

TECHNICAL MEMORANDUM

Selenium Fractionation and Speciation in Final Effluents of Selected San Francisco Bay Area Municipal Wastewater Treatment Facilities

Prepared for:

Bay Area Clean Water Agencies

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Background

San Francisco Bay is listed under section 303(d) of the Clean Water Act as impaired by selenium due to bioaccumulation in diving ducks leading to health advisories on their consumption by hunters. Selenium concentrations may also be above safe levels in other wildlife, potentially causing reproductive impacts in white sturgeon and other species.

Selenium (Se) occurs in various chemical forms with different oxidation states in the environment, which affects its chemical partitioning and biological uptake. Selenate, SeO_4^{2-} , with a +6 oxidation state (Se VI), is the dominant species in aerobic aquatic environments, but is the form least strongly bioaccumulated or adsorbed to particulate matter. Selenite, SeO_3^{2-} , with a +4 oxidation state (Se IV), is less abundant but much more strongly adsorbed and bioaccumulated. After uptake into microorganisms (e.g., bacteria and phytoplankton) these inorganic selenium species can be transformed into organic species such as the selenium containing amino acids, selenocysteine and selenomethionine, and incorporated into cellular peptides and proteins. Once taken up and transformed into organic forms in microbes and algae, selenium is transferred to and bioaccumulated in higher trophic organisms, with dietary uptake serving as the primary route of exposure. Although selenium chemical speciation is not static and can be altered through abiotic and biological processes within the Bay, understanding the speciation and partitioning of selenium loads is needed to understand their magnitudes relative to in Bay transformation and uptake processes.

Because of the differences in partitioning and biouptake, in addition to total selenium loads, the chemical speciation of various selenium sources is important to estimating their relative risks and any benefits of controls or other management actions. Previous work in the Bay characterized ambient concentrations of various selenium species as well as those of major inputs to the system including refineries and municipal dischargers (Cutter and San Diego-McGlone 1990). In that work, some refinery effluents showed selenite as a majority of their selenium discharge. Municipal wastewater effluent showed a different speciation, where selenate was often 70-90% of total dissolved selenium, selenite 10-20%, and all other species (primarily organo selenides) typically comprising 0-10% of dissolved Se. However, there were many exceptions, with instances where municipal effluents were not dominantly selenate, including cases of 100% selenite, >50% organic selenium, and others less extreme. Total Se concentrations in that work ranged ~3-28 ug/L in municipal effluents.

Following controls introduced at refineries, a subsequent study showed decreases in selenite loads and concentrations in both refinery effluent and the ambient environment (Cutter and Cutter 2004). More recent monthly monitoring at refineries (2010-2011) for the Selenium Characterization Study in North Bay (unpublished preliminary data) generally showed continued lower selenite and organic selenium species compared to selenate, averaging 21%, 24%, and 53% of dissolved selenium respectively, although distributions for individual samples still varied widely among plants and events (e.g., selenite ranging 0-99% of dissolved selenium).

Since that earlier study in the 1980's (Cutter and San Diego-McGlone 1990), selenium speciation in municipal wastewater effluent has not been measured widely in the Bay Area, so the Bay Area Clean Water Agencies (BACWA) sponsored a study conducted by

the San Francisco Estuary Institute (SFEI) to determine current speciation characteristics of effluents at selected municipal POTWs. In consultation with BACWA and the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB), SFEI selected for sampling treatment plants of three of the largest dischargers (East Bay Dischargers Association (EBDA), East Bay Municipal Utility District (EBMUD), and Central Contra Costa Sanitary District (CCCSD) and four smaller plants with the highest average total selenium concentrations in recent (2009-2010) discharge permit reporting to the SFBRWQCB.

Methodology

Sampling

Grab samples of final effluent post-chlorination and dechlorination were collected by treatment plant staff on four occasions: two during the wet season (November to March), and two in the dry season (April to October). Wet season samples were collected at least 6 to 8 hours following rain events that caused increased influent flow into the plant, allowing sufficient time for rain-influenced effluent to be sampled at the collection point. Dry season samples were collected in the morning on Mondays, primarily for logistical considerations. Monday morning sampling afforded sufficient time for sample preparation, shipping, and delivery to the Trent University analytical laboratory to conduct sample analysis within the desired holding time (~7 days). Samples at each site were collected into three 1L pre-cleaned HDPE bottles with minimal headspace, stored chilled in the dark at the treatment plants until pickup, then transported in coolers with wet ice to the EBMUD Laboratory for storage chilled (~4 C) in the dark until processing.

Processing

EBMUD Laboratory staff filtered ~800 ml to 1L of sample through pre-weighed 0.45 um pore-size nitrocellulose membrane filters to allow determination of total suspended solids (TSS), with subsequent digestion and analysis for particulate selenium at the EBMUD lab. The filtrate was collected and transferred to 3 ~250ml precleaned HDPE bottles with minimal headspace and sent to Trent University (Ontario, Canada) for dissolved-phase selenium species analysis. EBMUD retained a portion of the filtrate for dissolved phase (unspeciated) selenium analysis. Samples for total (whole water) Se determination at EBMUD were stored without further processing until analysis.

Laboratory analysis

EBMUD measured collected solids on filters for TSS by Standard Methods 2540. Pre-weighed filters with filtered material from selenium samples were dried in an oven at 103 to 105 C for a minimum of 1 hour, until stable weights were measured. TSS was then calculated for each sample as the difference between the initial and final filter weights.

EBMUD analyzed samples for total suspended solids and total, dissolved, and particulate phase selenium in-house. Samples were analyzed for selenium using Standard Methods SM 3114B, (manual) hydride generation atomic absorbance spectrometry. Samples were first digested in an oxidizing acidic solution, with Se(VI) then prereduced to Se(IV) by heating in a hydrochloric acid solution, and subsequently converted to volatile hydrides

in an acidic sodium borohydride solution, purged by inert carrier gas, and measured by atomic absorption spectrometry.

Discrete soluble selenium species in filtered effluent samples were measured by Trent University using anion-exchange chromatography-anion self-regenerating suppressor-inductively-coupled plasma-dynamic reaction cell-mass spectrometry (AEC-ASRS-ICP-DRC-MS). Samples were analyzed as is without digestion or dilution; methane was used as the reaction gas, and the major isotope ^{80}Se was used for quantification. An example chromatogram (Figure 1) shows a signal of hydrogen bromide ($^1\text{H}^{79}\text{Br}$), with the same mass as target ^{80}Se isotope, but its signal is well-separated from those of target selenium species by the anion-exchange column. Three known selenium species, selenite = Se(IV), selenate = Se(VI) and selenocyanate = SeCN, are identified, along with four unidentified species (with retention times or peaks labeled US1 to US4 in Figure 1).

