Sea Level Rise Model Comparison Memo

There are several sea level rise (SLR) inundation models available to estimate the extent of coastal flood inundation along the eastern Marin shoreline, each with particular advantages and disadvantages. With no officially recommended model, it is important to evaluate features of different models to understand which is best suited for a particular situation. As a critical first step in Marin Bay Waterfront Adaptation Vulnerability Evaluation (BayWAVE), Marin County Staff have evaluated strengths and limitations of two applicable models, the National Oceanic and Atmospheric Administration's (NOAA) Sea Level Rise Viewer and USGS's Coastal Storm Modeling System (CoSMoS), which can be viewed through the Our Coast, Our Future (OCOF) website. Additionally, a hybrid approach, like what was done for the *Richardson Bay Shoreline Study* combining the County's more accurate Digital Elevation Model (DEM) with bathtub SLR scenarios[1] is discussed, as well as Bay Conservation and Development Commission's (BCDC) *One Map, Many Futures* approach. To support the evaluation, staff has conducted Geographic Information Systems (GIS) comparisons of flooding extent using the NOAA and OCOF models throughout eastern Marin's shoreline and at several critical locations known to flood at current King Tide elevations (approximately 12 inches above MHHW). Additionally, possible scenarios have been identified within both models to reflect near-, medium-, and long-term scenarios.

It is important to mention that FEMA Flood Insurance Rates Maps (FIRM) were not considered in this evaluation. While FIRMs are used for regulatory purposes including general plans and building permits, they do not consider future SLR, which is the focus of BayWAVE. FEMA zone boundaries are based on historic data, while SLR models such as OCOF are based on future projections and therefore represent a different approach to flood mapping. FIRMs consider FEMA-certified levees, but do not acknowledge other elevation barriers like berms or access roads that could provide some flood protection. The FIRMs include riverine flooding in addition to direct coastal flooding while the SLR models address coastal flooding.

Staff presented these findings at the November 23, 2015, BayWAVE Technical Group meeting. The group consists of staff representatives from the cities, towns, and county departments, local agencies and public landowners, public safety representatives, utilities, resource agencies, and science and planning experts. The presentation was followed by a group discussion and Q & A, then by a vote on whether to use OCOF or NOAA. Of a total 28 representatives, 18 technical group members voted for OCOF and 4 for NOAA with the rest abstaining from a vote. *OCOF will be the primary model used for BayWAVE.* The Technical Group also selected a set of scenarios for the OCOF model. Scenarios will include 25 centimeters-no storm, 25 centimeters-100 year storm, 50 centimeters-no storm, 50 centimeters-100 year storm, 150 centimeters-no storm, 150 centimeters-100 year storm.

[1] Leventhal, Roger. 2015. *Richardson Bay Shoreline Study, Public Review Draft.* Marin County Flood Control and Water Conservation District.

AT-A-GLANCE

Considerations	**NOAA**	**OCOF**
Storm Surge	No	Yes
Flood Depth	No	Yes
Wave Height	No	Yes
Velocity	No	Yes
Address Lookup	No	Yes
DEM	5 meter	2 meter
Datum	Variable datum at MHHW for water elevation[2]	Variable datum at MHHW for water elevation[3]
Website minimum zoom-in scale	1''=1000'	1''=200'
Uncertainty Mapping	Via Confidence Mapping feature	Via Flood Potential feature
Used by other jurisdictions?	Contra Costa County, Alameda County, Santa Clara County, East Bay Regional Park District, Humboldt County, EPA Region 10, CA Department of Parks and Recreation, City of Benicia, CA Office of Planning and Research, Richardson Bay Shoreline Study[4]	San Mateo County[5], West Marin County, Southern California

[2] Both NOAA and OCOF use a "variable datum at MHHW for water elevation" and FEMA uses a "fixed datum" (NAVD88). Post processing would be required to convert elevations from the variable datums (i.e. MHHW) to a fixed datum (i.e. NAVD88) for comparison with FEMA maps

[3] Both NOAA and OCOF use a "variable datum at MHHW for water elevation" and FEMA uses a "fixed datum" (NAVD88). Post processing would be required to convert elevations from the variable datums (i.e. MHHW) to a fixed datum (i.e. NAVD88) for comparison with FEMA maps

[4] Modified version with more accurate Marin County DEMs

[5] San Mateo is working with OCOF to correct areas of known flooding not shown in model outputs, in addition to using the AECOM model to refine vulnerability assessment results.

