Framework for the Analysis of Coastal Infrastructure Vulnerability

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2018 | Enhancing DoD's Mission Effectiveness

Agenda/Topics

1. Discuss/Define types and approaches to Coastal Infrastructure Vulnerability Assessments
2. Introduce the Climate Preparedness and Resilience Register (CPRR) Framework
3. Define types of Performance Thresholds used in CPRR assessments of Coastal Infrastructure Vulnerability
4. Define work flows and performance models used in CPRR analyses
5. Demonstrate the CPRR framework and methods through case study examples

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Coastal Vulnerability Assessment Frameworks Literature Review

Author	Year	Main Focus	1	2	3	4
IPCC	1991	Common Methodology - Influential framework incorporating expert judgment and data analysis of socio-economic and physical characteristics to assist the user in estimating a broad spectrum of impacts from sea level rise.	Y	N	N	Y
Nicholls and Misdorp	1993	Synthesis of vulnerability analysis studies.	Y	N	N	Y
Nichols and Hoozemans	1996	Common Methodology (CM).	Y	N	Y	N
El-Raey	1997	Seven stage vulnerability assessment methodology.	Y	N	N	N
Klein and Nichols	1999	Identifies differences between the Common Methodology and IPCC Technical Guidelines.	Y	N	N	N
Kelly and Adger	2000	Focus on clarifying relationship between vulnerability and adaptation.	N	N	Y	N
Wu et al.	2002	This study demonstrates how sea-level rise increases the vulnerability of coastal communities to flooding associated with coastal storms.	Y	N	Y	N
Lewsey et al.	2004	Proposed sea level monitoring network and other measure to improve accuracy of climate forecasts.	Y	N	N	N
Ford and Smit	2004	Focus on arctic communities.	N	N	Y	N
Patt et al.	2005	Questions the validity of vulnerability assessments.	N	N	N	N
Patt and Dessai	2005	Focused on how to communicate uncertainty.	N	N	N	N
Tsimplis et al.	2005	Quantified the spatial and temporal dependency of sea level and wave heights on the North Atlantic Oscillation (NAO) for UK.	Y	N	Y	N
Smit and Wandel	2006	Adaptation in human communities are closely associated with adaptive capacity and vulnerability.	Y	N	Y	N
Füssel	2007	Defined two major interpretations of vulnerability end-point and starting point.	N	N	N	N
Johnson and Marshall	2007	Species specific vulnerability.	N	N	N	N
Tribbia and Moser	2008	Looked at what type of information is generally used.	Y	N	N	N
Snouwa et al.	2008	Mapping GIS approach looked at broad area and used IPCC technical guidelines.	Y	N	N	Y
Sterr	2008	Suggested that vulnerability assessment changes are more accurate at smaller scales.	Y	N	Y	N
Dwarakish et al.	2009	Standard assessment using coastal vulnerability index (CVI).	N	N	N	N
Hinkel and Klein	2009	Presented the development of the DIVA (Dynamic and Interactive Vulnerability Assessment) tool.	Y	Y	Y	N
Rosati and Kraus	2009	Looked at RSLR and impacts to elements of coastal navigation projects – jetties, channels, dredged material disposal sites.	Y	Y	Y	Y
Ionescu et al.	2009	Applies mathematical expressions to IPCC definitions.	N	N	N	N
Kumar et al.	2010	Uses 9 risk variables to define vulnerability.	N	N	N	N

Criteria used to compare frameworks

1. Scenarios
2. Common Tidal, Geodetic Vertical Datum Reference
3. Total Water Levels (Classification scheme for coastal water levels)
4. Performance

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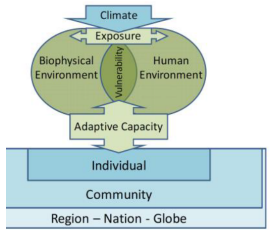

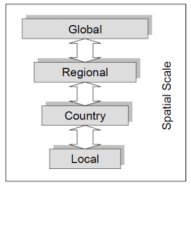

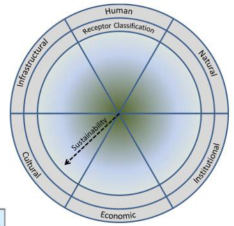

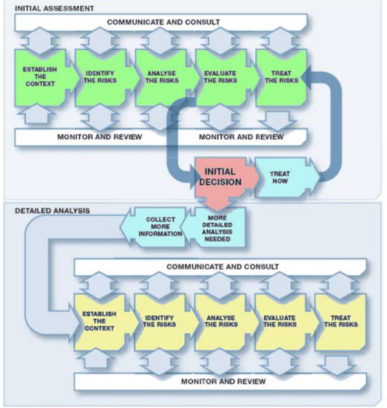

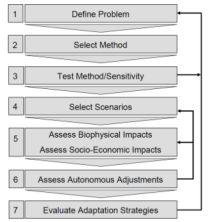

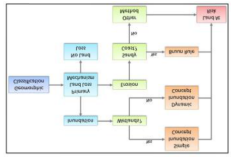

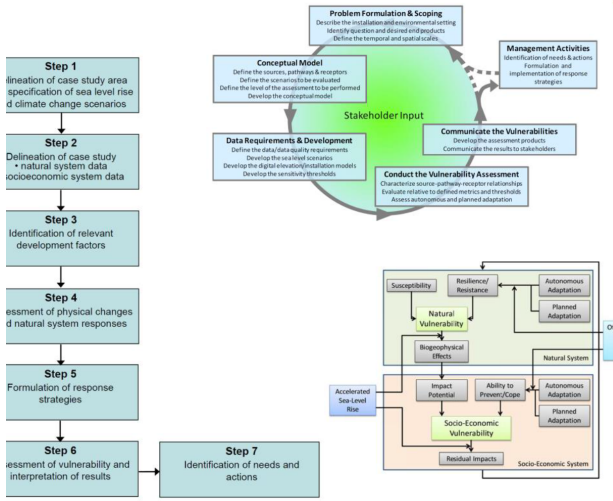

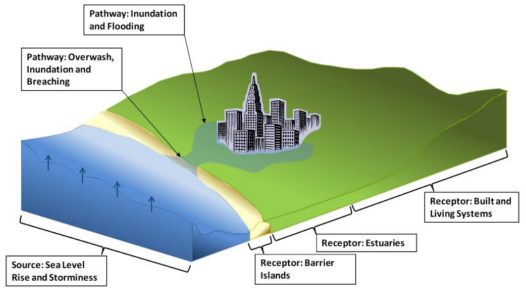

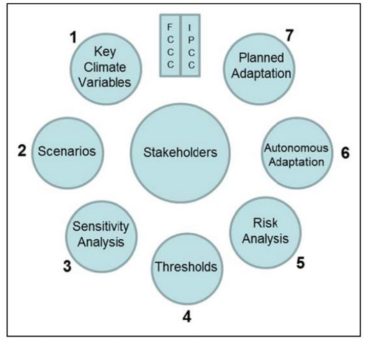

Approaches to Coastal Vulnerability Assessments

Types of Coastal Vulnerability Assessments

- **Impact focused** – Static time horizon – example year 2085, impacts may be developed under one or more scenarios
  - **"plan view"** – map impacts

- **Performance focused** – Dynamic time horizon, includes past and projected future under one or more scenarios
  - **"elevation view"** – plot time series against time scale
  - Able to assess vulnerability for a wide range of coastal infrastructure types – **Flood Risk Reduction, Navigation, Transportation, Environmental Restoration**

