Rosie the Riveter National Historic Park in Richmond during King Tides in January 2019. Photo courtesy of California Bay King Tides Project.

Chapter 6.0

APPENDIX

Introduction

The aim of this appendix is to familiarize the reader with the data and methodology used to conduct an analysis of shoreline and community asset exposure and vulnerability to sea level rise and storm events for the Adapting to Rising Tides (ART) Bay Area project. The majority of this analysis was conducted using a Geographic Information System (GIS). GIS is an ideal tool to support sea level rise adaptation planning because it can both perform spatial analyses and produce maps to visualize results. Of notable importance is that access to technology, data availability, scenario selection, and the number and type of assets influence the analysis design and the type of data results produced. The methodology described below was developed to understand the current and future risk of flooding to a variety of assets, including components of the transportation network, natural lands, future development areas, and vulnerable communities. In addition to the core analysis done for the assets described above, exposure analysis was conducted complementary shoreline features such as contaminated sites and critical facilities.

Maps of sea level rise (SLR) and storm surge flooding used in this analysis, were developed by the ART Program in 2017[1]. Assets were analyzed for their exposure to riverine flooding by analyzing FEMA's 100-year and 500-year flood zones for the project area. Additionally, assets were analyzed for their exposure to San Francisco County Precipitation data because San Francisco does not have surface streams and lacks riverine FEMA flood hazard zones.

In addition to the exposure of assets, additional spatial analysis was conducted to determine consequences of flooding to the assets mentioned above, ranking of consequences, and the categorization of high consequence exposed assets by various geographies.

For a contrasting methodology, refer to the ART Pilot Project - ART Vulnerability and Risk Assessment Report Appendix C. ART GIS Exposure Analysis - September 2012[2] or ART Contra Costa County GIS Methodology Appendix[3].

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[1] Adapting To Rising Tides; Bay Area Toll Authority, "Adapting To Rising Tides Sea Level Rise Analysis and

[2] Adapting To Rising Tides, "Adapting To Rising Tides Alameda Vulnerability and Risk Assessment Report: GIS Exposure Analysis."
[3] Adapting To Rising Tides, "Adapting to Rising Ties Contra Costa: GIS Methodology Appendix."

Current and Future Flood Data

SEA LEVEL RISE INUNDATION DATA

To inform an understanding of flood exposure in the ART Bay Area project, highly accurate and consistent sea level rise and storm surge flooding maps for all nine San Francisco Bay Area counties were developed. This mapping project was funded by the Bay Area Toll Authority (BATA) through the Metropolitan Transportation Commission (MTC) and extends the tools and products that BCDC and MTC developed through prior efforts as part of the ART program and applies them Bay-wide. AECOM, in collaboration with MTC and BCDC, created these flooding and shoreline overtopping mapping products for the entire SF Bay shoreline[4]. The maps capture permanent inundation and temporary flooding impacts from SLR scenarios from 0 to 66 inches and extreme high tide events from the 1-year to the 100-year extreme tide and include ten flood mapping scenarios (Table 1).

The mapping process involved highly accurate hydrodynamic modeling of base water elevation (Mean Higher High Water) and the utilization of a high resolution (1-m) topographic digital elevation model as primary model inputs. This resulted in inundation and shoreline overtopping maps, which were reviewed by key stakeholders in each county, who groundtruthed the preliminary maps and provided on-the-ground verification and supplemental data as needed to improve the accuracy of the maps. A total of ten water levels were chosen to represent over 50 combinations of SLR and storm events for each county. ART project staff used the maps and underlying data to examine the exposure and vulnerability of various assets to the each of the ten water levels (Table 1).

Inundation and shoreline overtopping data produced for each county was merged by AECOM to create a bay-wide inundation and overtopping map for each water level representing flood depth and overtopping depth in feet.

[4] Adapting To Rising Tides; Bay Area Toll Authority, "Adapting To Rising Tides Sea Level Rise Analysis and Mapping Report."

EXPOSURE MAPPING SCENARIOS

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference +/- 3 inches)
Scenario 1	MHHW + 12”	MHHW + 9 to 15”
Scenario 2	MHHW + 24”	MHHW + 21 to 27”
Scenario 3	MHHW + 36”	MHHW + 33 to 39”
Scenario 4	MHHW + 48”	MHHW + 45 to 51”
Scenario 5	MHHW + 52”	MHHW + 49 to 55”
Scenario 6	MHHW + 66”	MHHW + 63 to 69”
Scenario 7	MHHW + 77”	MHHW + 74 to 80”
Scenario 8	MHHW + 84”	MHHW + 81 to 87”
Scenario 9	MHHW + 96”	MHHW + 93 to 99”
Scenario 10	MHHW + 108”	MHHW + 105 to 111”

MHHW = Mean Higher High Water
“ = Inches

Table 1: Inundation Mapping Scenarios (inches above MHHW)

FEMA NATIONAL FLOOD HAZARD LAYER FLOOD RISK DATA

In addition to the ten sea level rise inundation scenarios, BCDC created a shapefile of the FEMA 100-year and 500-year flood zones in September 2017. At the time, the following geographies had preliminary status with FEMA: Bay adjacent areas in Alameda County, Bay adjacent areas in San Mateo County, Bay adjacent areas in Santa Clara County, and entire San Francisco County. 100-year flood zones are defined as the areas that will be inundated by a flood event having a 1-percent chance of being equaled or exceeded in any given year. The 500-year flood zone is defined as the limits of the base flood and the 0.2-percent-annual-chance. Assets were analyzed against this layer to determine the potential exposure to current flooding as a complement to the analysis of future flooding. This data was also used qualitatively to determine if an asset was potentially susceptible to combined tidal-riverine flooding.

SAN FRANCISCO PRECIPITATION EVENT DATA

The San Francisco 100-year Precipitation event data, was created by the San Francisco Public Utilities Commission, and represents the maximum depth and velocity of water on the land surface during or after a storm event, maximum volume of water within a defined flood resilience analysis area on the land surface during or after a storm event, and maximum flow rate and volume of water running over the land surface and entering a receiving water body. The flood resilience analysis areas are designated according to where major flooding occurs in response to the 100-year 3-hour storm event.

LIMITATIONS

The ART sea level rise inundation and overtopping analysis maps and data layers are appropriate for planning-level assessments and not for engineering design or construction purposes. However, these products help identify where additional detailed information is needed to confirm shoreline vulnerabilities and were considered appropriate for the needs of ART Bay Area.

However, there are notable limitations to these maps and the models that produced them. While the limitations did not preclude the use of the maps for the purposes described above, it is important to be aware of those flood-related impacts that are not included in these maps or models:

- **Riverine Flooding.** The inundation maps do not account for localized inundation associated with any freshwater inputs, such as rainfall-runoff events, or the potential for riverine overbank flooding in the local tributaries associated with large rainfall events. Inundation associated with changing rainfall patterns, frequency, or intensity as a result of climate change is also not included in this analysis.
- **Wave hazards.** For shorelines and developments directly along the bayshore, the consideration of wave hazards is required. Wave hazards, such as wave run-up and overtopping, are dependent on the shoreline type, roughness, slope, and other factors that require more detailed analysis than that presented in this project. In addition, wave run-up is excluded from this analysis as it may not increase linearly with sea level rise (i.e., a 1ft increase in SLR may lead to more than a 1ft increase in wave run-up). A coastal engineering assessment is required for both existing conditions and proposed adaptation strategies to adequately consider wave hazards and how they might change in the future with sea level rise.

- **Combined coastal-riverine events**. Extreme storm events in the Bay Area, particularly during El Niño winters, often include extreme Bay water levels and precipitation. The cumulative impacts of rainfall runoff and storm surge were not considered in this project; however, the combination of these factors would further exacerbate inland flooding. In nearshore developed areas, particularly in areas behind flood protection infrastructure with topographic elevations below the Bay water surface elevation during an extreme event, it is important to consider the impacts of heavy rainfall and storm surge occurring together. You can learn about resources for considering combined riverine-tidal impacts here.
- **Climate change and storminess.** Changes in storm frequency and magnitude due to climate change were also not examined in this project, but an evaluation of these dynamics may provide further insight into when adaptation strategies need to be implemented.
- **Groundwater**. Rising groundwater tables, primarily associated with sea level rise, can also impact flooding and drainage. The impacts of rising groundwater tables on watershed flooding are not well understood. With higher groundwater tables and rising sea levels, existing drainage systems will become less effective over time, and they may become completely ineffective with higher levels of sea level rise. Further evaluation of these factors is recommended.
- **Erosion and Subsidence**. Geomorphic processes related to the erosion of the shoreline or subsidence land around the shoreline are not captured in these maps. Our maps present a 'snapshot' of the shoreline and inland area topography.
- **Marsh Vegetation**. The inundation and flooding depths shown on heavily vegetated marsh plain surfaces may not be accurate due to vegetation interference with the bare-earth LiDAR signal, which may bias topographic elevation data high in these areas.
- **Salt Ponds and Wetlands.** Our maps assume that if areas are hydrodynamically connected to flood waters that these areas will fill up. This approach does not account for the physics of overland flow nor the volume of water available during any individual event. Therefore, the maps may overestimate the extent of flooding during a short duration flood impacting a salt pond or wetlands that can absorb and slow the movement of water.

Data Collection and Quality Control

Data collection and quality control were initial steps taken in our GIS analysis. Regional data sources used in the exposure analysis are listed in the Data Sources section. To ensure the exposure analysis described below accurately reflected real exposure of as asset, a quality control step was performed by BCDC staff to manually edit some transportation source data geometries so that alignments and locations of assets represented real-world locations.

Some additional data processing was necessary for point and line data, particularly for transportation assets, including buffering passenger rail station point data by 100-meters to approximate station footprints. Additionally, elevated stretches of transportation line segments (e.g. bridges and overpasses) were removed from the highway, commuter rail, freight rail, and active transportation GIS data so they would not be incorrectly identified as exposed segments in the Exposure or Consequence Analysis.

This included a processing step to visually inspect intersected transportation segments at each TWL and manually draw a bounding polygon representing elevated transportation segments (Transpo_SourceData_BridgeFix). The resulting polygon layer was used to select by location and delete out remaining elevated transportation segments. An assumption in this process is that the elevated roadway is not considered flooded until adjacent roadway segments on one or both sides of the elevated structure is also inundated. It is also important to note, that even though the elevated roadway itself may not be inundated, increased tidal scour at bridge and overpass footings, piers, and pilings can represent an important vulnerability, though not directly reflected in this Vulnerability assessment.

Despite BCDC staff efforts to find authoritative source data, perform quality control steps, and manually adjust data where feasible, there remained persistent problems with data accuracy for some assets that added known inaccuracies into the analysis. For further discussion of this, see Consequence Analysis below.

Exposure Analysis Methods

Sea level rise inundation, FEMA flood hazard zones, and San Francisco precipitation event vector GIS files were used to analyze the exposure of selected assets represented as vector point, line, or polygon GIS data to current and future flooding using ArcPy scripts and ESRI's ArcGIS Pro Version 2.3.2. The primary geoprocessing tools used in the analysis were the Intersect (Fig. 1) and Spatial Join (Fig. 2) functions in an ArcPy scripting model.

For the majority of Regional System assets, the intersect functions clipped asset vectors to flood scenario data to calculate asset specific summaries of exposure to each flood scenario (i.e. absolute miles highways exposed and percent of total highways exposed). The results of these analyses for each flood scenario were written into the attribute tables of each asset feature class and stored as a file geodatabase. In cases of no exposure for a given water level, no feature class was saved to the geodatabase. The total values used to calculate percentages include the full extent of the unexposed assets in the nine-county Bay area.

GIS SCRIPT FOR EXPOSURE ANALYSIS

```
Basic ArcPy Intersect Function: Perform intersect of asset and all total water level scenarios and save to new geodatabase

import arcpy, os

for fc in inunds:
arcpy.Intersect_analysis([ip,fc],os.path.splitext(os.path.basename(ip))[0]+"_"+os.path.splitext(os.path.basename(fc))[0],"NO_FID")

Transportation Bridge Fix ArcPy Function: Explode multipart features into individual segments, remove those within manually created bridge polygons and dissolve back onto the same exact field, effectively removing problematic segments.

import arcpy, os

for fc in inputs:	arcpy.MultipartToSinglepart_management(fc,os.path.splitext(os.path.basename(fc))[0]+"_Exp")
	arcpy.MakeFeatureLayer_management(os.path.splitext(os.path.basename(fc))[0]+"_Exp", "tempLayer")
	arcpy.SelectLayerByLocation_management("tempLayer", "COMPLETELY_WITHIN", polygon)
	arcpy.DeleteFeatures_management("tempLayer")
	dissolveFields = [f.name for f in arcpy.ListFields(os.path.splitext(os.path.basename(fc))[0]+"_Exp")][2:-2]
arcpy.Dissolve_management(os.path.splitext(os.path.basename(fc))[0]+"_Exp",os.path.splitext(os.path.basename(fc))[0]+"_Diss",dissolveFields)

	arcpy.DeleteFeatures_management(os.path.splitext(os.path.basename(fc))[0]+"_Exp")
	print("%s of %s shapefiles processed" % (counter, len(inputs)))
```

Figure 1. Exposure analysis script example.

For analyses that relied on parcel data (i.e. residential unit exposure for vulnerable communities and priority development areas), a spatial join function was performed

(Figure 2). This analysis was most appropriate given assumptions made by ART staff that if any part of a parcel was to be exposed by flooding, all residential units in that parcel would be considered impacted.

GIS SCRIPT FOR EXPOSURE ANALYSIS (cont.)

Basic ArcPy Spatial Join Function: Perform spatial join of parcels and all total water level scenarios and save to new geodatabase

```
import arcpy, os

for fc in inunds:

arcpy.SpatialJoin_analysis(parcels,fc,"Parcel_"+os.path.splitext(os.path.basename(fc))[0])
```

Figure 2. Parcel spatial join script example.

Additional processing steps were performed using the programming language R (R version 3.5.1 (2018-07-02) -- "Feather Spray") in RStudio (Version 1.1.463). Bay Area Cities, Counties, SFEI’s Operational Landscape Units as well as ART Bay Areas “Focus Areas” and “Regional Clusters” were spatially joined) to each exposed feature for subsequent data reporting and visualization by geography (Figure 3). If an exposed feature didn’t exist in a given boundary geography, it was indicated with a NULL value.

GIS SCRIPT FOR EXPOSURE ANALYSIS (cont.)

```
Basic ArcPy Spatial Join Function: Join various geographies to exposed assets


addGeos <- function (fc){
    fc <- sf::st_transform(fc,26910) #transformation to ESPG: 26910


    fc <- sf::st_join(fc,geo["Name"]) #spatial join of geography/jurisdictional name


    fc$equal <- sf::st_equals(fc) #indexing of duplicate geometries


    fc <- fc %>% group_by(equal) %>% mutate(Name= paste(Name, collapse = ";")) #collapsing of duplicate
entries concatenating the geography/jurisdictional name


    fc <- st_difference(fc) #removing the redundant geometries in order to avoid double-counting
}
```

Figure 3. Geographic boundary spatial join script example.

A limitation of the overall approach to exposure analysis included the inability to field validate the elevation of individual ART Bay Area assets in relation to predicted water level to confirm the exposure indicated in our desktop analysis. Instead, given the highly accurate digital elevation model and ground truthing conducted in the development of the flood mapping, we assume the flood mapping accounts for and includes variation in the surface elevation of ART Bay Area assets. To this end, data preparation and quality control described above was key to ensure the most accurate results of the exposure modeling.

Consequence Analysis Methods

In addition to the exposure analysis described above, a secondary analysis was conducted to better understand the regional consequence of flooding to the ART Bay Area Regional System assets. This analysis ran parallel to the exposure analysis and used the same source data. This section is organized by ART Bay Area Regional systems (e.g. Transportation, Priority Development Areas, Priority Conservation Areas, and Vulnerable Communities) and describes data processing and consequence analysis steps. For each Regional System, there is also a list of files (GIS or tabular) that were produced by the project.

Once consequence analysis was completed, a dense ranking (features that compare equally receive the same ranking number, and the next feature receives the next lowest ranking number) was performed on all Regional System asset features within a given total water level scenario (Figure 4). These rankings were then visually compared to identify ART Bay Area "Regional Clusters," groupings of the highest consequence assets (i.e. Top 5) across Regional Systems. Regional clusters were defined as having at least three of the highest ranking ART Bay Area asset categories in close proximity to one another. Regional Clusters were identified for each of the ten total water level scenarios.

GIS SCRIPT FOR EXPOSURE ANALYSIS (cont.)

Basic ArcPy Ranking Function: Rank consequence for all exposed assets within a given asset class and water level.

```
addRanks <- function (fc, sort_field){
  rank_field <- paste("Rank_",sort_field,sep="") #naming of rank column with indicator name
  if (length(which(names(fc) == sort_field)) >= 1) { #if column exists…
    add_column(fc,rank_field) #create matching rank column
    fc[[rank_field]] <- dense_rank(-fc[[sort_field]]) #densely rank the indicator in ascending order
starting at 1
  }
  return(fc)
}
```

Figure 4: Ranking script example.

A manual inspection for parcel ranking in PDAs and Vulnerable Communities was performed in to identify false positive exposure (e.g. when parcel boundaries extend into the Bay or creek channels), and artificially set rank to 0 in order to filter out this data.