SEA LEVEL RISE INUNDATION MODEL DESCRIPTIONS

NOAA

- **Link:** coast.noaa.gov/slr
- **Introductory Video:** Explaining the Sea Level Rise Viewer
- **Pros:** Measurements in feet, national effort and used more widely throughout Bay Area, can be used in lieu of/until the BCDC 'One Map Many Futures' is available for Marin County
- **Cons:** Does not include storms or other hazards, no flood depth data
- **Description:** The NOAA SLR Viewer is a visualization tool with one foot SLR increments ranging from 0 to 6 feet. It is referred to as a 'Bathtub Approach' as it is based on hydrological connectivity with inundated areas representing where water can flow under particular scenarios. The model does not account for waves, storm surges, erosions or other coastal hazards. Uncertainty is illustrated via the Mapping Confidence feature, which indicates high uncertainty/low confidence as places that may be mapped correctly less than 8 out of 10 times.[6]

OCOF

- **Link:** pointblue.org/ocof
- **Introductory Video:** Website Tutorials
- **Pros:** Includes storms, used for West Marin Vulnerability Assessment, website includes address lookup for homeowners, flood depth data available
- **Cons:** numerous strategies may confuse public, not used widely throughout the Bay Area
- **Description:** CoSMos incorporates both SLR and storm scenarios and can be viewed through the OCOF website. Static SLR at increments of 0, 25, 50, 75, 100, 125, 150, 175, 200, and 500 centimeters are coupled with storm events (none, annual, 20-year, and 100-year) to total 40 scenarios. The website includes guidance on choosing scenarios based on future ranges of SLR spanning several projections by various climate experts. OCOF is publically accessible and interested persons can use the interactive map with address lookup feature to view how specific assets (residents, businesses, etc.) could be impacted by SLR. Uncertainty is shown via the 'Flood Potential' feature with maximum/minimum inundation based upon a combination of uncertainty from elevation data, vertical land motion, tidal marsh accretion, and model physics.[7]

As such, both models may show different impacts of flooding due to variations in local topography. This may result in areas known to flood that are not shown in the modeled flooding layers and vice-versa.

Hybrid Approach

- **Link:** http://marinwatersheds.org/documents/2015.10.12_RichardsonBayShorelineStudy.pdf
- **Introductory Video:** None
- **Pros:** Finer DEM for improved local accuracy of SLR exposure zones, easier to understand by general public

[6] https://data.noaa.gov/dataset/noaa-office-for-coastal-management-sea-level-rise-data-mapping-confidence
[7] http://data.prbo.org/apps/ocof/index.php?page=flood-map

- **Cons:** More staff time, requires more technical GIS capabilities, does not include storms or other hazards
- **Description:** Both OCOF and NOAA SLR models use a coarser digital elevation model (DEM) then the Marin County DEM which has been adjusted for vegetation and local topography. Mirroring what was done for the Richardson Bay Shoreline Study, a hybrid approach can combine the County's DEM and bathtub inundation layers for a more locally accurate portrayal of SLR exposure zones. This will require significantly more staff time due to intensive GIS work in developing the model.

AECOM's One Map, Many Futures

- **Description:** AECOM's *One Map, Many Futures* approach is currently being developed for the Bay Area and will be available for Marin County in 2016. This approach uses FEMA transects with updated overtopping SLR data. As it is not yet available for Marin County, its users recommend starting with NOAA, whose scenarios are in accordance with the AECOM model scenarios, which would allow for the AECOM model to be used at a later date. It is staff's understanding that this is approach is being used by several efforts including Silicon Valley 2.0, as well as Contra Costa, Alameda, San Francisco, and San Mateo Counties.

FLOODING EXTENT COMPARISON

To further assess model applicability; Marin County Staff used GIS to compare the spatial extent of flood hazard/exposure zones for NOAA and OCOF layers (with no storms) at similar SLR increments: OCOF 25 centimeters (.8 feet) and NOAA 1 foot, OCOF 100 centimeters (3.3 feet) and NOAA 3 feet, and OCOF 150 centimeters (4.9 feet) and NOAA 5 feet. GIS data was overlaid onto Marin County aerial imagery to observe the extent of inland flooding for the full length of bayside Marin's shoreline.

