SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

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Total sediment loads estimates methodology narratives

A number of methods were developed to estimate sediment loads for each flood control channel. These are described below. The confidence in these loads estimated is wide ranging and follows the general scheme:

1. Measured recent sediment loads – Highest confidence
2. Measured historic sediment loads combined with measured recent flow gauging - reasonably high confidence
3. Measured historic sediment loads combined with a combination of measured and estimated flow from a regression with a neighboring gauge - moderately high confidence
4. Measured historic sediment loads from a short record combined with a combination of measured and estimated flow from a regression with a neighboring gauge - moderately low confidence
5. Measured historic flow and sediment loads from a short record combined with estimated flow from a regression with a neighboring gauge – low confidence
6. Loads derived from the regional area load relation for urban sediment sources temporally devolved using another local sediment gauge for watersheds with relatively high (>40% impervious cover) – low confidence
7. Loads derived from the regional area load relation for urban sediment sources temporally devolved using another local sediment gauge for watersheds with relatively high (<40% impervious cover) - very low confidence
8. Loads derived from the regional area load relation for non-urban sediment sources temporally devolved using another local sediment gauge - very low confidence
9. A combination method of regional non-urban and urban loads - very low confidence

Alameda Creek

Peak flow has been measured by the USGS for Alameda Creek at the Niles Canyon gauge (or nearby gauges slightly upstream) for the period water years 1892 to present; the longest running continuous gauging effort in the Bay Area. Despite the position of the gauge changing a few times, the entire record is published as station number 11179000. For this project, data for 1957 to present were retrieved. Suspended sediment loads have been computed by the USGS for the Niles gauge for water years 1957 to 1973, and 2000 to present. Bed loads for the Niles gauge have only been computed for the more recent period (water years 2000 – present). For this period bed load as a percentage of total load varied from 1 to 26%. Suspended (SS) and bed loads (BL) were computed for the Niles gauge location for missing water years from 1974 to 1999 using regression equations between peak flow and annual scale loads reported by Bigelow et al. (2008):

Annual SS load (metric t) = 22.186*peak flow (m^3/s)^1.5759

Annual BL load (metric t) = 0.2112* peak flow (m^3/s)^2.0346

This resulted in an annual average bed load contribution of 10% of total load for the 40 year period water years 1974 to 2013. Subsequently, an estimate of total load from Dry Creek at Union City was added to the load entering the flood control channel from Niles Canyon. The Dry Creek at Union City total load estimate was based on a regression relationship between peak flow and total annual load derived from data reported on page 12 of Beagle et al. (2011). This adjustment represented an annual average increase of 4% based on water years 1974 to 2013 (a 40 years averaging period) but for individual water years the increase was anywhere between less than 1% and 16%. No further increase was necessary between the confluence of Dry Creek and Alameda Creek and the head of tide because there are no further inputs downstream. In relative terms, confidence in sediment loads estimates for Alameda Creek are the highest for any system in the Bay Area.

Colma Creek

USGS measured flow in Colma Creek at South San Francisco (gauge 11162720) from water year 1964 to 1994 and in water year 1996. Annual suspended sediment loads were reported for water years 1966 to 1976. Flow for ungauged years for water years from 1957 to 2013 was not estimated. Instead, a direct estimate of suspended sediment loads for each water years was made using a regression between climate year SFO rainfall (inches) and water year annual suspended sediment load. Data for the first five years of this gauge site appear to fall in a completely different population (much higher sediment load) which was discussed by a USGS report (reference unavailable) as being caused by extensive development in the decade before. Only the last 6 years of the data were used and assumed to be more representative of modern conditions (McKee et al., 2013). Variation in SFO rainfall accounts for just 69% of the annual suspended sediment loads for water years 1971 to 1976 and based on a comparison of predicted versus measured loads for this period, the regression appears to underestimate load by about 18% for the period but no adjustment was made for this issue. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (2.8 km^2), the suspended sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (3.5 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 14% of annual average total load for WYs 2000-2013. Overall, loads estimates have been quantified with moderate confidence – improved confidence would be achieved through verification of the rating curve with recent data if it could be found or collected.

