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CWEMF
California Water & Environmental Modeling Forum

Coastal Flooding Under Existing and Future Conditions: Verification of the Technical Methods Manual

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Coastal Flooding & Sea Level Rise in California

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Photograph by Bob Battalio: Beach Boulevard, Pacifica, CA, January 10, 2016

Presentation Overview

- Coastal Hazards: Wave Runup, Erosion, and Sea-Level Rise
- Regional Hazard Maps
- Technical Methods Manual
- Detailed Wave Runup Calculations using a Response-Based Analysis
- Comparison of Detailed Calculations to TMM Methods
- Conclusions

Photograph by Bob Battalio: Beach Boulevard, Pacifica, CA, January 22, 2016

Coastal Hazards: Wave Runup, Erosion, and Sea-Level Rise

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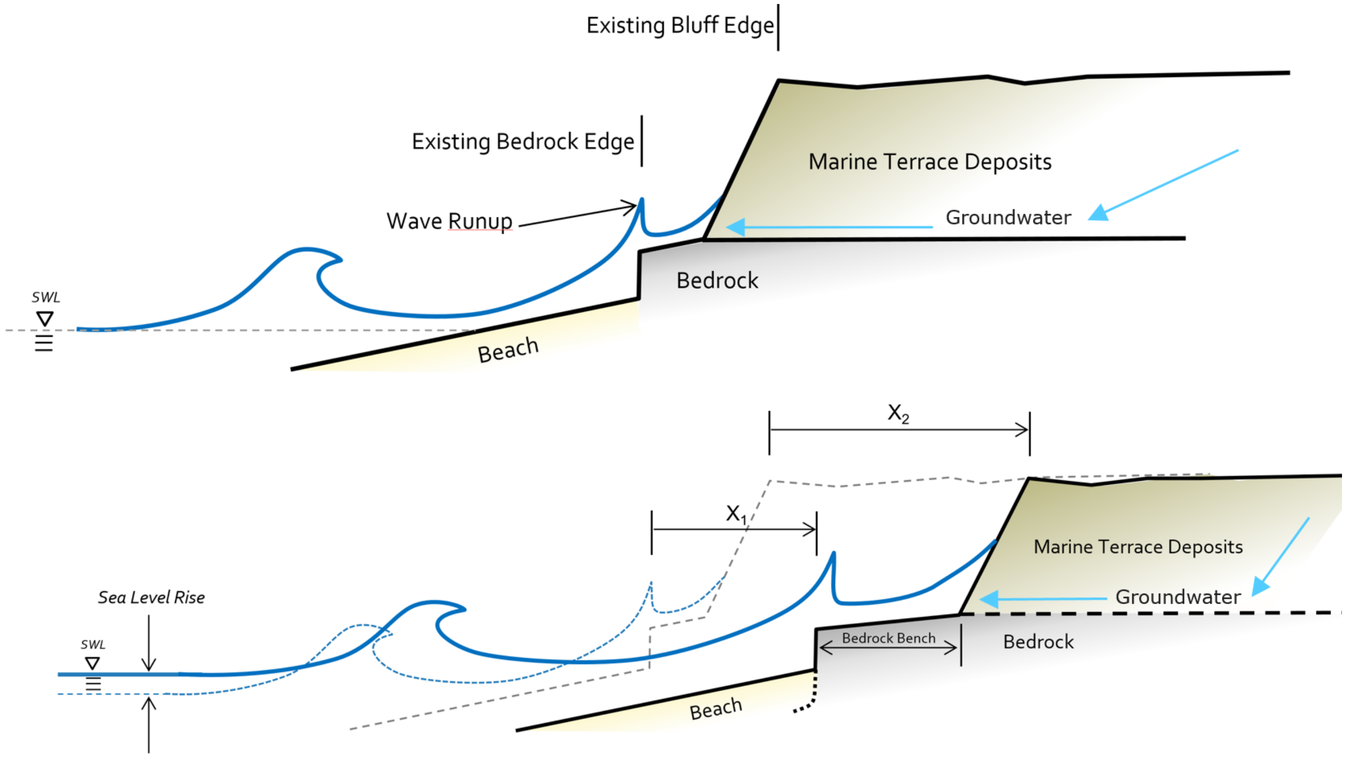
Coastal Flooding

- What causes coastal flooding?
  - High incoming waves (~ 15 feet high)
  - High water levels: storm surge, high tide (~ 5 feet above mean sea level)

- Extreme landward extents of wave runup
  - Intense wave breaking
  - Momentum transfer of incoming waves

Main factors

- Incoming wave characteristics:
  - long swells
  - short wind waves
- Beach Profile:
  - Mild slope
  - Steep slope
  - Mild slope with steep coastal barrier (common in California coast)
- Sea Level Rise



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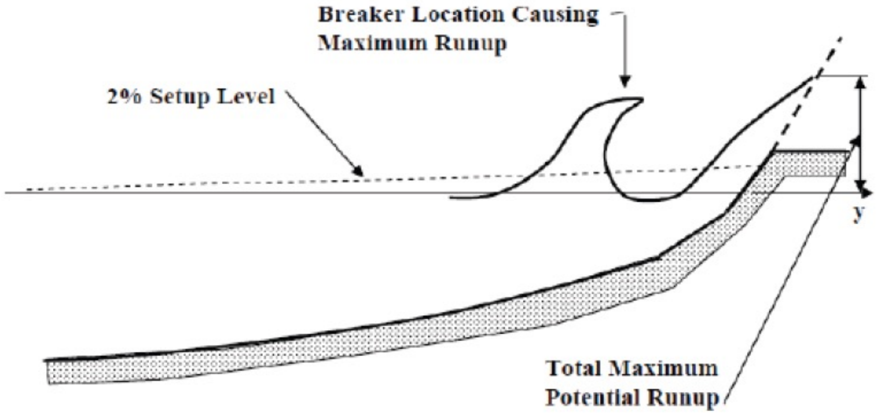
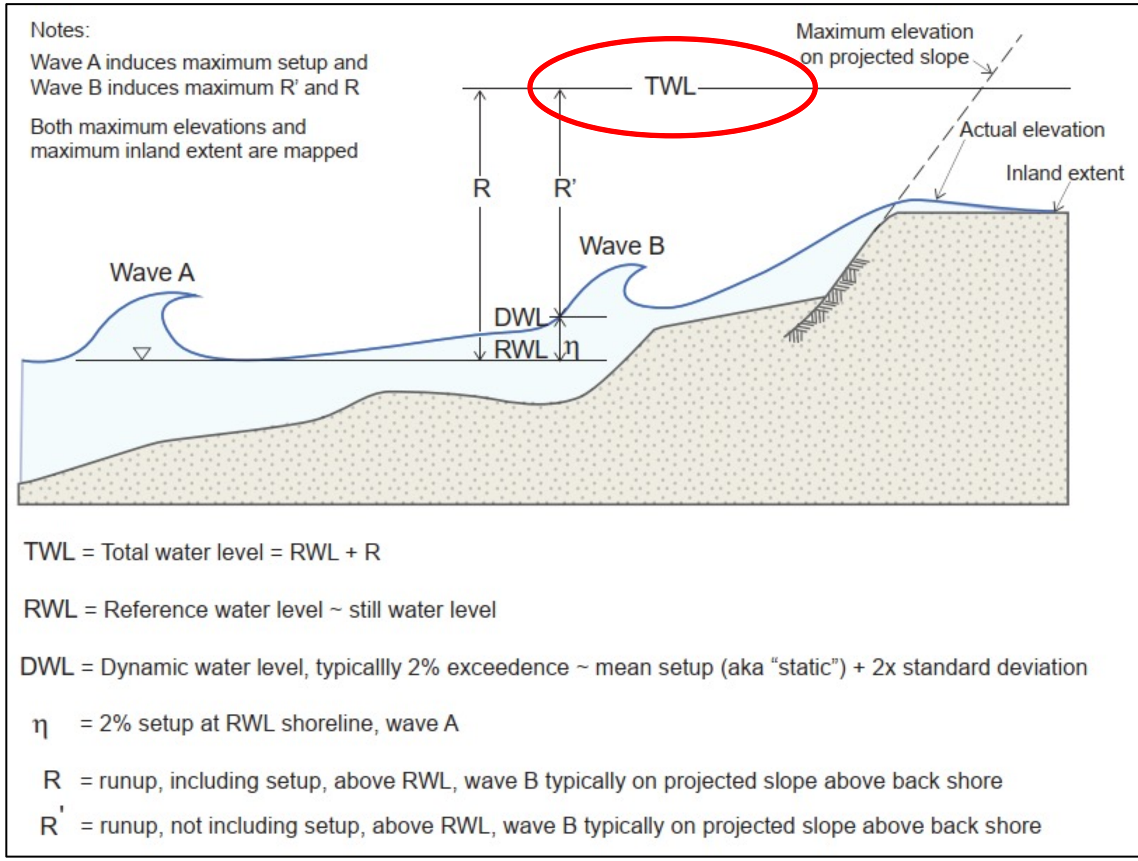
Wave Runup Methods