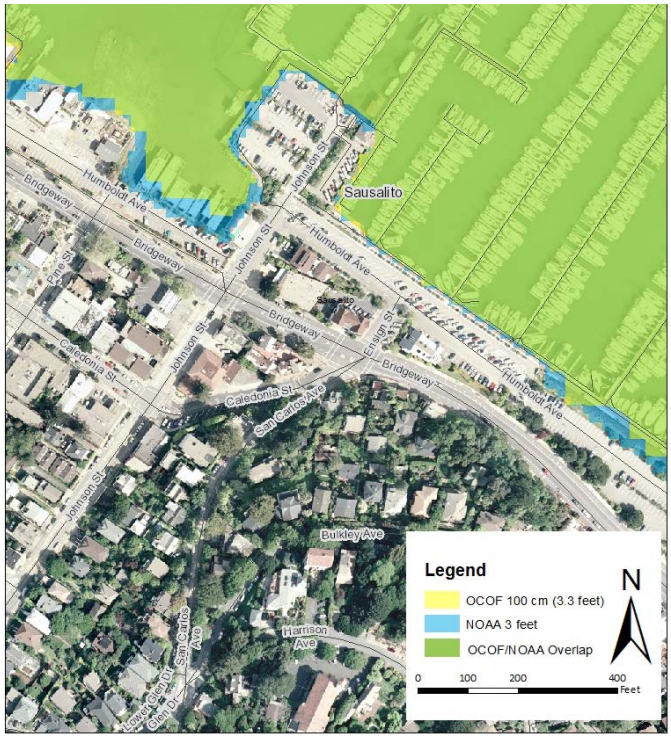

Exhibit 1. Sausalito's waterfront showing close overlap of OCOF/NOAA layers (green)

Based on this comparison, staff noted only minor differences of the two models throughout the majority of Marin's bayside as the inland extent of the flood hazard zones generally fell within close proximity of one another. Exhibit 1, 2 and 3 (maps of Sausalito's waterfront, Corte Madera Creek and San Rafael Canal Area, respectively with NOAA 3 feet SLR and OCOF 100 centimeters SLR) are prototypes for the majority of Marin's bayside shoreline. As illustrated in green, the two layers generally overlap. While the NOAA layer, as shown in

blue, extends slightly more inland in some locations, it is generally less than 50 feet and does not cover significantly more buildings/infrastructure.