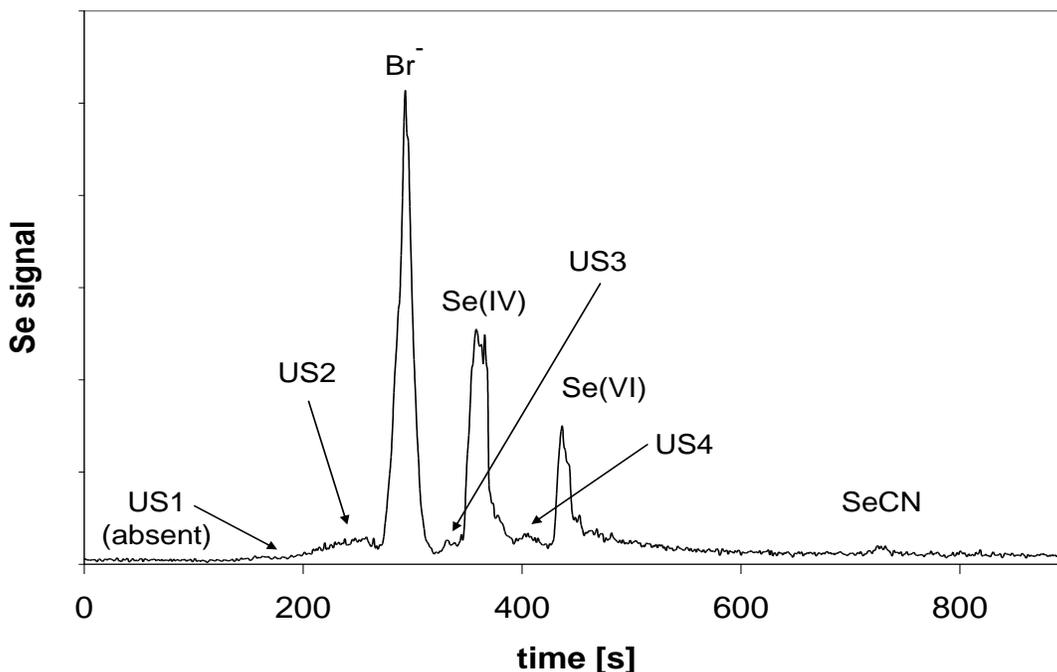


Figure 1 – Example AEC-ASRS-ICP-DRC-MS chromatogram. US1 to US4 indicate retention times for unidentified selenium containing species often found in these effluent samples.

Subsamples of the filtered samples sent to Trent University for analysis were analyzed for total dissolved Se using ICP-DRC-MS. Nitric acid was used to oxidize volatile Se species to non-volatile ones and yielded a more stable instrument response. Due to the bromide interference at atomic mass 80 (without column chromatography, not distinguished from ^{80}Se), the ^{78}Se isotope was used for measurement total dissolved Se.

A subsample of filtered material sent to Trent University was sent to Laurentian University for measurement of organic selenium species using selective sequential hydride generation-atomic fluorescence spectrometry (SSHG-AFS) using UV-assisted breakdown of organic matter and discrete organic Se compounds to the hydride generation-active Se(IV) (Chen et al., 2005). This method measures Se(IV) directly in the sample by HG-AFS, and then measures a separate sample aliquot which has been

digested by a combined oxidation-UV irradiation procedure. The latter treatment converts organic selenium species into Se(IV), with “organic selenium” (Se-org) estimated by difference between the two measurements.

Results

Tables of the results for individual samples collected and analyzed are reported in tabular form in the Appendix. Dissolved, particulate, and total selenium fractions were analyzed for all samples collected. Speciation of dissolved selenium was analyzed for all samples for all treatment plants, except for Delta Diablo, for which only the first two samples were sent to Trent University and analyzed.

Concentrations of selenium in whole water samples ranged 0.21 to 2.0 ug/L, much lower than in the earlier (Cutter and San Diego-McGlone 1990) study of Bay area treatment plants. Concentrations were higher in the wet weather events for most plants (Figure 2), significantly so with all plants considered together ($P < 0.05$, t-test), suggesting increased input of selenium from inflow and infiltration to the treatment plants in those periods. For many of the treatment plants considered individually, despite the small number of samples for each season ($n=2$), differences between wet and dry season averages were sometimes also significant ($p < 0.05$).

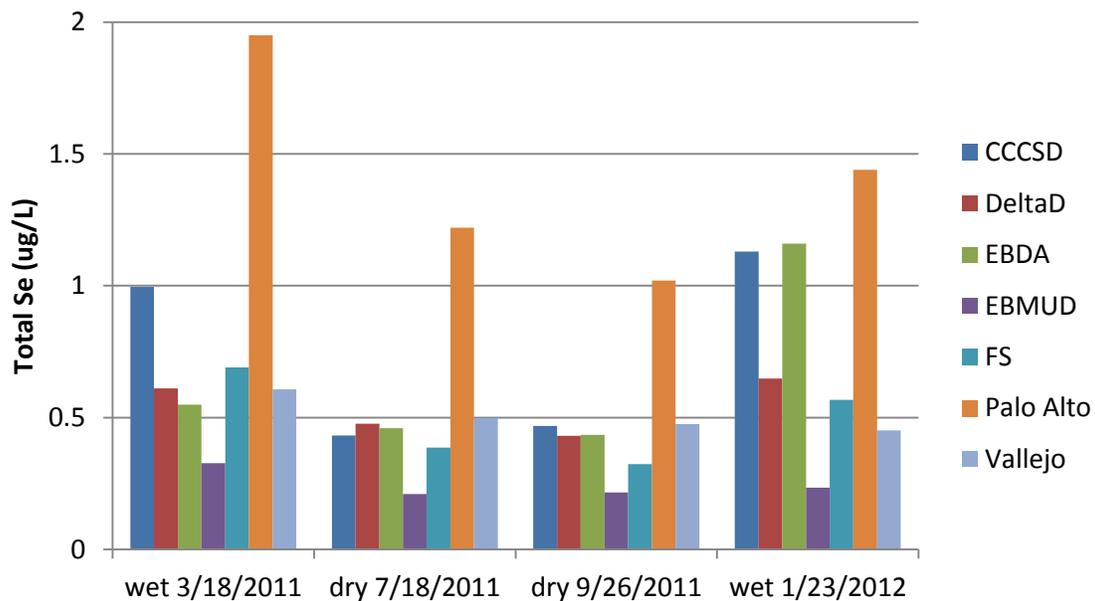


Figure 2 -Total selenium concentrations in wastewater effluents. Wet weather concentrations were higher than in dry season at most plants.

