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Rich Horner, PHD
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230 N. W. 55th Street
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SUBJECT: Caltrans BMP Retrofit Pilot Program – Continuous Deflective Separation Technology

Dear Mr. Rayback & Mr. Honer,

CDS Technologies, Inc. has carefully reviewed the 2000/2001 and 2001/2002 reports on the monitoring of the CDS units located in District 7, Los Angeles at the Orcas Avenue and Filmore Street sites on I-210. These reports contain a great deal of useful information regarding the characteristics of gross litter found in highway runoff and the effectiveness of the CDS technology in capturing that material.

We have conducted an extensive review of the reports and reanalyzed the data which is summarized in the attached report "Overview & Analysis of Caltrans District 7 Continuous Deflective Separation Pilot Study" (Overview & Analysis). We have found:

- The Scoping Study Methodology (Scoping Method) adopted by Caltrans and NRDC to evaluate the efficiencies of BMPs is so sensitive to small data sets that a single event can significantly distort the results.
- The Mass Balance Approach was not performed pursuant to the original established protocols. In 2001/2002 the Scoping Method was used to estimate effluent loads rather than using measured values for monitored events and *"burned"* sump sediment data rather than the *"pre-burned or dry mass"* data was used in calculating the captured solids load.
- The efficiency of the CDS units to capture solids in storm water runoff is significantly greater than reported. The Orcas Avenue site should have a removal efficiency of 65% rather than the reported 11% and the Filmore Street site should be 67% rather than -81%.

Caltrans and NRDC adopted the Scoping Method from a 1990 study conducted for the Federal Highway Administration (FHWA) that analyzed almost 1000 separate storm events at 31 highway runoff sites in 31 states. Caltrans, NRDC and the FHWA have acknowledged that there is a lack of confidence in data when the number of samples is small and that a single sample can distort results.

The Overview & Analysis clearly demonstrates the sensitivity and shortcoming in the Scoping Method – the 2001/2002 report indicates a highly improbable -81% removal of

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Total Suspended Solids (TSS) at the Filmore Street site yet almost 64 kg of material was removed from the CDS unit. Appendix B shows that by deleting highly questionable results for two of the 10 events changes the efficiency by almost 93% at this site.

The Mass Balance Approach (MBA) was developed by CDS Technologies, Inc after analysis of BMP monitoring studies conducted by Kinnetic Laboratories and USGS found that automatic samplers were not effective in collecting representative samples of solids in storm water runoff. The MBA overcomes these limitations by relying on accurate quantification of the solids captured in the CDS unit's sump and sampling of the discharge from the CDS unit which can be more accurately sampled since the larger solids have been removed. The MBA requires that solids in the runoff and collected in the sump be analyzed at comparable temperatures. The TSS method of analysis is performed at 103-105°C while the Total Volatile Solids method of analysis is performed at >500°C.

The MBA could not be performed for the 2000/2001 monitoring period because the solids captured by the CDS unit were not characterized. The MBA was performed for the 2001/2002 period; however, the analysis used *"burned" (>500°C)* data rather than *"pre-burned" (99.3°C)* data that was available. I had agreed to this approach, but our subsequent review of the 2001/2002 report found that *pre-burned"* data was available that was more consistent with the MBA protocol. The Overview & Analysis (Appendices D and E) correctly calculate the efficiencies using the MBA and show that the efficiencies are materially different than those developed from the Scoping Method as shown on page 7 of the Overview & Analysis.

I appreciate the time and effort that has been put forward in the testing and evaluation of the CDS Technologies by Caltrans and its consultants. I am sure that we all agree that our objective is to obtain the best possible data to objectively evaluate storm water BMPs. This study effort clearly demonstrates the importance in correctly designing and understanding the evaluation programs and the need for close coordination and communication throughout the studies to ultimately ensure there is joint agreement with the results. At this point CDS Technologies does not concur that the 2000/2001 and 2001/2002 reports accurately reflect the performance of the CDS Technology. I am requesting a response to the issues raised in the Overview & Analysis and that it be referenced in and appended to final BMP Retrofit Pilot Program report.

Please call me at 1-888-535-7559 or Gary Lippner at 916-486-1736 if you have any questions.

Sincerely,

Robert Howard

Robert Howard
President

APPENDIX D

MASS BALANCE APPROACH: COMPARISON OF SCOPING METHOD AND DATA FROM MONITORED EVENTS

APPENDIX B

SENSITIVITY OF SCOPING STUDY METHOD

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OVERVIEW & ANALYSIS OF CALTRANS DISTRICT 7 CONTINUOUS DEFLECTIVE SEPARATION PILOT STUDY

May 2003

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Although a number of parameters were monitored during the Caltrans studies Total Suspended Solids (TSS) is used in the following analysis of the differences in the results between the two methods.

Caltrans Scoping Study Methodology – BMP efficiencies are evaluated from a comparison of effluent and influent loadings (over a period of time) from the following relationship:

Efficiency (%) = [(Loading in – Loading out)/Loading in] x 100

A detailed step-by-step procedure to estimate pollutant loading using the Scoping Method is included in Appendix A. The methodology estimated loadings by:

- Determining EMCs from at least five representative storms
- Computing the expected mean EMCs using log normal distribution
- Measuring the wet season runoff volume or by calculating that volume using runoff coefficients, watershed area and rainfall depth
- Calculating the expected wet season influent and effluent loads by multiplying the expected mean EMC by the measured seasonal runoff volumes

The methodology was obtained from the FHWA report *Pollutant Loadings and Impacts from Highway Stormwater Runoff (Woodward-Clyde Consultants, May 1989).* Caltrans acknowledges the limitations of the procedure when applied to small data sets and indicates that other techniques will be employed as needed to make effective use of data. ASCE and USEPA in *Urban Stormwater BMP Performance Monitoring (EPA-821-B-02-001, April 2002)* describe ten different methods for BMP water quality monitoring data analysis.