Questions addressed by vulnerability assessment

- What does the inundation map for the current 1% coastal water level look like in 2085
- NOAA Sea Level Rise Viewer
- Lots of local products – California

- How will a coastal levee perform against non stationary risk levels caused by sea level change.
- How will current operations of surge barrier gates change in a 50 to 100 year time period under multiple sea level change scenarios
- How does pumping capacity and O&M costs change under rising sea levels
- Can we identify **tipping points/thresholds** across scenarios

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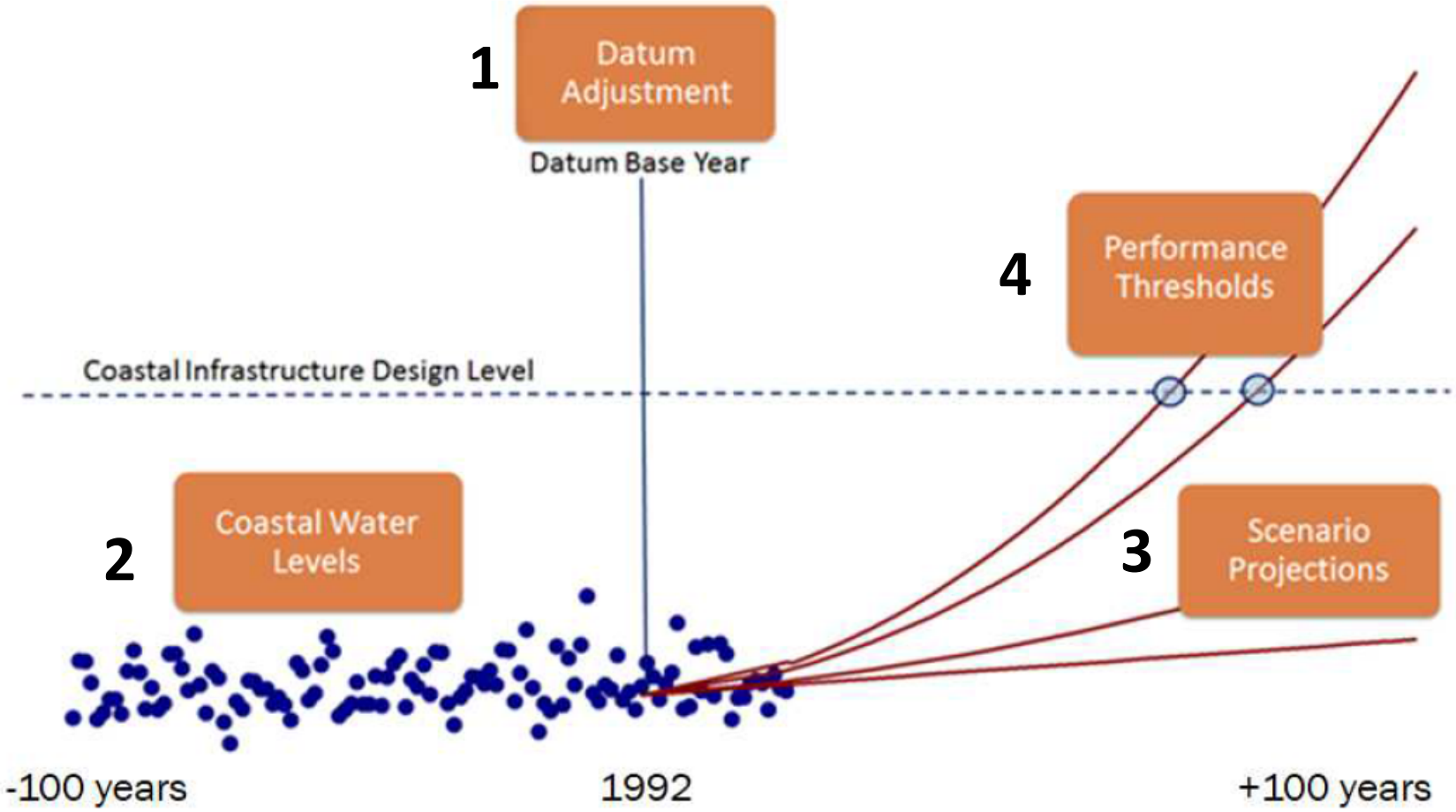
Climate Preparedness and Resilience Register (CPRR) (O'Brien, 2017)



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Climate Preparedness and Resilience Register (CPRR) (O'Brien, 2017)

General Climate Change Framework

Baseline → Data (Non stationarity) → Projections → Performance Impacts/Thresholds

CPRR Framework For Coastal Infrastructure

Datum Adjustment → Coastal Water Levels → Scenario Projections → Performance Thresholds/ Impacts

USACE Guidance

ER 1100-2-8160:
Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums

ECB 2018-3
Total Water Level Guidance (in Preparation)

ER 1100-2-8162
Incorporating Sea Level Change in Civil Works Programs

ER 1110-2-8159
Life Cycle Design and Performance
ETL 1100-2-1
Procedures to Evaluate Sea Level Change Impacts, Responses and Adaptation

Tools/Data Sources

VDatum
https://vdatum.noaa.gov/
NOAA tides and currents
https://tidesandcurrents.noaa.gov/

NOAA tides and currents
https://tidesandcurrents.noaa.gov/
Coastal Hazards System (CHS)
https://chswebtool.erdc.dren.mil/
Sea Level Change Curve Calculator
http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

Sea Level Change Curve Calculator
http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

NOAA Sea Level Rise Mapper
https://coast.noaa.gov/slr/
Sea Level Change Curve Calculator
http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

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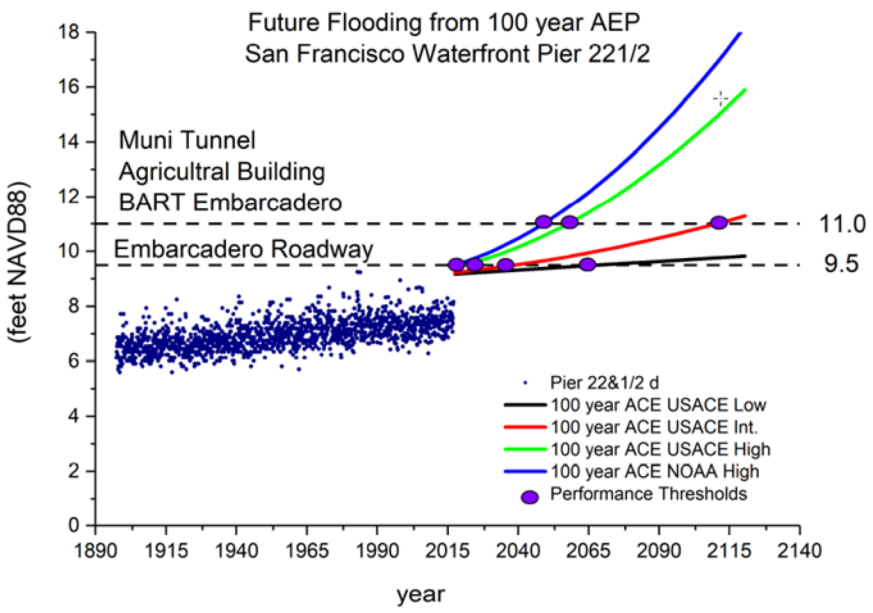
Performance Thresholds used in the CPRR Framework

- **Design** - defined as the engineering design level. Performance may continue past design level
- **Adaptation** – limit of performance for a particular engineered structure or measure
- **Cost/Operational** – continued performance occurs at a significant increase in cost or change in operations
- **Societal/Livability** – defined as the overall viability of basic infrastructure under future sea level change
- **Ad-Hoc** – defined for specific target or function

