# APPENDIX A. Additional Sediment Demand Information

## Study extent of baylands habitats

Habitat mapping adapted from the Goals Report (2015) is based on Bay Area Aquatic Resource Inventory (BAARI) data from 2009 in addition to areas identified as planned tidal marsh restoration circa 2015. The habitat categories used in this report are adapted from the *Baylands Goals Update* (Goals Project 2015) habitat categories, a reclassification of BAARI's habitat categories (Table A1).

**Table A1. Crosswalk between habitats mapped in the BAARI version 2.1 (SFEI-ASC 2017b) and the Goals Report (2015). Habitat extents were adapted from the Goals Report (2015) categories for tidal flats and tidal marshes.**

| Baylands Goals Update (2015) habitat category | BAARI Baylands 2009 habitat category |
|---|---|
| Tidal marsh | Tidal ditch |
| | Tidal marsh flat |
| | Tidal panne |
| | Tidal vegetation |
| Tidal flat | Tidal bay flat |
| | Tidal nascent vegetation |

## Quantifying sediment demands

Calculations of sediment demand needed in both the 'existing baylands' and 'existing baylands plus planned restoration' scenarios described in Chapter 2 account for the mass of sediment needed to raise habitats that are below tidal marsh elevations up to local mean higher high water (MHHW) elevations (in meters NAVD88). The volume of fill needed to raise elevations to local MHHW levels was calculated in GIS using the Cut Fill tool. The Cut Fill tool calculates the amount of volume needed to either raise or lower an existing land surface by subtracting the existing elevational surface from the desired elevational surface, resulting in volumetric outputs categorized by net gains, net losses, and unchanged areas. Unchanged areas signify land already at local MHHW levels and net positive areas (i.e. "net loss" areas) indicate land above MHHW. Unchanged and net positive areas were not factored into total sediment calculations based on an assumption that the areas above MHHW have high 'elevation capital' and therefore should be preserved in the face of rising sea levels. This analysis only considered the net negative areas (i.e., “net gain” areas) outputted from the Cut Fill tool since these areas need to be raised to MHHW elevations to meet in-progress and future planned restoration goals, based on the assumptions made in this study. Elevation data used to model current conditions in this analysis comes from the Coastal National Elevation Database (CoNED) topobathymetric model of San Francisco Bay (USGS 2013). This DEM has a cell size of 2m, and utilizes input data collected between 2004 and 2011. Tidal datums used to model desired elevational surface (i.e., local MHHW levels) were modeled by AECOM (2016). Averaged MHHW values for each OLU are listed in the Table A2. Habitats classified as existing tidal marsh (circa 2009, SFEI-ASC 2017b) was assumed to be at sufficient intertidal elevations for the purpose of restoration, so raising these areas to MHHW elevations was determined to be unnecessary.

**Table A2. Local MHHW averaged by baylands OLU.**

| OLU | MHHW (meters NAVD88) | MSL (meters NAVD88) | OLU | MHHW (meters NAVD88) | MSL (meters NAVD88) |
|---|---|---|---|---|---|
| 1- Richardson | 1.83 | 1.00 | 16- Point Richmond | 1.86 | 1.01 |
| 2- Corte Madera | 1.84 | 1.01 | 17- East Bay Crescent | 1.89 | 1.01 |
| 3- San Rafael | 1.85 | 1.01 | 18- San Leandro | 1.98 | 1.01 |
| 4- Gallinas | 1.88 | 1.02 | 19- San Lorenzo | 2.12 | 1.02 |
| 5- Novato | 1.90 | 1.03 | 20- Alameda Creek | 2.18 | 1.01 |
| 6- Petaluma | 1.91 | 1.04 | 21- Mowry | 2.24 | 1.00 |
| 7- Napa - Sonoma | 1.90 | 1.06 | 22- Santa Clara Valley | 2.28 | 1.00 |
| 8- Carquinez North | 1.84 | 1.07 | 23- Stevens | 2.25 | 1.00 |
| 9- Suisun Slough | 1.88 | 1.10 | 24- San Francisquito | 2.23 | 1.00 |
| 10- Montezuma Slough | 1.89 | 1.13 | 25- Belmont - Redwood | 2.16 | 1.00 |
| 11- Bay Point | 1.88 | 1.14 | 26- San Mateo | 2.10 | 1.01 |
| 12- Walnut | 1.87 | 1.10 | 27- Colma - San Bruno | 2.07 | 1.01 |
| 13- Carquinez South | 1.84 | 1.07 | 28- Yosemite - Visitacion | 2.03 | 1.01 |
| 14- Pinole | 1.90 | 1.05 | 29- Mission - Islais | 1.95 | 1.01 |
| 15- Wildcat | 1.88 | 1.02 | 30- Golden Gate | 1.84 | 0.99 |

Next, the habitat extents for both scenarios were multiplied by near-term (i.e., 2050) and long-term (i.e., 2100) sea level rise projections: 0.6 m (1.9 ft) and 2.1 m (6.9 ft) respectively. Sea level rise estimates were determined based on the State of California Sea-Level Rise Guidance Update’s (2018) medium-high risk aversion category projections, which specifies a 0.5% probability that sea level rise will meet or exceed 0.6 m (1.9 ft) by 2050 and 2.1 m (6.9 ft) by 2100 under high emission scenarios (based on Kopp et al. 2014). The resulting volume of soil needed were combined with the Cut Fill tool volumes to arrive at the total volume of soil needed for these habitats to keep pace under these two sea level rise projections.

The resulting volumes of sediment needed for tidal marsh to keep pace with sea level rise were converted to mass of sediment by using the mineral sediment component of dry bulk density estimates from the top 20-cm of soil core samples (analyzed in 2-cm intervals), adapted from Callaway et al. (2012) (Table A3). Volumes of sediment needed for tidal flats to keep pace with sea level rise were converted to mass of sediment by using bed bulk density estimates adapted from Lionberger and Schoellhamer (2009), which are based on data from Caffrey (2005), Sternberg and others (1986), and Bruce Jaffe (pers. comm.) (Table A4). Bulk density estimates for tidal flats and tidal marsh were averaged by the location of the sample based on subembayment. While most subembayment bulk density estimates for tidal marsh are based on samples collected from more than one marsh, the bulk density estimates averaged for Central Bay is based on samples collected only within Muzzi Marsh, a restoration project dating back to 1974. This is worth noting since Muzzi Marsh may not be representative of bulk density estimates found in older Central Bay marshes.

**Table A3. Mineral component of dry bulk density averaged across marshes by subembayment, calculated from the top 20 cm of core samples (adapted from Callaway et al. 2012).**

| **Subembayment** | **Avgerage Mineral Sediment Component of Dry Bulk Density** *(kg of sediment / m$^3$ of soil)* |
|---|---|
| Central Bay | 460 |
| San Pablo Bay | 400 |
| South Bay | 470 |
| Suisun Bay | 160 |

**Table A4. Dry bulk density averaged by subembayment, based on “UP Box” values reported in Lionberger and Schoellhamer (2009).**

| **Subembayment** | **Average Dry Bulk Density** *(kg of sediment / m$^3$ of soil)* |
|---|---|
| Central Bay | ~1000 |
| San Pablo Bay | 730 |
| South Bay | 730 |
| Suisun Bay | 860 |

Bulk density estimates for tidal marsh under the long-term sea level rise scenario (2.1 m) were averaged across 44 cm of core to account for surface sediment compaction (Table A5). This depth was the deepest common depth across all core samples analyzed by Callaway et al.

