Ben C. Gerwick, Inc.

Adaptive Measures for Sea Level Change

Jack Gerwick
Jean Toilliez

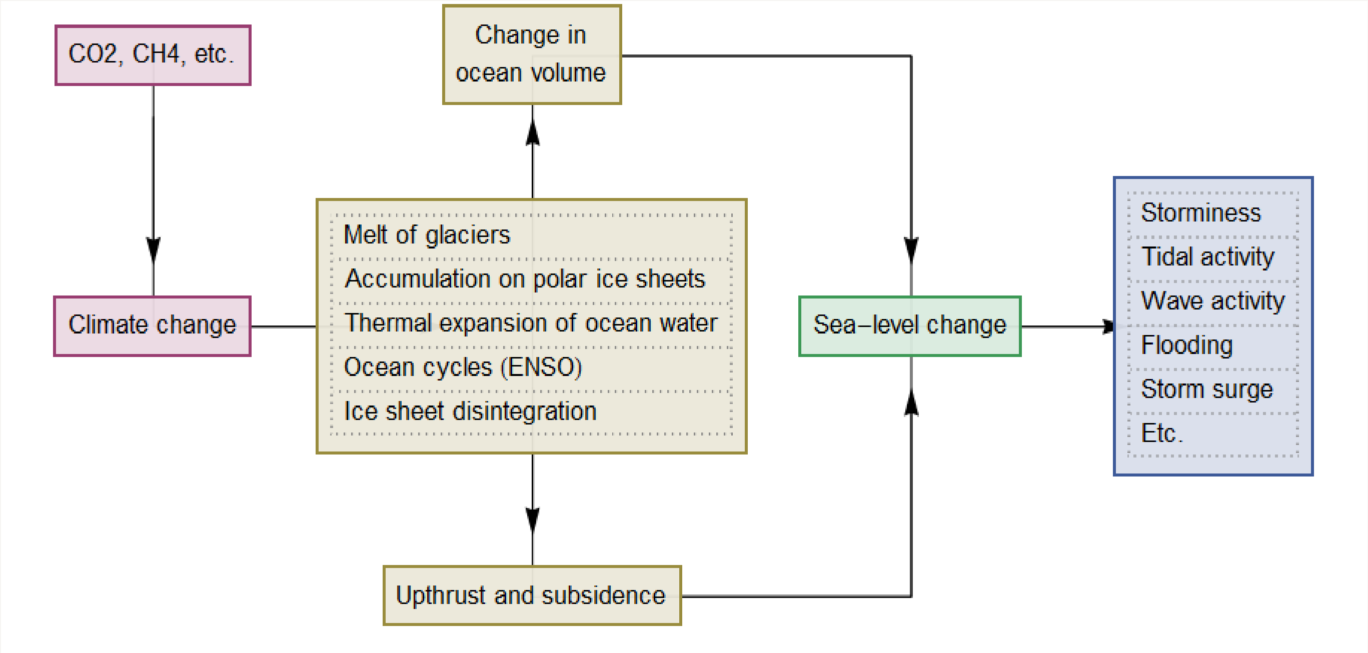
Ben C. Gerwick, Inc. | COWI

Outline

- Introduction to Sea Level Change
- Sea Level Change Project Approach
  - Inform
  - Analyze
  - Implement
- Case Studies
- Questions & Answers