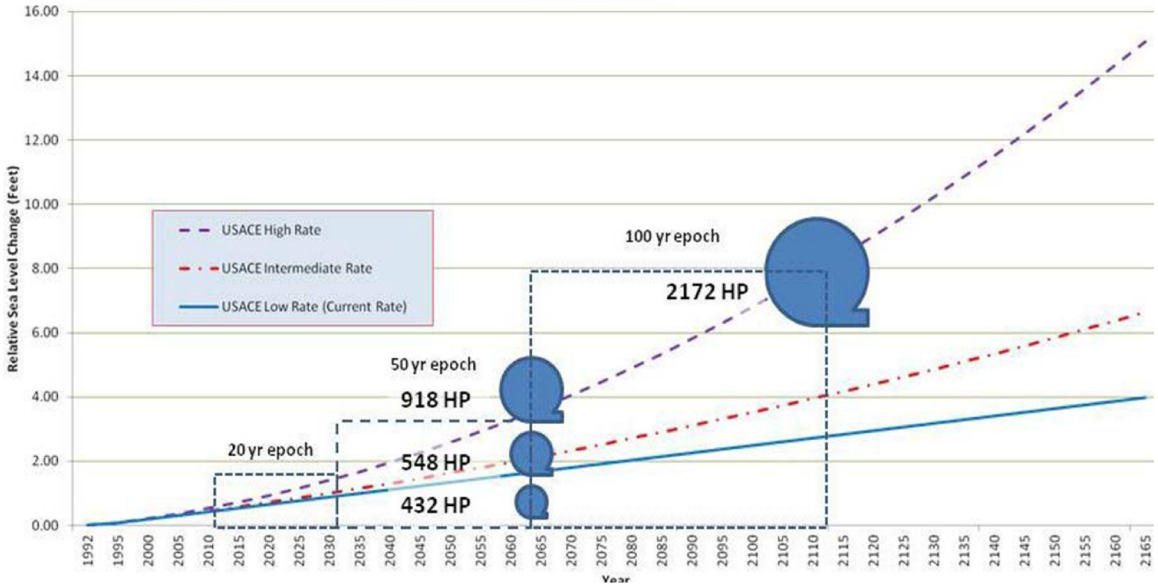
Performance Time Series Examples
Elevation, Function

Elevation-time, Critical Infrastructure Elevations



Levees
Floodwalls
Roadways
Navigation depth
Jetty crest height

Function-time, Pump efficiency, 1800 cfs pump station



Wave Overtopping
Pump efficiency
Navigation gate closures
Wetland accretion
Shoaling Rates

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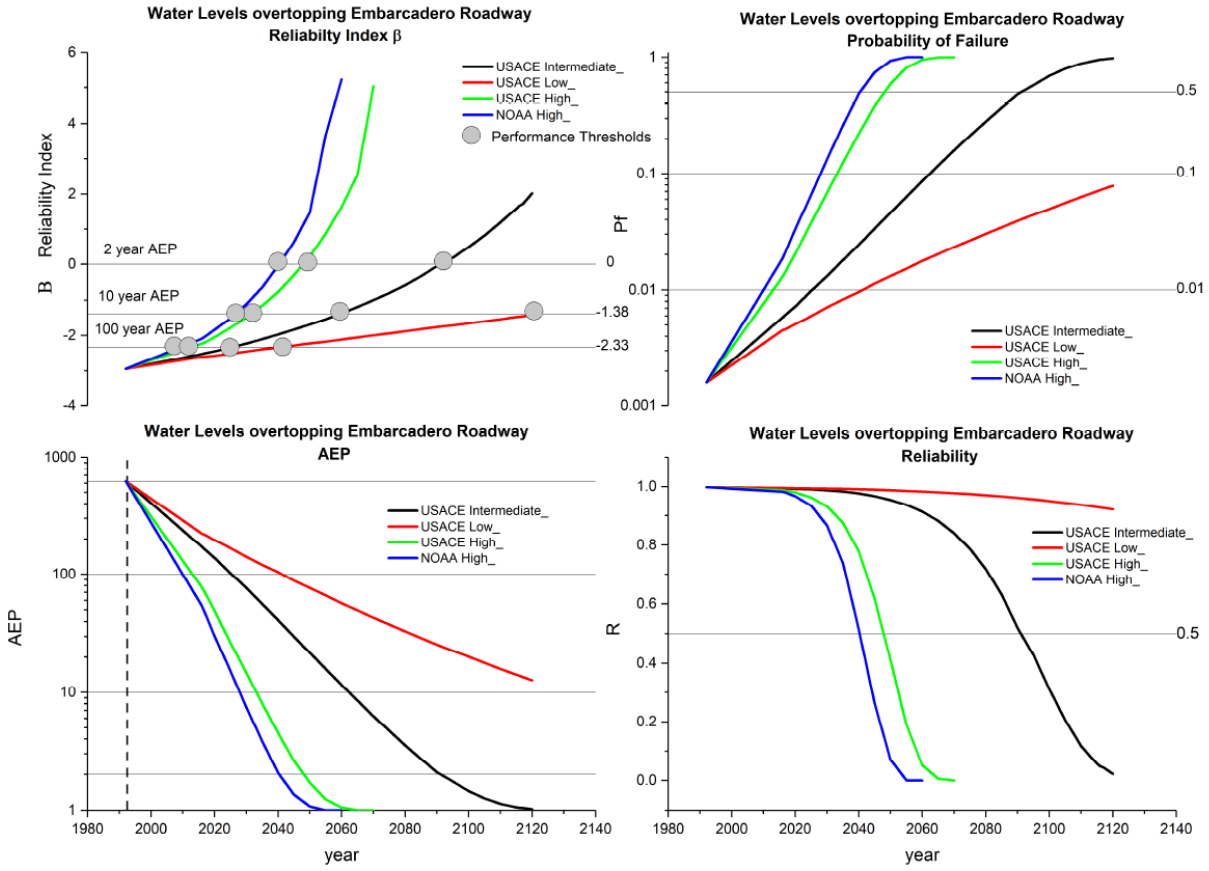
Performance Time Series Types
Reliability, Reliability based metrics



- Reliability-time performance models may be developed from Elevation-time and Function-time models
- Several reliability based metrics may be developed from a base reliability model
  - Reliability index
  - Probability of failure(non-performance)
  - Annual exceedance probability (AEP)
- Additional metrics allow multiple project elements to be compared together (by scenario)

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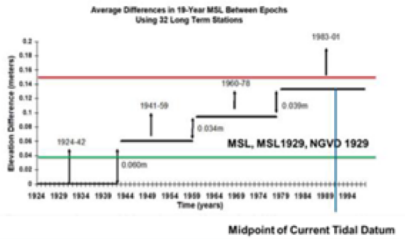
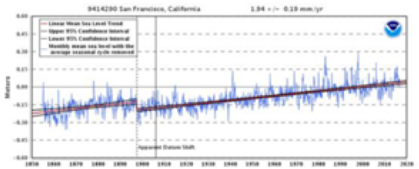
CPRR Framework Methods/Workflow



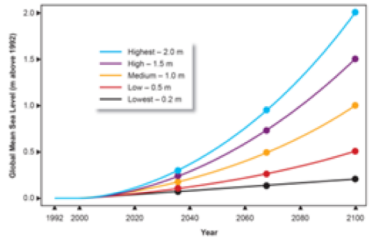
1. Datum Adjustment

- Adjust original design data to geodetic datum (NAVD88)
- Adjust tide gauge data to geodetic datum (NAVD88)
- Account for RSLC in historical water levels