(2012), so this depth was chosen for consistency across subembayments. This study assumes tidal flats have limited amounts of soil organic matter, making compaction less prevalent. Therefore, surface sediment compaction was not taken into account in sediment demand calculations of tidal flats.

**Table A5. Mineral component of dry bulk density averaged across marshes by subembayment, calculated from the top 44 cm of core samples (adapted from Callaway et al. 2012).**

| **Subembayment** | **Avg Mineral Sediment Component of Dry Bulk Density** *(kg of sediment / $m^3$ of soil)* |
|---|---|
| Central Bay | 460* |
| San Pablo Bay | 420 |
| South Bay | 510 |
| Suisun Bay | 230 |

**The average mineral sediment component of dry bulk density for Central Bay decreased to 380 kg of sediment / $m^3$ of soil when calculated using the top 44 cm of the soil cores for this subembayment. Since the ‘existing baylands + planned restoration’ scenario averages bulk density over a deeper core depth, from 20 cm to 44 cm to account for compaction, we expected the bulk density value to increase. Because a lower bulk density is counterintuitive to compaction, we instead used the bulk density estimate calculated for the top 20 cm of core (~460 kg sediment / $m^3$ of soil) used in the ‘existing baylands’ scenario for the Central Bay subembayment.*

## Correcting topobathymetric data gaps to refine sediment demand estimates

Although the DEM utilized to calculate sediment demand is based on topobathymetric data containing elevation for both dry and submerged parts of the study extent, there are submerged areas--many that are not currently tidal--without true bathymetric data. In these areas, the DEM reports the elevation of the water surface which would lead to incorrect calculations in terms of how much fill is needed to bring certain areas to local MHHW elevation if not removed or corrected for in this analysis. To identify these areas, we used the data layer created by SFEI and SPUR (2019) to identify portions of the DEM likely quantifying the elevation of the water surface (instead of the land surface) by using a neighborhood filter to identify flat areas. Approximately 9,300 acres of flat areas exist within the study extent. Of that area, 89% was appended with topobathymetric data from various sources and the remaining 11% was left as flat areas likely quantifying water surface elevations.

Table A6 details the type, resolution, assumptions, and source of elevation data collected to correct topobathymetric elevations of flat areas. Each dataset was reprojected, resampled, snapped to, and set to the same cell size of the original DEM. A conditional statement was used in ArcGIS to append known elevations to the flat areas in the original DEM. Most of the datasets had some raster elevation data which ranged in resolution. In the case of Cullinan Ranch and Pond A18 however, no known bathymetry data was available and so estimates from field observations were assigned to these areas.

**Table A6. Topobathymetric datasets appended to flat areas of the DEM used to determine polder fill volumes.**

| Dataset | Data type | Datum | Source | Resolution/Notes |
|---|---|---|---|---|
| Marin County LiDAR (2013) | Raster | WGS 1984 (Geoid 2003), NAVD 1988 | Callaway et al. 2012 | Contains 4 different raster resolutions. Raster DEM was created by interpolating LiDAR points classified as ground from the following LiDAR datasets with the listed point densities: (1) Golden Gate LiDAR (May 2010), 2 pts/m2; (2) FEMA (2007), 2 pts/m2; (3) California Ocean Protection Council (2010), 1 pt/m2. |
| USGS Boat Bathymetry | Raster | Vertical datum: NAVD 1988 | Susan De La Cruz, personal comm. (2018) | This dataset was collected in 2011 by the U.S. Geological Survey and has a resolution of 25 meters. |
| South San Francisco Bay 2004 Topographic LiDAR Survey | Raster | Horizontal datum: NAVD83; Vertical datum: NAVD88 | Foxgrover and Jaffe 2005 | 1-meter resolution DEM was generated from the bare earth lidar data points. |
| 2005 South Bay Salt Pond Boat Bathymetry | Raster | Vertical datum: NAVD88 | USGS 2005 | This dataset was collected in 2003 and 2004 by the U.S. Geological Survey. The data were created using a shallow water sounding system comprised of a single beam echosounder, differential GPS, and a laptop computer in a water-resistant case affixed to a Bass Hunter boat. Resolution is 25 meters. |
| Pond A18 | Field observations (single depth assigned to entire pond) | Depth was assumed to be 2ft NAVD88 | Ryan Mayfield, personal comm. (2018) | Assumptions made for depth based on best professional judgment adapted from field observations provided by Ryan Mayfield from the Citty of San Jose. |
| Cullinan Ranch | Field observations (single depth assigned to entire pond) | assumed 0.29 ft NAVD88 at Cullinan | Renee Spenst, personal comm. (2018) | Assumptions made for depth based on best professional judgment adapted from field observations provided by Renee Spenst of Ducks Unlimited. |

