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Small Tributaries Pollutants of Concern Reconnaissance Monitoring: Loads and Yields-based Prioritization Methodology Pilot Study

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Preface

This is one of two companion reports that were prepared. A second report prepared by Jay Davis and Alicia Gilbreath was focused on the use of congener patterns for identifying areas of potential high leverage. That report was titled “Small Tributaries Pollutants of Concern Reconnaissance Monitoring: Pilot Evaluation of Source Areas Using PCB Congener Data”. It can be downloaded at https://www.sfei.org/documents/small-tributaries-pollutants-concern-reconnaissance-monitoring-pilot-evaluation-source

Acknowledgements

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Executive Summary

Watershed yields (mass exported per unit watershed area) can be used as an indicator variable to help identify watersheds or source areas of higher management interest in relation to mass loads that impact the Bay. When prioritization includes an analysis of uncertainty, a recommendation can also be made for priority investigations necessary to reduce uncertainties. A method is presented for generating comparable yield estimates for small industrial watersheds where only a single storm has been sampled and for which a watershed boundary has been generated. The method generates standardized storm-based yields for each sampled site for a 0.5-year annual return frequency storm with 2-hour peak rainfall intensity.[1] No attempt has been made to estimate annual average yields (the metric upon which the TMDL was based). The method entails four steps:

1. Estimate storm runoff volume in the sampled watershed
2. Compute estimates of storm load for the sampled storm
3. Adjust estimates of storm load to a standard sized storm
4. Normalize standardized storm loads to the watershed area of interest to generate storm yields

This stepwise method was developed using data from Santa Clara County (generally) as a case study with a focus on nested sites within the Guadalupe River watershed. Based on this new method, relative watershed prioritization was estimated and estimates of leverage in relation to total watershed area and yields were developed and discussed.

Given the small nature of the pilot study, it is meant primarily to be a demonstration and proof of concept. Further development and testing in a greater number of areas with a wider range of conditions is needed. Suggested priorities for further work include a more thorough comparison of the results of this new method and previously used simpler prioritization metrics such as water concentration or particle ratio (a surrogate for PCB concentration on suspended sediment), and comparison of the results to the new congener profile-based method that was developed in parallel and described in the companion document.

[1] The yields are intended to support comparisons between sites for management consideration. If annual average yields are desired, the use of locally calibrated dynamic simulation models such as SWMM or HSPF that are being developed by stormwater programs to support reasonable assurance analysis (RAA) is recommended. Such models are being used to generate a baseline annual average load for WY 2002 (deemed a typical average year) and therefore would, by default, provide an estimate of yield for any spatial scale for a watershed or subwatershed within the calibration space.

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Introduction

The San Francisco Bay polychlorinated biphenyls (PCBs) total maximum daily load (TMDL) control plan called for implementation of measures to reduce PCBs loads entering the Bay via stormwater (SFBRWQCB, 2007). The most recent San Francisco Bay Regional Water Quality Control Board (Regional Water Board) Municipal Regional Stormwater Permit (MRP) places a focus on identifying watersheds, source areas, and source properties that are potentially most polluted (SFBRWQCB, 2015). To support this focus, a stormwater characterization monitoring program was implemented in water years (WYs) 2015, 2016, 2017, and 2018 (Gilbreath et al., 2018) and is continuing in WYs 2019 and 2020 whereby a time-weighted composite sample is collected during a single storm at sites of interest and analyzed for PCBs, suspended sediment concentration (SSC) and other pollutants. The method assumes that a concentration or particle ratio measured during a single storm is representative[2] of the general character of that watershed in relation to sources, transport processes, and mass loadings.

While cost effective, interpretation of the data collected through this sampling program to identify watersheds of high management interest has been challenging due to differing storm characteristics (intensity, duration, antecedent rainfall conditions) and the interplay with differing PCB source characteristics which has confounded comparisons between watersheds. Although concentration measured during a single storm for a given site does not strongly relate to the long-term annual average concentration for that site[3], across many sites there is a general relationship between storm event mean concentration (EMC) for a random storm and the true watershed character. Thus, when many sites are compared, we can make predictions from just one storm EMC to classify a site's long-term mean concentration into a low, medium, or high category. The most recent report (Gilbreath et al., 2018) compared data based on concentrations and particle ratios (the ratio of total PCBs to SSC) from 79 sites.

Although these prioritization methods have proved sufficient for helping to identify a number of high concentration sites for management consideration, they are less well suited to provide guidance on how to manage watersheds exhibiting low or moderate concentrations. These watersheds may contain relatively polluted patches of land within them and may deliver substantial loads to the Bay. Here we present a yields based ranking method that adjusts for storm size and land-use dilution factors to provide a robust alternative to ranking based on concentration and particle ratio alone. This report outlines the development of a yields-based ranking method and applies it to a pilot watershed area draining to South San Francisco Bay.

[2] The peer-reviewed literature is replete with studies that describe data from dry-weather flow, a few storms, or a partial year (a few months to 9 months of weekly sampling or monthly sampling), and the use such data to support management or policy decisions not always with the level of extreme care that the data representativeness should have caused.

[3] Event mean concentration for a single storm for a single site may vary substantially between storms by at least 10-fold for most pollutants in relation to storm specific source-release-transport processes that generate mass load and a different set of processes that convert rainfall into storm runoff volume that dilutes that load into the concentration we observe (pollutant mass released / storm volume = concentration observed).

Methods

Converting an observed EMC of PCBs usually reported in ng PCBs per liter into a yield of PCBs for a watershed area of interest for a standard sized storm event requires four general steps (Figure 1):

1. Generate an estimate of storm runoff volume in the sampled watershed
2. Combine the EMC with the storm volume to estimate the storm load for the sampled storm
3. Adjust the estimates of storm load to a standard sized storm
4. Normalize standardized storm loads to the watershed area of interest to generate storm yields

Step 1. Estimate storm runoff volume

Given no flow measurements were made within the reconnaissance-style field monitoring program, to estimate mass load, storm volume was estimated using an estimate of storm rainfall combined with the runoff coefficients from the latest calibration of the Regional Watershed Spreadsheet Model (RWSM: Wu et al., 2017).

Step 1a. Attain an estimate storm rainfall

Because there are no rain gauges at the majority of sampling sites, estimates of storm rainfall were made by extrapolating rainfall data from the available network of gauging stations. Storm rainfall data can be obtained from various sources, including local agency observation networks (city, county, and stormwater agencies), official NOAA cooperative rainfall observation sites, Remote Automated Weather Stations (RAWS), and Weather Underground observation sites (a San Francisco based company that collates a growing national network of crowd sourced data from a pre-approved list of vendors[4]). Wherever possible, reliable 15 minute data from the gage in closest proximity to the sampling site is preferential. Data were obtained at 15-minute resolution to allow for accurate estimation of storm volume for the sampled period (defined as two hours prior to the start time to the end time of the composite sample)[5] and peak 2-hour rainfall intensity for the storm (needed for the subsequent step of standard storm size normalization procedure described in detail below). Given the microclimates of the Bay Area, a nearby rain gauge several kilometers away may not be representative of rainfall for the sampled site. To adjust the rainfall up or down, data obtained from the nearest rain gauge were adjusted by the ratio of the 1-year return 2-hour rainfall at the sample site to the 1-year return 2-hour rainfall of the nearest rain gauge site using the NOAA 14 atlas (Perica et al., 2014)[6]. For an example of the adjustment, see Appendix 1.

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[4] There is no guarantee of data quality. These data and any weather data from any source should always be checked for quality for interstation-comparisons.

[5] For all watershed areas less than a few square kilometers in area, two hours should suffice but the time before the storm that rainfall and runoff should be counted for and the rainfall gap that is allowable within storm is estimated to be about two hours plus an additional 15 minutes for each additional 5 km^2.

[6] Note, a third source of data that has recently become available called "San Francisco Bay Area Climate-Smart Watershed Analyst - Beta Release" which was not evaluated but could be in the future. https://geo3.pointblue.org/watershed-analyst/index.php

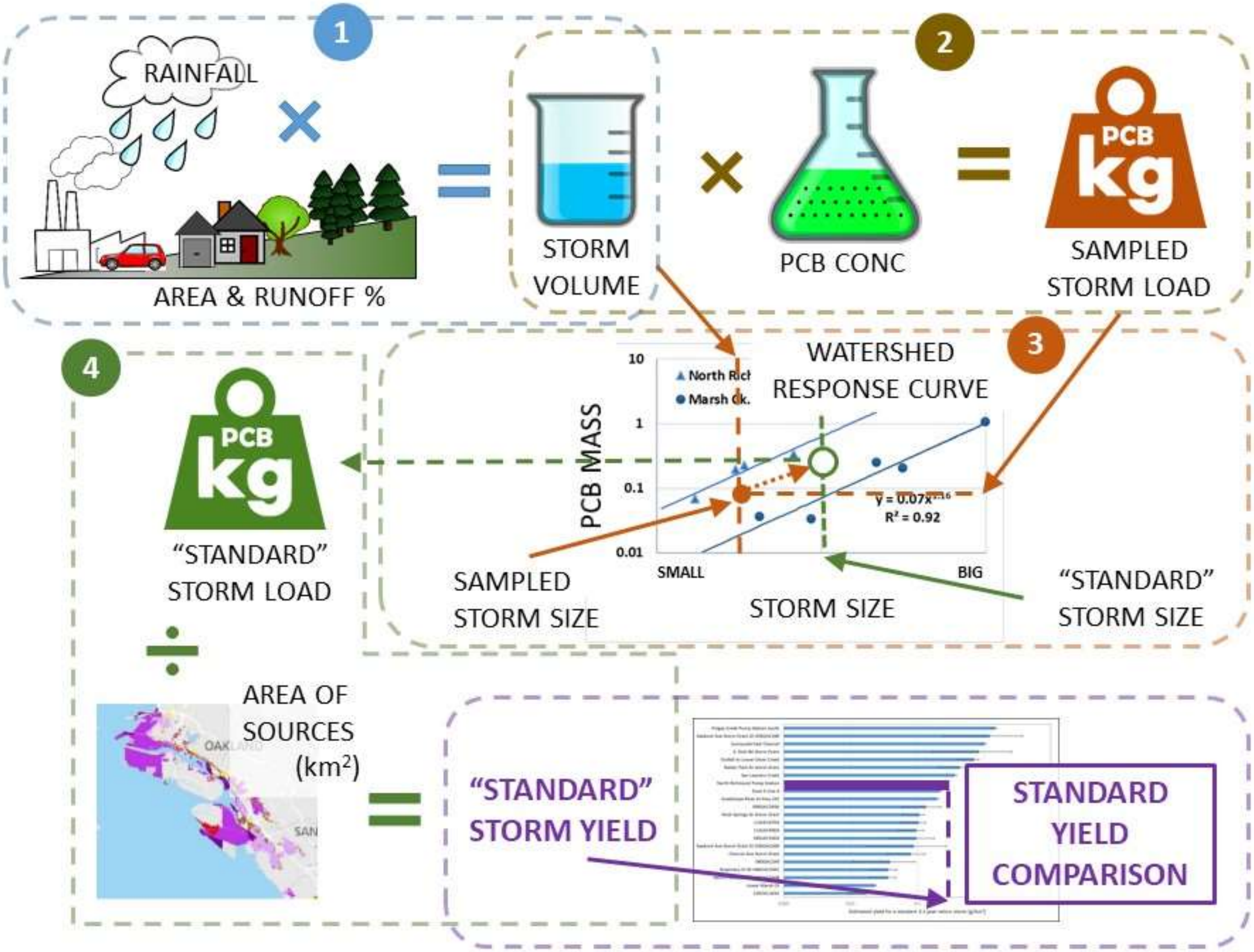

Figure 1. Conceptual model of the four steps used to generate standard yields.

To estimate uncertainties associated with the rainfall data adjustment factor, an equation that relates residual error to distance was derived (Figure 2). This was done using 10 rain gauges operated by the Santa Clara Valley Water District (see Appendix 2) and rainfall data for WY 2017 that included 10 storms ranging in duration from 4-12 hours (at the City of San Jose gauge) and ranging in magnitude from 0.12-0.84 inches (at the City of San Jose gauge). This method of determining error can be expanded to rain gauges located in the rest of the Bay Area in the future, but given the microclimates around the Bay, it is likely that three or more unique relationships may be appropriate. Based on this current pilot application for the South Bay, the uncertainty for rainfall estimates appear to range between an average of +/- 2.3% at 2 km to +/- 18% at 15 km and are described by the following equation:

Rainfall uncertainty (%) = 1.17 x distance (km)

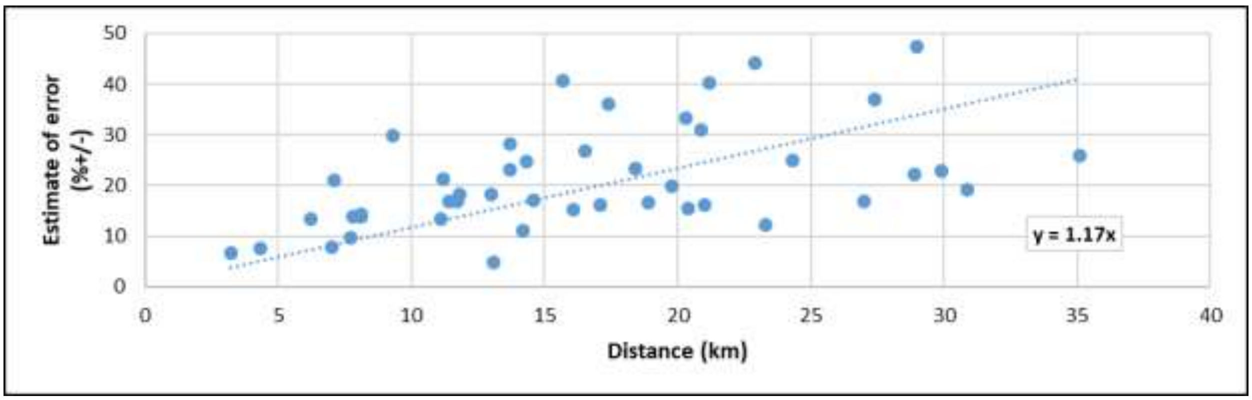

Figure 2. Relationship between the uncertainty of extrapolating rainfall from a local gauge site to a monitoring location of interest and the distance between.

Step 1b. Estimate storm volume

Once rainfall was estimated, it was combined with a runoff coefficient for each watershed of interest using the RWSM (Wu et al., 2017). The strength of this approach is that the RWSM can be used by anyone to generate a runoff coefficient (the % of rainfall that runs off a landscape) for any chosen watershed area in the Bay Area. The RWSM is regional in scale, easy to use, and of compatible sophistication with concentration data which is mostly available for only one storm. Despite the many strengths of the RWSM, the main weakness is a lack of accountability in the known variability of the ratio between rainfall to runoff between storms due to variations in storm size, intensity, and antecedent moisture conditions. This was evaluated by comparing the measured flow data from well-sampled watersheds (McKee et al., 2015) with volume estimates for storms generated from combining the average RC output from the latest calibration of the RWSM with the storm rainfall for the sampled storms. The measured and predicted runoff volumes were highly correlated (R^2~0.8, Figure 3A); however, the RWSM appears to overestimate individual storm runoff for small impervious watersheds by an average of 23%. The standard error of the prediction is 0.022 or +/- 42% of the mean measured runoff. It is logical that the bias and errors are larger than the original model (mean bias of -1%, a median bias of -5% and an estimated error range of +/- 25% (Wu et al., 2017)) because the RWSM was calibrated to average conditions in a mix of watersheds. As such, the RWSM tends to underestimate flow in larger mixed land-use watersheds and overestimate flow in smaller impervious watersheds. Uncertainty was also evaluated in relation to potential bias associated with antecedent rainfall and soil moisture (Figure 3B). There was no significant relationship observed ($p > 0.05$), indicating no seasonal effects for these smaller, well-sampled watersheds that were used in this analysis.