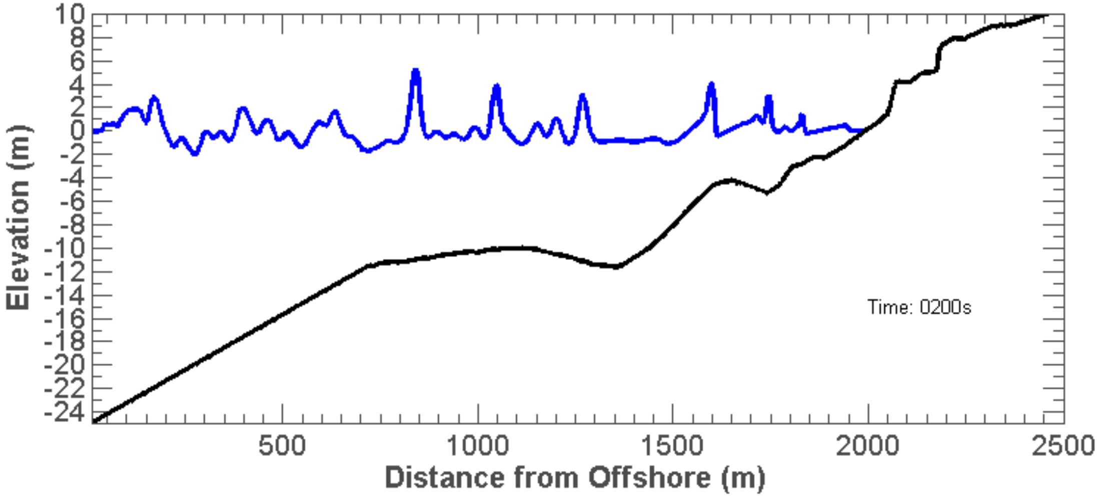
- Empirical methods using simple equations (e.g., Stockdon, TAW, etc.)
- Iterative methods with additional profile information (e.g., composite slope)



- Numerical methods (e.g., Xbeach, SWASH)

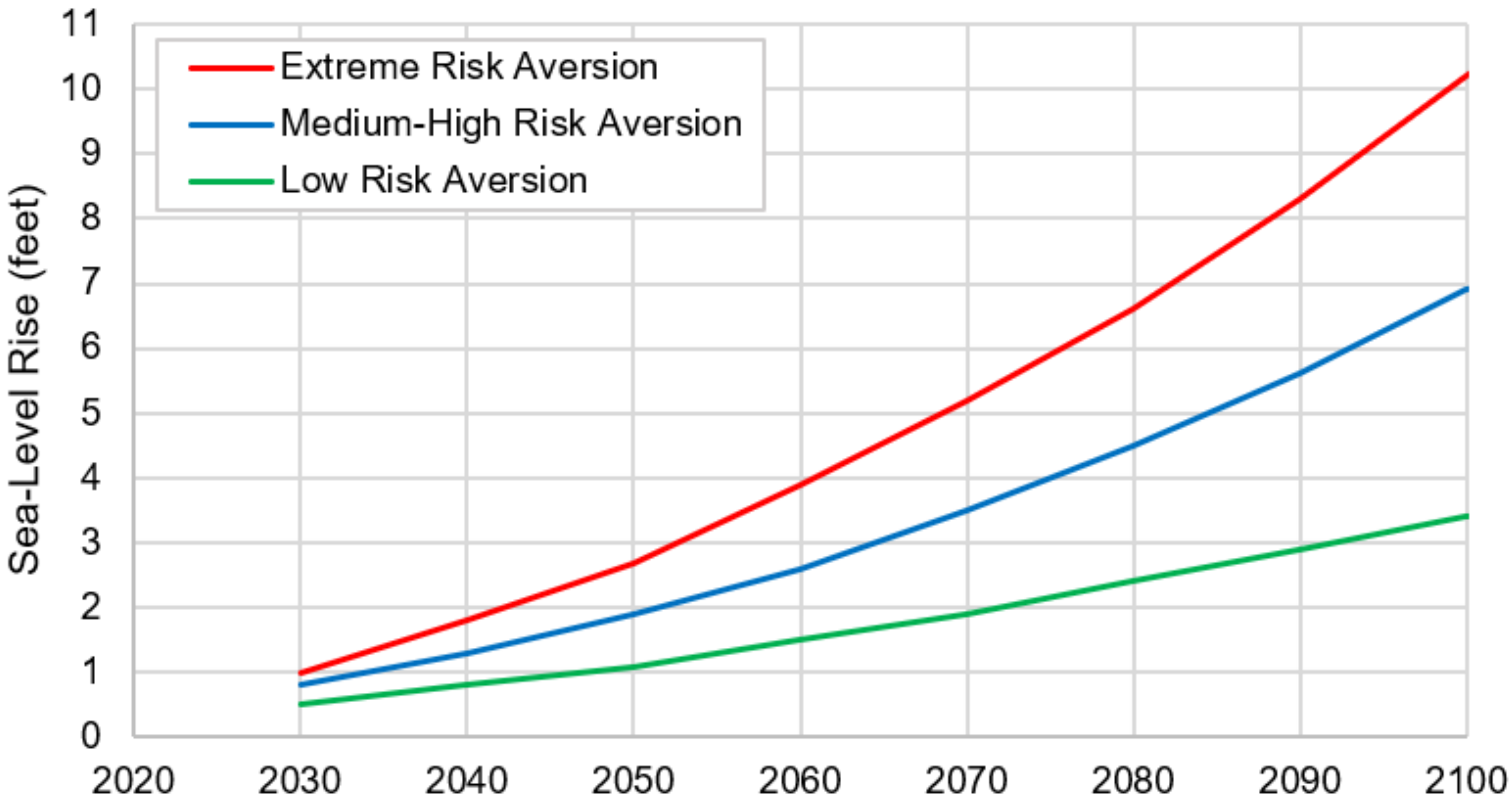


Source: Battalio et al. (2016)



Sea-Level Rise

- State of California Sea-Level Rise Guidance: OPC 2018
  - Three projections based on risk
  - Project out to 2150
- Federal Guidance: USACE, NOAA

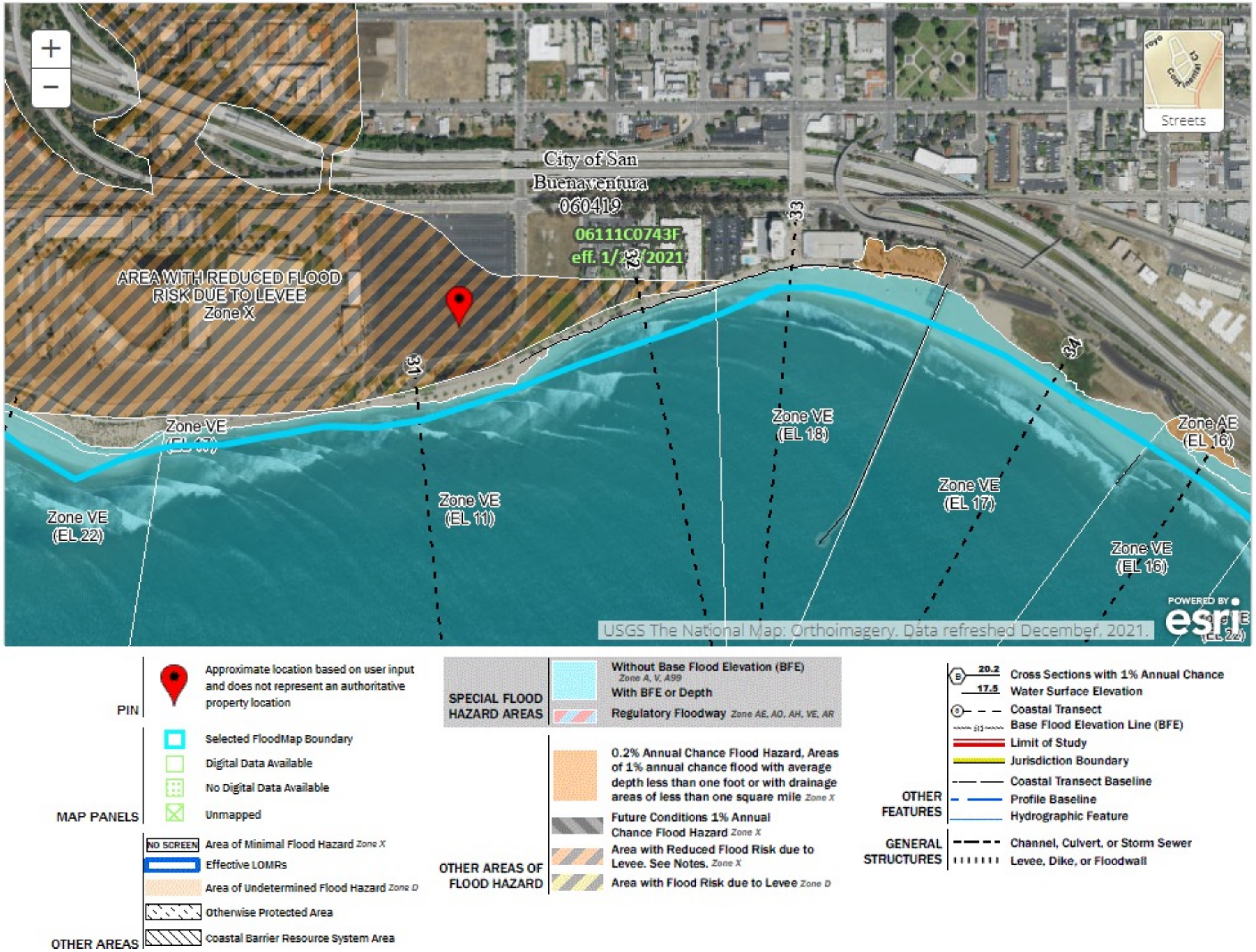


- Sea-Level Rise will accelerate and amplify coastal flooding

Regional Hazard Maps

FEMA Flood Maps

- Only for existing conditions (does not account for sea-level rise)
- Extreme wave runup extents / high velocity hazard zones
- Ponding, flooding areas
- 1% annual probability of occurrence (i.e., 100-year event)



