FINAL AUTHOR REVIEW DRAFT OF 8/29/01. FINAL VERSION TO APPEAR IN NOVEMBER 2001 ISSUE OF "INDUSTRIAL WASTEWATER" MAGAZINE (WEF PUBLICATION). CONTACT: KELLYE KRATCH 409-762-5477 (HOUSTON)
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Trickle Down Effect

Results of whole effluent toxicity testing and source tracing indicate that metal roofing materials contribute to elevated zinc concentrations in a major U.S. airport's stormwater discharges

By Scott A. Tobiason and Linda R. J. Logan

In 1994, the Port of Seattle (the Port), which owns and operates Seattle–Tacoma International Airport (STIA), secured a national pollutant discharge elimination system (NPDES) permit for stormwater and industrial wastewater treatment plant (WWTP) discharges. The industrial WWTP, unique to STIA, captures fuel spills from aircraft service areas and discharges dissolved-air floatation-treated effluent to Puget Sound. Overall, the industrial waste system drains about 370 ac (148 ha) or 28% of the airport, primarily the "airside" gate areas where aircraft undergo routine servicing, fueling, and deicing.

A system of 14 stormwater subbasins, drainage piping, and associated outfalls drain the remaining 963 ac (385 ha) or 72% of the airport, including the runways and taxiways. Four of these subbasins drain 17% of the total storm-drain system (SDS) to Miller Creek, eight subbasins drain the remainder to Des Moines Creek, and two minor subbasins combine with offsite areas draining to the Green River. All these receiving waters are important spawning and rearing streams for Coho salmon and cutthroat trout. To comply with intensive stormwater-monitoring requirements of the NPDES permit, the Port implemented a stormwater-management program that has generated more than 500 grab and composite samples with hundreds of results for a variety of stormwater constituents.

In March 1998, the Port's NPDES permit was revised to require, among other items, whole effluent toxicity (WET) testing of stormwater samples from the four principal outfalls:

- Storm drain south 3 (SDS3) and storm drain north 4 (SDN4), which drain 79% — 492 ac (200 ha) — of the airfield runways and taxiways;
- Storm drain east 4 (SDE4), which drains 149 ac (60 ha) of mostly access roadways and the airport's terminal and cargo building rooftops; and
- Storm drain north 1 (SDN1), which drains 14 ac (6 ha) of cargo building rooftops and roadways.

The outfall sampling locations for both SDE4 and SDN1 actually are located at in-pipe locations above the ultimate true outfall where drainage discharges from the pipe. These locations were chosen and listed in the permit in 1994 because they eliminated potential bias caused by runoff from other non-airport drainage in the vicinity.

WET testing is a common compliance requirement for point source industrial dischargers such as pulp mills and WWTPs, as it generally improves upon chemical-specific testing by taking into account aggregate or synergistic toxicity, unknown toxicants, and parameters that reduce constituent bioavailability (the fraction of a constituent that is available for uptake by aquatic organisms). However, requiring facilities to WET test stormwater discharges is not commonplace. For example, in Washington State, only 11 NPDES permittees have performed WET testing on stormwater or a mix of stormwater and industrial wastewater.

Also as part of its NPDES permit, the airport implemented a stormwater pollution prevention plan that includes stormwater best management practices (BMPs). As a result of this plan, the Port has remedied several inappropriate drainage connections that were identified by source-tracing sampling conducted in the past few years.

Methodology

Stormwater samples for WET testing were collected as flow-weighted composites using automatic samplers and flowmeters. Samples generally represented the majority of runoff, and, thus, results are considered event-mean concentrations. Where toxicity was detected for one outfall, source-tracing composite samples were collected subsequently using automatic samplers, and by taking automatic and manual grab samples at the principal sampling location and at points upgradient in the drainage piping.

Samples were collected using "clean techniques" for trace-metal sampling (U.S. Environmental Protection Agency Method 1669) adapted for stormwater sampling. WET testing was performed according to state and federal guidelines on 100%-stormwater samples, and on a series of samples tested at specific dilutions to estimate the effects concentrations explained below. Two organisms were tested concurrently according to permit requirements: *Daphnia pulex* (water fleas) and *Pimephales promelas* (fathead minnows). WET test results are expressed as:

- percent survival (in the 100% sample),

- the concentration of sample where 50% survival of the test organism occurred (LC50),
- the no-observed-effect concentration (NOEC), which is the maximum concentration of the test sample that produces no statistically significant mortality of test organisms, and
- the lowest-observed-effect concentration (LOEC), which is the lowest concentration that yields statistically significant mortality of test organisms.