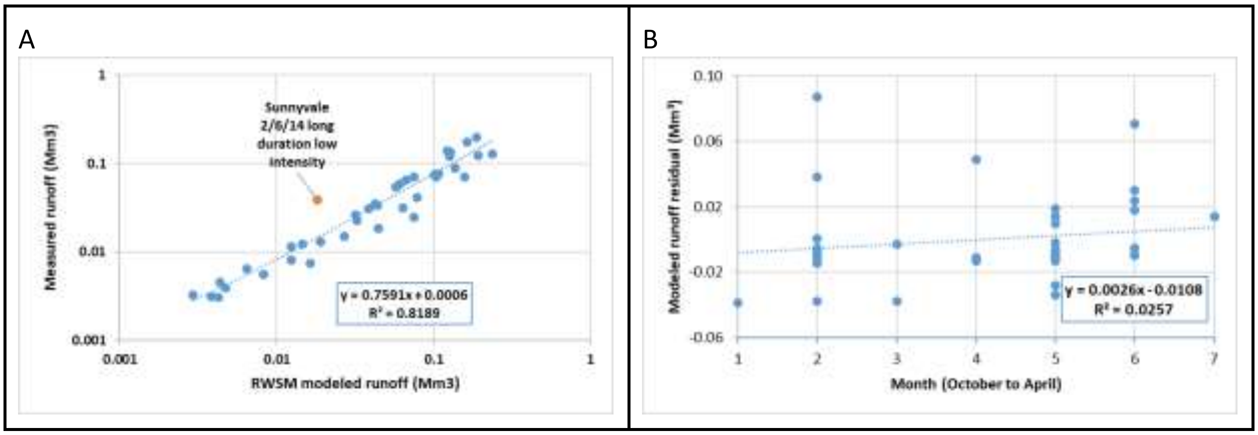

Figure 3. Uncertainty associated with using the Regional Watershed Spreadsheet Model (RWSM) (Wu et al., 2017) to generate estimates of runoff volume from combining storm-specific rainfall with RWSM runoff coefficients and watershed area (note the log-log display scale, while using linear regression on untransformed data). Measured flow data were from a subset of well-sampled watersheds (North Richmond Pump Station, San Leandro Creek, Zone 4 Line A, Sunnyvale East Channel, and Pulgas Creek Pump Station South). Guadalupe River and Marsh Creek were not used because they are large with mixed land-use and not representative of the small impervious watersheds that are of interest.

Step 2. Compute the storm load

Once the runoff volume has been estimated, the available EMC data measured during the sampled storm(s) can be used to estimate a storm load. Given first flush and overall concentration variability during storms, the gold standard for EMCs are those that have been captured using a flow-weighted composite methodology with many small sub-samples collected over a whole storm. However, the majority of the EMC data available were based on time-paced composites (Gilbreath et al., 2018) because the additional costs of flow measurement were deemed incompatible with the need for rapid and nimble decisions on where to sample during any given storm (McKee et al., 2012).

To estimate the size and bias of this uncertainty, EMCs generated from the load computations made at well-sampled watersheds[7] were compared with simple time-based EMCs computed for those same storms (Figure 4). Based on the graphical analysis, 99% of the variation in our best estimate of "real" EMCs derived from surrogate load computations can be explained by the EMCs derived from time-weighted samples. The standard error of the prediction was 2,300 pg/L, computed to be 14% at the median time-weighted EMC and just 7% of the mean EMC of the storms evaluated for this subset of well-sampled watersheds. Thus, using the EMC from time-paced composite samples to calculate storm loads was deemed reasonable.

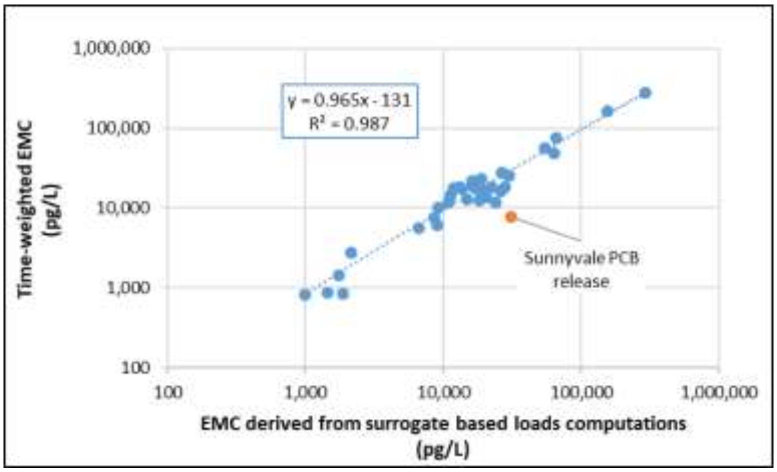

Figure 4. Comparison of time-paced event mean concentrations (EMCs) and flow-paced EMCs for our well-sampled storms (at least two rising and falling stage samples) in our well-sampled watersheds. The analysis excluded storms from Pulgas Creek Pump Station South which were extreme outliers. Note the log-log scale to allow for viewing of some of the smaller numbers but the use of linear regression in the equation.

Step 3. Adjust the storm load to a standard storm

A key challenge when comparing storm loads among sites is associated with the differing magnitude, frequency, and duration characteristics of the sampled storms. To address this, comparisons of storm loads among sites was done by adjusting storm load to that of a standard storm, similar to the unit hydrograph approach for rainfall. This was done rather than taking the simpler approach of a linear adjustment to rainfall because the relation between storm loads and rainfall follows a power, rather than linear, function that is site specific (McKee et al., 2017). There are three parts to adjusting the measured storm to a standard storm. The first involved developing a relationship between storm load and return frequency of rainfall for each well-sampled watershed to produce a set of raw adjustment

[7] Marsh Creek at Brentwood, North Richmond Pump Station at Gertrude Ave., San Leandro Creek at San Leandro Blvd., Zone 4 Line A at Cabot Blvd. Guadalupe River at Hwy 101, and Sunnyvale East Channel at Ahwanee Ave. Pulgas Creek Pump Station South was excluded from this analysis due to data being extreme outliers.

factors. The second involved relating these regression slopes (the raw adjustment factors) to land-use so that a user can determine the adjustment factor for any other watershed with specific land-use characters that differ from the well-sampled watersheds. The third and final step was to decide upon the defining characteristics of a standard storm.

Step 3a. Estimating the raw adjustment factors

The raw adjustment factors are the regression slopes (the power function equations) that form when rainfall is related to load for each well-sampled watershed. The objective of this step is to determine the power function equations for our well-sampled watersheds. This was done by relating storm load and rainfall storm return frequency. Storm return frequency[8] was based on partial duration[9] data from the NOAA 14 Atlas (Perica et al., 2014). The relationships were based on the return frequency of peak 2-hour rainfall intensity because the results of a Pearson correlation analysis suggested peak 2-hour rainfall during a storm was an adequate predictor of loads for smaller watersheds. The resulting graphical relationships between the annual return frequency of 2-hour peak intensity rainfall and load for the well-sampled watersheds (Figure 5) indicated that larger loads were generally observed during storms with a longer annual return frequency (i.e., higher rainfall).

The Pulgas PS South watershed did not fit the pattern of longer annual return frequency generating larger load. At Pulgas PS South watershed smaller storms (2-hour peak intensity annual return frequency < 0.4 years) had larger loads than larger, less frequent storms. Although difficult to explain from hydrologic theory, this suggests that Pulgas Creek PS South may have a rate-limited ongoing PCB source – e.g., a point source that is easily depleted during early season small storms and diluted by larger or later flows. It is also possible that the negative regression slope is an artifact of the small number of samples collected.

Step 3b.

The next step was to develop a defensible way of choosing which adjustment factor to adopt for any given site. This was explored for the well-sampled watersheds using land-use and source-area data. Raw land-use and source-area data as a percentage of watershed area were used in the analysis, in addition to the parameter groups used in the RWSM (Wu et al., 2017). Each land-use parameter combination was regressed against the regression slopes displayed in Figure 5. The two RWSM land-use parameters with the highest yield coefficients (Old industrial + Source Areas, and Old Commercial +

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[8] The number of occurrences of a storm of a given size (defined by both magnitude (amount of rainfall) and duration (the period over which the rainfall occurs, usually hours) in a period of years. For example, a return frequency of 1:1 means 1 storm of the prescribed size per year. A return frequency of 1:2 means 1 storm of the prescribed size every 2 years.

[9] Partial duration refers to the data collation that was used to determine the storm rainfall frequency analysis that is displayed by default in the NOAA 14 Atlas (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html). The partial duration series is a collation of all rainfall data from discrete storms larger than some arbitrary base magnitude such as smallest annual maximum for a given gauge. A user can choose the annual series (which is based on annual maximum storm rainfalls) from a drop down menu on the NOAA web site, but this is not what we have used in this report. There is a relationship between the two measures of return frequency but the partial series is usually considered more accurate for defining smaller events.

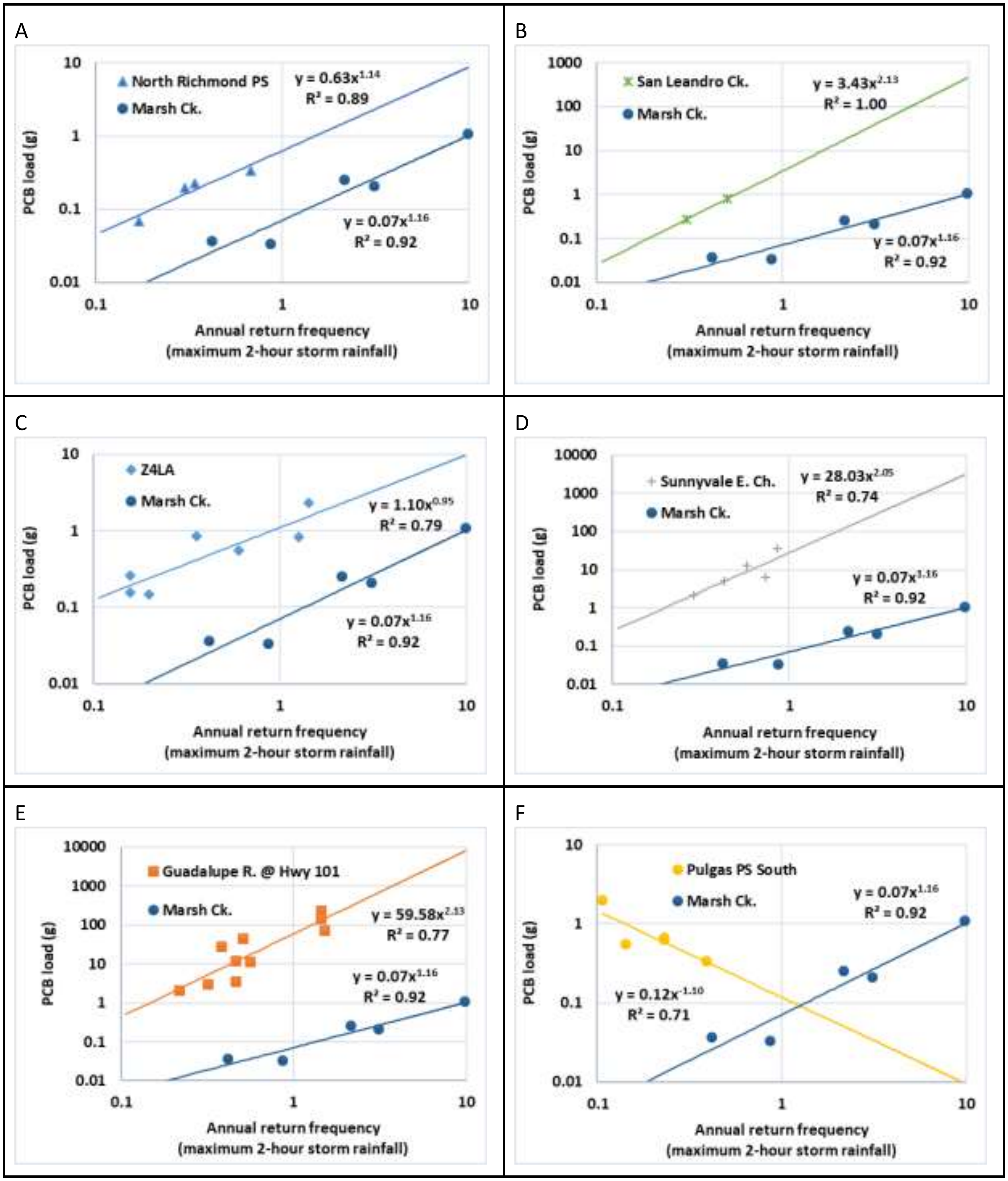

Figure 5. Relationships between rainfall annual return frequency (based on partial duration – see foot note 9) and measured storm loads in well-sampled Bay Area watersheds; each watershed is compared to Marsh Creek, the watershed with the lowest measured annual average yields as a baseline for comparison. Note also that just two well-sampled storms were available in the San Leandro watershed.

Old Transportation), when grouped together, were the best predictor of the adjustment factors (Figure 6). This land-use relationship was used to adjust sampled loads to a standard storm load in less-well-sampled watersheds. The standard error of the prediction is 0.70 or +/- 56% of the mean regression slope (the adjustment factor).

However, two well-sampled locations (Marsh Creek and San Leandro Creek) did not fit this relationship. Marsh Creek, with just 10% impervious cover all in the downstream area and 77% in open space and agricultural land-use, is an outlier from a land-use perspective and samples would have been much more drought-affected during WYs 2012-2014 than samples from more urbanized watersheds. Even though San Leandro Creek fits into the well-sampled group in terms of sample numbers, there were only two storms that had two samples taken on both the rising and the falling stage of the storm hydrograph. Thus, San Leandro Creek may be an outlier due to too few well-sampled events to adequately define a regression equation.

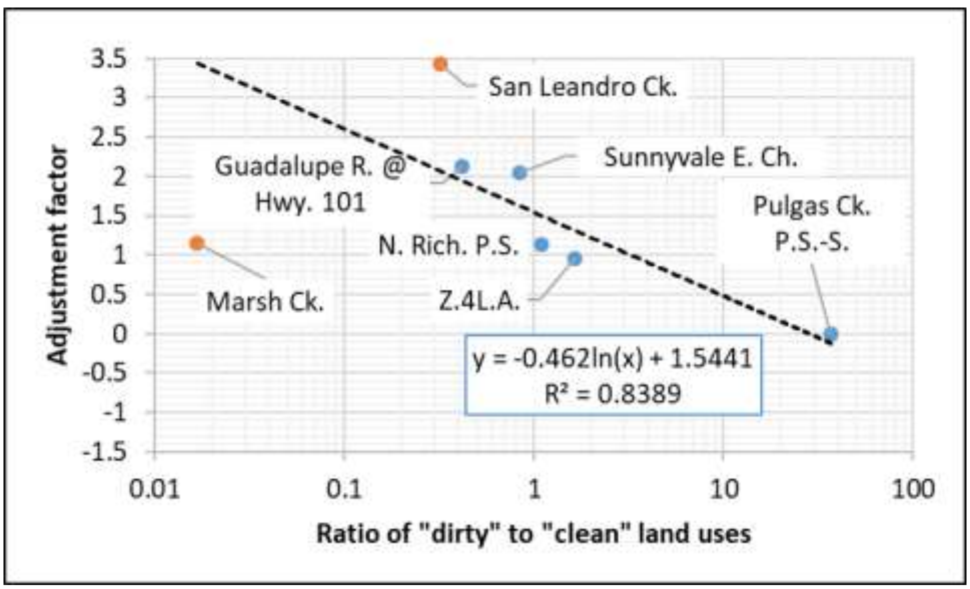

Figure 6. Estimation of the adjustment factor (regression slope) based on land-use. The RWSM land-use and source-area classes were used to define "dirty" land-uses and source areas[10] and "clean" land-uses[11] based on the Regional Watershed Spreadsheet Model (RWSM) (Wu et al., 2017). The regression slope of the relationship between the annual return frequency of the2-hour peak rainfall intensity and measured storm loads for Pulgas Creek PS South was zero.

