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Consideration of metals levels in identifying CSO abatement options

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Levels of total metals (Pb, Cu, Zn, Cr, Ni) from samples in Buffalo, NY, were generally higher in combined sewage than sanitary flow. Sewer separation should therefore be considered carefully when choosing combined sewer overflow (CSO) abatement options. The first flush phenomenon was typically observed for sampled CSO events and first flush control may be effective in reducing receiving water impacts. Event mean concentration is often used for runoff quality evaluation, without consideration of concentration variability. The Weibull and lognormal distributions best fit the event mean concentration data and could be used to assess contaminant loading variability.

Keywords: CSO; Event mean concentration; First flush; Probability distributions; Sanitary sewer flow; Total metals

1. Introduction

The US Environmental Protection Agency (US EPA) developed the Combined Sewer Overflow Control Policy of 1994 (40 CFR Part 122) with the objective of establishing a consistent national approach for controlling combined sewer overflows (CSOs) through more effective use of the NPDES (national pollutant discharge elimination system) permit program. An important component of the policy is that CSO permittees must develop a long term control plan (LTCP) for CSO abatement. Ultimately, the LTCP must provide for cost-effective CSO controls that will enable attainment of water quality standards in a receiving water body. In addressing this issue of water quality standards and protection of designated uses, the US EPA outlined two different approaches that a CSO permittee might use for the LTCP: a demonstration approach and a presumption approach (US EPA 1995). Under the demonstration approach, the permittee must successfully demonstrate the planned control program is adequate to meet water quality standards and protect designated uses, unless these cannot be met as a result of natural background conditions or other pollution sources (in which case a total maximum daily load (TMDL) must be developed).

Recognizing that a permittee may not be able to develop a full understanding of receiving water body dynamics and the levels of CSO control necessary to achieve water quality standards, the US EPA included the presumption approach as an alternative in the policy. The presumption approach allows the LTCP to be judged successful if one of two key criteria is met. The first of these is that no more than an average of four overflow events per year occur for which flow does not receive minimum treatment (primary clarification and disinfection of effluent); the permitting authority may allow up to an additional two CSO events per year. Secondly, elimination or capture for treatment of at least 85% by volume of the combined sewage collected in the system during precipitation events on a system-wide, annual average basis must be demonstrated (US EPA 1995).

Clearly, an important focus of the presumption approach is reduction of CSO volume and this can be accomplished in a variety of ways, including sewer separation. Sewer

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separation can be an attractive alternative for some municipalities, particularly in those areas that experience recurring problems with sewer back-ups (US EPA 1999). Sewer separation can simultaneously reduce back-up complaints and the volume of CSO discharge (thereby addressing the 85% capture criterion noted above). For a net positive impact on the receiving water body, however, it must be determined that the pollutant loads are not simply being diverted from the CSOs to the storm water discharge of a separated system.

The CSO control policy also requires the permittee to characterize CSO discharges, and an event mean concentration approach often is employed to calculate contaminant loadings. Frequently, there is little information regarding the variability of the event mean concentration and this has implications for the level of assurance in making loading estimates (Behera *et al.* 2000). Furthermore, the event mean concentration approach cannot address the effectiveness of control measures, for example, that target the first flush of a CSO event.

The objectives of this paper are threefold. First, the levels of total Cr, Cu, Zn, Pb, and Ni in wet weather (combined) and dry weather (sanitary) flow from various locations in Buffalo, NY, are examined using simple summary statistics as well as frequency analysis. Second, the relative contribution of storm water runoff to the total metals load is examined by comparing levels in combined flow and sanitary flow. Third, the first flush phenomenon for total metals is examined and discussed in terms of abatement strategy.

2. Methods

Sampling of wet weather and dry weather flow in the combined sewer system of Buffalo, NY, was conducted in 1997, 1998 and 2000. An automated sampling system, consisting of a Marsh-McBirney Model 370c flow meter connected to an ISCO 2700 pump sampler was installed at one site in the Babcock St. sewershed between 3May and 3 September 1997; and again between 1 June and 30 September 1998. The sample site was located in a 1.75 m diameter pipe that acted as the main collector draining the sewershed. The flow meter was programmed to record at five-minute intervals and wet weather sample collection was initiated when flow depth in the sewer was greater than 0.25 m. A 100 mL sample was collected at 42.5 m^3 flow intervals and the 100 mL samples were composited in one 4-L polyethylene bottle housed within the pump sampler. The pump sampler was fitted with Teflon-lined tubing (except for the small section in the pump housing which was silicon). The tubing was replaced regularly and the pump collected pre-sample rinses to avoid cross-contamination. The Babcock St. sewershed was selected for study because it is a major CSO discharge point within the city, it has mixed land use, including a variety of industrial types (Irvine 1999), and historical sewer flow and quality data were available (e.g. Irvine *et al.* 1993, Pratt *et al.* 1995, Loganathan *et al.* 1997, Irvine 2002).