Corte Madera Creek

USGS has measured flow in Corte Madera Creek at Ross (gauge 11460000) from water year 1952 to 1993 and in water year 1996 and then from water year 2010 to present. Annual suspended sediment loads were reported for water years 1978 to 1980 and 2010 to present. Bed load data is only available for water years 1978 to 1980. Flows for missing periods between water years 1957 and 2013 were estimated using a regression with Novato Creek which explained 73% of the variability. A regression relation was developed between monthly suspended sediment loads and monthly gauged flow and used to estimate suspended sediment loads for the unmeasured periods. This relationship explained 87% of the variability between flow and suspended sediment load. Similarly, a regression between flow and monthly bed load explained 78% of the variability. Based on the 1978 to 1980 period when both bed load and total load were computed, bed load comprised 10% of total load. Using the regression equations to estimate loads for the entire 1957 to 2013 period, bed load is estimated to comprise 13% of the total load. Given a free flowing watershed area of 41.2 km^2 at the gauge location, the regional bed load equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504) provided an estimate of just 3.6% of the total load being transported as bed load. Corte Madera Creek does not fit the regional model for bed load and in fact was one of three outliers that was removed along with Zone 6 Line B at Warm Springs Boulevard at Fremont and Temescal Ck. above Lake

Temescal at Oakland when developing the regional bed load regression. Informal observations of large bed lag deposits made by Pearce and McKee in water year 2006 after a large storm event supports the hypothesis that there is a disproportionately large bed load component to sediment transport in this channel. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (1.05 km^2), the suspended sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (4.9 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 12% of annual average total load for WYs 2000-2013. Overall, total sediment load estimates for this watershed are likely fairly accurate. The proportion of bed loads relative to total load is less accurate and would be better supported if more recent measurements were available. It is not unlikely that bed load is underestimated.

Coyote Creek

The USGS has monitored flows on Coyote Creek at Hwy 237 (11172175) for water years 1999 to present. Peak flows for missing water years between 1957 and 2003 were estimated using regression with either Coyote Creek near Gilroy (gauge 11169800) or Guadalupe River at Hwy 101/ San Jose (gauges 11169025 and 11169000). The USGS has published monthly and annual scale suspended sediment loads for water years 2004 to present with the exception of WY 2008. There are no bed load data available for any water year. Suspended sediment loads for water years 1957 to 2003 and for 2008 were estimated using a regression between measured or estimated annual peak flow and annual measured suspended sediment loads. Confidence is reasonably high in the suspended sediment estimates especially for the gauged period. Bed loads were estimated to be 10% of annual total loads based on the regional bed loads regression equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504). Confidence is much lower for bed load. No adjustment was necessary for head of tide position since the gauge site is only just upstream from the head of tide. Given the recent nature of suspended loads measurements, despite the lack of bed loads, over all there is high confidence in the estimated total loads.

Guadalupe River

The USGS has monitored flows on Guadalupe River at San Jose (11169000) for water years 1932 to 2002 and on Guadalupe River at Highway 101 (11169025) for water years 2002 to present. Comparison of data during a 12 month overlap in the operation of the two gauges indicates that the data are essentially contiguous. The USGS has published monthly and annual scale suspended sediment loads for water years 2003 to present. Monthly and annual scale bed load data are only available for water year 2005. Suspended sediment loads for water years 1957 to 2002 were estimated using a regression between monthly flow and suspended sediment and bed load developed using the 2003-2012 data making the assumption that flow at 11169000 was equivalent to measurements now being made a few miles downstream at the 101 gauge. Confidence is reasonably high in the suspended sediment estimates especially for the gauged period, and relatively lower for bed loads given only one year of monitoring in 2005 when peak flows were not remarkable. Based on these methods, bed load was estimated to be 10.7% of total load. This is not remarkably different from the estimate based on the regional bed load equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504) of 12.9%. Over all, loads estimates for Guadalupe River at Hwy 101 (gauge 11169025) are of high quality. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (12.7 km^2), the sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (5.6 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area taking into account the area upstream from reservoirs. Together this resulted in an additional 7% of annual average total load for WYs 2000-2013.