The FHWA report based on 993 separate storm events collected at 31 highway runoff sites distributed among 11 states notes that there is a lack of confidence in data when the number of samples is small and that a single sample can distort results.

The sensitivity of the Scoping Method when applied to a small data set is demonstrated by calculations presented in Appendix B. These calculations clearly demonstrate that use of the Scoping Method in the project, where sample size is small, is not appropriate and provides misleading results. Removal efficiencies at the Filmore site for the 2001-02 season changed by almost 93% when calculations were performed using the Scoping Method and simply deleting two monitoring events. One event deleted had an extremely high EMC (186 mg/L) compared to the rest of the data while the other event had a very small EMC (1 mg/L).

CDS Mass Balance Analysis Approach – The MBA was developed by CDS Technologies, Inc. to overcome the inherent difficulties using automatic samplers to obtain representative samples of material suspended in storm water *runoff* including sediments larger than very fine sand and gross pollutants. The MBA was also developed to address the erroneous data that results from the TSS method of analysis of suspended sediments that has been identified by the USGS.

The MBA requires that material captured in the sump of the CDS unit be removed, sampled and characterized for pollutants of concern. This information combined with the mass of pollutants discharged and bypassed from the CDS unit and mass of pollutants contained primarily in the sump and the separation chamber provides the most accurate method of determining loading of the *runoff* – influent (schematic attached, Appendix C). The efficiency is determined by:

$$\text{Efficiency} = \frac{\text{SumpLoad} + \text{Separation Chamber Load}}{\text{Outlet Load} + \text{Sump Load} + \text{Sump Chamber Load} + \text{Bypass Load}}$$

Critical to the MBA are the accurate measurement of the runoff volumes over the period of evaluation, quantification of each of the loads and analysis of samples of each "load" with laboratory methods that use comparable temperatures. Total Suspended Solids (TSS) analysis of water samples and analysis of solids are performed at 103-105°C while Total Volatile Solids are performed at 550±50°C that drives off organic matter, intrinsic water and volatile minerals that are measured by the TSS method of analysis.

2000-2001 Efficiencies – Caltrans (October 2001) reported TSS removal efficiencies of 29% for the Orcas Avenue unit and 3% for the Filmore Street unit as determined by the Scoping Method.

A MBA analysis was not possible because material captured in the sump was not fully quantified or characterized as required in the OMMP and CDS MBA protocols; however, using *only* gross pollutant data the efficiency at the Orcas Avenue site was 62% by weight and at the Filmore Street site it is 41%.

Following is a summary of the efficiencies using the different methods:

Site	Scoping Method	Mass Balance
Orcas Avenue	29%	62%
Filmore Street	3%	41%

The following can be concluded from an analysis of the gross pollutant data:

- The gross pollutants at both sites are dominated by vegetative material with vegetative material 76 to 91% of the gross pollutant volume.
- The CDS unit removed over 78% of the gross pollutants by volume and 76% by weight at the Orcas Avenue site; however, these results were skewed by 48 and 56 percent removals when the unit was bypassed in January 2001 during a major storm event (4.33 inches of rainfall) with intensities of 1.92 in/hr. During this event the CDS unit lacked capacity due to inadequate maintenance and hydraulic limitations when mosquito controls were implemented.
- The CDS unit at the Filmore Street site removed over 93% of the gross pollutants by volume and 90% by weight.

2001-02 Efficiencies – Caltrans (September 2002) reported 2001-02 TSS removal efficiencies of 11% for the Orcas Avenue unit and -81% for the Filmore Street unit as determined by the Scoping Method. Capture of over 32.3 kg of dry solids at the Orcas Avenue site and over 63.7 kg at the Filmore Street site strongly suggest that either or both the OMMP or the Scoping Method do not provide accurate methods of determining efficiency of the CDS units to capture material suspended in storm water runoff. The results also confirm the FHWA's, Caltrans' and NRDC's concern with the Scoping Method when there are only a limited number of events monitored and data points.

Caltrans reported the MBA efficiencies for both of the sites as 33%; however, there were some inconsistencies in the methods used to calculate the MBA efficiencies:

- Outlet loads were calculated using the Scoping Method while measured values were actually available for monitored events.
- The sump and bypass loads used in the MBA were based on *incinerated* samples even though the MBA calls for determination of all loads using comparable temperatures i.e. TSS is performed at 105°C while TVS (Inorganic Mass) are performed at 550±50°C that drives off organic matter, intrinsic water and volatile minerals that are measured in the TSS method of analysis.

Use of Scoping Method in Mass Balance Approach

Caltrans used the Scoping Method for determination of the outlet loads in the MBA analysis rather than using measured values during monitored events and estimated values for non-monitored events.

Pollutant loadings were determined by multiplying the mean EMCs determined from the monitored events and the total volume of runoff during the wet season. This approach assumes that the EMCs are the same for both monitored and non-monitored events. During the 2001-02 season at the Orcas Avenue site 64.4% of the total rainfall and 87.6% of the runoff were monitored and at the Filmore Street site 76.7% of the rainfall and 83.3% of the total runoff were monitored. This represents a significant capture of monitored rainfall events and measured flow and provides a sound basis for using a combination of actual data for monitored events and estimated data for non-monitored events. The approach also likely overestimates the loadings for non-monitored events because many of those events had very small intensities where TSS values are expected to be less than the annual means derived monitored events where storm events had higher intensities and volumes.