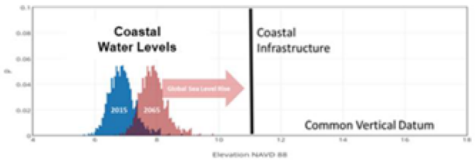
2. Coastal Water Levels

- TWL model for critical/design water level
  - Hydrodynamic model output
- Offshore wave buoy data
- Computation of wave run up, overtopping
- Tide Gauge Analysis
  - Statistical tests for non-stationarity
  - Detrending, de-tiding time series
  - Application of statistical distribution models, i.e. GEV, GPD, Logistic



3. Scenarios

- Global Sea Level Rise, Relative Sea Level Change
- Equation with “b” constant
  - Observed/Historical
  - USACE
  - NOAA
- Unique Storm Events
  - Example Hurricane Sandy with SLR
- Scenario based future time series created by adding RSLC to Statistical Model created in #2



4. Performance Thresholds

- Develop simple performance models for range of infrastructure types
- Define limit state for analysis (original design, ad hoc values)
- Determine critical performing TW, frequency and duration
- Apply correct TWL(s) or combination of TWL component

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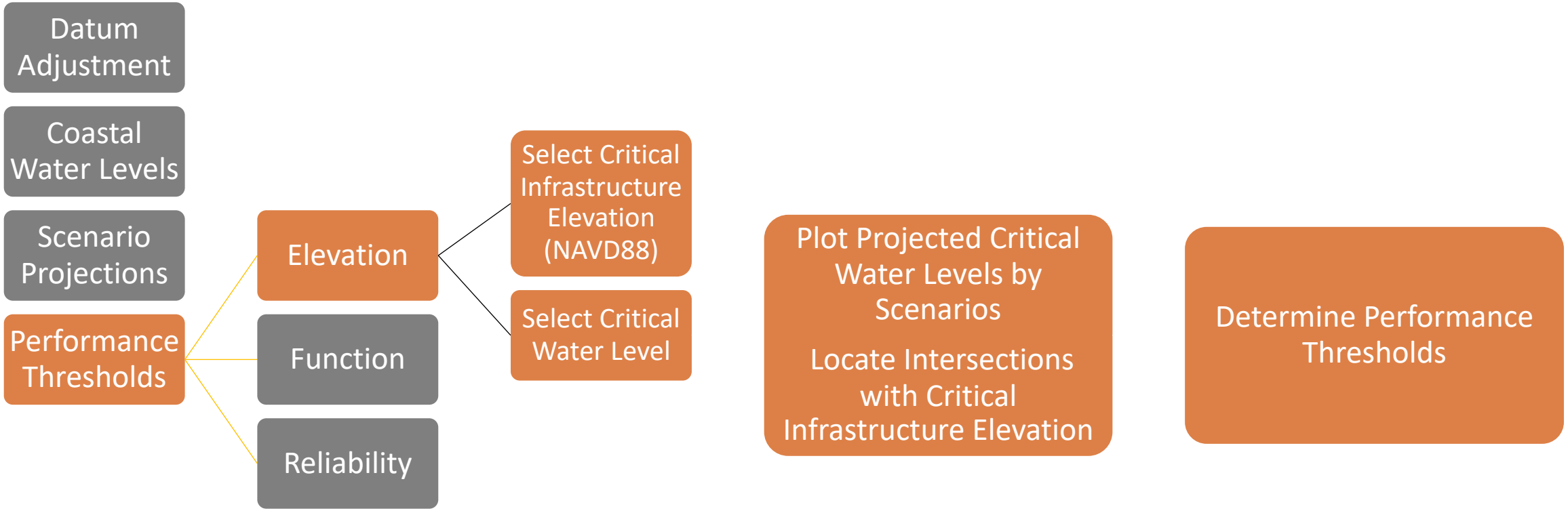
CPRR Framework Methods/Workflow
Elevation-Time Series Example



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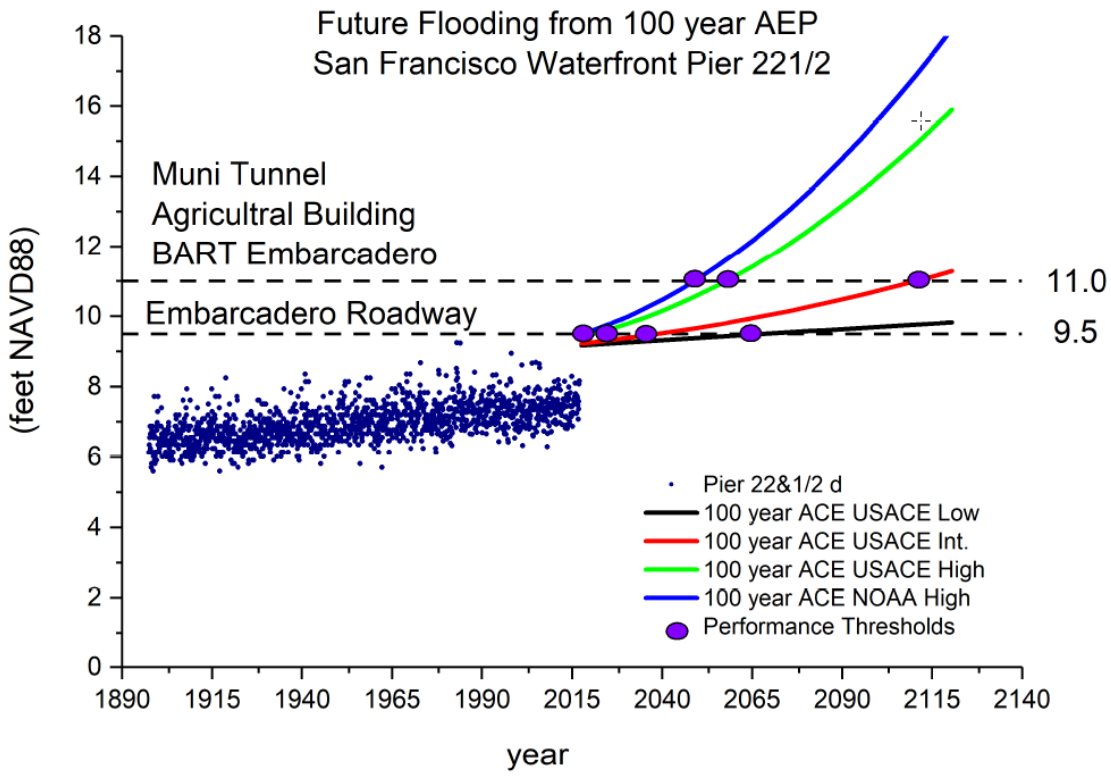
CPRR Examples – Elevation (Design) threshold for several Key Infrastructure features, San Francisco waterfront



			Threshold Range/Scenarios			
Infrastructure Element	Performance Metric (feet NAVD88)	Coastal Water Level (feet NAVD88)	USACE Low (year)	USACE Intermediate (year)	USACE High (year)	NOAA High (year)
Embarcadero Roadway	SWL > 9.50	King Tide	> 2120	2097	2051	2043
	SWL > 9.50	10-year AEP	> 2120	2068	2036	2031
	SWL > 9.50	100-year AEP	2068	2038	2021	2018
Agriculture Building, Muni Tunnel, BART Embarcadero	SWL > 11.00	King Tide	> 2120	> 2120	2076	2065
	SWL > 11.00	10-year AEP	> 2120	> 2120	2065	2056
	SWL > 11.00	100-year AEP	> 2120	2109	2057	2047