Napa River

USGS has measured flow in Napa River at Napa (gauge 11458000) from water year 1960 to present. Annual and monthly suspended sediment and bed loads have been reported by the USGS for water year 1978 only. There are no more recent measurements for suspended loads. Monthly flows at Napa River at Napa for water years 1957-1959 were estimated using a regression relation with flows in Napa River near Saint Helena (11456000). This relationship explained 97% of the variability. Suspended sediment and bed loads were estimated for the missing months from water year 1957 to 2013 using a regression relation between monthly discharge in WY 1978 and monthly recorded bed loads and total loads for the same months. The regression functions generated explained 98% and 90% of the variability in bed loads and total loads respectively when one of the bed load measurements that appeared very low relative to discharge (April 1978) was excluded from the regression function. Based on these methods, 3% of the total load was estimated to be transported as bed load. Using the regional bed load regression equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504) and the free flowing watershed area at the Napa gauge site (135 mi^2 equivalent to 350 km^2), bed load is estimated to be 11.8% of total annual load, more than triple the estimate made from observations during WY 1978. Water year 1978 was a relatively wet year (flow peaked at 15,300 cfs; a storm of between a 5 and 10-year return frequency) and the USGS did a relatively great job of making suspended and bed load measurements at quite high discharge (~7,500 cfs). Therefore, for that year, we can have relatively high confidence in the computed loads. However, given the historic nature of the suspended sediment and bed load observations and the fact that water year 1978 was a very wet year that followed two very dry years, the total sediment load estimates for this location remain only moderately certain. To rectify this issue, new sediment load observations need to be made at the gauge location for a period of about four years aiming to cover a range of climatic variability. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (4.3 km^2), the suspended sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (34.5 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 14% of annual average total load for WYs 2000-2013.

There are loads entering the Napa River Flood Control Channel downstream from the Napa River at Napa gauge (11458000) from 12 creeks (Huichica Creek, Carneros Creek, Home Hill Creek, Napa Creek, Milliken/Sarco Creek, Tulucay Creek, Napa State Hospital Creek, Suscol Creek, Sheehy Creek, Fagan Creek, North Slough, American Canyon Creek) that together add to approximately another 143 km^2. Total sediment loads from these creeks could be computed separately but has not been done.

Novato Creek

USGS has measured flow in Novato Creek at Novato (gauge 11459500) from water year 1947 to present. No sediment load measurements have been made by the USGS. Suspended sediment loads were estimated using the North Bay regional regression reported by McKee et al (2012) in the special issue of Marine Geology for sediment processes in San Francisco Bay. The North Bay regional regression was based on annual or wet season load and peak annual flow and took the following form:

SS load (metric t) = 5.3569*peak Q (m^3/s)^1.7378)

Bed loads were estimated using the regional regression (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504) and a watershed area of 17.6 $mi.^2$ equivalent to 45.6 km^2. Resulting estimate was an average of 3.8% of total load being transported as bed load. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (1.9 km^2), the suspended sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (11.1 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 31% of annual average total load for WYs 2000-2013. Overall the sediment loads for this site are deemed to be highly uncertain. To rectify this issue, a sediment monitoring program at the gauge location is recommended at least for one wet season but ideally for three or four consecutive wet season period to verify suspended and bed loads for this watershed. Based on a review of Collins, 1998 and PWA 2002, there does not appear to be any other information to support improved SS or BL estimates. These current estimates need review by local County staff as a reality check and must be considered very uncertain (low confidence).

Permanente Creek

USGS has monitored flow in Permanente Creek at Monte Vista for the short period of water years 1985 to 1987. Total sediment loads were reported for the same period; no suspended sediment and bed loads were individually reported. Monthly flows for the unmonitored period from water years 1957 to 2013 were estimated using a regression relation between the San Francisquito Creek gauge (11164500) and the Permanente gauge (11166575) which accounts for 70% of the flow variability. Total sediment loads were estimated using a regression derived from monthly measured flow for WY85-87 and measured total sediment load which was then applied to the estimate flow record. The regression only accounts for 86% of the variability and, based on a comparison of the measured versus predicted loads, appears to underestimate load by about 30% but no adjustment was made for this reason. There are no reported discrete bed load measurements so annual bed loads were estimated using the regional bed load equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504). The resulting bed load estimate is 1.7% of total load at the Monte Vista gauge location. Given the lack of measured flows, the historic nature of the reported total loads, and no recent measurements to verify these loads, confidence in loads estimates for this site are low. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (8.4 km^2), the suspended sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (24.8 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 604% (6.04-fold) of annual average total load for WYs 2000-2013. These loads estimates are very uncertain.