A comparison of the of the efficiencies for both the Orcas Avenue and Filmore Street units determined by the Scoping Method using the *Annual EMC* for monitored and non-monitored events and using a combination of measured values for monitored events and the *Annual EMC* for non-monitored events (Attachment D) produces significant differences in efficiency demonstrating the sensitivity of the Scoping Method when there is a small data set.

These results are summarized as follows:

Site	Mass Balance - A	Mass Balance - B
Orcas Avenue	31%	45%
Filmore Street	33%	50%

Mass Balance A – *Outlet Loads* determined by applying Annual EMC to monitored and non-monitored events
Mass Balance – *Outlet Loads* determined by applying Annual EMC to non-monitored events and measured values for monitored events

Temperature Correction
To correctly perform the MBA it is essential that all analysis of the monitored effluent and captured solids (sump load) be performed on a comparable basis. The MBA calls for determination of <u>all</u> loads using comparable temperatures i.e. TSS is performed at 103-105°C and captured solids (sump load) are measured at a comparable temperature. The TVS (Inorganic Mass) method of analysis should not be used on the captured solids (sump load) because it is performed at a temperatures of 500±50°C that drives off organic matter, intrinsic water and volatile minerals that are measured by the TSS method of analysis.

Data presented by Caltrans in Table 1-j "Captured Non-Volatile Solids Summary" is a combination of both the *"dry mass"* where analysis were performed at 200°F (93.3°C) (ref. Figure 1-56 through 1-59 of July 2002 report) and *"inorganic mass"* where analysis were performed at >500°C). The *"post-burned"* samples lost from 26–49% of their mass during this incineration process confirming that the TVS method removes a significant portion of the solids captured and removed by the CDS unit. Caltrans in its MBA calculations used the *"post-burned"* load that significantly underestimates the efficiency of the CDS units.

Using comparable analytical temperatures (TSS at 103-105°C and *"dry mass"* at 93.3°C) the following efficiencies for each of the methods described in the previous section were determined (Attachment E).

Site	Mass Balance - A	Mass Balance - B
Orcas Avenue	54%	65%
Filmore Street	51%	67%

Mass Balance A – *Outlet Loads* determined by applying Annual EMC to monitored and non-monitored events
Mass Balance B – *Outlet Loads* determined by applying Annual EMC only to non-monitored events and applying individual EMCs to individual volumes

<u>Discussion of Alternative Methods</u>

The Scoping Method determines efficiency of storm water BMPs comparing influent and effluent pollutant loadings determined by EMCs applied to flows measured or estimated over a period of time. There are several fundamental deficiencies in the method when applied to BMPs designed to capture sediments larger than 63 micron (very fine sand) and when there are limited data sets. An analysis of data (Appendix A) collected during the project to evaluate several CDS units confirms the FHWA's, Caltrans' and NRDC's concern and clearly demonstrates that wide variations in BMP efficiencies are reported when limited data is available for analysis. The Caltrans OMMP further relies on use of automatic samplers to collect samples of *runoff* and that have been found to narrowly define TSS when larger sediments and gross pollutants are present.

The CDS Technologies' Mass Balance Analysis approach overcomes the Scoping and OMMP shortcomings by measuring material captured within the CDS unit and sampling the effluent or discharge from the unit after larger sediment particles are removed. The MBA has an additional advantage of capturing trash and debris allowing the characterization of gross pollutants that are sampled by traditional sampling techniques. The MBA also allows the full characterization of pollutant load reductions to document compliance with TMDLs.

Caltrans has evaluated the effectiveness of two CDS units to capture and retain trash, floatables and sediments. Ten storm events were monitored at the Orcas Avenue site and 17 events at the Filmore Street site over a two-year period. The effectiveness of the CDS units was measured using two different methods – Scoping Study Methodology and the Mass Balance Approach.

2000-01 Study Period

Method of Evaluation	Orcas Avenue	Filmore Street
Scoping Study	33%	-23%

Mass Balance Approach – Analysis was not feasible because material captured in the CDS sump was not quantified or characterized during 2000-01. The efficiency using only gross solids data found the Orcas Avenue unit to achieve a 62% reduction and the Filmore Street unit achieved a 41% reduction during the 2000-01 period.

2001-02 Study Period

Method of Evaluation	Orcas Avenue	Filmore Street
Scoping Study	11%	-81%
Mass Balance – A	33%	33%
Mass Balance – B	45%	50%
Mass Balance – C	54%	51%
Mass Balance - D	65%	67%

Mass Balance - A – *Outlet Loads* determined using Scoping Method

Mass Balance - B - *Outlet Loads* determined by applying Annual EMC only to non-monitored events and applying individual EMCs to individual volumes
Mass Balance - C - Mass Balance (A) and *Pre-Burned* (dry mass) data
Mass Balance - D - Mass Balance (B) and *Pre-Burned* (dry mass) data

Summary and Conclusions

The Scoping Study Method and Mass Balance Approach produce significantly different results that are attributed to:

- The results from a single event can significantly distort the analytical results when using the Scoping Method is applied to small data set.
- Incorrect use of "*burned*" sump sediment data in the Mass Balance Approach method rather than using the "*dry mass*" data that was derived from a method that used temperatures comparable to the TSS method of analysis.
- Application of mean EMCs to the entire annual runoff to determine influent and effluent loads rather than using actual measured values for monitored events.
- Limitations of automatic samplers to collect representative samples of solids in storm water *runoff*.