Source: https://www.fema.gov/flood-maps

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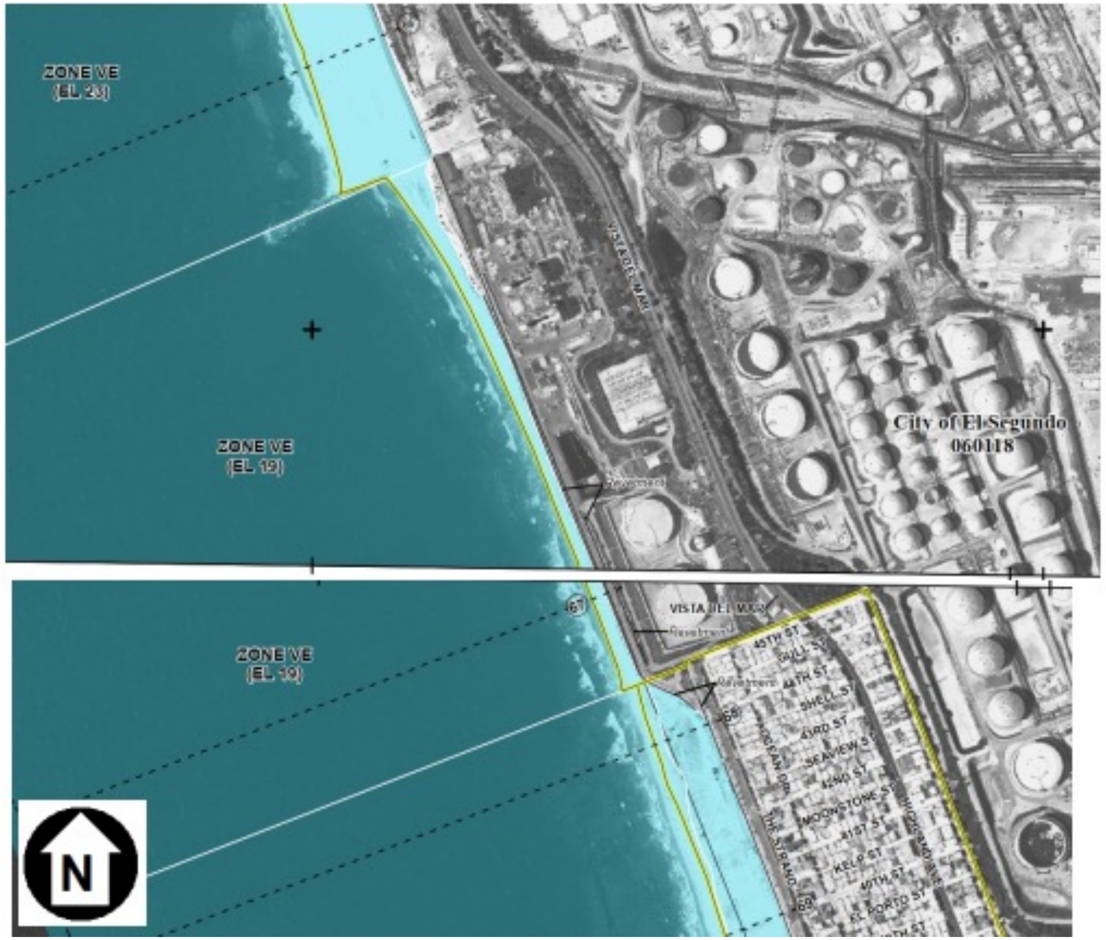
FEMA Map: Flood hazards for existing condition – no sea-level rise

- Example site on shore of El Segundo, Santa Monica Bay

- High-velocity wave hazard zone
- Elevation of flood zones



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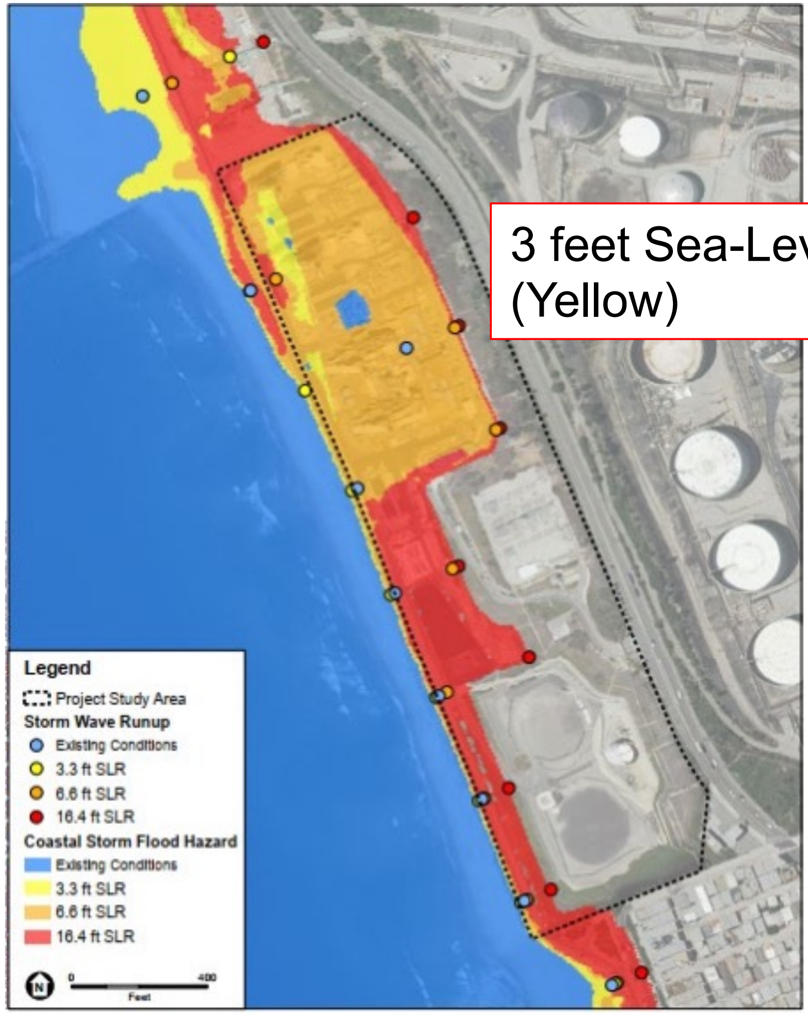
Future Conditions Maps: Coastal Resilience (left), CoSMoS (right)

3 feet Sea-Level Rise



3 feet Sea-Level Rise (Yellow)

- Example site on shore of El Segundo, Santa Monica Bay

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Technical Methods Manual

Technical Methods Manual

- Funded by DWR and Ocean Science Trust
- Purpose:

  Provide Guidance for the State to help planners and engineers modify existing FEMA maps to account for sea-level rise

- Peer-reviewed by experts from industry and public agencies (including Coastal Commission, FEMA, USGS, consulting firms, others)

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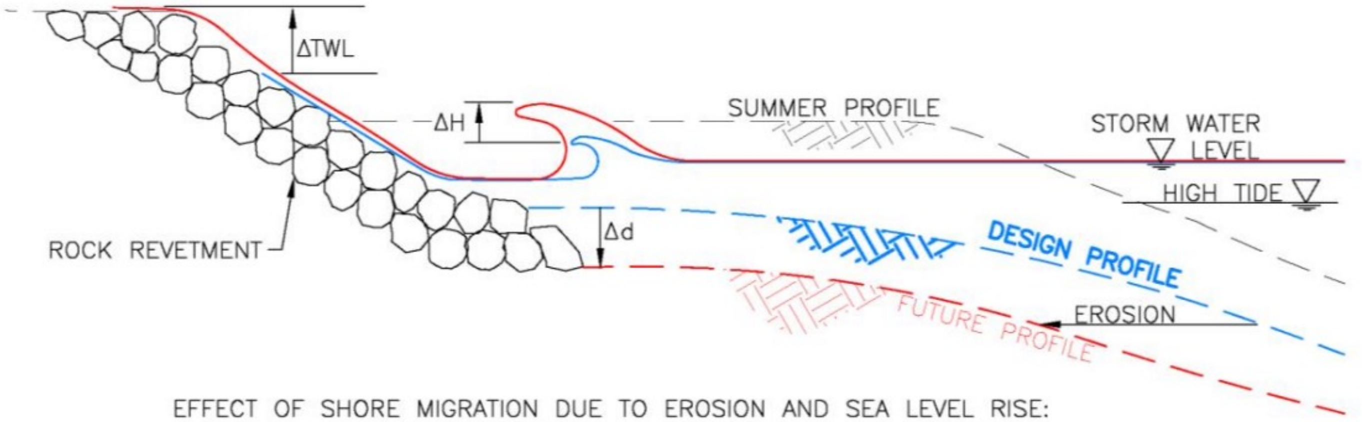
Battalio et al. (2016): https://www.oceansciencetrust.org/wp-content/uploads/2016/12/Technical-Methods-Manual_FINAL_2016_12_02_clean.pdf

Challenges in forecasting the flood extents

- Shore Morphology
  - How runup extends over different beach profiles?
  - How to incorporate morphology in runup calculations?
  - How to represent shore protection structures?
- Sea level rise
  - How to include the effect of SLR in runup extents?
  - How the beach profile responds to sea level rise?
  - Which sea level rise projection to use?