A "perfect" nontoxic score would equate to 100% survival in the sample, with LC50, NOEC, and LOEC concentrations greater than 100% of the sample.

To investigate the causes of toxicity for the only outfall exhibiting significant toxicity (outfall SDN1), the port implemented a multiphase source-tracing study that involved WET testing, metals chelation, and chemical-specific analysis of stormwater samples to reveal clues about the potential sources of toxicity. Chelation is a chemical process that renders ions (in this case divalent, free metals) non-bioavailable. The bioavailable free-metal ion fraction of a metal generally is considered responsible for toxicity to aquatic organisms. Only the daphnia were used as the WET-test organism during this source tracing because the initial WET testing had shown that they were more sensitive than the fathead minnows.

The source-tracing phase focused on zinc, because runoff from SDN1 historically has exhibited higher zinc concentrations than other outfalls. During this source-tracing study, runoff samples from upgradient tributary areas also were tested to determine where and under what conditions toxicity could be attributed. These potential source areas upstream of the SDN1 sampling location isolate runoff from four cargo-building rooftops with nonmetal (membrane) roofing, two cargo-building rooftops with galvanized metal roofing, and adjacent roadways — 3.6 ac (1.5 ha) of road plus 0.75 ac (0.30 ha) of a smaller cargo-building rooftop with metal roofing. Metal roofing on the facilities mentioned was uncoated, unpainted galvanized material ranging from 3 to 10 years old. Importantly, as mentioned earlier, the SDN1 "outfall" sampling point is in-pipe, more than 1000 linear ft (305 linear m) above the ultimate discharge outfall of the piping, and more than 0.5 mi (0.80 km) upgradient from the receiving stream.

Results and Discussion

During initial WET testing, all eight test results for two of the four outfalls tested (SDS3 and SDN4) met Washington State Department of Ecology performance standards for survival of water fleas and fathead minnows. Because these outfalls demonstrated no toxicity and met Department of Ecology performance standards, additional testing was deemed unnecessary.

The remaining two outfalls, SDE4 and SDN1, were sampled during additional storms to corroborate initial mixed test results. Of the five SDE4 samples evaluated for WET, the average survival rates for the water fleas and fathead minnows were 96% and 85.8%, respectively — above Department of Ecology performance standards (a minimum of 65% in single samples and 80% average). Therefore, further testing of the SDE4 outfall was unnecessary.

However, samples collected from SDN1 continued to exhibit toxicity — notably, the samples had about twice as much zinc as samples from the three other outfalls. Table 1 (p. XX) summarizes the WET testing results for all four outfalls. Chemical analyses were performed to characterize all of the 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.

In the five SDN1 composite samples tested, total recoverable zinc concentrations ranged from 175 to 487 µg/L, well within the range of historical data for SDN1. Dissolved zinc in these samples ranged from 33 to 117 µg/L, and comprised 18% to 58% of the total zinc.

To determine the possible causes of the toxicity in SDN1, the Port launched a source-tracing study of associated drainage to the outfall. The evaluation focused on metals, because, in general, other potential toxicants such as ammonia and surfactants were absent or detected at levels unlikely to affect test-organism survival. Treating the SDN1 source-tracing samples with chelating agents that bind dissolved metals confirmed that metals (particularly zinc), were the principal source of toxicity.

Source tracing samples were taken from upstream locations in the SDN1 drainage to isolate runoff from specific rooftops and other contributory areas. These grab and composite samples indicated that the zinc was associated primarily with runoff from the uncoated galvanized metal rooftops of two 1-ac (0.40-ha) cargo buildings, but not the nearby nonmetal rooftops of the four other cargo buildings.

Synthetic storm-runoff samples obtained by spraying domestic water on one of the metal rooftops showed zinc concentrations and toxicity similar to the actual storm samples. The rooftop area tested was located well away from an air-conditioning unit, a potential source of metals associated with exposed cooling coils and condensate. The domestic water was nontoxic with zinc levels about 15 times lower than post-rooftop application.

In all source-tracing samples associated with the metal roofing, dissolved zinc ranged from 61% to 92% of the total recoverable metal. These results further support the idea that the two metal rooftops were a principal source of zinc, since much of the zinc in runoff occurred principally in the dissolved form. Subsequent samples of runoff from the drip edges have further corroborated the zinc levels attributable to the metal roofing. The data also suggested that the smaller metal-roofed cargo building might also be a zinc source in the SDN1 subbasin, though less-significant overall than the two larger cargo buildings.

