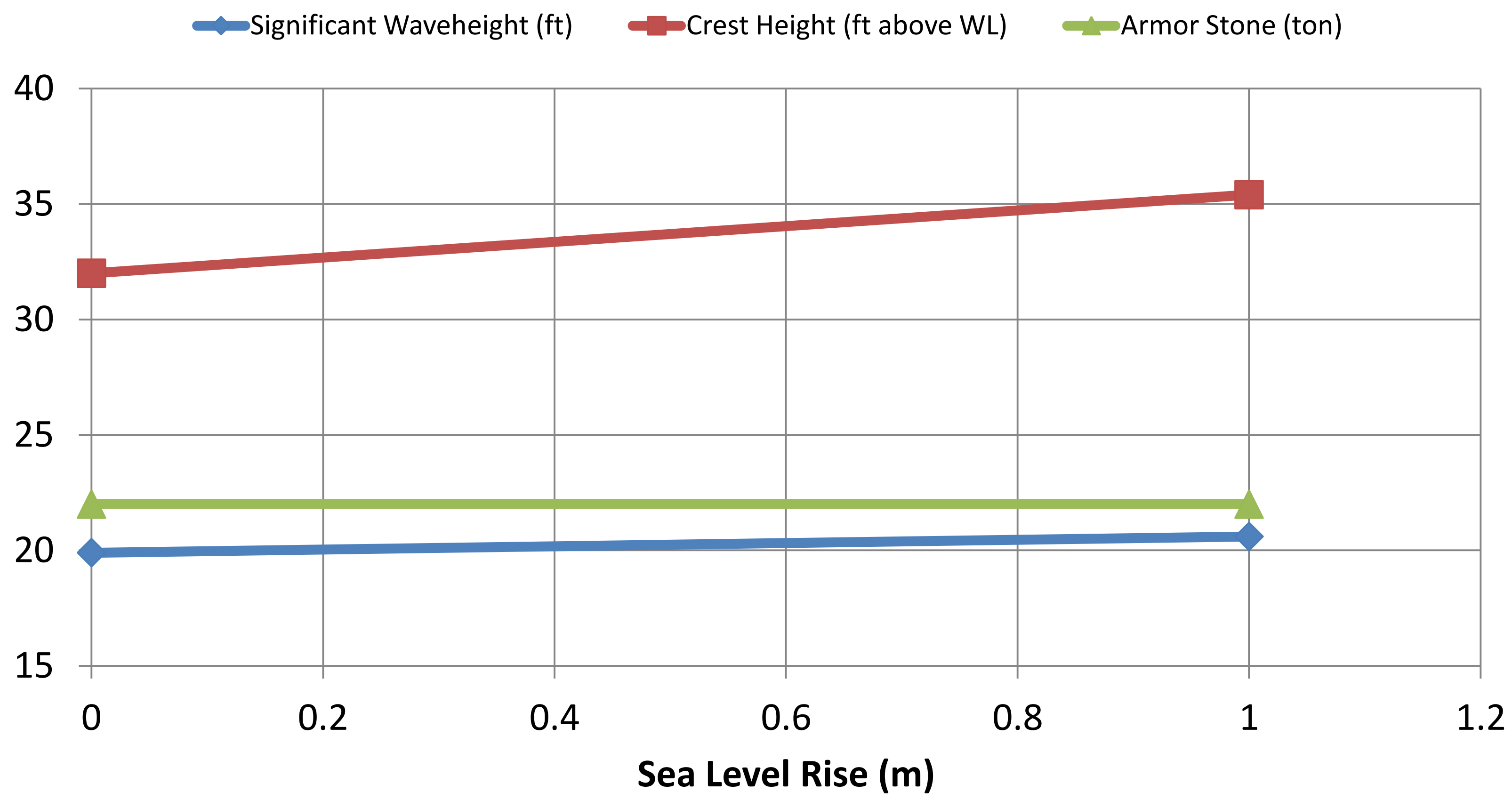
PIER 400 ORIGINAL DESIGN OPTIMIZATION