TRANSPORTATION

Commuter Rail Lines

Consequence of inundation to commuter rail lines was measured as average weekday ridership flow—the total number of people who travel along a given stretch between two stations on an average weekday. This indicator was chosen because the primary users of the Bay Area's rail transit are commuters, and interruptions to this system would have major impacts on both the economy and residents of the region. Although no single dataset of passenger flows exists for the Bay Area, the project team was able to make use of transit ridership data available from each operator to calculate or approximate ridership flows. A limitation of this indicator is that ridership data available for each operator were not always available for the same year or at the same level of quality.

Note that the input GIS dataset of commuter rail lines from MTC does not include stretches of track used by Amtrak for long distance service, but not commuter rail service. These stretches of track are not considered part of the commuter rail network by MTC and were therefore not included in this analysis.

PROCESSING AND CONDITIONING

1. The Commuter Railway Lines feature class was dissolved by operator so that each operator's entire track was represented by a single feature. Note that the input dataset from MTC does not include stretches of track used by Amtrak for long distance service, but not commuter rail service. These stretches of track are not considered part of the commuter rail network by MTC and were therefore not included in the analysis.
2. The Commuter Rail Stations feature class was used to split the Commuter Railway Lines feature class at the location of each station. The result was a series of line segments, one segment between each station.
3. The feature class was then clipped to the OLU layer (version modified by BCDC staff to include bay waters), so that the following steps were not performed on portions of the rail system outside the analysis area.

4. Average weekday passenger flow values were joined to each segment of track. Average weekday ridership flows are defined as the average number of passengers who travel through a given portion of track on an average weekday. Average weekday ridership flows were generated using different methods for each operator, based on the type and quality of data available:

    a. BART – Flow values were generated using entry-exit matrices made public by BART. Where multiple lines run on the same stretches of track (for example, the Transbay Tube), flow values for each line were added together.

    b. VTA – Flow values were generated using an extensive raw trip database made public by VTA.

    c. MUNI – Flow values were generated from MUNI's ridership census. Note that while the MUNI system includes buses and street cars, only MUNI light rail lines were included in this analysis.

    d. Caltrain – Flow values were extrapolated from Caltrain's annual passenger count by train.

    e. SMART – Data that could be used to generate flow values between each station was unavailable for SMART. Instead, system-wide average weekday ridership of 2,263 was calculated from annual weekday ridership and applied to all stretches of track operated by SMART. This likely overestimated flow values, especially for stretches at the end of line. The project team determined that this overestimation was not a major concern for two reasons; 1) Because regular SMART service only began in August 2017, ridership numbers during the first year are likely significantly lower than future average system performance, and 2) based on the thresholds for High, Medium, and Low consequence scores (see below), all exposed SMART track received a consequence score of 1.

5. Capitol Corridor and ACE – since these operators run on the same lines, ridership flow values were generated separately and then values for each stretch of track were summed.

    a. Capitol Corridor – Recent data that could be used to generate flow values was not available. Instead, data on average daily ridership by train by station for FY07-08 was used to define general ridership patterns on the line. These patterns were extrapolated to system-wide annual ridership values for FY16-17. This analysis assumed that the ridership pattern at the new Fairfield-Vacaville station is similar to Suisun-Fairfield.

b. ACE – Flow values were generated using the ACE Passenger Rail Forecasting model developed by AECOM for the ACEforward Program.

6. Once all flow values were joined, the feature class was intersected with the OLU boundaries, so that the results can be summarized by OLU. Segments that intersect more than one OLU were split into multiple features.
7. Due to data limitations, certain elevated commuter rail (e.g. bridges and overpasses) were falsely indicated as inundated. In some cases, this was the only inundation for a given rail and water level resulting in inaccurate consequence scores and OLU ranking. Due to this error, a processing step was taken to visually inspect intersected rail segments at each TWL and manually draw a bounding polygon representing elevated rail segments (Transpo_SourceData_BridgeFix). The resulting polygon layer was used to select by location and delete out elevated rail segments. An assumption in this process is that the elevated rail is not considered flooded until adjacent rail segments on one or both sides of the elevated structure are also inundated. It is also important to note, that even though the elevated rail itself may not be inundated, increased tidal scour at bridge and overpass footings, piers, and pilings can represent an important vulnerability, though not reflected in this Consequence Analysis.
8. To ensure the Consequence Analysis described below accurately reflects real exposure of the asset, a quality control step was performed by BCDC staff to manually edit source data geometry so that alignments of line segments were located over existing railbeds.
9. The resulting feature class, Transpo_PassRailLines_Input_Final, is a feature class of all commuter rail lines, split into segments by station, with average weekday passenger flow values for each segment.

CONSEQUENCE ANALYSIS

1. Transpo_PassRailLines_Input_Final was clipped by an inundation polygon for each of the ten total water levels. The result is a series of feature classes representing the impacted stretches of commuter rail lines under each TWL, with passenger flow values for the impacted segments. If a portion of a rail segment was impacted, its passenger flow was considered impacted because all trains would not be able to pass through the inundated portion.
2. High/Medium/Low ranges for rating consequence were developed for passenger flow using the 108” TWL. The passenger flow values for all impacted segments under the 108” TWL were separated into three quantiles

(buckets with an equal number of segments in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Average Weekday Passenger Flow Range
Low	0 - 2,500
Medium	2,500 - 20,646
High	20,646 - 236,300

Files

Unless otherwise noted, these are GIS files stored in the Transpo_PassRailLines_Output_Final.gdb Geodatabase.

Commuter Rail Stations

Consequence of inundation to commuter rail stations was measured as average weekday exits from each station. This indicator represents the amount each station is used compared to others in the system. Like Commuter Rail Lines, ridership data available for each operator were not always available for the same year or at the same level of quality.

Note that the input GIS dataset of commuter rail stations from MTC does not include stations used by Amtrak for long distance service, but not commuter rail service. These stretches of track are not considered part of the commuter rail network by MTC and were therefore not included in this analysis.

Rail lines and stations were assessed separately because they have different physical properties and locations, but also because the consequence of inundation is different. If a station is impacted, this will only affect the transit riders who use that station. However, if a line is impacted, this will affect all transit riders whose trip would take them on that stretch of track. For example, a neighbourhood station with comparatively few exits may exist on a busy line. If both the station and line are impacted, the consequence of the station being inundated is less than the consequence of the line being inundated. While both passenger flows and station exits are measures of ridership, they present different consequences. In the analysis, this nuance is captured by assessing lines and stations as separate asset types with different indicators.

PROCESSING AND CONDITIONING

1. The input Commuter Rail Stations feature class was clipped to the OLU layer (version modified by BCDC staff to include bay waters), so that the following steps were not performed on portions of the rail system outside the analysis area.
2. Note that the input dataset from MTC does not include stations used by Amtrak for long distance service, but not commuter rail service. These stretches of track are not considered part of the commuter rail network by MTC and were therefore not included in the analysis.
3. Average weekday ridership values were joined to each station point. Average weekday ridership values are the sum of entrances and exits. In cases where only data on entrances or exits were available these values were multiplied by 2 to estimate ridership. Average weekday ridership values were generated using different methods for each operator, based on the type and quality of data available:
    a. BART – data on average weekday exits by station are publicly available. These values were multiplied by 2 to estimate ridership by station.
    b. VTA – data on average weekday exits by station are publicly available. These values were multiplied by 2 to estimate ridership by station.
    c. MUNI – average weekday exists by station were generated from MUNI's ridership census. Note that while the MUNI system includes buses and street cars, only MUNI light rail stations were included in this analysis.
    d. Caltrain – average weekday exists by station were extrapolated from Caltrain's annual passenger count by train.
    e. SMART – average weekday exits by station were estimated by converting annual weekday ridership to average weekday ridership, and then allocating this value across the system based on the proportion of riders entering and exiting from each station.
    f. Capitol Corrido and ACE – since these operators stop at the same stations, ridership flow values were generated separately and then values for each stretch of track were summed.
        i. Capitol Corridor – Recent data that could be used to generate values for average weekday ridership were not

available. Instead, data on average daily ridership by train by station for FY07-08 were used to define general ridership patterns on the line. These patterns were extrapolated to system-wide annual ridership values for FY16-17 and ridership were used to calculate entrances and exits. This analysis assumed that the ridership pattern at the new Fairfield-Vacaville station is similar to Suisun-Fairfield.

   ii. ACE – ridership values generated using the ACE Passenger Rail Forecasting model developed by AECOM for the ACEforward Program.

4. On inspection of the feature class, there appeared to be little uniformity regarding the location of the point relative to its corresponding station. To improve the spatial accuracy of the analysis, all points located within OLUs were compared to satellite imagery in ArcGIS Pro and adjusted based on the following rules.
   a. For stations where the same platform serves both directions, the point was moved to the center of the station building/canopy.
   b. For stations with two platforms, one serving each direction, the point was moved to midway between the two stations (usually in the middle of a street intersection).
   c. For stations with no surface-level terminal, the point was moved midway between all surface-level entryways.
5. Once the locations of station points were reviewed and adjusted, a 100-meter buffer was applied to all station points. This buffer distance was chosen for the following reasons:
   a. Upon inspection of several stations from different operators, it appeared that a 100-meter buffer from the center of each station would include the entire platform(s) for almost all stations.
   b. For stations with large underground terminals and several entryways spanning multiple city blocks, it was determined that there were no TWLs where an entryway was impacted but the inundation polygon did not touch the 100-meter buffer.
   c. This buffer distance would match the buffer distance applied by BCDC to critical infrastructure in other analyses.
6. Once all ridership values were joined, the feature class was intersected with the Operational Landscape Units (OLU) boundaries, so that the results can be summarized by OLU.

7. The resulting feature class, Transpo_CommRailStations_Input_Final, is a series of circles with a radius of 100 meters, one for each commuter rail station, with average weekday ridership values.

CONSEQUENCE ANALYSIS

1. Transpo_PassRailStations_Input_Buffered was clipped by an inundation polygon for each of the ten total water levels. The result is a series of feature classes representing impacted commuter rail stations under each TWL, with ridership values for the impacted segments.
2. High/Medium/Low ranges for rating consequence were developed for average weekday ridership using the 108" TWL. The ridership values for all impacted segments under the 108" TWL were separated into three quantiles (buckets with an equal number of segments in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Average Weekday Passenger Flow Range
Low	0 – 499
Medium	500 – 2,995
High	2,995 - 97,052

Files

Unless otherwise noted, these are GIS files stored in the Transpo_PassRailStations_Output_Final.gdb Geodatabase.

Freight Rail

The primary consequence of freight rail lines becoming inundated is disruption to regional goods movement. The amount of cargo transported on each line was measured in freight trains per day. This unit is not particularly granular, but it was the best data available for the entire region. Although data on cargo weight or cargo value would have been preferred, the project team found that the differences in freight trains per day between stretches of track were different enough to enable the relative impact this analysis is based on.

PROCESSING AND CONDITIONING

1. The input California Rail Network feature class was clipped to the Operational Landscape Units layer (version modified by BCDC staff to include bay waters), so that the following steps were not performed on portions of the rail system outside the analysis area.
2. The resulting feature class was dissolved by railroad subdivision so that each subdivision was represented by a single feature.
3. Values for the average daily freight trains were joined to each line. For stretches of track that are part of multiple lines, freight trains per day were first determined separately for each line and then summed. Freight trains per day were determined using the following methods:
4. For the majority of lines, including all those that experience significant traffic, the number of freight trains per day was determined from Table 5.1 in the 2016 MTC Goods Movement Plan. Note that the values in this table are 2020 LOS Projections, not values representing current activity as this data was not regionally available.
5. For the segments of track in Richmond owned by the Richmond Pacific Railroad, Curtis Savoye, Vice President of Operations for the Richmond Pacific Railroad, gave estimates of freight cars per day for each line. These numbers were converted to freight trains per day using a conversion factor of 80 cars per train.
6. The remaining heavy rail lines were confirmed to not carry freight based on web research. These lines are used by tourist or historic passenger trains.
7. Once all freight train activity values were joined, the feature class was intersected with the OLU boundaries, so that the results can be summarized by OLU. Segments that intersect more than one OLU were split into multiple features.
8. Due to data limitations, certain elevated freight rail (e.g. bridges and overpasses) were falsely indicated as inundated. In some cases, this was the only inundation for a given rail and water level resulting in inaccurate consequence scores and OLU ranking. Due to this error, a processing step was taken to visually inspect intersected rail segments at each TWL and manually draw a bounding polygon representing elevated rail segments (Transpo_SourceData_BridgeFix). The resulting polygon layer was used to select by location and delete out elevated rail segments. An assumption in this process is that the elevated rail is not considered flooded until adjacent rail segments on one or both sides of the elevated

structure are also inundated. It is also important to note, that even though the elevated rail itself may not be inundated, increased tidal scour at bridge and overpass footings, piers, and pilings can represent an important vulnerability, though not reflected in this Consequence Analysis.

9. To ensure the Vulnerability Analysis described below accurately reflects real exposure of the asset, a quality control step was performed by BCDC staff to manually edit source data geometry so that alignments of line segments were located over existing railbeds.
10. The resulting feature class, Transpo_FreightRail_Input_Final, is a feature class of all freight rail lines, with average daily freight train values for each segment.

CONSEQUENCE ANALYSIS

1. Transpo_FreightRail_Input_Final was clipped by an inundation polygon for each of the ten total water levels. The result is a series of feature classes representing impacted heavy rail lines under TWL, with average daily freight train values for the impacted segments. If a portion of a rail segment was impacted, its entire consequence values was considered impacted because all trains travelling on that segment would not be able to pass through the inundated portion.
2. High/Medium/Low ranges for rating consequence were developed for average daily freight trains using the 108” TWL. The daily freight train values for all impacted segments under the 108” TWL were separated into three quantiles (buckets with an equal number of segments in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Average Daily Freight Trains
None	0
Low	0.33 – 4
Medium	5 – 12
High	13 - 30

Files

Unless otherwise noted, these are GIS files stored in the Transpo_FreightRail_Output_Final.gdb Geodatabase.

Highways

The consequence of inundation to highways was measured using three different indicators: traffic volume, truck traffic volume, and Lifeline Routes. Annual average daily traffic (AADT) is the total volume of vehicle traffic on a highway for a year divided by 365 days. Annual average daily truck traffic (AADTT) is the total volume of truck traffic on a highway for a year divided by 365 days. AADT represents the importance of the highway to the general population, including commuters. AADTT represents the importance of the highway to cargo and freight transport. These indicators were chosen because they are standard measures of traffic flow used in transportation planning and are regionally available for the entire Bay Area. Both AADT and AADTT volumes were provided by Caltrans at discreet points along the highway system. Lifeline Routes are designated by MTC and represent routes that are of critical importance to regional mobility.

PROCESSING AND CONDITIONING

1. The State and National Highways shapefile was clipped to the study area and then dissolved by highway number and direction, so that all segments of the same highway in the same direction became a single feature. Highways designated as Lifeline Routes were tagged as such by adding an additional attribute.
2. The feature class was then clipped to the Operational Landscape Units layer (version modified by BCDC staff to include bay waters), so that the following steps were not performed on portions of the highway system outside the analysis area.
3. The resulting highways feature class was then split at the location of each Truck AADT (AADTT) point. AADTT points were chosen because AADTT points always overlap with AADT points, but many AADT points do not have a corresponding AADTT value.
4. The AADT and AADTT values at the endpoints of each highway segment were averaged and then joined to each highway segment. For highway segments that only had an AADT/AADTT value at one endpoint, that value was used.

5. This feature class was intersected with the Operational Landscape Units (OLU) boundaries, so that the results can be summarized by OLU in a later phase. Segments that intersect more than one OLU were split into multiple features.
6. Next, elevated stretches of highway were removed from the dataset so they would not be incorrectly included as exposed segments in the following Consequence Analysis. The “Bridge” attribute in OpenStreetMap’s highways layer was determined to be a good proxy for elevated highway. A series of geoprocessing operations were used to attach this attribute to the official Caltrans highways layer used in the previous steps, and then remove elevated portions of highway segments.
7. The resulting feature class, Transpo_Highways_Input_Final, is a highways layer (without elevated stretches) split into segments by AADTT point, with AADT and AADTT values for each segment. These values represent the annual average daily passenger vehicle and truck traffic that flows through that segment of highway.
8. Due to the OSM bridge attribute, noted above, not being comprehensive across all elevated structures in the project area, as well as small discrepancies between the extent of the attributed segments and inundation polygons, certain elevated roads (e.g. bridges and overpasses) were falsely indicated as inundated. In some cases, this was the only inundation for a given roadway and water level resulting in inaccurate consequence scores and OLU ranking. Due to this error, a processing step was taken to visually inspect intersected roadway segments at each TWL and manually draw a bounding polygon representing remaining elevated roadway segments (Transpo_SourceData_BridgeFix). The resulting polygon layer was used to select by location and delete out remaining elevated roadway segments. An assumption in this process is that the elevated roadway is not considered flooded until adjacent roadway segments on one or both sides of the elevated structure is also inundated. It is also important to note, that even though the elevated roadway itself may not be inundated, increased tidal scour at bridge and overpass footings, piers, and pilings can represent an important vulnerability, though not reflected in this Consequence Analysis.
9. To ensure the Consequence Analysis described below accurately reflects real exposure of the asset, a quality control step was performed by BCDC staff to manually edit source data geometry so that alignments of line segments were located over existing roadways.

CONSEQUENCE ANALYSIS

1. Transpo_Highways_Input_Final was clipped by an inundation polygon for each of the ten total water levels. The result is a series of feature classes representing the impacted stretches of highway under each TWL, with AADT and AADTT values for the impacted segments. If a portion of a highway segment was impacted, its entire AADT and AADT values were considered impacted because all vehicles would not be able to pass through the inundated portion.
2. High/Medium/Low ranges for rating consequence were developed for both AADT and AADTT using the 108” TWL. The AADT values for all impacted segments under the 108” TWL were separated into three quantiles (buckets with an equal number of segments in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence. This process was then repeated for AADTT values.