The plants with the lowest and highest selenium concentrations also generally remained the same among both wet and dry season events, suggesting consistent selenium input sources for each area. However, only the difference between the highest concentration plant and all the others was significant ($p < 0.05$, t-test); the plant with the lowest average concentration was not significantly different from plants other than the highest when all

events were included. The lack of significance for other pairings is likely due to the small number of samples (n=4) and the variation between wet and dry season results within a plant. Analyzing only within a single season, sample numbers are further reduced (n=2), so significant differences between most pairs of plants (other than the lowest versus highest) are still not found.

Dissolved selenium concentrations covered virtually the same range as total selenium, from 0.17 to 1.9 ug/L. Consistent with the dissolved fraction constituting the majority of selenium in effluent (Figure 3), the dissolved selenium fraction was highly correlated to total selenium concentrations ($R^2 = 0.99$), and ranged from 71 to 101% of total (unfractionated) selenium, averaging (\pm stdev) 89(\pm 8) % (Table 1). The patterns of higher concentrations in wet season samples at most plants remained the same, although the differences were slightly outside the threshold for significance ($p=0.053$, t-test). Plants with the lowest and highest concentrations remained the same, again with a significant difference ($p<0.05$, t-test) between the highest versus all others, but few significant differences between most other pairs.

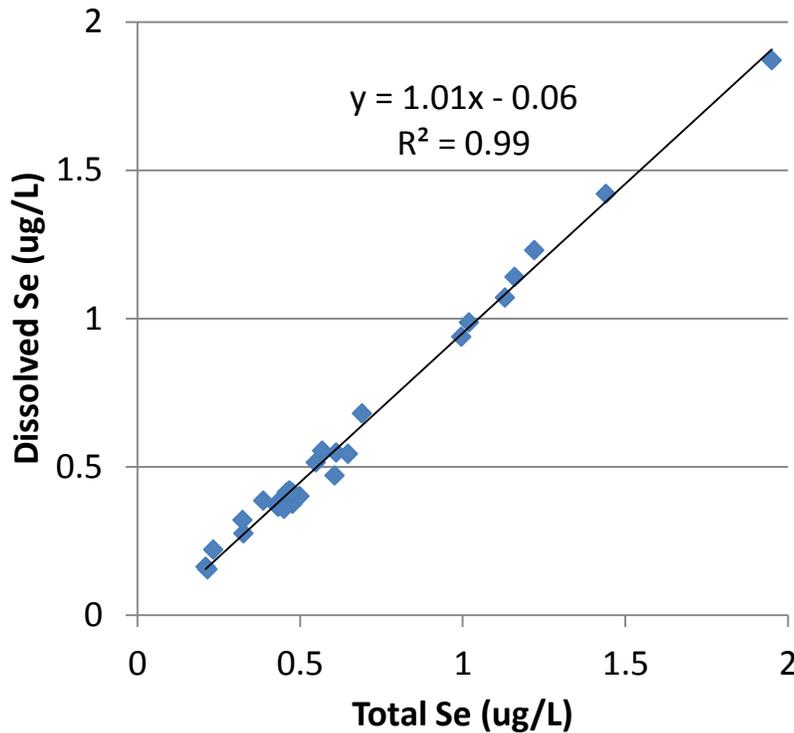


Figure 3 -Dissolved versus total selenium concentrations. Dissolved selenium constitutes the majority of selenium in effluent.

Table 1 -Average percentages (\pm stdev) of dissolved and particulate fraction selenium in municipal wastewater effluents. Selenium was dominantly dissolved phase at all plants.

	Dissolved	Particulate
CCCS	91(\pm 5)	7(\pm 4)
DDSD	85(\pm 5)	9(\pm 3)
EBDA	92(\pm 6)	8(\pm 4)
EBMUD	82(\pm 10)	7(\pm 4)
FSSD	99(\pm 1)	2(\pm 1)
Palo Alto	98(\pm 2)	1(\pm 0)
VSFCD	81(\pm 4)	14(\pm 2)
All	89(\pm 8)	7(\pm 5)

Particulate Se was consistently only a small fraction, ranging 1 to 14% of total (unfractionated) selenium in effluent. No seasonal patterns were apparent in particulate selenium, with high concentrations occurring in dry season for some plants and in the wet season for others (Figure 4), and no significant differences between seasons for all plants considered together. However, there were significant differences ($P < 0.05$, t-test) among some treatment plants (i.e. between those with the lowest and highest concentrations for both all seasons combined, and wet or dry season individually), with the same plants generally at the higher and lower ends of the range for all the sampling events. These differences in particulate Se in samples correlated moderately ($R^2 = .43$) and significantly ($p = 0.001$) to the total particulate mass (total suspended solids, TSS Figure 5), suggesting similar partitioning behavior of Se among plants.

As a check of the internal consistency of the results for analysis of Se fractionation, the selenium as sums of dissolved and particulate fractions generally added up to close to the same concentrations as separately analyzed (unfractionated) total selenium samples, ranging 81 to 102% of the total samples (Figure 6). The largest relative deviations were in the lowest concentration samples, where analytical noise would be expected to be largest relative (as a percentage) to reported concentrations, even if the nominal variations (i.e. in $\mu\text{g/L}$) are similar across the range.

There was also reasonably good agreement and correlation ($R^2 = 0.90$) between concentrations reported for the dissolved fraction analyzed by EBMUD compared to those reported by Trent (Figure 7). Relative percent differences between the labs ranged up to 60%, but most were in a lower range (35% or lower, averaging 12%).

For most of the samples, selenate was the dominant dissolved phase species, accounting for 5% to 92% of dissolved selenium species in individual samples, averaging (\pm stdev) 40(\pm 24)% (Figure 8, Table 2) for all samples together. The organic selenium analyzed by Laurentian University was often the next most abundant, accounting for 0% to 76% (average 33(\pm 21)%) of dissolved selenium. Selenite typically accounted for a smaller portion (1% to 46%, average 15(\pm 17)%), with the various unidentified species isolated by anion exchange chromatography (US1 to US4) and selenocyanate (SeCN) accounting for the remainder (average 8(\pm 10)% and 4(\pm 7)% of dissolved selenium respectively).