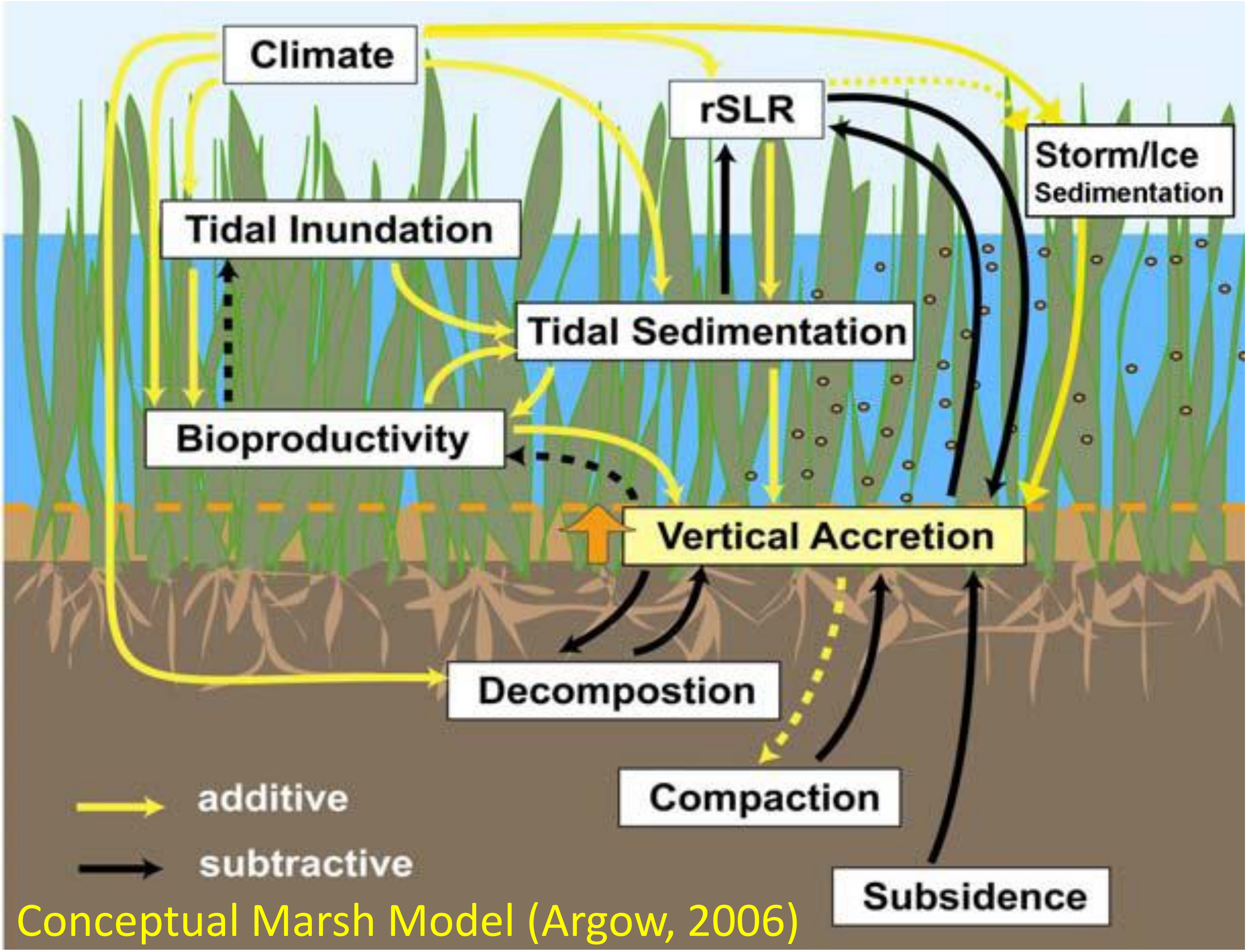
PIER 400 DESIGN OPTIMIZATION WITH SLR