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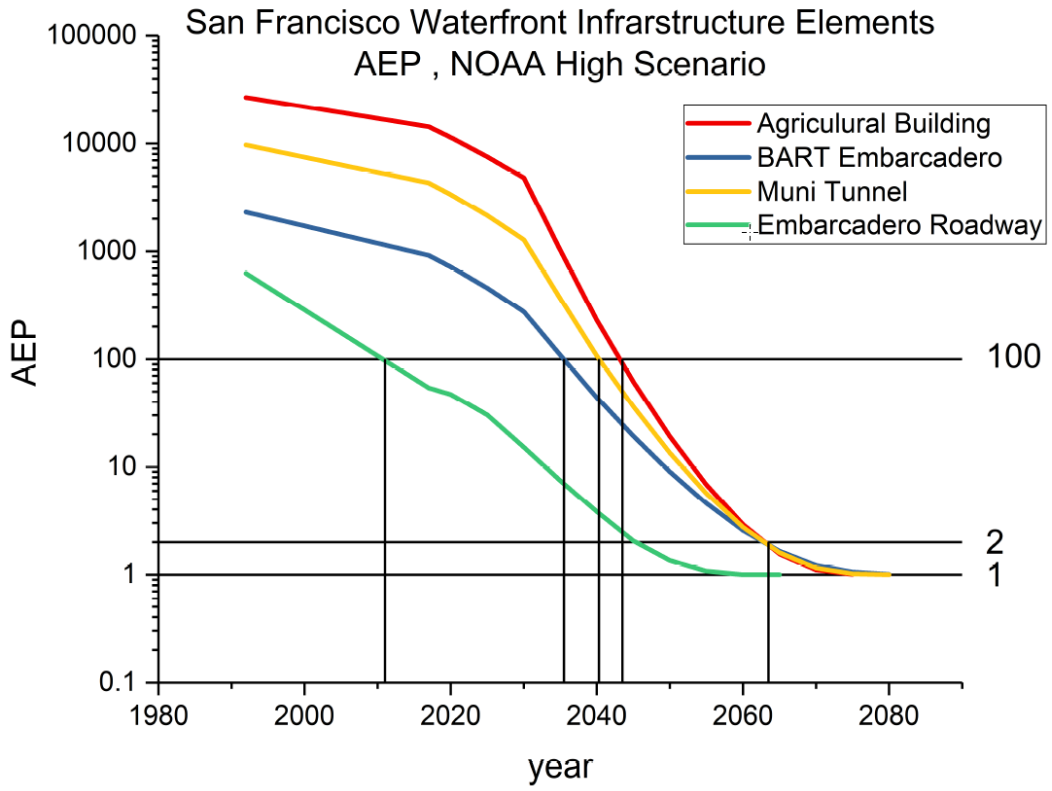
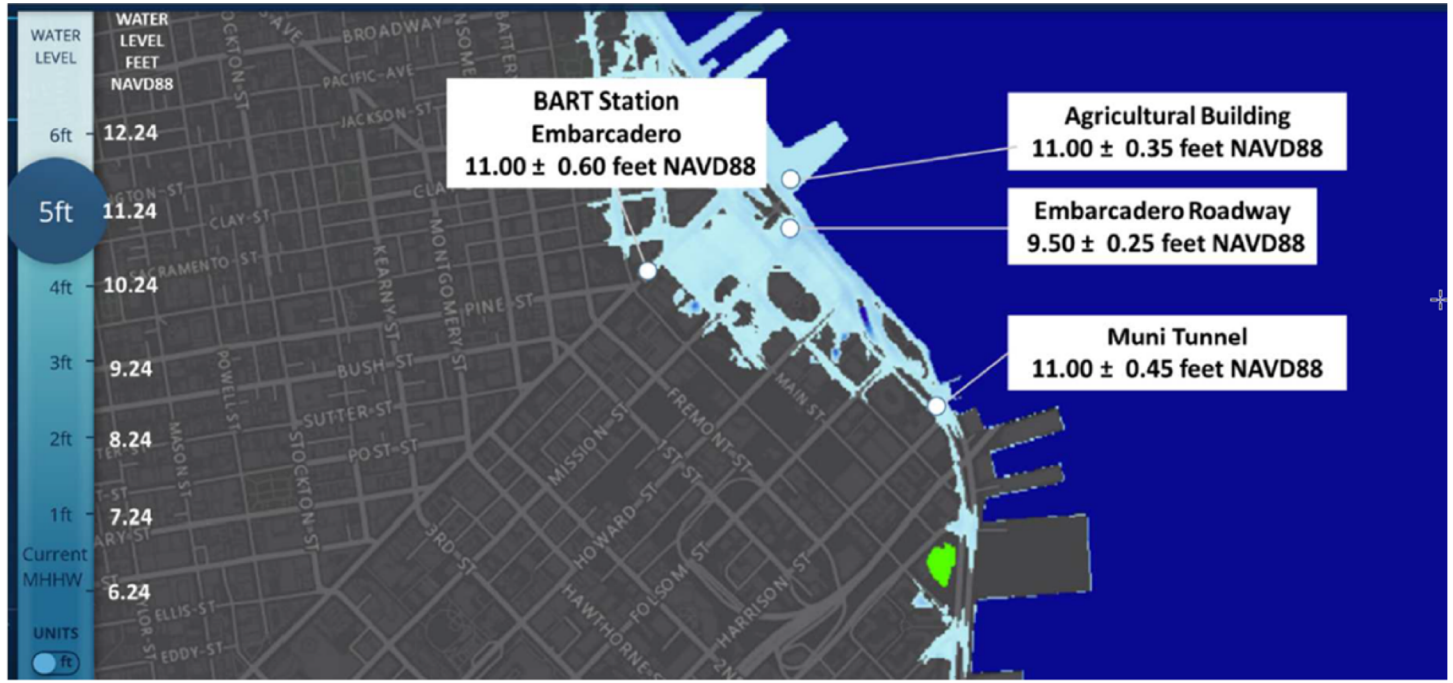
CPRR Examples – Elevation threshold for several Key Infrastructure features, San Francisco waterfront (AEP)