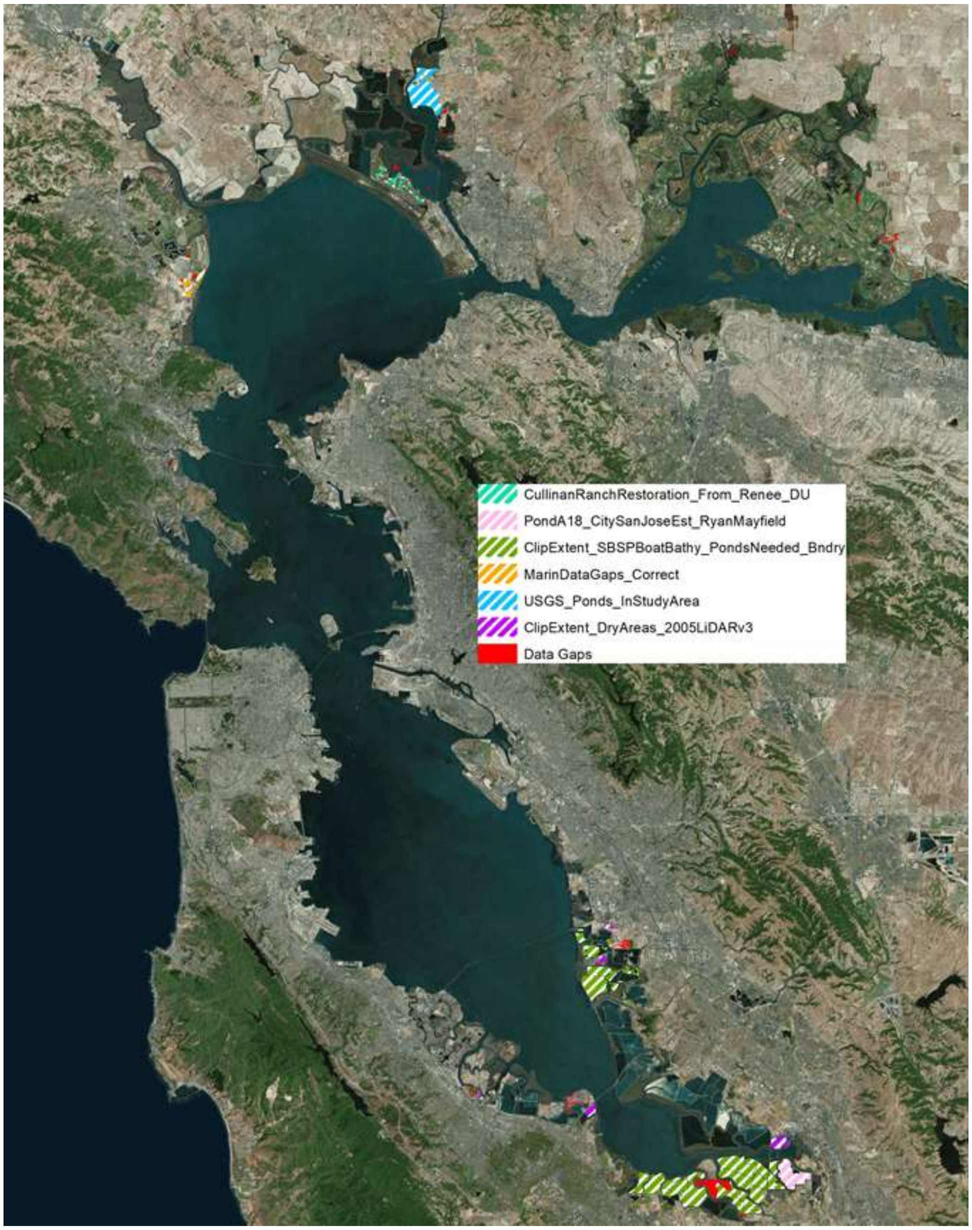
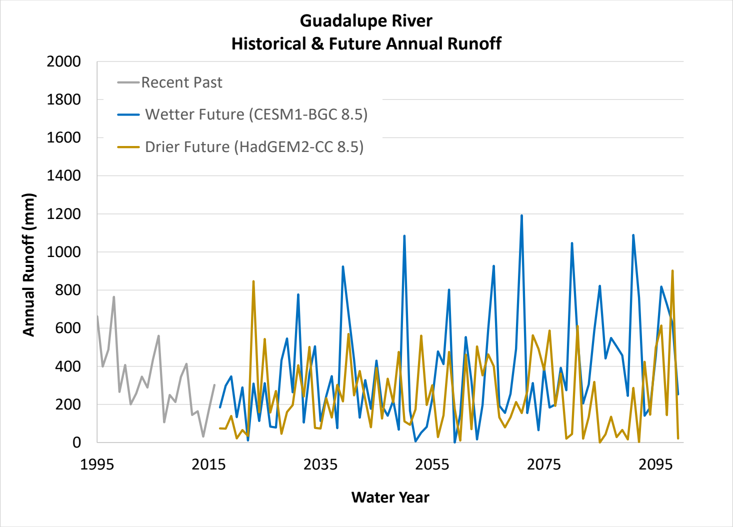
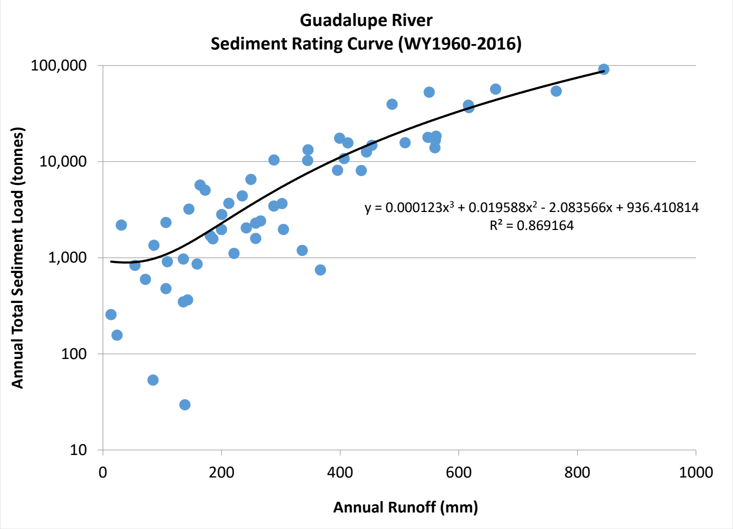


Figure A1. Locations of topobathymetric data appended to flat areas of the DEM used to determine polder fill volumes.

# APPENDIX B. Additional Sediment Supply Information





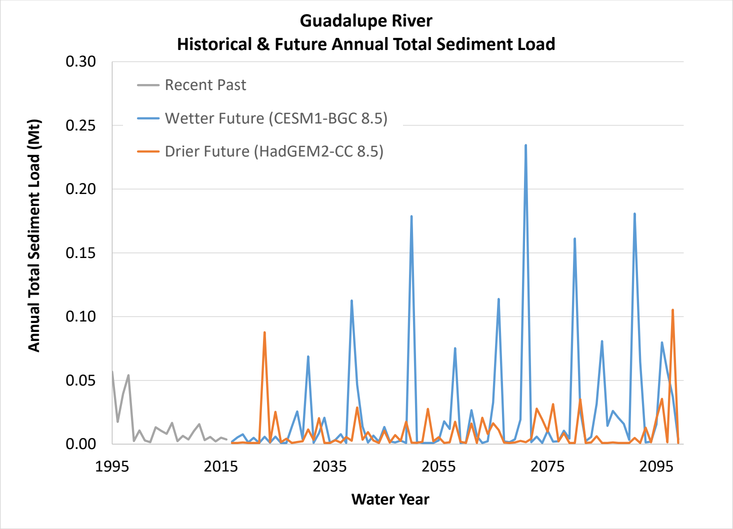


Figure B1. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the Guadalupe River watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.