Pinole Creek

The US Geological Survey measured peak flow from water years 1953 to 1977 in Pinole Creek (11182100). SFEI measured suspended sediment load for water year 2004 (Pearce et al., 2005). No bed load measurements have been recorded for the watershed. Peak flow measured at San Ramon Creek at San Ramon (gauge number 11182500) by the USGS was used to estimate peak flow in Pinole Creek from water years 1978 to 2013 using a power function that explained 81% of the variability. Suspended sediment load was estimated for the full record using an East Bay specific regional regression:

SS load (metric t) = 106.89*peak Q (cms)^1.2736 (McKee et al 2013)

Bed load was estimated using a regional regression for the whole Bay Area:

BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504

For Pinole Creek bedload turned out to be an additional 2.8% of the total annual average load. County staff have suggested that our loads estimates for Pinole Creek may be too low. A comparison of the estimated water year 2004 load derived from this regression (11,909 metric t) to the measured 2004 load (9,964 metric t) shows reasonable agreement (84%). Thus suspended sediment loads estimates made from the regional regression were adopted. It is possible that the regional bed load regression is providing estimated loads that are too low for Pinole watershed. The nearest watershed where there is measured bed load is Wildcat Creek, where data collected from 1978 to 1980 showed bed load ranging between 2.1 and 3.9% of total load. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (2.23 km^2), the sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (9.8 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 41% of annual average total load for WYs 2000-2013.

San Francisquito Creek

The USGS has monitored upstream flows on San Francisquito Creek (gauge number 11164500) for water years 1957 to present. The USGS has published annual scale suspended sediment loads for water years 1962 to 1969. Bed load data have been reported by the USGS for the same period. Suspended sediment loads for water years 1957 to 2013 were estimated using a regression between annual flow and annual suspended sediment loads. This regression relation accounted for 93% of the variability and was preferred (for this site) over the relationship between peak flow and annual suspended sediment loads (which have been more universally accepted and applied (McKee et al., 2013)) due to peak flow only explaining 81% of the suspended sediment variation. Bed load was estimated based on review of the NDC (2010 report). Bed load estimates were based on the sum of bed load from the two main tributaries of San Francisquito Ck (Los Trancos and Bear) downstream from the Searsville Lake dam and the assumption of no sediment flow through the dam. This estimate is about half the estimate from the historical rating based on the work of Porterfield for gauge 11164500. There are two issues that are highlighted in the NDC text (pages 6, 10, 11, and 12). 1. There is evidence from recent sampling (Balance Hydrologics Inc.) that the rating curve has not functionally changed, and 2. That their long term estimate was developed by applying an instantaneous rating curve to daily average flow. The second issue is fundamentally flawed and would cause a low bias in sediment loads estimates even though they thought they were staying consistent with Porterfield, 1980 and Brown and Jackson, 1973. This issue was discovered partly because of the disparity between earlier data in NDC (2010) Table 3-2 (data for 1962-69) which agree with the Brown and Jackson rating and later data in NDC (2010) Table 3-2 for 1964-1998 which appear to be about 3/4 of the data based on the same rating. BL was reported by NDC 2010 to be 13% based on their deductive reasoning around the Porterfield data. This is slightly higher than the best professional judgement quoted by Balance Hydrologics Inc. of 10%; 13% was adopted. Using the regional bed load equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504) a bed load estimate of 4.4% can be derived using the free flowing area of the watershed at the 11164500 gauge. Overall, the estimates of suspended load for San Francisquito appear reasonable given support for the historic rating curves by sampling in the 2000s by Balance Hydrologics. Bed load estimates appear highly uncertain. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (6.3 km^2), the sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (12.2 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area taking into account the area upstream from reservoirs. Together this resulted in an additional 23% of annual average total load for WYs 2000-2013.

San Leandro Creek

No measurements of either flow or sediment loads have been made by the USGS in San Leandro Creek. However, a field program for measurement of flow and suspended sediments was carried out from water year 2012 to 2014 in support of characterizing concentrations and loads of a suite of trace pollutants (Gilbreath et al., 2015). Monthly flows and suspended sediment loads from this effort were climatically extended using a regression between measurements made in San Leandro Creek and long term measurements of monthly flows made in Dry Creek at Union City a few miles to the south. Bed load was then estimated using the regional bed load equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504) and the free flowing watershed area at the San Leandro measurement site (San Leandro Blvd) (3.44 mi^2 equivalent to 8.9 km^2). Bed load was estimated to be 1.6% of total annual load. This may be a low estimate for this site given that the area upstream from the gauge drains the low East Bay hills and given the loose and abundant bed sediment on the bed in the channel at San Leandro Blvd. Thus, we have low confidence in the bed load estimate but given recent actual measurements of suspended load (albeit for a short period), we have moderate confidence overall in the total sediment load for the watershed. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (2.1 km^2), the suspended sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (1.2 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 28% of annual average total load for WYs 2000-2013.