Dry weather (sanitary flow) grab samples were collected at the Babcock St. site using a Sigma 700 pump sampler during regular business hours. The Sigma sampler was fitted with Teflon-lined tubing (except for the small section in the pump housing which was silicon) and samples were collected in polyethylene bottles. Sample collection and handling procedures for wet and dry weather flow were designed to minimize the risk of sample contamination, following US EPA Method 1669.

Wet weather sampling in 2000 was done at 20 sites throughout the city of Buffalo during three CSO events that occurred on 9 June, 7 August and 23 August, in support of the LTCP for the city. Sampling methodology was described in detail by Malcolm Pirnie, Inc. (2001). Sampling for the most part was done manually by field crews using Teflon-lined bailers. At a couple of high traffic sites it was necessary to use pump samplers fitted with Teflon-lined tubing. Samples were collected every 15 minutes for a period of up to five hours. Depending upon the site, samples from the first 45 minutes were either composited into one bottle, or analyzed separately, to represent the first flush of the event. Samples for the remaining portion of the overflow event were either composited into one bottle, or analyzed separately (depending on the site), to represent the ‘‘rest of storm’’ conditions.

Dry weather sampling in 2000 was done at seven sites on two different dates, 4 May and 7 September. Single grab samples were collected at the sites using the same procedure as was done for the wet weather sampling.

The samples collected in 1997 and 1998 were analyzed using Inductively Coupled Plasma (ICP) atomic emission spectroscopy. The digestion procedure followed US EPA Method 200.2 and the instrument analysis procedure followed US EPA Method 200.7. The method detection limits were: Pb – 0.0061 mg/L; Cu – 0.0038 mg/L; Zn – 0.0014 mg/L; Cr – 0.001 mg/L; and Ni – 0.0062 mg/L. Quality control procedures were outlined in a US EPA-approved Quality Assurance Project Plan and included: undigested reference for initial calibration (every batch); reference samples (every 10th sample with a minimum of one per batch); sample duplicates; blanks (every 10th sample with a minimum of one per batch); and standard reference material (every 10th sample with a minimum of one per batch). Samples met quality assurance criteria with the exception that Zn was detected in the blank for one sample batch. The results for this batch were flagged but because the samples had values much higher than that detected in the blank, the results were used directly. Mean

Table 1. Total metals levels (mg/L) for Babcock St. sewershed.

	Pb		Cu		Zn		Cr		Ni	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Wet weather, 1997	0.1229	0.1012	0.0776	0.0849	0.4123	0.2633	0.0182	0.0152	0.0125	0.009
Wet weather, 1998	0.1283	0.1387	0.356	0.7866	0.9888	1.3915	0.0317	0.0293	0.0779	0.1928
Dry weather, 1997	0.0074	0.0058	0.0136	0.009	0.0587	0.0309	0.0026	0.0023	0.0031[a]	0[a]
Dry weather, 1998	0.0074	0.0033	0.0335	0.0318	0.0505	0.0112	0.0037	0.0023	0.0068	0.0038

[a]All samples were below detection limit. A value of one-half the detection limit was substituted. S.D. – sample standard deviation.

Table 2. First flush and rest of storm levels (mg/L) for 2000 sampling.