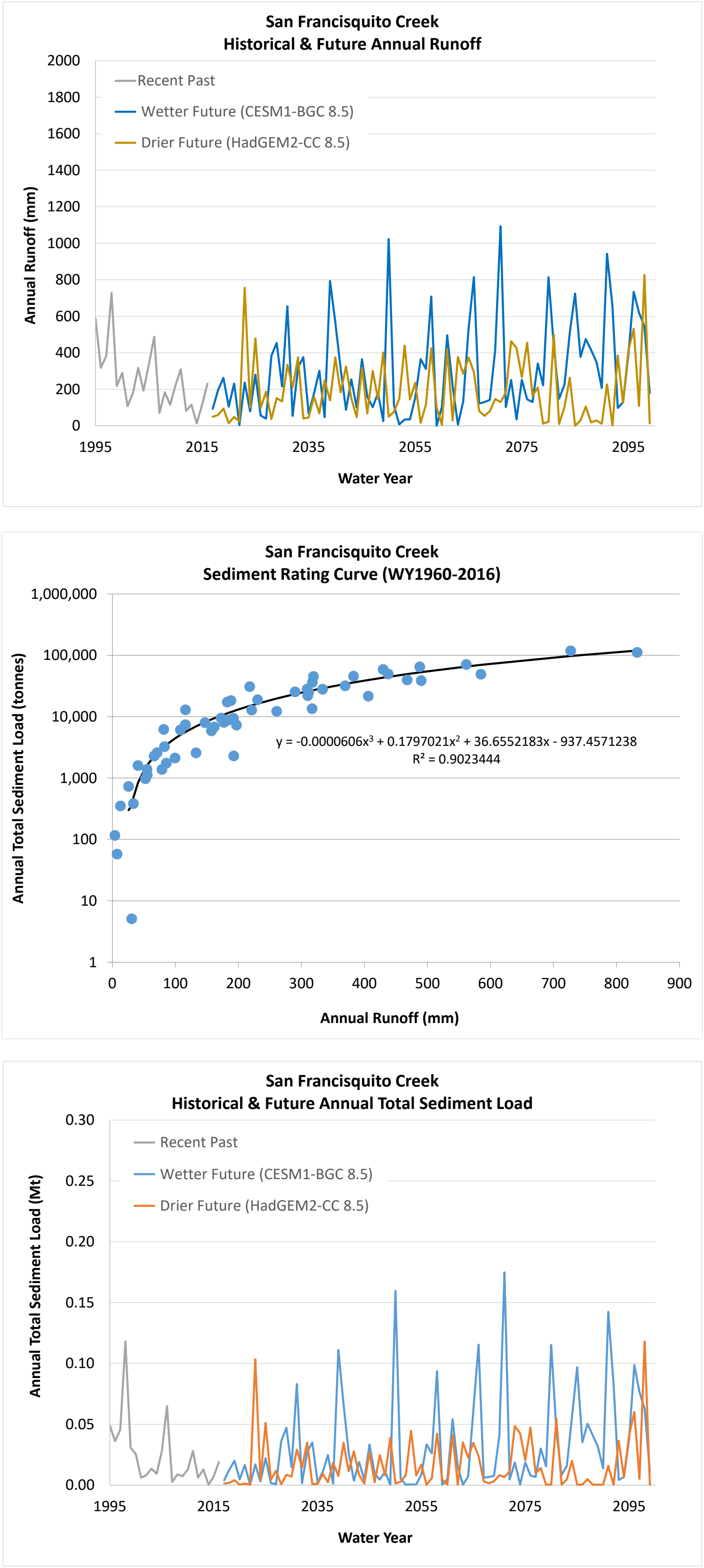
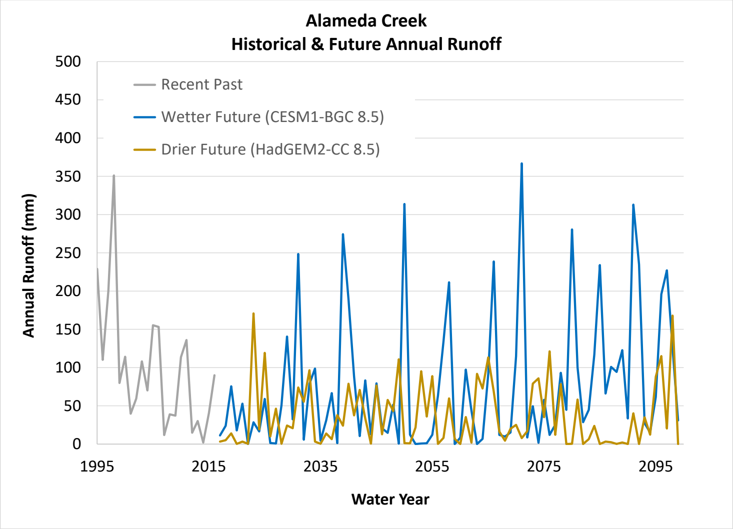
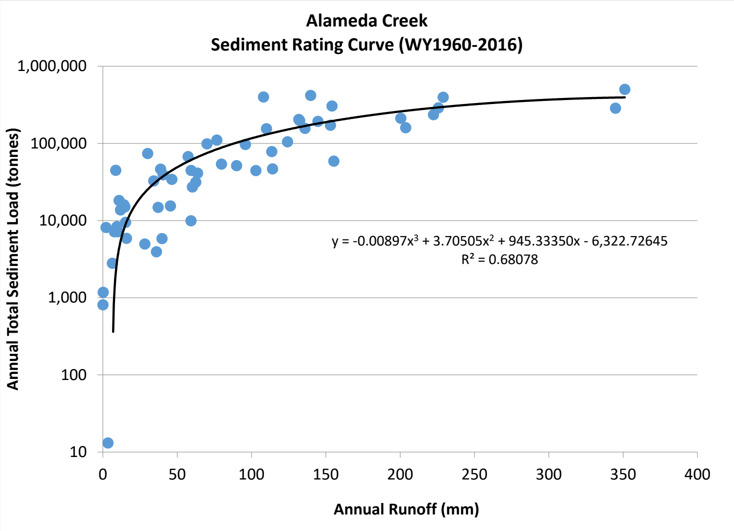


Figure B2. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the San Francisquito Creek watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.





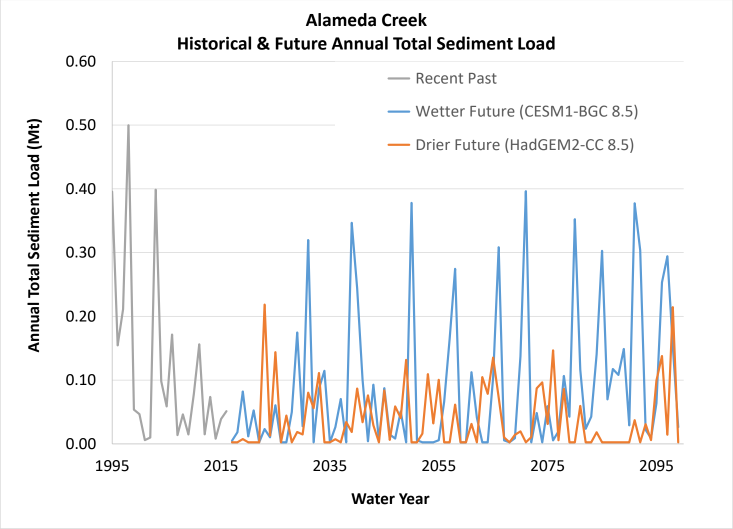


Figure B3. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the Alameda Creek watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.