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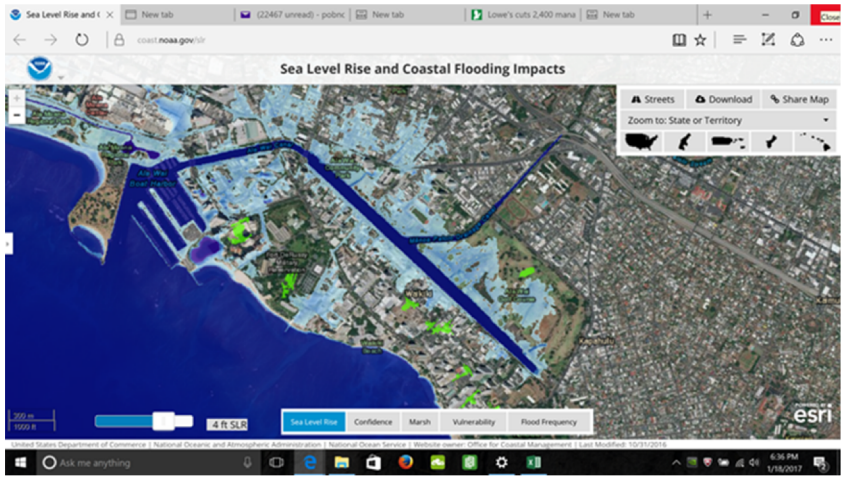
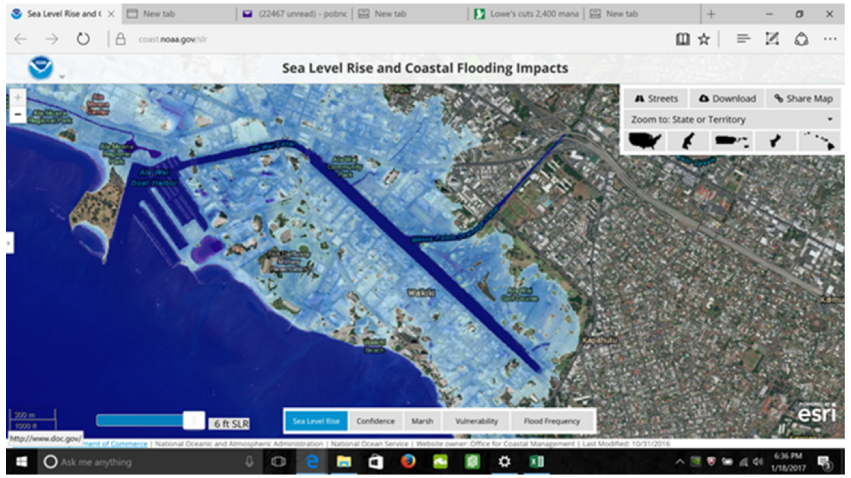
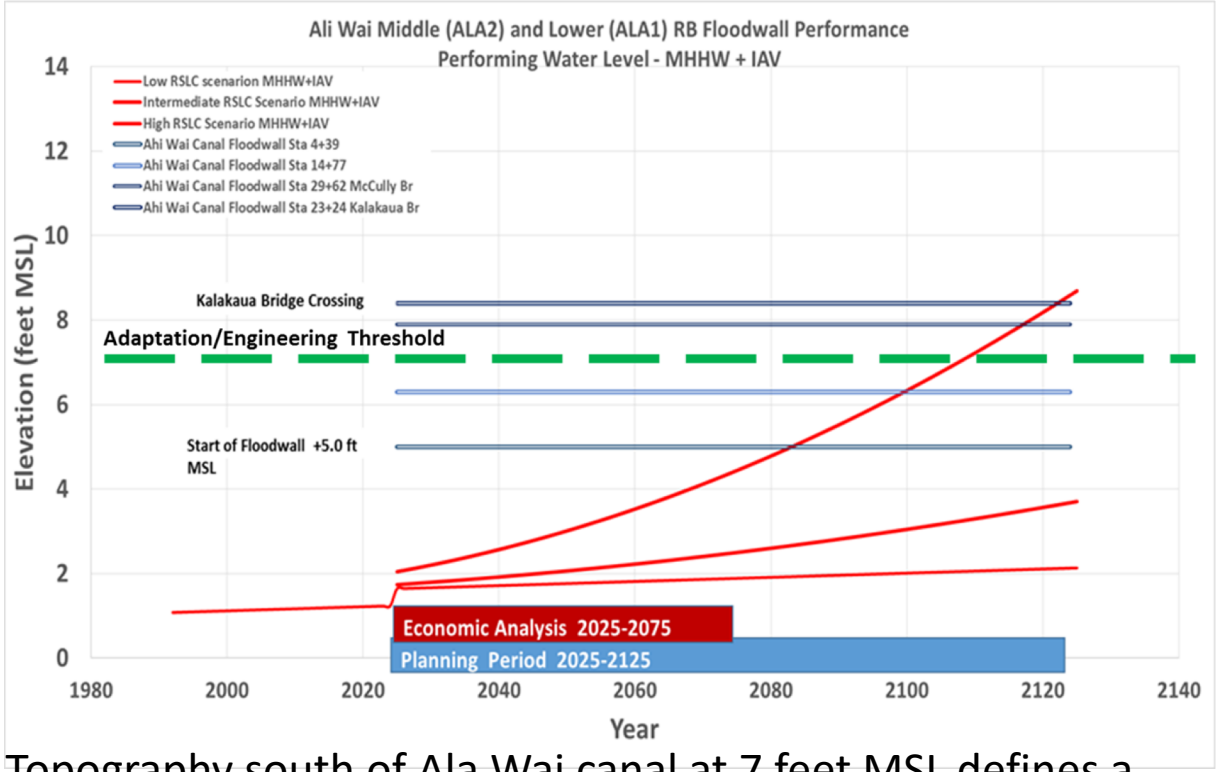
CPRR Examples – Adaptation Threshold defined by topography and flooding pathways, Ala Wai canal, Hawaii



5 feet MSL
Flooding transmitted by Ala Wai canal



7 feet MSL
Flooding transmitted by Ala Wai canal + **open coast**



Topography south of Ala Wai canal at 7 feet MSL defines a adaptation threshold. Design elevations for a proposed floodwall above 7 feet will not ameliorate flooding south of the canal, since the flood pathways have changed

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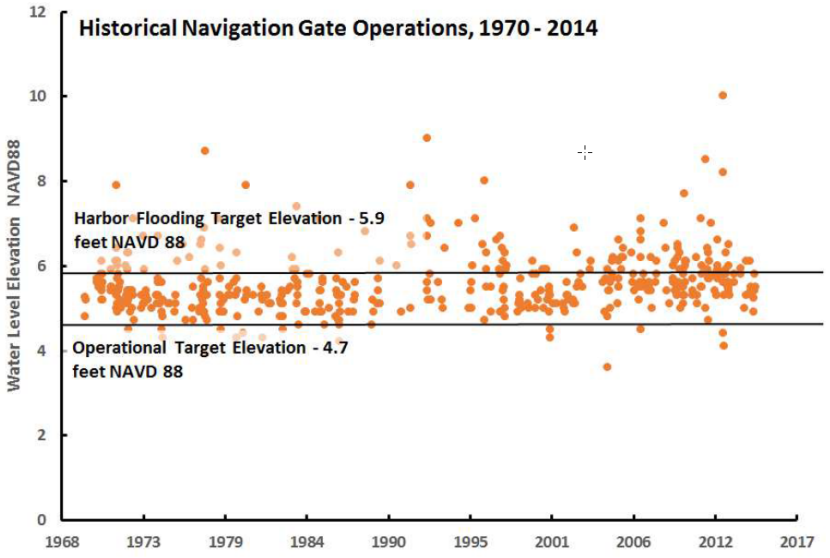
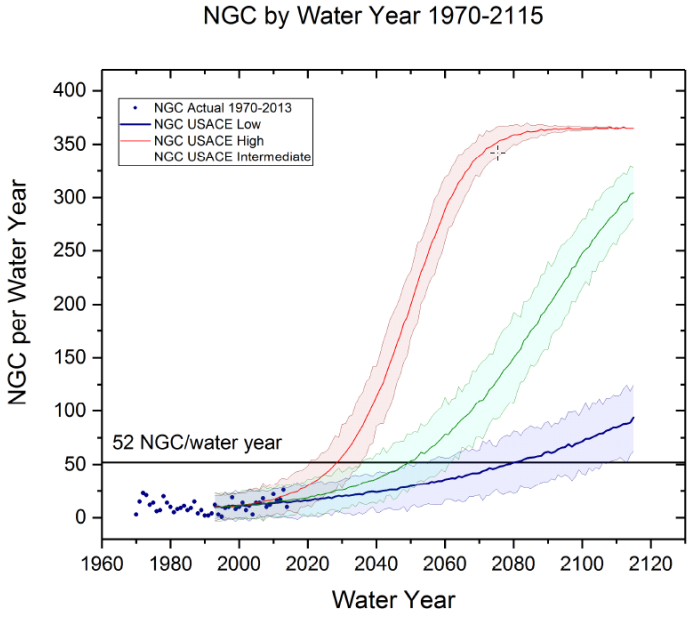
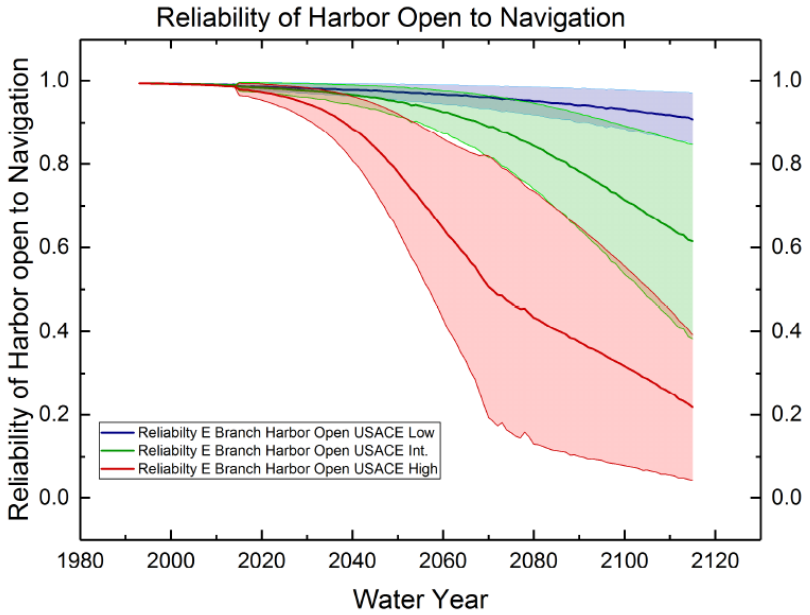
CPRR Examples – Cost/Operational Threshold Navigation Gate Closures (NGC) for a Surge Barrier