Consequence	AADT Range	AADTT Range
Low	0 - 44,000	0 - 2,259
Medium	44,000 - 148,500	2,259 - 5,900
High	148,500 - 275,000	5,900 - 25,359

3. Since Lifeline Routes are binary, the Lifeline Routes consequence score was treated differently. Highway segments that were Lifeline Routes were given a score of 1, and Highways that were not Lifeline Routes were given a score of 0.

Files

Unless otherwise noted, these are GIS files stored in the Transpo_Highways_Output_Final.gdb Geodatabase.

Bus Routes

Consequence of inundation to the Bay Area's bus systems was measured by the number of high-quality transit corridors impacted under each total water level. Ideally, this analysis would have used rider flow data similar to the Commuter Rail Lines consequence indicator. However, regional data on bus ridership was unavailable, and few operators have reliable data for their systems.

The PMT agreed that High-Quality Transit Corridors could be used as a proxy for ridership. High Quality Transit Corridors are defined by the California Public Resources Code as a fixed-route bus corridor with headway of 15 minutes or better during the morning and evening peak periods, or a fixed-route bus corridor with headway of 15 minutes for better during both the morning and evening peak periods in an adopted Regional Transportation Plan (RTP).

A limitation of this consequence indicator is that in the High-Quality Transit Corridors dataset available from MTC there are no bus lines in the North Bay counties that fit the definition described above. While the fact that no bus lines in the North Bay meet the High-Quality Transit Corridor criteria means that the consequence of inundation to these systems is comparatively low, it also means that impacts to bus systems in the North Bay, however minimal, were omitted from the analysis.

PROCESSING AND CONDITIONING

1. Data on ridership by bus route was not regionally available. Instead, the PMT agreed that High-Quality Transit Corridors could be used as a proxy for ridership. High Quality Transit Corridors are defined by the California Public Resources Code as a fixed-route bus corridor with headway of 15 minutes or better during the morning and evening peak periods, or a fixed-route bus corridor with headway of 15 minutes for better during both the morning and evening peak periods in an adopted Regional Transportation Plan (RTP).
2. The High-Quality Transit Corridors feature class available from MTC are polygons formed from a ¼ mile buffer around bus routes meeting the criteria mentioned above. Using operator and route number attribute information in the Transitland bus routes layer, qualifying bus routes on the Bay Area Bus Routes line feature class were tagged.
3. Bus routes that did not meet the high-quality transit corridor definition were removed from the analysis.
4. The remaining features were then dissolved by route number and operator so that each route was represented by a single feature.

5. The feature class was then intersected with the OLU boundaries, so that the results can be summarized by OLU. Routes that intersect more than one OLU were split into multiple features.
6. The resulting feature class, Transpo_HQBusRoutes_Input_Final, is a feature class of all high-quality transit bus routes, split by OLU.
7. Due to data limitations, certain elevated roadways (e.g. bridges and overpasses) were falsely indicated as inundated. In some cases, this was the only inundation for a given bus route and water level resulting in inaccurate consequence scores and OLU ranking. Due to this error, a processing step was taken to visually inspect intersected bus route segments at each TWL and manually draw a bounding polygon representing elevated roadway segments (Transpo_SourceData_BridgeFix). The resulting polygon layer was used to select by location and delete out elevated roadway segments. An assumption in this process is that the elevated roadway is not considered flooded until adjacent roadway segments on one or both sides of the elevated structure are also inundated. It is also important to note, that even though the elevated roadway itself may not be inundated, increased tidal scour at bridge and overpass footings, piers, and pilings can represent an important vulnerability, though not reflected in this Consequence Analysis.
8. To ensure the Consequence Analysis described below accurately reflects real exposure of the asset, a quality control step was performed by BCDC staff to manually edit source data geometry so that alignments of line segments were located over existing roadways.

CONSEQUENCE ANALYSIS

1. Transpo_HQBusRoutes_Input_Final was clipped by an inundation polygon for each of the ten total water levels resulting in a series of feature classes representing impacted high-quality bus routes under each TWL.
2. Next, the number of impacted high-quality bus routes was summed by OLU. The result was a feature class of the OLU boundaries for each TWL, with the total number of impacted high-quality bus routes for that TWL.
3. High/Medium/Low ranges for rating consequence were developed for the number of impacted high-quality bus route using the 108” TWL. The results by OLU for the 108” TWL were separated into three quantiles (buckets with an equal number of OLUs in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Number of Impacted High Quality Bus Routes
None	0
Low	1 - 10
Medium	11 - 20
High	21 - 87

Files

Unless otherwise noted, these are GIS files stored in the Transpo_HQBusRoutes_Output_Final.gdb Geodatabase.

Active Transportation

The consequence of inundation to the Bay Area's active transportation system was measured using two indicators – miles of Bay Trail impacted and miles of regional bicycle infrastructure impacted. Although miles impacted is technically a measure of exposure, no data on ridership is currently available at the regional level for active transportation assets.

High quality linework for the Bay Trail was readily available, but linework for regional bicycle routes was not. While some Bay Area cities have extensive GIS data on their bicycle infrastructure, data was not available for the entire region. The project team considered using crowdsourced data from OpenStreetMap, but this linework has many gaps, does not differentiate between local and regional routes, and was found to mostly represent streets where bicycles are permitted, rather than streets with physical bicycle infrastructure. In lieu of a perfect dataset, the project team used data from Caltrans on bicycle access on the state highway system and alternate routes. This dataset was found to be a reasonable representation of regional bicycle routes, although important routes that are not on an alternate route for state highways are omitted.

PROCESSING AND CONDITIONING

1. Data on ridership or use of active transportation infrastructure was not regionally available. Instead, the PMT decided to use length of impacted

trail per OLU as the consequence indicator for both the Bay Trail and the regional bicycle routes, which were assessed separately.

2. In the Bay Trail feature class, segments of trail are designated as “Spine”, “Connector”, or “Spur”. Spine segments are the primary route of the circular network, connector segments connect the spine to inland areas, and spurs are short trails that extend off the spine along the shoreline. For the purposes of this analysis, all portions of the Bay Trail designated as spurs were removed from the analysis.
3. In the Bay Trail feature class, segments of trail are designated as “Existing” or “Proposed”. Both Existing and Proposed segments of trail were included in this analysis, as it is anticipated that most, if not all, proposed segments will be existing by the time that sea level impacts are felt regionally.
4. Both the Bay Trail and Caltrans Bicycle Routes layers were processed in parallel. Each layer was dissolved into a single feature. Then each layer was intersected with the Operational Landscape Units feature class. This split the single features into segments by OLU.
5. Due to data limitations, certain elevated roadways and path (e.g. bridges and overpasses) were falsely indicated as inundated. Due to this error, a processing step was taken to visually inspect intersected baytrail and bike route segments at each TWL and manually draw a bounding polygon representing elevated roadway or trail segments (Transpo_SourceData_BridgeFix). The resulting polygon layer was used to select by location and delete out elevated roadway or path segments. An assumption in this process is that the elevated roadway or path is not considered flooded until adjacent roadway or path segments on one or both sides of the elevated structure are also inundated. It is also important to note, that even though the elevated roadway or path itself may not be inundated, increased tidal scour at bridge and overpass footings, piers, and pilings can represent an important vulnerability, though not reflected in this Consequence Analysis.
6. To ensure the Consequence Analysis described below accurately reflects real exposure of the asset, a quality control step was performed by BCDC staff to manually edit Bay Trail source data geometry so that alignments of line segments were located over existing roadways or paths.

CONSEQUENCE ANALYSIS

1. The consequence analyses for the Bay Trail and regional bicycle routes were carried out in parallel using the same method. The input feature

classes were clipped by an inundation polygon for each of the ten total water levels. The result is a series of feature classes representing impacted trail segments under each TWL. The total length of impacted trail segments under each TWL was summed by OLU. The result was a feature class of the OLU boundaries for each TWL, with the total length of impacted Bay Trail or regional bicycle route in feet and miles for that TWL.

2. High/Medium/Low ranges for rating consequence were developed for length of impacted Bay Trail and regional bicycle routes separately using the 108" TWL. The results by OLU for the 108" TWL were separated into three quantiles (buckets with an equal number of OLUs in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Miles of Impacted Bay Trail	Miles of Impact Bicycle Route
None	0	0
Low	0.08 – 6.04	0.003 – 2.75
Medium	6.05 – 11.34	2.76 – 9.48
High	11.35 – 48.66	9.49 – 26.86

Files

Unless otherwise noted, these are GIS files stored in the Transpo_BayTrail_Output_Final.gdb and Transpo_BikeRoutes_output_Final.gdb Geodatabases, respectively.

Ferry Terminals

Consequence of inundation to the Bay Area's ferry terminals was measured in average weekday ridership by terminal. Weekday ridership was chosen because it is substantially higher than weekend or average ridership and represents the primary purpose of the ferry system. Ridership data was obtained from major ferry operators. Terminals that do not serve commuters on weekdays as well as non-commuter ferry operators were excluded from this analysis, as the project team agreed that they are not critical to the region's transportation system.

A limitation of this analysis is that without data on the height of terminal structures above the land they are built on, elevated terminals with inundated land beneath them may be identified as impacted, when in reality they are not. The result of this limitation is that almost all ferry terminals are shown as exposed at 12” TWL and beyond. To remedy this, site visits to each ferry terminal would be necessary.

PROCESSING AND CONDITIONING

1. Ferry terminal extents were digitized by hand using ArcGIS Pro satellite imagery.
2. Terminals that do not serve commuters on weekdays were removed from the analysis.
3. Ridership values were joined to each terminal polygon, using different methods for each ferry operator. For terminals that serve both operators, ridership was calculated separately for each operator and then summed.
    a. WETA provided ready-to-use data on average daily boarding by terminal.
    b. For Gold Gate Ferry, data on annual ridership by route and average weekday ridership system wide for fiscal year 2017 was accessed online. Annual ridership by route was used to determine the proportion of passengers riding on each route. These proportions were applied to average weekday ridership system wide to calculate average weekday ridership by line. Ridership by line was compared to route maps to apply ridership values to the corresponding terminals
    c. Note that non-commuter ferry operators were excluded from this analysis.
4. The feature class was then intersected with the Operational Landscape Unit (OLU) boundaries, so that the results can be summarized by OLU.
5. The resulting feature class, Transpo_FerryTerminals_Input_Final, is a feature class of all ferry terminals with average weekday ridership values, split by OLU.

CONSEQUENCE ANALYSIS

1. Transpo_FerryTerminals_Input_Final was clipped by an inundation polygon for each of the ten total water levels. The result is a series of feature classes representing impacted ferry terminals under each TWL, with average weekday ridership values for the impacted segments. Note that a limitation of this analysis is that without data on the height of terminal structures above the land they are built on, the result of this analysis is that all ferry terminals are impacted at 12” of sea level rise and beyond.

2. High/Medium/Low ranges for rating consequence were developed for average daily freight trains using the 108” TWL. Average weekday ridership values under the 108” TWL were separated into three quantiles (buckets with an equal number of terminals in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.
3. The impacted terminals under each TWL were then assigned consequence scores based on these ranges:

Consequence	Average Daily Ridership
Low	XXX – 250
Medium	250 – 1,000
High	1,000 – 6,867

Files

Unless otherwise noted, these are GIS files stored in the Transpo_FerryTerminals_Output_Final.gdb Geodatabase.

Airports

It is already widely accepted by decision-makers in the Bay Area that major airports are critical regional assets that are threatened by sea level rise. Consequence of inundation to airports was measured using two indicators: total annual enplanements (boardings) and total annual cargo weight by airport. Note that airfields not classified as Primary Commercial Service Airports by the FAA were excluded from this analysis. Reliable cargo data for these airports does not exist and the project team found that the values available for annual passengers were so low (mostly corporate flights or hobby pilots) that these airfields could not be considered regionally critical assets.

For the major airports, if any of the operations area was impacted under a given total water level, all enplanements and cargo in that airport are considered impacted. This reflects the strong emphasis on operational safety at airports, as well as the fact that airports have a variety of complex below ground mechanical and electrical infrastructure that, if inundated, would have cascading impacts beyond just the flooded area. Note that although San Jose International Airport is certainly a critical regional asset, it is not vulnerable to sea level rise, even under the 108” TWL.

PROCESSING AND CONDITIONING

1. For this asset type, little processing or conditioning was necessary. Enplanements by airport and cargo by airport were joined to the airport extents feature class.

CONSEQUENCE ANALYSIS

1. As only two airports were assessed (Oakland and San Francisco – San Jose is not vulnerable), the project team manually assessed the exposure of the assets to sea level rise by overlaying the airport boundaries and runways feature classes with the inundation polygon for each total water level. Satellite imagery from ArcGIS was also used to ground truth the datasets.
2. An airport was considered exposed if any portion of the operations area was overlapped by the corresponding inundation polygon. For both SFO and OAK, there is a clear point at which each airport becomes vulnerable:

SFO – 12" TWL

SFO – 24" TWL

OAK – 24" TWL

OAK – 36" TWL

3. High/Medium/Low ranges for rating consequence were developed for both enplanements and cargo using the 108" TWL. The values for all major commercial airports within the study area (Oakland, San Francisco, and San Jose) were separated into three quantiles (buckets with an equal number of

airports in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Annual Enplanements (Upper Bound)	Annual Cargo Weight (lbs) (Upper Bound)
Low	-	100,000,000
Medium	6,413,850	500,000,000
High	26,900,048	1,152,000,000

Files

Unless otherwise noted, these are GIS files stored in the Transpo_Airports_Output_Final.gdb Geodatabase

Seaports

Consequence of inundation to seaports was measured by the impact to the total annual value of exports and imports by port. This indicator was chosen over cargo volume because cargo volume would overemphasize goods with low value but high weight, such as concrete, gravel, or recyclables.

The project team recognized that seaports are very large assets with a variety of components that have varying levels of sensitivity and consequence to flooding. Inundation of some portions of a port will likely not completely impact the port's ability to move goods. To this end, the project team decided to estimate the proportion of export/impact value that would be impacted by calculating the proportion of transportation infrastructure within each port inundated under each total water level. Transportation infrastructure (roads and railways) are critical to moving goods in or out of a port, and linework for both was regionally available. Although this method does not consider network impacts on redundancy, or vulnerability of other port components, with the resources and data available to the project team, this method resulted in a more nuanced analysis than considering an entire port impacted if only a portion was inundated.

PROCESSING AND CONDITIONING

1. The source Port Extents feature class did not include several privately-owned ports in the Bay Area. It also included areas within port jurisdictions that are not related to port operations, such as piers converted to office space in San Francisco, or non-maritime real estate holdings in Oakland. To ensure that the feature class was representative of all maritime shipping operations in the Bay Area, the following modifications were made:
    a. Port of San Francisco – all terminals were removed except for cargo terminals 80 and 92-96.
    b. Port of Oakland – added UPPR railroad yard and seaport logistics complex. Removed the area north of the Bay Bridge and non-maritime areas.
    c. Port of Richmond – added storage areas and removed Point San Pablo.
    d. Port of Benicia – connected polygons along Bayshore Road.
    e. Digitized port extents for Port of Martinez, Port of Shelby, and Port of Crockett using ArcGIS Pro satellite imagery
2. The OpenStreetMap centerlines feature class needed to be filtered to remove unnecessary lines, including boundary/census lines, abandoned railroad tracks, waterways, ferry lines, tunnels, and underwater cables.
3. The remaining transportation infrastructure (roads and railroads) centerlines were clipped to the port extents so that only lines within the port operations areas remained.
4. The port transportation infrastructure feature class was then intersected with the port extents. This tagged each line with the name of the port it was located within.
5. Next, the transportation infrastructure feature class was dissolved by port name, so that all lines within a given port became a single feature.
6. The total length of transportation infrastructure within each port was calculated.
7. The result of this process was, Transpo_Seaports_Inputs_Roads-Rails, a feature class of all roads and railroads within port operations areas, with one feature representing each port, and the total length of roads/rails calculated for each port.

CONSEQUENCE ANALYSIS

1. Transpo_Seaports_Inputs_Roads-Rails was clipped by an inundation polygon for each of the ten total water levels. The result is a series of feature classes representing impacted roads/rails under each TWL.
2. The length of roads/rails inundated was calculated by port for each total water level.
3. These values were divided by the total length of roads/rails within each port to generate the percent of transportation/infrastructure impacted for each port under each total water level.
4. These percentages were multiplied by the annual trade value of each port to estimate the economic impact of each total water level on each port. Note that a limitation of the port trade values dataset is that it only includes the value of goods imported from or exported to foreign countries, so it does not include the value of goods shipped to other ports in the United States.
5. High/Medium/Low ranges for rating consequence were developed for impacted trade value using the 108” TWL. Impacted trade values under the 108” TWL were separated into three quantiles (buckets with an equal number of ports in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Impacted Trade Value (2017 dollars)
None	0 – 250,000
Low	250,000 – 213,536,572
Medium	213,536,572 – 2,994,610,723
High	2,994,610,723– 37,943,392,543

Files

Unless otherwise noted, these are GIS files stored in the Transpo_Seaports_Output_Final.gdb Geodatabase.