San Lorenzo Creek

The USGS has measured monthly and peak flow in San Lorenzo Creek at San Lorenzo for water years 1968 to 1978 and from water years 1988 to present. Flows have been measured at San Lorenzo Creek at Hayward for water years 1957 to 1983, and 1998 to 2013. Flows have also been measured at San Lorenzo Creek above Don Castro reservoir for water years 1981 to 1994 and for water years 1998 to 2013. Monthly and annual suspended sediment loads have been measured by USGS for water years 1990 to 1993 and 2009 to 2013. Bed load data is only available for the earlier period. Regression equations between flow and sediment loads were developed using monthly data. Missing monthly flow was estimated using a regression between monthly San Lorenzo Creek at Hayward or San Lorenzo Creek ab Don Castro reservoir (4/83-9/87 only) and flow at San Lorenzo Creek at San Lorenzo. Total sediment and bed load was estimated using a regression between monthly measured flow for WYs 90-93 and measured total and BL sediment load. Given the regression equations between monthly flow and total load and bed load only explained 80% and 55% of the variability respectively, it is very likely that the total load estimates are biased low by as much as 35%. No upwards adjustment was attempted for this theoretical bias. Based on these methods, bed load as a function of total load equated to just 1.7%, less than the 6.4% that would be predicted using the regional bed load equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504). No adjustment of loads were necessary since the head of tide is very near the lower gauge location. Overall, loads for this location are deemed to be relatively accurate. Improvements could be made by further measurements of bed load data.

Sonoma Creek

USGS has measured flow in Sonoma Creek at Agua Caliente (gauge 11458500) from water year 1956 to 1981 and 2002 to present. Annual suspended sediment loads have been reported by the USGS for water years 1956 to 1962. There are no more recent measurements for suspended sediment loads and no bed loads have ever been measured. Peak flows were estimated for the missing record between water year 1982 and 2001 using a regression relationship between peak flow at Napa, Napa River (gauge 11458000) and peak flow at the Sonoma gauge (11458500). Flow at Napa explained 89% of the variability of the Sonoma gauge. Annual scale suspended sediment loads were estimated using a regression between peak flow (either measured or estimated) and annual scale suspended sediment loads for the observational period. Peak flow at the Sonoma gauge explained 78% of the variability of annual scale sediment load at the Sonoma gauge. This regression function was used to estimate sediment loads for the unmeasured period between water year 1957 and 2013. A comparison between mean of measured loads and the mean derived from loads estimated using the regression appears to be biased about 28% low. Bed loads were estimated using the regional bed load regression equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504). Using this equation and the area at the Sonoma gauge site (58.4 mi^2 equivalent to 151.3 km^2), bed load is estimated to be 7.4% of total annual load. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (4.4 km^2), the suspended sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious area (83.7 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 28% of annual average total load for WYs 2000-2013. Given the historic nature of the suspended sediment observations and the lack of bed load information, the total sediment load estimates for this location remain moderately uncertain. To rectify this issue, new sediment load observations including some bed load measurements need to be made at the gauge location for a period of about four years aiming to cover a range of climatic variability.

Sunnyvale East Channel

No measurements of either flow or sediment loads have been made by the USGS in Sunnyvale East Channel. However, a field program for measurement of flow and suspended sediments was carried out from water year 2012 to 2014 in support of characterizing concentrations and loads of a suite of trace pollutants (Gilbreath et al., 2015). Monthly flows and suspended sediment loads from this effort were climatically extended using a regression between measurements made in Sunnyvale East Channel and long term measurements of monthly flows made in nearby Saratoga Creek (Gauge 11169500). This resulted in an annual average yield of 25.4 t/km^2 which was applied to the watershed area at the head of tide. Bed load was then estimated using the regional bed load equation (BL:Total load% = 0.4689*Area (km^2)^0.5504) and the free flowing watershed area at the Sunnyvale East Channel at the head of tide (17.2 km^2). Bed load was estimated to be 2% of total annual load. This makes reasonable sense for this location given no large bed sediment bars or other features are visually present. Thus, given recent actual measurements of suspended load (albeit for a short period), we have high confidence overall in the total sediment load for the watershed. No adjustment for head of tide was necessary.