	Pb		Cu		Zn		Cr		Ni	
Site	Mean FF[a]	Mean ROS[a]	Mean FF	Mean ROS	Mean FF	Mean ROS	Mean FF	Mean ROS	Mean FF	Mean ROS
NDWQ1	0.04685	0.02676	0.25583	0.07084	0.56938	0.25094	0.01458	0.01983	0.04083	0.03873
SCDWQ1	0.11967	0.06367	0.048	0.03633	0.27	0.114	0.00367	0.00333	0.007	0.004
SCDWQ2	0.0875	0.069	0.062	0.042	0.285	0.14	0.002	0.0015	0.0065	0.0065
SCDWQ3	0.0815	0.0565	0.039	0.032	0.145	0.165	0.0025	0.0015	0.004	0.0035
SCDWQ4	0.069	0.0755	0.06433	0.051	0.23333	0.53	0.00233	0.005	0.0043	0.004
SCDWQ6	0.18233	0.15438	0.09408	0.02805	0.33333	0.23958	0.00704	0.00617	0.01388	0.01238
SCDWQ7	0.1565	0.09	0.13	0.0795	0.485	0.185	0.0025	0.0045	0.0095	0.005
SCDWQ8	0.215	0.1	0.0805	0.03433	0.32	0.15333	0.01	0.00467	0.01	0.00567
SCDWQ9	0.09279	0.05671	0.06788	0.03476	0.595	0.16752	0.009	0.0051	0.01233	0.00705
SCDWQ13	0.14453	0.03506	0.09518	0.02488	0.44856	0.21068	0.02114	0.00354	0.01913	0.00477
SCDWQ14	0.08333	–[b]	0.06633	–	0.30333	–	0.00833	–	0.00767	–
SCDWQ15	0.22	0.192	0.0655	0.064	0.355	0.305	0.0145	0.0125	0.0155	0.017
SJDWQ1	0.27088	0.094	0.2305	0.065	8.81875	0.09899	0.006	0.0065	0.00888	0.0075
SJDWQ2	0.11054	0.06211	0.0645	0.04789	0.204	0.204	0.00692	0.00361	0.01325	0.008
SJDWQ3	0.04034	0.04688	0.02783	0.03674	0.15367	0.20007	0.00408	0.00456	0.00525	0.00675
SJDWQ4	0.00235	0.0019	0.005	0.0065	0.0385	0.01909	0.0025	0.0025	0.0055	0.00353

[a]FF – first flush; ROS – rest of storm; [b]– Not enough data collected to calculate mean.

Table 3. Dry weather and event mean levels, total metals, (mg/L) for 2000 sampling.

	Pb		Cu		Zn		Cr		Ni	
Site	Mean dry	Mean EMC[a]	Mean dry	Mean EMC	Mean dry	Mean EMC	Mean dry	Mean EMC	Mean dry	Mean EMC
NDWQ1	0.022	0.03118	1.17	0.11345	1.43	0.32637	0.37	0.01839	0.38	0.03874
SCDWQ6	0.0255	0.15613	0.02525	0.07958	0.0795	0.26967	0.01125	0.00617	0.0035	0.01221
SCDWQ9	0.0104	0.07211	0.042	0.04778	0.117	0.3977	0.005	0.00686	0.01	0.0095
SCDWQ14	0.0295	0.04004	0.0515	0.02883	0.195	0.1285	0.0065	0.00433	0.0085	0.00246
SJDWQ1	0.2	0.27479	1.08	0.2314	4.8	9.27	0.036	0.00579	0.0195	0.00898
SJDWQ2	0.0081	0.09345	0.0365	0.05674	0.165	0.21101	0.007	0.00598	0.067	0.0112
SJDWQ3	0.0023	0.04314	0.0065	0.03296	0.087	0.18355	0.0035	0.00444	0.003	0.00626

[a]EMC – event mean concentration.

relative percent difference (RPD), as a measure of precision, was less than 35% for each metal.

The samples collected in 2000 were analyzed using ICP, following SW-846 Method 6010. The method detection limits were: Pb – 0.0003 mg/L; Cu – 0.001 mg/L; Zn – 0.005 mg/L; Cr – 0.001 mg/L; and Ni – 0.002 mg/L. Quality assurance procedures followed the US EPA Region II guidance documents *Evaluation of Metals Data for the*