➢ Technical Method Manual:

- Adjusting FEMA maps for sea level rise
- Providing parametrized equations
  - Including the effect of beach profile shape
  - Parameterizing beach morphology responses under rising sea levels
  - Overtopping and landward extent of V-Zone



EFFECT OF SHORE MIGRATION DUE TO EROSION AND SEA LEVEL RISE:

1. BEACH NARROWS AND DROPS IN ELEVATION
2. WATER DEPTH AT STRUCTURE INCREASES (Δd)
3. BREAKING WAVE HEIGHT INCREASES (ΔH≈Δd)
4. WHEN ΔH/Ho≥1.5, STRUCTURE FAILURE POSSIBLE
5. TWL INCREASES, CAN RESULT IN OVERTOPPING
   ΔTWL ≈ 2ΔH TO 4ΔH
6. SLR INCREASES ALL PARAMETERS DIRECTLY IN ADDITION TO SHIFTING PROFILE LANDWARD, CUMMULATIVE EFFECT IS STRUCTURE FAILURE & FLOODING

Figure 3.4
Response to SLR on Armored Backshores with Depth-Limited Breaking Waves

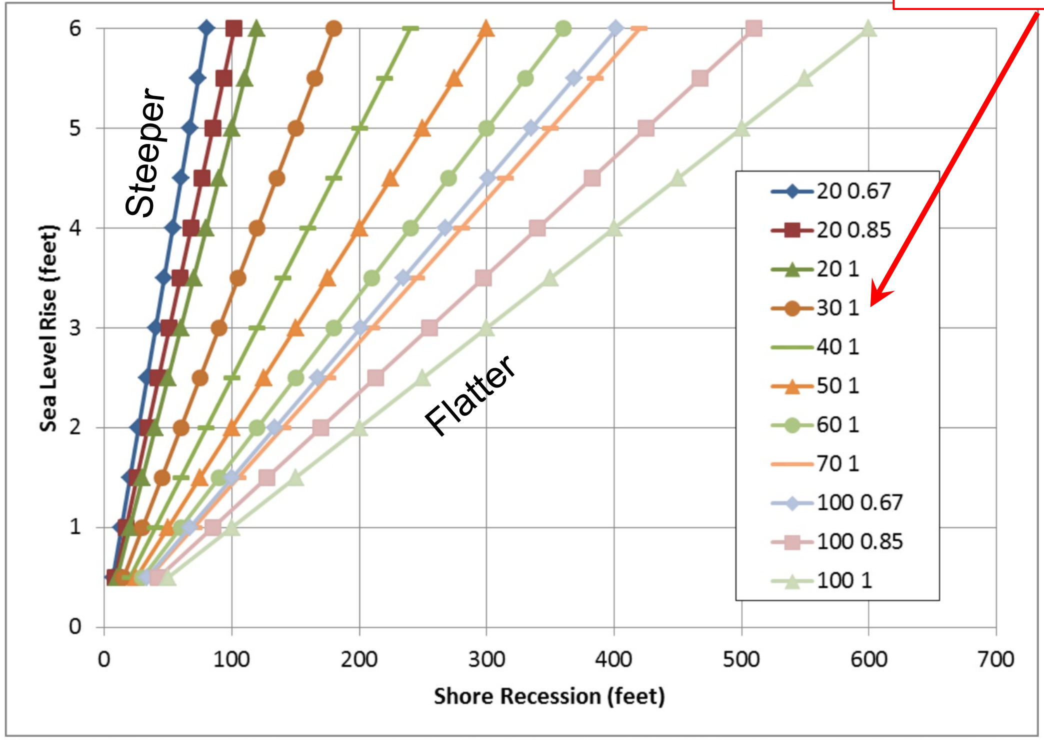
Technical Methods Manual

- Parameterizing shore recession under sea level rise

Shore recession = a*(SLR/shore face slope)

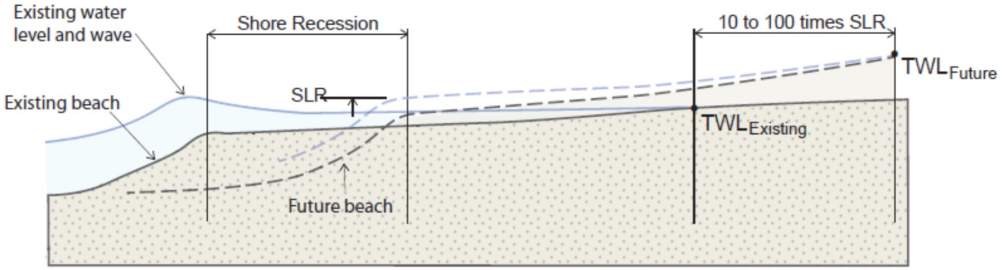
a = dune face reduction factor
- Function of shore face depth and effective dune height

Inverse of Slope of shore

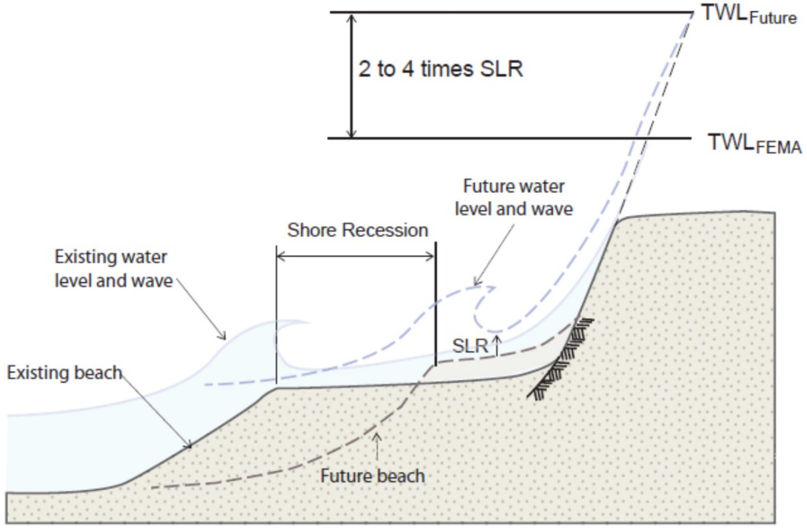


In the legend, the first number is the inverse of the slope (e.g. 20 indicates a slope of 1/20=0.05) and the second number is "a." Note that "a" does not have a great effect for the steeper slopes

Figure 3.2
Plot of Relative Shore Recession for a Shore Face Depth of 40 Feet and a Range of Reduction Factor "a" Values Associated with Backshore Sand Contributions



Erodible backshore: TWL future = TWL existing + SLR and shore recession



Erosion resistant backshore: TWL future = TWL existing + (2 to 3) SLR

Figure 3.1
Shore Morphology response to sea level rise and effect on total water level for erodible (top) and erosion resistant (bottom) backshores. These are schematics, and not to scale: Specifically the shore recession (top) should be 10 to 100 times the SLR but is drawn only about 2 times greater in order to fit on the page, See Figure 3.2 for computed distances.