- Surge Barrier protects a small harbor from coastal flooding due to hurricanes and nor'easters
- Historical NGC 1970-2014 ranged from 0 to 26 per water year
- The surge barrier is not staffed, crew are dispatched to operate barrier as needed. A operational threshold of 52 NGC/water year (once per week) was defined as a significant cost threshold, since the surge barrier would have to be staffed with a full time crew due to the increased closure frequency







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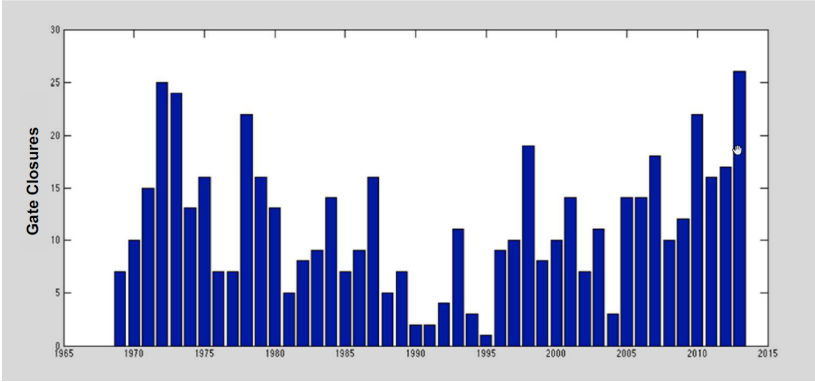
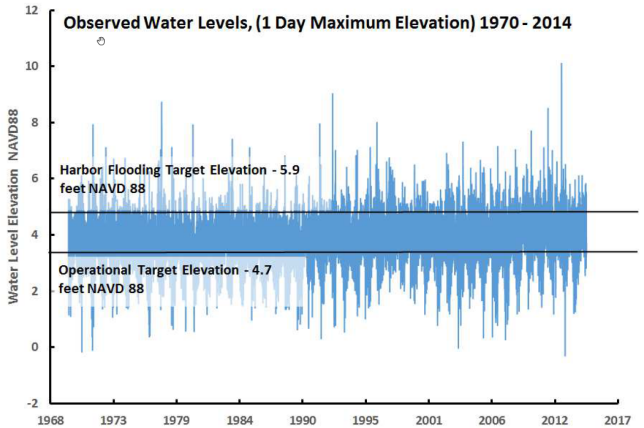
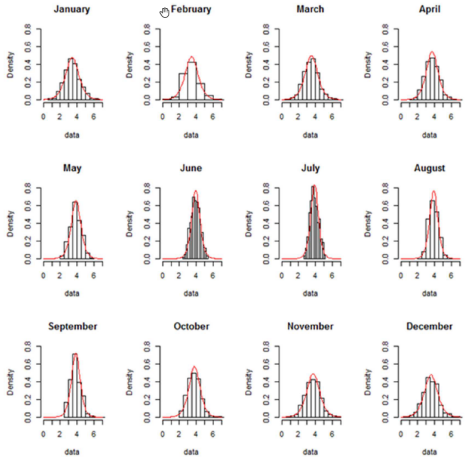
CPRR Examples – Cost/Operational Threshold Navigation Gate Closures (NGC) for a Surge Barrier, Methods

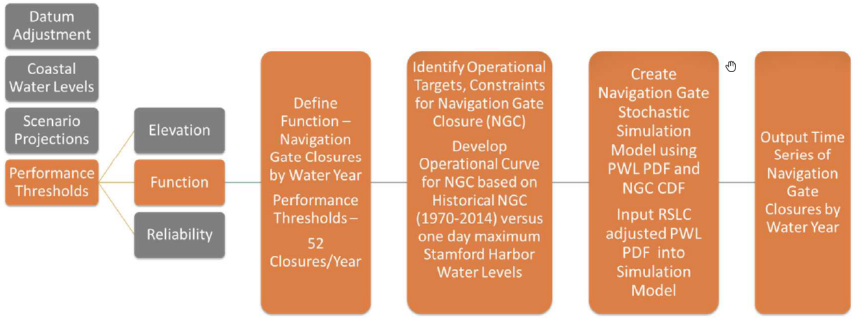
NGC per Water Year, 1970-2014



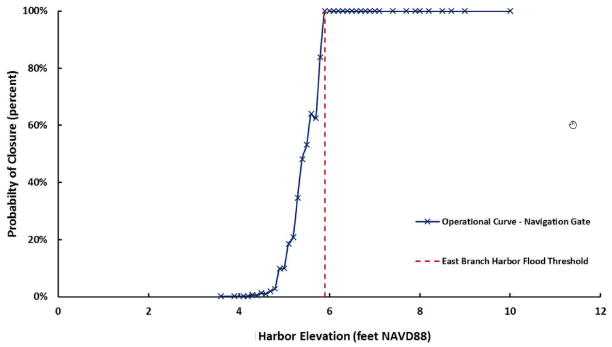




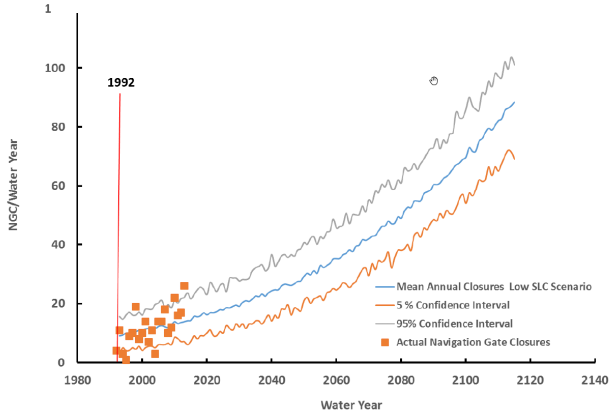
CPRR Workflow Diagram



NGC Operation CDF (1970-2014)