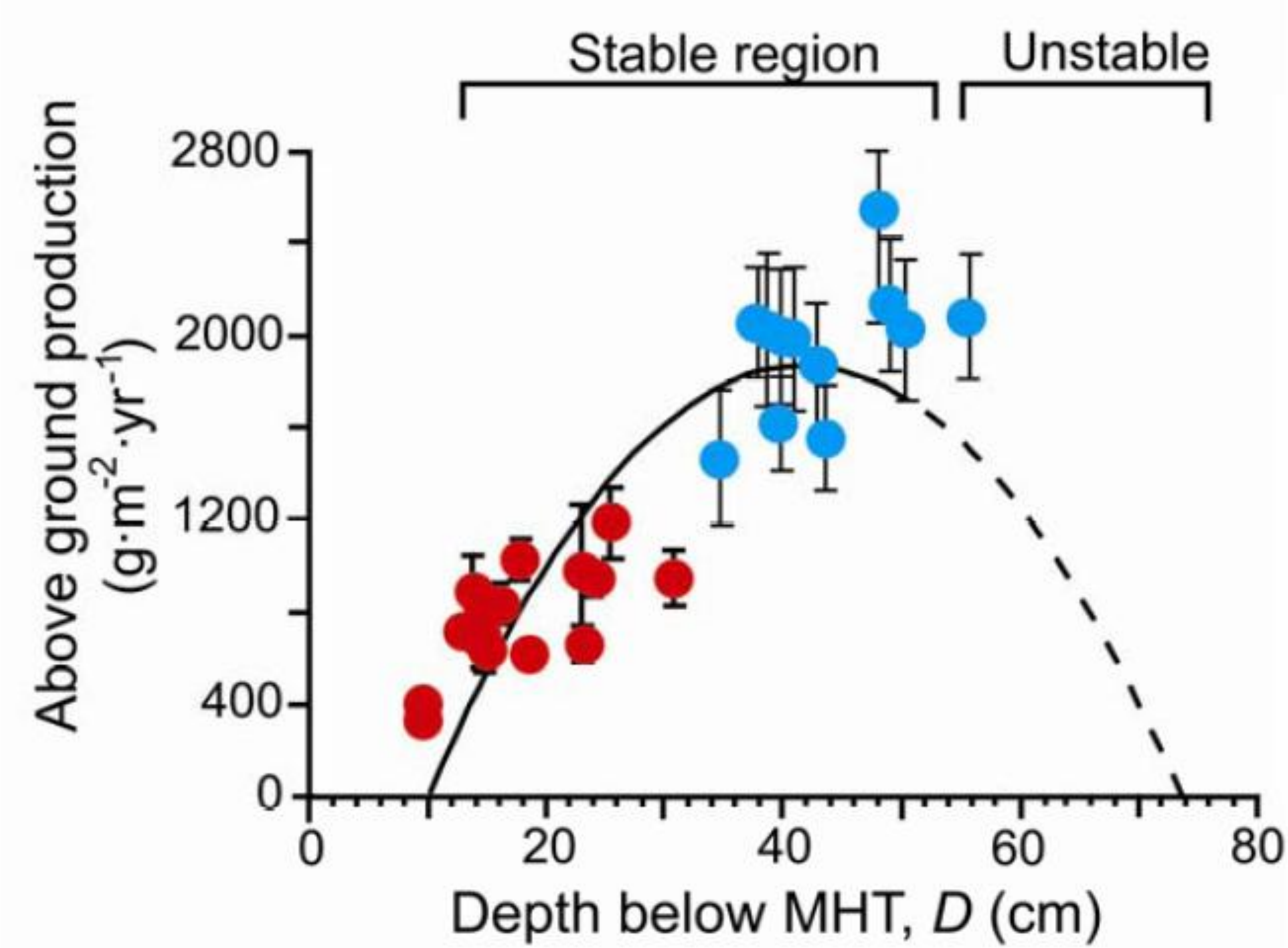
Changes To Pier 400 Rock Dike For 1m SLR