[10] RWSM parameters in the "dirty" potentially PCB-contaminated land use and source area group: Old industrial, Old Transportation, Old Commercial land use, Rail Transportation, Recycling for Drums, Air Transportation, Electric Power, Military, Electric Transfer, and Oil Refineries source areas.

[11] RWSM parameters in the "clean" lesser potentially PCB-contaminated land use and source area group: Open Space, Agricultural, New Residential, New Commercial, New Transportation, New Industrial, and Old Residential land use.

Step 3c. Choosing the characteristics of a standard storm for watershed inter-comparisons

The storm annual return frequency for watershed inter-comparison was set at a 2:1-year, 2-hour peak intensity storm to minimize the size of the load adjustments needed for the majority of sampled watersheds, but this decision can be adjusted in the future if additional sampling is more successful at capturing larger storms. By using a common storm, the amount of adjustment needed to convert storm loads made from field observations to a consistent storm size has been minimized.

A 1:1-year annual return frequency storm could have been chosen and is the storm load that occurs on average once every year and is thus easy to understand. For the graphs shown in Figure 5, it corresponds mathematically to the point on the line described by a power function (load = mX^a) when m = 1, the point at which the load is equal to the regression slope (exponent a). But there are two reasons why this choice is likely suboptimal. First, smaller storms cumulatively transport more PCB load over a decadal time scale than larger storms (Gilbreath and McKee, 2015; Davis et al., 2017). Second, most storms we have sampled were small with a return more frequent than 1:1-year storm (the median annual return frequency of the 2-hour peak intensity of storms sampled in the well-sampled watersheds between WYs 2003 and 2014 was 0.5). These adjustments described by steps 3a, 3b, and 3c are computed using the following equations.

(1) Land-use ratio = RWSM "dirty" parameters area / RWSM "clean" potentially PCB-contaminated parameters area
(2) [12]Adjustment factor = -0.462*LN(Land-use ratio) + 1.5441
(3) Adjusted load (g) = measured storm load (g)*(0.5-return freq of measured storm)$^{\text{Adjustment factor}}$

If the return frequency of the measured 2-hour peak storm intensity is greater than 0.5 (say for example a 0.8-year return 2-hour peak intensity storm was sampled), the result would be a downward adjustment of loads. If the annual return frequency of the measured 2-hour peak storm intensity is less than 0.5 (say for example a 0.3-year return 2-hour peak intensity storm was sampled), the result would be an upward adjustment of loads. The amount of downward or upward adjustment is a function of the size of the field measured storm and the choice of adjustment factor (see Appendix 3 for a hypothetical computation example).

Step 4. Normalize standard storm load by area

The final step for comparing watersheds is to normalize the standardized loads estimates to the watershed area of interest to generate yields (mass/unit area). Consistent with the loads adjustment technique described above, the two "dirtiest" potentially PCB-contaminated RWSM parameters (Old Industrial and Source Areas and Old Commercial and Old Transportation) were used in the area normalization step. In choosing these areas, we are not suggesting they are uniform within or between watersheds, but rather we are making a best estimate of the relative portion of the area that may be

[12] Note that in cases where this equation returns a negative number (>96.5% "dirty land uses"), zero slope (adjustment factor) is assumed.

producing the majority of the PCB mass (and conversely, the portion of the watershed that is diluting the mass with cleaner stormwater volume and sediment mass).

Alternatively, normalization to the whole watershed area could have been chosen and has proven very useful in the past for easy comparisons to data from other parts of the world (Gilbreath et al., 2015; McKee et al., 2017). However, it is less sensitive for regional scale comparisons since it does not adjust for the dilution of stormwater EMCs by water and sediment derived from "cleaner" less PCB-contaminated land-uses within the watershed. Such dilution can vary 2- to 10-fold, given small patches of contamination likely generate > 80% of the mass loads in some watersheds.

Given the focus of recent sampling in watersheds with a high proportion of Old Industrial land-use, it was tempting to use the land-uses and source areas that comprise the Old Industrial and Source Areas parameter in the RWSM in the area normalization step (see Appendix 4 for land-use and source area category definitions). However, this would not work for watersheds that don't have any of these land-uses and source areas[13]. Therefore, from a practical standpoint, it was necessary to use a more inclusive land-use parameter. Based on the RWSM outputs, on average, 64% of PCB annual loads are estimated to be derived from Old Industrial and Source Areas, and a further 32% is estimated to come from Old Commercial and Old Transportation areas; together these account for a total of 96% of the loads.

To evaluate the uncertainties associated with normalization to the area of Old Industrial and Source Areas and Old Commercial and Old Transportation within each watershed, climatically averaged loads in the well-sampled watersheds (McKee et al., 2015) were graphically compared to the areas associated with these "dirty" potentially PCB-contaminated RWSM parameters (Wu et al., 2017). Based on this analysis, 90% of the loads were explained by the presence of these "dirty" potentially PCB-contaminated land-uses (Figure 7). The standard error of the prediction based on this model is 19 g or +/- 7% of the mean annual PCB load.

Results

To demonstrate its utility, the new loads and yields-based watershed ranking method was applied to a small set of watersheds using readily and publicly available datasets that leverage peer-reviewed work already completed by the RMP and Federal agencies (See Appendix 5 for a check list of data requirements). A total of 22 watersheds, including a group of watersheds nested in the Guadalupe River watershed in addition to the seven of the well-sampled watersheds discussed throughout this document, were chosen for this demonstration (Table 1). These watersheds range in size from 0.060-233 km^2 (a ~4,000-fold variation). Land-use distributions range from 16-98% potentially PCB-contaminated, RWSM "dirty" land-uses and source areas (Old Industrial and source areas plus Old Commercial and Old Transportation) with the exception of Marsh Creek where only 1.6% of the watershed was comprised of these land-uses. PCB concentrations measured using time-based

[13] This is a limitation of the method of normalization to some choice of land uses and source areas. Watersheds with none of the chosen land uses and source areas cannot be included in the analysis. As will be discussed later, when the portion of these land uses approaches zero, there may be problems with dividing by a small number which can produce large errors if the uncertainty of that small number is high.

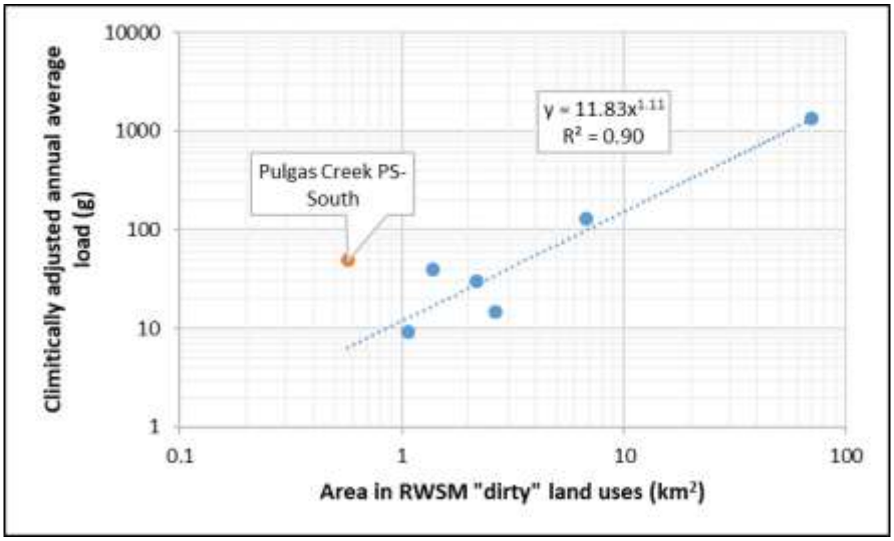

Figure 7. Uncertainty associated with normalizing loads by Regional Watershed Spreadsheet Model (RWSM) land-uses to estimate yields. RWSM “dirty” land-uses are defined as Old Industrial and Source Areas and Old Commercial and Old Transportation.

composite ranged from 880- 450,000 pg/L (a ~500-fold variation), whereas estimated concentrations on suspended sediment (particle ratios) ranged from 3.0-8,200 ng/g (a ~2,700-fold variation).

Based on the methodological steps outlined, estimated loads for the sampled storm adjusted to a 0.5-year return storm ranged from 0.00092-14 g (a ~15,000-fold variation). Estimated 0.5-year return 2-hour peak rainfall intensity storm yields ranged from 0.018-1.5 g/km^2 (a ~80-fold variation). The uncertainty of the results for the seven well-sampled watersheds is small and due to the error associated with the normalization step (7-10%). For the rest of the watersheds, the estimated errors increased proportionally in relation to the size of the adjustment between the measured storm annual return frequency to the standard storm (0.5-year annual return frequency) and the distance between the nearest rain gauge and the sampling site. Total errors ranged from 60-290% (Table 1). While these may seem like large errors, they are actually similar in size to the 95% confidence interval around the mean PCB concentration for Pulgas Creek PS South data which is 155%. The watershed identification based on this new stepwise loads-based method is shown along with uncertainty in Figure 8. Based on this new analysis, the following six watersheds were estimated to have the greatest standardized storm yields:

1. Pulgas Creek Pump Station South
2. Seabord Ave Storm Drain SC-050GAC580
3. Sunnyvale East Channel
4. E. Gish Rd Storm Drain
5. Outfall to Lower Silver Creek
6. Ridder Park Dr Storm Drain

Table 1. Results of the pilot analysis showing prioritization based on estimated yields for a standard storm size (0.5-year return) and comparisons to prioritizations based on field data on time-paced concentrations and particle ratios (the ratio of PCB concentration to suspended sediment concentration in water).

									Step 1	Step 2	Step 3				Step 4	Step 5				
Watershed/ Catchment	County	Total Area (km2)	RWSM "dirty" (old industrial and source areas plus RWSM old commercial and old transportation)	Nested Guadalupe Site?	PCBS (ng/g)	Rank	PCB time-paced EMC (pg/L)	Rank	Estimated storm volume for the sampled storm (m3)	Estimated storm load for the sampled storm (Best) (g)	Factor to adjust estimated storm load to standard storm load	Return frequency of maximum rainfall intensity (inches/2 hr) based on NOAA 14 Atlas (years)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (Best) (g)	Adjustment of loads (%)	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (Best) (g/km2)	Rank	Size of uncertanty (Range as a % of best)	Rank	Change from concentration based rank	Change from particle ratio based rank
Pulgas Creek Pump Station South	San Mateo	0.584	98%	No	8,222	1	447,984	1	*	*	*	*	0.83	*	1.5	1	10%	17	0	0
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	1.35	98%	No	236	6	19,915	6	80,713	1.61	0.00	2.4	1.6	100%	1.2	2	290%	1	4	4
Sunnyvale East Channel	Santa Clara	14.8	46%	No	343	4	96,572	2	*	*	*	*	6.8	*	1.0	3	14%	16	-1	1
E. Gish Rd Storm Drain	Santa Clara	0.438	96%	Yes	99	13	14,365	9	26,132	0.38	0.040	2.4	0.35	94%	0.84	4	290%	3	5	9
Outfall to Lower Silver Creek	Santa Clara	0.171	86%	No	783	2	44,643	4	2,544	0.11	0.70	0.56	0.10	92%	0.71	5	61%	15	-1	-3
Ridder Park Dr Storm Drain	Santa Clara	0.497	84%	No	488	3	55,503	3	2,236	0.12	0.77	0.30	0.18	147%	0.43	6	101%	8	-3	-3
San Leandro Creek	Alameda	8.94	24%	No	66	17	8,614	12	*	*	*	*	0.78	*	0.36	7	10%	18	5	10
North Richmond Pump Station	Contra Costa	1.96	54%	No	241	5	13,226	11	*	*	*	*	0.29	*	0.27	8	9%	19	3	-3
Zone 4 Line A	Alameda	4.17	63%	No	82	16	18,442	7	*	*	*	*	0.57	*	0.22	9	9%	20	-2	7
Guadalupe River at Hwy 101	Santa Clara	233	30%	Yes	115	11	23,736	5	*	*	*	*	14		0.19	10	8%	21	-5	1
099GAC240A	Santa Clara	1.21	49%	Yes	149	8	6,420	13	4,640	0.030	1.6	0.26	0.081	271%	0.14	11	120%	6	2	-3
Rock Springs Dr Storm Drain	Santa Clara	0.829	47%	No	128	9	5,252	15	9,648	0.051	1.6	0.56	0.042	83%	0.11	12	61%	14	3	-3
113LGC670A	Santa Clara	0.228	58%	Yes	103	12	3,200	18	3,049	0.0098	1.4	0.39	0.014	141%	0.10	13	73%	13	5	-1
113LGC900A	Santa Clara	0.0602	16%	Yes	55	19	884	22	587	0.00052	2.3	0.39	0.00092	176%	0.10	14	73%	12	8	5
083LGC430A	Santa Clara	0.239	66%	Yes	65	18	5,380	14	1,017	0.0055	1.2	0.22	0.015	279%	0.10	15	147%	5	-1	3
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	2.80	56%	No	186	7	13,472	10	99,292	1.3	1.4	2.4	0.14	10%	0.088	16	290%	2	-6	-9
Charcot Ave Storm Drain	Santa Clara	1.79	49%	No	123	10	14,927	8	12,738	0.19	1.6	0.94	0.071	37%	0.080	17	119%	7	-9	-7
083GAC240	Santa Clara	1.11	61%	Yes	38	20	2,693	19	2,065	0.006	1.3	0.15	0.027	480%	0.039	18	207%	4	1	2
Rosemary St SD 066GAC550C	Santa Clara	3.64	46%	Yes	89	14	4,112	17	25,019	0.10	1.6	0.68	0.063	61%	0.037	19	79%	10	-2	-5
North Fourth St SD 066GAC550B	Santa Clara	1.01	68%	Yes	87	15	4,174	16	8,665	0.036	1.2	0.68	0.025	70%	0.036	20	79%	9	-4	-5
Lower Marsh Ck	Contra Costa	83.6	1.6%	No	3.0	22	1,445	21	*	*	*	*	0.031	*	0.023	21	7%	22	0	1
129CNC165A	Santa Clara	1.51	52%	Yes	35	21	2,050	20	10,204	0.021	1.5	0.66	0.014	67%	0.018	22	76%	11	-2	-1
	Minimum	0.0602	1.6%		3		884						0.00092		0.018		7%		-9	-9
	Maximum	233	98%		8,222		447,984						14		1.5		290%		8	10
	Range	3,869	60		2,741		507						14,861		83					

* Data for these cells cannot be computed for our well-sampled watersheds where there were multiple samples taken during multiple storms over multiple water years.

Note, the minimum of two significant figures quoted in these tables to allow others to post-manipulate the data is no claim of accuracy or precision.