Technical Methods Manual

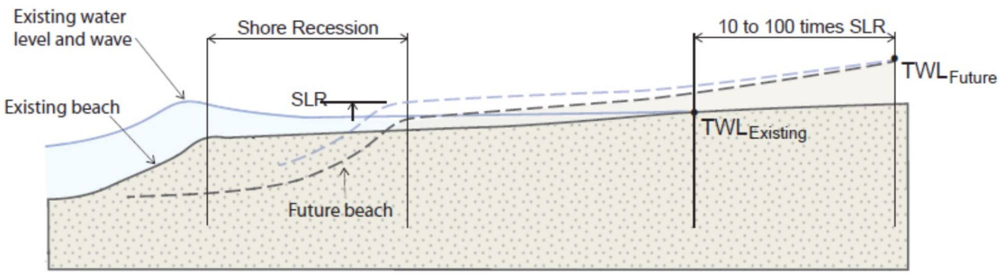
- Parameterizing runup extents with sea level rise

$$TWL_{future} = TWL_{existing} + SLR*F(Morphology)$$

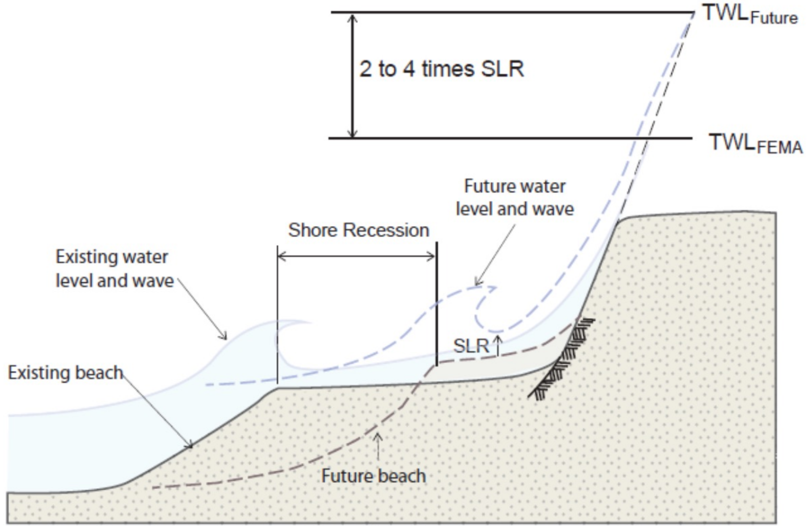
- F (morphology) = 1, erodible backshores
- F (morphology) = 1 to 4 **(or higher)**, erosion resistant backshores

TABLE 3.1
MORPHOLOGY FUNCTION SUMMARY

Backshore	Waves	Morphology Function (MF) values, ΔTWL=(MF)*SLR	Explanation and simplifying assumption
Erodible		1.0	Shore adjusts to sea level rise, runup does not change
Erosion resistant	non-breaking waves	1.0	Runup does not change
Erosion resistant	breaking waves –default values	2.0 to 3.0 2.0	Backshore cannot adjust, runup is amplified: Intermediate range and value
Erosion resistant	breaking seas	2.0 to 2.5+ 2.0	Backshore cannot adjust, runup is amplified: High steepness seas have lower relative runup
Erosion resistant	breaking swell	3.0 to 4.0+ 3.0	Backshore cannot adjust, runup is amplified: Low steepness swells have higher relative runup



Erodible backshore: TWL future = TWL existing + SLR and shore recession



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Detailed Calculations of Wave Runup using a Response-Based Analysis

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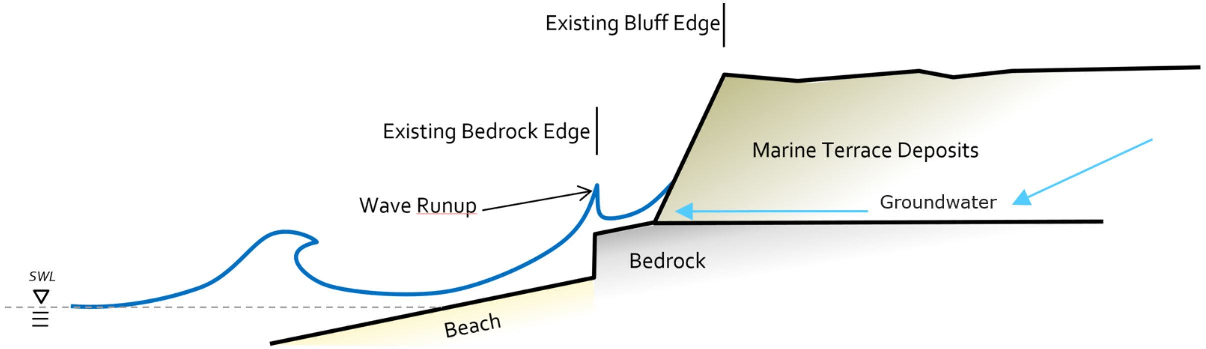
Overview of Response-Based Analysis

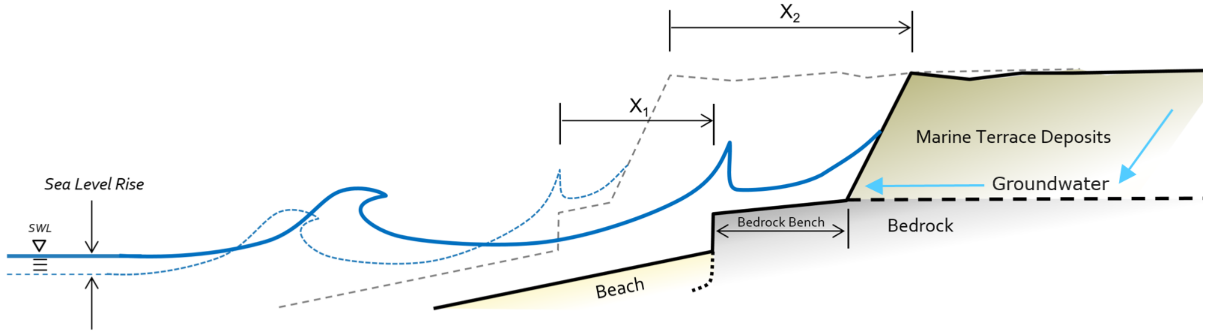
- Focuses analysis on "response" parameter as opposed to inputs
  - → Wave runup (TWL) = Response Parameter
  - → Wave height, period, water level = Input Parameter
- Requires coincident input data: wave height and period, water level, profile conditions
- Time-series based approach: Statistical analysis performed on computed wave runup for duration of modeled storm events

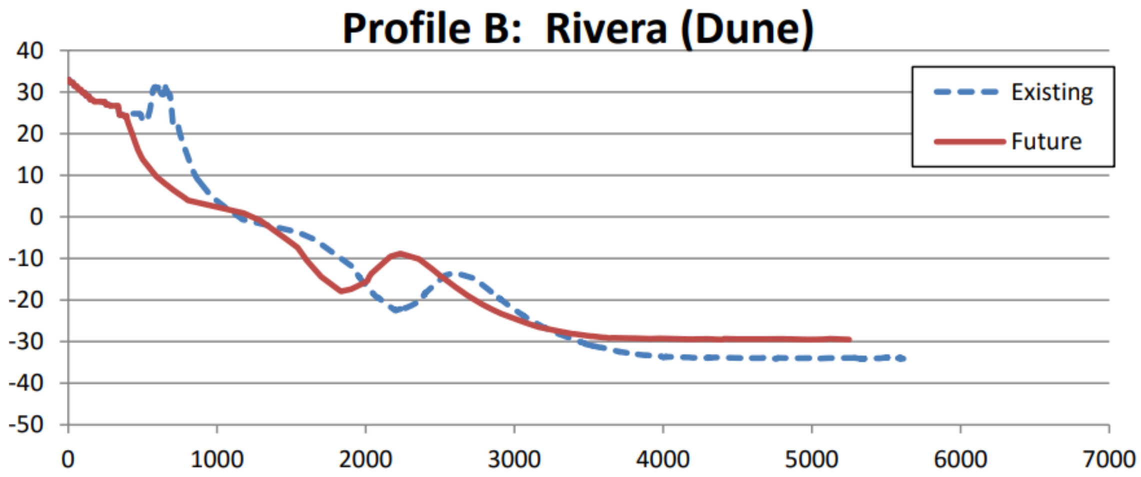
- Note
  - Specific wave and water level conditions that result in 100- and 500-year events not explicitly known and could result from several combinations of wave and water levels
  - Yields a more realistic representation of statistics as compared to the "event selection" approach, where wave and water level are assumed to be independent random variables, and selected to result in an approximate 100-year (or other) event

Shore Response – Used in Wave Runup Calc

- Beach (erodible)
- Bluff (erosion resistant)
- Shore Protection Structure (erosion resistant)