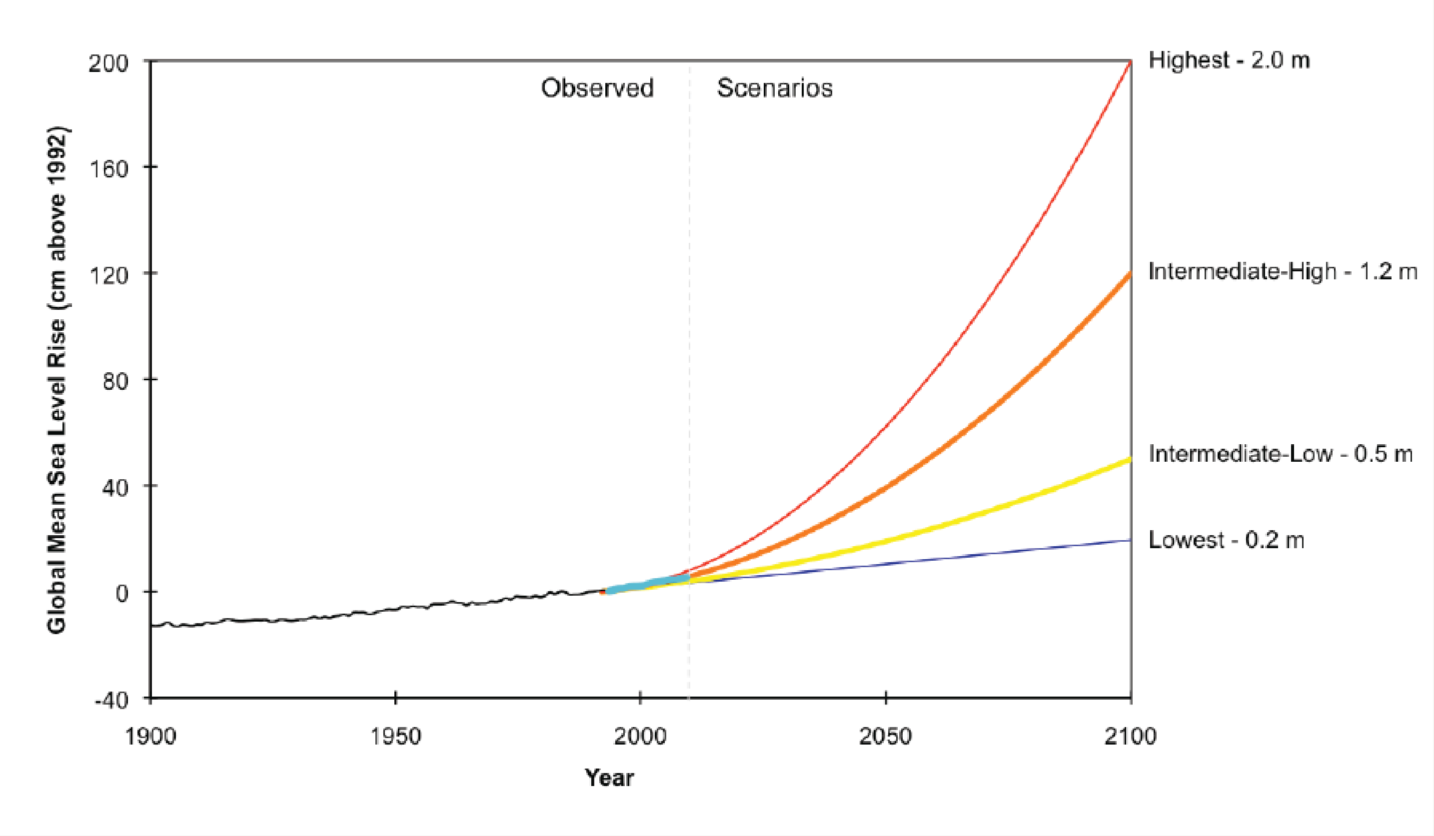
The Process of Sea Level Change

- Sea levels have been changing for millions of years.
- Common concern is that sea level rise is accelerating globally.
- There are both **global** and **local** contributing factors to the effect of sea level change.