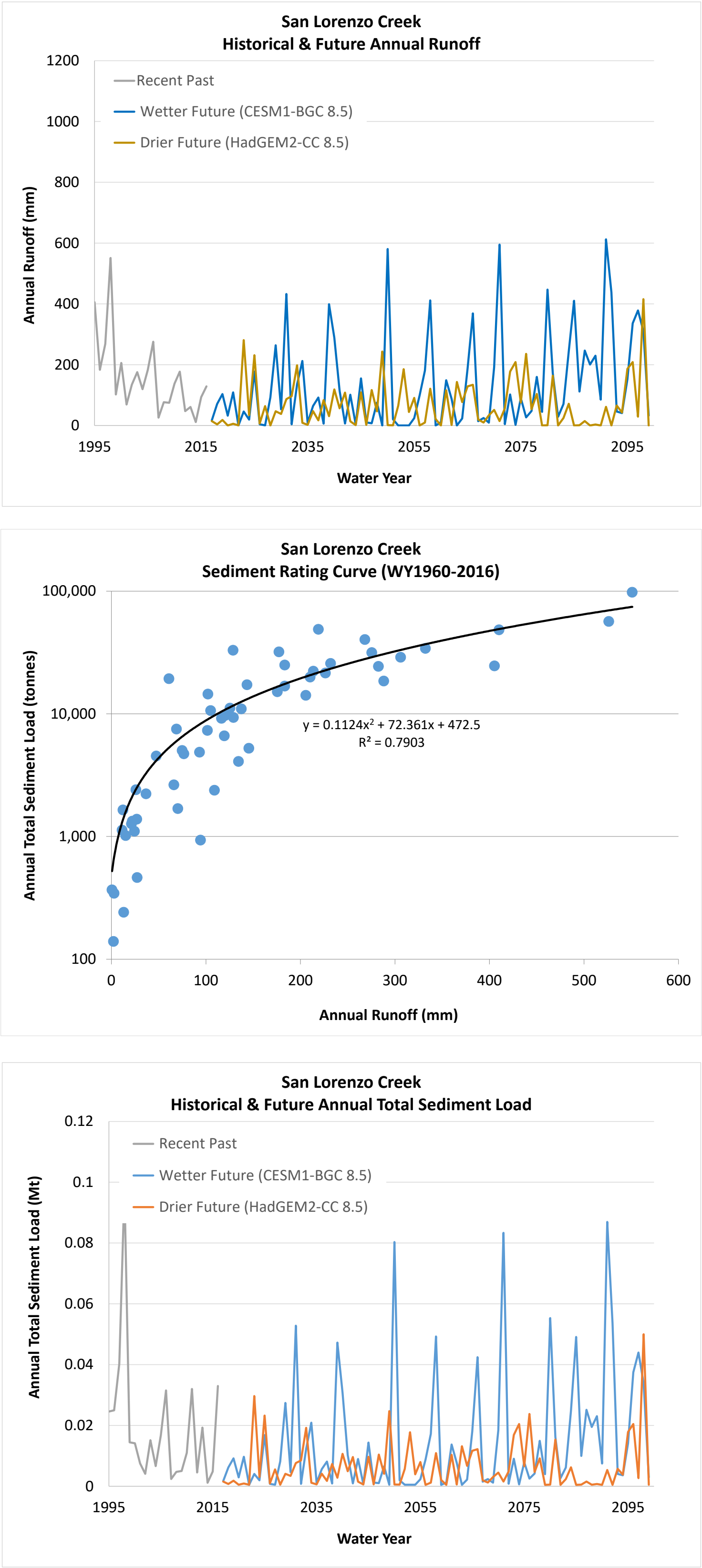
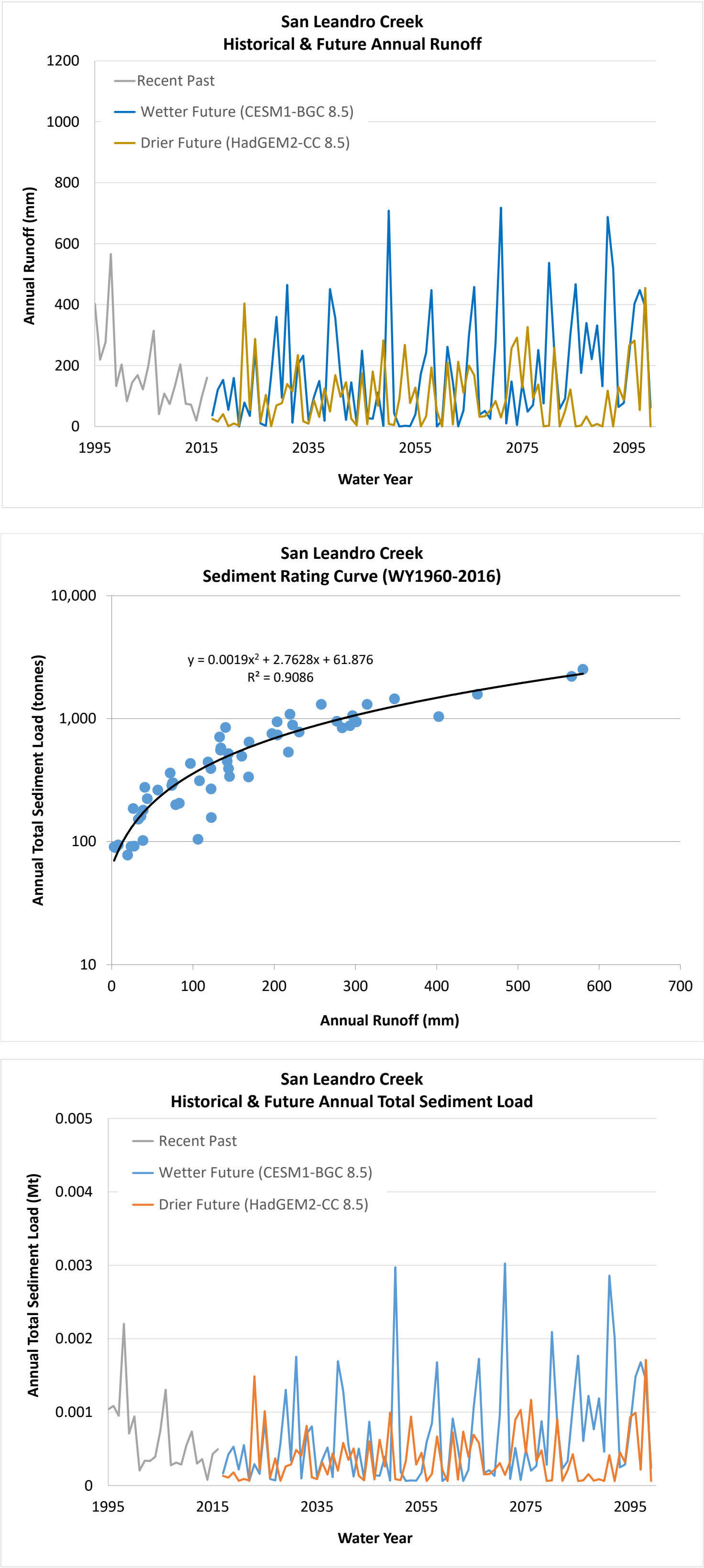


Figure B4. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the San Lorenzo Creek watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.



San Leandro Creek
Historical & Future Annual Runoff

San Leandro Creek
Sediment Rating Curve (WY1960-2016)

San Leandro Creek
Historical & Future Annual Total Sediment Load

Figure B5. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the San Leandro Creek watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.