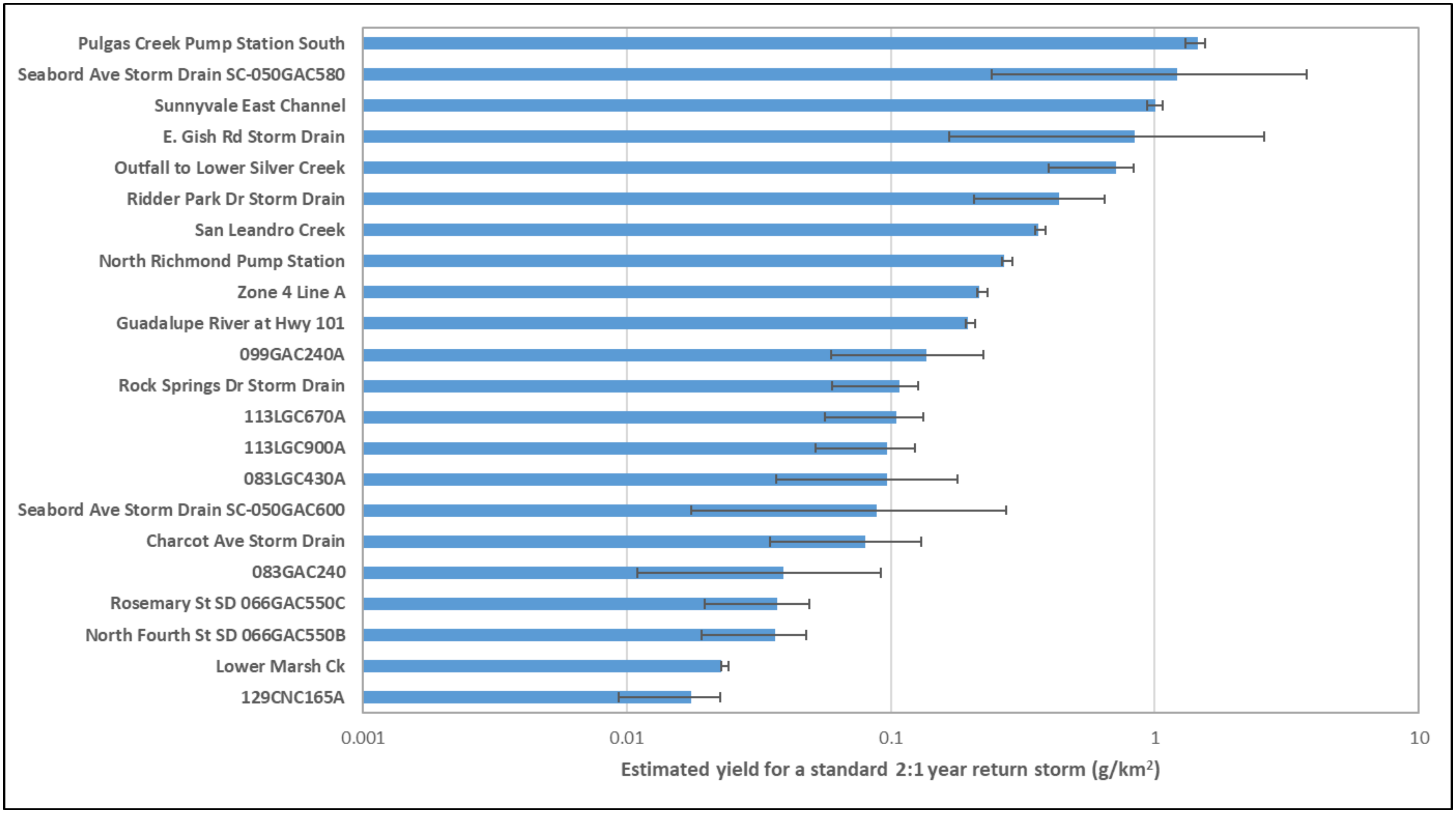

Figure 8. Watersheds prioritized according to estimated yields following the methods described in the previous sections. Uncertainties vary mainly in relation to the annual return frequency of the storm measured in the field in relation to the standard storm and the distance between the sampling location and the nearest rain gauge. The size of the uncertainty gives a sense of which watersheds would benefit from more data collection. High yields and high uncertainty would indicate the highest need for further field sampling to verify the potential for management interest.

In some cases, these results contrast with previous identifications based on concentration and particle ratios (Table 1). For example, E. Gish Rd Storm Drain rose five places in relation to prioritization based on concentration and nine places in relation to prioritization based on particle ratio; San Leandro Creek rose five and ten places for concentration and particle ratio, respectively. On the other end of the spectrum, Charcot Ave Storm Drain dropped nine places in relation to prioritization based on concentration and seven places in relation to prioritization based on particle ratio.

This analysis also enables us to ask other questions. The disparity in loadings in relation to sources and land-uses is called leverage (Stenstrom et al., 1984; Park et al., 2009) and is computed as the percent contribution of load divided by the percent contribution of land area. Stenstrom et al. (1984) and Park et al. (2009) contended that management efforts in areas with higher leverage were likely to be effective at lower overall cost. East Gish Road Storm Drain, a subwatershed nested within the Guadalupe River with an area of just 0.438 km^2 (0.19% of the Guadalupe watershed area) has an estimated load of 0.36 g or 2.6% of the total Guadalupe River load. It therefore has a relative leverage of 14 (Table 2). When leverage is considered on the basis of yields in relation to the land-uses and sources areas of interest, the yields in E. Gish Road Storm Drain were estimated to be 4.3-fold higher than those of Guadalupe River at Hwy 101. These results were not predicted from the field-based stormwater measurements of concentrations and particle ratios, which were less than those measured for Guadalupe River watershed as a whole.

On closer examination of information from the E. Gish Road Storm Drain watershed, this conclusion may be reasonable. East Gish Road Storm Drain is a very small watershed with 75% of its land-use in Old Industrial and Source Areas and 21% of its land-use in Old Commercial and Old Transportation together comprising 96% of RWSM “dirty” land-uses and source areas (Table 2). It was sampled during a rare

Table 2. Relative leverage of subwatersheds sampled so far in the Guadalupe River watershed (Relative leverage = percent contribution of load divided by the percent contribution of land area).

Watershed/ Catchment	Tot. Area (km2)	Portion of Guadalupe Watershed by area (%)	Old Industrial & Source Areas (%)	Old Commercial and Old Transportation (%)	PCBS (ng/g)	PCB time-paced EMC (pg/L)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (Best) (g)	Estimated load contribution to Guadalupe River at Hwy. 101 (%)	Size of uncertanty (Range as a % of best)	Relative leverage (whole watershed)	Relative leverage (land use and source areas of interest)
Guadalupe River at Hwy 101	233	-	4.3%	26%	115	23,736	14	-	8.4%	-	-
E. Gish Rd Storm Drain	0.438	0.19%	75%	21%	99.0	14,365	0.35	2.6%	290%	14	4.3
099GAC240A	1.21	0.52%	28%	21%	149	6,420	0.081	0.59%	120%	1.1	0.70
083LGC430A	0.239	0.10%	26%	40%	64.7	5,380	0.015	0.11%	147%	1.1	0.50
113LGC670A	0.228	0.098%	52%	5.9%	103	3,200	0.014	0.10%	73%	1.0	0.54
North Fourth St SD 066GAC550B	1.01	0.44%	28%	40%	87.0	4,174	0.025	0.18%	79%	0.42	0.19
083GAC240	1.11	0.48%	28%	33%	38.4	2,693	0.027	0.20%	207%	0.41	0.20
Rosemary St SD 066GAC550C	3.64	1.6%	12%	34%	89.0	4,112	0.063	0.46%	79%	0.30	0.19
113LGC900A	0.0602	0.026%	5.3%	10%	55.3	884	0.00092	0.0067%	73%	0.26	0.50
129CNC165A	1.51	0.65%	41%	12%	35.4	2,050	0.014	0.10%	76%	0.16	0.09

Note, the minimum of two significant figures quoted in these tables to allow others to post-manipulate the data is no claim of accuracy or precision.

storm (estimated 2.4-year return) and had a SSC of 145 mg/L (about double the median for sampling locations in the Bay Area). The relatively high SSC may have contributed to a relatively lower prioritization by particle ratio when compared to other small watersheds. Compared to the yield for its whole watershed area, the yield for land-uses and source areas of interest was only 104% of the whole watershed yield so this is not a major factor contributing to the higher prioritization based on yields. Because of its very high percentage of potentially polluting land-uses and source areas (a watershed similar to Pulgas Creek PS South), its measured load was only adjusted down by 6%. The assumption of management relevance in this case is mostly influenced by this adjustment. Had the predicted adjustment factor been greater (e.g., similar to Zone 4 Line A), the loads would have been adjusted down more. Therefore, to verify this result, sampling during any size storm smaller than a 2.4-year return should be conducted to explore if the source-release-transport processes in this watershed are as efficient as the land-use would suggest.

The watersheds designated 099GAC240A and 083LGC430A also have slightly higher leverage than Guadalupe in terms of area. In these cases, the loads were all adjusted upward (by 271% and 279%, respectively) due to small storms being sampled (return frequencies of 0.26 and 0.22 respectively) and the yields were also adjusted up (by 204% and 151%, respectively) due to the moderate amount of land-uses and source areas of interest being in RWSM "dirty categories" (49% and 66%, respectively). However, in these cases, relative leverage based on yields in association with land-uses and source areas of interest did not provide similar supporting evidence. In these cases, sampling larger storms of > 0.5-year return at these sites would verify these results.

Discussion

Summary of estimated uncertainties

Although the pilot is small in nature relative to the total number of sampled watersheds in the Bay Area, these preliminary results indicate priorities could change. For example, if there are two neighboring watersheds of similar size but Watershed A has 5% Old Industrial and had a field sampled EMC of 10,000 ng/L and Watershed B has an Old Industrial area of 15% and had a field sampled EMC of 3,000 ng/L, a greater management focus would be placed on Watershed A based on concentrations. But if the estimated storm yields were similar or even higher in Watershed B because of the differing make up of land-use in the remainder of each watershed and the differing storm characteristics sampled for each, the relative ranking could change. Unmasking false positives (as this example indicates can happen) or scaling up false negatives (to take into account dilution from cleaner land-uses), provides new insights into which watersheds to prioritize. By taking into account dilution effects of water and sediment runoff from cleaner land-uses within watersheds, as well as scaling to the same annual return frequency based on the loads from individual monitored storms, we reduce the inter-site and inter-event variations due to the influence of these factors. Thus, even for watersheds where we have only a single storm sampled at a downstream monitoring site, we can better identify the watersheds that may have sub-areas with higher than typical PCB yields. Although some of these watersheds may have large diluting water and sediment sources, their dilute PCB loads may be of net benefit to the Bay (Davis et al., 2014). However, reducing sub-areas with higher yields within the larger watersheds may result in yet lower concentrations and particle ratios, further speeding the recovery of the nearby receiving waters and eventually the Bay as a whole.

Our uncertainty estimates also provide a new and unique way to assess additional data collection needs. Both Seabord Ave Storm Drain SC-050GAC580 and E. Gish Rd Storm Drain have high uncertainty due to being sampled during a rare storm (2.4-year annual return frequency 2-hour peak storm rainfall intensity causing greater uncertainty in the estimate of a common 0.5-year 2-hour peak rainfall intensity return load), pointing out a need for further field verification. Because of high proportions of RWSM "dirty" (Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation) land-uses and source areas in these watersheds, no, or very little, adjustment for relative PCB source areas was made to the loads from the measured storm. Additional sampling is needed to verify these assumptions.

As with any exercise in data interpretation, there is uncertainty and bias associated with field and laboratory measurements and the assumptions being made. One of the weaknesses of the previous prioritization methods that used concentrations in water or particle ratios was a lack of any formal methods of estimating uncertainty in those priorities. Yet it was well known that differing storm characteristics (e.g., intensity, duration, antecedent rainfall conditions) of the sampled storms interacted with differing PCB source characteristics to cause unknown directional biases that confounded comparisons between watersheds for relative prioritization and management importance (Gilbreath et al., 2018). Estimating the uncertainty of the representativeness of a single concentration or particle ratio associated with a composite sample taken during a single storm is just not possible; statistically it is biased but there is no way of knowing the direction or size of that bias. At best, one can estimate the variation seen in other similar watersheds (where multiple storms have been measured), and assume variances are similar for similar watersheds, but even then it is not possible to determine if the concentration was typical, low bias, or high bias relative to the actual EMC for that particular watershed.

The proposed watershed-scale inter-comparison method includes more factors associated with our conceptual understanding of the rainfall-runoff based source-release-transport processes occurring during storms. It also provides an alternative method of prioritizing Bay Area watersheds for management prioritization by evaluating adjustment factors for bias and estimating the uncertainties associated with these adjustments. The graphical display of loads or yields with the estimates of uncertainty provides a useful tool for helping to prioritize investments for further investigations that would lead to a possible reduction in uncertainty, as well as to help prioritize potential investigations in sub-areas within watersheds that would have otherwise received little scrutiny due to low or moderate measured concentrations or particle ratios. In addition, the discussion of uncertainty provides a mechanism for making decisions on how to reduce uncertainty beyond data collection, which could include decisions about modeling (see the trends strategy for the details on the proposed modeling needs: Wu et. al., 2018).

As described in the previous sections, there is uncertainty associated with data manipulation in each of the steps in this new interpretation method. Given some manipulations are made in relation to the rainfall-runoff processes that are unique to the sampling date and time, the uncertainty will be unique for each watershed, thus giving the stormwater manager a sense on how data weakness may be improved (Table 3). These uncertainties or the formulas used to describe them are used to derive a total uncertainty (RMS error) for each unique sampling event in each unique watershed.

Table 3. Summary of estimated uncertainties associated with the watershed-scale loads and yields based prioritization method. Note, since the computation of uncertainties is part of the method, the absolute magnitude of the errors would change slightly in future expanded applications.

Uncertainty	Uncertainty (%)	Comment
Watershed-scale runoff coefficient obtained from the RWSM	42	Focus was on how well the RWSM predicted storm runoff volume for small impervious watersheds. Therefore, Guadalupe River and Marsh Creek watersheds were excluded from the uncertainty analysis.
Rainfall estimation by extrapolation from the nearest 15-minute recording gauge.	Varies for each location. Uncertainty = 1.17 x distance (km) for Santa Clara County gauges	The technique was chosen to be simple and applicable by any user. In this pilot analysis, we used rain gauge data from SCVWD and all storms measured during one water year (2017). In the future, we could test other metrics such as mean annual precipitation (MAP) or a specific duration and frequency such as a 2 yr, 3-hour storm. We will also need to expand the analysis to other climate zones in the Bay Area.
Event Mean Concentration (EMC)	7	Time-paced EMCs are biased a little low due to the underrepresentation of higher concentrations at higher flow rates. We compared the flow-paced EMCs for well-sampled storms in our well-sampled watersheds with the simple average of the samples to make an estimate of this bias.
Adjustment of the measured storm load to a standard storm	The uncertainty is watershed specific and proportional to the ratio of the annual return frequency of measured storm to standard storm.	This is overall likely to be the largest uncertainty for most watersheds. Uncertainties can easily be > 50%. However, uncertainty was minimized by selecting a standard storm that was similar to most storms measured during our field campaigns.
Adjustment of the standard storm load to a standard source area	7	We modeled this uncertainty based on the ability of land-use to predict loads in our well-sampled watersheds. A future improvement would be to develop a progressive estimate of uncertainty that recognizes the uncertainty associated with normalization to area of interest would get larger as the ratio of the land-use of interest to the total watershed area gets smaller.

How do uncertainties influence the results?

As discussed, there are a number of uncertainties in the yields used for prioritization that collectively range between 61-291% for less well-sampled watersheds. Functionally, yields could be anywhere from 3-fold too large (median = 1.5-fold too large for the reconnaissance watersheds in this pilot study) to 5-fold too small (median = 2.1-fold too small for the reconnaissance watersheds in this pilot study). There are some aspects of the uncertainties that have been touched upon in previous sections that should be considered carefully when interpreting the results:

1. It was previously noted that the near zero adjustment factor (functionally no adjustment) for Pulgas Creek PS South-like watersheds is an assumption with high uncertainty. This will be tested further in the sensitivity analysis section that follows using the mean regression slope for the adjustment factor to see how the relative prioritization changes.