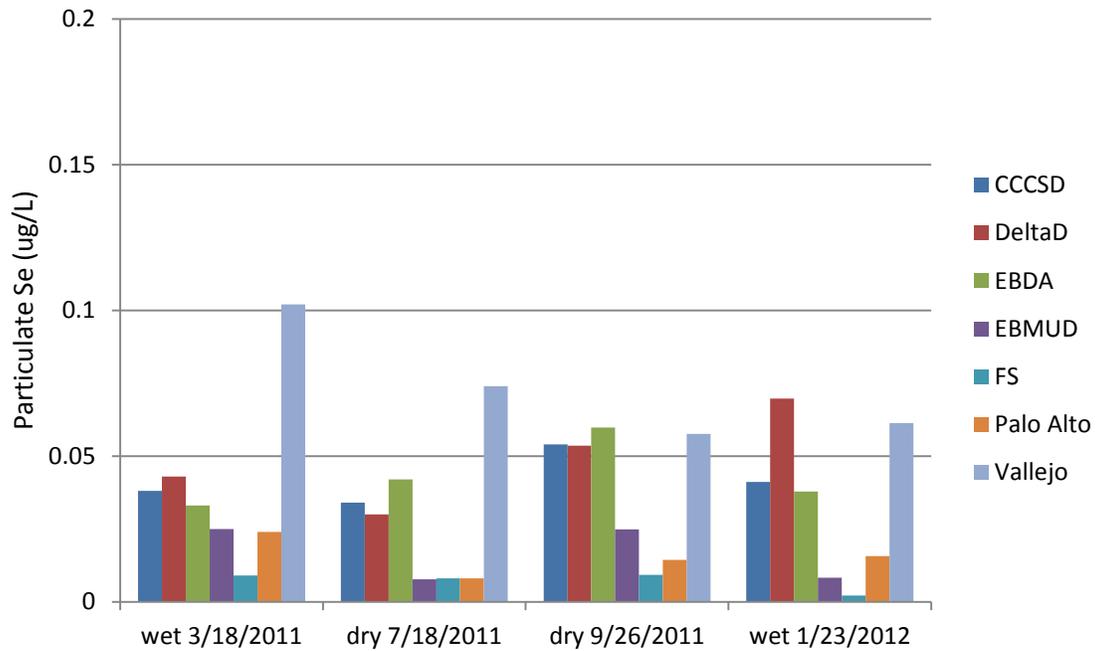


Figure 4 - Particulate selenium in effluent samples. Particulate selenium showed no seasonal patterns, with the highest concentrations occurring in the dry season at some plants and in the wet season at others.

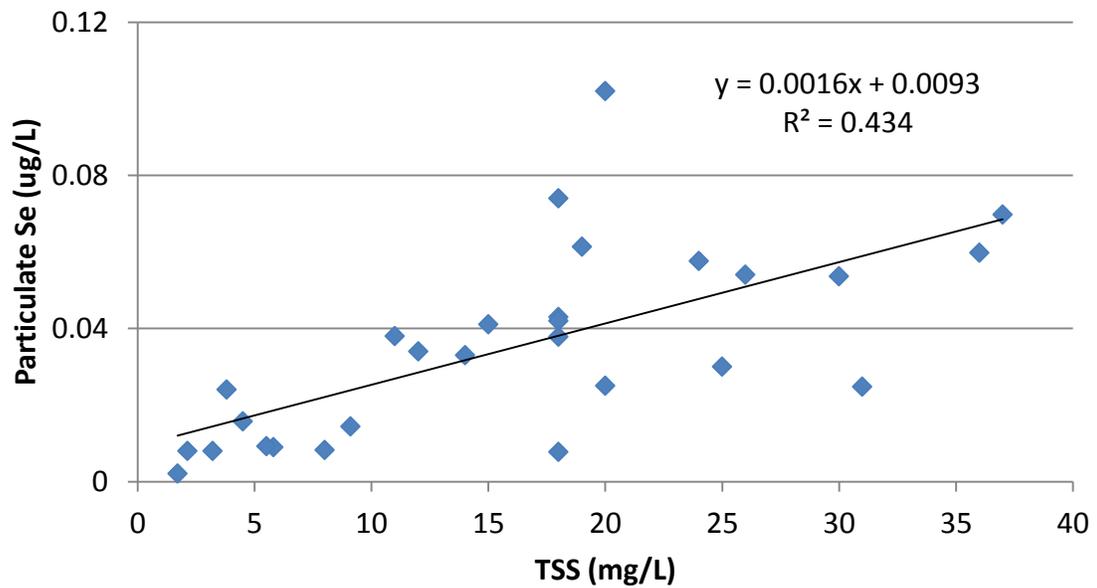


Figure 5 -Particulate selenium versus total suspended solids. Particulate selenium generally correlated to total suspended solids, suggesting similar partitioning behavior and concentrations of selenium in solids among plants and events.

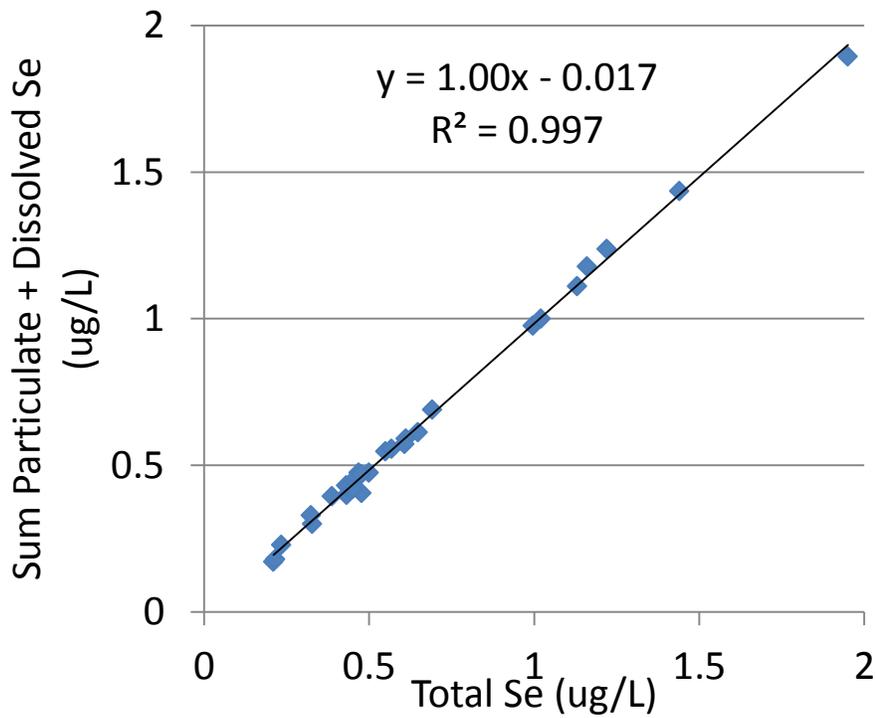


Figure 6 -Sum of dissolved and particulate fractions compared to total selenium. Sums of fractions generally were equivalent to total fractions within the range of analytical precision.

