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STORMWATER WHOLE EFFLUENT TOXICITY (WET) TESTING AND SOURCE TRACING AT SEA-TAC INTERNATIONAL AIRPORT

Scott A. Tobiason
Environmental Management Specialist
Port of Seattle
17900 International Blvd
Seattle, WA 98188

Linda R. J. Logan
Toxicology Manager
Parametrix Incorporated
Kirkland, WA

ABSTRACT

During a twelve month period in 1998-99, the Port of Seattle characterized the whole effluent toxicity (WET) of stormwater samples from four outfalls at Seattle-Tacoma International Airport (STIA.) This testing was conducted in accordance with USEPA and Washington State guidelines and the Port's individual NPDES stormwater permit for the airport. The WET tests used two aquatic organisms, a water flea (*Daphnia pulex.*) and the fathead minnow (*Pimephales promelas.*)

All eight test results for two of the outfalls met the Washington State Department of Ecology performance standards for survival for each organism. These two outfalls drain 79% (200 ha, 492 ac) of the airfield runways and taxiways. Nine of ten test results for a third outfall, that drains 60 hectares (149 acres) of mostly access roadways and the terminal and cargo building rooftops, also met the performance standards. In contrast, seven of nine WET results for a fourth outfall that drains 6 hectares (14 acres) of rooftops and roadways were below the performance standards and led to a subsequent source tracing investigation.

Supplemental sampling and analysis, including metals chelation with EDTA indicated that zinc was the most likely source of toxicity in samples from this fourth outfall. Further investigations revealed that about 0.8 hectare (2 acres) of zinc-galvanized metal rooftop on two air cargo buildings was the principal source of the zinc, where typically 50% or more was in the dissolved form. Synthetic runoff samples obtained by spraying domestic water on the metal rooftops also exhibited toxicity and considerable zinc, while the raw domestic water did not. The Port is investigating opportunities to remedy this apparent source of toxicity in the runoff that originated from a tenant-owned facility. As a result of this work, the Port is considering policy development that would address rooftop materials.

KEYWORDS

NPDES, stormwater, whole effluent toxicity, zinc, rooftop materials

INTRODUCTION

This paper describes stormwater whole effluent toxicity testing (WET) and subsequent source tracing conducted by the Port of Seattle at Seattle-Tacoma International Airport (STIA). This testing was conducted in part to meet NPDES permit requirements and in part to support best management practices (BMPs) at the airport. The Port of Seattle owns and operates STIA, which lies about mid way between the cities of Seattle and Tacoma, Washington. The airport was built in the 1940s and expanded throughout the years to become the 18th busiest airport in the U.S. The areas surrounding the airport urbanized and incorporated as the cities of Seatac, Des Moines, and Burien.

The STIA stormwater drainage system (SDS) drains fourteen principal subbasins through a variety of outfalls, four that drain to Miller Creek, eight that drain to Des Moines Creek and two that drain to a City of Seatac system. Both Creeks flow several miles directly to Puget Sound and receive runoff from surrounding urban areas. These outfalls drain a total of 390 ha (963 ac) which contain about 44% impervious surfaces. Another 150 ha (370 ac) of impervious surfaces where aircraft are serviced (terminal gates and ramps) drain to the Industrial Waste System (IWS) and the Industrial Waste Treatment Plant (IWTP). The IWTP provides dissolved air flotation (DAF) treatment for aircraft related fuel spills, and discharges to Puget Sound through a marine outfall.

Five of the STIA stormwater subbasins drain the airfield runways and taxiway areas, three drain principally the "landside" terminal drives, access freeways, cargo roadways and various rooftops. The six other outfalls drain other minor areas. Recent Annual Stormwater Monitoring Reports showed that total petroleum hydrocarbons (TPH), metals and other constituents were lower in airfield outfall samples when compared to results from the landside subbasin outfalls that have considerable passenger vehicle traffic (POS 1996, 1997). The four outfalls tested for WET represent 68% of the total SDS service area and contain most of the landside and airfield activity.

In 1994, the Port secured a National Pollutant Discharge Elimination System (NPDES) permit for the stormwater and IWTP discharges. The required intensive stormwater monitoring program has been in place since 1994, and has generated a considerable volume of sample data for many stormwater constituents. A revision to the permit took effect in March 1998 requiring the WET testing on stormwater samples from four principal outfalls. In Washington State, only eleven NPDES permittees have performed WET testing on stormwater or a mix of stormwater and industrial wastewater. WET testing is a common compliance requirement for point source industrial discharges such as pulp mills and wastewater treatment plants (WDOE, 1998). WET testing generally improves upon chemical-specific testing because it measures aggregate toxicity, or lack thereof, addresses unknown toxicants, and takes bioavailability into account.

Another key permit item at STIA, the Stormwater Pollution Prevention Plan (SWPPP) implements a variety of stormwater best management practices (BMPs). The Port has already remedied a variety of inappropriate drainage connections, such as drainage from vehicle washing, that were identified by source tracing sampling conducted in the past few years.

METHODOLOGY

All samples tested were collected according to the Port's Procedure Manual for Stormwater Monitoring (POS, 1999) as flow-weighted stormwater composites using ISCO model 3700 automatic samplers and model 4150 or 4230 flowmeters. Samples generally represented the majority of runoff and are thus considered as event-mean concentrations (EMCs), a common term used to judge intra-event representativeness and inter-event comparability of a stormwater sample. For the outfall where samples exhibited toxicity, source-tracing composite samples were collected concurrently using three automatic samplers programmed to sample a similar duration of the hydrograph for each pipe. This source tracing also used grab samples taken automatically and manually at several of the upstream locations.

Samples were collected using the "clean techniques" approach for trace metal sampling (EPA method 1669) adapted for stormwater sampling (EPA 1995, POS 1999a.) Results from field equipment blanks indicated that these techniques were generally adequate (blanks had metals below detection limits). The results of the Port's routine quality control field blanks and duplicates indicate ongoing effective sampling techniques (POS, 1999c.)