SLR & MARSHES


Climate
rSLR
Storm/Ice
Sedimentation
Tidal Inundation
Tidal Sedimentation
Bioproductivity
Vertical Accretion
Decompostion
Compaction
Subsidence
additive
subtractive
Conceptual Marsh Model (Argow, 2006)

MORRIS ET AL 2002*Spartina Alterniflora*



BATOQUITOS LAGOON BASINS

BATOQUITOS

BATOQUITOS MARSH

- California Cordgrass

(*Spartina foliosa*)

Along channels and low end of marsh

- Pickleweed

(*Sarcocornia pacifica*)

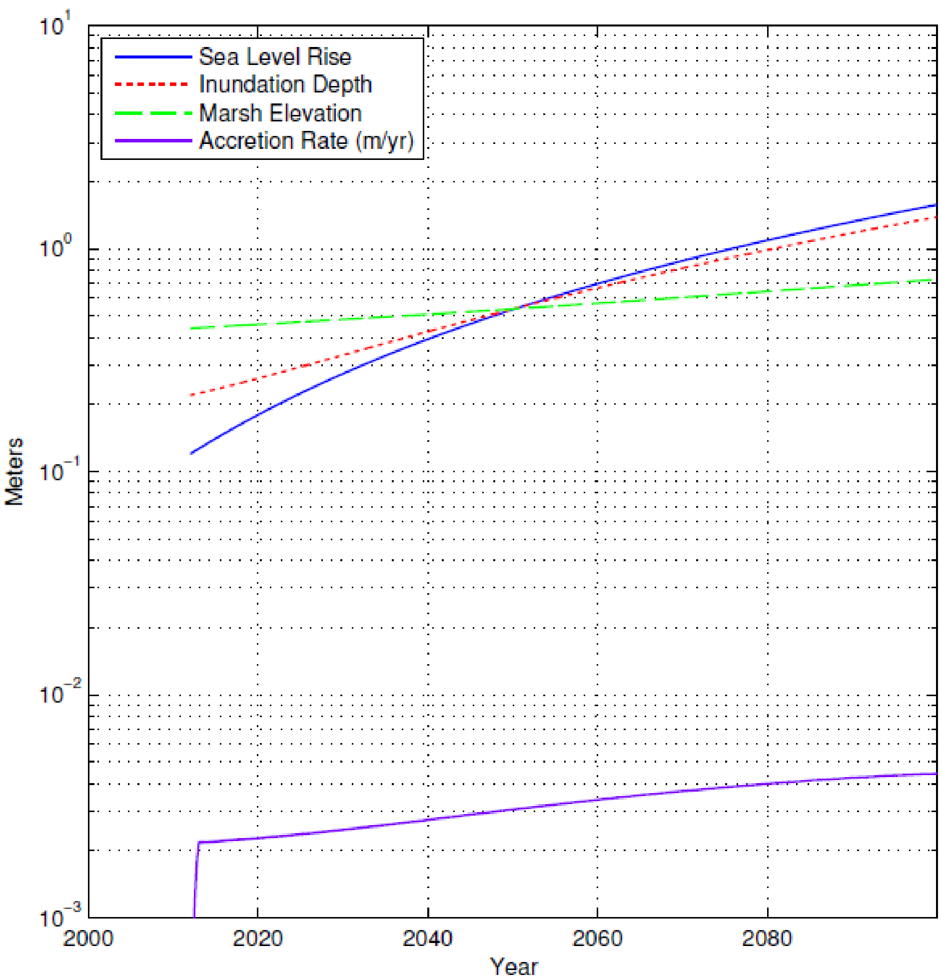
Dominant on the marsh plain

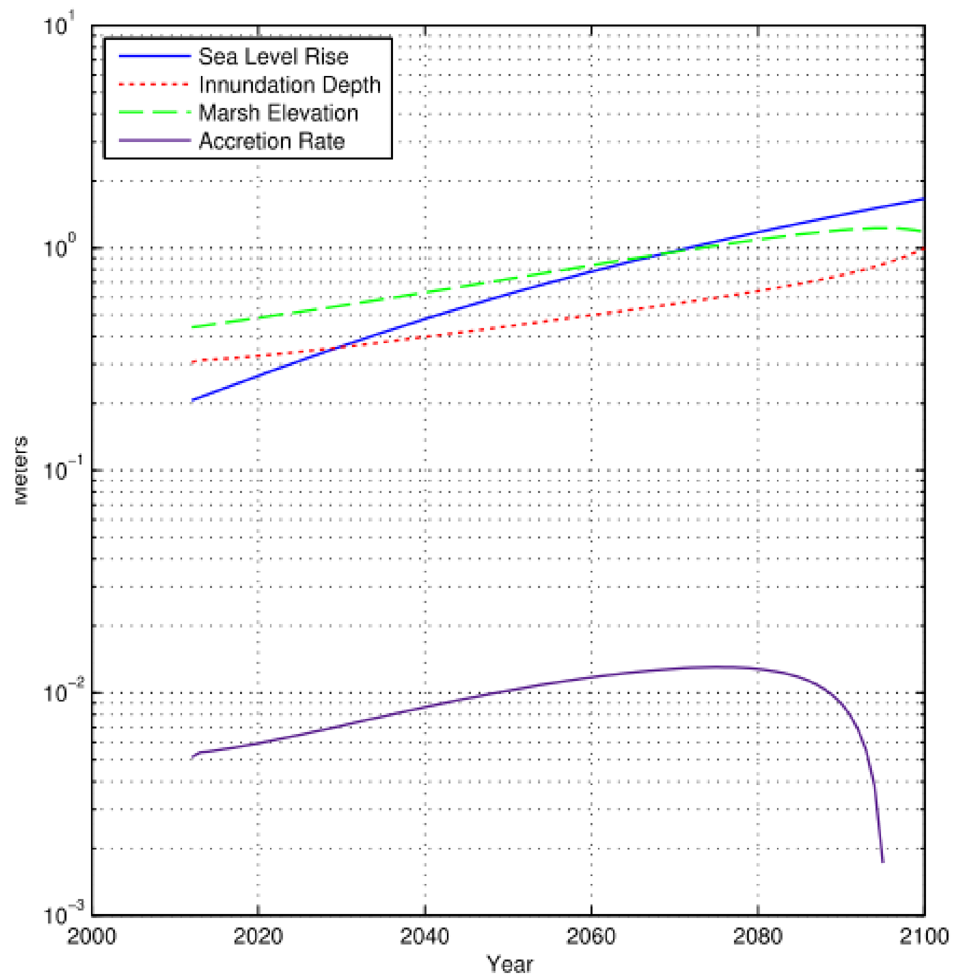
BATOQUITOS LAGOON

- MHW = 0.66 m NGVD29
- MSL= 0.12 m NGVD29
- Subsidence = - 0.36 mm/year
- Initial Marsh Elevations (NGVD29)
  - East Basin= 0.26 m
  - Central Basin= 0.30 m
  - West Basin= 0.44 m
- Morris/Krone models calibrated to historical data

KRONE

MORRIS





FINAL OBSERVATIONS

- Adaptive management is a logical strategy for managing SLR
- Generally better to fortify over time rather than immediately (especially for existing structures)
- For new structures, adaptive management and build-it-now alternatives should be compared to find the best solution
- Planning is crucial, owners need a “Story to Tell” Action is time dependent