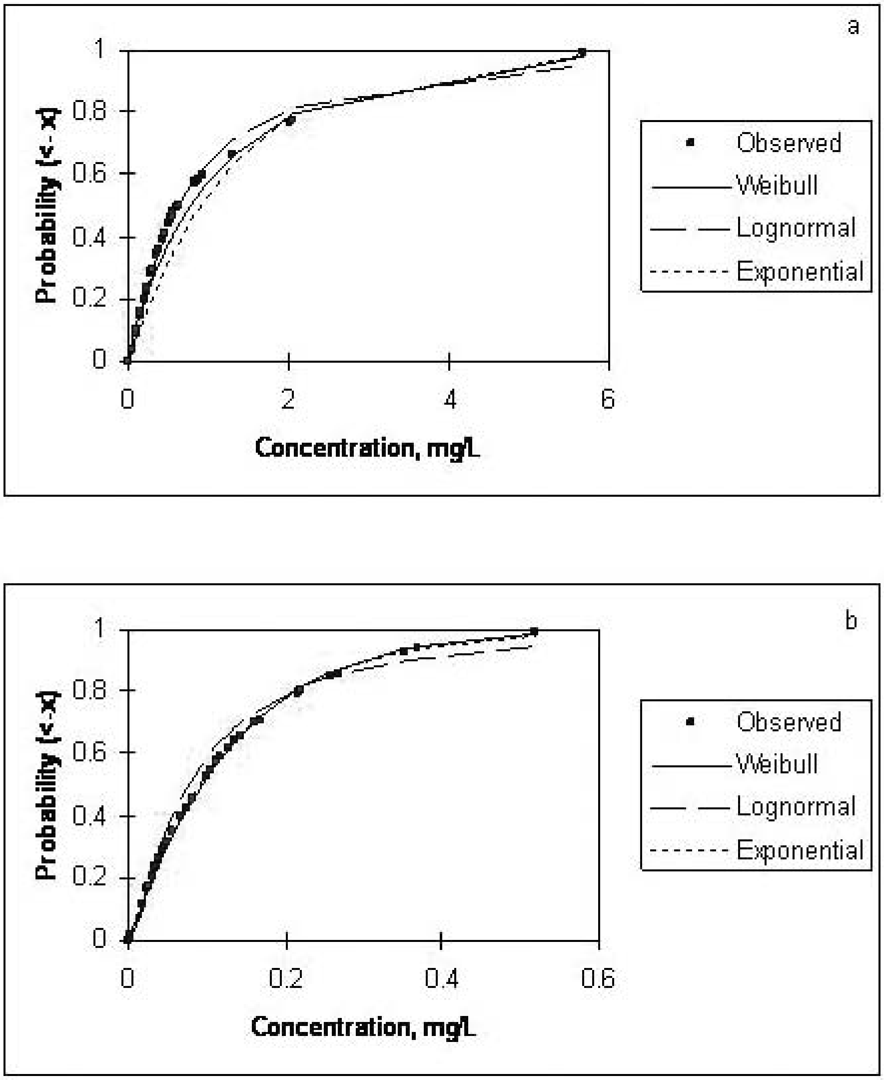

Figure 1. Fitted probability distributions for event mean concentration, Babcock St. sewershed, 1997–1998, (a) Zn; and (b) Pb.

Contract Laboratory Program, SOP Revision XI, 1992 and *Evaluation of Water Quality Parameters for CLP in Multiconcentration Water, 1994* and included matrix spikes, laboratory control samples and sample duplicates. All data were reviewed by a Water Quality Data Review Committee consisting of chemists, environmental scientists and engineers working on the project. Of the 465 samples analyzed for sewers and receiving water bodies, only 20 Zn results were flagged for not meeting quality assurance criteria due to a low level blank contamination. The mean RPD was less than 35% for each metal. All sample analyses for the projects described in this paper were done by laboratories that held New York State Department of Health certification.

3. Results

A total of 16 wet weather events and 4 dry weather grabs (on separate days) were collected in each of 1997 and 1998 and results are summarized in table 1. Because the wet weather samples represented a flow-proportioned composite for individual events, the data in table 1 represent an averaged event mean concentration, with a corresponding standard deviation.

Results for the 2000 wet weather sample collection are summarized in table 2, where the first flush data for each site were averaged across the three overflow events, as were the "rest of storm" data. It should be noted that of the 20 sites, one site did not overflow during the sample period, two sites only overflowed for the 23 August event, and one site only overflowed for the 7 August event. The results for these sites were therefore not included in table 2. Table 3 summarizes the 2000 results for dry weather sample collection, as well as the calculations of an event mean concentration, which combined the time-proportioned data for both the first flush and "rest of storm" presented in table 2.