WET testing was performed according to State and Federal guidelines (WDOE, 1998; EPA, 1991)on 100% stormwater samples plus a series of samples tested at specific dilutions. Results are expressed as percent survival in the100% sample plus the LC50, NOEC and LOEC estimates[1]. WET testing and chemical analyses were initiated within acceptable holding times.

To investigate the causes of toxicity in the SDN1 samples, the Port implemented a multiphase source-tracing study that used concurrent WET testing, metals chelation[2] and chemical-specific analysis of stormwater samples to reveal clues about the specific sources of toxicity. Only *Daphnia pulex* were used as the test organism since initial testing showed that the daphnia were more sensitive than the fathead minnows.

This source tracing focused on zinc because SDN1 runoff has historically exhibited higher zinc concentrations than other outfalls (see Figure 1). Note the considerable number of historical samples (twenty for SDN1) denoted by "N=" below each boxplot in the figure. During these additional sampling events in SDN1, upstream source area runoff samples were also tested to determine where and under what conditions the problems occurred. These potential source areas upstream of the SDN1 sampling location isolate runoff from the Transiplex building rooftops (a

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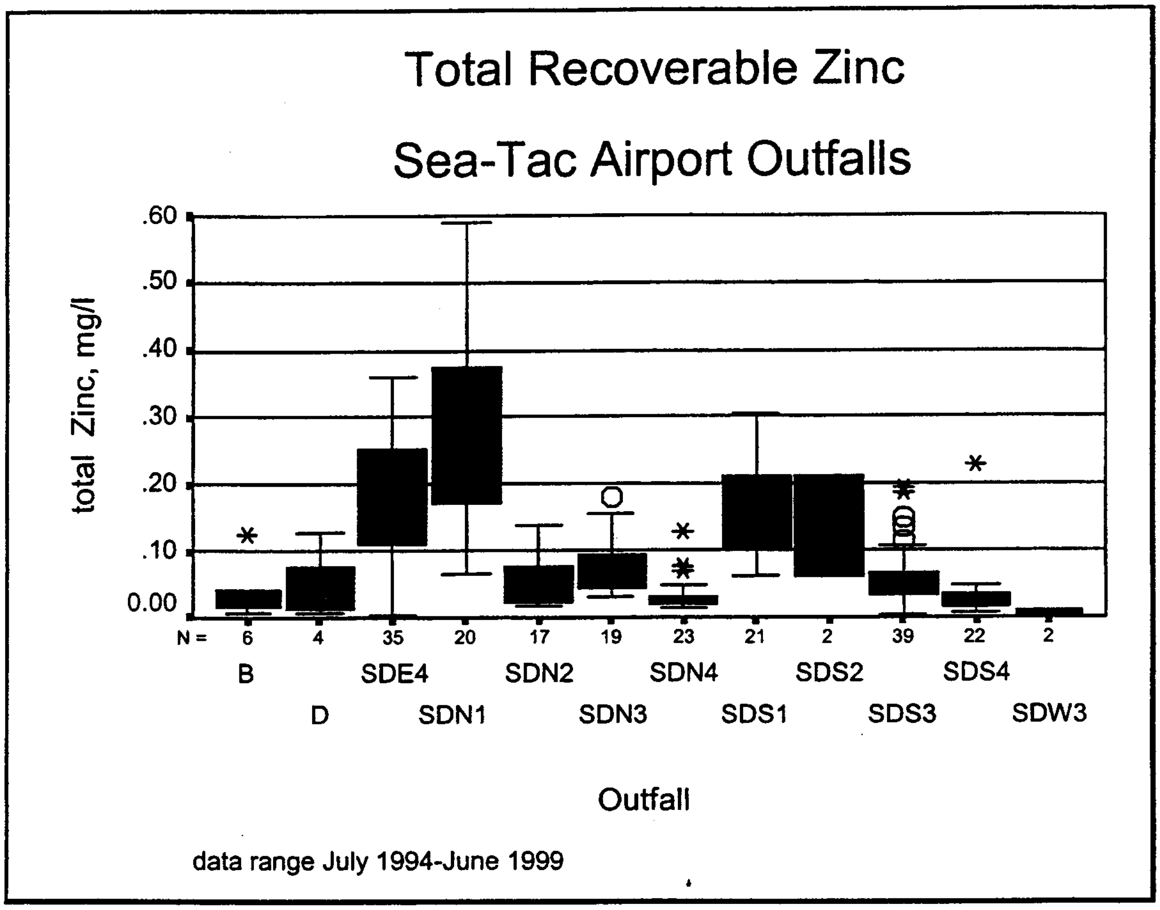
[1] The LC50 is the concentration of sample where 50% survival of the test organism occurred. The no observed effect concentration (NOEC) is the maximum concentration of the test sample that produces no statistically significant harmful effect on the test organisms compared to controls in a specific test. The lowest observed effect concentration (LOEC) is the lowest concentration that has a statistically significant deleterious effect on test organisms compared to controls in a specific test (Rand, 1995.)

[2] Chelation is the chemical process whereby ions, free metals in this case, are rendered non-bioavailable by binding to a host molecule that forms a stable complex. Free metal ions that are "bioavailable" are the form generally considered to be responsible for toxicity to aquatic organisms.

total of 4 buildings), AFCO cargo building rooftops (2 buildings), and Air Cargo Road (which also contains runoff from the recently constructed east expansion of the FedEx building rooftop.)