PRIORITY DEVELOPMENT AREAS

Priority Development Areas (PDAs) are places identified by Bay Area communities as areas for investment, new homes and job growth in MTC's Plan Bay Area. Unlike the transportation asset class, which is made up of a variety of different asset types, PDAs are a single asset type. For all PDA indicators, consequence was assessed at the parcel level and then summarized by PDA for inclusion in the analysis.

Residential Housing Units and Jobs 2010, 2040 and Growth

The consequence indicators chosen to measure impact to PDAs include 2040 job spaces, 2040 residential units, projected growth in job spaces 2010-2040, and projected growth in residential units 2010-2040. The years and units reflect the parcel-level regional projections produced by Plan Bay Area's Urban Sim model. Residential units are essentially households, but they refer to the physical space that can accommodate a household, not the people. Similarly, a job space is the physical space that accommodates a job, not the job itself. A development with 50 apartments has 50 residential units and an office building with space for 100 desks has 100 job spaces.

Note that while PDAs are located in areas that are currently developed, they represent only the portion of developed area where increased density or transit investment is beneficial to regional land use and transportation objectives. PDAs were nominated by elected officials of local jurisdictions and approved by the ABAG Executive Board as part of Plan Bay Area 2040[5].[6] The Consequence Analysis did not consider impacts to residential units or job spaces outside of PDA boundaries.

The PMT decided to use 2040 projections over 2010 values for both indicators because the impacts of sea level rise will be experienced in the future. This is the only indicator in the entire analysis for which robust future projections were readily available. The team decided to include projected growth in both job spaces and residential units as additional indicators in order to highlight PDAs where sea level rise will impact developments that have not yet been constructed. It is important to make this distinction because it is possible to intervene or modify designs for future developments.

To calculate consequence, a key assumption made in this analysis is that once a parcel is exposed to flooding, even marginally, the entire number of residential units in that parcel is considered impacted. This assumption reflects a conservative understanding that flooding has many direct and indirect impacts for a person's ability to enjoy their home. Indirect impacts such as flooding of walkways,

[5] "Priority Development Areas | Plans + Projects | Our Work | Metropolitan Transportation Commission."

foundations, electrical systems may all contribute to an individual or family being displaced. Since we don't have data to reflect these indirect impacts, we maintain the assumption that any flooding to a parcel impacts all the people living in it. This assumption works well for small parcels, but for large parcels this assumption serves as a limitation to the analysis. Large undeveloped parcels (e.g. former military lands) that have large projected growth for 2040, show high numbers of residential units impacted when exposed to flooding, despite the fact that the flooding may not be in the location where future development may occur. A related but separate limitation of this analysis is the existence of parcel boundaries that extend bayward of the MHHW line. These parcel boundaries intersect even small amounts of flooding despite the fact that no buildings exist in these parts of the parcel and inaccurately indicate impacted residential units. Future efforts should be made to refine parcel boundaries to both current and future developed areas on the shoreline.

PROCESSING AND CONDITIONING

1. The CSV file of Plan Bay Area Job Spaces and Residential Units by Parcel for 2010 and 2040 provided by MTC was joined to a parcel map of the 9 counties by APN.
2. Residential and employment growth by parcel was calculated by subtracting 2040 values from 2010 values. The result was a parcel feature class with 6 consequence indicator values: the number of residential units in 2010, job spaces in 2010, residential units projected for 2040, job spaces projected for 2040, change in residential units projected for 2010 to 2040, and change in job spaces projected for 2010 to 2040.
3. To reduce the number of polygons in the dataset, parcels that did not have residential units or job spaces for both 2010 and 2040 were eliminated from the feature class.
4. The Priority Development Areas (PDAs) feature class was dissolved by PDA. This converted portion of PDAs that were split into different features because portions have different lead agencies back into a single feature.
5. The dissolved PDAs feature class was then intersected with the Operation Landscape Units (OLUs) boundaries feature class. This tagged each PDA with the OLU that it is within. PDAs that fell into multiple OLUs were split into multiple features, each tagged with the OLU that the portion fell within.

CONSEQUENCE ANALYSIS

1. The following analysis was performed twice—once with the feature class of PDAs dissolved by PDA name and intersected by OLU (henceforth referred to as “PCAxOLU”) and once with the original PDAs feature class. The results of the PCAxOLU run, because they are split by OLU, were incorporated into this analysis. The results of the PDA run were generated so that the results could be analyzed by PDA, irrespective of OLU, if desired at a later stage.
2. Inundation polygons were used to select and extract parcels within PDAs impacted by each of the ten total water levels. Feature classes of only impacted parcels within PDAs were saved for each total water level. This method of exposure analysis means that if a parcel partially overlapped an inundation polygon, it was considered impacted under that TWL. In some cases, this may overestimate the number of households/jobs impacted, as the portion of the parcel impacted may not be the built area.
3. Using the ArcGIS Pro Summarize Within tool, the values of the 6 consequence indicators by parcel were summed by PDAxOLU (and separately by PDA). Summarize Within performs a spatially weighted calculation, so if a parcel was partially located within a PDA, only a portion of the consequence indicator values were allocated to that PDA based on the proportion of the area of the parcel that was within the PDA. This ensured that consequence indicators outside PDA boundaries would not be counted. It also ensured that consequence indicators for parcels that fell on the boundary of multiple PDAxOLU polygons would not be double counted. The result of this process was a feature class for each total water level of PDAxOLU polygons with the total impact quantified for each of the 6 consequence indicators.
4. High/Medium/Low ranges for rating consequence were developed for each of the 6 consequence indicators using the 108” TWL. Consequence indicator values under the 108” TWL were separated into three quantiles (buckets with an equal number of PDAxOLU polygons in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	2010		2040		Change 2010 – 2040*	
	Residential Units	Job Spaces	Residential Units	Job Spaces	Residential Units	Job Spaces
None	0	0	0	0	-221 – 0	-2,427 – 0
Low	1 – 162	1 – 539	1 – 440	1 – 539	1 – 136	1 – 1,592
Medium	162 – 714	539 – 5,342	440 – 2,350	539 – 6,425	136 – 2,570	1,592 – 5,939
High	714 – 8,261	5,342 – 79,405	2,350 – 32,109	6,425 – 79,288	2,570 – 23,848	5,939 – 31,905

5. The 0 consequence range for residential units change and job spaces change includes negative values. This is because in some cases parcels are projected to experience a net decrease in residential units or job spaces from 2010 to 2040. Since the purpose of this consequence indicator was to highlight vulnerable areas that projected to experience growth, these cases of net loss were assigned a consequence score of zero.

Files

Unless otherwise noted, these are GIS files stored in the PDA_Output_Final.gdb Geodatabase.

PRIORITY CONSERVATION AREAS

Priority Conservation Areas (PCAs) are open spaces that provide agricultural, natural resource, scenic, recreational, and/or ecological values and ecosystem functions. These areas are identified through consensus by local jurisdictions and park/open space districts as lands for inclusion in Plan Bay Area 2040.[7]

While PCAs are generally regionally significant open spaces, they represent only the portion of open spaces or habitats that local jurisdictions decided to prioritize. A primary purpose of the PCA program was to channel One Bay Area Grant funding into areas that are currently being pressured by urban development. Therefore, some important natural areas that are already protected or are currently being restored were omitted during the designation process. Some developed areas were designated as PCAs by local jurisdictions to make them eligible for urban greening funding. This analysis does not calculate impacts to ecosystem services outside of PCA boundaries.

The following indicators were chosen to measure the impact of sea level rise on PCAs. A justification for each indicator, as well as notable caveats or concerns, is documented in the subsections that follow:

- Soil Organic Carbon
- Habitat
    - Tidal Wetlands
    - Depressional Wetlands
    - Lagoons
- Threatened and Endangered Species
    - Ridgeway Rail
    - Western Snowy Plover
    - Salt Marsh Harvest Mouse
- Crop Production
- Stormwater Management
    - Runoff Retention
    - Stormwater Infiltration
- Photo Visitation Rates

Note that the level of detail in this subsection is greater than in the discussion of Transportation, PDAs, and Vulnerable Community indicators. This is because the indicators used for PCAs are not standard or common measures, like AADT for highways or impacted residential units for PDAs. For less commonly understood measures of consequence used for PCAs, a more in-depth explanation is necessary, as well as a summary of the research the project team conducted to verify that the data used was an accurate and accepted measure of the chosen indicator. For each

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[7] Association of Bay Area Governments, "Priority Conservation Areas."

PCA consequence indicator, a discussion of the caveats for each dataset is also included.

Soil Organic Carbon

Tidal wetlands are recognized as storing significant amounts of organic carbon on a scale equal to, if not greater than, tropical rainforests, which has garnered them specific attention in climate change mitigation. Although the San Francisco Bay (Bay) region has lost a significant amount of its historic wetlands to development pressures over the past 100 plus years, valuable wetland habitats still remain, and large-scale restoration efforts in the South Bay and the North Bay are seeking to restore and increase the amount of wetland habitat. However, if the wetlands cannot keep pace with sea level rise, or if they cannot migrate inland due to the presence of inland development, the carbon sequestration and climate change mitigation potential of these wetlands will be lost. The use of an environment indicator that captures this valuable ecosystem service was therefore desired by the PMT and the RWG.

The carbon sequestration potential of the Bay wetlands varies based on many factors, including vegetation type, density, and salinity. Currently, a regional data set of carbon sequestration potential does not exist. Instead, the project team used an alternative metric – the percentage of soil organic matter in the tidal wetlands – as a proxy for carbon sequestration. The percentage of organic carbon can be measured directly, but this requires considerable preparatory work and cost. Therefore, most researchers calculate percent soil organic matter instead, which is directly related to the percentage of organic carbon.

For a large geographic area such as the Bay, the collection and processing of sufficient soil cores to characterize the diversity of the region would be time consuming and expensive. Luckily, the US National Cooperative Soil Survey has developed a nationwide soil survey inventory called the Soil Survey Geographic database (SSURGO) that can be used as a proxy for field-collected soil data. The database contains a multitude of variables relating to each soil type, often including the percent soil organic matter, and soil maps have been digitized and georeferenced for incorporation into spatial analyses.

SSURGO data were used in the analyses for the 'Carbon Sequestration and Greenhouse Gas Emissions' chapter of the 2016 San Francisco Baylands Ecosystem Habitat Goals Update to assess carbon variability throughout the Bay, and to calculate potential carbon loss through conversion of tidal wetlands over time. Although there are known issues with using SSURGO data in tidal wetlands (see Holmquist et al. 2018), the project team is confident that this Bay-wide data set of soil organic carbon is sufficient to use as a first estimate for demonstrating the variability in soil carbon across the Bay's tidal wetlands – and based on a review of available data sets, the SSURGO data represents the best available data at this time.

To provide support for using the SSURGO data, the project team compared the results from soil cores collected throughout the Bay from Callaway et al. (2012) with the SSURGO data. Callaway et al (2012) collected multiple soil cores at six natural marshes within Bay to quantify both organic carbon content and historic organic carbon sequestration rates. These sites span a salinity gradient from saline to nearly freshwater and thus are a representative sample of the Bay's tidal wetlands. The project team plotted both the average percent organic matter and carbon sequestration rates (g C m-2 yr-1) at these sites on the map of SSURGO data used in the Goals Update and found relatively strong agreement. Site-level variation does occur within the carbon sequestration rates, which are not shown presently, but the data are consistent enough to support using the SSURGO-based map of soil organic matter as an environmental indicator at this time.

Caveats: Although the comparison between the Callaway et al (2012) soil cores and the SSURGO data shows good agreement, the use of percent soil organic carbon as a proxy for carbon sequestration may underestimate the carbon sequestration potential of the Bay's tidal wetlands. Additional soil core information is available from multiple sources to create a more representative and accurate representation of carbon sequestration, but additional research and funding is required to coordinate and translate this data into a regionally-available data set. In addition, the carbon sequestration potential over time will vary with sea level rise as well as other factors such as sediment availability, restoration, development, and additional climate factors. Although the use of percent soil organic carbon is the best available proxy for carbon sequestration at this time, additional research in this field should be conducted and coordinated across the region.

Core-based values of a) percent soil organic matter and b) carbon sequestration rates from six natural marshes across the Bay are plotted on the average soil organic matter estimates from the national SSURGO soils database. Map colors relate to ranges of each value. (WT = Whale's Tail, CC = China Camp, PRM = Petaluma River Marsh; CI = Coon Island; RR = Rush Ranch; BrI = Brown's Island)

Habitat and Species

The Natural Capital Project (NatCap) summarized the distribution of habitats and species across multiple scales. Of primary interest for ART Bay Area is the habitat and species found within the PCAs and within the SLR Vulnerability Zone. Although NatCap analysed a suite of 20 habitat and species found in the Bay Area, the analysis focuses on a subset of three habitat types (e.g., tidal wetlands, depressional wetlands, and lagoons) and three species that are threatened and endangered (e.g., ridgeway rail, snowy plover, and the salt marsh harvest mouse). It should be noted that the salt marsh harvest mouse was not included in NatCap's original suite of species, but the salt marsh harvest mouse was added for this analysis because its habitat areas around the Bay are limited, and the mouse does not have the ability to migrate from one area of the Bay to another in the same manner as bird species.

Habitat data were identified and compiled by NatCap through the NFWF San Francisco Bay Coastal Resilience Assessment and provided by Point Blue Conservation Science (project in progress). These data were nominated for inclusion by key experts during Point Blue's stakeholder engagement process. Many of these data come from prior local and vetted habitat data compiled by the San Francisco Estuary Institute including the California Aquatic Resource Inventory and Bay Area Aquatic Resource Inventory. The data for the salt marsh harvest mouse is from the California Natural Diversity Database. This database includes all mouse sightings since 1938. For this assessment, only sightings between 2000 and the present were included in order to assess the mouse's current habitat range throughout the Bay Area.

HABITAT

Three habitat indicators were selected for inclusion in this analysis. The spatial distribution of these habitats within the PCAs is shown on Figure 5.

- **Tidal Wetlands** are valued for their carbon sequestration potential, and also for the habitat, flood reduction, wave attenuation, and water quality improvement capabilities. In general, tidal wetlands vary from saline to brackish. They exist as both large tracts of contiguous habitat and as small fringing areas along more urbanized shorelines. Even small pockets of tidal marsh can be teeming with wildlife, providing excellent public access opportunities for bird watching.
- **Depressional Wetlands** are generally located inland from tidal wetlands and are periodically or permanently inundated with freshwater. Depressional wetlands also provide value habitat for a wide variety of species.
- **Lagoons** in the Bay Area are generally areas adjacent to the Bay shoreline that have been diked off from the Bay for salt production or commercial purposes such as former agricultural areas. These areas are included because they represent excellent opportunities for tidal marsh restoration, and the many of the lagoons in the North Bay and the South Bay are currently part of large-scale restoration projects with a goal of restoring the lagoons to tidal marsh in a phase approach over the coming decades.

THREATENED AND ENDANGERED SPECIES

Three species indicators associated with federal listed species under the Endangered Species Act were selected for inclusion in this analysis.

- **Ridgway's rail**, formerly known as the California clapper rail is an endangered species of bird that is found principally in the tidal marshes around the Bay. In the 19th century, unregulated hunting diminished the rail population, and in the 20th century, rampant development reduced the salt marsh habitat by 85, further diminishing the rail's numbers. The ridgeway rail is a 'chicken-sized' bird that rarely flies.
- **Western snowy plover** is a small threatened shorebird that nests on coastal beaches, with a subset of the population found nesting around the Bay. Plovers nest on the dry salt ponds, and on isolated islands and pond berms located within the active and former salt producing ponds located along the Bay shoreline in the North and South Bay. The snowy plovers preferred habitat is at risk of disappearing due to sea level rise.
- **Salt Marsh Harvest Mouse** is an endangered rodent that lives within Bay Area tidal marshes. The mouse is endangered due to its limited range, historic decline in population, and continuing threat of habitat loss due to development encroachment along the Bay shoreline. The mice depend heavily on vegetation cover to avoid predation, particularly pickleweed and tules.

Caveats: This assessment uses the best available data on habitat availability and species range under existing conditions. Exposure to sea level rise is assessed by overlaying the habitat and species data layers with the 10 total water levels. This simple overlay approach does not capture the full impact or consequence of sea level rise. In addition, different habitats and species may be more or less impacted by sea level rise or be able to adapt.

Concern was expressed at a Regional Stakeholder Working Group meeting about the correlation between ridgeway rail and tidal marsh habitats. However, based on a review of the available data, the ridgeway rail's species distribution is limited to a subset of the tidal marsh areas; therefore, the inclusion of the ridgeway rail as an indicator is recommended.

Crop Production

The San Francisco Bay Area (Bay Area) supports approximately 237,000 acres of prime farmland that produce fruits, vegetables, meat, dairy, and wines as well as an array of ecosystem services that provide benefits for wildlife, and jobs that contribute to the Bay Area economy. This analysis uses data available from Bay Area Greenprint (Greenprint), a comprehensive compilation of more than 30 key metrics that measure and map the diverse value of natural and agricultural lands.

The Greenprint geodatabase contains multiple metrics related to Bay Area agricultural lands. With the indicator characteristics in mind, the potential of the following four potential agricultural data layers was assessed:

- **Crop production –** the average dollar value of crops produced for each agricultural type, according to data reported to the county-based Agricultural Commissioners.
- **Farmland of Local Importance –** Land of importance to the local agricultural economy as determined by each county's board of supervisors and a local advisory committee. Source: Farmland Mapping and Monitoring Program; Minimum Acreage Threshold: 10.0 acres.
- **Farmland of Statewide Importance –** Similar to Prime Farmland but with minor shortcomings, such as greater slopes or less ability to store soil moisture. Land must have been used for irrigated agricultural production in the last four years. Source: Farmland Mapping and Monitoring Program; Minimum Acreage Threshold: 10.0 acres.
- **Prime farmland –** Farmland with the best combination of physical and chemical features able to sustain long term agricultural production. This land has the soil quality, growing season, and moisture supply needed to produce sustained high yields. Land must have been used for irrigated agricultural production in the last four years. Source: Farmland Mapping and Monitoring Program; Minimum Acreage Threshold: 10.0 acres.