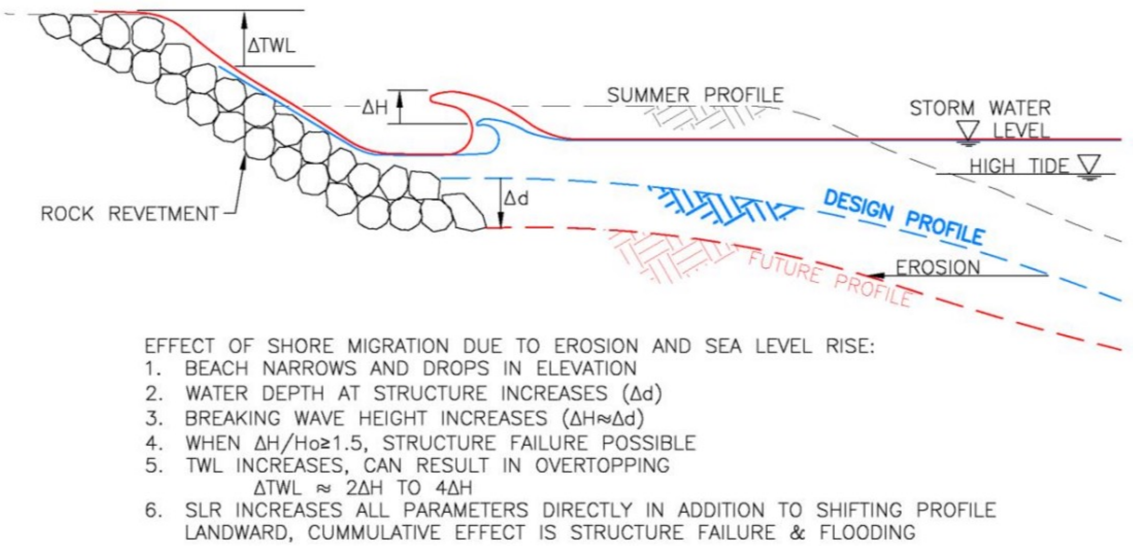
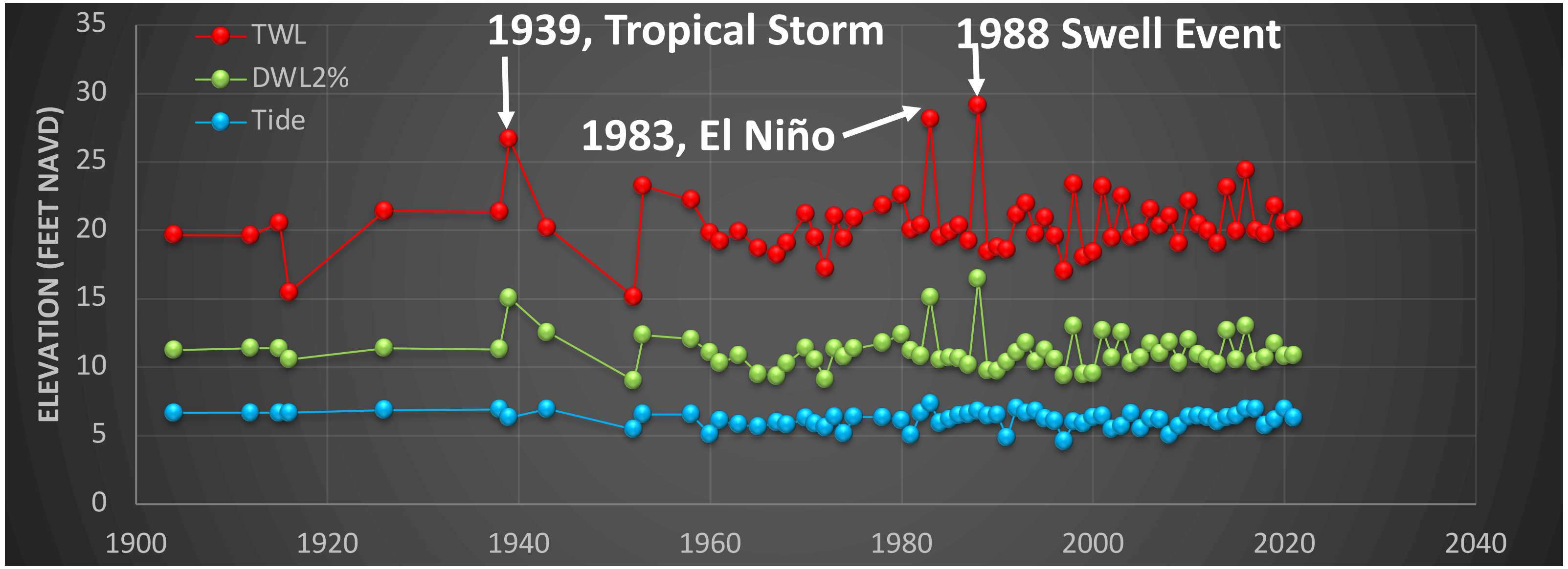


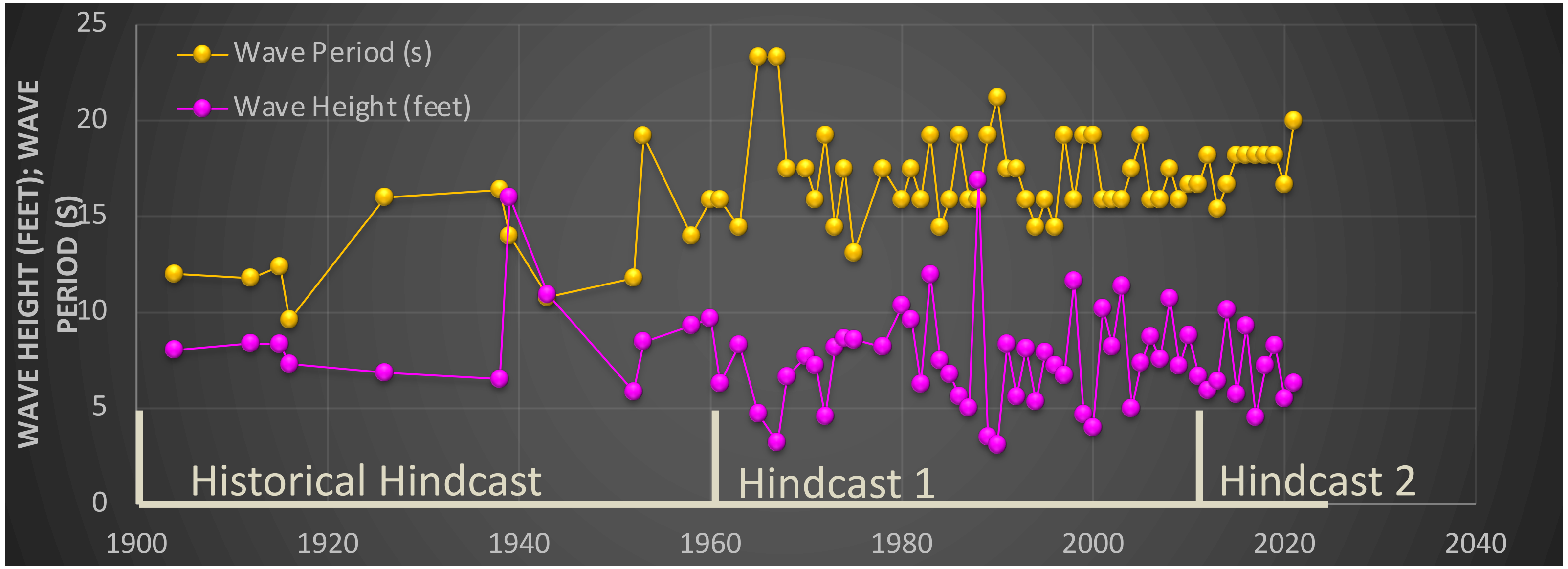
Figure 3.4
Response to SLR on Armored Backshores with Depth-Limited Breaking Waves

Response-Based Analysis: Annual Max Coincident Water Level-Wave Events

- Top Plot
  - Total Water Level
  - Dynamic Water Level 2%
  - Still Water Level (tide)
- Bottom Plot
  - Unrefracted Wave Height, Ho'
  - Wave period

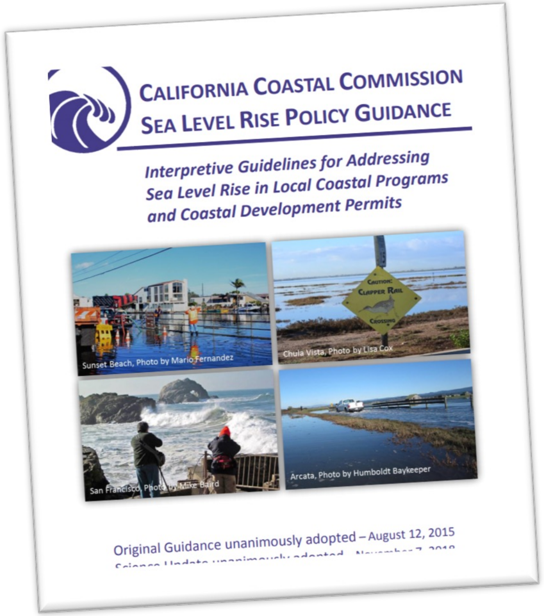
- Time series of computed annual max TWL from coincident wave and water level conditions