The true efficiency of the CDS units to capture solids suspended in storm water runoff is likely to be closer to the methods used to determine Mass Balance - D than the Scoping Method. It is highly unlikely that the CDS unit generated solids as indicated by the negative 81% efficiency determined by the Scoping Method for the Filmore Street site. This unlikely negative annual removal was highly influenced by the first storm event of the year, which reported a negative 142 percent removal. This is impossible as the unit was cleaned prior to this storm event. With no material in the unit scour could not have occurred, thus the result would mean the CDS unit created material. The capture of over 63.7 kg of solids at this site during that 2001-02 period should have triggered a careful review of the appropriateness of the Scoping Method for evaluation of BMPs such as the CDS units. The capture and measurement of solids at each of the sites suggests that the Mass Balance Approach is a more accurate method of determining BMP efficiency.

APPENDIX A

SCOPING STUDY METHOD

Estimating Pollutant Loadings and BMP Efficiency

Background

This section provides a brief literature review and background information on constituent loading calculation and estimation techniques which were used in selecting the appropriate methods for analyzing data obtained from the BMP monitoring program. Several documents outlining constituent load estimation methods and/or related topics were reviewed. The techniques are generally very similar, and a few representative documents will be briefly discussed here. Summaries from a few key studies are also provided.

The EPA's Nationwide Urban Runoff Program (1982) measured constituent concentrations at 85 sites for 200 storms throughout the United States, and the results were published in 1983. This study is probably the most comprehensive study of its type available. The study began by testing the assumed log-normal distribution of the data, which was determined to be valid. Site specific rainfall/runoff characteristics were found to be very important to the results. Federal Highway Administration (FHWA) has outlined a procedure for estimating impacts to streams and lakes receiving highway stormwater runoff in a three volume report entitled as, "Pollutant Loadings and Impacts from Highway Stormwater Runoff" (1990). Volume III of the report, entitled as "Analytical Investigation and Research Report", tested the validity of the lognormal distribution, which is then used in presenting the methodology used in data analysis. Results indicated that when an underlying population has a lognormal distribution, the mean and variance of the population should be obtained by computing the mean and standard deviation of the logarithmic transforms of the data.

Volume I of the FHWA 1990 report, entitled as "Design Procedure", provides worksheets to calculate runoff and constituent loading parameters from inputs such as drainage area, rainfall data, streamflow, Event Mean Concentration (EMC), and soluble fractions (defined as soluble fraction of each measured constituent). One worksheet is provided to calculate runoff from the site characteristics, and another is given to calculate constituent mass load in pounds per year from highway runoff characteristics. The annual mass load is computed according to the following equation:

$$AML = EMC * MVR * N * 0.00006245$$

where: AML is the annual mass load in pounds per year,
EMC is the event mean concentration in mg/L,
MVR is the mean volume of runoff from a storm event at the specified site in cubic feet,
N is the average number of storms per year,

0.00006425 is a conversion factor to convert results to annual mass in pounds per year,

The Flint Creek Watershed Project (1995) was initiated by the Morgan County Soil and Water Conservation District to improve and protect the water quality of Flint Creek, located in Northwestern Alabama. To determine the best approach, annual constituent loadings were estimated for Total Suspended Solids, BOD5, Total Kjedahl Nitrogen, Phosphorous, and Nitrogen for land uses including, industrial and commercial, residential, cropland, pasture, and grazing type uses. For industrial and commercial land uses, the following equation was used to estimate annual constituent loads:

$$M = R * K * A * C * 0.227$$

where: M = Constituent Loading (lbs/yr)
R = Rainfall (in/yr)
K = Runoff Coefficient
A = Drainage Area (acres)
C = Pollutant Concentration in Runoff (mg/L)
0.227 = Unit Conversion Factor

The Santa Monica Bay Restoration Project included annual estimates of constituent loading to Santa Monica Bay from stormwater runoff. The constituent loadings were tabulated for various land uses, including residential, commercial, industrial, and open spaces. Water quality measurements were taken at 22 selected locations. Pollutant loads were obtained by multiplying the stormwater flow rate by a constituent concentration. The runoff is affected by land use, so the following load estimating model was used to account for variation in land use:

$$\text{Load} = \Sigma M_a * X_a$$

where: M is concentration of constituents for land use a, and
X is runoff from land use a.

Finally, in review of the "1996-1997 Caltrans Detention Basin Monitoring Plan", NRDC outlined a loading estimation method which is very similar to the FHWA method discussed above and recommended to arrange the loading calculations on one or more computerized spreadsheets for convenience (November 12, 1996 Memorandum from Richard Horner to Ed Dammel and Bob Smith). The recommended method can be used to estimate wet season and annual loading given calculated event loadings. If possible, NRDC suggested to obtain continuously recorded local flow data and a series of representative local EMC readings. Assuming log-normal distribution of EMCs, the mean of the EMCs can be calculated using an applicable statistical relationship. In addition to the constituent load estimations, NRDC recommended that BMP efficiencies be evaluated from a comparison of effluent and influent loadings (over a period of time) from the following relationship:

Efficiency (%) = [(Loading in - Loading out)/Loading in] x 100

Methodology

The recommended methodology for estimating effluent and influent constituent loadings for the subject detention basins was obtained from FHWA report *Pollutant Loadings and Impacts from Highway Stormwater Runoff.* This method is very similar to the NRDC recommended procedure discussed above. Caltrans and NRDC acknowledge the limitations of the procedure when it is applied to small data sets. Statistical analysis will be performed for each year of the program and for the overall monitoring period of two years. Other numerical techniques will be employed as needed to make the most effective use of the data set.