2. The method is very sensitive to the amount of land area of interest (Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation land-uses and source areas) within each of the watersheds. Caution should be exercised when this number approaches 5% or when it is mostly Old Commercial and Old Transportation rather than Old Industrial and Source Areas. Under these circumstances, yields can be unreasonably elevated due to uncertainties in land-use and source area mapping, as well as effectively attributing loads originating from open space or other low-yield areas to the computed areas of interest through use of the latter as a divisor. Given the fact that most sampling sites have been focused on areas with a higher proportion of older industrial land-use, this should not be a concern in most instances. These concerns will also be tested by using a variety of area normalization choices (no normalization, normalization to other land-uses, normalization to whole watershed areas) in the sensitivity analysis section that follows.
3. There are also unquantified uncertainties associated with antecedent field condition and artifacts in the generation of the relationships between storm load and storm annual return frequency—an issue that may have caused the negative regression slope of the relationship for Pulgas Creek PS South watershed. Although a near zero adjustment factor is conceptually possible (e.g., a source area with a relatively constant emission rate producing a relatively constant load without regard to storm size), this seems very unlikely in a mixed land-use watershed, and a negative regression slope as would be inferred from the few samples to date collected in Pulgas Creek PS South watershed would be even less likely. Further sampling of watersheds like Pulgas Creek PS South and San Leandro Creek are needed to better characterize these relationships.

Given these acknowledged uncertainties, the best use of this method will be to provide a new line of evidence to complement other lines of evidence already employed for identifying high-leverage watersheds (e.g., concentration, particle ratio, land-uses and source areas, history of development, other anecdotal evidence such as spills, high erosion rates, or general “housekeeping” property stewardship issues).

Sensitivity analysis

A sensitivity analysis was carried out to explore how the loads, yields, and relative ranking of each watershed would change in relation to the choices made about the use of various steps or magnitude of various parameters. The sensitivity analysis involved holding all things constant except for the testing parameter and evaluating the changes in that parameter on ranking results (since comparison between watersheds using relative ranking provides managers guidance on where to potentially place earlier effort to cost effectively reduce PCB loads). During evaluation of these results, the reader should keep in

mind the relatively small nature of this pilot study (just 22 watersheds, seven of which are well-sampled and therefore manipulated with fewer steps) compared to the number of watersheds that could be tested at sites where suitable sampling has already been completed (> 90 watersheds).
Sensitivity was explored in relation to four variables:

1. Sensitivity to rainfall adjustment: Although in most cases the amount of rainfall adjustment was small because there was a rain gauge in relatively close proximity, some stakeholders questioned if the rainfall extrapolation was needed. For this analysis, the base case (rainfall adjusted using a factor derived from the NOAA 14 atlas as described in Step 1) was compared to a new case (rainfall recorded at the nearest gauge site was representative of rainfall that occurred at the sampling site (an assumption whose validity is highly dependent on the local topography as well as distance to the nearest gauge site)).
2. Sensitivity to adjustment to a standard storm (choice of the adjustment factor): As discussed in detail in previous sections, the choice of adjustment factor is one of the largest uncertainties associated with estimating a set of standard storm loads. To minimize the uncertainty, the method uses land-use to predict the adjustment factor. Here, sensitivity to this decision is tested using a comparison between: The base case (a unique adjustment factor computed for each watershed based on land-use characteristics) and new case based on an average adjustment factor of 1.25.
3. Sensitivity to adjustment to a standard storm (choice of annual return frequency): To reduce the size of the adjustment necessary and thus reduce uncertainty in this step, an annual return frequency standard storm size that was similar in return frequency to the majority of storms sampled (we chose a 0.5-year annual return frequency since most storms sampled were relatively small). However, some stakeholders questioned the use of such a small (common) storm due to the very large difference between the load that was estimated and the annual average load upon which the TMDLs and permit regulations are based. Whether storm size matters was explored using a sensitivity analysis by comparing: The base-case scenario of a 0.5-year annual return frequency storm (the storm that occurs twice on average in any one year), which represents a majority of data collected to date in the Bay Area and therefore, the storm size that, on average, reduces the absolute size of the adjustment and a new case of a 1:1-year annual return frequency storm that is simpler to understand and represents the storm load that occurs, on average, once every year.
4. Sensitivity to area normalization: Loads vary in relation to watershed size, thus organizing watersheds by an estimated storm load will fail to highlight the relative impacts of PCBs sources between watersheds. Therefore, it was necessary to normalize loads by area to estimate the yields for the more polluted parts of a watershed. But stakeholders asked, should we normalize at all and if so, which area should we use and how does this decision influence the interpretations and resulting decisions? The sensitivity of the comparative ranks was explored using three scenarios against the base case (normalization to the area within each watershed of RWSM Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation land-uses), including (a) No normalization (stakeholders wanted this tested as well), (b) Normalize to Old Industrial and Source Areas, and (c) Normalize to whole watershed area.

Based on this relatively small pilot study (just 22 watersheds, seven of which are well-sampled and therefore manipulated with fewer steps), the sensitivity analysis summarized in Table 4 provided some surprising results and some useful context for decision making. For the details on the results of each variable and explanations on why specific watersheds changed ranks, please see Appendix 6. The sensitivity analysis generally indicated little impact associated with:

- Rainfall adjustment: Little impact on loads, yields, and rankings for 21 out of 22 watersheds. Larger impacts were observed in less common instances where the closest operating rain gauge during a storm of interest was 3-6 miles away when larger adjustments were warranted that cause larger and justifiable impacts to the loads and yields estimates.
- Loads adjustment factor: Little difference to the loads, yields, and rankings for 18 of 22 watersheds. Larger impacts and uncertainties were observed in less common instances when land-use falls far from average and when a rare storm was sampled.
- Adjustment to a standard sized storm: Little difference to the loads, yields, and rankings for 19 of 22 watersheds. The largest upward adjustments occurred in watersheds that were sampled during small common storms and had estimated steep regression slopes (greater adjustment factors). These outcomes provide further argument for adopting the 0.5-year annual return frequency storm as the standard since it keeps the median adjustment to a minimum.
- Sensitivity to area normalization (normalizing to whole watershed area): Little difference to the yields and rankings for 18 of 22 watersheds. Down or upshifts generally occurred inversely in relation to the portion of land-use in RWSM Old Industrial and Source Areas and Old Commercial and Old Transportation.

Larger sensitivity impacts were found for:

- Sensitivity to area normalization (un-normalized loads based ranking): This made the largest impact to relative ranking (14 out of 22 watersheds had changes in rank of three or more positions with relative changes as large as nine places). This was expected since such a scheme essentially ranks by watershed size (Appendix Figure 6-1).
- Sensitivity to area normalization (normalizing to Old Industrial and Source Areas only): This made a moderate impact on yields and relative ranking for nine out of 21 watersheds (one watershed could not be analyzed due to a lack of Old Industrial and Source Areas land-use). Larger or smaller impacts occurred in watersheds in relation to the ratio of RWSM Old Industrial and Source Areas to RWSM Old Commercial and Old Transportation.

These results indicate that the decisions made during each step were generally robust for ranking but also provided further context for considering the results when adding the generated information to the weight of evidence approach to management decisions. Although we recommend against using loads for ranking purposes in the context of this method since watershed area strongly influences the outcomes, we realize that loads-based ranking may have merit in other contexts. We recommend against

Table 4. Summary of results from the sensitivity analysis.

		Sensitivity to rainfall adjustment		Sensitivity to adjustment to a standard storm (choice of slope adjustment factor)		Sensitivity to adjustment to a standard storm (choice of annual return frequency)		Sensitivity to area normalization					
WatersA1:B23hed/ Catchment	County	Rank (assume rainfall = to nearest gauge)	Change	Rank (assume mean slope adjustment = 1.25)	Change	Rank (adjusted to a 1 year annual return frequency storm)	Change	Rank (based on 0.5-year annual return frequency storm load	Change	Rank (based on adjusted load normalized to RWSM old industrial and source areas)	Change	Rank (based on area normalization to whole watershed)	Change
Pulgas Creek Pump Station South	San Mateo	1		1		3	Down 2	4	Down 3	2	Down 1	1	
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	2		9	Down 7	4	Down 2	3	Down 1	3	Down 1	2	
Sunnyvale East Channel	Santa Clara	3		2	Up 1	1	Up 2	2	Up 1	1	Up 2	5	Down 2
E. Gish Rd Storm Drain	Santa Clara	4		10	Down 6	6	Down 2	7	Down 3	5	Down 1	3	Up 1
Outfall to Lower Silver Creek	Santa Clara	5		3	Up 2	5		11	Down 6	7	Down 2	4	Up 1
Ridder Park Dr Storm Drain	Santa Clara	6		4	Up 2	8	Down 2	9	Down 3	9	Down 3	6	
San Leandro Creek	Alameda	7		5	Up 2	2	Up 5	5	Up 2	*	(No rank)	9	Down 2
North Richmond Pump Station	Contra Costa	8		6	Up 2	9	Down 1	8		8		7	Up 1
Zone 4 Line A	Alameda	9		7	Up 2	11	Down 2	6	Up 3	6	Up 3	8	Up 1
Guadalupe River at Hwy 101	Santa Clara	10		8	Up 2	7	Up 3	1	Up 9	4	Up 6	13	Down 3
099GAC240A	Santa Clara	11		13	Down 2	12	Down 1	12	Down 1	14	Down 3	10	Up 1
Rock Springs Dr Storm Drain	Santa Clara	12		12	Down 1	13	Down 1	15	Down 3	10	Up 2	14	Down 2
113LGC670A	Santa Clara	14	Down 1	14	Down 1	14	Down 1	21	Down 8	18	Down 5	12	Up 1
113LGC900A	Santa Clara	17	Down 3	17	Down 3	10	Up 4	22	Down 8	11	Up 3	20	Down 6
083LGC430A	Santa Clara	13	Up 2	16	Down 1	17	Down 2	19	Down 4	13	Up 2	11	Up 4
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	15	Up 1	11	Up 5	15	Up 1	10	Up 6	12	Up 4	15	Up 1
Charcot Ave Storm Drain	Santa Clara	16	Up 1	15	Up 2	16	Up 1	13	Up 4	16	Up 1	16	Up 1
083GAC240	Santa Clara	18		20	Down 2	19	Down 1	17	Up 1	20	Down 2	18	
Rosemary St SD 066GAC550C	Santa Clara	19		18	Up 1	18	Up 1	14	Up 5	15	Up 4	19	
North Fourth St SD 066GAC550B	Santa Clara	20		19	Up 1	20		18	Up 2	19	Up 1	17	Up 3
Lower Marsh Ck	Contra Costa	21		21		21		16	Up 5	17	Up 4	22	Down 1
129CNC165A	Santa Clara	22		22		22		20	Up 2	21	Up 1	21	Up 1

* Could not be computed because there is zero land-use in this category.

narrowing the area normalization step to the use of lesser area (RWSM Old Industrial and Source Areas alone).

Summary and Recommendations

A new loads and yields-based prioritization method has been developed and pilot tested in 22 watersheds that included a group of watersheds nested in the Guadalupe River watershed and seven well-sampled watersheds. The method is appropriate for application in watersheds where reconnaissance sampling has been conducted, the watershed boundary has been delineated to allow for determination of land-use using GIS data, and rainfall data are available (using local rain gauges). The method entails four steps:

1. Estimate storm runoff volume in the sampled watershed
2. Compute estimates of storm load for the sampled storm
3. Adjust estimates of storm load to a standard sized storm
4. Normalize standardized storm loads to the land-uses and source areas of interest to generate storm yields

Based on this new method, the six highest yielding watersheds corresponding with the 0.5 annual return frequency 2-hour peak rainfall intensity storms (yields of 0.43 - 1.5 g/km^2) of the 22 watersheds considered were:

1. Pulgas Creek Pump Station South
2. Seabord Ave Storm Drain SC-050GAC580
3. Sunnyvale East Channel
4. E. Gish Rd Storm Drain
5. Outfall to Lower Silver Creek
6. Ridder Park Dr Storm Drain

Based on the estimated yields, relative prioritization in relation to concentrations or particle ratios rose or fell for various watersheds. For example, Seabord Ave Storm Drain SC-050GAC580 rose four places in relation to its prioritization for both concentration and particle ratio. Similarly, E. Gish Rd Storm Drain rose five places relative to its prioritization based on concentration and nine places relative to its prioritization based on particle ratio. Thus, overall this new method is poised to provide new evidence for management consideration. Of these six, E. Gish Rd Storm Drain was the only one located within Guadalupe. This watershed is estimated to have a relative leverage of 14 in relation to total watershed area and is estimated to have yields 4.3-fold greater than Guadalupe River at Hwy 101 as a whole, although uncertainties are high for this watershed due to a rare storm being sampled and a high proportion of land-uses and source areas causing a near zero adjustment factor (functionally little adjustment for storm size).

The sensitivity analysis results provide some evidence for the robustness of the method but further testing with a larger data set would help to further confidence. Generally, it appears that the decisions made during each step were robust for enhancing watershed comparisons for relative ranking.

Overall, given the limited scope of the pilot study, it should be considered primarily as a proof of concept. Further development and testing in a greater number of watersheds with a wider range of conditions is needed. High priorities for further work include:

1. Further develop and apply this prioritization method to all Bay Area watersheds where reconnaissance sampling has been carried out (90-100 watersheds in total, including sampling by the Santa Clara and San Mateo programs (EOA, 2017a, b), and by the RMP (Gilbreath et al., 2018)). This would allow the development and testing of the method for:
    a. Other microclimates (necessitating the need to further explore uncertainties associated with interpolation of rainfall from a gauge location to the watersheds of interest)
    b. Other nested systems to further explore the concepts of leverage
    c. The standard storm adjustment factor in step 3 (a key factor influencing the resulting loads)
    d. The normalizing factor (step 4) (a key factor influencing the resulting yields)
    e. Watersheds that have been sampled twice as a test on how well the method performs
    f. Yield thresholds beyond which differing actions might be considered. Threshold categories could include: no need, maybe a need, and certainly a need to follow up. Once categories were developed, investigations into how placement in relation to each threshold changes with sensitivity assumptions should be made.

2. Compare the results of the loads and yields-based prioritization method with those from the new congener-based methods (presented in the companion document, see preface for details) that used PCB congeners to help identify source areas contributing most to the PCB mass exported from the watershed via stormwater, and to illustrate variability in PCB mobilization from source areas over time.
3. Apply statistical methods to identify influential factors for identifying new sites of potential high loads and yields where reconnaissance sampling could be conducted.

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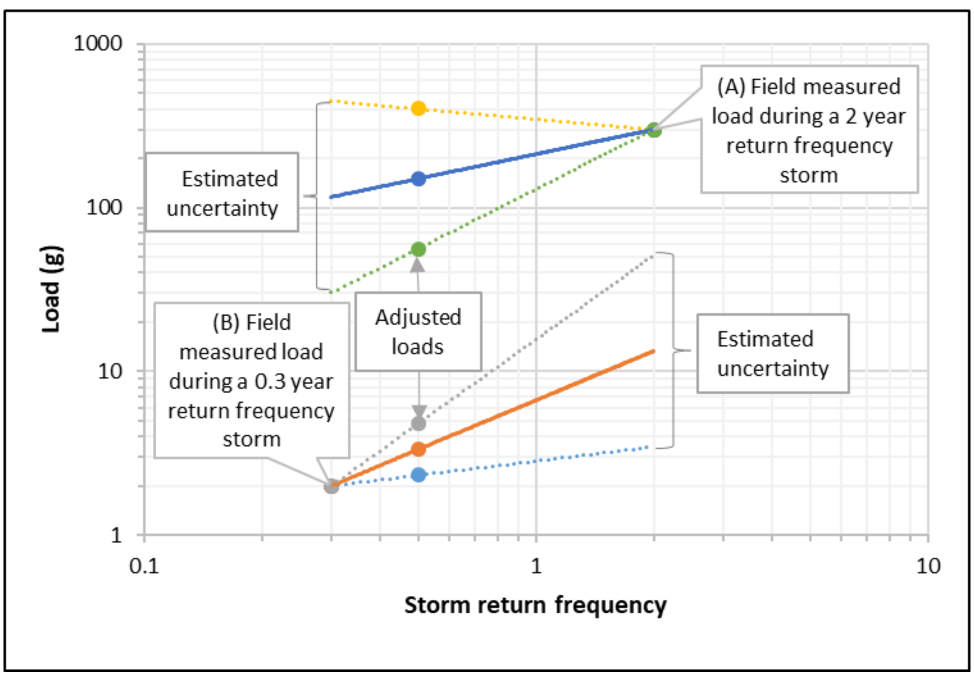
Appendix 1. Example of adjustment of storm rainfall measured at the nearest rain gauge to estimate rainfall at the sampling site.