The BestFit™ software, a Microsoft Excel spreadsheet add-in (Palisade Corporation 1996), was used to identify the distribution(s) that best reflected the wet weather metals data for 1997 and 1998 (combined). BestFit™ compared the sample data with 21 theoretical probability distributions, using a maximum likelihood estimator approach. Subsequently, Chi-square and Kolmogorov-Smirnov test statistics were calculated to evaluate goodness-of-fit and BestFit™ ranked the fit of each distribution based on the test statistic results. The rankings of the most appropriate distributions may differ for the two test statistics because of different emphasis in the calculation of the statistics (Palisade Corporation 1996). An examination of the top three rankings for each metal and each statistic indicated that the Weibull distribution provided the best overall fit, followed by the lognormal distribution. The exponential distribution appeared most appropriate for Pb and Cr, but less appropriate for Cu, Zn and Ni. Results of the Weibull, lognormal, and exponential distributions fit for Zn and Pb are shown in figure 1. The results for Zn were representative of the results for Cu and Ni, while the results for Pb were representative of the results for Cr.

4. Discussion

Mean metals levels in the wet weather samples for the Babcock St. sewershed tended to be higher, with larger standard deviations, in 1998 as compared to 1997 (table 1). There was less difference for the dry weather results between the two years. The reason for the higher levels, particularly in Cu, Zn, and Ni, is not entirely clear, although event characteristics may have had an influence. Total CSO volume for all events monitored in 1997 was 1,727 m^3, with an event mean CSO volume of 108 m^3. Total CSO volume for all events monitored in 1998 was 3,572 m^3, with an event mean CSO volume of 595 m^3. The larger events in 1998 may have introduced runoff and contaminants from additional source-areas that included old industrial lots and railway land found throughout the Babcock St. sewershed.

Metals levels for the Babcock St. sewershed wet weather samples (1997 and 1998) and samples collected throughout Buffalo in 2000 were generally in the same range as those observed for other cities in the "Golden Horseshoe" from Toronto, Ontario, around the western end of Lake Ontario, to Rochester, NY. For comparison purposes, these data are reproduced in table 4. The data for Hamilton, ON (table 4) represent the mean and standard deviation of 20 grab samples collected through nine CSO events from a mixed land use sewershed in the north eastern section of the city. The data for Toronto, ON (table 4) represent mean CSO concentrations from seven sewersheds that had different land uses.

Results for the Babcock St. sewershed (table 1) suggest that mean metals levels associated with wet weather flow were higher than mean metals levels in dry weather flow. Student t-tests confirmed that in both 1997 and 1998 the mean levels of Cr, Pb and Zn for the wet weather samples were significantly higher ($\alpha = 0.05$) than the mean levels in dry weather samples. The mean level of Cu for wet weather samples was significantly higher ($\alpha = 0.05$) than the mean level for dry weather samples in 1997, but the significance level rose to 0.06 for the 1998 data. The results for 2000 (table 3) indicate that metals levels in wet weather samples were generally greater than dry weather samples at four of the seven sites (SCDWQ6, SCDWQ9, SJDWQ2,

Table 4. Metals levels (mg/L) for other cities in the Golden Horseshoe.

Source	City	Pb		Cu		Zn		Cr		Ni	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Irvine *et al.*, 1998	Hamilton, ON	0.0902	0.0777	0.0949	0.1149	0.676	0.887	0.0244	0.0330	0.0102	0.0088
Behera *et al.*, 2000	Toronto, ON	–	–	0.08	0.004 – 0.3[a]	0.27	0.011 – 0.77[a]	–	–	–	–
D'Andrea and Maunder, 1993	Toronto, ON	0.12	–	–	–	–	–	–	–	–	–
Moffa, 1990	Rochester, NY	0.14	–	–	–	–	–	–	–	–	–

S.D. – standard deviation; [a]represents data range rather than standard deviation.

SJDWQ3). Sites NDWQ1 and SJDWQ1 were notable exceptions to this general trend as the event mean concentration:dry weather concentration ratio generally was less than one (Pb being the exception with a ratio greater than one). Malcolm Pirnie, Inc. (2001) noted that NDWQ1 was downpipe of three plating companies and a large brass works company, while SJDWQ1 was downpipe of a hospital, a large axle company and a plating company.