Ben C. Gerwick, Inc. | COWI

Sea Level Change Projections

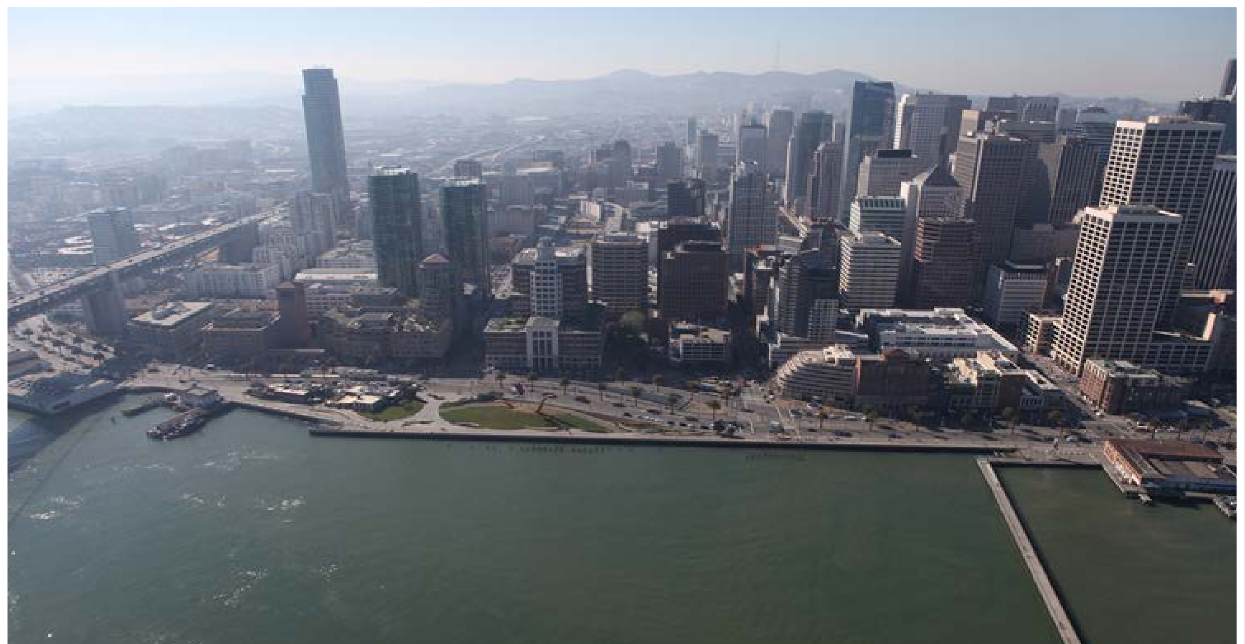


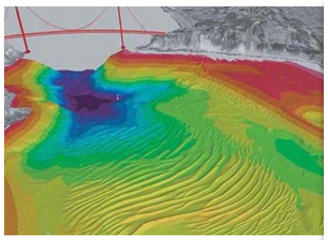
Ben C. Gerwick, Inc. | COWI

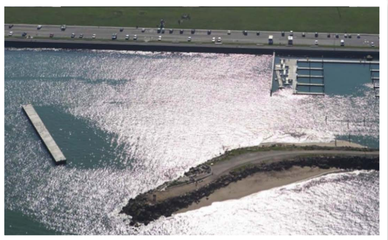
California Regulatory Environment

- MOTEMS (2013 CBC)
  - All MOTs shall consider the predicted SLR over the remaining life of the terminal. Consideration shall include variation in fender locations, additional berthing loads, and components near the splash zone.
- Bay Conservation and Development Commission (BCDC)
  - New projects affected by future sea level rise must be set back from shoreline to avoid flooding, be elevated above expected flood levels, be designed to tolerate flooding, or employ other means of addressing flood risks.
- California Coastal Commission
  - Sea-Level Rise Policy Guidance provides recommended steps for addressing SLR in Coastal Commission planning and regulatory actions.

Sea Level Change Adaptation And Marine Infrastructure







INFORM **ANALYZE** **IMPLEMENT**

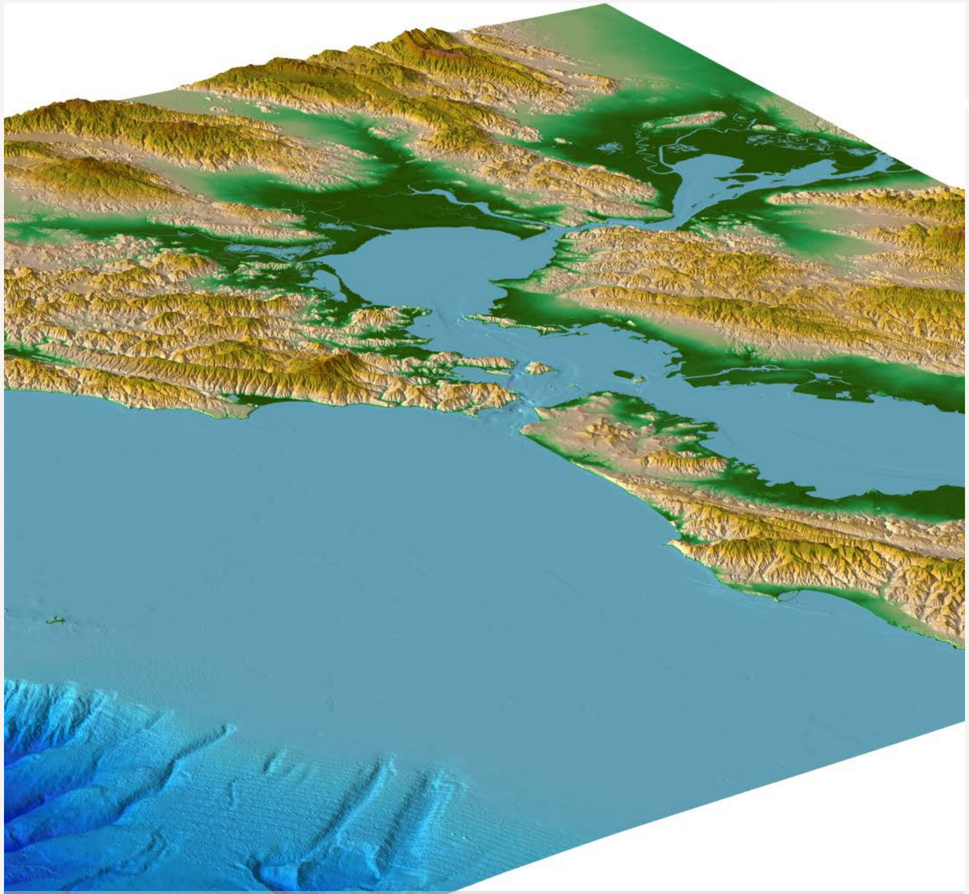
Define and Agree Upon the Scope for Analysis

- Agree upon the base assumptions
  - Consider the issues specific to the site/structure
  - Determine the design life
- Determine and prioritize the driving concerns
  - Define tolerable risk
  - Identify base and compounding factors
- Plan which scenarios to analyze
  - Define appropriate level of effort

Analyze

Data Acquisition

- Components
  - Maps
  - Facilities
  - Topography
  - Bathymetry
  - Geotechnical and Geological
  - Land uses