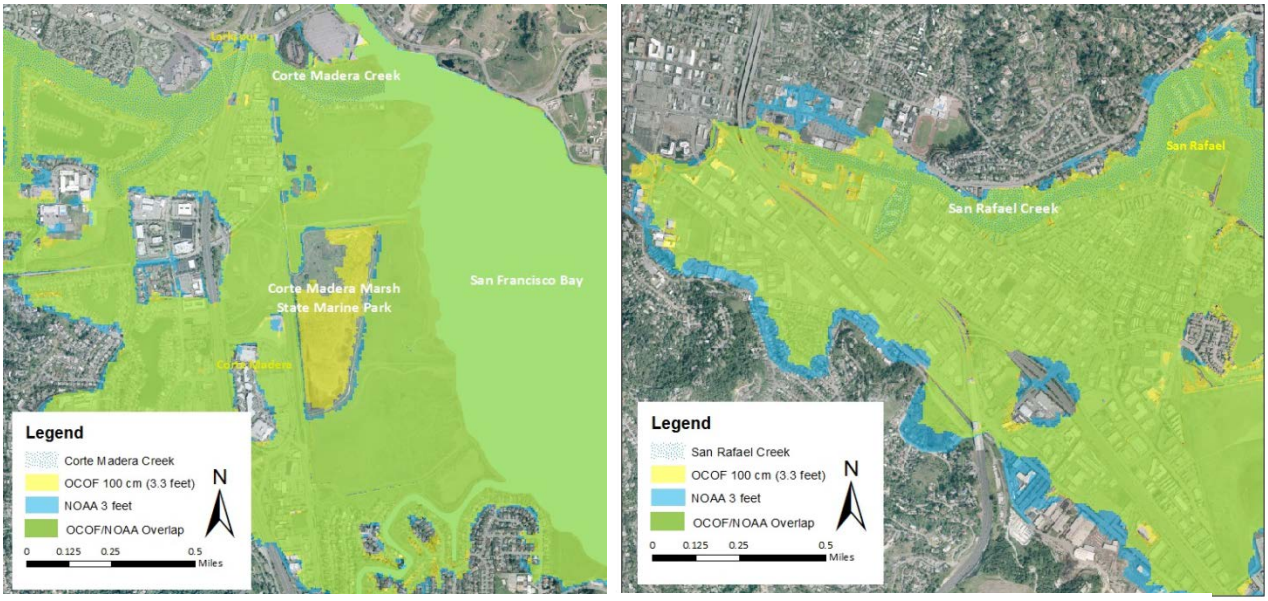

Exhibit 2 (left) and 3 (right). Mouth of Corte Madera Creek and San Rafael Creek, respectively, showing close overlap of OCOF/NOAA layers (green), except in Corte Madera State Marine Park covered predominantly by OCOF layer.

There are a small number of exceptions, when the NOAA layer does extend more significantly further inland and covers built assets that the OCOF layer does not (e.g. Exhibit 4 – Tamalpais Valley, Exhibit 5 – Novato). While scenarios generally build upon one another and higher scenarios would likely capture the assets not exposed at lower OCOF scenarios, short term impacts may not be accounted for in these particular locations and therefore may need to be assessed separately if OCOF is used.

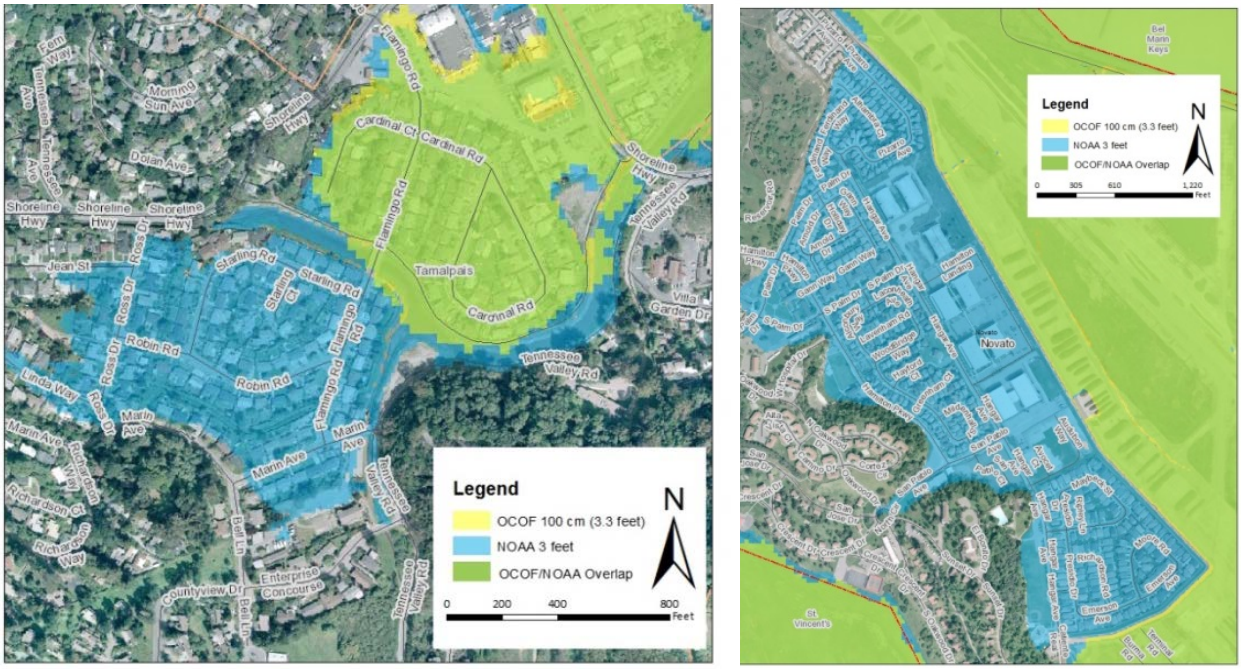

Exhibit 4 (left) and 5 (right). NOAA layer (blue) extending further inland in Tam Valley and Novato respectively

Additionally there are cases in which the OCOF layer (and in some cases the NOAA layer) at lower scenarios does not cover low-lying areas where people live, including places known to get flooded in regular King Tide events such as the Manzanita Parking Lot (Exhibit 6). Such cases would also generally be flooded under higher scenarios and therefore could still be assessed for vulnerability under a range of scenarios that include near-, medium-, and long-term. However, such an approach would not account for short term impacts in these particular locations and they may need to be assessed separately in a method to be determined.