NGC Forecast Model



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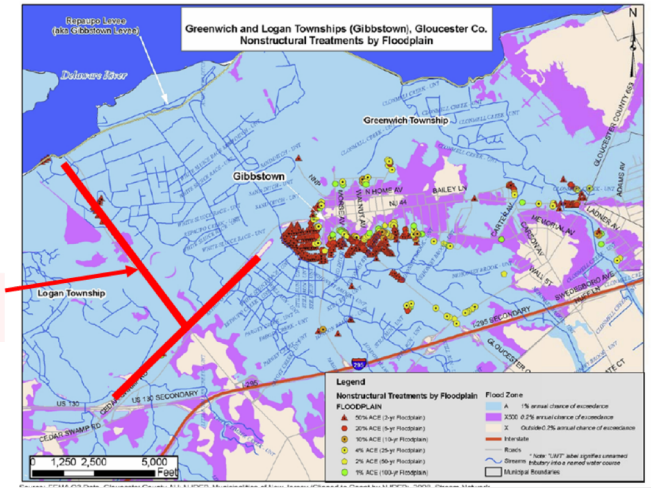
CPRR Examples – Societal/Livability Threshold defined by transportation network

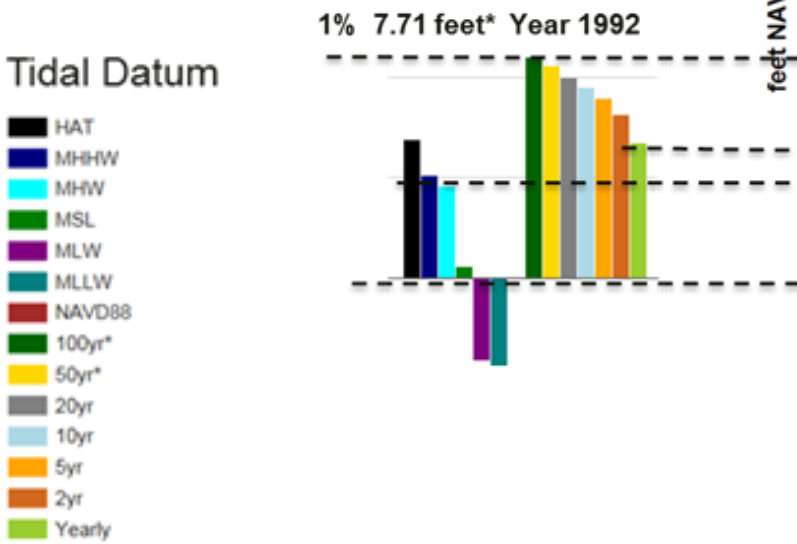
	Feet NAVD88		
Year	2015	2065 H	2100 H
MHHW	3.8	6.4	9.1
1 yr event	4.9	7.5	10.2

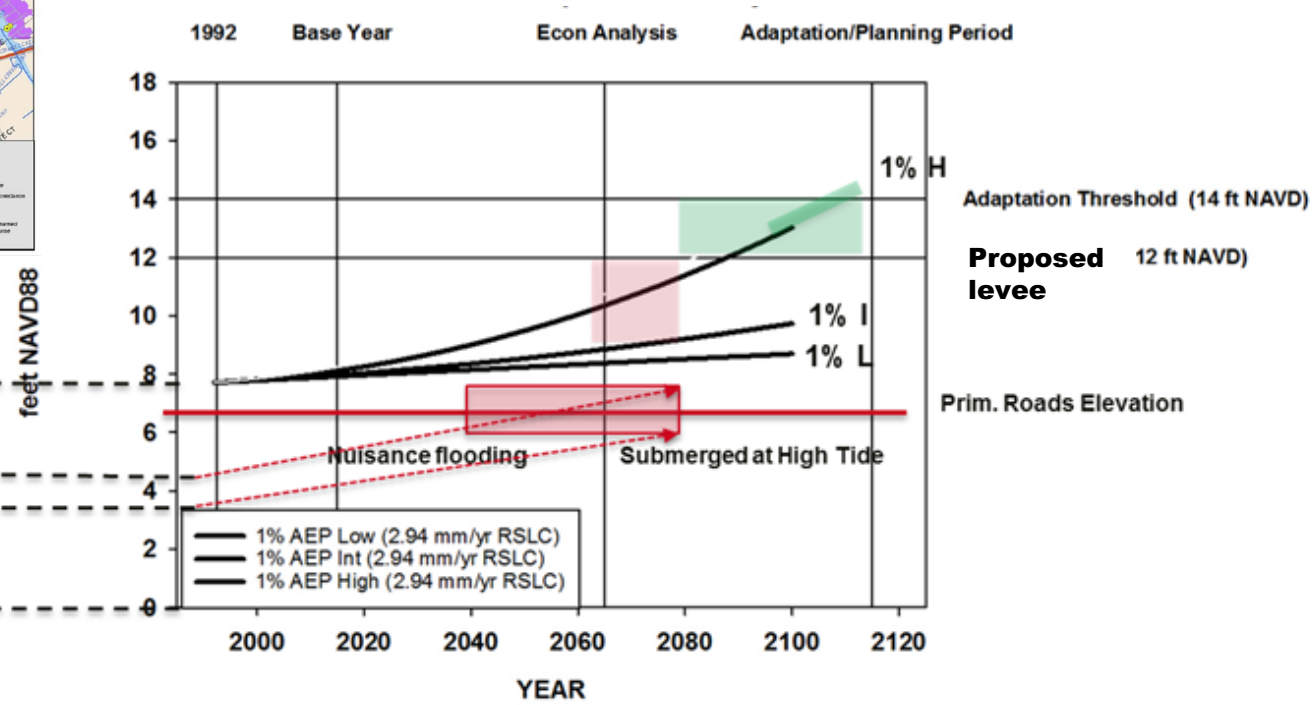


Cr. Elev # 1
Primary Roads

If Primary Road elevations = 6 to 8 feet, road and drainage infrastructure could be underwater or flooded for significant periods of time

Would non-structural measures (raising homes) be effective ?





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CPRR Summary Points

- CPRR Framework informs robust Coastal Vulnerability Assessments
- Tiered approaches possible, additional levels of detail may be added
- Approach is scalable, and be used on a wide range of coastal infrastructure types
- Allows for separable a design element analysis which may be incorporated into a systems approach which isolates the most vulnerable elements
- Design parameter uncertainty may be incorporated into the vulnerability assessments as more information becomes available using reliability-time series
- The CPRR Framework is very effective in assessing adaptive and resilience measures necessary to maintain performance of existing coastal infrastructure and for planning/engineering proposed coastal infrastructure

Case Studies, More Information

Colorado State University

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A framework for the analysis of coastal infrastructure vulnerability under global sea level rise

The assumption of hydrologic stationarity has formed the basis of coastal design to date. At the beginning of the 21st century, the impact of climate variability and future climate change on coastal water levels has become apparent through long term tide gauge records, and anecdotal evidence of increased nuisance tidal flooding in coastal areas. Recorded impacts of global sea rise on coastal water levels have been documented over the past 100 to 150 years, and future water levels will continue to change at increasing, unknown rates, resulting in the need to consider the impacts of these changes ...

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