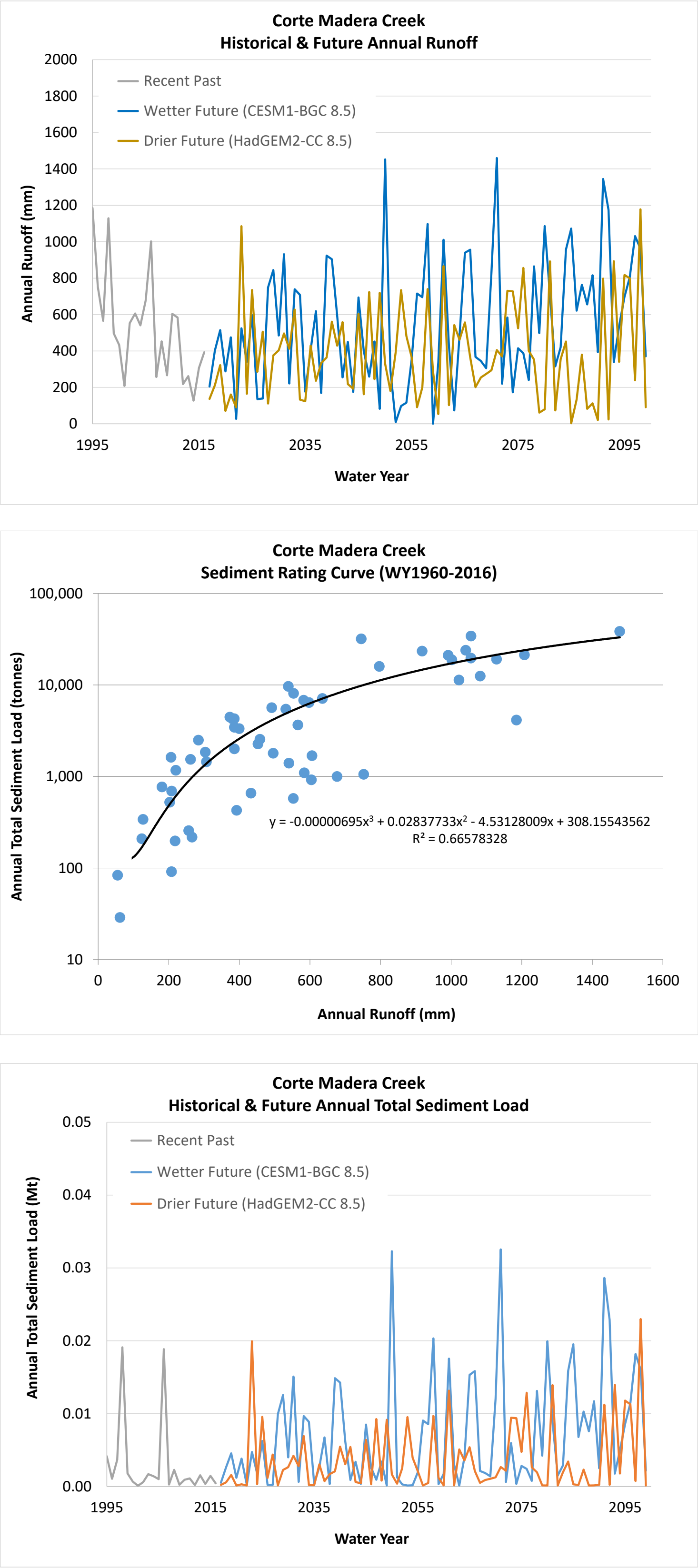


Figure B6. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the Corte Madera Creek watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.

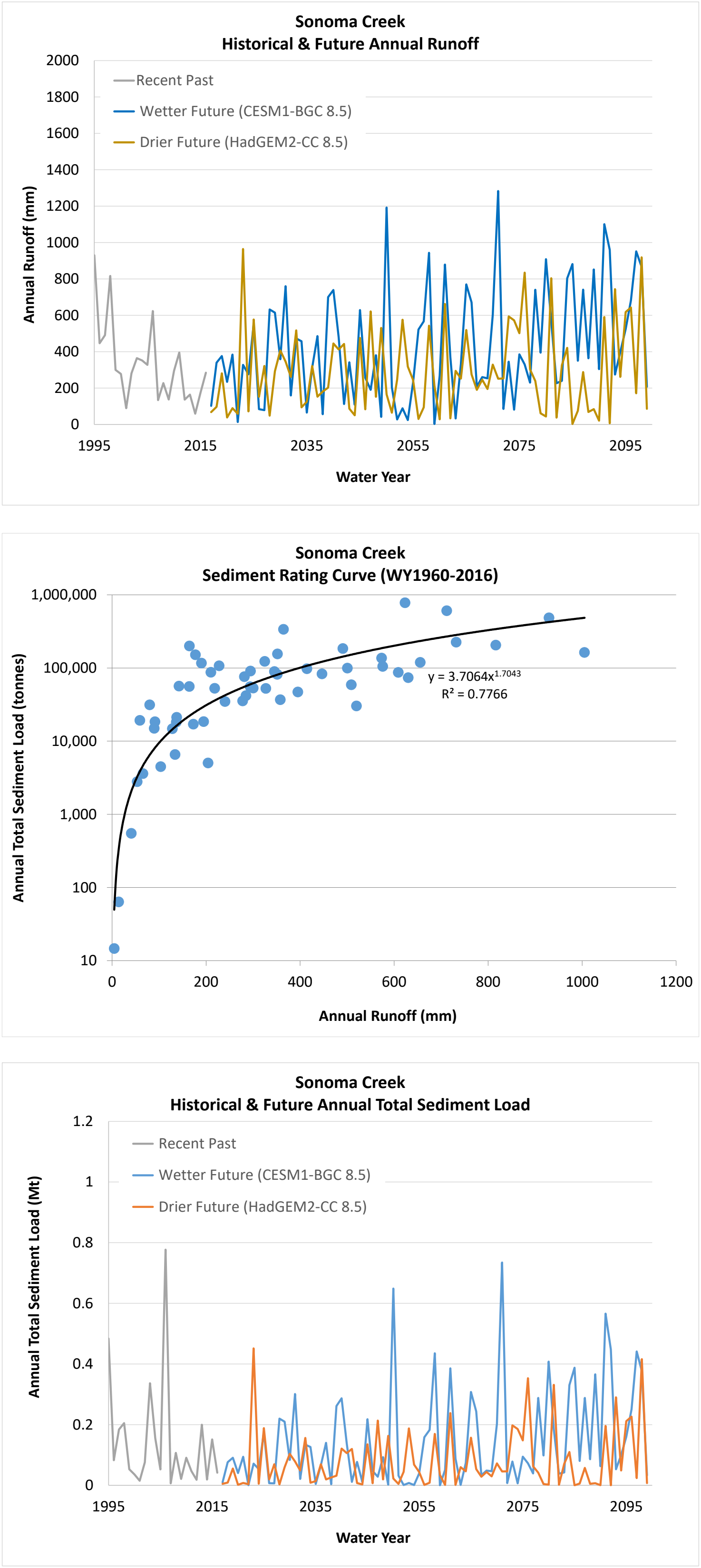


Figure B7. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the Sonoma Creek watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.