For all four data layers, the data is presented as point values. For crop production, each point is assigned an average dollar value based on annual crop production at that location. For the other three data layers, each point is assigned an average acreage value. Within the sea level rise vulnerability zone (the area potentially inundated by 108 inches of sea level rise, or 66 inches of sea level rise coupled with a 100-year coastal flood event), the North Bay counties of Napa, Sonoma, and Marin have the majority of the farmland. Solano also has extensive farmland, but it is primarily inland of the sea level rise vulnerability zone.

In general, the crop production data layer provides the same spatial coverage of the other three data layers, while also providing a robust economic indicator that provides spatial variation across the farmland, with the highest dollar values associated with farmland that is both prime farmland and farmland of state importance. Based on a spatial assessment, the crop production data layer satisfies the desirable indicator characteristics of being regionally available, quantifiable, and more importantly, discrete.

Caveats: This economic indicator may under-value the farmland in Marin County that has a designation of local importance, as the crop production dollar values in these areas are low compared to the neighboring farmland in Napa and Sonoma Counties. In addition, this economic indicator does not account for the grazing land that is prominent throughout the North Bay counties. At this time, a standardized economic dollar value for the grazing lands has not been identified, but this can be flagged and added to a future update of the analysis.

It should also be noted that additional indicators, most notably groundwater recharge and stormwater pollutant load reduction, will help quantify some of the ecosystem service values provided by agricultural lands – including grazing lands. Therefore, crop production dollar value is included as the most appropriate economic indicator for agricultural lands, and the ecosystem services are captured under additional environmental indicators.

Stormwater Management

NatCap developed a new approach for assessing the stormwater management services provided by natural habitats and existing land use within the InVEST software. NatCap focused on several potential indicators for stormwater management benefits. Two indicators were selected for inclusion in the analysis: runoff retention and stormwater infiltration.

Runoff retention corresponds to the retention of stormwater by pervious land use based on average annual rainfall. Runoff retention is beneficial given the detrimental effects of polluted stormwater discharge into the Bay. Stormwater infiltration is a related service, corresponding to the percolation of stormwater past the root zone, potentially recharging groundwater for human and non-human purposes.

RUNOFF RETENTION

Average annual runoff retention was calculated using the EPA's Stormwater Management Model (SWMM), based on average annual rainfall data 1981-2010 obtained from the California Basin Characterization Model, four different soil groups (corresponding to different soil infiltration rates) based on the USDA Web Soil Survey, and 5 land use categories (from 100% impervious to 100% pervious, with and without tree canopy, and bar soil) based on NOAA's land use land cover data.

The average annual runoff retention represents the volume of stormwater that is retained each year by pervious surfaces and natural infrastructure, rather than being conveyed through the storm sewer network and discharged to the Bay or conveyed to the Bay through direct runoff.

Caveats: Currently, the model does not consider green infrastructure that has been constructed to retain stormwater runoff. A consistent Bay-wide data set of implemented green infrastructure projects was not available. However, the acreage of green infrastructure elements is likely small compared to the acreage off pervious services; therefore, the exclusion of green infrastructure is not considered a significant source of error.

The model also does not represent lateral interactions (i.e., hydrologic routing between land use areas). The model assumes that impervious areas (i.e., urban areas) are connected to storm sewer systems, and the captured stormwater drains directly to the Bay. However, it should be noted that most sewer systems are designed for the 5-year or 10-year, 3-hour event. Rainfall events that exceed this frequency and duration would exceed the capacity of the sewer system, increasing the resulting runoff and urban stormwater flood risks. Low-lying areas that naturally retain stormwater when the sewer systems exceed their capacity can be a flood risk concern and stormwater retention may not be desirable in all areas.

Although there are limitations to this runoff retention indicator, the assessment uses industry-approved models, acceptable data sources as inputs, and reasonable assumptions. The assessment was also reviewed by Stanford University professors with relevant hydrology expertise. This data set appears to represent the best available regional data set for approximating runoff retention potential.

Extending this assessment to consider future total water levels adds additional caveats. As Bay water levels rise, the ability of storm sewer systems to discharge to the Bay via gravity outfalls will be compromised, increasing the potential for backwater flooding. In some areas of the Bay, such as the far South Bay, pump stations are already required to discharge stormwater flows to the Bay. These changing dynamics are not considered when completing a simple GIS assessment overlaying the runoff retention potential with the 10 mapped total water levels. However, as a first cut at assessing the loss of areas that can retain stormwater runoff, the inclusion of this sea level rise assessment is appropriate.

STORMWATER INFILTRATION

NatCap estimated groundwater recharge potential using the stormwater infiltration values calculated by the SWMM model, using the same soil and land use classifications noted for the runoff retention indicator (see Figure 8). The assumption is that stormwater that infiltrates below the root zone can recharge the groundwater basins underlying much of the Bay Area. This assumption is not entirely valid and is discussed below in the caveats and concerns. However, this indicator is still recommended for inclusion to estimate the amount of stormwater that can infiltrate below the root zone. This indicator is referred to as “stormwater infiltration” in this analysis, rather than “groundwater recharge potential”, to provide greater transparency related to the physical process that is estimated by the indicator.

Caveats: Recharge of the deep aquifers that contain potable water is valuable because the groundwater can be extracted for multiple water uses. However, recharge of the shallow groundwater layer is often not desirable, particularly in the low-lying coastal areas around the Bay where the shallow groundwater layer is often near the surface (i.e., within 5 feet of the ground surface). This shallow groundwater layer is hydraulically connected to the Bay and fluctuates with the Bay's tidal cycles, rainfall events, and drought periods.

The assessment does not consider the physics of groundwater flow. Rainfall that infiltrates in the hills around the Bay will flow downslope within the shallow groundwater layer, resulting in increased groundwater 'recharge' in the low-lying areas. This dynamic is not currently captured in the stormwater infiltration indicator.

Photo User Days

NatCap estimated visitation rates to Bay Area PCAs using social media, focused on geotagged photographs shared on the website Flickr between 2005 and 2015. NatCap is also analyzing geotagged tweets shared on Twitter, but this analysis is not yet complete. Scientists have traditionally estimated visitation based on surveys conducted at entrances to major attractions; however, this approach is expensive and time consuming, and is challenging to implement on a small scale to estimate visitation at the vast array of PCAs located throughout the nine counties. The use of "photo user days" to estimate visitation has been used at major recreational sites around the world. The social media-based visitation rates correlate well with empirical visitation rates in Wood et al, 2013; however, the social media-based visitation rates are generally lower than the empirical data. Only a portion of visitors to any given site take and post geotagged photographs and share them on Flickr. Therefore, the Photo Visitation Rates can be used as a proxy for actual Visitation Rates, with an understanding that actual visitation rates are likely higher than estimated using this approach. The use of photo visitation rates as a proxy is reasonable given that this data will be applied consistently across entire the Bay Area; therefore, the bias introduced by this indicator is uniform for the region.

Caveats: As noted above, social media-based visitation rates have been shown to correlate well with empirical visitation rates; however, the social media-based visitation rates are generally lower than the empirical data. The data presented in Wood et al, 2013 also highlighted the strong correlation relative to broad regional groups, such as the combined 360 US National Parks, or the combined 49 California state beaches. The data presented by Wood et all, 2013 also included significant scatter; therefore, it is not clear if the correlation between photo visitation and empirical visitation would be as strong if only one park or one beach was evaluated.

NatCap's approach did not validate or correlate the photo visitation rates with any empirical data from throughout the Bay Area. This analysis would increase the confidence that this approach is valid when applied at this scale. It is likely that individual stakeholders may have annual empirical visitation data for a specific park or open space area that can be used to validate the approach, and better understand any bias or under-estimation that may be introduced by relying on social media posts. A cross validation of the photo visitation rates with Twitter visitation rates would provide another metric for validating the approach, assuming both social media platforms produce similar trends in visitation.

PROCESSING AND CONDITIONING

1. The PCA boundaries feature class was intersected with the Operation Landscape Units (OLUs) boundaries feature class. This tagged each PCA with the OLU that it is within. PCAs that intersected multiple OLUs were split into multiple features, each tagged with the OLU that the portion fell within. Because the PCA boundaries feature class has many overlapping polygons, the intersection was performed using an iterator in ArcGIS Pro Model Builder. This intersected each PCA polygon with the OLU boundaries feature class individually, and then merged all the resulting polygons into a single feature class (henceforth referred to as PCAxOLU).
2. The PCAxOLU feature class was clipped by the inundation polygons for each of the ten total water levels. This generated a feature class for each total water level representing the area within each PCAxOLU impacted under that TWL.
3. Dollar value of annual crop production data was provided by Bay Area Green Print as an attribute in a 30m point grid. The point grid was converted to a 30-meter resolution raster with each cell centered over the original point, and the value of the cell equal to the dollar value of annual crop production within that 30 meter by 30-meter grid cell.
4. Percent soil organic matter was provided in the USGS SSURGO Database as an attribute in a soil type polygon feature class. Soil feature classes for each of the nine counties were merged into a single feature class, which included percent organic matter as an attribute.
5. For the three habitat types and three endangered species areas, Natural Capital provided tables with the results of summing the total impacted area of each habitat type or endangered species area within each PCAxOLU polygon under each total water level. Habitat areas and snowy

plover/ridgeway rail areas were previously identified and compiled by Natural Capital through the NFWF San Francisco Bay Coastal Resilience Assessment and provided by Point Blue Conservation Science (project in progress). Salt marsh harvest mouse areas were identified using data from the California Natural Diversity Database. These results were split by total water level so they could be joined to PCAxOLU polygons during the consequence analysis.

6. For stormwater retention and stormwater infiltration, no processing or conditioning was required. Natural Capital provided the outputs of their InVEST software for stormwater retention and stormwater infiltration as 30-meter resolution rasters, with cell values equal to the stormwater retention or infiltration potential of that grid cell in cubic meters.
7. Photo user days (a proxy for visitation rates) also did not require additional processing or conditioning. Natural Capital provided a 30-meter resolution raster, with cell values equal to the number of photos uploaded to Flickr between 2005 and 2017 taken within that grid cell.
8. The result of these steps was a raster grid for each consequence indicator (with the exception of habitat types and endangered species areas) whose values could be summed by the PCAxOLU inundation feature classes generated in step 2.

CONSEQUENCE ANALYSIS

1. For consequence indicators that were provided or converted into rasters (photo user days, crop production, stormwater retention, and stormwater infiltration), the Feature Statistics to Table tool developed by USGS was used to sum the value of raster cells within each polygon of the PCAxOLU inundation feature classes. This tool was used instead of the native ArcGIS Pro Zonal Statistics as Table tool because Zonal Statistics does not work properly with feature classes that include overlapping polygons. The result of this process was a feature class for each total water level with consequence values by PCAxOLU polygon.
2. Note that a limitation of this tool was that it does not sum values for polygons that were smaller in area than the input raster grid. Because of this, some PCxOLU polygons received bull values – in particular the Bay Area Water Trail PCAs, which are 25 ft buffers around kayak landings. However, if these polygons had received values, they would have been very low. Therefore, the project team felt comfortable assigning them a score of 0.
3. For consequence indicators where the vulnerability analysis was already performed by Natural Capital, the ouput tables were joined to the PCAxOLU

polygons. The result was a feature class for each total water level with consequence values for habitat and endangered species consequence indicators by PCAxOLU polygon.

4. For soil organic matter, the SSURGO soil map was clipped to the PCAxOLU polygons, then intersected with each of the inundation polygons. For each total water level, the total area inundated in each PCAxOLU polygon was multiplied by the corresponding organic matter value. Soil polygons within the same PCAxOLU were then dissolved to obtain the sum of acres x organic matter within each PCAxOLU.
5. High/Medium/Low ranges for rating consequence were developed for each of the 11 consequence indicators using the 108” TWL. Consequence indicator values under the 108” TWL were separated into three quantiles (buckets with an equal number of PDAxOLU polygons in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Ecosystem Services				
	Photo User Days	Stormwater Retention (m3)	Stormwater Infiltration (m3)	Annual Crop Value ($)	Soil Organic Matter*
None	0	0	0	0	0
Low	1 – 14	1 – 5,925	1 – 337	1 – 2,380	0.1 – 3.43
Medium	14 – 122	5,925 – 73,862	337 – 3,877	2,380 – 318,012	3.43 – 113.31
High	122 – 12,581	73,862 – 25,574,289	3,877 – 1,303,631	318,012 – 10,148,442	113.31 – 86,934.35

Consequence	Habitats (m2)			Endangered Species (m2)		
	Depressional Wetlands	Tidal Marshes	Lagoons	Ridgway's Rail	Snowy Plover	Salt Marsh Harvest Mouse
None	0	0	0	0	0	0
Low	1 – 8,102	1 – 7,202	1 – 10,803	1 – 6,302	1 – 11,704	1 – 66,620
Medium	8,102 – 122,438	7,202 – 199,861	10,803 – 225,969	6,302 – 133,241	11,704 – 960,595	66,620 – 1,095,636
High	122,438 – 17,075,537	199,861 – 14,832,049	225,969 – 20,242,708	133,241 – 3,222,088	960,595 – 10,923,950	1,095,636 – 2,464,956

* The units for soil organic matter are Area (acres) x Weighted % Soil Organic Matter

Files

Unless otherwise noted, these are GIS files stored in the PCA_Output_Final.gdb Geodatabase.

VULNERABLE COMMUNITIES

Social Vulnerability

Block groups with elevated social vulnerability to flooding were identified as part of the Stronger Housing, Safer Communities project (2015, ABAG, BCDC). This assessment rated social vulnerability by block group based on a series of indicators from the American Communities Survey 2016 5-Year Estimates that were chosen and vetted through an extensive stakeholder engagement process. Block groups were assigned different levels of social vulnerability based on the number of indicators for which thresholds based on Bay-Area wide percentiles were exceeded. Block groups rated as having moderate, high, or highest social vulnerability were considered vulnerable communities and the number of residential units in impacted parcels within them were assessed as consequence.

Indicators from ACS	Social Vulnerability Rating
Renters	Moderate
Under 5	4-5 indicators in 70th percentile; and/or
Very low income	3 indicators in the 90th percentile
Not U.S. citizens	
Without a vehicle	High
People with disability	6-7 indicators in the 70th percentile; and/or
Single parent families	4-5 indicators in the 90th percentile
Communities of Color	
Over 65 who live alone	Highest
Limited English proficiency	8+ indicators in the 70th percentile; and/or
Without a high school degree	6+ indicators in the 90th percentile
Severely housing cost burdened	

Vulnerability to Contamination

Block groups vulnerable to pollutant contamination from flooding were identified using data from the Environmental Effects category of CalEnviroScreen 3.0 compiled by CalEPA Office of Environmental Health Hazard Assessment. Like social vulnerability, block groups were assigned different levels of vulnerability to contamination based on the number of indicators for which percentile-based thresholds were exceeded, based on state-wide percentiles. Block groups rated as having moderate, high, or highest vulnerability to contamination were considered vulnerable communities and the number of residential units in impacted parcels within them were assessed as consequence. The level of contamination vulnerability of each block group was then used to assign sensitivity scores.

Indicators from CalEnviroScreen 3.0	Contamination Vulnerability Rating
Proximity/exposure to: • Land with hazardous substances • Groundwater contamination • Hazardous waste generation and storage facilities • Contaminated water bodies • Solid waste facilities	Moderate 4 indicators in the 70th percentile; and/or Total contamination score between 70th – 80th percentile High 5 indicators in the 70th percentile; and/or Total contamination score between 80th – 90th percentile Highest 4 indicators in the 90th percentile; and/or Total contamination score above 90th percentile

To calculate consequence, a key assumption made in this analysis is that once a parcel is exposed to flooding, even marginally, the entire number of residential units in that parcel is considered impacted. This assumption reflects a conservative understanding that flooding has many direct and indirect impacts for a person's ability to enjoy their home. Indirect impacts such as flooding of walkways, foundations, electrical systems may all contribute to an individual or family being displaced. Since we don't have data to reflect these indirect impacts, we maintain the assumption that any flooding to a parcel impacts all the people living in it. This assumption works well for small parcels, but for large parcels this assumption serves as a limitation to the analysis. Large undeveloped parcels (e.g. former military lands) that have large projected growth for 2040, show high numbers of residential units impacted when exposed to flooding, despite the fact that the flooding may not be in the location where future development may occur. A related but separate limitation of this analysis is the existence of parcel boundaries that extend bayward of the MHHW line. These parcel boundaries intersect even small amounts of flooding despite the fact that no buildings exist in these parts of the parcel and inaccurately indicate impacted residential units. Future efforts should be made to refine parcel boundaries to both current and future developed areas on the shoreline.

PROCESSING AND CONDITIONING

1. Block groups with a social vulnerability ranking of moderate or higher were selected and extracted from the input block group dataset.
2. Likewise, block groups with a contamination vulnerability ranking of moderate or higher were selected and extracted from the input block group dataset.
3. Social and contamination vulnerable block groups were intersected separately with the OLU boundaries. This tagged each block group with the OLU that it is within. Block groups that fell into multiple OLUs were split into multiple features, each tagged with the OLU that the portion fell within. These intersected block groups became the assets for which consequence was assessed for both social and contamination vulnerability.
4. Plan Bay Area 2010 data on the number of residential units per parcel was joined to the parcel boundaries feature class by APN.