Estimating Pollutant Loading

The following is a step-by-step guide in estimating constituent loadings using the FHWA method:

1. Collect stormwater runoff samples from five representative storms.

2. Analyze water samples for desired water quality parameters and obtain EMCs.

3. Tabulate EMCs.

4. Measure runoff volume per storm. If problems occur with obtaining flow data, multiply runoff coefficient (unitless) by watershed area (in acres) and rainfall depth per storm (in inches) to obtain runoff volume (acre-in).

5. Convert runoff volume from acre-in to liters using the conversion factor: acre-in = 102,790 liters.

For single event constituent loading calculation, perform Steps 6a and 7a, otherwise skip to Step 6b:

6a. Multiply EMCs (in μg/l or mg/l) from Step 2 by runoff volume (in liters) from Step 5 to obtain constituent load in μg or mg.

7a. Convert constituent load from μg or mg to pounds (lbs) using the conversion factors: 1 mg = 0.00000220 lbs and 1 μg = 0.00000000220 lb.

For average wet season loading estimations, perform Steps 6b and 7b:

6b. Take natural log of EMCs from Step 2.

7b. Compute mean (μ) and variance (s^2) of natural logs obtained from Step 6b from the following equations:

$$\mu = \frac{x}{n}$$

$$s^2 = \frac{\left(n \quad x^2 - \left(\quad x\right)^2\right)}{n(n-1)}$$

where: x is the natural log of EMCs.
Σx represents the summation of data points (x).
n is the number of data points (x).

8. Compute expected value a (also known as mean of the EMC) using the following formula:

$$a = e^{(\mu + s^2/2)}$$

9. Compute upper and lower confidence limits x_{hi} and x_{lo} from μ, s, and standardized normal deviate, z, using the equation:

$$x = e^{(\mu +/- zs)}$$

The value of z corresponds to a given probability of exceedence, which can be converted to a confidence level. For a confidence level of 90%, for example, the z value corresponding to 0.90 is 1.28. Values for z can be obtained from a standard normal distribution table.

10. Compute runoff volume per wet season by multiplying runoff coefficient (unitless) by watershed area (in acres) and rainfall depth per wet season (in inches) to obtain runoff volume (acre-in), and converting to liters by using the conversion factor from step 5 above.

11. To obtain expected constituent load in the wet-season, multiply expected value (mean of the EMC) from Step 8 by the runoff volume obtained from Step 10. Convert to pounds (lbs) using the conversion factor provided in Step 7a.

11. To obtain expected constituent load in the wet-season, multiply expected value (mean of the EMC) from Step 8 by the runoff volume obtained from Step 10. Convert to pounds (lbs) using the conversion factor provided in Step 7a.

12. To obtain the 90% confidence limits for expected constituent loadings in the wet-season, repeat Step 11, substituting the confidence limits from Step 9 for the expected value.

Computing BMP Efficiency

As mentioned previously, BMP (detention basin and CSF) efficiencies may be evaluated by comparing effluent and influent loadings over the entire wet season from the following equation:

$$\text{Efficiency (\%)} = [(\text{Loading in} - \text{Loading out})/\text{Loading in}] \times 100$$

For the detention basins, since the residence times are expected to be fairly long (longer than a typical event duration), cumulative loadings over a series of events should be used in estimating BMP efficiency. When using a multiple events for basin efficiency calculations, it is necessary to have a complete loading record or representative loadings. Since the CSF residence times are expected to be fairly short and the CSFs should be operating under steady state conditions, the EMC (or the mean EMC for a series of events) can be substituted for loading in the efficiency equation above.

To demonstrate the sensitivity of the Scoping Method when limited data is available an analysis of the Filmore Street site is presented. There were 10 storm events that were monitored in 2001-02 season at the Filmore Street CDS unit. Using the Scoping Study method outlined in Appendix A, expected seasonal influent and effluent EMCs were calculated using a lognormal distribution. The expected removal efficiency at this site was calculated to be –81% as shown in Table B.1.

Table B.1: 2001-02 Season Average TSS Removal at Filmore Street CDS

Event	Influent EMC	Log (Influent EMC)	Effluent EMC	Log (Effluent EMC)	Efficiency
1	77	4.34	186	5.23	-142%
2	55	4.01	75	4.32	-36%
3	31	3.43	32	3.47	-3%
4	100	4.61	56	4.03	44%
5	28	3.33	7	1.95	75%
6	39	3.66	59	4.08	-51%
7	30	3.40	1	0.00	97%
8	27	3.30	24	3.18	11%
9	26	3.26	31	3.43	-19%
10	23	3.14	36	3.58	-57%
Log-mean		3.65		3.32	
Log-variance		0.25		2.08	
Avg. EMC per Scoping Method	$e^{(\text{Log-mean} + \text{Log-variance}/2)}$				
AVG. INFLUENT EMC =	43.60	AVG. EFFLUENT EMC =	78.73	REMOVAL EFFICENCY =	-81%

A closer look at the effluent EMC data indicates that effluent EMCs for the event 1 and event 7 seem to be extreme measurements when compared to the rest of the data (see Figure 1). To demonstrate the sensitivity of the Scoping Study method on these extreme events for small data sets, three sets of calculations were performed on the EMC data for 2001-02 wet season.