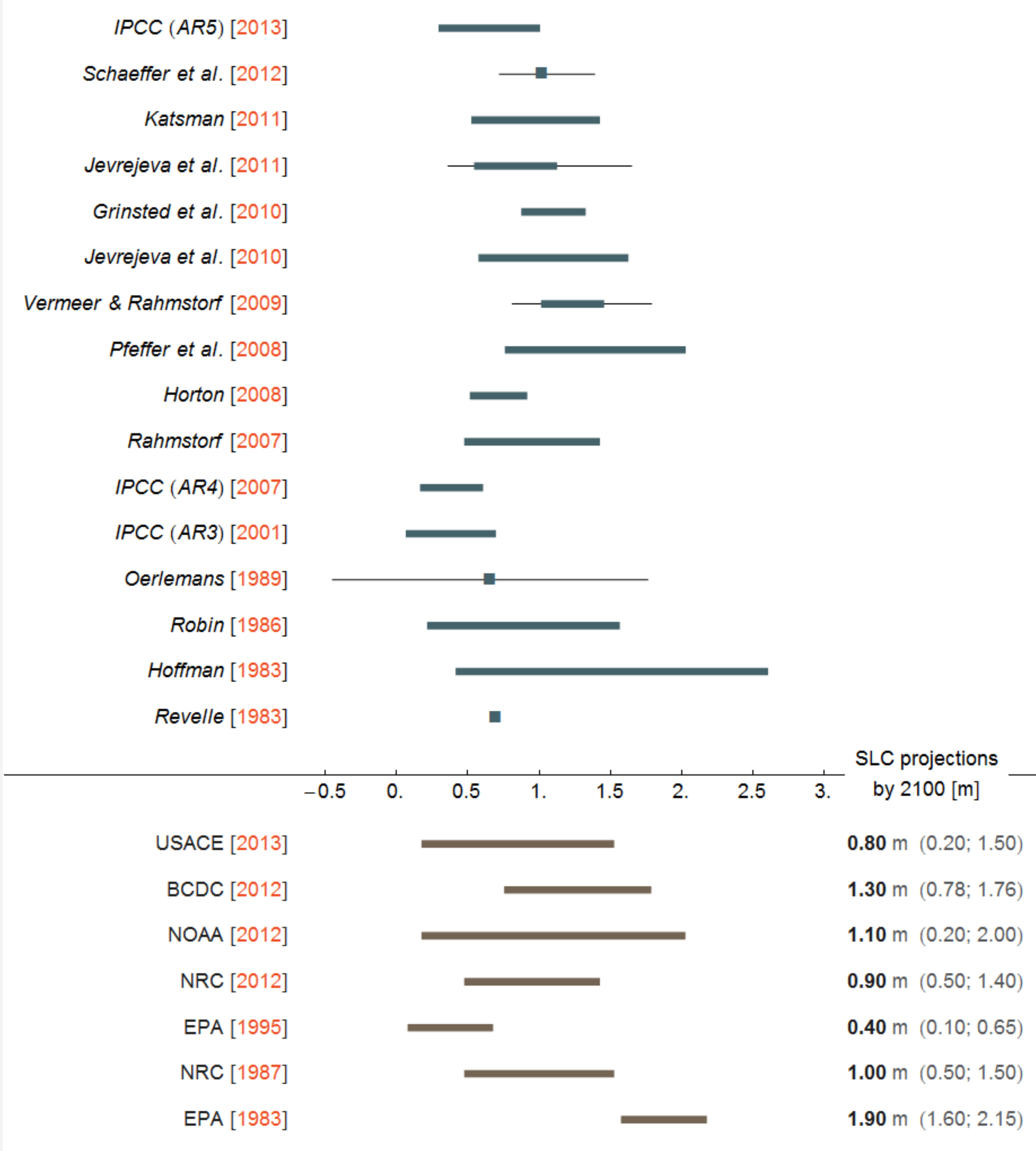


- NOAA Digital Elevation Model (DEM) of San Francisco Bay. Vertical exaggeration: 3. Vertical datum is NAVD88. (NOAA 2011)

Analyze

Long-term Projections

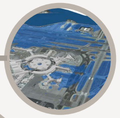
- Identify what projection is appropriate for the project
  - Can be based upon location as well as regulatory requirements
  - Owner tolerance for risk



Ben C. Gerwick, Inc. | COWI

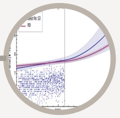
Analyze

Compounding Phenomena

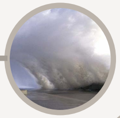


Eustatic sea level change

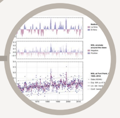
Simultaneity of events



Return periods



Waves



Ocean cycles

Ben C. Gerwick, Inc. | COWI

Analyze

Simultaneity of Events

- Component stack
  - Astronomical Tides
  - Rainfall
  - Tsunami
  - Surge
- Flooding response can be non-linear
  - Small variations: big consequences
- Other things to consider
  - Effect on tidal cycles
    Flick et al. 2003
  - Longer storm duration
    National Research Council 2012