		Rainfall (inches)	
Location		**Measured rainfall at a gauge site 5 km away**	**Estimated rainfall for sample site**
Estimate of 2 hr 1 yr return rainfall (NOAA 14 Atlas)		0.75	0.85
Activity	Time		
Beginning of rain storm	11/9/2016 23:30:00	0.01	0.011
	11/9/2016 23:45:00	0.02	0.023
	11/10/2016 0:00:00	0.01	0.011
	11/10/2016 0:15:00	0.01	0.011
	11/10/2016 0:30:00	0.02	0.023
Composite sub-sample 1	11/10/2016 0:45:00	0.03	0.034
	11/10/2016 1:00:00	0.07	0.079
Composite sub-sample 2	11/10/2016 1:15:00	0.02	0.023
	11/10/2016 1:30:00	0.06	0.068
Composite sub-sample 3	11/10/2016 1:45:00	0.09	0.102
	11/10/2016 2:00:00	0.13	0.147
Composite sub-sample 4	11/10/2016 2:15:00	0.15	0.170
	11/10/2016 2:30:00	0.10	0.113
Composite sub-sample 5	11/10/2016 2:45:00	0.08	0.091
	11/10/2016 3:00:00	0.06	0.068
Composite sub-sample 6	11/10/2016 3:15:00	0.03	0.034
	11/10/2016 3:30:00	0.03	0.034
	11/10/2016 3:45:00	0.01	0.011
	11/10/2016 4:00:00		0.000
	11/10/2016 4:15:00	0.01	0.011
End of rain storm	11/10/2016 4:30:00	0.01	0.011
	Total storm rainfall	**0.95**	**1.08**
	Peak 2-hour rainfall intensity	**0.70**	**0.79**

Appendix 2. Rain gauges used to estimate the uncertainty of extrapolating rainfall from a local gauge site to a monitoring location of interest.

Name	SCVWD Station code	Latitude	Longitude	Elevation (ft)	Rainfall (1 yr 6 hr return) (in)
City of San Jose	Alert ID 1453	37.34944444	-121.9044444	66	0.785
Sunnyvale WTP	Alert ID 1521	37.35527778	-122.0591667	204	0.982
Mountain View	Alert ID 1515	37.39416667	-122.0597222	76	0.879
West Yard	Alert ID 1511	37.30805556	-121.9944444	208	1.01
Guadalupe Slough	Alert ID 2053	37.45333333	-122.0320587	13	0.819
Alamitos	Alert ID 2065	37.24722222	-121.8705556	200	0.946
Penetencia WTP	Alert ID 2070	37.39833333	-121.8352778	389	0.845
Palo Alto	Alert ID 2099	37.45555556	-122.1005556	8	0.868
MaryKnoll Fields	Alert ID 1454	37.33222222	-122.0808333	436	1.24
Evergreen	Alert ID 1516	37.29861111	-121.7569444	445	1.05

Appendix 3. Hypothetical example of adjusting a field measured load to the load of a standard 2-hour peak intensity storm and a hypothetical illustration of the uncertainties associated with that adjustment (represented as dotted lines). As discussed in the text, we chose a storm 2-hour peak intensity size that occurs on average 2 times each year (0.5 annual return frequency). In the hypothetical example (A), a storm was sampled in a watershed that was comprised of 90.6% RWSM "dirty" potentially PCB-contaminated land-uses and source areas or a ratio of 9.6 "dirty":"clean." Based on this, the adjustment factor was 0.5. This storm was large and had a load of 300 g and an estimated annual return frequency of two years based on its peak 2-hour rainfall intensity. The estimated storm load that would occur during a more common storm 2-hour peak intensity size of 0.5-year return is 150 g with an uncertainty of 56-401 g. The large uncertainty in this case is associated with the large adjustment needed between a 2-year return and a 0.5-year return 2-hour peak storm intensity. Note that for error estimation, the adjustment factor was allowed to go negative despite a negative slope between annual return frequency of the storm 2-hour peak intensity and loads being nonsensical; this was required by the method to avoid the errors getting smaller if the regression slope was near zero. In the second hypothetical example (B), a storm was sampled in a watershed that was comprised of 76.5% RWSM "dirty" potentially PCB-contaminated land-uses and source areas or a ratio of 3.25 "dirty":"clean." Based on this, the adjustment factor was 1.0. This storm was relatively small and had an estimated annual return frequency of just 0.3 years based on its peak 2-hour rainfall intensity. The estimated storm load that would occur during a storm 2-hour peak rainfall intensity size of 0.5-year return is 3.3 g with an uncertainty of 2.3-4.8 g. The relatively small uncertainty in this case is associated with the small adjustment needed between a 0.3 and a 0.5-year return storm 2-hour peak rainfall intensity; this is a more typical case and matches much of our field data.



Appendix 4. PCBs parameterization and relative yields based on the RWSM (Wu et al., 2017).

<table>
<tr><th>Land-use</th><th>PCBs Model Area (km2)</th><th colspan="2">PCBs Land-use Grouping for the Model Area</th><th>Yield (g/km2)</th><th>Relative Yield</th></tr>
<tr><td>Agriculture</td><td>999</td><td rowspan="6">Ag / Open / New Urban</td><td rowspan="6">71%</td><td rowspan="6">0.05</td><td rowspan="6">1</td></tr>
<tr><td>Open Space</td><td>2992</td></tr>
<tr><td>New Industrial</td><td>143</td></tr>
<tr><td>New Residential</td><td>409</td></tr>
<tr><td>New Commercial</td><td>111</td></tr>
<tr><td>New Transportation</td><td>152</td></tr>
<tr><td>Old Residential</td><td>922</td><td>Old Residential</td><td>14%</td><td>0.60</td><td>12</td></tr>
<tr><td>Old Commercial</td><td>253</td><td rowspan="2">Old Commercial and Old Transportation</td><td rowspan="2">10%</td><td rowspan="2">16</td><td rowspan="2">320</td></tr>
<tr><td>Old Transportation</td><td>394</td></tr>
<tr><td>Old Industrial</td><td>101</td><td rowspan="7">Old Industrial and Source Areas</td><td rowspan="7">3%</td><td rowspan="7">61</td><td rowspan="7">1220</td></tr>
<tr><td>Transportation Rail</td><td rowspan="6">134</td></tr>
<tr><td>Recycling - Drums</td></tr>
<tr><td>Transportation Air</td></tr>
<tr><td>Electric Power</td></tr>
<tr><td>Military</td></tr>
<tr><td>Electric Transfer</td></tr>
<tr><td>Cement</td><td colspan="2" rowspan="3">Not used as PCBs Source Areas; integrated into other land-use categories.</td><td rowspan="3">NA</td><td rowspan="3">NA</td><td rowspan="3">NA</td></tr>
<tr><td>Oil Refineries</td></tr>
<tr><td>Crematoria</td></tr>
<tr><td>Water</td><td>114</td><td>Not attributed coefficients</td><td>2%</td><td>NA</td><td>NA</td></tr>
</table>

Appendix 5. Checklist of information needed to carry out the new loading and yields-based watershed comparison and ranking method.

Data type	Units	Source	How it can be obtained
Watershed specific runoff coefficient.	%	Wu et al., 2017	Contact SFEI for a copy of the model.
Watershed boundary.	-	City stormwater drainage maps	Contact local city stormwater representative or public works department.
Total watershed area.	km^2	City stormwater drainage maps	Use a GIS computer program to determine the area inside the watershed boundary.
Estimated storm specific total rainfall and peak 2-hour rainfall intensity for the watershed of interest.	mm	Direct measurement if available (minimum 1-hour time step)	Contact local city stormwater representative or public works department
		Estimation by extrapolation from a nearby gauge	Local agency observation networks including city, county, and stormwater agencies), official NOAA cooperative rainfall collection sites, Remote Automated Weather Stations (RAWS), and Weather Underground.
Estimate of 6 hr, 1 yr return rainfall for the sampling site and the site of the nearest rain gauge.	mm	Perica et al., 2014	Enter the GIS coordinates or street address for the sites of interest into the NOAA 14 atlas web based portal: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html
The annual return frequency of the peak 2-hour rainfall intensity for storm of interest for the sampling site or a nearby gauge.	yrs	Perica et al., 2014	Magnitude, duration, frequency equations are not published on line but these can be derived from the published tables that result from entering the GIS coordinates or street address for the sites of interest into the NOAA 14 atlas web based portal: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html. Use the resulting equation to estimate the annual return frequency of the storm of interest.
Storm specific event mean concentration (EMC) for the watershed of interest.	pg/L	Field sampling during storms using appropriate sampling techniques	Local stormwater representative for data collected during WY 2018. For a compilation of data collected by the RMP, prior to WY 2018, see Gilbreath et al 2018.
Watershed area covered by the land-use types and source areas: Old industrial + source areas, and Old Commercial + Old Transportation.	km^2	Wu et al., 2017	Contact SFEI for a copy of the model.

Appendix 6. Sensitivity analysis.

A sensitivity analysis was carried out to explore how the loads, yields and relative ranking of each watershed would change in relation to the choices made about the use of various steps or magnitude of various parameters. The sensitivity analysis involved holding all things the same except for the testing parameter and evaluating the changes in that parameter on ranking results (since comparison between watersheds using relative ranking provides managers guidance on where to potentially place earlier effort to cost effectively reduce PCB loads). During evaluation of these results, the reader should keep in mind the relatively small nature of this pilot study (just 22 watersheds, seven of which are well-sampled and therefore manipulated with fewer steps) compared to the number of watersheds that could be tested (> 90 watersheds where suitable sampling has been completed). Sensitivity was explored in relation to four variables:

1. Sensitivity to rainfall adjustment:
2. Sensitivity to adjustment to a standard storm (choice of the adjustment factor – functionally the regression slope):
3. Sensitivity to adjustment to a standard storm (choice of annual return frequency)
4. Sensitivity to area normalization:
   a. No normalization (stakeholders wanted this tested as well),
   b. Normalize to Old Industrial and Source Areas, and
   c. Normalize to whole watershed area.

Sensitivity to rainfall adjustment

Although in most cases the amount of rainfall adjustment was small because there was a rain gauge in relatively close proximity, some stakeholders questioned if the rainfall extrapolation was needed. Table 6-1 shows the relative rankings based on two assumptions:

1. The base case (rainfall adjusted using a factor derived from the NOAA 14 atlas as described in Step 1), and,

2. A new case for which we assumed the rainfall recorded at the nearest gauge site was representative of rainfall that occurred at the sampling site (an assumption whose validity is highly dependent on the local topography as well as distance to the nearest gauge site).

Based on the data in this small pilot application, the adjustment of the rainfall appears to make little difference to the loads, yields, and rankings because the rainfall adjustment itself is small (Table 6-1). However, we contend that the rainfall adjustment is a necessary step that adds increased accuracy to the estimate of loads, yields, and relative rankings and management importance. In some cases, a large adjustment was justified and made a measurable difference to the loads and yields estimates. Changes in loads and yields ranged between 80-126% and a maximum change of three ranking places occurred at the site designated 113LGC900A. This site was 6.2 km from the nearest rain gauge that was in operation during the sampled storm. In this case, the adjustment increased the estimated rainfall at the sampling site by 25% compared to the nearest gauge during that storm.

Table 6-1. Sensitivity of loads and yields estimates and yield based rankings to the choice of whether or not to adjust the rainfall between a measurement gauge some distance away from a sampling site and the sampling site.

Watershed/ Catchment	County	Rank (A1:B23based on adjusted rainfall)	Rain gauge site: Total Storm Rainfall (in)	Distance between the sampling site and the nearest rain gauge (km)	NOAA 14 6 hr 1 year return storm depth for the sampling site (in)	NOAA 14 6 hr 1 year return storm depth for the nearest 15 min recording rain gauge (in)	Estimated (adjusted) storm rainfall for the sampling location (in)	Amount of adjustment (%)	Estimated storm load for the sampled storm (adjusted rainfall) (Best) (g)	Estimated storm load for the sampled storm (assume rainfall = to nearest gauge) (Best) (g)	Return frequency of maximum rainfall intensity (inches/2 hr) based on NOAA 14 Atlas (Years)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (adjusted rainfall) (Best) (g)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (assume rainfall = to nearest gauge) (Best) (g)	Change in loads and yield relative to the base case	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (adjusted rainfall) (Best) (g/km2)	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (assume rainfall = to nearest gauge) (Best) (g/km2)	Rank (based on adjusted rainfall)	Rank (assume rainfall = to nearest gauge)	Change
Pulgas Creek Pump Station South	San Mateo	*	*	0	*	*	*	*	*	*	*	0.832	0.832	100%	1.46	1.46	1	1	
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	City of San Jose	3.35	4.2	0.802	0.785	3.42	102%	1.61	1.57	2.43	1.61	1.57	98%	1.2	1.2	2	2	
Sunnyvale East Channel	Santa Clara	*	*	0	*	*	*	*	*	*	*	6.77	6.77	100%	1.0	1.0	3	3	
E. Gish Rd Storm Drain	Santa Clara	City of San Jose	3.35	1.9	0.775	0.785	3.31	99%	0.38	0.38	2.43	0.357	0.357	100%	0.85	0.85	4	4	
Outfall to Lower Silver Creek	Santa Clara	City of San Jose	0.87	3.4	0.763	0.785	0.85	97%	0.11	0.12	0.56	0.105	0.108	103%	0.71	0.73	5	5	
Ridder Park Dr Storm Drain	Santa Clara	City of San Jose	0.27	3.2	0.784	0.785	0.27	100%	0.12	0.12	0.30	0.182	0.182	100%	0.44	0.44	6	6	
San Leandro Creek	Alameda	*	*	0	*	*	*	*	*	*	*	0.784	0.784	100%	0.36	0.36	7	7	
North Richmond Pump Station	Contra Costa	*	*	0	*	*	*	*	*	*	*	0.286	0.286	100%	0.27	0.27	8	8	
Zone 4 Line A	Alameda	*	*	0	*	*	*	*	*	*	*	0.569	0.569	100%	0.22	0.22	9	9	
Guadalupe River at Hwy 101	Santa Clara	*	*	0	*	*	*	*	*	*	*	13.6	13.6	100%	0.19	0.19	10	10	
099GAC240A	Santa Clara	City of San Jose	0.28	5.1	0.801	0.785	0.29	102%	0.030	0.029	0.26	0.082	0.079	97%	0.14	0.13	11	11	
Rock Springs Dr Storm Drain	Santa Clara	City of San Jose	0.87	5.7	0.772	0.785	0.86	98%	0.051	0.052	0.56	0.042	0.043	102%	0.11	0.11	12	12	
113LGC670A	Santa Clara	West Yard	0.79	5.9	1.16	1.01	0.91	115%	0.010	0.0085	0.39	0.014	0.012	87%	0.10	0.091	13	14	Down 1
113LGC900A	Santa Clara	West Yard	0.79	6.2	1.26	1.01	0.99	125%	0.00052	0.00042	0.39	0.00092	0.00073	80%	0.098	0.078	14	17	Down 3
083LGC430A	Santa Clara	City of San Jose	0.32	2.7	0.791	0.785	0.32	101%	0.0055	0.0054	0.22	0.0153	0.0151	99%	0.097	0.096	15	13	Up 2
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	City of San Jose	3.35	4.2	0.802	0.785	3.42	102%	1.34	1.31	2.4	0.135	0.135	100%	0.087	0.087	16	15	Up 1
Charcot Ave Storm Drain	Santa Clara	City of San Jose	0.47	3.9	0.793	0.785	0.47	101%	0.19	0.19	0.94	0.0700	0.0698	100%	0.080	0.079	17	16	Up 1
083GAC240	Santa Clara	West Yard	0.19	9.1	0.793	1.01	0.15	79%	0.0056	0.0071	0.15	0.0270	0.0340	126%	0.039	0.050	18	18	
Rosemary St SD 066GAC550C	Santa Clara	City of San Jose	0.67	1.3	0.773	0.785	0.66	98%	0.10	0.10	0.68	0.0627	0.0640	102%	0.037	0.038	19	19	
North Fourth St SD 066GAC550B	Santa Clara	City of San Jose	0.67	1.4	0.773	0.785	0.66	98%	0.036	0.037	0.68	0.0251	0.0256	102%	0.036	0.037	20	20	
Lower Marsh Ck	Contra Costa	*	*	0	*	*	*	*	*	*	*	0.0313	0.0313	100%	0.023	0.023	21	21	
129CNC165A	Santa Clara	Alamitos	0.48	5.6	0.872	0.946	0.44	92%	0.021	0.023	0.66	0.0139	0.0151	109%	0.018	0.019	22	22	

* Data for these cells cannot be computed for our well-sampled watersheds where there were multiple samples taken during multiple storms over multiple water years.
Note, the minimum of two significant figures quoted in these tables to allow others to post-manipulate the data is no claim of accuracy or precision.