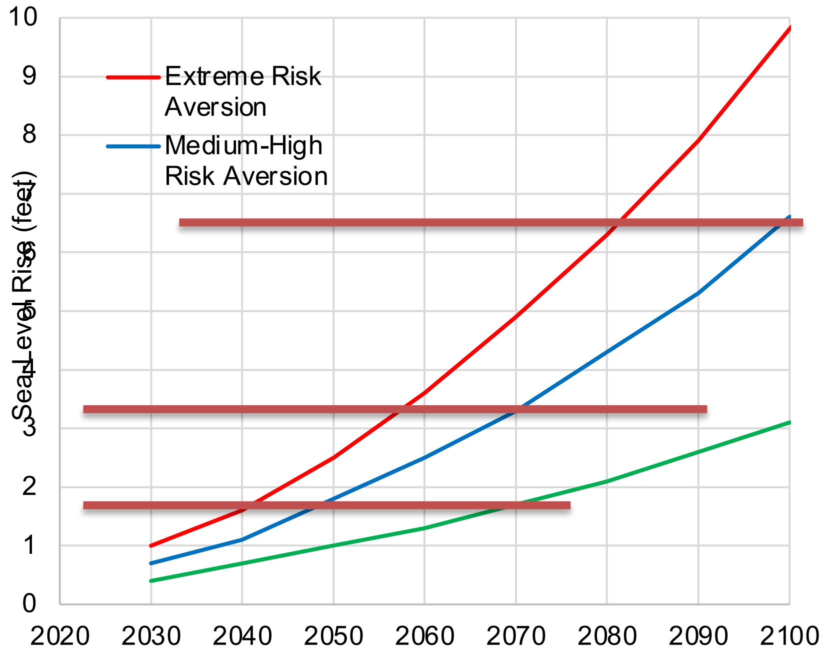
Incorporating Sea-Level Rise

- Established the projected sea level rise range for the proposed project
  - Define Expected Project Life
  - Determine Sea Level Rise Range
- Estimate wave runup for existing conditions
- For future cases with sea-level rise:
  - Compute new profile: shore response analysis
  - Re-compute wave runup calculations to yield future time series of TWL
  - Conduct extreme value analysis on results



- Select SLR values used based on risk aversion (med-high shown)

year	SLR (feet)
2050	1.8
2070	3.3
2100	6.6



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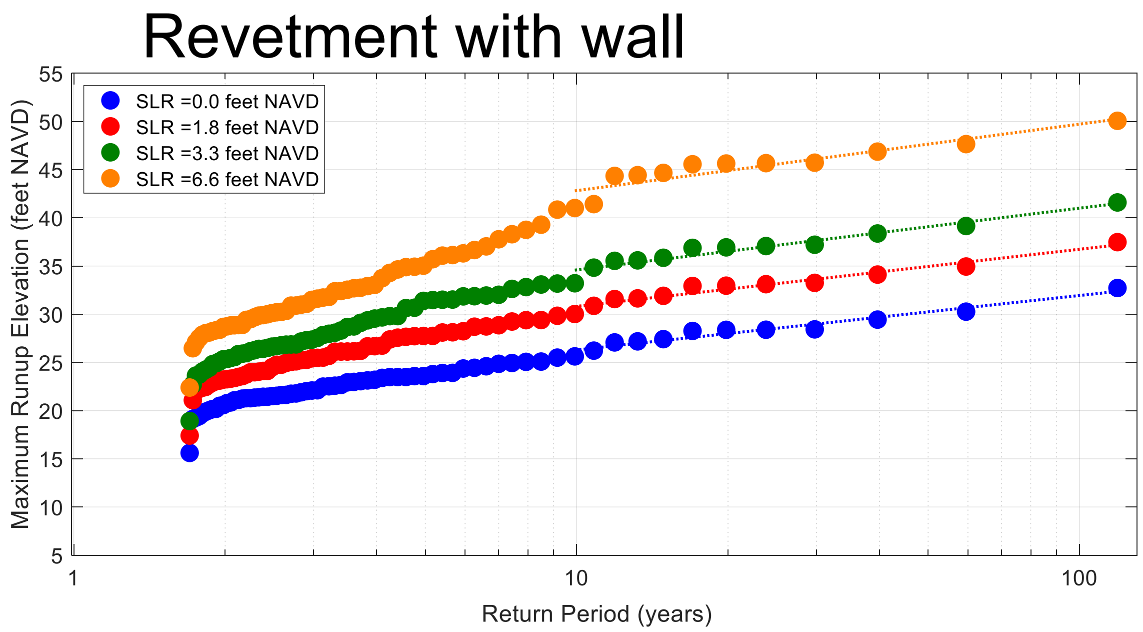
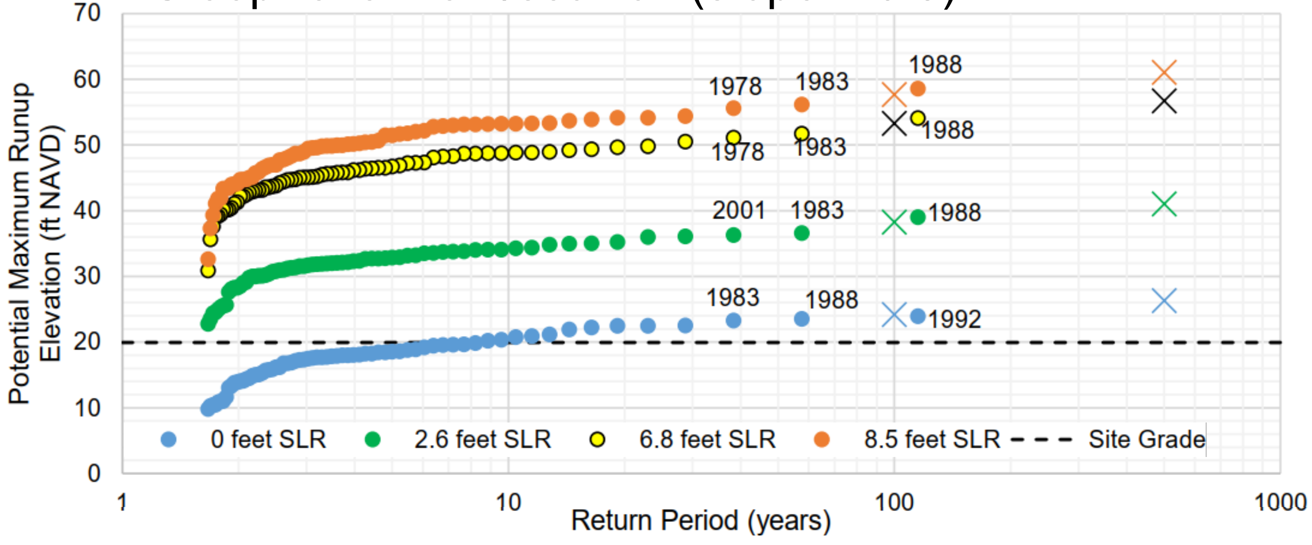
Total Water Level as Function of Return Period

- Convert time series of annual maximum events to "frequency" (annual exceedance probability)
- Conduct extreme value analysis to estimate extremes (note figure at right uses a logarithmic fit to computed TWL)