Figure 1 Boxplot of Historical Zinc in STIA Stormwater Samples



RESULTS AND DISCUSSION

Because all WET test results from two of the outfalls, SDS3 and SDN4, demonstrated no toxicity, sampling requirements for these two outfalls were completed early in the program during the fall and winter months of 1998-1999. All test results for these two outfalls met the Washington State Department of Ecology performance standards[3] for individual results so that additional testing was not necessary. The remaining two outfalls, SDE4 and SDN1, were sampled during additional storms to corroborate results from the first two tests. For SDE4, the additional sampling and WET testing met the required standards. As a result, further testing was not necessary. Of the five SDE4 samples evaluated for WET, the average survival of 96% for

[3] According to WAC 173-205, for acute WET tests the average survival in 100% effluent must be at least 80%, and no single sample must have less than 65% survival. For outfall SDE4, one of ten test results exhibited 63% survival, just below the minimum performance standard of 65% survival for a single test.

the daphnid and 85.8% for the fathead minnow were above the Ecology performance standards. However, samples collected from SDN1 continued to exhibit toxicity. As a result, the Port engaged in the SDN1 source-tracing study described below.

Table 1 summarizes the WET testing results; because the NOEC, LOEC and LC50 values were generally 100% they are not listed in this table. Chemical analyses were performed to characterize these WET test samples and compare results with the 5-year data history for each outfall. Because these results were within the ranges of the historical data for each outfall, the WET test samples are considered to be comparable to other historical samples. Table 2 lists the individual sample results and ranks.

Table 1 WET Testing Summary

Outfall (#)	Sample date	WET, % survival daphnid	WET, % survival Fathead	note
SDE4	11/19/98	90	100	
(002)	1/21/99	100	98	
	2/23/99	95	63	1
	3/24/99	95	98	1
	7/2/99	100	70	1,2
	Average	*96*	*85.8*	
SDS3	11/13/98	90	98	
(005)	1/14/99	80	95	
	Average	*85*	*96.5*	
SDN1	11/13/98	80	40	
(006)	1/14/99	30	78	
	3/24/99	10	63	1
	5/11/99	5	not tested	1
	7/2/99	not tested	33	2,3
	11/6/99	60	not tested	2,3
	Average	*37*	*53.5*	
SDN4	11/13/98	75	100	
(007)	1/14/99	100	100	
	Average	*87.5*	*100*	

In the table above, the shaded values indicate that the individual result was below the performance standard of 65% survival. Also, the following notes correspond to those indicated in Table 1.

1. These samples are re-tests to corroborate previous results.
2. In the July 2, 1999 samples the fathead control survival of 72.5% was below the performance standard of >90%.
3. These samples were taken for source-tracing.

Table 2 Sample Results Summary

		concentration, mg/l														WET, % survival	
SDE4	pH	TSS	Turb	BOD5	NH3	Surf	glycols	TRCu	TRPb	TRZn	disCu	disPb	disZn	Hard	cond	daphnid	fathead
11/19/98	8.1	66	52	6.8	0.5	na	2	0.032	0.031	0.163	not analyzed			16	37	90	100
% rank		82%	88%	54%				64%	81%	58%							
1/20/99	8.2	92	52	5.8	0.10	0.06	2	0.022	0.013	0.168	0.006	0.001	0.012	14.5	34	100	98
% rank		96%	88%	41%				35%	28%	61%							
2/22/99	7.2	53	44	2	0.5	na	2	0.015	0.022	0.108	0.004	0.001	0.042	10	36	95	[redacted]
% rank		60%	81%	0%				19%	52%	22%							
3/24/99	6.3	41	32	5.9	0.57	0.26	2	0.020	0.017	0.134	not analyzed			10	31	95	98
% rank		32%	74%	45%				29%	39%	41%							
7/2/99	6.2	45	39	6.8	1	na	na	0.026	0.013	0.141	not analyzed			14	41	100	70
% rank		46%	76%	55%				47%	29%	46%							
avg	7.1	54	40	5.3	0.5	0.1	2	0.037	0.017	0.139	0.005	0.001	0.041	13	36	96	86
avg rank		63%	81%	39%				39%	46%	46%							

		concentration, mg/l														WET, % survival	
SDS3	pH	TSS	Turb	BOD5	NH3	Surf	glycols	TRCu	TRPb	TRZn	disCu	disPb	disZn	Hard	cond	daphnid	fathead
11/13/98	7.5	24	29	17.6	0.5	na	11.5	0.022	0.004	0.189	0.014	0.001	0.038	24	69	90	98
% rank		96%	96%	85%			87%	22%	68%	100%							
1/13/99	6.8	22	16	7.8	0.5	na	11	0.023	0.004	0.030	0.013	0.001	0.012	20	52	80	95
% rank		93%	87%	39%			83%	25%	65%	13%							
avg	7.1	23	23	13	0.5		11	0.023	0.004	0.110	0.013	0.001	0.025	22	61	85	97
avg rank		95%	92%	62%				24%	67%	57%							

		concentration, mg/l														WET, % survival	
SDN4	pH	TSS	Turb	BOD5	NH3	Surf	glycols	TRCu	TRPb	TRZn	disCu	disPb	disZn	Hard	cond	daphnid	fathead
11/13/98	7.5	22	15	2	1	na	2	0.025	0.001	0.127	0.021	0.001	0.049	24	75	75	100
% rank		94%	89%	0%				23%	81%	100%							

Table 2 (continued)