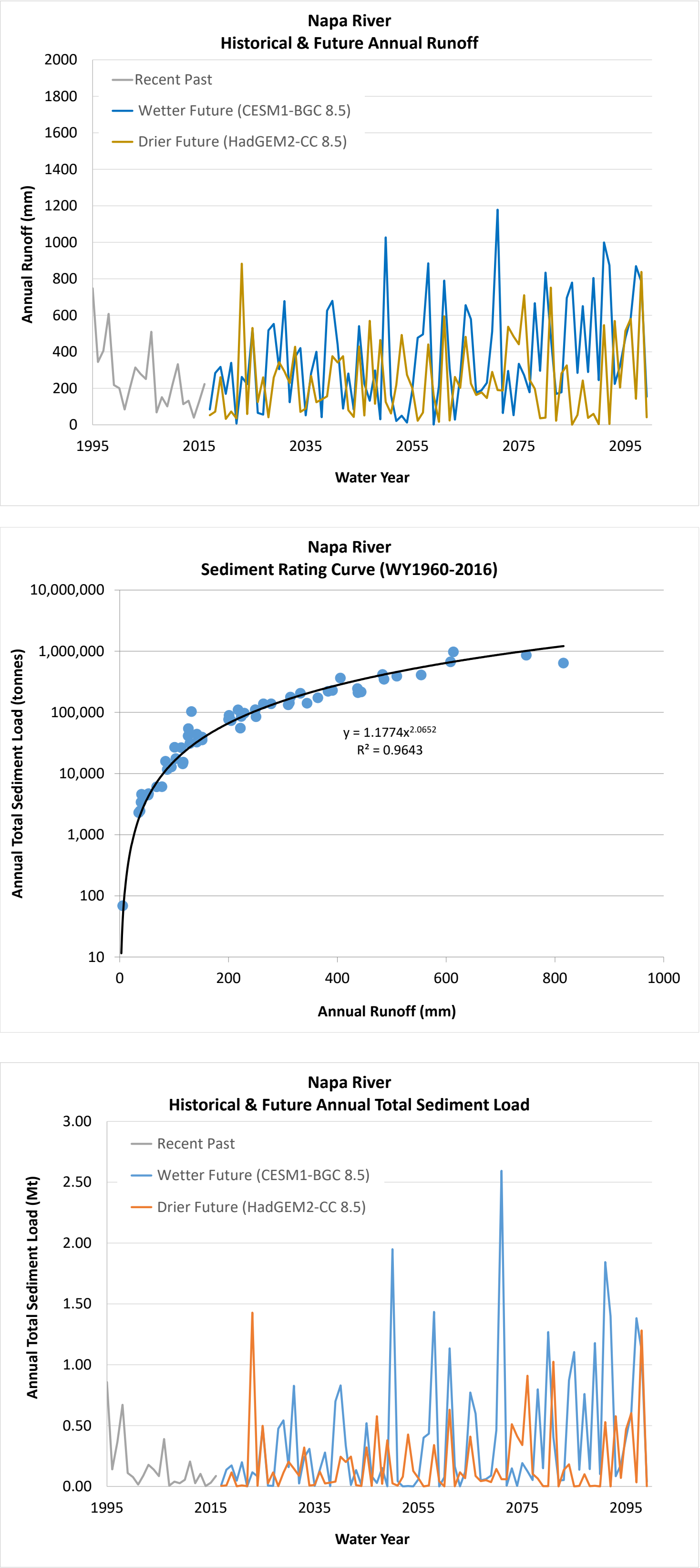
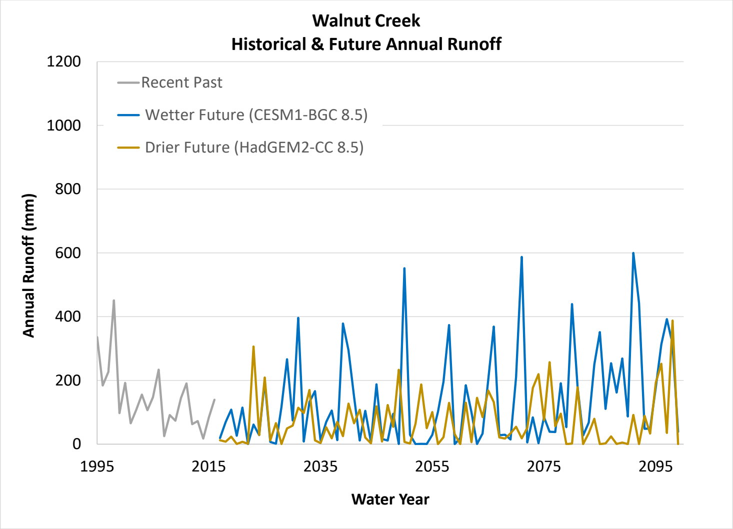
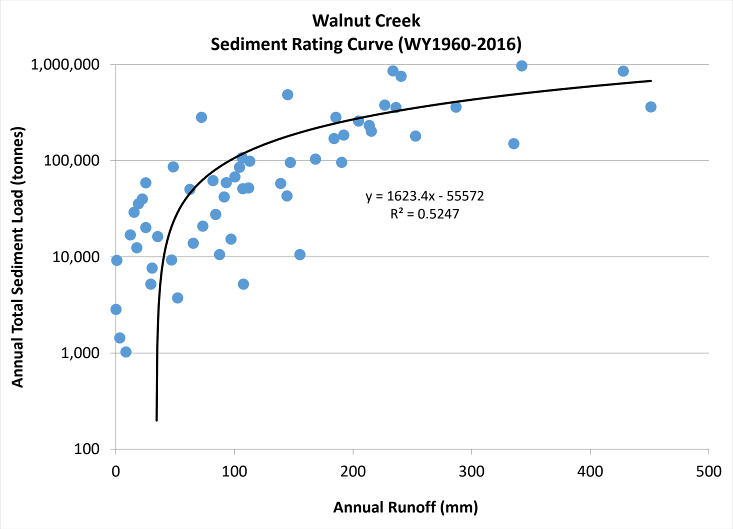


Figure B8. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the Napa River watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.





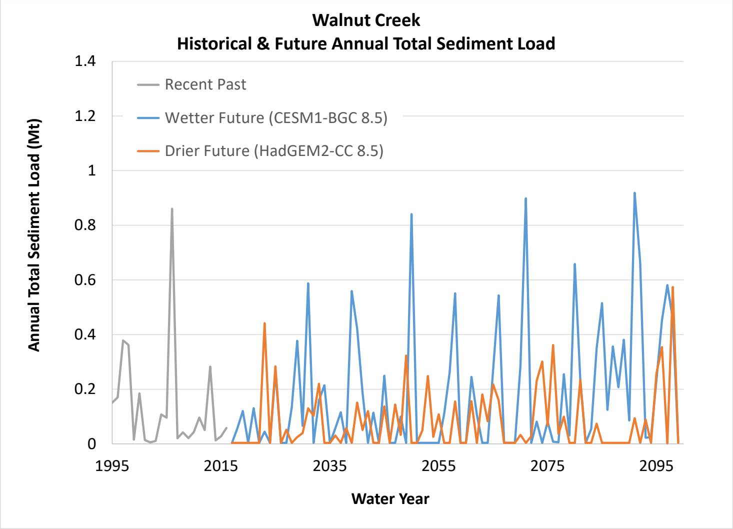


Figure B9. Time series of modeled historical and future annual runoff, annual sediment rating curve, and time series of historical and future annual sediment load for the Walnut Creek watershed. Modeled runoff was provided by Lorraine Flint (USGS, ret) and annual sediment loads are from SFEI-ASC 2017a and Schoellhamer et al. 2018.