Sunnyvale West Channel

No measurements of either flow or sediment loads have been made by the USGS in Sunnyvale West Channel. We are not aware of any other field program of measurement. Given the similarity of size and land use between Sunnyvale East and West channels, suspended and bed loads estimates were made by scaling Sunnyvale East load estimates by an area ratio, thus loads in the west channel are estimated to be 42% smaller than the East channel. Given relatively recent measurements in the east channel, we have moderate confidence in loads estimates done this way. We performed a quick aerial photo “Google Earth” review of the watershed and channel characteristics to check these assumptions were reasonable.

Walnut Creek

Peak flows were measured and reported by USGS at Walnut Creek at Walnut Creek (11183500) and a little further downstream at Walnut Creek at Concord (11183600) during water years 1957 to 1992 and then again for one year in water year 1997. Suspended sediment loads estimates were completed by the USGS for water years 1966 to 1970 based on a rating curve that was developed from data collection from 1957 to 1962; neither the original data nor loads estimates for water years 1957-1962 have been obtained. There are no more recent sediment records. Flow data measured at Walnut Creek at Walnut Creek for water years 1957 to 1968 were adjusted up by 7.6% to be consistent with the gauged record for the latter period at Concord. Flow estimates for the unmeasured period water year 1993 to 2013 (with the exception of 1997) were estimated based on a regression relation with continuous data collected at San Ramon Creek at San Ramon (gauge number 11182500) that explained 85% of the variability. Suspended sediment collected during the 1957-62 water years at Walnut Creek at Walnut Creek were collected for a discharge range between 1.0 and 2180 cfs, with particle-size distributions determined for nine selected samples to determine the percentage of sand, silt, and clay. A sediment-transport rating curve was developed but is not considered well defined because samples were not collected over the entire range of streamflow. During November and December of 1970, four SS samples were collected at the Walnut Creek at Concord gauge further downstream at discharges between 200 and 500 cfs; although concentrations were lower, there was not sufficient evidence to indicate a trend although that possibility could not be ruled out. Disregarding Porterfield's recommendation for more sediment measurements, no additional data were collected. Suspended sediment loads were initially estimated (during this current work) using a regression relation between peak annual flow for each water year at the Concord gauge (either measured or estimated) and annual scale sediment loads assuming 15% bedload. The regression relation described 99% of the variability in suspended sediment loads largely because the loads from 1966 to 1970 were developed by rating curve with flow. The situation is not very satisfactory and upon discussion with County staff and review of the USACE (2012) report, it was decided to use the rating curves that resulted from the "computational analysis" that was based more on circumstantial evidence and engineering judgment in addition to field measurements of bed texture for predicting volumes of sediment. In the USACE (2012) modeling work, sediment inflow was used as a primary calibration parameter. The result was a downward adjustment of the estimated sediment loads by an average of 33%. The methods result in an annual average suspended sediment load of 157,000 metric t which is 57% greater than the estimate made by McKee et al. (2011) of just 100,000 metric t per year that was based on combining a very small single storm data set collected in WY 2011 with a climatically averaged flow estimate for WYs 1971-2000. These loads are also much greater (1.75-fold) than estimates provided by McKee et al (2013) of just 74,500 metric t (WYs 1995-2010) that used a different (sub-regional) method to estimate discharge and the rating curve generated from the USGS 1966-1970 annual loads estimates. The average bed load contribution based on the USACE model was estimated to be 19% (1973-2012). This is 54% greater than the 12.3% average estimate that can be made from the regional bed load regression equation (BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504). However, at this time there are no other data or methods available to make improved estimates. Overall, we deem the current sediment loads estimates for this watershed to be of low to moderate quality. Further flow and sediment load data collection during 3-5 water years capturing at least a 1:3 year return storm would provide enough evidence for either verifying or adjusting the existing rating curves.