1/13/99	6.8	7	9.2	2	0.5	na	2	0.020	0.001	0.034	0.014	0.001	0.027	28	56	100	100
% rank		57%	78%	0%				9%	27%	77%							
avg	7.1	15	12	2	0.8		2	0.023	0.001	0.081	0.018	0.001	0.038	26	66	88	100
avg rank		76%	84%					16%	54%	89%							
		concentration, mg/l														WET, % survival	
SDN1	**pH**	**TSS**	**Turb**	**BOD5**	**NH3**	**Surf**	**glycols**	**TRCu**	**TRPb**	**TRZn**	**disCu**	**disPb**	**disZn**	**Hard**	**cond**	daphnid	fathead
11/13/98	8.0	53	46	2	0.5	na	na	0.024	0.025	0.487	0.006	0.001	0.110	16	20	80	40
% rank		63%	100%	0%				67%	79%	94%							
1/13/99	7.0	78	31	2	0.5	na	na	0.024	0.048	0.182	0.005	0.001	0.033	8	22	30	78
% rank		94%	75%	0%				61%	100%	33%							
3/24/99	6.6	61	40	4.86	1	na	na	0.015	0.010	0.175	not analyzed			16	22	10	63
% rank		69%	88%	53%				30%	44%	28%							
5/11/99	7.1		26		0.24	0.25	na	0.046	0.004	0.276	0.043	0.001	0.117	14.2		5	
% rank			53%					86%	10%	74%							
7/2/99	6.1	69	25	4.28	0.3	na	na	0.038	0.009	0.238	not analyzed			10	21	na	35
% rank		83%	52%	36%				83%	32%	69%							
11/6/99	6.7	26	20	4.1	0.08	0.06	na	0.108	0.009	0.120	0.005	0.001	0.069	11.3		60	na
avg	6.9	57	32	3.5	0.48	0.06	na	0.042	0.020	0.240	0.005	0.001	0.071	12	21	40	60
avg rank		77%	79%	22%				60%	64%	56%							
Blanks		concentration, mg/l														WET, % survival	
	pH	**TSS**	**Turb**	**BOD**	**NH3**	**Surf**	**glycols**	**TRCu**	**TRPb**	**TRZn**	**disCu**	**disPb**	**disZn**	**Hard**	**cond**	daphnid	fathead
11/6/99	na	na	na	<4	<0.01	<0.03	na	<0.002	<0.002	<0.005	<0.002	<0.002	<0.005	1.17	na	na	na
11/6/99	na	na	na	<4	<0.01	<0.03	na	<0.002	<0.002	<0.005	<0.002	<0.002	<0.005	1.17	na	na	na

na=not applicable; Turb = turbidity, NTU; Surf=surfactants; glycols= ethylene + propylene; Hard=hardness; cond =specific conductance

<method detection limit (MDL), value shown is 1/2 MDL

exceeds single value and/or average criterion for survival

The SDN1 samples generally had about twice as much zinc as samples had from the three other outfalls. In four composite samples tested, total recoverable (TR) zinc concentrations ranged from 120 to 487 μg/l, mostly within the interquartile range of the historical data for SDN1. Dissolved zinc ranged from 33 to 117 μg/l, and comprised 18 to 58% of the total zinc (see Table 2.) The discussions below focus on metals, because in general other potential toxicants such as ammonia and surfactants were absent or at levels not likely to affect test organism survival.

Treating the SDN1 source tracing samples with chelating agents that bind dissolved metals confirmed that metals were the principal source of toxicity, with specific indications for zinc. Samples taken from SDN1 drainage isolated from specific rooftops and other contributory areas indicated that the zinc was primarily associated with uncoated galvanized metal rooftops of the AFCO cargo buildings, but not the nearby non-metal rooftops of the five Transiplex buildings. Synthetic storm runoff samples obtained after spraying domestic water on the AFCO rooftops showed zinc concentrations and toxicity similar to the actual storm samples. The domestic water was not toxic and had about 15 times less zinc than the synthetic runoff sample. These results indicated that the AFCO rooftops were the principal source of zinc. However, the data suggest that other, less significant sources may exist in the SDN1 subbasin. Others have shown that galvanized metal rooftops can leach metals and cause aquatic toxicity (Good, 1993; Mason, 1999.)

Field Investigations

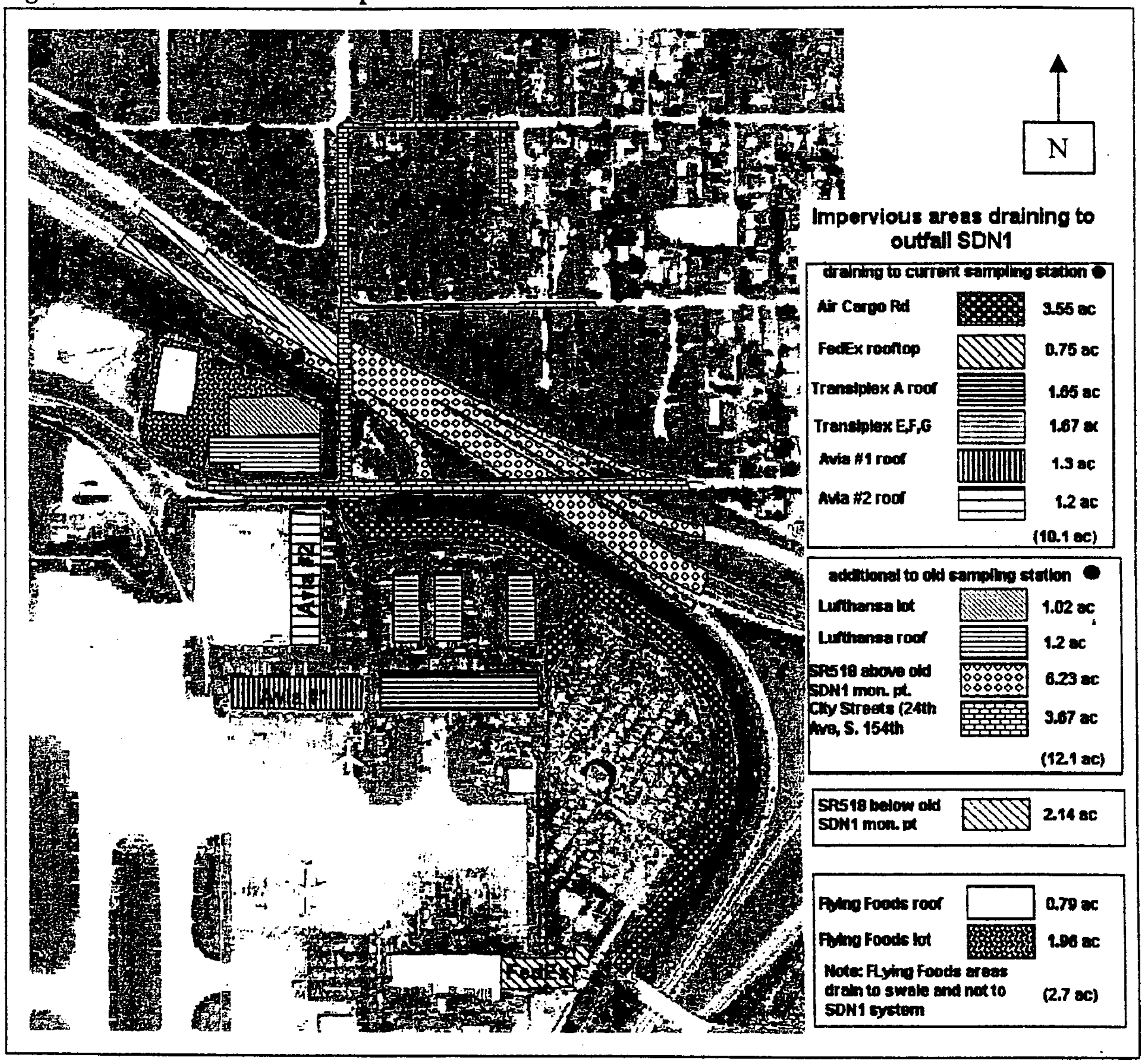
Plans and field investigations (including remote video camera surveys conducted in 1996) verified that only reinforced concrete pipe (RCP) and plastic (PVC) piping drains the SDN1 system. None of the SDN1 drainage passes through corrugated metal pipe (CMP), a potential source of zinc due to galvanized coatings. Also, unlike the three other subbasins evaluated using WET testing, SDN1 runoff receives little to no contact with vegetation and soils; runoff flows directly from the impervious surfaces into the constructed drainage system. This fact may explain why hardness values in the SDN1 samples (8 to 16 mg/l) were about half those of samples from the three other subbasins tested. In general, metals toxicity increases as hardness drops.