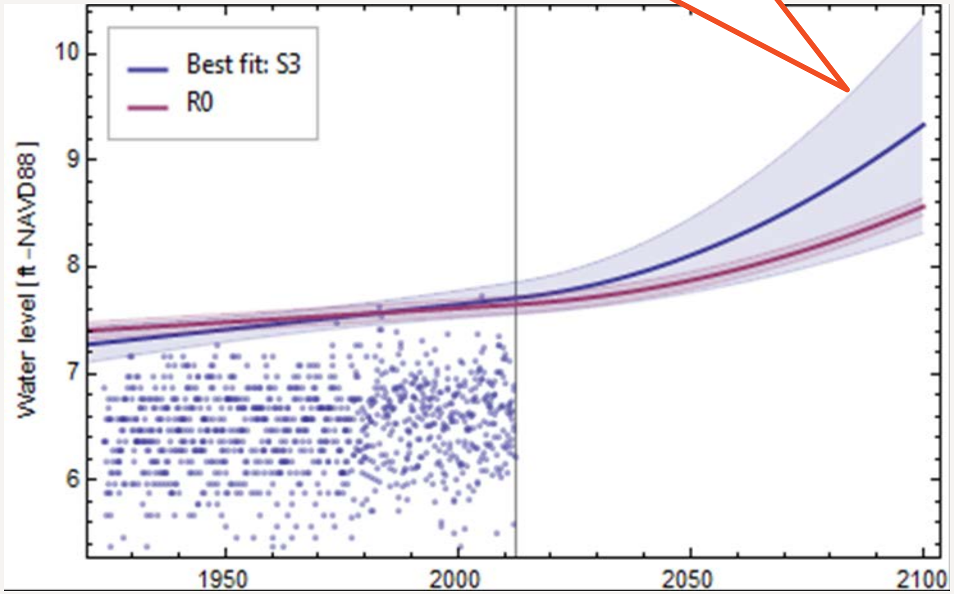
Ben C. Gerwick, Inc. | COWI

Analyze

Return Periods and Levels

- Return level is increasing
  - Higher elevations
- Return period is decreasing
  - Rare events are now more frequent
- Cumulative risk of occurrence is increasing"
  - $P = 1 - \left(1 - \frac{1}{T(t)}\right)^n$

With sea-level rise, the "100-year" flood level **today** is not the same as the "100-year" flood level in **50 years**



Analyze

Wave Height and Storminess

- Waves
  - Larger
  - More frequent
- Flooding
  - Overtopping
  - Run-up
- Loads
  - Slamming
  - Breaking
  - Erosion

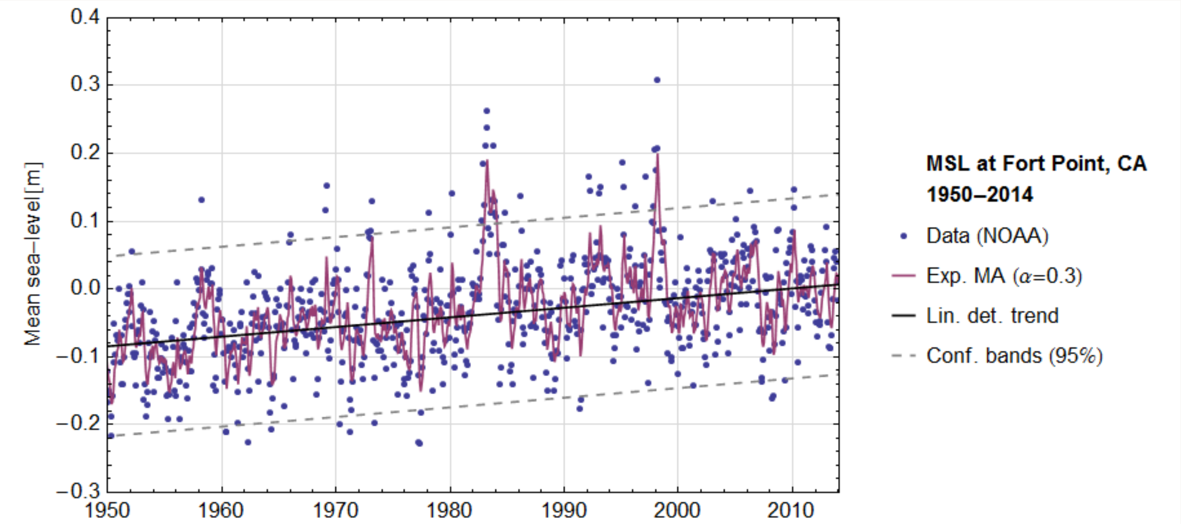
- "For the coast of the U.S. Pacific Northwest over 30 years, wave height increases have had a more significant role in the increased frequency of coastal flooding and erosion than has the rise in sea level." – *Ruggiero, 2013*

Global versus Local Sea Level Change

- Although a global increase in sea level is a key consideration, local dynamic response of the land is also important
- This is a key LOCAL factor affecting NET sea level change
  - Induced by subsidence, subsurface resource extraction (oil/gas/water), glacial rebound, permafrost degradation, continental plate movement
- Examples
  - Cook Inlet, AK has a negative NET sea level rise due to regional ground uplift; -17 mm/year
  - Grand Isle, LA had a NET sea level rise ~3x greater than the global trend in the 20th century; +10 mm/year

Global vs. Local Trends

- Mean sea-level is dependent on many physical parameters
- Mean may possibly deviate from historical trends and long-term projections
- **Illustration**
  - Fort Point, CA
  - MSL exhibits strong positive deviations from historical trends
  - These two events point out to strong El Nino phases



Cost Consequences of Failure

Photograph GP_ 11

1) Direct damages

(e.g. structures, equipment, freight, land, etc.)