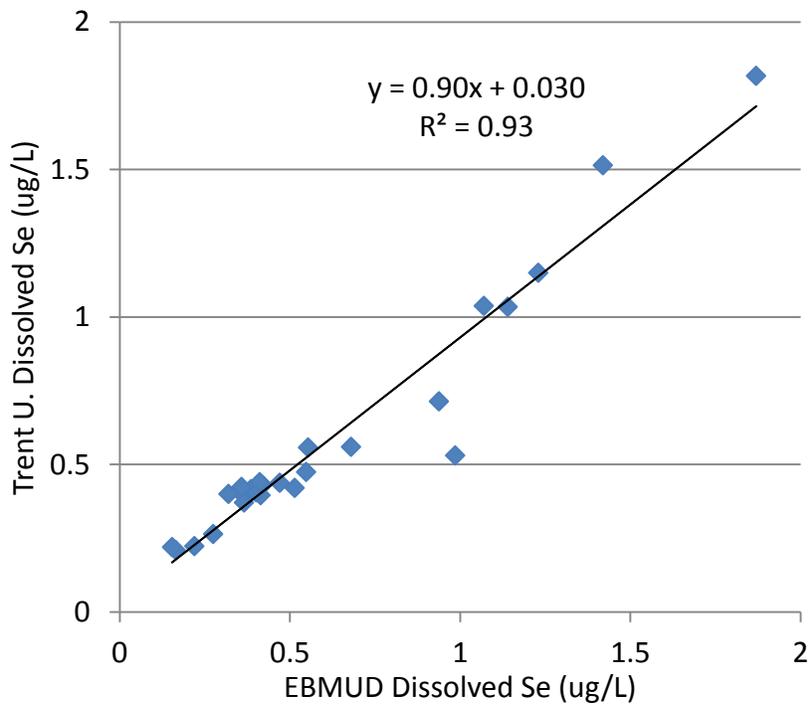


Figure 7 -Dissolved selenium concentrations reported by Trent versus EBMUD. Results were generally similar between laboratories for most samples.

Two plants had unique dissolved species distributions; Palo Alto had dominantly selenite (Se IV), significantly ($p < 0.05$, t-test) higher than all other plants, and Vallejo samples had primarily the organic selenium species reported by Laurentian University, significantly higher than three of the six other plants. Selenium originating from different sources can have different speciation characteristics, and bacteria such as those in sludge reactors are capable of transforming selenium species (van Hullenbusch et al. 2007). The specific causes of the differences in these Bay Area plants is unknown, and would require analysis of samples from water suppliers, influent, and/or other points in the water supply and treatment stream to determine their origin.

Table 2 -Average (%(\pm stdev)) contribution of individual species to dissolved fraction selenium. SeCN = selenocyanate, Org Se (LU) = organo selenium species analyzed by Laurentian University, and UnID'd Se (TU) = the sum of unidentified selenium species by anion chromatography analyzed by Trent University.

	Selenate (Se VI)	Selenite (Se IV)	SeCN	Org Se (LU)	US1 – US4 (TU)
CCCSD	33(\pm 9)	9(\pm 10)	13(\pm 15)	42(\pm 14)	3(\pm 3)
DDSD	37(\pm 2)	8(\pm 4)	5(\pm 3)	44(\pm 2)	6(\pm 7)
EBDA	57(\pm 19)	6(\pm 5)	3(\pm 1)	28(\pm 14)	7(\pm 8)
EBMUD	36(\pm 19)	17(\pm 5)	4(\pm 4)	27(\pm 21)	17(\pm 20)
FSSD	78(\pm 12)	2(\pm 1)	2(\pm 1)	13(\pm 15)	5(\pm 5)
Palo Alto	23(\pm 8)	48(\pm 14)	1(\pm 0)	20(\pm 13)	8(\pm 4)
VSFCD	12(\pm 6)	11(\pm 4)	3(\pm 1)	65(\pm 12)	9(\pm 10)
All	40(\pm 24)	15(\pm 17)	4(\pm 7)	33(\pm 21)	8(\pm 10)

One sample from CCCSD had an unusually high proportion of selenocyanate, about ten times higher than in any other samples. On requested reexamination of the instrument data, the laboratory confirmed the identification and quantification of selenocyanate; the peak location and ratio of selenium isotopes in the sample were consistent with that identification. Although at a much lower concentration, the second highest concentration of selenocyanate was also in a sample from CCCSD, which suggests that the other result was a valid signal.

Seasonal differences in mean concentrations were not significant for any species when considering all the plants together, as there was large variation among all the plants within each season. However, some selenium species in individual plants showed significant differences between seasons. For selenite (Se IV) and selenate (SeVI), only CCCSD showed significantly ($p < 0.05$ t-test) higher concentrations in wet season. For the sum of unidentified species by anionic chromatography (analyzed by Trent), only Vallejo samples showed significantly higher concentrations in the wet season. Organo-selenium species (reported by Laurentian) and selenocyanate showed no significant seasonal patterns for any of the plants.