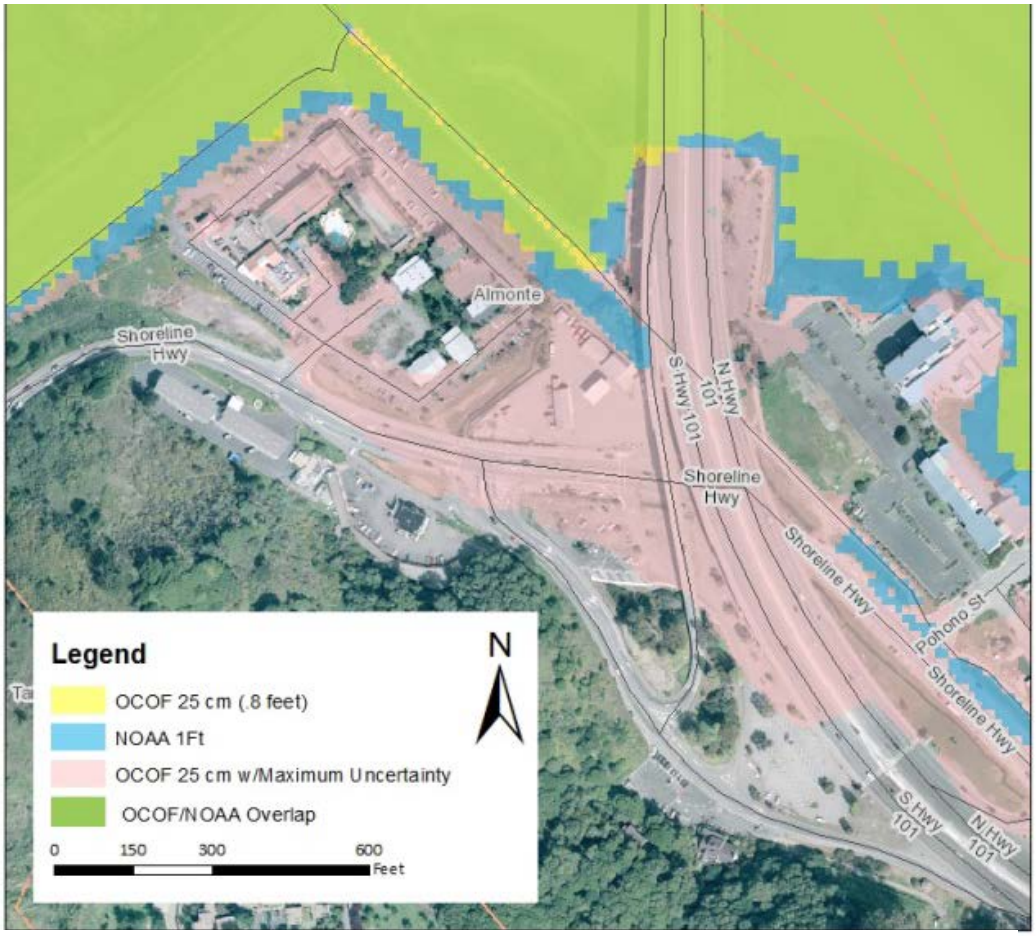

Exhibit 6. Manzanita Parking Lot, which gets flooded annually during King Tides events, is not shown as flooded under near-term OCOF or NOAA scenarios.

SCENARIO SELECTION

Following model selection, scenarios should be chosen as the basis of the Vulnerability Assessment. Scenarios should span a range of time to reflect near term (≈2030), medium term (≈2050), and long term (≈2100) horizons and when combined, should cover the full range of impacts to affected bayside communities by the end of the century.