Wildcat Creek

Peak flow in Wildcat Creek has been measured for water years 1976-1997 by the USGS. The USGS measured total load for water year 1977 and suspended load and bed load for water years 1978 to 1980. Peak flows for water years 1957 to 1975 and for 1998 to 2013 were estimated using a regression relationship between peak flows in San Ramon Creek at San Ramon (gauge number 11182500) and Wildcat Creek at Vale Road. The regression relationship described 71% of the variation. Estimated suspended sediment loads were computed based on a regression relation between monthly flows either measured or estimated (using San Ramon data) and measured loads. The estimated relationship between bed load and suspended sediment load was estimated from the regional regression (2.5%):

BL:Total load% = 0.4689*Free Flowing Area (km^2)^0.5504

Since there are no recent data for the watershed, and data were collected during relatively dry years (except 1980 which was about a 1:3 year storm for other gauges in the region), it seems possible that the estimated loads are too low. However, the estimated long-term average loads appear to be reasonable relative to 1980. In addition, greater efforts have been made since the late 70s to manage erosion and reduce sediment erosion in the Wildcat watershed (Collins, 2000). In addition, the estimated annual average long-term load is less than the measured load – thus at least the regression estimator has not caused a climatic adjustment of the loads outside the realm of possibility. Collins (2000) estimated a total sediment yield for the long term (post European contact period) of 3,500 tons/mi^2/y equivalent to 27,000 ton/y at the gauge site (area = 7.79 mi^2) based on geomorphic field observations of erosion across the entire watershed and assumptions about transport, storage and bulk density. The Collins estimate is close to the annual average estimate for period 1957-2013. The loads thus estimated were deemed acceptable and likely quite accurate. The final load estimate was then adjusted for the area downstream from the gauge and upstream from head of tide by two methods. For the impervious area (2.53 km^2), the sediment load was estimated using the average of Bay Area urban sediment loads (40 t/km^2). The SS and BL estimates for the pervious areas (1.53 km^2) between the gauge and the head of tide were then made but scaling up the respective SS and BL loads at the gauge by a factor of additional pervious area. Together this resulted in an additional 9% of annual average total load for WYs 2000-2013.

Other Creeks

We estimated sediment loads for the remaining 16 flood control channels included in this study (Alhambra Creek, Rodeo Creek, San Pablo Creek, Lion Creek, Old Alameda Creek, Adobe Creek, Calabazas Creek, Lower Penitencia Creek, Matadero Creek, San Thomas Aquino Creek, Stevens Creek, Belmont Creek, San Bruno Creek, Coyote Creek Marin, Gallinas Creek, and Petaluma River) using a consistent method. For each channel, the long term annual average total load estimate was generated using a two-part method:

a) For the impervious area of each watershed, the average annual suspended sediment loads were assigned a rate of 40 metric t per square km (40 t/km^2) of impervious area. The estimate of 40 t/km^2 was derived from the average of Regional Monitoring Program (RMP) studies on suspended sediment loads on Guadalupe River (the urban portion between the Hwy 101 and Almaden expressway gauges), San Leandro Creek (downstream from the reservoirs), Pulgas Creek Pump Station south watershed, Zone 4 Line A watershed, Sunnyvale East Channel, and the watershed of North Richmond Pump Station). These studies represent the best data locally on suspended sediment loads in highly urbanized watersheds and indicate a relatively consistent sediment production rate of between 21-61 t/km^2 for Bay Area urbanized systems.

b) For the pervious (non-urban) portion of the watershed, total loads (suspended + bed load) were estimated based on a regional regression between land area and total sediment load developed from the local empirical data. The empirical data for 16 systems in the Bay Area was climatically averaged before developing the area-load relationship. The equation for the average annual total load estimate was: Total average annual load (tons) = 1045.8* area downstream from reservoirs^0.7594.

This method was superior to other scaling methods since it takes into account the very different nature of sediment production between urbanized areas of watersheds that are very highly managed for erosion and where sediment production is associated with buildup-wash-off processes and sheet erosion and pervious portions of watersheds that may have sediment production from multiple processes including landslides, debris flows, bed and bank erosion, and as well are more generally sheet erosion. Given the unique ratio of pervious to impervious area in each watershed, the method provides a unique estimate of sediment production that goes beyond the estimate that would otherwise be derived from applying a single regional regression equation.

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