Sensitivity to adjustment to a standard storm (choice of the adjustment factor)

As discussed in detail in previous sections, the choice of adjustment factor is one of the largest uncertainties associated with estimating a set of standard storm loads for watersheds that have been sampled during just one or two storms. During the development and testing of this step-wise adjustment method, we tried to minimize the uncertainty by using watershed characteristics to estimate the slope of the relationship between annual return frequency of storms and storm loads (Figure 6) for a given watershed of interest (remember, the slope is used as the adjustment factor for scaling the storm loads up or down to a standard storm size as defined by return frequency). In addition, we tried to reduce the size of the adjustment necessary by selecting a standard storm size annual-return frequency that was similar in return frequency to the majority of storms we have sampled and are likely able to sample in the future[14] (we chose a 0.5-year annual return frequency since most storms sampled were relatively small). It is this first point that is perhaps the hardest to understand and is tested here for sensitivity using a comparison between:

1. The base case (a unique adjustment factor) was computed for each watershed based on land-use characteristics (Figure 6); and
2. A new case based on an average regression slope (the average of the six regression slopes illustrated in Figure 5, excluding March Creek and San Leandro Creeks which appear to be outliers in Figure 6[15] and assuming the slope of the regression for Pulgas Creek PS South is zero). The average slope we used as the adjustment factor for this case was 1.25 for all watersheds regardless of land-use characteristics.

Based on the data in this small pilot application, the adjustment factor appears to make little difference to the loads, yields and rankings in most cases (up or down rank by one or two places or no change at all for 18 of 22 watersheds) (Table 6-2) with changes in yields ranging between 82-127% in these cases. However, there were large load, yield and rank downward changes for Seabord Ave Storm Drain SC-050GAC580 (14% of the base yield and down seven places) and E. Gish Rd Storm Drain (15% of the base yield and down six places). In these two cases, the base case adjustment factor was estimated to be zero or near zero, thus the measured storm loads were not originally adjusted. In addition, these two watersheds were sampled during rare storms with an annual return frequency of ~2.4 years. Thus, when the new adjustment factor of 1.25 was applied during this sensitivity analysis, there was a large down adjustment of loads due to both the factor change (~0 → 1.25) and the large difference between the measured and standard storm (2.4 → 0.5-year return frequency). The watershed designated 113LGC900A also went down in loads, yields, and rank, in this case three places in response to a yield of 77% of the base case. This watershed has ~16% RWSM "dirty" (Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation) land-uses and was sampled during a small storm with an estimated annual return frequency of ~0.39 years. In this case the average adjustment factor was less than the one estimated by land-use characteristics used in the base case. As a result, the load in this

[14] To sample larger storms as a standard for our dataset would require long term study with little or no sampling in some years when no larger storms occur and larger effort in wetter years and during events when conditions were met. This is untenable given budget constraints and staffing resources.
[15] For explanations for why we think Marsh Creek and San Leandro Creek are outliers, see discussion section associated with Figure 6.

Table 6-2. Sensitivity of loads and yields estimates and yield based rankings to the choice of adjustment factor. The base case is for adjustment factor estimated in relation to land-use characteristics for each unique site. An alternative adjustment factor was tested that was equal to the mean slope (1.25) of the relationship for each watershed excluding Marsh Creek and San Leandro Creek (outliers) and assuming the regression slope between rainfall annual return frequency and storm load was zero for the Pulgas Creek Pump Station South watershed.

Watershed/ Catchment	County	Estimated storm load for the sampled storm (base case) (g)	Factor to adjust estimated storm load to standard storm load (base case)	Factor to adjust estimated storm load to standard storm load (assume mean slope adjustment = 1.25)	Max 2-hr intensity at rain gauge site (in)	Return frequency of maximum rainfall intensity (inches/2 hr) based on NOAA 14 Atlas (years)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (base case) (g)	Upward or downward adjustment (base case)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (assume mean slope adjustment = 1.25) (g)	Upward or downward adjustment (assume mean slope adjustment = 1.25)	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (base case) (g/km2)	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (assume mean slope adjustment = 1.25) (g/km2)	Change in yield relative to the base case	Rank (base case)	Rank (assume mean slope adjustment = 1.25)	Change
Pulgas Creek Pump Station South	San Mateo	*	*	*	*	*	0.83	*	0.83	*	1.5	1.5	100%	1	1	
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	1.6	0	1.25	0.63	2.4	1.6	100%	0.22	14%	1.2	0.17	14%	2	9	Down 7
Sunnyvale East Channel	Santa Clara	*	*	*	*	*	6.8	*	6.8	*	1.0	1.0	100%	3	2	Up 1
E. Gish Rd Storm Drain	Santa Clara	0.38	0.040	1.25	0.63	2.4	0.35	94%	0.052	14%	0.84	0.12	15%	4	10	Down 6
Outfall to Lower Silver Creek	Santa Clara	0.11	0.70	1.25	0.32	0.56	0.10	92%	0.10	87%	0.71	0.67	94%	5	3	Up 2
Ridder Park Dr Storm Drain	Santa Clara	0.12	0.77	1.25	0.19	0.30	0.18	147%	0.23	186%	0.43	0.55	127%	6	4	Up 2
San Leandro Creek	Alameda	*	*	*	*	*	0.78	*	0.78	*	0.36	0.36	100%	7	5	Up 2
North Richmond Pump Station	Contra Costa	*	*	*	*	*	0.29	*	0.29	*	0.27	0.27	100%	8	6	Up 2
Zone 4 Line A	Alameda	*	*	*	*	*	0.57	*	0.57	*	0.22	0.22	100%	9	7	Up 2
Guadalupe River at Hwy 101	Santa Clara	*	*	*	*	*	13.6	*	14	*	0.19	0.19	100%	10	8	Up 2
099GAC240A	Santa Clara	0.030	1.6	1.25	0.16	0.26	0.081	271%	0.066	222%	0.14	0.11	82%	11	13	Down 2
Rock Springs Dr Storm Drain	Santa Clara	0.051	1.6	1.25	0.32	0.56	0.042	83%	0.044	87%	0.11	0.11	104%	12	12	Down 1
113LGC670A	Santa Clara	0.010	1.4	1.25	0.36	0.39	0.014	141%	0.013	136%	0.10	0.10	96%	13	14	Down 1
113LGC900A	Santa Clara	0.00052	2.3	1.25	0.36	0.39	0.001	176%	0.00070	136%	0.097	0.075	77%	14	17	Down 3
083LGC430A	Santa Clara	0.0055	1.2	1.25	0.12	0.22	0.015	279%	0.015	281%	0.097	0.098	101%	15	16	Down 1
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	1.3	1.4	1.25	0.63	2.4	0.14	10%	0.19	14%	0.088	0.12	135%	16	11	Up 5
Charcot Ave Storm Drain	Santa Clara	0.19	1.6	1.25	0.43	0.94	0.071	37%	0.086	45%	0.080	0.098	122%	17	15	Up 2
083GAC240	Santa Clara	0.0056	1.3	1.25	0.15	0.15	0.027	480%	0.024	437%	0.039	0.036	91%	18	20	Down 2
Rosemary St SD 066GAC550C	Santa Clara	0.10	1.6	1.25	0.36	0.68	0.063	61%	0.070	68%	0.037	0.042	112%	19	18	Up 1
North Fourth St SD 066GAC550B	Santa Clara	0.036	1.2	1.25	0.36	0.68	0.025	70%	0.025	68%	0.036	0.036	98%	20	19	Up 1
Lower Marsh Ck	Contra Costa	*	*	*	*	*	0.031	*	0.031	*	0.023	0.023	100%	21	21	
129CNC165A	Santa Clara	0.021	1.5	1.25	0.44	0.66	0.014	67%	0.015	71%	0.018	0.019	107%	22	22	

* Data for these cells cannot be computed for our well-sampled watersheds where there were multiple samples taken during multiple storms over multiple water years.
Note, the minimum of two significant figures quoted in these tables to allow others to post-manipulate the data is no claim of accuracy or precision.

new scenario was adjusted up less than in the base case due to the lower adjustment factor, causing a lower estimate in loads and yields for the 0.5-year return frequency standard storm. In another case, rank went up five places in Seabord Ave Storm Drain SC-050GAC600 (yields were 135% of the base case) due to an adjustment factor that was less than the rare storm that was sampled (1.4 → 1.25). There were also smaller relative downward changes for three watersheds that had relatively similar yields (the watersheds designated 113LGC670A, 113LGC900A, 083LGC430A).

Overall, the amount of adjustment needed (the difference between the return frequency of the storm that was sampled and a standard storm of annual return frequency of 0.5 years) that was expected to have a strong influence on the estimated loads, yields and ranks (as described in Steps 3 and 4), appears to have lesser influence after all (except in a few explainable cases). However, it is still generally recommended that watersheds with greater portions of land-use in RWSM "dirty" (Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation) land-uses should be sampled during storm conditions that are predicted to approximate a standard storm (whatever that is finally chosen to be).

Sensitivity to adjustment to a standard storm (choice of annual return frequency)

As discussed in detail in previous sections, the choice of the standard size storm is another one of the potentially large uncertainties associated with estimating a set of standard storm loads for our watersheds that have been sampled during just one or two storms. We tried to reduce the size of the adjustment necessary and thus reduce uncertainty in this step by selecting an annual return frequency standard storm size that was similar in return frequency to the majority of storms we have sampled (we chose a 0.5-year annual return frequency since most storms sampled were relatively small). However, some stakeholders questioned the use of such a small (common) storm due to the very large difference between the load that was estimated and the annual average load upon which the TMDLs and permit regulations are based. The published peer-reviewed literature is replete with studies that describe data from dry-weather flow, a few storms, or a partial year (a few months to 9 months of weekly sampling or monthly sampling) that were used to support management or policy decisions and not always with the level of extreme care that the data representativeness should have caused[16]. Below we explore why storm size matters using a sensitivity analysis by comparing:

1. The base-case scenario of a 0.5-year annual return frequency storm (the storm that occurs twice on average in any one year), which represents a majority of data collected to date in the Bay Area and therefore, the storm size that, on average, reduces the absolute size of the adjustment; and
2. A new case of a 1:1-year annual return frequency storm that is simpler to understand and represents the storm load that occurs, on average, once every year.

Based on the data in this small pilot application, the adjustment to a standard-sized storm appears to make little difference to the rankings in most cases (up or down rank by one or two places or no change at all for 19 of 22 watersheds) (Table 6-3), but since the storms we sampled were all relatively small, as expected, the loads and yields went up as much as 500% over the base case. There were large rank

[16] We don't reference the studies here but the authors would be happy to send you a half dozen such studies that describe meager sampling designs and resulting data that were used to support management decisions.

Table 6-3. Sensitivity of loads and yields estimates and yield based rankings to the choice of return frequency of the standard storm for the case is a 0.5-year annual return frequency storm (the storm size that on average minimizes the size of the loads up or down adjustment), and estimates for a 1-year annual return frequency storm.

Watershed/ Catchment	County	Tot. Area (km2)	RWSM "dirty" (old industrial and source areas plus RWSM old commercial and old transportation) (km2)	RWSM "dirty" (old industrial and source areas plus RWSM old commercial and old transportation)	Estimated storm load for the sampled storm (Best) (g)	Factor to adjust estimated storm load to standard storm load	Return frequency of maximum rainfall intensity (inches/2 hr) based on NOAA 14 Atlas (years)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (base case) (g)	Upward or downward adjustment	Estimated storm load for the sampled storm adjusted to 1 yr return (new case) (g)	Upward or downward adjustment	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (base case) (g/km2)	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (adjusted to a 1 year annual return frequency storm) (g/km2)	Change in yield relative to the base case	Rank (base case)	Rank (adjusted to a 1 year annual return frequency storm)	Change
Pulgas Creek Pump Station South	San Mateo	0.584	0.571	98%	*	*	*	0.83	*	0.83	*	1.5	1.5	100%	1	3	Down 2
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	1.35	1.32	98%	1.6	0.00	2.4	1.6	100%	1.6	100%	1.2	1.2	100%	2	4	Down 2
Sunnyvale East Channel	Santa Clara	14.8	6.76	46%	*	*	*	6.8	*	28	*	1.0	4.1	414%	3	1	Up 2
E. Gish Rd Storm Drain	Santa Clara	0.438	0.422	96%	0.38	0.040	2.4	0.35	94%	0.36	97%	0.84	0.86	103%	4	6	Down 2
Outfall to Lower Silver Creek	Santa Clara	0.171	0.147	86%	0.11	0.70	0.56	0.10	92%	0.17	149%	0.71	1.2	162%	5	5	
Ridder Park Dr Storm Drain	Santa Clara	0.497	0.419	84%	0.12	0.77	0.30	0.18	147%	0.31	250%	0.43	0.74	170%	6	8	Down 2
San Leandro Creek	Alameda	8.94	2.17	24%	*	*	*	0.78	*	3.4	*	0.36	1.58	438%	7	2	Up 5
North Richmond Pump Station	Contra Costa	1.96	1.06	54%	*	*	*	0.29	*	0.63	*	0.27	0.59	220%	8	9	Down 1
Zone 4 Line A	Alameda	4.17	2.63	63%	*	*	*	0.57	*	1.1	*	0.22	0.42	193%	9	11	Down 2
Guadalupe River at Hwy 101	Santa Clara	233	69.8	30%	*	*	*	14	*	60	*	0.19	0.85	438%	10	7	Up 3
099GAC240A	Santa Clara	1.21	0.591	49%	0.030	1.6	0.26	0.081	271%	0.24	802%	0.14	0.40	295%	11	12	Down 1
Rock Springs Dr Storm Drain	Santa Clara	0.829	0.390	47%	0.051	1.6	0.56	0.042	83%	0.13	252%	0.11	0.33	303%	12	13	Down 1
113LGC670A	Santa Clara	0.228	0.131	58%	0.0098	1.4	0.39	0.014	141%	0.036	373%	0.10	0.28	264%	13	14	Down 1
113LGC900A	Santa Clara	0.0602	0.00944	16%	0.00052	2.3	0.39	0.00092	176%	0.0046	881%	0.097	0.48	500%	14	10	Up 4
083LGC430A	Santa Clara	0.239	0.158	66%	0.0055	1.2	0.22	0.015	279%	0.036	657%	0.097	0.23	236%	15	17	Down 2
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	2.80	1.56	56%	1.3	1.4	2.4	0.14	10%	0.37	28%	0.088	0.24	271%	16	15	Up 1
Charcot Ave Storm Drain	Santa Clara	1.79	0.879	49%	0.19	1.6	0.94	0.071	37%	0.21	109%	0.080	0.24	295%	17	16	Up 1
083GAC240	Santa Clara	1.11	0.683	61%	0.0056	1.3	0.15	0.027	480%	0.067	1205%	0.039	0.10	251%	18	19	Down 1
Rosemary St SD 066GAC550C	Santa Clara	3.64	1.69	46%	0.10	1.6	0.68	0.063	61%	0.19	187%	0.037	0.11	305%	19	18	Up 1
North Fourth St SD 066GAC550B	Santa Clara	1.01	0.692	68%	0.036	1.2	0.68	0.025	70%	0.057	159%	0.036	0.083	228%	20	20	
Lower Marsh Ck	Contra Costa	83.6	1.38	2%	*	*	*	0.031	*	0.070	*	0.023	0.051	223%	21	21	
129CNC165A	Santa Clara	1.51	0.793	52%	0.021	1.5	0.66	0.014	67%	0.039	188%	0.018	0.050	283%	22	22	
								Minumum	10%		28%			100%			
								Maximum	480%		1205%			500%			
								Median	94%		188%						