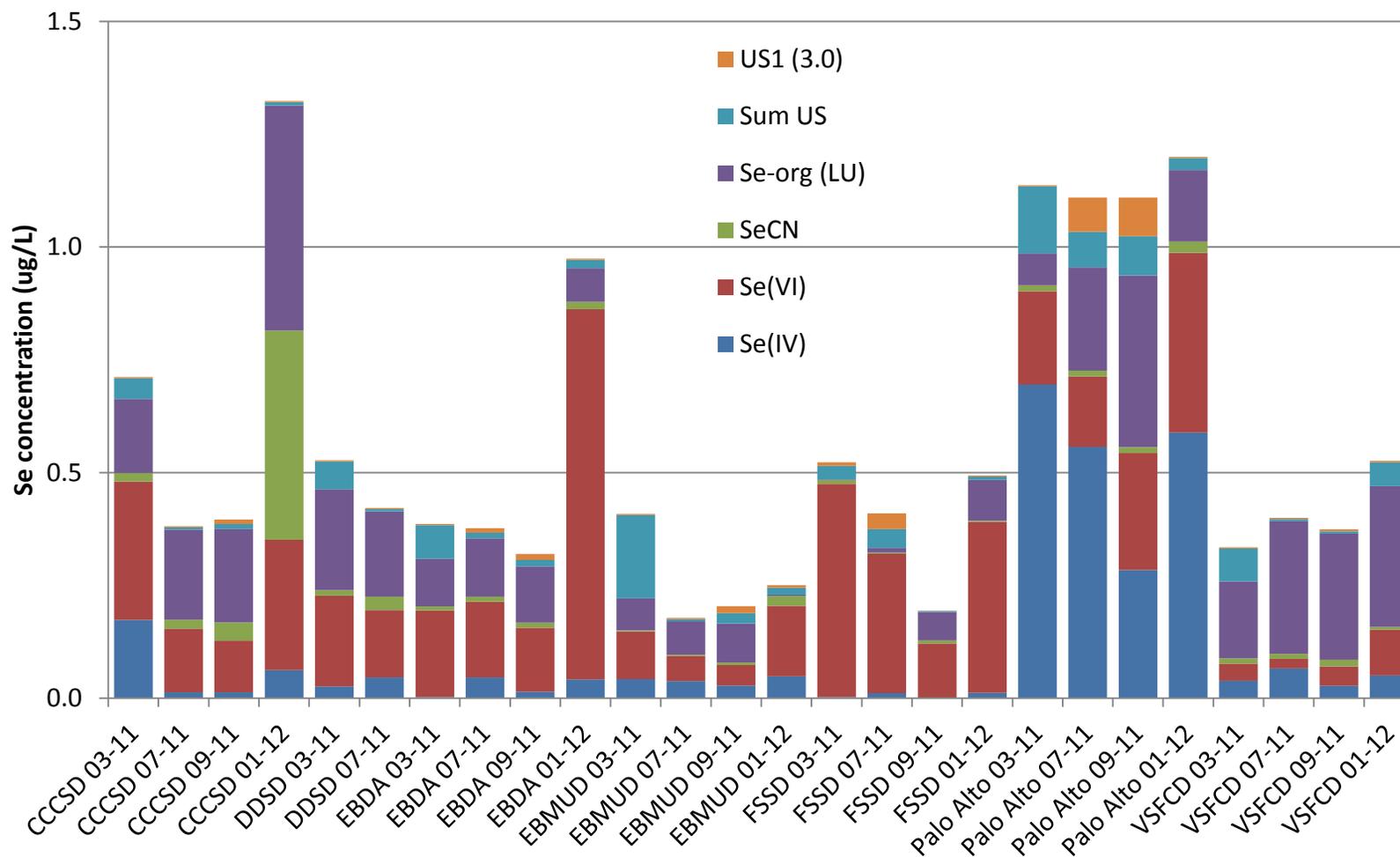


Figure 8 - Dissolved fraction selenium speciation. Selenate (Se VI) was the dominant species, with organic selenium (Se-org, as analyzed by Laurentian University), and selenite (Se IV) as the next most abundant species in most samples. However, two plants had atypical distributions, one with dominantly selenite, and another mostly organic selenium in all sample events. There was also one sample with unusually high selenocyanate (SeCN). Wet weather events were sampled on 03-11 and 01-12

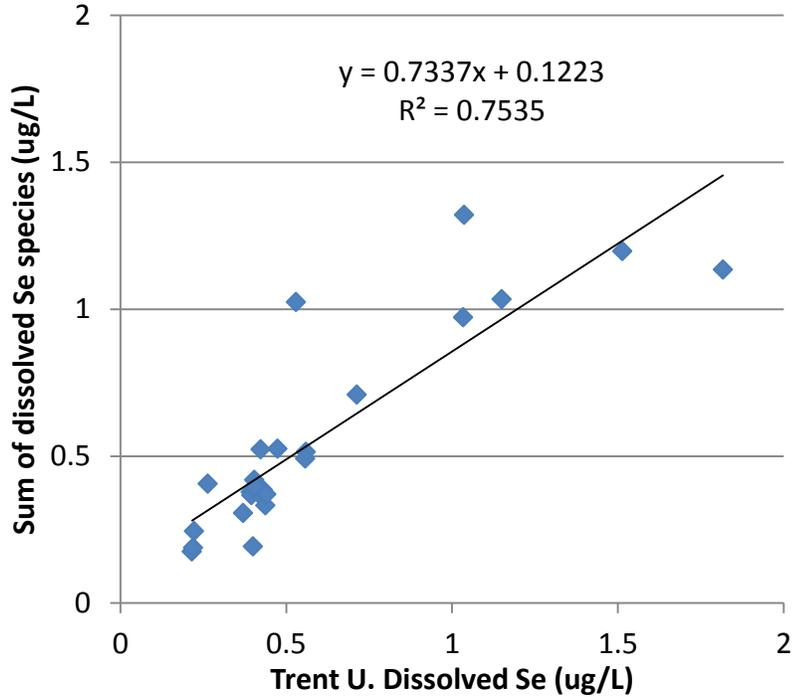


Figure 9 - Sum of all Se species versus unspicated dissolved Se concentrations. The sum of species includes organic selenium reported by Laurentian; the low bias relative to unspicated dissolved Se reported by Trent suggests little or no overlap with the unidentified selenium species reported by Trent in anion exchange chromatography.

Because analyses by Trent (by AEC-ASRS-ICP-DRC-MS) and Laurentian (by SSHG-AFS) were performed on parallel subsamples rather than sequentially analyzing the same sample, the possibility exists that there is overlap in some of the unidentified selenium species reported by Trent and the organic selenium species reported by Laurentian. Sums of the quantified species including and excluding organic selenium species reported by Laurentian were therefore compared to separate analyses of (unspicated) dissolved selenium performed by Trent. If both analyses reported some of the same species, the sum including the Laurentian results would double count those species, resulting in a high bias of the sum compared to the unspicated analysis concentration. A plot of the sum of species including the Laurentian results however still mostly biases low compared to unspicated dissolved selenium analyses (Figure 9). A regression with the sums excluding the Laurentian results showed an even lower bias (slope of 0.70 versus the 0.73 shown), and a slightly worse correlation ($R^2 = 0.70$), so it is likely that there is little to no overlap in the species reported by Trent and Laurentian.