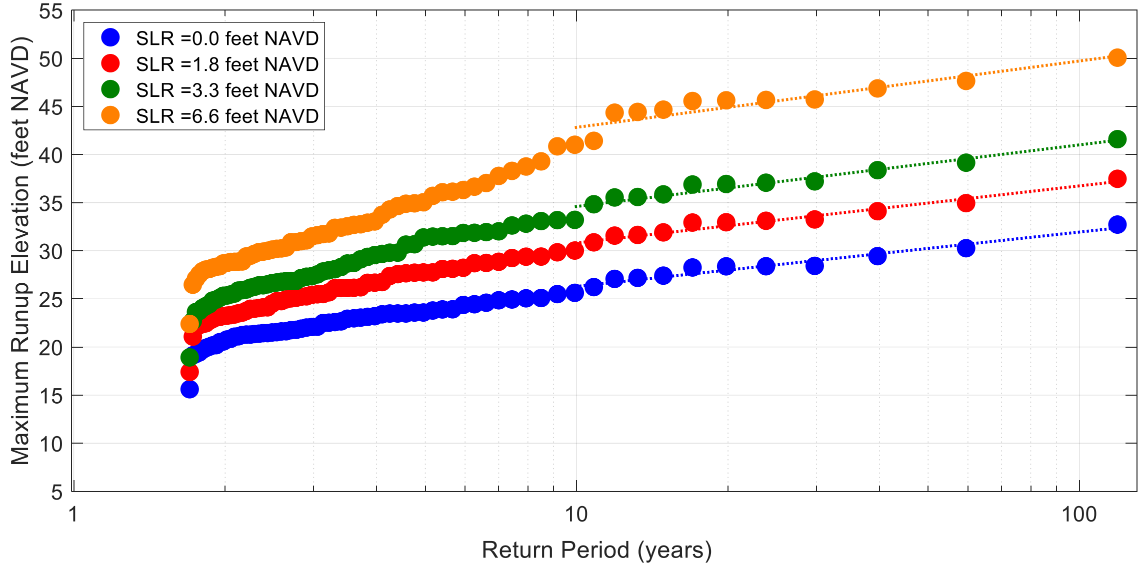


Total Water Level as Function of Return Period: 4 Different Profile Cases

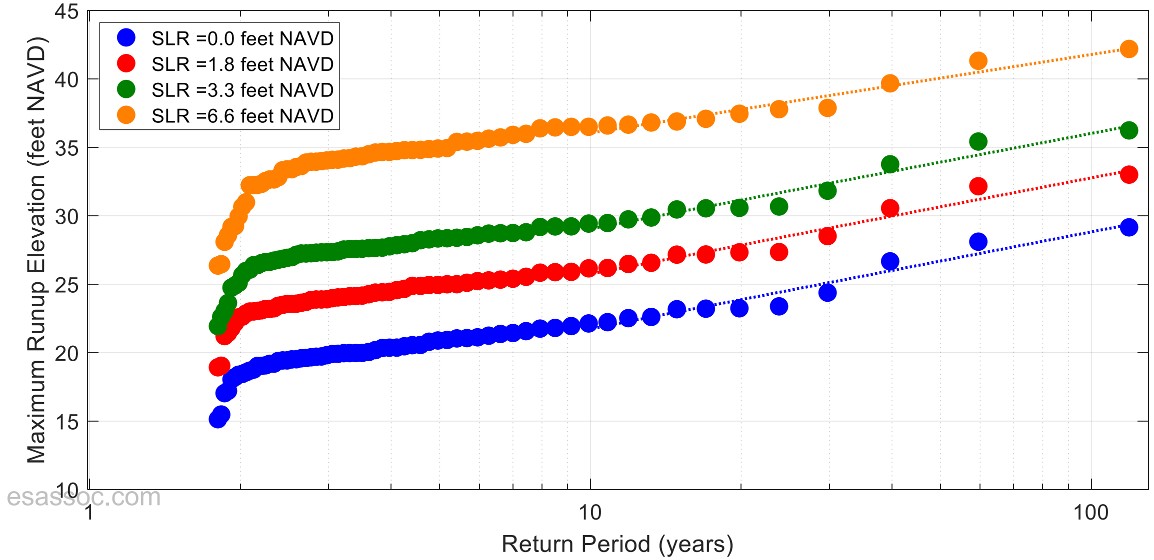
Steep revetment/seawall (slope = 0.5)



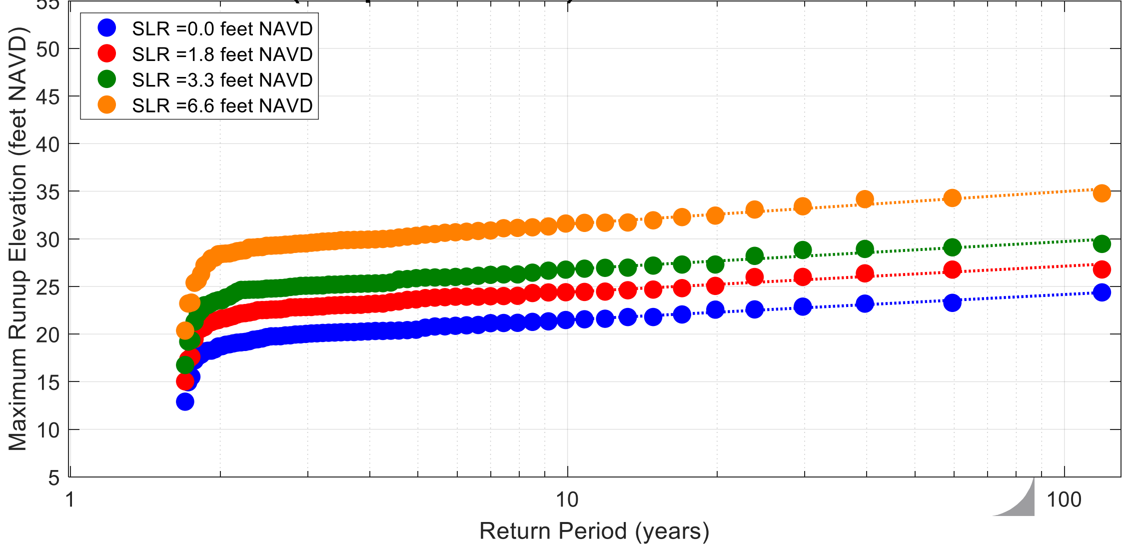
Revetment (slope = 0.6)



Flatter Revetment/Embankment (slope = 0.3 to 0.4)



Beach (slope = 0.18)



Comparison of Detailed Calculations to TMM Methods

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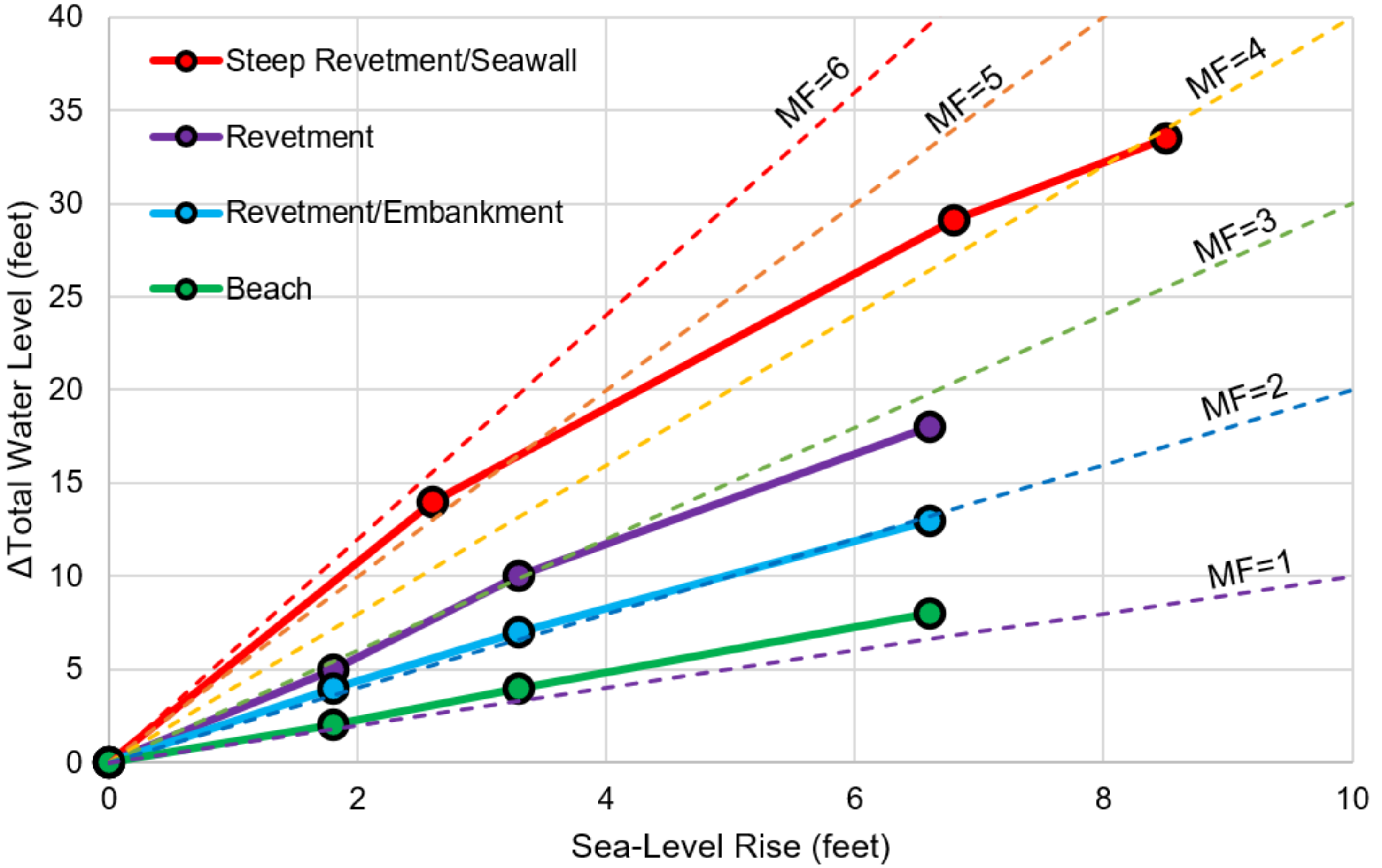
Comparison to the DWR Technical Methods Manual

- Detailed calculations for different shore types fit well with recommended values of the morphology function
- Where backshore cannot adjust, runup is amplified; results indicate that amplification with MF>4 is possibility
- For erodible backshore (beach) the TWL increases at same rate as sea-level rise
- Indicates that TMM can provide simple and fast estimates of future extreme wave runup elevations with sea-level rise



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Conclusions

Conclusions and Final Thoughts

- Detailed calculations of wave runup using a response-based analysis for different shore types and geometries show close agreement with the DWR Technical Methods Manual approach
- Distribution of total water level is strongly affected by the profile shape
- Wave runup is dependent on morphologic response of the shore to sea-level rise:
  - For erodible shores, TWL increases at the same rate as sea-level rise
  - For erosion resistant shores, TWL increases at higher rates than sea-level rise
- Technical Methods Manual:
  - Simple parameterized equations for shoreline recession and sea level rise.
  - Establishes recommendations for a “Morphology Factor” to amplify wave runup with sea-level rise
- Regional maps and simple TMM calculations are an effective “first cut” at assessing hazards and estimating likely future flood elevations and extents.
- Existing condition TWL is important: TMM calcs yield the future change in total water level, so it is important to make sure the existing TWL is accurate (lots of method uncertainty)
- Detailed calculations are important to provide further reassurance for design and permitting stages
- Next steps:
  - Using high-resolution phase-resolving models (SWASH, XBeach-NH, BOUSS-2D) to account for more physical processes and compare with practical approaches.
  - Collect field data of profiles, water levels, and runup in the surf zone

Thank you

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