CONSEQUENCE ANALYSIS

1. The vulnerability analyses for social vulnerability and contamination vulnerability were carried out in parallel using the same method. The only difference was which input block groups had been extracted from the full block groups layer based on the thresholds discussed above.
2. Parcels within socially vulnerable block groups impacted under each total water level were selected using inundation polygons and extracted as 10 separate feature classes. In some cases, this may overestimate the number of households/ impacted, as the portion of the parcel impacted may not be the built area.

3. Parcels within block groups vulnerable to contamination impacted under each total water level were selected using inundation polygons and extracted as 10 separate feature classes. In some cases, this may overestimate the number of households/ impacted, as the portion of the parcel impacted may not be the built area.
4. The ArcGIS Pro Summarize Within tool was used to sum the total number of impacted residential units by total water level within each socially vulnerable block group. The result was a feature class for each TWL of the socially vulnerable block groups, with the number of impacted residential units within each block group for that TWL.
5. Similarly, the ArcGIS Pro Summarize Within tool was used to sum the total number of impacted residential units by total water level within each block group vulnerable to contamination. The result was a feature class for each TWL of the block groups vulnerable to contamination, with the number of impacted residential units within each block group for that TWL.
6. High/Medium/Low ranges for rating consequence were developed separately for social and contamination vulnerability using the 108” TWL. Consequence indicator values under the 108” TWL were separated into three quantiles (buckets with an equal number of impacted block groups in each). The upper and lower bounds of each quantile became the ranges for high, medium, and low consequence.

Consequence	Socially Vulnerable Block Groups (# of impacted residential units)	Block Groups Vulnerable to Contamination (# of impacted residential units)
None	0	0
Low	1 – 102	1 – 78
Medium	102 – 328	78 – 293
High	328 – 5,367	293 – 6,378

Files

Unless otherwise noted, these are GIS files stored in the VC_Output_Final.gdb Geodatabase.

Recommendations and Considerations

Asset and indicator data used in the analysis was limited to that which was regionally available or possible to generate with available project resources. As the region considered updating this exposure and consequence analysis, additional or improved datasets will greatly improve the accuracy of the analysis. This subsection describes the data that would most improve the ability to understand regional vulnerability.

CONSIDERATIONS FOR DATASET IMPROVEMENTS

Asset Type	Dataset/Improvement	Priority Level	Notes
PDAs	Updated parcel-level residential units and job spaces data more recent than 2010, and updated projections for 2050	High	2010 data is now nearly a decade old. Updated data will likely become available as part of Horizon.
Vulnerable Communities	Updated parcel-level residential units data more recent than 2010	High	2010 data is now nearly a decade old. Updated data will likely become available as part of Horizon.
Active Transportation	Counts or modelling to estimate relative use of sections of Bay Trail and regional bicycle network	High	The analysis had no way to prioritize portions of Bay Trail or bicycle routes that are more frequently used.
Commuter Rail Lines and Stations	Regional passenger ridership data in the same format, year	High	Ridership data from the same year and format will ensure that differences in score are due to actual differences in ridership.
PCAs	Accurate carbon sequestration potential data	High	Percent organic matter is a very rough proxy and the available data was not easily summarized by PCA.
Commuter Rail Lines and Stations	Origin-Destination Ridership data for SMART (Sonoma Marin)	Medium	As SMART ridership is low relative to other operators, more granular data will likely result in SMART lines and stations still receiving low consequence scores.
Active Transportation	Complete regional bicycle routes GIS linework	Medium	The Caltrans bicycle routes dataset is regional but omits bicycle routes that are not alternatives to state highways

Bus Routes	Counts or modelling to estimate ridership by line	Medium	High Quality Transit Corridors are a rough proxy for ridership and omit North Bay bus routes. However, bus routes are moveable assets, so understanding their vulnerability is not as critical as more permanent/expensive assets.
Bus Depots	Number of actively used buses stored at each depot (or similar metric)	Medium	Bus depots are critical to the functioning of bus systems, but no consequence indicator data was regionally available.
Freight Rail	Freight value, weight, or other more granular measure of goods movement than freight trains per day	Low	Freight trains per day enabled adequate differentiation between impacted lines.
PCAs	Real visitation rate data or enough to calibrate and convert photo-user days to visitation numbers.	Low	Photo user days are an adequate measure of relative visitation.

Data Sources

SEA LEVEL RISE INUNDATION, OVERTOPPING, AND FLOOD

Dataset	Purpose	Year	Data Type	Source
Adapting To Rising Tides Bay Area Sea Level Rise Analysis & Mapping Project	Flood Hazard	2016	GIS – Polygons, Lines	Adapting To rising Tides; AECOM
100-year and 500-year Flood Hazard Zones	Flood Hazard	2017	GIS - Polygons	FEMA; BCDC
San Francisco 100-year Precipitation Event	Flood Hazard	2017	GIS – Polygons	SFPUC

BOUNDARIES

Dataset	Purpose	Year	Data Type	Source
Cities	Boundary	2018	GIS – Polygons	MTC
Counties	Boundary	2018	GIS - Polygons	MTC
Operational Landscape Units	Boundary	2019	GIS – Polygons	SFEI
Focus Areas	ART Bay Area Boundary	2019	GIS – Polygons	Digitized by BCDC
Regional Hotspots	ART Bay Area Boundary	2019	GIS - Polygons	Digitized by BCDC

COMMUTER RAIL LINES

Dataset	Purpose	Year	Data Type	Source
Commuter Railway Lines*	Asset	2018	GIS - Lines	MTC
Commuter Rail Stations	Geoprocessing		GIS - Points	MTC
BART Weekday Average Entry-Exit Matrices	Consequence Indicator	2017	Table	BART
Valley Transportation Authority	Consequence	2016	Database	VTA

Ridership Database (Santa Clara)	Indicator			
MUNI Ridership Census by Train	Consequence Indicator	2016	Table	MUNI
Caltrain Passenger Counts by Train	Consequence Indicator	2017	Table	Caltrain
SMART Onboard Survey Results and Annual Weekday Ridership (Marin)	Consequence Indicator	2018	Presentation Slides	SMART
Altamount Corridor Express (ACE) Ridership Forecasting and Operations Model	Consequence Indicator	2015	Table	Calculated by AECOM for the ACEforward Program
Capitol Corridor ridership load by train by station (FY07-08)**	Consequence Indicator	2008	Table	Caltrans
Capitol Corridor Annual Ridership (FY 2017)	Consequence Indicator	2017	Table	Capitol Corridor JPA

**Older ridership data was used to define system wide ridership patterns, which were then applied to 2017 annual ridership numbers (see below).

COMMUTER RAIL STATIONS

Dataset	**Purpose**	**Year**	**Data Type**	**Source**
Commuter Rail Stations	Asset	2018	GIS - Points	MTC
BART Weekday Average Exits by Station	Consequence Indicator	2017	Table	BART
VTA Light Rail Ridership by Station	Consequence Indicator	2018	Table	VTA
MUNI Ridership Census by Train	Consequence Indicator	2016	Table	MUNI
Caltrain Passenger Counts by Train	Consequence Indicator	2017	Table	Caltrain
SMART Onboard Survey Results and Annual Weekday Ridership	Consequence Indicator	2018	Presentation Slides	SMART
ACE Ridership Forecasting and Operations Model	Consequence Indicator	2015	Table	Calculated by AECOM for the ACEforward Program
Capitol Corridor average daily ridership by train by station (FY07-08)	Consequence Indicator	2008	Table	Caltrans
Capitol Corridor Annual Ridership (FY16-17)	Consequence Indicator	2017	Table	Capitol Corridor JPA

FREIGHT RAIL

Dataset	Purpose	Year	Data Type	Source
California Rail Network	Asset	2013	GIS - Lines	Caltrans
Freight trains per day by line (2020 Projections)	Consequence Indicator	2016	Report	MTC Goods Movement Plan
Freight trains per day by line (Richmond Pacific spurs only)	Consequence Indicator	2018	Email	Richmond Pacific Railroad

HIGHWAYS

Dataset	Purpose	Year	Data Type	Source
State and National highways	Asset	2016	GIS - Lines	Caltrans
Elevated Highways	Asset Refinement	2018	GIS - Lines	OpenStreetMap
California Highway Passenger Vehicle Traffic Volumes denoted as Annual Average Daily Traffic (AADT)	Consequence Indicator	2016	GIS - Points	Caltrans
California Highway Truck Traffic Volumes denoted as Annual Average Daily Truck Traffic (AADTT)	Consequence Indicator	2016	GIS - Points	Caltrans
Lifeline Routes	Consequence Indicator	2018	GIS - Lines	MTC

BUS ROUTES

Dataset	Purpose	Year	Data Type	Source
Bay Area Bus Routes	Asset	2018	GIS - Lines	Transitland
High Quality Transit Corridors	Asset Refinement	2018	GIS - Polygons	MTC

ACTIVE TRANSPORTATION

Dataset	Purpose	Year	Data Type	Source
Bay Trail Alignment	Asset	2018	GIS - Lines	MTC
State Highways Bicycle Access and Alternate Routes	Asset	Unknown	GIS - Lines	Acquired from Caltrans by BCDC

FERRY TERMINALS

Dataset	Purpose	Year	Data Type	Source
Ferry Terminal Extents	Asset	2018	GIS - Polygons	Digitized by BCDC
Golden Gate Ferry Annual Ridership by Route and Average Weekday Ridership System-wide (FY 2017)	Consequence Indicator	2017	Table	GGF
WETA Average Weekday Boarding by Terminal (2017)	Consequence Indicator	2017	Table	WETA

AIRPORTS

Dataset	Purpose	Year	Data Type	Source
Airport Extents	Asset	2018	GIS - Polygons	MTC
Airport Runways	Asset Refinement	2018	GIS - Lines	OpenStreetMap
Enplanements by Airport	Consequence Indicator	2017	Table	FAA
Cargo by Airport	Consequence Indicator	2017	Table	FAA

SEAPORTS

Dataset	Purpose	Year	Data Type	Source
Port Extents	Asset	2016	GIS - Polygons	Caltrans (not available online)
Street Centerlines	Asset Refinement	2018	GIS - Lines	OpenStreetMap
Railroad Centerlines	Asset Refinement	2018	GIS - Lines	OpenStreetMap
Bay Area Ports Trade Value	Consequence Indicator	2018	Table	USA Trade Online (US Census)

PRIORITY DEVELOPMENT AREAS

Dataset	Purpose	Year	Data Type	Source
Priority Development Area Boundaries	Asset	2018	GIS - Polygons	MTC
Bay Area Parcel Map	Asset Refinement	2010	GIS - Polygons	MTC
Plan Bay Area Job Spaces and Residential Units by Parcel for 2010 and 2040 (Urban Sim model run 7224)	Consequence Indicator	2010	Table	MTC[8]

PRIORITY CONSERVATION AREAS

Dataset	Purpose	Year	Data Type	Source
Priority Conservation Area Boundaries	Asset	2018	GIS - Polygons	MTC
Dollar Value of Annual Crop Production	Consequence Indicator	2017	GIS - Points	Bay Area Green Print
Percent Soil Organic Matter (proxy for carbon sequestration)	Consequence Indicator	2018	GIS - Polygons	USDA SSURGO Database
Area of impacted habitat areas (tidal wetlands, depression wetlands, lagoons) by PCA by total water level	Consequence Indicator	2018	Tables	Natural Capital/Point Blue
Area of impacted ridgeway rail and snowy plover habitat by PCA by total water level	Consequence Indicator	2018	Tables	Natural Capital/Point Blue
Area of impacted salt marsh harvest mouse habitat by PCA by total water level	Consequence Indicator	2018	Tables	Natural Capital/CNDDB
Stormwater Runoff Retention Potential	Consequence Indicator	2018	GIS - Raster	Natural Capital
Stormwater Runoff Infiltration Potential	Consequence Indicator	2018	GIS – Raster	Natural Capital
Photo User Days (Proxy for visitation rates)	Consequence Indicator	2005-2017	GIS - Raster	Natural Capital

[8] Plan Bay Area data on number of job spaces and number of residential units for 2010 and 2040 were provided to the project team as a CSV file by Elizabeth Theocharides, Land Use modeler at MTC via email on November 26, 2018. According to her, Run 7224 is the official model output used for Plan Bay Area 2040.

VULNERABLE COMMUNITIES

Dataset	Purpose	Year	Data Type	Source
Social Vulnerability by Block Group	Asset	2018	GIS - Polygons	BCDC/ACS
Contamination Vulnerability by Block Group	Asset	2018	GIS - Polygons	BCDC/ CalEnviroscreen 3.0
Bay Area Parcel Map	Asset Refinement	2010	GIS - Polygons	MTC
Plan Bay Area Units by Parcel (Urban Sim model run 7224)	Consequence Indicator	2010	Table	MTC
American Community Survey 2012-2016 Estimates	Demographics - Consequence Indicator	2016		ACS
U.S. Census, 2010 & American Community Survey 2012-2016 Estimates	Population – Consequence Indicator			
CalEnviroScreen (CES) 3.0	Asset Refinement	2016	GIS - Polygons	CalEPA OEHHA; for description of data inputs refer to CES 3.0 Report
Community Air Risk Evaluation (CARE)	Asset Refinement	2014	GIS - Polygons	Bay Area Air Quality Management District 2014; For description of air pollution and health records inputs refer to methods report for identifying cumulative impact areas
Communities of Concern (CoC)	Asset Refinement	2018	GIS - Polygons	Metropolitan Transportation Commission, 2018; derived from American Community Survey 2012-2016
Disadvantaged Communities (DAC)	Asset Refinement		GIS - Polygons	CA Dept. of Water Resources
Urban Displacement Index	Asset Refinement	2017	GIS - Polygons	UC Berkeley 2017; see Regional Early Warning System for Displacement Typologies Report for data inputs

CONTAMINATION

Dataset	Purpose	Year	Data Type	Source
Superfund sites	Contamination – Consequence Indicator	2017	GIS – Points/Polygons	Compiled by CalEPA OEHHA 2017; inputs from US EPA
Impaired Water Bodies	Contamination – Consequence Indicator	2017	GIS - Points	Compiled by CalEPA OEHHA 2017; inputs from CA Water Board
Reported Cleanup Activity Sites	Contamination – Consequence Indicator	2017	GIS - Points	Compiled by CalEPA OEHHA 2017; inputs from CA Water Board
Leaking Underground Storage Tanks	Contamination – Consequence Indicator	2017	GIS - Points	Compiled by CalEPA OEHHA 2017; inputs from CA Water Board
Reported Groundwater Threats	Contamination – Consequence Indicator	2017	GIS - Points	Compiled by CalEPA OEHHA 2017; inputs from CA Water Board
Hazardous Waste Storage Facilities	Contamination – Consequence Indicator	2017	GIS - Points	Compiled by CalEPA OEHHA 2017; inputs from DTSC
Solid Waste Landfills	Contamination – Consequence Indicator	2017	GIS - Polygons	Compiled by CalEPA OEHHA 2017; inputs from CalRecycle

CRITICAL FACILITIES

Dataset	Purpose	Year	Data Type	Source
Natural Gas Stations	Local Assessments	2018	GIS - Points	California Energy Commission (2018). Substations. ArcGIS Online.
Natural gas Pipelines	Local Assessments	2018	GIS - Lines	California Energy Commission (2018).
Powerplants	Local Assessments	2018	GIS - Points	California Energy Commission (2018).
Substations	Local Assessments	2018	GIS - Points	California Energy Commission (2018).
Transmission Lines	Local Assessments	2018	GIS - Lines	California Energy Commission (2018).
Community Facilities and Infrastructure	Local Assessments	2018	GIS - Points	California Dept of Public Health (2018)
Police Stations	Local Assessments	2009	GIS - Points	Pacific Institute (2009)
Fire Stations	Local Assessments	2009	GIS - Points	Pacific Institute (2009)
Wastewater Treatment Plants	Local Assessments	2018	GIS - Points	CalEPA (2018).

The Natural Capital Project

From Stanford University, The Natural Capital Project (NatCap) operates as a global partnership of influential actors in academia, conservation, government, development banks, private investment, and business. Our core partners are Our network includes more than 50 research institutions and 250 implementing partners worldwide, allowing for direct engagements in over 60 countries and for our InVEST software platform to be used in an additional 125 countries.

NatCap works to integrate the value nature provides to society into major decisions. The world's ecosystems can be seen as capital assets; if well-managed, their lands, waters, and biodiversity yield a flow of vital benefits that sustain human life. Relative to other forms of capital, natural capital is poorly understood and undergoing rapid degradation. Often, the benefits nature provides to people are widely appreciated only upon their loss. The Natural Capital Project aims to change that paradigm. The ultimate objective is to improve the well-being of all people and nature by motivating greater and more targeted natural capital investments.

NatCap worked with the Bay Area Conservation and Development Commission's (BCDC) Adapting to Rising Tides program to help inform the ART Bay Area SLR Vulnerability Assessment. NatCap focused on quantifying the multiple benefits provided by natural landscapes throughout the nine-county Bay Area and evaluating the vulnerability of these services to the effects of sea level rise.

INVEST

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a suite of free, open-source software models used to map and value the goods and services from nature that sustain and fulfill human life (Sharp et al. 2018). As the flagship tool of the growing Natural Capital Software Platform, InVEST helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people.