Metals levels in combined sewer overflows reflect the relative contribution from dry weather and wet weather flow. Table 1 and the results of the statistical testing show that metals levels for the Babcock St. sewershed were greater for wet weather samples. This trend also was observed at the majority of other sample sites for the 2000 data, but discharge to the sewer system from larger facilities or facilities with particular processing activities can change the wet weather:dry weather concentration ratio. In general, however, it seems that the Buffalo Sewer Authority industrial pre-treatment program has been effective in managing the quality of wastestream discharge as part of the sanitary flow. To enable the Buffalo Sewer Authority to comply with its state pollutant discharge elimination system (SPDES) permit and with US EPA requirements, the pre-treatment control program was developed. The current pre-treatment control program was updated and approved in 1984 to meet state and federal regulations. The Buffalo Sewer Authority pre-treatment requirements and the mechanisms to implement the program were incorporated into the authority's sewer use regulations. The primary legal mechanism for controlling industrial discharge to the sewer system is through the Buffalo pollutant discharge elimination system (BPDES) permit process. Industries that are considered to have a potential impact on the sewer system, and/or the treatment plant, and/or the environment are issued a BPDES permit to control their discharge. The Buffalo Sewer Authority conducts a sampling program to help ensure permit compliance.

It also is important to emphasize that for most sewers in the City of Buffalo, the relative mass loading of metals from wet weather flow would be greater for a CSO event than the loading from the sanitary flow because of the greater flow volume. Sources of the metals in the wet weather flow include: atmospheric washout associated with rainfall; street washoff; runoff from industrial, commercial and residential roofs directly connected to the sewer system; and runoff and erosion from paved and unpaved industrial, commercial and residential property. Runoff from pervious and impervious urban surfaces also would include metals deposited on these surfaces from dry fallout of atmospheric emissions (e.g. Irvine *et al.* 1989, Irvine and Loganathan 1998, Pitt *et al.* 2005).

Marsalek *et al.* (1999) evaluated the toxicity of CSOs and storm water at 15 sites in Southern Ontario using a battery of seven bioassays. The highest frequency of severe and moderate toxicity was found at highway runoff sites; frequency of CSO toxicity was lower. In a study performed for the Ontario Ministry of Environment and Energy to examine the costs of CSO control for sites in Ontario, CH2M Hill Engineering Ltd. (1992) did not evaluate sewer separation, in view of its high cost and limited environmental benefits. Furthermore, it was noted in this study that analyses conducted for the cities of Kingston and St. Catharines showed sewer separation negatively impacted receiving water quality. The US EPA (1999) reported both positive and negative impacts on receiving water quality as the result of sewer separation in different US cities, noting that without mitigation, increased loads of storm water pollutants could enter receiving water bodies. While the US EPA (1999) concluded that sewer separation had been used effectively in many US cities, it also recommended that an evaluation of the most appropriate CSO control should be performed prior to selecting sewer separation (or any other measure). Municipalities such as Buffalo that principally operate a combined sewer system, but separate a portion of that system, may be subject to the US EPA Storm Water Phase II Rules, in addition to the Combined Sewer Overflow Control Policy of 1994. The Storm Water Phase II Rules require the permit holder to develop and implement a program with the goal of preventing or reducing pollutant runoff from municipal operations, but do not require discharge quality monitoring (US EPA 1996, 2000). Although sewer separation currently is an accepted CSO control strategy in the US, the philosophy could change, and this might lead to additional treatment costs for a municipality.

The mean first flush and rest of storm concentrations for the 2000 sample sites were presented in table 2 and the first flush:rest of storm ratios are summarized in table 5. Although a first flush effect frequently was observed, it was not a universal phenomenon. One site, SJDWQ3, typically did not exhibit a first flush:rest of storm ratio greater than one, probably because this site predominantly

Table 5. Summary of first flush to rest of storm ratios.

Metal	Mean ratio (all sites combined)	Number of sites with mean ratio greater than, equal to, or less than 1
Pb	1.73	13 sites > 1; 2 sites < 1
Cu	1.96	13 sites > 1; 2 sites < 1
Zn	7.59	11 sites > 1; 3 sites < 1; 1 site = 1
Cr	1.52	9 sites > 1; 5 sites < 1; 1 site = 1
Ni	1.51	12 sites > 1; 2 sites < 1; 1 site = 1

was creek water and it took longer than the study-defined first flush period of 45 minutes for the contribution from the watershed to reach this site. Saget *et al.* (1996) noted that identification of a first flush effect could influence CSO control design, but based on their analysis of suspended sediment, COD and BOD_5 data from storm and combined sewers, concluded that the first flush phenomenon was uncommon. Hall and Anderson (1988) observed a first flush phenomenon for insoluble metals in storm water runoff, but a secondary peak of soluble metals that had greater toxicity (as measured by a *Daphnia* 96-hour test) also was observed. Hager (2001) reviewed the results of several studies conducted throughout the US and found in some cases a well-defined first flush effect was observed and in other cases it could not be identified. It was concluded that the first flush could be very site-specific and affected by many variables, including storm characteristics.