* Data for these cells cannot be computed for our well-sampled watersheds where there were multiple samples taken during multiple storms over multiple water years.
Note, the minimum of two significant figures quoted in these tables to allow others to post-manipulate the data is no claim of accuracy or precision.

increases of five places for San Leandro Creek, four places for the watershed designated 113LGC900A, and three places for Guadalupe River at Hwy 101. The large change in San Leandro Creek can be ignored in this context and is an artifact of the high uncertainty in the relationship between rainfall return frequency and storm loads (Figure 5), which is based on just two well-sampled storms and discussed as an outlier (Figure 6). The watershed designated 113LGC900A is a small watershed within the Guadalupe River watershed that has 16% RWSM "dirty" (Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation) land-uses and thus was estimated to have an adjustment factor of 2.3. It was sampled during a small storm of 0.39-year annual return frequency so the base case was adjusted up by 176% to estimate the 0.5-year annual return frequency load, whereas it was adjusted up by a factor of 881% or 8.81-fold to estimate the 1-year annual return frequency load. The change in Guadalupe was also a result of a relatively steep relationship between rainfall return frequency and storm loads (Figure 5). In this case, an adjustment factor of 2.13 in a watershed characterized by 30% RWSM "dirty" (Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation) land-uses was based on field measurements and deemed to be very reliable.

These three large changes in relative rank estimates cause some concern in the robustness of the method, but the small relative changes seen in 19 of 22 watersheds is very encouraging. We suggest this is further argument for adopting the 0.5-year annual return frequency storm as the standard. As also shown in Table 6-3, when using the 0.5-year annual return frequency storm as the standard, the median adjustment for 22 the watersheds was 94% of the measured storm. In contrast, if the 1 -year annual return frequency storm was adopted as the standard, the median adjustment would have been 188% for the measured storms. The maximum upward adjustment would rise from 480% (4.8-fold) to 12-fold.

Sensitivity to area normalization

Loads vary in relation to watershed size, thus organizing watersheds by an estimated storm load will fail to highlight the relative impacts of PCBs sources between watersheds. Therefore, it was necessary to normalize loads by area to estimate the yields for the more polluted parts of a watershed. But stakeholders ask which area should we use and how does this decision influence the interpretations and resulting decisions? Here we explore the sensitivity of the comparative ranks to the choice of area used in the normalization step. We explored three scenarios against the base case (normalization to the area within each watershed of RWSM Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation land-uses and source areas):

1. No normalization (stakeholders wanted this tested as well)
2. Normalize to Old Industrial and Source Areas
3. Normalize to whole watershed area

- Rank based on loads alone

As discussed in detail in previous sections, the last step (that of area normalization) is a critical step for increasing the sensitivity. Based on the data in this small pilot application, organizing the watersheds based on the estimated load for a 0.5-year annual return frequency storm made the largest impact on which watersheds to prioritize. A total of 14 out of 22 watersheds had changes in rank of three or more positions, ranging between nine places up and eight places down (Table 6-4). This is to be expected since ranking based on load is strongly influenced by the size of the watershed (Guadalupe River at Hwy 101, for example, ranked number one and Sunnyvale East Channel, the 3rd largest watershed in our dataset ranked number two under this scheme). However, the size of the watershed is not the only factor; land-use and pollutant generation likely explains the rest of the scatter (Figure 6-1). It is interesting to note that the area of RWSM "dirty" (Old Industrial and Source Areas plus RWSM Old Commercial and Old Transportation) is a better predictor of PCB loads than the area of Old Industrial alone or Old Industrial plus Source Areas (Figure 6-1).

- Normalize to Old Industrial and Source Areas

For the second sensitivity test, nine out of 21 watersheds changed rank by three or more positions when normalizing to RWSM Old Industrial & Source Areas only. Changes ranged between six places up and five places down compared to the base scenario (Table 6-4). In this case, only 21 watersheds could be ranked because the site on San Leandro Creek had no Old Industrial and Source Areas land-use area upstream. In this analysis, the watersheds with the largest upshift were those that had a large ratio of RWSM Old Industrial and Source Areas to RWSM Old Commercial and Old Transportation (Zone 4 Line A, Guadalupe River at Hwy 101, the watershed designated 113LGC900A, Seabord Ave Storm Drain SC-050GAC600, and Lower Marsh Ck). The exception was Sunnyvale East Channel which was already ranked high; it also has a large ratio of RWSM Old Industrial and Source Areas to RWSM Old Commercial and Old Transportation. In contrast, those watersheds that had the largest downshifts had a small ratio of RWSM Old Industrial and Source Areas to RWSM Old Commercial and Old Transportation.

- Normalize to whole watershed

For the last test in this series of sensitivity analyses, the estimated 0.5-year annual return frequency storm loads were normalized to whole watershed area. In comparison to the base case, just four out of 22 watersheds had changes in rank of three or more positions up or down with changes ranging between four places up and six places down (Table 6-4). In this case, those that went down in rankings were those that have a relatively low portion of land-use in RWSM Old Industrial and Source Areas to RWSM Old Commercial and Old Transportation. The exception was Lower Marsh Creek which was already ranked low. Downshifts were more concerning in the context of the objectives of this overall project, which was to locate watersheds patches that could be of high management importance. In contrast, watersheds that went up in ranking were North Fourth St SD 066GAC550B and the watershed designated 083LGC430A, both tributaries of the Guadalupe River that have a moderate amount (66-68%) of RWSM Old Industrial and Source Areas to RWSM Old Commercial and Old Transportation land-uses. Note that Outfall to Lower Silver Creek, Ridder Park Dr. Storm Drain, Seabord Ave Storm Drain SC-050GAC580, Pulgas Creek PS South, and E. Gish Rd Storm Drain did not change much in rank since all have upwards of 84% land-use in RWSM Old Industrial and Source Areas to RWSM Old Commercial and Old Transportation.

Table 6-4. Sensitivity of watershed prioritization to the area used for the normalization step (Step 4).

Watershed/ Catchment	County	Tot. Area (km2)	Old Industrial & Source Areas - Area (km2)	RWSM "dirty" (old industrial and source areas plus RWSM old commercial and old transportation) (km2)	Adjusted load normalized to RWSM old industrial and source areas plus RWSM old commercial and old transportation (base case) (g/km2)	Estimated storm load for the sampled storm adjusted to 0.5 yr return (Best) (g)	Adjusted load normalized to RWSM old industrial and source areas (g/km2)	Adjusted load normalized to whole watershed area (g/km2)	Rank (base case)	Rank (based on storm load for the sampled storm adjusted to 0.5 yr return)	Change	Rank (based on adjusted load normalized to RWSM old industrial and source areas)	Change	Rank (based on area normalization to whole watershed)	Change
Pulgas Creek Pump Station South	San Mateo	0.584	0.317	0.571	1.5	0.83	2.6	1.42	1	4	Down 3	2	Down 1	1	
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	1.35	0.983	1.32	1.2	1.6	1.6	1	2	3	Down 1	3	Down 1	2	
Sunnyvale East Channel	Santa Clara	14.8	0.605	6.76	1.0	6.8	11	0.46	3	2	Up 1	1	Up 2	5	Down 2
E. Gish Rd Storm Drain	Santa Clara	0.438	0.328	0.422	0.84	0.35	1.1	0.80	4	7	Down 3	5	Down 1	3	Up 1
Outfall to Lower Silver Creek	Santa Clara	0.171	0.136	0.147	0.71	0.10	0.77	0.61	5	11	Down 6	7	Down 2	4	Up 1
Ridder Park Dr Storm Drain	Santa Clara	0.497	0.287	0.419	0.43	0.18	0.63	0.37	6	9	Down 3	9	Down 3	6	
San Leandro Creek	Alameda	8.94	0	2.17	0.36	0.78	NA	0.088	7	5	Up 2	*	(No rank)	9	Down 2
North Richmond Pump Station	Contra Costa	1.96	0.426	1.06	0.27	0.29	0.67	0.15	8	8		8		7	Up 1
Zone 4 Line A	Alameda	4.17	0.558	2.63	0.22	0.57	1.0	0.14	9	6	Up 3	6	Up 3	8	Up 1
Guadalupe River at Hwy 101	Santa Clara	233	9.97	69.8	0.19	14	1.4	0.058	10	1	Up 9	4	Up 6	13	Down 3
099GAC240A	Santa Clara	1.21	0.335	0.591	0.14	0.081	0.24	0.067	11	12	Down 1	14	Down 3	10	Up 1
Rock Springs Dr Storm Drain	Santa Clara	0.829	0.0961	0.390	0.11	0.042	0.44	0.051	12	15	Down 3	10	Up 2	14	Down 2
113LGC670A	Santa Clara	0.228	0.118	0.131	0.10	0.014	0.12	0.060	13	21	Down 8	18	Down 5	12	Up 1
113LGC900A	Santa Clara	0.0602	0.00321	0.00944	0.097	0.00092	0.29	0.015	14	22	Down 8	11	Up 3	20	Down 6
083LGC430A	Santa Clara	0.239	0.0625	0.158	0.097	0.015	0.24	0.064	15	19	Down 4	13	Up 2	11	Up 4
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	2.80	0.521	1.56	0.088	0.14	0.26	0.049	16	10	Up 6	12	Up 4	15	Up 1
Charcot Ave Storm Drain	Santa Clara	1.79	0.501	0.879	0.080	0.071	0.14	0.039	17	13	Up 4	16	Up 1	16	Up 1
083GAC240	Santa Clara	1.11	0.316	0.683	0.039	0.027	0.084	0.024	18	17	Up 1	20	Down 2	18	
Rosemary St SD 066GAC550C	Santa Clara	3.64	0.448	1.69	0.037	0.063	0.14	0.017	19	14	Up 5	15	Up 4	19	
North Fourth St SD 066GAC550B	Santa Clara	1.01	0.286	0.692	0.036	0.025	0.088	0.025	20	18	Up 2	19	Up 1	17	Up 3
Lower Marsh Ck	Contra Costa	83.6	0.239	1.38	0.023	0.031	0.13	0.00037	21	16	Up 5	17	Up 4	22	Down 1
129CNC165A	Santa Clara	1.51	0.613	0.793	0.018	0.014	0.023	0.009	22	20	Up 2	21	Up 1	21	Up 1

*San Leandro Creek, where monitoring took place at San Leandro Boulevard, has no old industrial and source areas land-use up stream. As a result, this watershed could not be ranked using this method of normalization.

Note, the minimum of two significant figures quoted in these tables to allow others to post-manipulate the data is no claim of accuracy or precision.

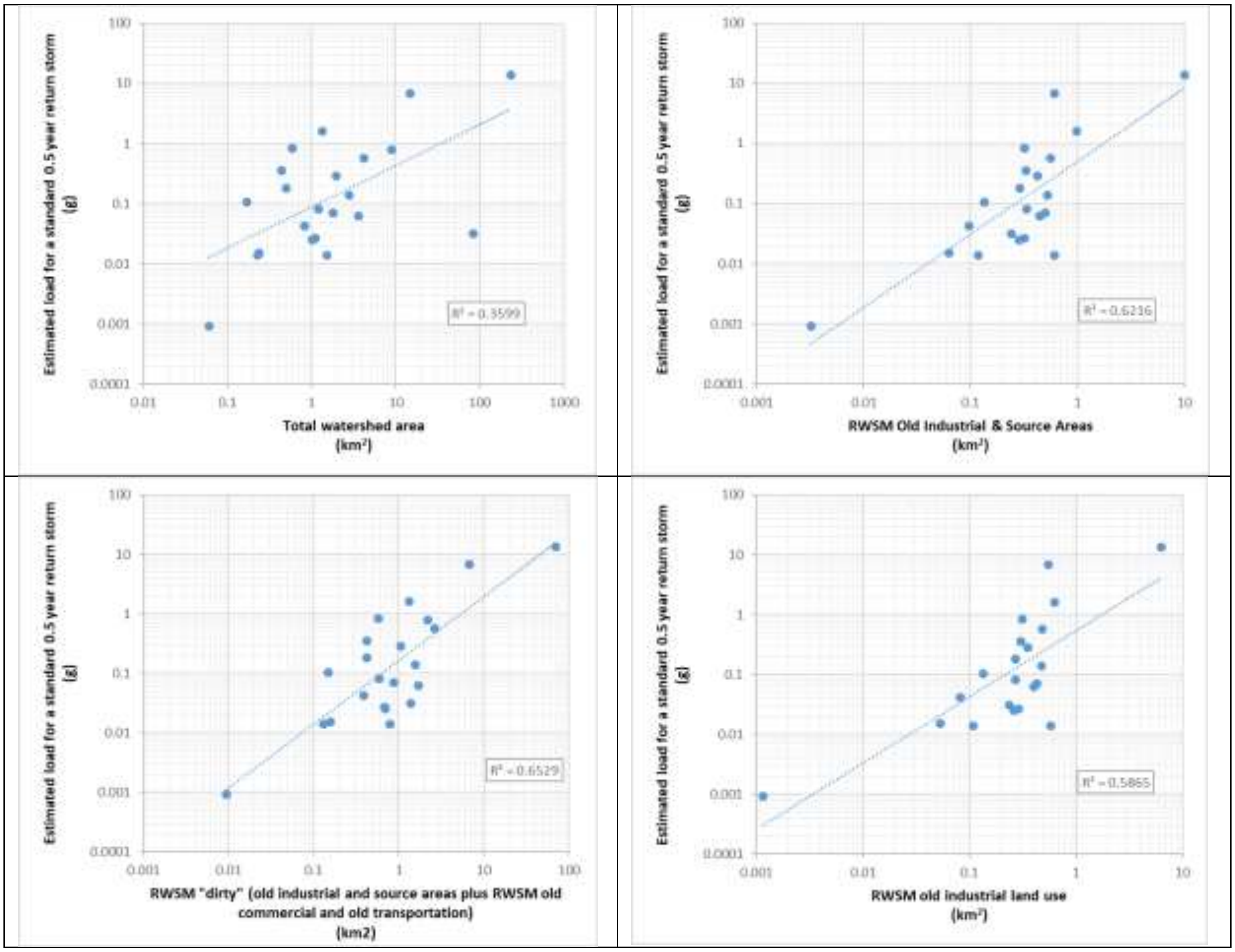


Figure 6-1. Relationships between various land-use characteristics and the estimated 0.5-year annual return frequency storm PCB loads.