Building plans indicated that the two AFCO buildings were constructed about 1989 using a total of about 2 acres of uncoated galvanized sheet-steel roofing (POS 1990, Bethlehem Steel, 1995.) Field reconnaissance verified these materials on AFCO building #2, which is assumed identical to the other building given that both were designed and built as part of the same project. These rooftops represent 25% of the total SDN1 area draining to manhole SDN1-41, the current sampling station for NPDES permit compliance (see Figure 2). However, recent reconnaissance found the FedEx cargo building rooftop materials to also be uncoated, galvanized metal similar to the AFCO rooftops. This eastern portion of the FedEx facility was added in 1997 and drains to SDN1, unlike the existing western portion that drains to the IWS.

Other field inspections verified that drainage from AFCO rooftops was the principal discharge present in the pipes where samples were collected. The AFCO #2 rooftop is in good condition, and has about eight small ventilation stacks, a single air conditioning unit, and no other equipment installed.

Other minor amounts of runoff from a limited area of pavement along several loading docks also combines with the AFCO rooftop drainage. Grab samples from this runoff exhibited considerable copper and zinc that could influence the test organisms. To prevent this drainage from influencing the subsequent samples taken in this study, the outlet of the trench drain that receives this runoff was blocked at the beginning of June 1999. This action did not result in any drainage problems as the affected runoff flows immediately to an adjacent trench drain that connects to the IWS. These drainage connections were verified during dry-weather flow and/or dye testing in March 1999.

Figure 2 SDN1 Subbasin Map



Source Tracing

Three storm events were sampled in early 1999: January 13 (1.07"), March 8 (0.28") and March 24 (0.28".) During the first and last of these three storms, grab samples were taken during the rising and falling limbs of the runoff event to determine the relative degree of temporal variation in metals concentrations. The sample results are plotted in Figure 3 and Figure 4 below. For comparisons, these figures show historical interquartile ranges (dashed lines for the 25th and 75th percentile) for samples from SDE4; a comparable landside subbasin with considerable roadway and rooftop drainage, but one that did not exhibit WET toxicity. Working left to right in the figures, the results indicate the following.

1. Concentrations of copper and zinc in Transiplex rooftop runoff samples showed:
   - consistently lower concentrations than other locations sampled,
   - little difference between samples taken at different times during the discharge (denoted by a sequence number after the sample date), and
   - results less than the interquartile range from landside outfall SDE4.
2. Runoff from the loading dock trench drain generally had higher copper and zinc than the other source areas tested, and was higher than the median for SDE4.
3. In the AFCO rooftop runoff, TR zinc varied to a greater degree than the road aggregate samples. Two rooftop samples had considerably higher TR zinc than the road samples and exceeded the SDE4 interquartile range.

In general, metals were mostly present in the dissolved form in all samples. Dissolved to total recoverable metals ratios for copper and zinc ranged from 0.21 to 0.91, with an average of about 61% dissolved. Total recoverable zinc results from the AFCO building rooftops during the March 24, 1999 event ranged from 66 to 92% dissolved.

Based on these initial findings of the source tracing study, the ensuing work incorporated the following considerations:

- it was unlikely that the Transiplex rooftops contributed toxic concentrations of metals,
- subsequent WET testing and chelation focused on samples from three locations that isolate the apparent source of zinc.

Subsequent WET Testing and Chelation Results

Flow-weighted composite samples were collected from these three locations during three storm events and analyzed for WET and specific chemical constituents. Two of these sample sets were processed using chelation to determine if and to what extent metals were associated with toxicity. Samples of runoff produced by spraying the rooftops with domestic water were also tested for WET with and without chelation.

Testing the stormwater following chelation yielded interesting and meaningful results. After reducing the bioavailability of metals using two different chelating agents, test organisms exhibited higher survival rates. In conjunction with the chemistry data, these results confirmed metals as the source of toxicity. Furthermore, based on the methods of Hockett and Mount

(1996), the pattern of toxicity reduction following chelation confirmed that zinc[4] was indeed the most likely source of toxicity. These tests use EDTA (ethylenediaminetetraacetic acid) and sodium thiosulphate (STS) as chelating agents. Comparing bioassay results before and after adding these agents indicates if and to what degree metals influence toxicity. According to the matrix developed for this method, strong toxicity removal by EDTA coupled with weak removal by STS indicates zinc as a likely source.