Two rounds of chelation testing verified that toxicity in SDN1 samples and upstream sub-area samples was associated with divalent metals, most likely zinc. After reducing the bioavailability of metals using two chelating agents — ethylene diamine tetra acetic acid (EDTA) and sodium thiosulphate (STS) — test organisms exhibited higher survival rates. In conjunction with the chemistry data, these results confirmed metals as the source of toxicity. Furthermore, the pattern of toxicity reduction following chelation confirmed that zinc was the most likely source of toxicity. A comparison of bioassay results before and after chelating agent addition indicates if, and to what degree, metals influence toxicity. According to a matrix developed for this method, strong toxicity removal by EDTA coupled with weak removal by STS indicates zinc, rather than copper, as a likely source. Also, to rule out potential toxic effects of low pH, samples with low pH were adjusted to at least 6.0, though this did not improve survival significantly. Table 2 (p. XX) outlines the results of chelation testing.

Finally, despite the considerable dissolved zinc concentrations (100 to 400 μg/L, averaging 66% of total recoverable zinc), a limited amount of particulate zinc was present in runoff samples from metal rooftops, suggesting sources in addition to dissolution of zinc by galvanic corrosion. However, runoff samples from the four nearby nonmetal (membrane) rooftops showed much lower zinc concentrations, ranging from 38 to 48 μg/L, with about 10 to 20 μg/L in the particulate form. Because these zinc levels from nonmetal roofing were about an order of magnitude less than those from the metal roofing, atmospheric deposition in the vicinity does not appear to be a significant contributor to the zinc levels observed.

Field Investigations

Building plans and field-investigation results (including remote video-camera surveys), verified that only reinforced concrete, ductile iron, and polyvinyl chloride piping drain the SDN1 system — no SDN1 drainage passes through corrugated (galvanized) metal pipe, a potential zinc source. According to industry literature, ductile iron material should not contribute zinc in drainage passing through the piping. Furthermore, unlike the three other subbasins that had been WET tested, SDN1 runoff has no contact with vegetation and soils. Instead, runoff flows directly from impervious surfaces (rooftops and roadways), into the constructed drainage system. This may explain why hardness values in the SDN1 samples (8 to 16 mg/L) were about half those of samples from the other subbasins. For several metals, including zinc, toxicity increases as hardness decreases (in other words, bioavailability is reduced).

Building plans indicated that the two metal-roofed cargo buildings were constructed in 1989 with about 2 ac (0.81 ha) of uncoated, galvanized sheet-steel roofing. Field reconnaissance verified these materials were present and in good condition on both buildings. Each rooftop has a number of small passive ventilation stacks, while the principal rooftop tested also had one air-conditioning unit with limited corrosion of the roofing near it. Together, these two rooftops represent 25% of the total impervious area draining to the SDN1 "outfall" sampling station.

Additional inspections showed that runoff from a cargo loading dock area of about 500 ft^2 (46 m^2) also combined with the runoff from the two metal rooftops. Though samples of this loading-dock runoff exhibited similar zinc and copper concentrations to the metal roof runoff, it was not expected to contribute significantly to the overall loading and metals toxicity because it was less than 0.1% of the total SDN1 drainage area. Nonetheless, as a BMP, the Port re-rerouted the loading-dock drainage to the industrial waste system during this study. SDN1 samples continued to exhibit similar patterns in toxicity after this rerouting was completed (see Table 2).

Considerations and mitigation options

Importantly, the point where the metal-roof runoff enters actual streams is more than 0.5 mi (0.8 km) downgradient from the WET-testing and source-tracing focus. This runoff passes through natural open channels and a constructed stormwater management pond where it combines with runoff from public roadways before entering the stream. In-stream samples have not indicated toxicity or elevated zinc. Because of the manner in which sampling points historically were located for the Port's current NPDES permit, the Port must sample at the in-pipe location where the toxicity was found. Nonetheless, the Port is pursuing a proactive solution to the apparent source of zinc toxicity, and will conduct further WET testing to determine if runoff from other rooftops is problematic.

Initial cost estimates for re-roofing or painting the metal roofing exceed $200 000 per building. As a result, the Port is investigating stormwater treatment by certain media suited for zinc removal. Promising media tested recently in controlled laboratory experiments include commercially available CSF® deciduous leaf compost produced by Stormwater Management Inc. (Portland, Ore.) and acid-modified soybean hulls developed by the U.S. Department of Agriculture Agricultural Research Service Southern Regional Research Center (New Orleans, La.). Both the leaf compost and the soybean hulls are agricultural waste products that can be recycled as water-treatment media. Other media tested proved unsuitable or even generated some degree of toxicity.

Implementation concepts include deploying the media in commercially available Stormfilter™ cartridges in below-grade, pre-cast vaults; or in cartridges adapted for above-grade downspouts. These options amount to a new stormwater BMP option that appears much more cost-effective than re-roofing or painting. Further studies will characterize the long-term performance and operations and maintenance costs for these options.