Van Buren *et al.* (1997) identified four areas in which frequency analysis and identification of appropriate underlying probability distributions may be useful for runoff quality analysis: pollutant load estimation; probability of compliance with water quality criteria; performance assessment of runoff controls and BMPs; and evaluation of censored water quality data. Behera *et al.* (2000) noted that the probability distribution of a pollutant load could be derived from the probability distributions of runoff volume and the event mean concentration. Often, however, the probability distribution of the event mean concentration is replaced by a constant event mean concentration value because limited data preclude identification of an appropriate distribution.

Many studies must deal with the issue of censored data (i.e. concentration data reported as less than the detection limit). Clearly, in calculating an event mean concentration, values below detection limit present a challenge. Historically, these below detect results were assigned a value of 0, $\frac{1}{2}$ detection limit, or detection limit, to facilitate calculation of the event mean concentration (e.g. Gleit 1985, El-Shaarawi and Dolan 1989), but more objective and rigorous methods (e.g. maximum likelihood estimations, normal regression/log normal regression, Lambert Method) are now commonly applied to estimate the mean and standard deviation of a censored data set (Fleury 1994).

In order to operationalize these estimation methods, an assumption about the underlying data distribution must be made and often the lognormal distribution is selected as appropriate (e.g. Novotny and Witte 1997, Van Buren *et al.* 1997). Behera *et al.* (2000) noted that for storm water runoff and CSO data from Toronto, the gamma and exponential distributions were appropriate, in addition to the lognormal, while Maestre *et al.* (2005) found the lognormal and 3-parameter lognormal generally to be best for data collected from throughout the US. For a minority of constituents, Maestre *et al.* (2005) also found the gamma or exponential distributions to be appropriate. The results of the distribution fitting for our data indicated that, overall, the Weibull and lognormal distributions were best, although the exponential distribution also was appropriate for Pb and Cr. It is possible that different sources existed for Pb and Cr, as compared to Cu, Zn, and Ni, resulting in slightly different frequency distributions, but this could not be evaluated in this study.

5. Conclusion

The results from Buffalo show that total metals concentrations in wet weather flow typically were greater than total metals concentrations in dry weather flow. This finding underscores some important implications for CSO abatement. First, for those sites where wet weather concentrations are greater, the corresponding loading contribution from wet weather flow also would be greater. Totten Sims Hubicki Associates, Donald G. Weatherbe Associates & Elizabeth Leedham (2001) recently produced the *Storm water Pollution Prevention Handbook* for the Ontario Ministry of Environment and Energy and summarized case studies from nine communities throughout the province of Ontario. Several of the communities serviced by separate sewer systems identified storm water discharge as negatively impacting receiving water quality and habitat. The municipal response to this challenge ranged from disconnection of downspouts to construction of exfiltration systems and storm water quality ponds.

In summary, it appears that there are some environmental concerns associated with discharge of untreated storm water runoff from separate sewer systems. Although the results from Buffalo and other cities also suggest that the level of impact may be site specific (and should be evaluated on a site by site basis), the option of sewer separation *as an environmental BMP* should be considered carefully.

The first flush phenomenon generally was observed for total metals in the Buffalo samples, but not all studies concur with the universality of such a phenomenon (Saget *et al.* 1996, Hager 2001). Hager (2001) noted CSO control in the US often is designed around the capture of first flush, although there also appears to be some discussion that this is not sufficient. For Buffalo, capture of the first flush would control initially high concentrations of metals discharging to the receiving water bodies. First flush control may be particularly important for municipalities that do not have the financial capability for more extensive control measures.

In evaluating the frequency distributions of the wet weather event mean concentrations, it was found that the Weibull and lognormal distributions generally provided the best fit. When considering specific metals, the exponential distribution also was viable for Pb and Cr.

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