Discussion

Overall, the results are similar to those in previous studies examining selenium fractionation and speciation in municipal wastewater dischargers. Most selenium was found in the dissolved fraction, with only a small percentage in particulate forms. Among the dissolved selenium forms, selenate (Se VI) was the dominant species for most locations, with unspecified organic species and selenite (Se IV) accounting for smaller portions of the dissolved species. However, also similar to previous results, the relative

contributions of various dissolved selenium species were somewhat variable among plants and events.

A correlation of particulate selenium concentration with total suspended solids suggests that solids removal is generally effective at reducing the particulate fraction in discharged effluent. Increased solids removal for effluents with higher TSS can reduce that fraction further, but will not prevent uptake or re-partitioning of dissolved fraction selenium to particulate phases once released into the environment. The latter processes, as well as particulate selenium inputs from riverine and tributary sources are likely important in determining ambient concentrations, as effluent discharged from municipal wastewater plants (approximately 600 million gallons per day, or 830 million cubic meters per year), combined with particulate selenium average concentrations measured in this study ($\text{avg}(\pm\text{stdev}) = 0.035(\pm 0.025) \text{ ug/L}$) yielded estimated loads of only $29(\pm 20) \text{ kg}$ per year. In comparison, the Delta delivers an estimated 47 to 686 kg of particulate selenium per year ((Abu-Saba and Ogle 2005), using data from Cutter and co-authors). Most of the fifteen-fold variation in Delta loads was from variations in annual flow, as particulate selenium concentrations in the Delta used for that calculation varied by less than a factor of two (Doblin et al. 2006). The suspended particulate selenium in the Bay (based on the difference between areally averaged total (0.119 ug/L) and dissolved (0.100 ug/L) selenium concentrations from Regional Monitoring Program data 2005 to 2010, and an approximate Bay volume of 6.7×10^9 cubic meters) yields an inventory of 128 kg. Thus upper end estimates of annual particulate selenium loads from municipal wastewater are approximately equal to minimum Delta loads, and less than half the Bay inventory

Concentrations of dissolved selenium were generally much higher, averaging ($\pm\text{stdev}$) $0.606(\pm 0.416) \text{ ug/L}$, yielding annual loads of $503(\pm 345) \text{ kg/year}$ from municipal wastewater. These loads were above the low end of estimated dissolved selenium discharge from the Delta (282 to 9570 kg/year (Abu-Saba and Ogle 2005)), and of the same magnitude as the inventory in the water column estimated using RMP data from 2005 to 2010 (666 kg). The load estimated here for municipal wastewater is likely to be near its upper limit, as the sampled facilities include three of the largest dischargers, and the smaller plants sampled include those with the highest selenium concentrations in previous discharge permit monitoring reported to the SFBRWQCB. Because of this overrepresentation of plants with previously high reported concentrations in the sampled group of facilities, the simple mean concentration reported here is likely higher than would be obtained by a flow weighted mean of all municipal wastewater plants in the region, and thus likely represents a conservative maximum load from municipal wastewater sources.

Another factor likely leading to an overestimate from use of a simple mean of results for this study is the over-representation of wet season selenium concentrations, which tended to be higher than those collected in the dry season. Although dry periods in the wet season were not sampled, it would be expected that the water and selenium sources in those periods would be more similar in constitution and thus concentrations to dry season samples rather than wet season rain event samples. More refined estimates dissolved and particulate selenium fraction loads, or of individual dissolved selenium species could be made using the data provided here, but their results would largely depend on the assumptions made for unsampled locations and periods. For example, wet season

concentrations could be applied to all days in a designated wet season period, any days with measurable precipitation, or the number of days with influent flow above some baseline for each plant. Similarly, assumptions would need to be made about the effluent characteristics of unsampled facilities to get more refined estimates; remaining facilities could be assumed to have concentration distributions similar to the sampled group, similar to the lowest concentration sites in the sampled group (since few facilities likely have comparably high total selenium), or estimated by relative percentages of water supplied from sources with known lower to higher selenium concentrations (e.g. from reservoirs in the Sierra Nevada, Delta pumps, or local groundwater respectively).

The speciation data collected in this study can be used in building mass balance estimates of selenium species in the Bay, and consequently the selenium exposure risk posed by various loads interacting with environmental transport and transformation processes can be estimated. A key step is the initial uptake into the food web by bacteria or phytoplankton. Uptake rates are variable among species, but ambient concentrations of dissolved selenium species measured or estimated through mass balance models can be applied to uptake rates reported in the literature via models (e.g., (Meseck and Cutter 2006), and assimilation efficiencies for higher trophic organisms then used to estimate risk posed to species of interest. The USGS DYMBAM model (Luoma and Presser 2006) uses a similar approach, although rather than tracking individual dissolved Se species it simplifies the initial uptake to a range of partition coefficients (K_d) to particulate selenium forms under scenarios which are then accumulated through the food web.

Information on exposure and effects on biota are most abundant and unambiguous for the simpler inorganic species, selenate and selenite, as these can be easily added in purified form for toxicological and uptake studies. There is also information on selenocyanate uptake for at least one species of algae; although its uptake was lower than for selenate or selenite, there was also evidence of biotic formation of selenocyanate (Simmons and Wallschläger 2011). Uptake studies of organic selenium species are also generally performed using spikes of purified forms such as seleno-amino acids, Operationally defined organic selenium species such as characterized in this study require assumptions about the (likely mixed and complex) species present (e.g., assuming their uptake is analogous to known species such as a seleno-amino acid), or require more involved digestion and separation techniques to distinguish and quantify specific individual species. Alternatively, uptake studies can potentially be undertaken with operationally defined mixtures, but results may be variable among samples depending on the underlying mixture of true chemical species.

Although it is clear that differences among facilities in particulate selenium are mostly due to differences in total suspended sediments (TSS) discharged, the specific causes of differences in total (primarily dissolved) selenium among plants and between wet and dry season were not examined here. However, a likely cause is differences in water supplies used for the service areas of different plants, e.g., high selenium (2-8 ug/L) is found in groundwater for some wells in South Bay (Santa Clara Valley Water District 1994) , with another (but less likely) possibility being distinctive residential or industrial uses of selenium containing products for different areas. The differences in wet versus dry season contributions may also be due to infiltration from groundwater sources, or from selenium in wet deposition; although atmospheric sources in this region may not be

identical, a study from Maryland (Mason et al. 2000) reported average concentrations of 0.49(\pm 0.70) ug/L, greater than concentrations in dry season effluents for some facilities reported here. Similarly, differences in dissolved selenium species among plants (e.g. high selenite and organic selenium found in some plants here) would require sampling of influent and possibly other process points to determine their origin.