The multi-service, modular design of InVEST provides an effective tool for balancing the environmental and economic goals of diverse decision-makers. InVEST models are spatially-explicit, using maps as information sources and producing maps as outputs. These models are based on production functions that relate change in ecosystem structure and function and social and economic factors with variation in services that ecosystems provide to people (Tallis and Polasky 2009). InVEST returns results in either biophysical terms (e.g., tons of carbon sequestered) or economic terms (e.g., net present value of that sequestered carbon). The spatial resolution of analyses is flexible, allowing users to address questions at local, regional, or global scales.

In the ART Bay Area assessment, NatCap used several InVEST models to quantify the current provision of key ecosystem services provided by natural landscapes in the Bay, and to understand how these services might change with sea level rise.

Citations:

1. Sharp, R., et al. 2018. InVEST 3.7.0.post27+ug.h0fb6c74c6697 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.
2. Tallis, Heather, and Stephen Polasky. "Mapping and valuing ecosystem services as an approach for conservation and natural-resource management." *Annals of the New York Academy of Sciences* 1162.1 (2009): 265-283.

PRIORITY ECOSYSTEM SERVICES

The priority ecosystem services selected for this analysis were identified through a series of meetings with the ART Bay Area project management team. The selection was informed by the desired benefits provided by the Priority Conservation Area (PCA) Network. Final services included coastal protection (which included two services, wave attenuation and flood accommodation), stormwater retention, recreation, and habitat availability. Subsequent sections provide background information and methodologies for each model.

Coastal Protection Methodology

WAVE ATTENUATION

Model Introduction

Coastal ecosystems have the potential to reduce the risks to communities and infrastructure from sea-level rise and storms. Through their ability to attenuate waves, trap sediments, and accommodate flood waters, coastal ecosystems can help to stabilize shorelines and prevent inundation of coastal areas. In the following section we address the coastal protection service of wave attenuation provide by wetlands in San Francisco Bay.

To understand wave attenuation provided by coastal ecosystems in San Francisco Bay, we applied the Wave Height Analysis for Flood Insurance Studies (WHAFIS) model (FEMA 1998). WHAFIS is a 1-D wave propagation model that predicts wave height and wave period along a transect perpendicular to the shoreline (Figure. 5). The model calculates increases and decreases in wave height resulting from the balance between wind generation and wave dissipation by marsh plants caused by drag forces of the plants on water flow. Inputs to the model include bed elevation, water level, initial wave height and period, wind speed, and vegetation parameters. The model produces results for wave height, wave period, and wave crest elevation at locations along the transect (Divoky 2007, FEMA 2007).

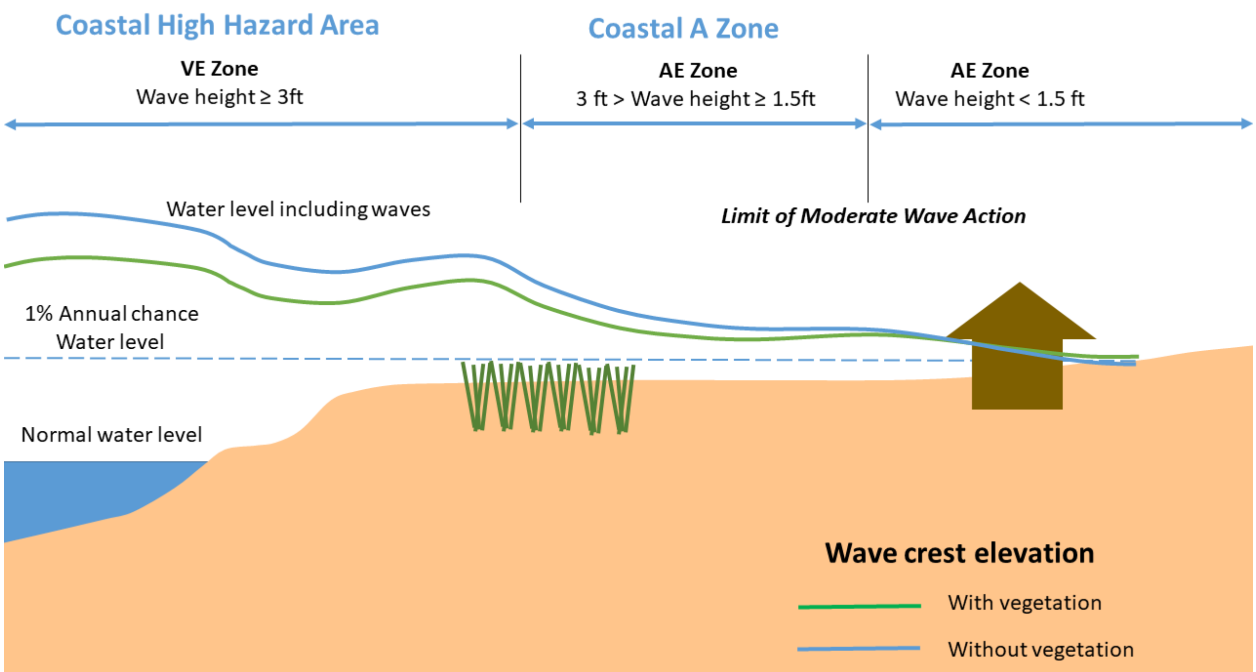

Figure 5. Schematic of cross shore transect and inputs and outputs of WHAFIS model

Application of the Model to Assess Wave Attenuation Across Bay Area Conservation Networks

To understand wave attenuation provided by coastal ecosystem across the San Francisco Bay Area, we applied WHAFIS to 286 transects distributed around the nine counties. We used the model to estimate wave heights at locations along those transects for two scenarios: 1) with vegetation and 2) without vegetation. The differences in wave heights between the two scenarios is an estimate of the wave attenuation provided by vegetation.

Collecting the data needed to run WHAFIS for each of the 286 transects and parameterizing the model for all nine counties would have been beyond the scope of this work. However, we were able to leverage the extensive experience of local experts and massive amount of input data collected for the San Francisco Bay Coastal Study. The Coastal Study was initiated by FEMA to update the Flood Insurance Rate Maps and conducted by a suite of consulting firms in the Bay (including, AECOM, MBaker, and Silvestrum Climate Associates). Each firm took responsibility for applying WHAFIS in a subset of the counties in the Bay. After collecting all the data from the diverse firms, counties, and FEMA housing the outputs from the Coastal Study we re-ran the analysis to estimate wave attenuation for the "with habitat" scenario (green line in Figure 5 above). Next we created an identical set of inputs, but removed vegetation from the model and reran the analysis to estimate wave heights without the frictional effects of vegetation (blue line in Figure 5 above). These are the results for the "no vegetation" scenario.

Setting up the "no vegetation" scenario involved creating a new set of input data in which all the points on the transects labeled as vegetation were changed to no vegetation. The model includes both a generic vegetation option or "card" (VE) which calls generic parameter values for vegetation and an option to include species-specific vegetation information (VH). These codes (or "cards" as they are called by WHAFIS) give the model information such as vegetation density, height, and drag coefficient which the model in turn uses to estimate wave attenuation. The no vegetation code (IF) indicates no frictional effects. Thus, for the first scenario, "with vegetation" we ran WHAFIS with the original VH and VE codes from the FEMA work. For the second scenario, "without vegetation" we changed all VHs and VEs to IF and reran the model.

We produced values for wave height and wave crest elevation for each location along each transect for both scenarios. Wave height is the distance between the elevation of a wave crest and the neighboring trough. Wave crest elevation is the distance between the highest point of the water surface (i.e., the water level including waves) relative to an arbitrary datum which in this work is the North American Vertical Datum (NAVD). From these data we calculated two metrics for each transect: 1) the maximum difference in wave height and wave crest elevation between the two scenarios and 2) the difference in the width of the high wave hazard zone for each transect between the two scenarios. We assumed high wave hazard zones were areas with wave heights greater than 1.5 ft based on the new delineation of the Limit of Moderate Wave Action (LLLMW, Figure 5, FEMA 2017). Finally, we overlaid each transect with maps of the vegetation and maps of the PCA, BPAD, and other natural land networks to determine in which network the critical vegetation for wave attenuation is located.

Data inputs and sources

The extensive input data and sources for the SF Bay Coastal Study are documented in the Coastal Study Reports for each county/region of the Bay (e.g., BakerAECOM 2016) so we do not repeat these in the table below. The only new source of data we used during the analysis was a spatial data layer of vegetation to classify the wetland habitat on each transect within each natural land network.

Data	Description	Data details (type, year, resolution)	Source and link
Coastal wetlands	Current distribution of wetland habitat	Shapefile, 2009	Wetlands data identified through the NFWF San Francisco Bay Coastal Resilience Assessment, compiled and provided by Point Blue Conservation Science (project in progress) https://www.nfwf.org/coastalresilience/Pages/regional-coastal-resilience-assessments.aspx

Model Parameters

Parameter	Description	Data details	Source, link, citations
VH	Species-specific vegetation	Species-specific parameters for vegetation density, stem height, drag coefficient	FEMA 2007, Technical memorandum 2011
VE	Generic vegetation	Generic parameters for vegetation density, stem height, drag coefficient	
IF	No vegetation		

Local model validation

We did not conduct formal validation of the model results. However, we did consult with local experts during the application of the model (Kris May (Silvestrum), Jeremy Mull (AECOM)) and elicited input and feedback on modeled results (Jeremy Lowe (SFEI)).

Model limitations and considerations

This analysis includes a few key limitations. The first is that we only looked at wave attenuation provided by wetland vegetation. Other ecosystems in the Bay also attenuate waves and these include seagrass, oysters, and other intertidal and coastal vegetation. Thus, we likely underestimate the role of natural systems in reducing risk from coastal hazards in the Bay. The second main limitation is that our analysis only considered the frictional effects of vegetation and ignored elevation related effects. In addition to reducing waves through exerting drag on wave flow, wetlands may also reduce waves via a change in elevation. Wave dissipation increases in areas of higher frictional effects and higher elevation. Since areas where wetlands have been restored in the Bay also tend to be higher in elevation, due to their accumulate sediments, our results likely also underestimate the total contribution of wetlands to wave attenuation. Future iterations of this analysis may include the bathymetric contribution of wetlands to wave attenuation.

Citations:

3. BakerAECOM (2016). FEMA Region IX. California Coastal Analysis and Mapping Project/Open Pacific Coast Study. Sea Level Rise Pilot Study. Future Conditions Analysis and Mapping San Francisco County, California. URL: https://default.sfplanning.org/plans-and-programs/local_coastal_prgm/CCAMP_OPC_SLR_PilotStudy_FINAL_25Jan2016.pdf.
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8. Washington, DC.
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11. *of Moderate Wave Action.* Fact Sheet. Washington, DC.
12. Technical Memorandum (2011). North San Francisco Bay *Vegetation Parameters for WHAIS Modeling.* Northwest Hydraulic Consultants.

FLOOD WATER ACCOMMODATION

Model Introduction

Flooding of coastal communities in San Francisco Bay is expected to increase as a result of sea level rise during tidal and storm events (Barnard et al., 2019). Potential adaptation approaches vary widely in their ability to directly reduce risk and provide additional benefits or impacts. Increasing awareness of the ecological and social impacts of shoreline hardening (Gittman et al., 2015) have expanded research into alternate flood hazard adaptation approaches that work with nature to deliver risk reduction while minimizing environmental and economic externalities. Here we investigate the risk reduction benefits of strategic accommodation of flood water in natural areas to reduce flood depth in areas with valuable infrastructure.

“Accommodation” refers to a shoreline strategy that allows rising coastal waters to inundate new areas through restoring tidal flow to coastal regions and removing other flow impediments in front of areas that can be strategically flooded during tidal and storm events with minimal damage, in an attempt to reduce flood extent and depth in other locations (Holleman and Stacey, 2014; Wang et al., 2018). To estimate the potential for natural areas like coastal marshes, forests, parks, etc. to accommodate flood water, we create an integrated assessment model that links changes in shoreline adaptation strategies to total flood depth, and total flood depth to expected flood damages to coastal properties. The integrated assessment model employs the numerical modeling approach described in Wang et al. (2018) to estimate flood depths throughout the nine county SF Bay area under sea level rise and tidal forcing conditions. To calculate expected damages, the model uses data on the value of coastal properties derived from FEMAs General Building Stock and depth-damage functions from the US Army Corps of Engineers to model damage as a function of flood height at the census block scale (Figure 6).

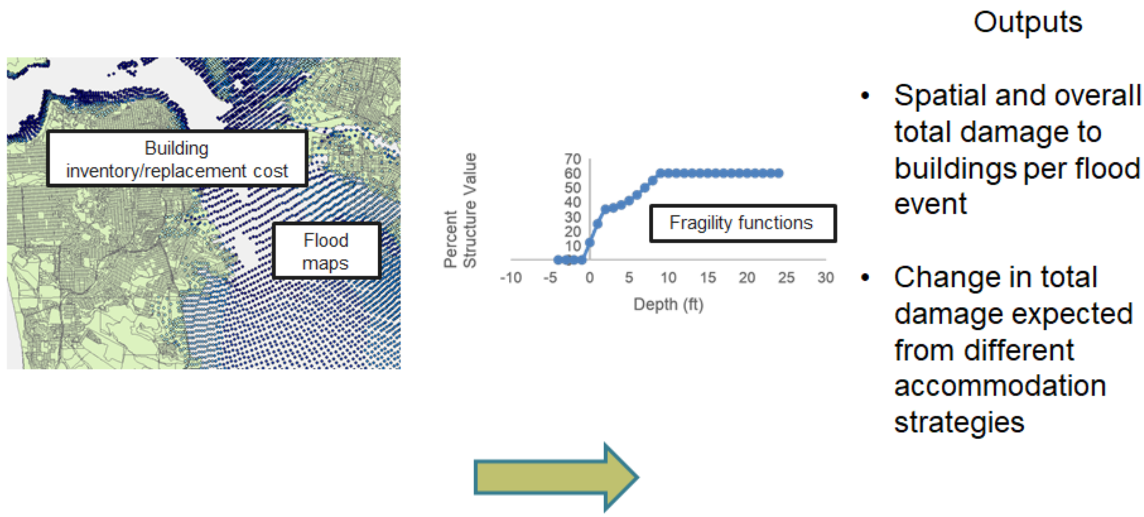

Figure 6. General structure of integrated assessment model.

Application of the Model to Assess Accommodation Across Bay Area Conservation Networks

As this particular integrated assessment modeling is new, we do not attempt to provide a comprehensive assessment of the potential for flood water accommodation in natural areas across the San Francisco Bay study area. Rather, we estimate the accommodation service under a set of rather limited but liberal parameter values in an attempt to measure the potential scope of this service. If we are able to observe significant values at this scale, then future work can refine the scope to more pragmatic intervention scales and under more modest climatic forcing conditions.

We parameterized the model assuming 72 inches of sea level rise under current building stock conditions and simulate the effect of allowing two large scale natural area networks to flood to show the accommodation potential of these natural area networks (Figure 7). To do this, these two networks, the ABAG Priority Conservation Area network and the Bay Area Protected Area Database are hydrologically separated from the coast in their respective scenario model runs by simulating levees along the coastline in front of each network. The integrated model is run under three conditions: 1) no change from current conditions (“No Walls”); 2) Levees in front of BPAD areas (“BPAD”); 3) Levees in front of PCA areas (“PCA”). The lost potential accommodation service from these two networks is then derived by subtracting total expected damages under the No Walls scenario from the respective network scenario (Figure 8). We measure this as lost potential accommodation service as the general tenor of discussion in the Bay Area is oriented towards defending the coastline versus allowing for strategic flooding; as a result the scenario interpretation is the potential lost accommodation service if levees were erected in front of these networks. However, this scenario analysis could be re-conceptualized as "what if existing walls in front of the respective network were removed" with some additional model runs.

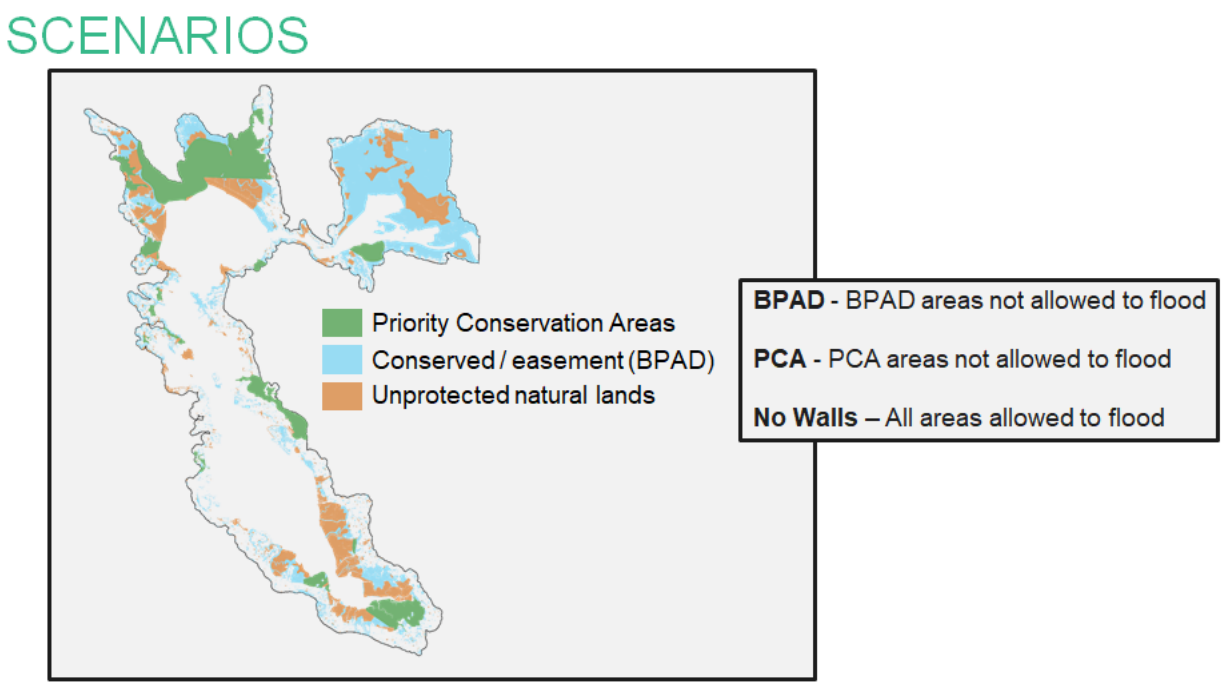

Figure 7. Networks assessed for flood water accommodation and scenarios. Unprotected natural lands are not included in the scenario analysis.