Other potenital toxicants such as surfactants and ammonia were absent or at levels not suspected of affecting the test organisms. For samples with low pH, adjusting pH to within acceptable ranges produced little to no toxicity reduction. Survival in laboratory blanks was unaffected by the chelation testing. These results are summarized in Table 3.

In the May 11, 1999 samples, survival was 5% in the SDN1 sample. Subsequent chelation with EDTA dramatically improved survival to 85 to 100%. Because there was limited improvement in survival after the STS additions, results suggest zinc as the source of toxicity. In other words, there were little to no toxic effects due to bioavailable forms of other metals, such as copper, that tend to bind with the STS. In both the road and AFCO rooftop aggregate samples, survival was zero, indicating sources of toxicity in drainage from each of these source areas. It is important to note that this storm was relatively small (0.14") and that composite samples taken during this event would not meet the minimum rainfall depth criteria (0.20") for NPDES reporting at STIA (POS, 1999b.) There were few other suitable storms for sampling until early fall 1999.

The November 6, 1999 composite samples tested were from a more typical storm of 0.68 inches. The SDN1 sample and AFCO roof sample each showed a strong improvement in survival after treatment with EDTA. In contrast, the STS additions yielded little to no improvements in survival for these two samples. The sample of aggregate runoff from Air Cargo road, and the Transiplex and FedEx rooftops behaved similarly, though initial survival was higher (70%) and chelation results less dramatic. Nonetheless, the chelation results indicate a mild degree of toxicity associated with metals (predominantly zinc, and possibly copper) in this aggregate sample of road and other rooftop runoff. Total recoverable zinc was similar between the roads and AFCO runoff samples, yet, the dissolved fraction in the roof sample (0.097 mg/l) was nearly twice as high the road sample (0.056 mg/l.) Copper concentrations were near or below levels suspected to cause toxicity (less than 0.010 mg/l.)

Samples of synthetic runoff produced by spraying the rooftop of the AFCO #2 building also exhibited toxicity, while the source water did not (see Table 4.) Two sets of screening tests were conducted on 100% roof runoff sample, the domestic source water, and a control. The domestic source water used for this test was sampled at the outlet of the hose on the tank truck used in the test. The rooftop area tested was well away from the single air-conditioning unit, a potential source of metals associated with exposed cooling coils. Because sample values fell within acceptable test ranges, no pH adjustments were necessary prior to WET testing these samples.

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[4] Hockett and Mount's approach also suggests lead or nickel as potential toxicants, however, historic concentrations of lead and nickel in SDN1 samples were below levels that might have caused toxicity. Lead analyzed during this study was similarly low, and generally not detected. Therefore, this approach indicated zinc as the principal metal attributable for toxicity.

Figure 3 Copper in Initial Screening Grab Samples

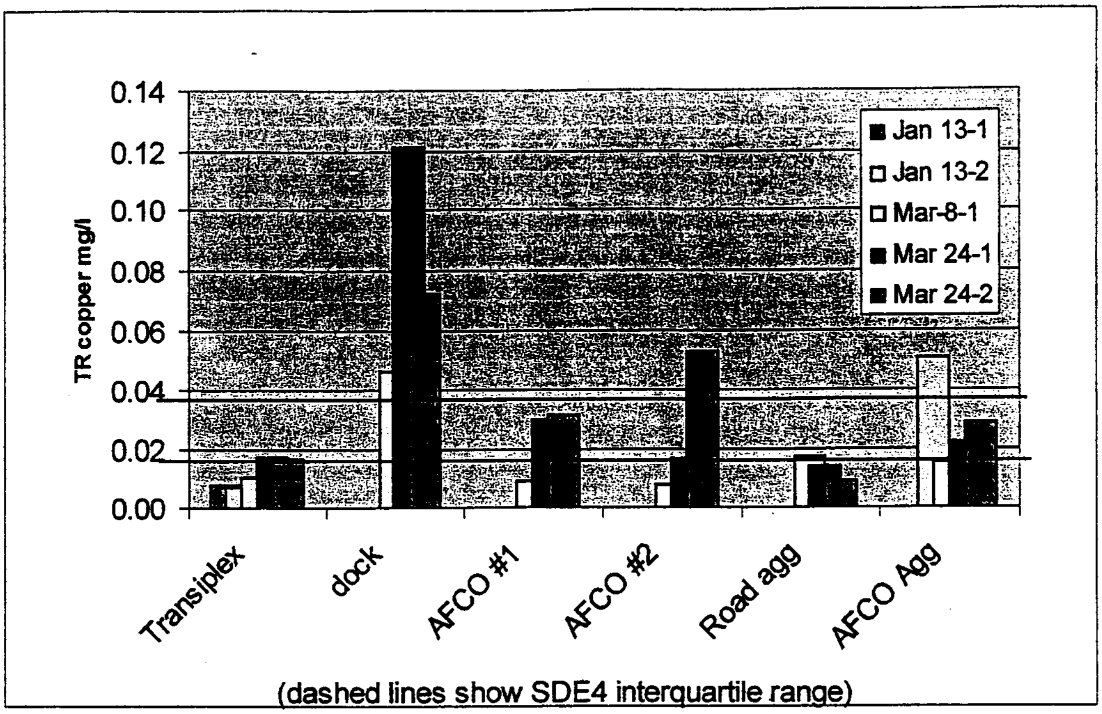
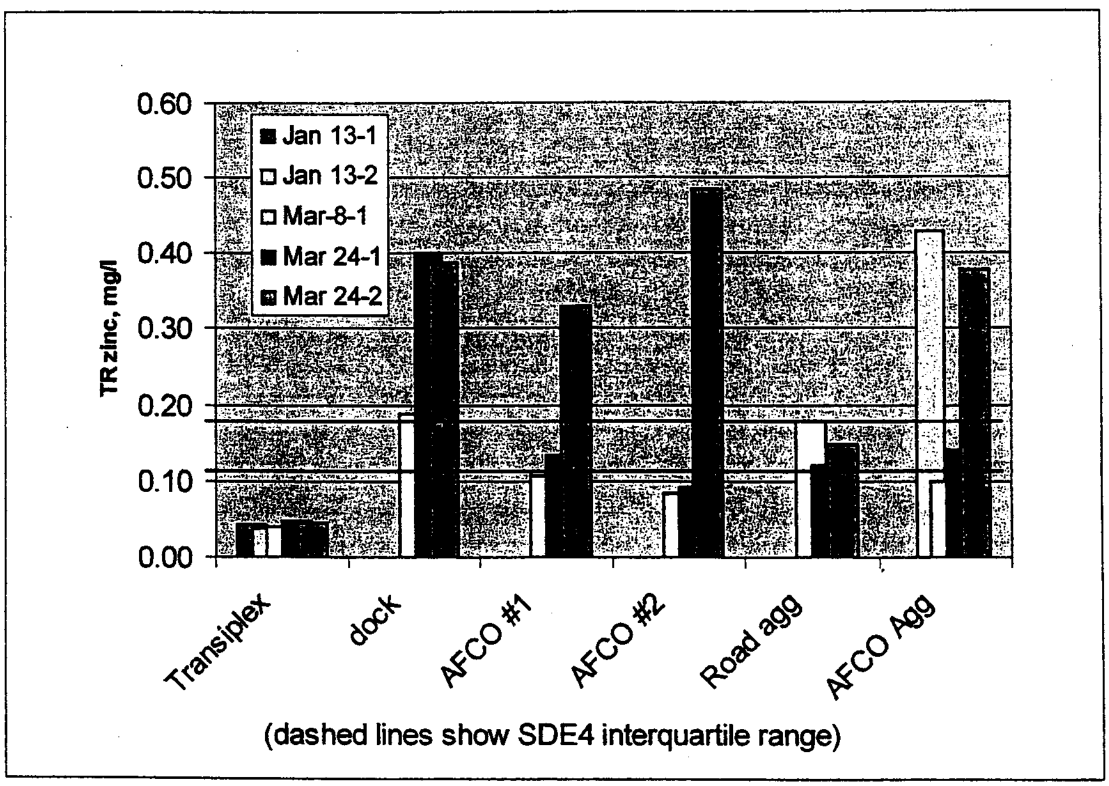