Despite these remaining uncertainties, this work provides improved understanding of the characteristics of selenium in municipal wastewater discharges in the Bay area. In combination with information currently being collected on other regional loads (e.g., petroleum refinery effluent, and stormwater flows), a more complete picture of selenium sources and fate can be constructed for the region, to allow better assessment and management of the risk posed to the local ecosystem by selenium.

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Appendix

Appendix Table 1 – Analytical results for samples collected from municipal wastewater facilities. Analyzing labs: EB=EBMUD, TU=Trent U., LU=Laurentian U. Results reported in ug/L unless otherwise noted. For calculating sums of species, <MDL results were substituted by ½ MDL.

Facility	Sample Date	Dissolved Se (EB)	Particulate Se (EB)	Sum Fractions (EB)	Total Se (EB)	TSS mg/L (EB)	Selenite (TU)	Selenate (TU)	Selenocyanate (TU)	US1 (TU)	US2 (TU)	US3 (TU)	US4 (TU)	Organic Se (LU)	Sum Species (TU)	Dissolved Se (TU)	DOC mg/L (TU)
CCCS	3/18/2011	0.938	0.038	0.976	0.996	11	0.173	0.307	0.020	< 0.005	0.039	< 0.005	< 0.005	0.164	0.709	0.713	8.3
CCCS	7/18/2011	0.365	0.034	0.399	0.432	12	0.013	0.141	0.020	< 0.005	< 0.005	< 0.005	< 0.005	0.199	0.378	0.394	12.4
CCCS	9/26/2011	0.42	0.054	0.474	0.468	26	0.013	0.114	0.041	0.010	< 0.005	< 0.002	< 0.005	0.207	0.386	0.430	11.5
CCCS	1/23/2012	1.07	0.0411	1.1111	1.13	15	0.062	0.289	0.464	< 0.005	< 0.005	< 0.005	< 0.005	0.499	1.321	1.037	10.8
DDSD	3/18/2011	0.548	0.043	0.591	0.611	18	0.026	0.201	0.012	< 0.005	0.054	< 0.005	< 0.005	0.224	0.525	0.474	14.0
DDSD	7/18/2011	0.375	0.03	0.405	0.477	25	0.046	0.149	0.030	< 0.005	< 0.005	< 0.005	< 0.005	0.189	0.419	0.403	16.7
DDSD	9/26/2011	0.378	0.0536	0.4316	0.431	30											
DDSD	1/23/2012	0.543	0.0697	0.6127	0.648	37											
EBDA	3/18/2011	0.514	0.033	0.547	0.549	14	< 0.005	0.192	0.009	< 0.005	0.067	< 0.005	< 0.005	0.106	0.383	0.421	12.7
EBDA	7/18/2011	0.414	0.042	0.456	0.46	18	0.046	0.168	0.011	0.010	< 0.005	< 0.005	< 0.005	0.129	0.367	0.396	13.6
EBDA	9/26/2011	0.366	0.0598	0.4258	0.435	36	0.014	0.142	0.011	0.013	< 0.005	< 0.002	< 0.005	0.125	0.306	0.370	12.1
EBDA	1/23/2012	1.14	0.0378	1.1778	1.16	18	0.041	0.821	0.016	< 0.005	0.013	< 0.005	< 0.005	0.075	0.972	1.034	11.4
EBMUD	3/18/2011	0.275	0.025	0.3	0.327	20	0.042	0.105	< 0.005	< 0.005	0.178	< 0.005	< 0.005	0.071	0.406	0.264	15.0
EBMUD	7/18/2011	0.165	0.008	0.173	0.21	17	0.038	0.061	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.079	0.101	0.21	16.0
EBMUD	7/18/2011	0.16	0.0075	0.1675		19	0.038	0.050	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.069	0.090	0.22	16.0
EBMUD	9/26/2011	0.154	0.0248	0.1788	0.216	31	0.028	0.045	0.006	0.016	< 0.005	< 0.005	< 0.005	0.086	0.188	0.220	14.8
EBMUD	1/23/2012	0.22	0.0082	0.2282	0.234	8	0.049	0.156	0.021	0.006	0.008	< 0.005	< 0.005	< 0.005	0.245	0.223	9.3
FSSD	3/19/2011	0.68	0.009	0.689	0.691	5.8	< 0.005	0.472	0.009	0.008	0.017	< 0.005	< 0.005	0.001	0.515	0.559	6.0
FSSD	7/18/2011	0.386	0.008	0.394	0.387	2.1	0.011	0.309	< 0.005	0.035	< 0.005	< 0.005	< 0.005	0.010	0.375	0.416	9.8
FSSD	9/26/2011	0.32	0.0092	0.3292	0.324	5.5	< 0.002	0.120	0.007	< 0.002	< 0.005	< 0.005	< 0.005	0.063	0.193	0.400	7.4
FSSD	1/23/2012	0.554	0.0021	0.5561	0.568	1.7	0.012	0.379	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.090	0.491	0.557	6.4
Palo Alto	3/18/2011	1.87	0.024	1.894	1.95	3.8	0.695	0.207	0.013	< 0.005	0.096	< 0.005	0.033	0.071	1.134	1.817	8.1
Palo Alto	7/18/2011	1.23	0.008	1.238	1.22	3.2	0.557	0.156	0.013	0.076	< 0.005	< 0.005	< 0.005	0.229	1.033	1.150	9.4
Palo Alto	9/26/2011	0.986	0.0144	1.0004	1.02	9.1	0.284	0.259	0.013	0.086	< 0.005	< 0.005	< 0.005	0.381	1.024	0.530	7.3
Palo Alto	1/23/2012	1.42	0.0157	1.4357	1.44	4.5	0.588	0.399	0.025	< 0.005	0.022	< 0.005	< 0.005	0.158	1.197	1.514	7.2
VSFCD	3/18/2011	0.47	0.102	0.572	0.607	20	0.038	0.038	0.012	< 0.005	0.066	< 0.005	< 0.005	0.171	0.332	0.438	9.0
VSFCD	7/18/2011	0.401	0.074	0.475	0.499	18	0.066	0.021	0.011	< 0.005	< 0.005	< 0.005	< 0.005	0.294	0.397	0.405	14.9
VSFCD	9/26/2011	0.412	0.0576	0.4696	0.476	24	0.027	0.043	0.015	0.004	< 0.005	< 0.005	< 0.005	0.280	0.370	0.440	10.2
VSFCD	1/23/2012	0.358	0.0613	0.4193	0.451	19	0.050	0.101	0.007	< 0.005	0.007	< 0.005	0.044	0.312	0.523	0.423	8.6