# APPENDIX C. Quantifying Management Opportunities

### Table C1. Density factors used to convert volumes to mass in Figure 4.1 for different sediment types.

| Sediment type | Conversion Factor | Unit | Conversion Factor | Unit | Source | Notes |
|---|---|---|---|---|---|---|
| Sediment behind dams | 74.1 | lb/ft3 | 1.19 | metric t/m3 | NHC 2004 | Estimated density of 1.0 tons/yd3 for deposition in Searsville Lake reservoir (San Francisquito Creek). See next tab for source link. |
| Fluvial reaches of creeks | 103.7 | lb/ft3 | 1.66 | metric t/m4 | NHC 2004 | Estimated assumed average density for instream deposition of 1.4 tons/yd3 of tributaries upstream of Searsville Lake. Adapted from Sediment budget 1995 to 2000 for Searsville Lake. See next tab for source link. |
| Tidal reaches of creeks | 50.0 | lb/ft3 | 0.80 | metric t/m5 | Porterfield et al. 1961 | A specific weight of 50 lb/ft3 was used by DWR and USGS for suspended sediment...that by the DWR by analyzing numerous samples of muds from the shoal areas of the Bay, and that by the USGS by computations of specific weight based on the average particle size of the material transported by the Sacramento River. |
| Dredged bay mud | 97.0 | lb/ft3 | 1.55 | metric t/m6 | SSSBS 2015 | Geotechnical considerations related to using Bay mud as fill for wetland restoration based on personal comm. with Nick Malasavage (US ACE). Normally consolidated Bay mud has a total unit weight of 97 lbs/ft3 (Nick Malasavage, personal comm.) |
| Dredged oyster shell | as is | -- | -- | -- | Lind Tug and Barge, 2018 | Assuming measured in volumes and converted to tons using conversion factor of bulk density since tonnage is 0.5 of the volumes reported. |
| Dredged sand | 102.4 | lb/ft3 | 1.64 | metric t/m8 | Atwater et al. 1977 | Merritt Sand; Based on Table 1 in Atwater et al. for fine and medium-grained sand with subordinate silt (Eolian deposits from the late Pleistocene and Holocene). Bulk density 1.9-2.2 g/cm3, moisture content 15-25 percent. To find conversion factor: =(average(1.9,2.2)*(1-.20))=1.64 g/cm3 dry bulk density factor |
| Landfilled soils | as is | -- | -- | -- | -- | Assumes weight recorded at landfill corresponds to dried weight, when applied as daily cover or other material. Based on assumption that weight recorded by converting volume by density. |
| Biosolids | 20 | % solids | -- | -- | Greg Kester, pers. comm.. | Assuming 80% moisture so multiplied reported weight by 0.20 to determine approximate weight of solids which is assumed to be predominantly organic matter. Assumption based on personal comm. with XX. |

## Excavated Soils

Data on the soils landfilled in the San Francisco Bay Area was collected from the California Department of Resources Recycling and Recovery (CalRecycle), who maintain a database on the landfill reports of materials received. These data include information on the tonnage of “Daily Cover” (DC) materials, including soils. This accounting is only a fraction of the total *excavated* soils in the region: some are stockpiled; others are bought/traded on the “market” for various construction, mitigation and shoreline restoration projects. However, because of the significant flows of soils *to* landfills (in terms of their magnitude and consistency), landfilled soils were focused upon here for their alternative use potential. Numerous materials can be considered DC (depending on the landfill), including green waste, shredded tires, and other bulk masses that are useful in tamping down solid wastes to deter scavenging, and prevent windblown trash, odors and particulates from emanating from the site.

The analysis contains data from only 7 of the 9 regional counties: San Francisco has no landfills, and Sonoma’s county was deemed unreliable in a pedigree matrix, and rejected. While the tracking of the quantitative *amounts* of soils is deemed robust, it should be emphasized that very little is known about the general class of “excavated soils” in terms of their various *qualities* in this analysis: CalRecycle does not measure or include information about moisture content (which can dramatically affect measured soil *mass*); the presence of contaminants (which would impact reuse potential); or geotechnical characteristics (important in landform-building applications).

## Treated Biosolids

The California Association of Sanitation Agencies (CASA) maintains a database on the wastewater treatment plants and other sewage and sludge processing facilities in California (generalized and referred to herein as WWTPs). One of the metrics tracked at these facilities is the amount of treated biosolids that are “prepared” (produced) in addition to information pertaining to their end-of-life phase (agricultural application, landfilling, incineration, etc.). This analysis focused on the mass of the biosolids prepared at WWTPs in the 9-county Bay Area region, and the proportion of this amount sent to landfills. Whereas the total prepared amount of biosolids was collected, only the tabulation of primary landfill disposal site quantities were analyzed, because secondary and tertiary sites were considered to be of negligible amounts in the context of the analysis and numbers-rounding techniques applied.

Biosolids undergo a variety of processes, including dewatering to reduce their mass and extract various concentrated compounds. The dataset analyzed was assumed to have an average total solids (TS) percentage of 22%, which is generally achieved through manual de-watering/pressing, as opposed to air-drying and seasoning, which can increase TS to 50% or higher, but is time-consuming and entails more handling, storage capacity for solar drying, and the management of sludge that may “weep” out of drying piles on the ground’s surface (as opposed to evaporating).

Biosolids have been studied and utilized in a variety of shoreline applications in many parts of the world over many decades, but they present numerous regulatory and permitting issues, owing to their high nutrient content, the concentration of certain metals, and the presence of various contaminants including micro- and nanoplastics, pharmaceuticals and other compounds, including pathogenic vectors (bacteria, viruses, protozoa, helminths). Biosolids are grouped into two classes as pertains to pathogen reduction: Class A contain no detectable pathogens, and Class B may contain trace amounts.

Biosolids are useful in conditioning depleted soils as an amendment, but present particular issues in their reuse, including the aesthetic impacts (odors) that may arise from their reuse near dwellings or human-use areas. One important note regarding WWTPs is that they are very often located as low in elevation (and thus close to the shoreline) as possible to benefit from gravity-facilitated collection networks, and are thus potentially in very close proximity to possible shoreline reuse sites, especially as compared to agricultural application destinations in the Central Valley, for example.

### Construction and Demolition Wastes (CDW)

Wastes are a ubiquitous product of general construction and demolition processes, though many industries have dramatically improved their resource efficiency and waste-recovery practices in recent years, and some planning departments require special plans and provisions for doing so in order to satisfy permitting requirements. While this report does not attempt to quantify the CDW flows in the region, as a rapidly growing and evolving urban metropolis, they are surely considerable in size, and inevitably intensify with the turnover of building stock and infrastructure; which can be estimated by proxy as a function of population rise. While some streams within overall CDW flows are unsuitable for reuse in environmental applications, others including those derived from organic products (wood, paper, linoleum) and biochemically inert mineral-based products may be useful as resources in shoreline adaptation projects.