Figure 4 Zinc in Initial Screening Grab Samples



Copper and zinc were generally two orders of magnitude higher in this synthetic runoff than the domestic water (see Table 5.) Dissolved copper and zinc fractions, respectively, were 58% and 52% of the total metals measured in the roof runoff. Lead was not detected in either the roof runoff or source water samples. The source water showed non-detectable copper, lead and dissolved zinc. Total recoverable zinc was about 16 times greater in the roof runoff than in the source water. Note also that the source water pH was more than a point higher than the two rain runoff samples tested for chelation. Therefore, these samples show that the roofing material readily leaches metals, particularly zinc. Because about half the total zinc was dissolved in this test, the results indicate that the AFCO roofing generated some degree of metals in particulate form. It is unlikely that this particulate fraction was due to atmospheric deposition since runoff samples from nearby rooftops of different construction (the four Transiplex building rooftops' material is a non-metal, single-ply membrane) had much lower metals, especially zinc (see Figures 5 and 6).

Table 3 Chelation Testing Results

Date	Station	pH	Percent survival (*Daphnia pulex*)							
					EDTA addition			STS addition		
			pH unadj.	pH adj.	0.5 mg/l	3 mg/l	8 mg/l	1 mg/l	5 mg/l	10 mg/l
5/11/99	SDN1	7.1	5%	NA	85%	100%	100%	0%	40%	15%
5/11/99	Road agg	6.1	0%	0%	NA	NA	NA	NA	NA	NA
5/11/99	AFCO Roofs	5.4	0%	25%	NA	NA	NA	NA	NA	NA
5/11/99	Blanks	8.3	100%	NA	100%	100%	100%	100%	100%	95%
11/6/99	SDN1	6.7	60%	NA	95%	90%	90%	65%	60%	75%
11/6/99	Road agg	6.8	70%	NA	100%	100%	85%	90%	70%	60%
11/6/99	AFCO Roofs	4.9	0%	0%	5%	0%	55%	0%	0%	0%
11/6/99	Control	7.5	100%	NA	NA	NA	NA	NA	NA	NA