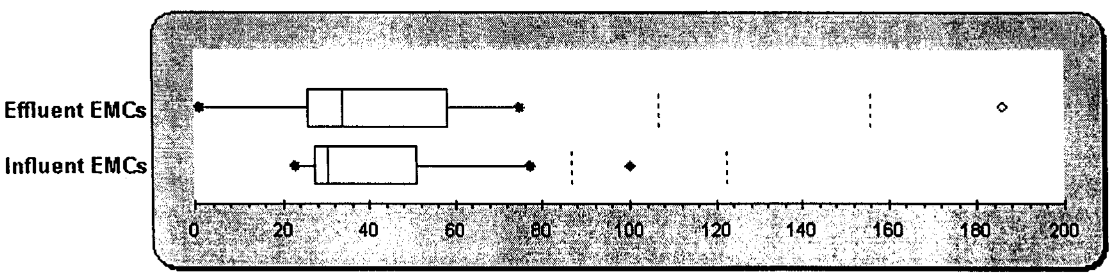


Figure 1: Box and Whisker Plot for EMCs at Filmore CDS

First, the season average was calculated using the scooping study method and ignoring Event 1 that had an effluent concentration of 186 mg/L. TableB.2 indicates that season average efficiency went up to –42% by ignoring this event. In other words, a single event had an almost 50-percent change in removal efficiency.

Table B.2: 2001-02 Season Average TSS Removal Discarding Event 1

Event	Influent EMC	Log (Influent EMC)	Effluent EMC	Log (Effluent EMC)	Efficiency
2	55	4.01	75	4.32	-36%
3	31	3.43	32	3.47	-3%
4	100	4.61	56	4.03	44%
5	28	3.33	7	1.95	75%
6	39	3.66	59	4.08	-51%
7	30	3.40	1	0.00	97%
8	27	3.30	24	3.18	11%
9	26	3.26	31	3.43	-19%
10	23	3.14	36	3.58	-57%
Log-mean		3.57		3.11	
Log-variance		0.22		1.84	
Avg. EMC per Scoping Method		$e^{(\text{Log-mean} + \text{Log-variance}/2)}$			

AVG. INFLUENT EMC =	39.65	AVG. INFLUENT EMC =	56.26	REMOVAL EFFICIENCY	-42%

For the second set of calculations, Event 7 that had an effluent concentration of 1 mg/L was discarded. As shown in Table B.3 the season removal efficiency using the Scoping Study Method was found to be –33%. In this case, seasonal removal efficiency increased by 60 percent when this event was left out. Event 7 had a very low effluent EMC and one would expect that deleting this event would lower the seasonal removal efficiency. To the contrary, there was about 60 percent increase in the efficiency when this event was discarded.

Table B.3: 2001-02 Season Average TSS Removal Discarding Event 7

Event	Influent EMC	Log (Influent EMC)	Effluent EMC	Log (Effluent EMC)	Efficiency
1	77	4.34	186	5.23	-142%
2	55	4.01	75	4.32	-36%
3	31	3.43	32	3.47	-3%
4	100	4.61	56	4.03	44%
5	28	3.33	7	1.95	75%
6	39	3.66	59	4.08	-51%
8	27	3.30	24	3.18	11%
9	26	3.26	31	3.43	-19%
10	23	3.14	36	3.58	-57%
Log-mean		3.67		3.69	
Log-variance		0.28		0.81	
Avg. EMC per Scoping Method		$e^{(\text{Log-mean} + \text{Log-variance}/2)}$			

AVG. INFLUENT EMC =	45.15	AVG. EFFLUENT EMC =	60.20	REMOVAL EFFICIENCY =	-33%

Lastly as shown in Table B.4, season removal efficiency was calculated to be –6% when both events 1 and 7 were ignored. This amounts to almost 93-percent change from the original value calculated in Table B.1

Table B.4: 2001-02 Season Average TSS Removal Discarding Events 1 & 7

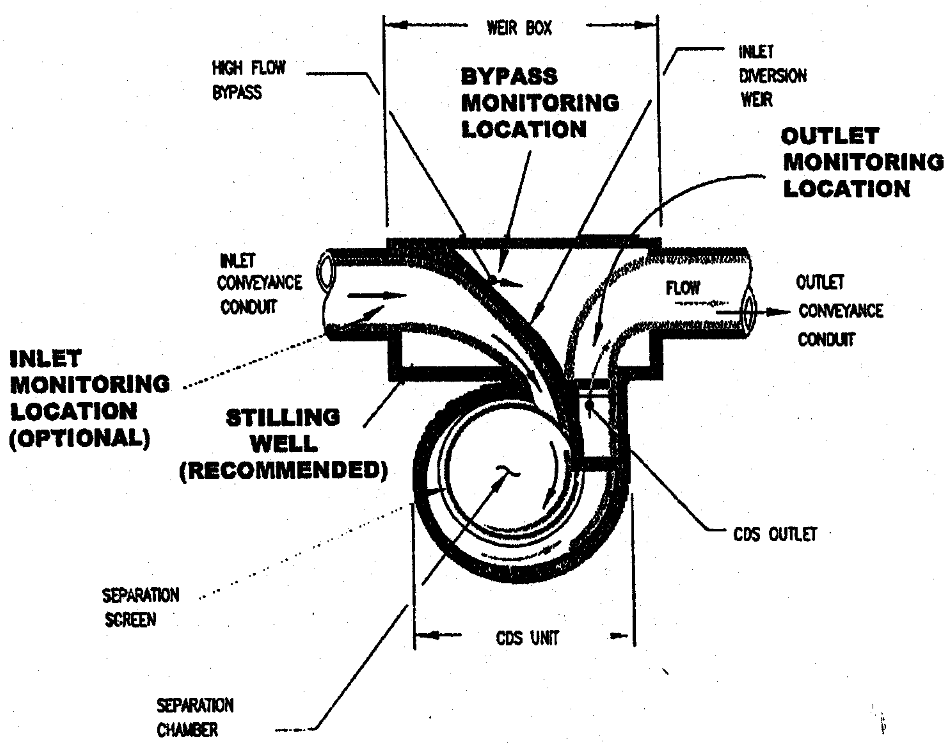
Event	Influent EMC	Log (Influent EMC)	Effluent EMC	Log (Effluent EMC)	Efficiency
2	55	4.01	75	4.32	-36%
3	31	3.43	32	3.47	-3%
4	100	4.61	56	4.03	44%
5	28	3.33	7	1.95	75%
6	39	3.66	59	4.08	-51%
8	27	3.30	24	3.18	11%
9	26	3.26	31	3.43	-19%
10	23	3.14	36	3.58	-57%
Log-mean		3.59		3.50	
Log-variance		0.24		0.54	
Avg. EMC per Scoping Method	$e^{(\text{Log-mean + Log-variance/2})}$				
AVG. INFLUENT EMC =	40.85	AVG. EFFLUENT EMC =	43.38	REMOVAL EFFICIENCY =	-6%