Conclusions

Multiple WET tests from three major drainage areas representing 641 ac (256 ha) showed that the majority of the airport's runoff was nontoxic. However, there was a distinct source of zinc toxicity in discharges from the relatively small SDN1 subbasin. Results of WET testing, chelation, and other tests, indicated that the SDN1 zinc was attributable to uncoated galvanized-metal rooftops of two air-cargo buildings. Dissolved zinc concentrations are higher for this roof runoff than for other locations sampled at the airport.

The results also indicate that the third, smaller cargo facility rooftop also may be a source of zinc toxicity, though probably less significant for the SDN1 system than the two larger buildings. So far, no problems have been detected with the nonmetal roofing. Follow-up WET testing of SDN1 runoff is planned to verify the corrective actions currently under investigation. The results of this study may support stormwater source-control BMPs that would limit the use of uncoated galvanized-metal roofing materials with direct drainage to sensitive water bodies.

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For Further Reading
ADD WEFTEC BIBLIOGRAPHY

Table 1 WET Testing Summary (composite samples)

Outfall	Sample date	WET, % survival		Copper, µg/l		Zinc, µg/l	
		Daphnid	Fathead	Total recov.	Dissolved	Total recov.	Dissolved
SDE4	11/19/98	90	100	32	na	163	na
	1/21/99	100	98	22	6	168	12
	2/23/99	95	63	15	4	108	42
	3/24/99	95	98	20	na	134	na
	7/2/99	100	70	26	na	141	na
7-yr range (1)		*na*	*na*	*15-83, 24 (51)*		*26-360, 134 (51)*	
SDS3	11/13/98	90	98	22	14	189	38
	1/14/99	80	95	23	13	30	12
7-yr range (1)		*na*	*na*	*22-91, 29 (58)*		*29-136, 41 (58)*	
SDN1	11/13/98	80	40	24	6	487	110
	1/14/99	30	78	24	5	182	33
	3/24/99	10	63	15	na	175	na
	5/11/99	5	not tested	46	43	276	117
	7/2/99	not tested	33	38	na	238	na
	11/6/99	60	not tested	108	5	120	69
7-yr range (1)		*na*	*na*	*14-57, 20 (37)*		*66-550, 192 (37)*	
SDN4	11/13/98	75	100	25	21	127	49
	1/14/99	100	100	20	14	34	27
7-yr range (1)		*na*	*na*	*23-67, 31 (42)*		*16-69, 21 (42)*	

Shaded cells indicate results below WA Dept of Ecology minimum standards. Note 1: 7-year range is 25th to 95th percentiles, median and number of samples (n) for total recoverable metal

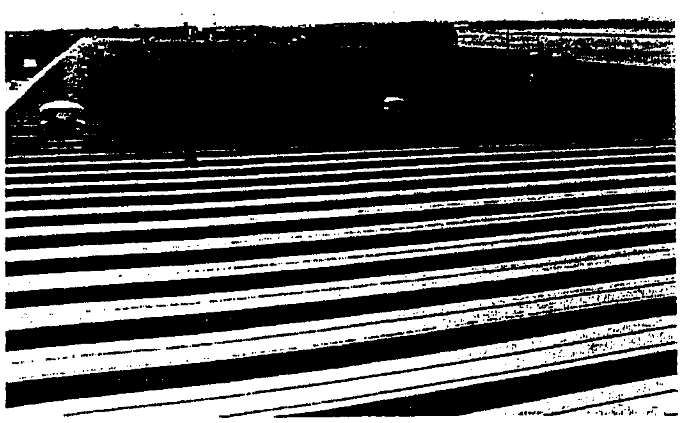

Photo: Based on the results of whole effluent toxicity tests and source-tracing investigations, the Port of Seattle is investigating treatment of runoff from uncoated galvanized-metal materials on rooftops like this one

Table 2 SDN1 SampleChelation Testing Results (composite samples)

Date	Station	pH	Percent survival (*Daphnia pulex*)							
			pH unadj.	pH adj.	EDTA addition (mg/l)			STS addition (mg/l)		
					0.5	3	8	1	5	10
5/11/99	SDN1 (aggregate)	7.1	5%	na	85%	100%	100%	0%	40%	15%
5/11/99	Roads	6.1	0%	0%	na	na	na	na	na	na
5/11/99	Metal 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 (aggregate)	6.7	60%	na	95%	90%	90%	65%	60%	75%
11/6/99	Roads	6.8	70%	na	100%	100%	85%	90%	70%	60%
11/6/99	Metal 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