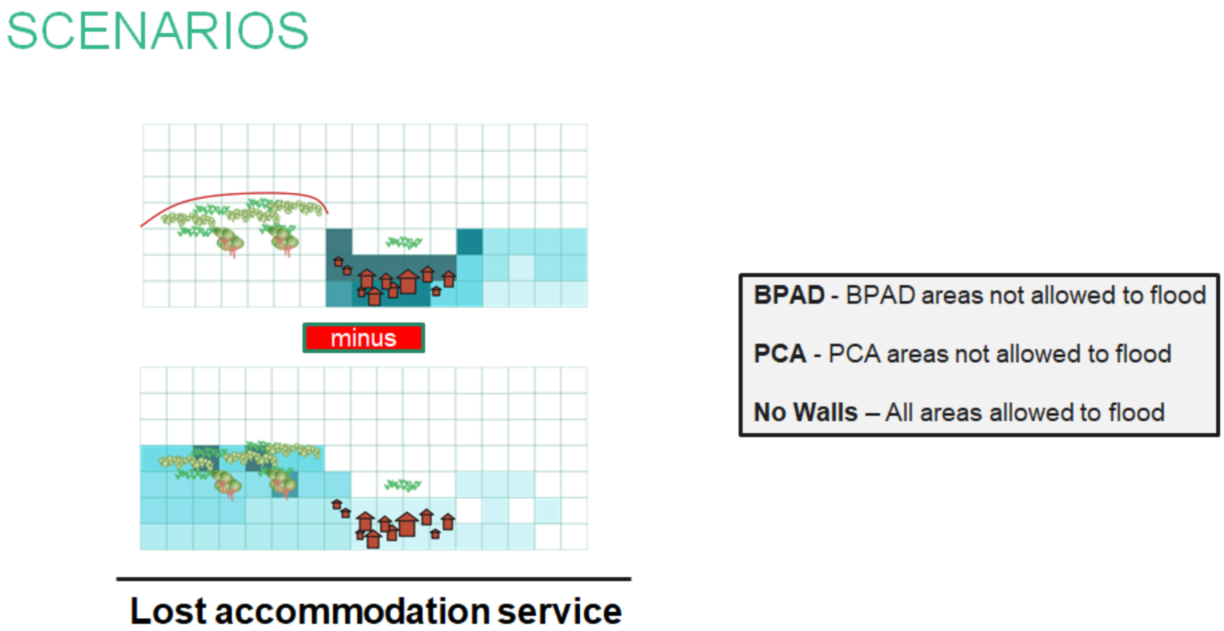

Figure 8. Lost accommodation service.

Data inputs and sources

Please see Wang et al. (2018) for description of numerical flood modeling inputs, aside from 72” sea level rise parameter unique to this study.

Data	Description	Data details (type, year, resolution)	Source and link
General building stock	Distribution of structures throughout the study area and replacement cost	Shapefile, census block resolution, 2010	FEMA
Depth damage functions	Functions that relate flood depth to replacement cost as a function of property value	Varies across structure type	Various sources, direct communication with US Army Corps Staff in SF office

Local model validation if applicable

The numerical flood modeling work was validated in Wang et al. (2017). Expected damage function modeling was not validated in this study area, but as a national dataset has been validated in other locations (i.e. Schultz, 2017).

Model limitations and considerations

This analysis includes a wide array of limitations that comes with an initial exploratory study of this adaptation strategy. Many of these are common to other large-scale integrated assessment models. In particular, the modeling only captures uncertainty through a basic min/mean/max approach for only one domain of uncertainty (flood depth within census blocks). We do not attempt to model changing building stock characteristics through time and generally abstract from other dynamics aside from considerations of sea level rise. Since flood damages in the Bay Area due to sea level rise, tidal impacts, and storm events are not generally acute events like those associated with tsunamis or hurricanes, these damage estimates are best interpreted as upper bounds on potential damage versus potential realized damage. Unlike in acute events, the longer-term gradual processes in the Bay Area allow significant scope for individual behavioral response that may mitigate some of these damages.

Citations:

1. Barnard, P.L., Erikson, L.H., Foxgrover, A.C., Hart, J.A.F., Limber, P., O'Neill, A.C., van Ormondt, M., Vitousek, S., Wood, N., Hayden, M.K. and Jones, J.M., 2019. Dynamic flood modeling essential to assess the coastal impacts of climate change. Scientific reports, 9(1), p.4309.

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12. Shultz, S., 2017. Accuracy of HAZUS general building stock data. Natural Hazards Review, 18(4), p.04017012.

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14. Wang, R.Q., Stacey, M.T., Herdman, L.M.M., Barnard, P.L. and Erikson, L., 2018. The influence of sea level rise on the regional interdependence of coastal infrastructure. Earth's Future, 6(5), pp.677-688.

Recreation Methodology

VISITATION

Model Introduction

We measure the demand for outdoor recreation in a given area based on the volume of geolocated social media posts created in that area. This demand metric is in units of "user-days", or more precisely photo-user-days (PUD) and twitter-user-days (TUD). PUD measurements are derived from a large public database of geotagged photographs shared on the website Flickr and represent the long-term patterns of recreational use over the past 10+ years. TUD measurements are derived from publicly shared, geotagged tweets, accessed from the Twitter Streaming API. These data have been shown to be correlated with on-site measures of outdoor recreation in a wide variety of places (Wood et al. 2013, Sessions et al. 2016, Donahue et al 2018). See Wood et al. 2013 for a full description of the methods behind PUD, which also apply to TUD.

Application of the Model to Assess Recreation Across Bay Area Conservation Networks

Objective 1: Regional recreation and exposure to sea-level rise

Background: We summarized demand for recreation, in terms of PUD, in three different broad categories of land across the nine Bay Area counties:

1. Priority Conservation Areas (PCAs),
2. Protected Areas (Bay Area Protected Areas Database - BPAD)
3. Natural landcover types (NLCD)

For these regional categories, we answered two questions:

Q1) What percent of the total regional recreation occurs within each of these land networks?

Q2) Within each land network, what percent of that network's recreation is exposed to inundation under various sea-level-rise scenarios?

Methods: To address these questions, we created a stack of raster datasets all aligned to the extent and grid cell size of the NLCD 30x30 meter grid for the full nine-county Bay Area. This stack of rasters included:

- *Recreation demand:* the total PUD for each cell, based on Flickr photographs taken from 2005 - 2017

- *PCA network:* a shapefile representing the PCA boundaries was burned onto the raster, creating a presence/absence grid that indicates if a cell is inside or outside the PCA network.
- *BPAD network:* a shapefile representing the BPAD boundaries was burned onto the raster, creating a presence/absence grid that indicates if a cell is inside or outside the BPAD network.
- *Natural landcover types*: a reclassification of the NLCD raster, where all landcover types associated with developed areas were classified as 0, and all other landcover types were classified as 1. Because many activities other than outdoor recreation may be represented in the photographs and tweets, we filtered those datasets geographically and excluded all posts located in “developed” areas, as defined by NLCD landcover categories. The NLCD is at 30-meter resolution and is able to resolve urban greenspace. We do not exclude posts from those areas.
- *Sea-level rise inundation:* a presence/absence raster for each SLR scenario where 1 indicates an inundated grid cell, 0 indicates not inundated.

Recreation demand can be summarized for the areas representing any combinations of the presence/absence rasters. For example, we queried this stack of rasters to answer the following types of questions:

- How many PUDs are inside the PCA network and exposed to inundation from SLR scenario A?
- How many PUDs are inside the BPAD network, but outside of the PCA network, and exposed to inundation from SLR scenario A?
- How many PUDs are inside the BPAD network, outside of PCAs, and outside of inundated areas from SLR scenario A?

More details on the methods, including the code to reproduce results is here: https://github.com/davemfish/NatCap-sfbay/blob/master/regional_recreation_slrscenarios.ipynb

Objective 2: Recreation in Priority Conservation Areas

Background: Here we focused on the following questions:

- Do current Priority Conservation Area (PCA) network provide opportunities for recreation?
- How is recreation demand spread across the individual PCAs?
- Which PCAs provide recreation areas that are most exposed to flooding under sea-level-rise scenarios?

Methods: We measured the baseline recreation demand in each PCA by using the PCA boundaries to spatially query the databases of geotagged photographs and tweets, and calculate PUD and TUD for each PCA, following the methods described above. Accurate measurements of PUD and TUD for an area depended on the accuracy of the GIS data representing the boundary. We found that the PCA boundaries varied in accuracy and precision, so we scored the GIS data quality of each PCA as follows:

- **0 (poor):** Counting geotagged photos/tweets within this polygon will not produce an accurate measure of the recreational use in the PCA. This could be due to 1) poor spatial representation of a PCA (e.g. the SF Water Trail represented only by points at access locations), 2) the fact that the PCA boundary represents something aspirational (e.g. a proposed trail that does not yet exist), or 3) factors that confound 2-D spatial queries (e.g. the fact that the Ohlone Greenway is directly underneath a BART line. Photos/tweets collected in that polygon may have come from BART passengers, not Greenway visitors).
- **1 (adequate):** Improvements could be made to the polygon. e.g. more detailed digitizing to exclude streets or housing that happen to be inside a PCA polygon that is otherwise designated as "natural landscape".
- **2 (good):** Our estimates of recreation demand are most reliable for PCAs with good data quality, and least reliable for PCAs with poor data quality. Unlike in Objective 1, we did not filter the photo and tweet databases to exclude posts from developed urban areas. PUD and TUD counts here represent all available geotagged posts from within a PCA's boundary.

In order to measure the exposure of a PCA's recreation to sea-level rise, we first intersected each PCA boundary polygon with the inundation zone polygon for each SLR scenario (BCDC completed these intersections and handed off the resulting GIS data). We then used the new boundaries to count PUD and TUD inside the inundated area, for each PCA and for each SLR scenario. Finally, we summarized results as the proportion of a PCA's baseline PUD that is inside the flood zone of each SLR scenario, for each PCA. Same for TUDs.

More details, including interactive plots of results and the code to reproduce are here: https://nbviewer.jupyter.org/github/davemfish/NatCap-sfbay/blob/master/pca_rec.ipynb (with interactive plots)
https://github.com/davemfish/NatCap-sfbay/blob/master/pca_rec.ipynb (without plots)

Model limitations and considerations

This method does not predict future recreation patterns, rather it is an assessment of the exposure of the current recreation patterns to inundation under different SLR scenarios. Those patterns have some potential to adapt to rising seas, but this analysis was not simulating any adaptation or mitigation strategies.

Citations:

1. Wood, S. A., Guerry, A. D., Silver, J. M., & Lacayo, M. (2013). *Using social media to quantify nature-based tourism and recreation.* Scientific reports, 3, 2976.

    15. Sessions, Carrie, et al. (2016). Measuring recreational visitation at US National Parks with crowd-sourced photographs. Journal of environmental management 183: 703-711.

    16. Donahue, Marie L., et al. (2018). Using social media to understand drivers of urban park visitation in the Twin Cities, MN. Landscape and urban planning 175: 1-10.

Habitats and Endangered Species Methodology

HABITAT DISTRIBUTION

Model Introduction

The habitat and species assessment summarizes the distribution of habitats and species at multiple scales. The analysis used a raster-based intersection approach, executed in R, at a user-defined resolution. The analysis then quantified the exposure of habitats and species to alternative sea-level rise or inundation scenarios.

Application of the Model Across Bay Area Conservation Networks

For application across the San Francisco Bay, we explored habitat and species at two scales and across ten flooding scenarios. In doing so, the analysis focused on three questions:

1. How are habitats and species distributed across the Priority Conservation Area (PCA) network as a whole, relative to the Bay Area Protected Database (PBAD) network or other natural lands?
2. How are habitats and species distributed within individual Priority Conservation Areas?
3. How are habitats and species across the network (**#1**) and individual PCAs (**#2**) exposed to varying inundation scenarios?

The analysis quantified the distribution of 20 habitats and species in the Bay, with a deeper focus on five. These 20 habitats and species were Fish and Wildlife Elements data identified through the NFWF San Francisco Bay Coastal Resilience Assessment, compiled and provided by Point Blue Conservation Science (Crist et al., 2019). Briefly, habitats were included based on local identification by experts or state or federal recognition (e.g. ESA listing, State Wildlife Action Plans). Data sources included local databases (i.e. California and Bay Area Aquatic Resource Inventory (CAARI and BAARI)) and federal sources (e.g., Environmental Sensitivity Index (ESI)). We further synthesized five habitats that were identified as being especially important: Ridgeway rail, snowy plover, agricultural habitat, vernal pools, and tidal marshes.

Habitats and species were evaluated at two scales: first, across the PCA network as a whole with comparisons to BPAD and other natural lands and, secondly, across individual PCAs. In addition, for the purposes of the OLU profile sheets, we also evaluated individual PCAs intersected with OLUs. At both scales, we quantified the area exposed to each of ten inundation scenarios. These inundation scenarios represent different total water levels.

The results of the raster analysis produced the area within each geounit (i.e. the network as a whole, PCAs, PCAs x OLUs) as a spreadsheet (i.e. habitats_in_geounits) and the area of habitat exposed under each inundation scenario within each geounit (i.e. inundated_habitat_area_per_geounit).

These data can be used to identify the most important PCAs in terms of key habitat and species distribution, and those PCAs where habitat is most vulnerable to inundation. To identify the most important PCAs, the habiats_in_geounits file was sorted by a given habitat for area within each PCA. PCAs containing greater habitat area were interpreted as more important. The patterns of inundation for the habitats within these PCAs can then be further explored (i.e. using the inundated_habitat_area_per_geounit data).

Data inputs and sources

Data	Description	Data details (type, year, resolution)	Source and link
Habitat and species distribution	Current distribution of 20 habitats and species	Shapefile, varying years	Fish and Wildlife Elements data identified through the NFWF San Francisco Bay Coastal Resilience Assessment, compiled and provided by Point Blue Conservation Science (Crist et al., 2019)
Conservation networks	PCA, BPAD, and other natural	Shapefile	Obtained from BCDC

	lands		
Priority conservation areas	186 individual priority conservation areas	Shapefile	Obtained from BCDC
Inundation scenarios	10 total water levels	30m raster	Obtained from BCDC

Model Parameters

Parameter	Description
250m	Resolution for network analysis
500m	Resolution for individual PCA analyses

Model validation if applicable

Habitat data were identified and compiled through the NFWF San Francisco Bay

. These data were nominated for inclusion by key experts during their stakeholder engagement process. Many of these data come from prior local and vetted habitat data compiled by the San Francisco Estuary Institute including the California Aquatic Resource Inventory (CARI) and Bay Area Aquatic Resource Inventory (BAARI).

Model limitations and considerations

This approach represented a distribution summary and exposure to inundation based on overlay. Since exposure to inundation is captured as a simple overlay, it did not capture the impact or consequence of sea-level rise. Different habitats and species may be more or less impacted by sea-level rise or able to adapt.

Citations:

1. BAARI: https://www.sfei.org/baari
2. CARI: https://www.sfei.org/cari
3. Crist, P.J., S. Veloz, J. Wood, R. White, M. Chesnutt, C. Scott, P. Cutter, and G. Dobson. Coastal Resilience Assessment of the San Francisco Bay and Outer Coast Watersheds. 2019. National Fish and Wildlife Foundation.

Stormwater Retention Services Methodology

RUNOFF RETENTION, GROUNDWATER RECHARGE AND FLOOD REDUCTION

Model Introduction

We calculated the following three metrics to capture the stormwater management services: **runoff retention** (volume and water quality), **groundwater recharge**, and **flood reduction**. Runoff retention corresponds to the retention of stormwater by pervious land uses, which is beneficial given the detrimental effects of polluted stormwater discharge into the Bay. Groundwater recharge is a related service, corresponding to the percolation of stormwater past the root zone, potentially recharging groundwater for human and non-human purposes. Flood hazard reduction is the retention and slowing down of water during large storm events, which reduces the volume of water and flow rates downstream.

Application of the Model Across Bay Area Conservation Networks

The Bay-wide service assessment used a simple pixel-by-pixel model quantifying the stormwater infiltration, runoff volume and pollutant load retained locally based on precipitation, land cover, and soil data. Detailed methods on the application of the InVEST stormwater and flood risk models in the Bay Area are detailed in Hamel et al. 2019. Please refer to this paper for details on this analysis.

Citations:

1. Hamel, P., Garcia, A., Schloss, C., Rohde, M.M., Guerry, A.D., Wyatt, K. (2019). *Stormwater management services maps for the San Francisco Bay Area.* Working paper. Available at: https://naturalcapitalproject.stanford.edu