The above calculations clearly demonstrate that the Scoping Study Method is very sensitive to these extreme measurements. This re-iterates limitations of this procedure when applied to small data sets as acknowledged by FHWA, Caltrans and NRDC.

APPENDIX C

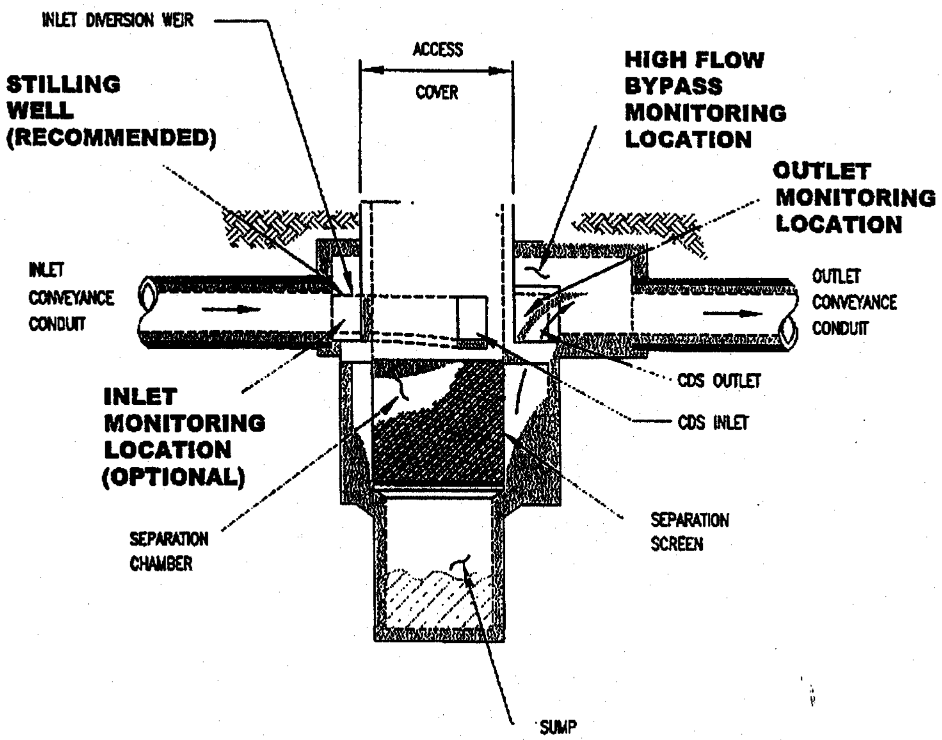
CDS EVALUATION PROTOCOLS MONITORING LOCATIONS

CDS EVALUATION PROTOCOLS – MONITORING LOCATIONS



PLAN VIEW

CDS EVALUATION PROTOCOLS – MONITORING LOCATIONS



EFFICIENCY DETERMINATION

$$\text{EFFICIENCY} = \frac{\text{SUMP LOAD + SEPARATION CHAMBER LOAD}}{\text{OUTLET LOADS + SUMP LOAD + SEPARATION CHAMBER LOAD + BYPASS LOADS}}$$

SUMP LOAD = DRY WEIGHT SOLIDS X POLLUTANT CONCENTRATION

SEPARATION CHAMBER = CHAMBER MASS X POLLUTANT CONCENTRATION

OUTLET LOADS = Σ INDIVIDUAL STORM EVENT LOADS (MASS X EMC)

BYPASS LOADS = Σ INDIVIDUAL STORM EVENT BYPASS LOADS (MASS X EMC)

ELEVATION

ORCAS AVENUE CDS

Mass Balance A: *Outlet Loads* determined by applying Annual EMC to monitored and non-monitored events

Event Date	EMC (mg/L)	Flow (L)
11/12/2001	63	45759
11/24/2001	20	75912
12/20/2001	35	17366
1/27/2002	5	120789
2/17/2002	28	4538
3/17/2002	59	4222
Non Monitored	-	40944
	Annual Avg. = 41.21*	**Annual Vol.= 309528**