The National Research Council's (NRC) Report: *Sea-Level Rise for the Coasts of California, Oregon, and Washington* includes specific projections for the aforementioned time periods, and could serve as a basis for scenario selection as follows:

Time Period	NRC Projection	Corresponding NOAA Scenarios	Corresponding OCOF Scenarios (SLR only)
2000-2030 (near term)	4-30 centimeters / 1.56 to 11.8 inches	1 foot	25 centimeters
2000-2050 (medium term)	12-61 centimeters / 4.7 to 24 inches	1,2 feet	25, 50 centimeters
2000-2100 (long term)	42-167 centimeters / 16.5 to 65.7 inches	2 feet, 3 feet, 4 feet, 5 feet	50, 75, 100, 125, 150 centimeters

- NOAA Scenarios

  If NOAA is used the most obvious scenarios would be:
  1 foot - near term
  2 feet - medium term
  5 feet - far term (furthest outlying)

- OCOF Scenarios (SLR Only)

  If OCOF is used, the most obvious SLR scenarios would be:
  25 centimeters - near term
  50 centimeters - medium term
  150 centimeters - far term (furthest outlying)

  From there, storm scenarios should be carefully selected to capture the full extent of potentially impacted assets under the cumulative scenarios. The use of 100 year storm scenarios would ensure that all assets within each scenario are chosen, and would be consistent with what San Mateo County is proposing for their three SLR scenarios (current, 2050 and 2100).[8]

  The drawback with using only *combined* SLR and storm scenarios is that such scenarios do not identify which assets are only exposed to storm surges and therefore only subject to temporary flooding, as opposed to assets exposed only to storms which are not subject to permanent inundation. As assets exposed to permanent inundation merit different considerations for

[8] Arcadis. 2015 *San Mateo County Vulnerability Assessment, Methodology.*

adaptation planning than assets subject only to storm impacts, it is important that the Vulnerability Assessment considers both impacts separately. Thus it may be worth assessing vulnerabilities for all three SLR scenarios *with and without* the 100 year storm, as follows:

- OCOF Scenarios (SLR Only and Storm)

25 centimeters, no storm	25 centimeters with 100 year storm
50 centimeters, no storm	50 centimeters with 100 year storm
150 centimeters, no storm	150 centimeters with 100 year storm

TECHNICAL GROUP MEETING

Models and scenario selection was a focus of the November 23, 2015, BayWAVE Technical Group meeting. The group consists of staff representatives from the cities, towns, and county departments, local agencies and public landowners, public safety representatives, utilities, resource agencies, and science and planning experts. To support the discussion, staff presented information and maps, as outlined in this memo, of models, particularly NOAA and OCOF. Following the presentation the committee discussed strengths and limitations of each model. To conclude the meeting, a vote was taken on preferred models. Of a total 28 representatives, 18 committee members in favor of OCOF and 4 in favor of NOAA. After the vote staff asked if any committee members could not live with using OCOF, to which no one responded yes. *As the majority of the committee voted for OCOF, OCOF will be the primary model used for BayWAVE.* Staff discussion following the Committee meeting included the decision to use the aforementioned scenarios: 25 centimeters-no storm, 25 centimeters-100 year storm, 50 centimeters-no storm, 50 centimeters-100 year storm, 150 centimeters-no storm, 150 centimeters-100 year storm.

Staff will also consider AECOM's *One Map, Many Futures* when available for Marin County in March 2016. Depending on progress and staff capacity, this model could be integrated into BayWAVE to augment the assessment conducted thus far with the OCOF model, following San Mateo County's example.

CONCLUSION

Sea level rise planning is uncertain and the practice it to use the best available science to assist with the planning effort. Choosing a SLR model is an important first step in BayWAVE, upon which to further build the Vulnerability Assessment. There is no universally accepted model, and both the NOAA and OCOF models have strengths and limitations. In summary NOAA is more widely used by organizations and jurisdictions throughout the Bay Area and beyond, and can be easier to comprehend by the general public, particularly those with limited understanding of SLR science. Unlike OCOF however, NOAA does not consider storms surges and therefore does not account for as wide a range of climate impacts.

Based on a majority vote of the technical committee, OCOF will be the primary model used for BayWAVE. The following scenarios will serve as the basis for the Vulnerability Assessment: 25 centimeters-no storm, 25 centimeters-100 year storm, 50 centimeters-no storm, 50 centimeters-100 year storm, 150 centimeters-no storm, and 150 centimeters-100 year storm.

REFERENCES

Arcadis. 2015 *San Mateo County Vulnerability Assessment, Methodology.*

Leventhal, Roger. 2015. Richardson Bay Shoreline Study, Public Review Draft. Marin County Flood Control and Water Conservation District.

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