2) Indirect costs

(e.g. lost wages, business interruptions, cleanup costs)

Rotten Meat From Katrina Still in Gulfport Neighborhood

"It's nine months now. They say, 'Well, you ought to be used to it by now.' You ain't gonna get used to that smell. My gosh," said resident Gary Tatum.

The meat had been stored at the Port of Gulfport. Katrina washed it in to yards covering an eight block span. The meat in the yards has been picked up, but the meat in hard-to-see areas has not.

3) Intangible consequences

(e.g. quality of life, environmental damages, loss of essential services)

Analyze

Integrated Information Supports Smart Decision-Making

AUTODESK. esri Ben C. Gerwick, Inc. | COWI

Path Forward
Alternatives to Consider

Protect

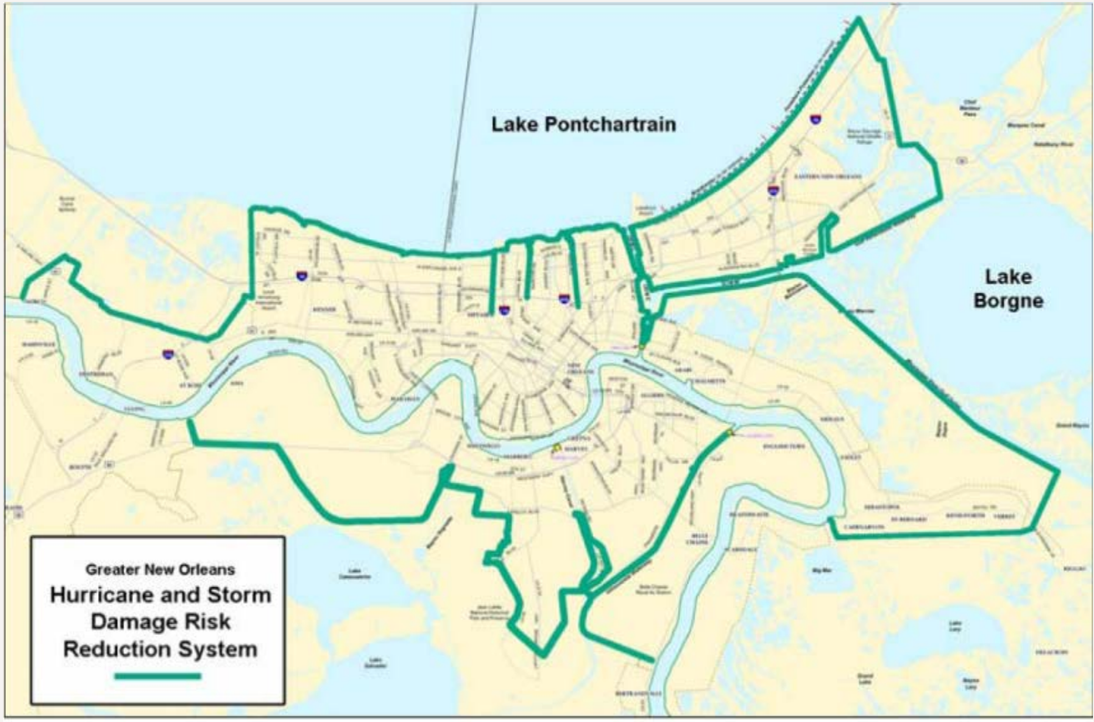
Accommodate

Manage

Case Study - Protect

IHNC Storm Surge Barrier

- Hurricane Katrina in 2005
- USACE Protection System for New Orleans



Case Study - Protect

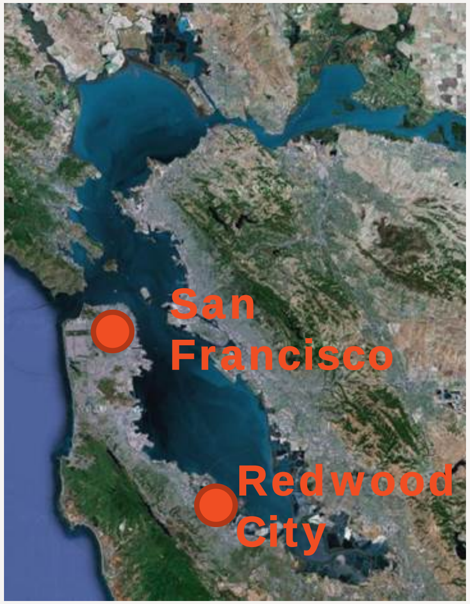
IHNC Storm Surge Barrier

- Floodwall with navigable gates
- SLR, subsidence, and local settlement considered