*Calculated using Scoping Method

Separation Chamber Load (Sump Load), S = 6366 g
Bypass Load, B = 32g

Outlet Load, O = (Annual EMC from lognormal distribution) X (Total Annual Volume)

$$O = \frac{41.21 \times 309528}{1000} = 12755.47 \text{ g}$$

$$\text{Efficiency, } E = \frac{S}{S+B+O} \times 100$$

$$E = \frac{6366}{6366 + 32 + 12755.47} \times 100 = 31\ \%$$

Mass Balance B: *Outlet Loads* determined by applying Annual EMC to non-monitored events and measured values for monitored events

Event Date	EMC (mg/L)	Flow (L)	Effluent Load (g) {EMC X Flow}
11/12/2001	63	45759	2882.82
11/24/2001	20	75912	1518.24
12/20/2001	35	17366	607.81
1/27/2002	5	120789	603.95
2/17/2002	28	4538	127.06
3/17/2002	59	4222	249.10
	Sub-Total	**268584**	**5988.98**
Non Monitored	41.21*	40944	1687.30

Event Date	EMC (mg/L)	Flow (L)	Effluent Load (g) {EMC X Flow}
	Annual Total	309528	7676.28

*Calculated using Scoping Method

Separation Chamber Load (Sump Load), S = 6366 g
Bypass Load, B = 32g

Outlet Load, O = $\sum(EMC)(FLOW)$ = 7676.15 g

$$\text{Efficiency, } E = \frac{S}{S+B+O} \times 100$$

$$E = \frac{6366}{6366+32+7676.15} \times 100 = 45\ \%$$

FILMORE CDS

Mass Balance A: *Outlet Loads* determined by applying Annual EMC to monitored and non-monitored events

Event Date	EMC (mg/L)	Flow (L)
10/30/2001	186	4159
11/12/2001	75	90925
11/24/2001	32	196892
11/29/2001	56	18267
12/2/2001	7	28216
12/20/2001	59	65797
1/27/2002	1	201739
2/17/2002	24	35977
3/5/2002	31	7106
3/17/2002	36	8522
Non Monitored	-	131735
	Annual Avg. 78.73*	**Annual Vol. 789335**

*Calculated using Scoping Method

Separation Chamber Load (Sump Load), S = 31,164 g
Bypass Load, B = 92 g

Outlet Load, O = (Annual EMC from lognormal distribution) X (Total Annual Volume)

$$O = \frac{78.73 \times 789{,}335}{1000} = 62{,}143.85 \text{ g}$$

$$\text{Efficiency, } E = \frac{S}{S + B + O} \times 100$$

$$E = \frac{31{,}164}{31{,}164 + 92 + 62{,}143.85} \times 100 = 33\ \%$$

Mass Balance B: *Outlet Loads* determined by applying Annual EMC to non-monitored events and measured values for monitored events

Event Date	EMC (mg/L)	Flow (L)	Effluent Load (g) {EMC X Flow}
10/30/2001	186	4159	773.57
11/12/2001	75	90925	6819.38
11/24/2001	32	196892	6300.54
11/29/2001	56	18267	1022.95
12/2/2001	7	28216	197.51
12/20/2001	59	65797	3882.02

Event Date	EMC (mg/L)	Flow (L)	Effluent Load (g) {EMC X Flow}
1/27/2002	1	201739	201.74
2/17/2002	24	35977	863.45
3/5/2002	31	7106	220.29
3/17/2002	36	8522	306.79
	Subtotal	**657600**	**20588.25**
Non Monitored	78.73*	131735	10371.50
	Annual Total	**789335**	**30959.74**

*Calculated using Scoping Method

Separation Chamber Load (Sump Load), S = 31,164 g
Bypass Load, B = 92g

Outlet Load, O = $\sum(EMC)(FLOW)$ = 30,959.74 g

$$\text{Efficiency, } E = \frac{S}{S+B+O} \times 100$$

$$E = \frac{31{,}164}{31{,}164 + 92 + 30{,}959.74} \times 100 = 50\ \%$$

APPENDIX E

MASS BALANCE APPROACH CALCULATIONS

MASS BALANCE APPROACH CALCULATIONS

$$\text{Efficiency} = \frac{\text{Sump Load + Separation Chamber Load}}{\text{Outlet Load + Sump Load + Separation Chamber Load + Bypass Load}}$$

Orcas Avenue

Scoping Study Method using estimated Annual EMC for monitored and non-monitored events and pre-burned (dry mass) values for loads.

$$\text{Efficiency} = \frac{14{,}681(a) + 60(b)}{12{,}755 + 14{,}681 + 60 + 32} = \frac{14{,}741}{27{,}528} \times 100 = 54\%$$

(a) Table 1-j September 2002 report
(b) Table 1-o July 2002 report

Scoping Study Method using estimated Annual EMC for non-monitored events and measured values for monitored events and pre-burned (dry mass) values for loads.

$$\text{Efficiency} = \frac{14{,}681 + 60}{7676 + 14{,}681 + 60 + 32} = \frac{14{,}741}{22{,}509} \times 100 = 65\%$$

Filmore Street

Scoping Study Method using estimated Annual EMC for monitored and non-monitored events and pre-burned (dry mass) values for loads.

$$\text{Efficiency} = \frac{63{,}747(a) + 133(b)}{62{,}144 + 63{,}747 + 133 + 90} = \frac{63{,}880}{126{,}114} \times 100 = 51\%$$

(a) Table 1-j September 2002 report
(b) Table 1-p July 2002 report

Scoping Study Method using estimated Annual EMC for non-monitored events and measured values for monitored events and pre-burned (dry mass) values for loads.

$$\text{Efficiency} = \frac{63{,}747 + 133}{30{,}960 + 63{,}747 + 133 + 90} = \frac{63{,}880}{94{,}930} \times 100 = 67\%$$