NA-not applicable

Figure 5 Copper in Composite Samples

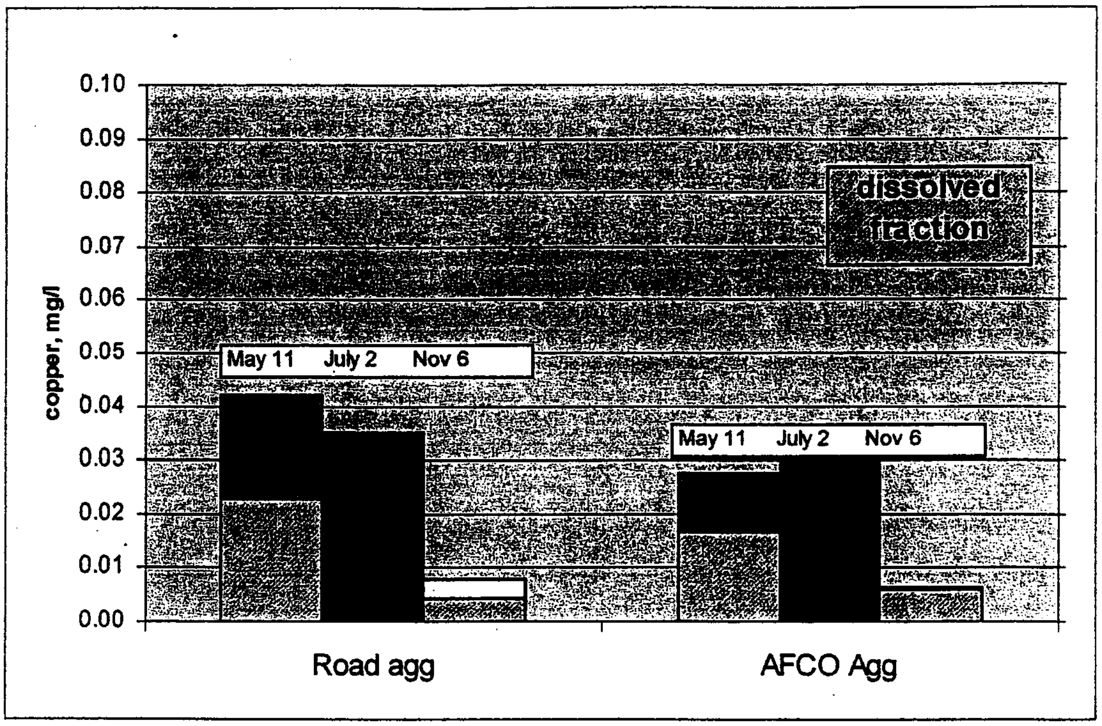


Figure 6 Zinc in Composite Samples

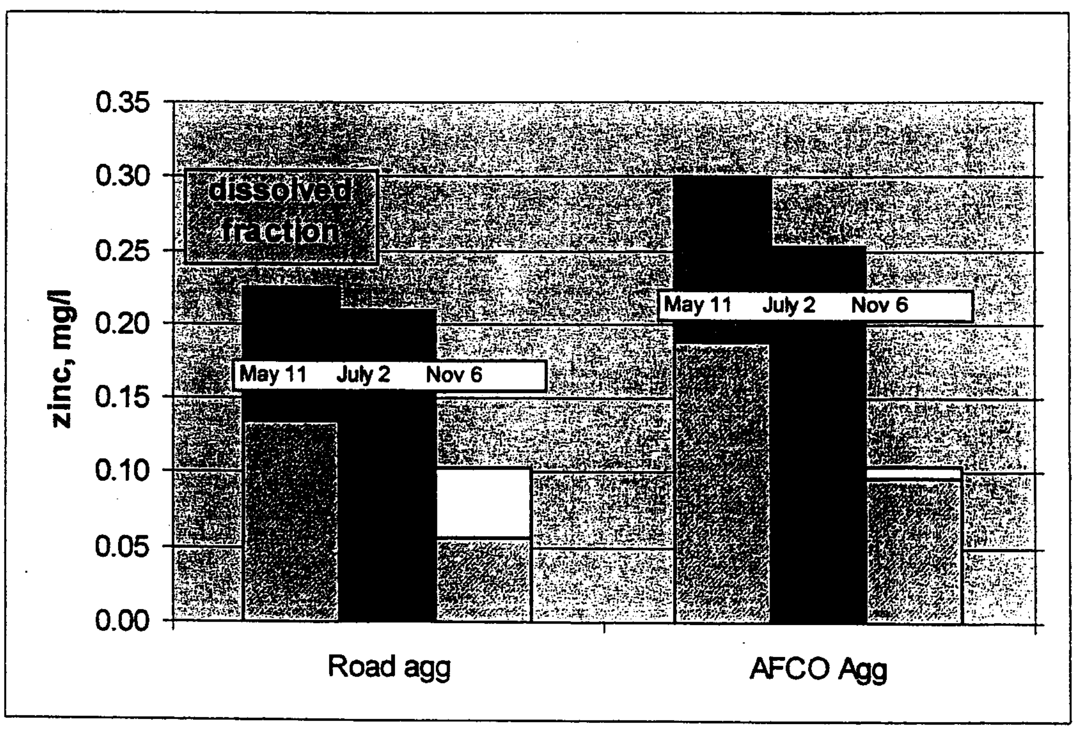


Table 4 Synthetic Runoff WET Test Results

Sample	pH	Percent Survival (D. *pulex*)
Test 1		
Control	8.0	95%
Roof runoff	6.7	0%
Source water	6.7	90%
Test 2		
Control	7.8	100%
Roof runoff	6.8	0%
Source Water	6.8	100%

Table 5 Synthetic Runoff Metals Concentrations (mg/l)

Sample	TR Cu	Diss Cu	TR Pb	Diss Pb	TR Zn	Diss Zn	hardness
Roof runoff	0.034	0.023	<0.002	<0.002	0.286	0.148	27.4
Source water	<0.002	<0.002	<0.002	<0.002	0.018	<0.005	23.8

CONCLUSIONS

Favorable test results indicated the absence of toxicity in stormwater samples collected from three principal outfalls at Seattle-Tacoma International Airport. These samples met the Washington State Department of Ecology WET testing performance standards. However, the WET testing revealed problems at one stormwater outfall, SDN1, where toxicity was associated with zinc that has been historically higher than at other outfalls.

The WET testing and chelation point to the AFCO Air Cargo building rooftops as at least one distinct source of toxicity with zinc as the likely toxicant. The chemical-specific results indicate that zinc in the stormwater samples is associated with the building materials, namely the uncoated galvanized metal roofing. Other tests have shown that dissolved zinc is higher in this roof runoff than for other locations. Because of the limited number of samples, inconsistent toxicity responses and indications after chelation, it is not clear whether the aggregate runoff from Air Cargo Road, and the Transiplex and FedEx rooftops is problematic. Yet a limited degree of toxicity associated with metals is suggested for these other sources, possibly attributable to metal rooftops on the FedEx building. Results do not suggest problems associated with the Transiplex roofing, which is not galvanized metal. Follow up WET testing of SDN1 runoff is planned to verify corrective actions. The findings of this study point to a consideration for stormwater source control BMPs that restrict the use of uncoated galvanized metal roofing materials.

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