Ben C. Gerwick, Inc. | COWI

Port of Redwood City

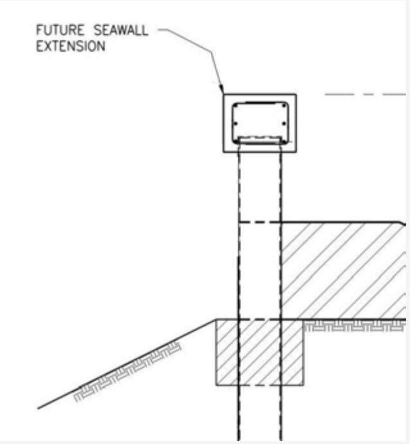
- Project Features
  - Aggregate Berth
  - Seawall
  - Building
- Sea Level Change
  - Consideration of required by BCDC
  - Site was subject to flooding so new seawall was required regardless of sea level change considerations



Case Study - Accomodate

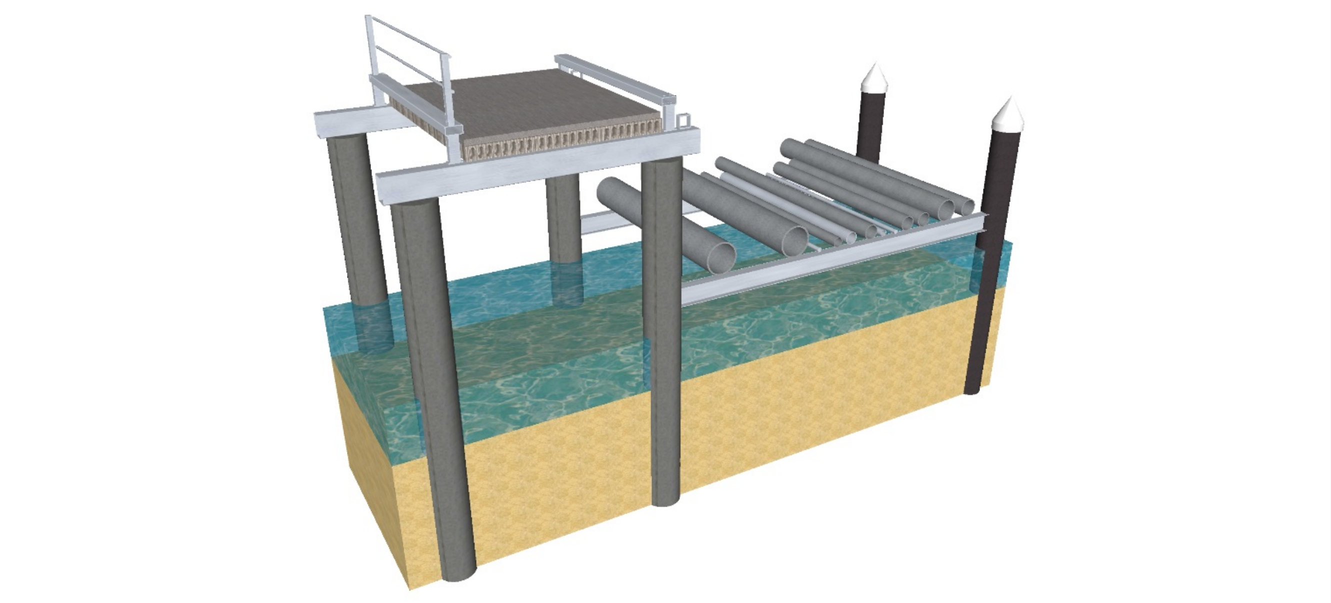
Port of Redwood City

- Flooding
  - Seawall
  - Adaptive design
- Operations
  - Utilities
  - Mooring and Berthing Hardware and Geometry
  - Deck Elevation for Loading Operations



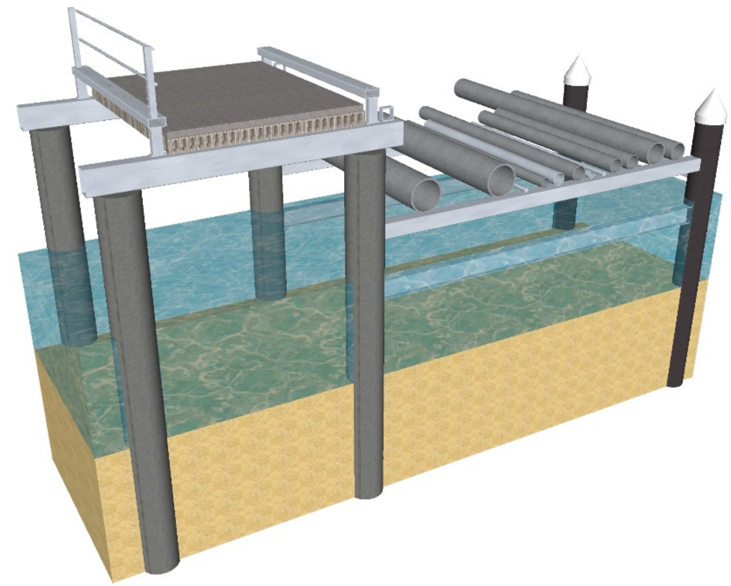
Case Study – Pipeway and Roadway

- Replace existing mile long trestle
- Improved seismic performance
- Improve access with addition of roadway
- SLR criteria
  - Consideration required by regulation
  - Challenge as existing piping will continue to service the marine terminal



Case Study – Pipeway and Roadway

- SLR Considerations
  - Higher pipeway beam included as part of design, however will not be installed until required
  - Existing piping would be removed, new beam installed, then new piping installed

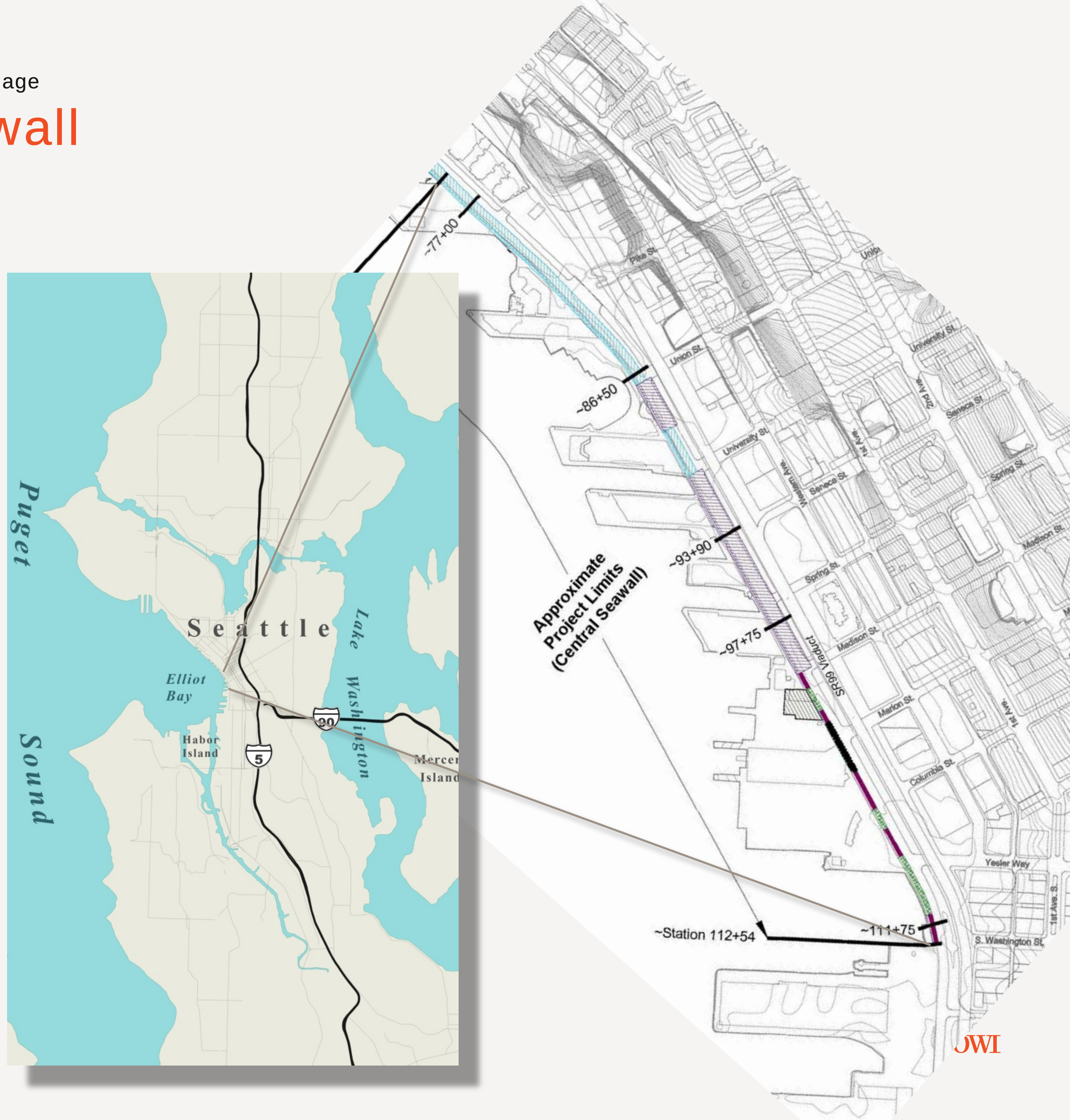


Ben C. Gerwick, Inc. | COWI

Case Study – Accommodate / Manage

Elliot Bay Seawall

- 3,500 ft long seawall replacement
- Project driven by seismic performance of existing wall
- Construction started with completion schedule for 2016



Case Study – Accommodate / Manage

Elliot Bay Seawall

- Varying levels of SLR scenarios considered
- Seawall Structure
  - Year 2100
  - High estimate
- Beach and Habitat
  - Year 2050
  - Medium estimate

Ben C. Gerwick, Inc. | COWI

Conclusions

- Projections of sea level change vary
  - Locally, globally, and within the scientific community
- Agencies have implemented sea level change into regulation
- Established a rational approach for incorporating sea level change considerations into design and have implemented practical measures to reduce risk