Willing

**Pre-Filed Testimony of Dr. Peter Willing**

**Submitted on behalf of Appellant**
**Airport Communities Coalition**

**PCHB No. 01-160**
***ACC & CASE v. Dept. of Ecology & Port of Seattle***

**February 22, 2002**

Dr. Peter Willing declares as follows:

1. I am over the age of 18, am competent to testify, and have personal knowledge of the facts stated herein.

2. My education and experience consists of a Master of Science degree and a Doctor of Philosophy degree, both from the Department of Natural Resources at Cornell University, Ithaca, New York. My graduate work concentrated on the relationships between land use and water quality of lakes and streams. I have taken specialized training courses in fluvial geomorphology and stormwater management.

3. I am a Principal in the Bellingham firm of Water Resources Consulting, L.L.C., which I founded in 1989. The firm specializes in hydrology of surface and ground waters, water quality, monitoring network design, storm water management strategy, and hydrologic basis of water rights. I have served in public sector positions including general manager of a mid-sized public water system and environmental manager for a municipal electric utility. I hold Adjunct Faculty appointments in the Department of Geology and Huxley College at Western Washington University, Bellingham.

4. I am a member of the American Water Resources Association and the American Geophysical Union.

5. My resume is attached as Attachment A to this testimony.

6. During my professional career I served for five years as general manager of a water supply utility that operated its own direct filtration potable water treatment system. I trained water treatment plant operators in water treatment methods and related scientific principles, supervised major overhauls and construction in the treatment plant, reviewed engineering submittals, and held responsibility as manager for the operations, compliance, and reporting for the plant. I held a Class 3 Water Treatment Operator certification from the State of Washington for ten years.

7. In my consulting career I have designed, built, and operated water treatment systems based on slow sand filtration, coagulation, and disinfection. I have spent much of my professional career on assignments involving the relationship between land use and water quality, both surface and groundwater. I am familiar with the King County Surface Water Design Manual, as well as stormwater management guidance from other jurisdictions.

8. I have reviewed the Port of Seattle and Department of Ecology declarations, briefs, and exhibits submitted in opposition to ACC's motion for stay. I have also reviewed additional documents and scientific literature in preparing my testimony. The documents I have chiefly relied upon are listed in Attachment B .

9. I have reviewed the Department of Ecology's Water Quality Certification No. 1996-4-02325 for construction of a third runway at SeaTac Airport, issued on August 10, 2001 and then amended and re-issued on September 21, 2001. The certification contains a number of defects that cause it to fall considerably short of reasonable assurance that the project will not violate water quality standards. In particular, I will address streamflow impact and the Port's plan for augmentation of flows in SeaTac area streams, and the management of stormwater. Both have severe and unacceptable implications for the quality of waters of the State of Washington.

**Low Flow Impacts And Streamflow Augmentation Scheme**

10. The long and varied history of low flow augmentation plans at SeaTac requires a summary. The Port of Seattle's inability to propose a reliable and convincing water source for flow augmentation in Des Moines Creek was one of four reasons why the Port was forced to withdraw its application for 401 certification in 1998. Since then

the Port has successively expanded and contracted the application of its flow augmentation scheme to Miller, Walker, and Des Moines Creeks.

11. The following is a brief chronology of the Port's flow augmentation proposals. In July 2000, the Port's "preferred option" for augmentation was to use water from a Port-owned well. In August the Port maintained the preference for the well source, but also discussed Seattle Public Utilities water as an alternative. By September 2000, the Port had decided that "the primary source is water from Seattle Public Utilities." By December 2000 the Port's plan had reverted to the existing Port-owned well on the Tyee Golf Course as the source of augmentation water. However, in different documents at that same time, the Port also proposed to construct additional storage facilities that would hold stormwater for augmenting dry season low stream flows. In January 2001 the Port was still "investigating other sources of water in the [Des Moines Creek] basin."

12. Sometime after January 2001, the stormwater storage concept gained currency as the planned mode of flow augmentation. However, it required substantial retrofitting and revision of the December 2000 Stormwater Management Plan because the announced volumes of required stormwater storage did not agree with the volumes shown on the plans for individual detention facilities. Revisions continued with the July 2001 "Low Flow Analysis/Flow Impact Offset Facility Proposal," the version of

the concept that was available to the Department of Ecology as a basis for issuance of its 401 decision in August 2001. Subsequent to the issuance of the 401 Certification, in December 2001, the Port released a further version of the "Low Flow Analysis and Summer Low Flow Impact Offset Facility Proposal."

13. The first two flow augmentation schemes that were proposed by the Port had serious defects that disqualify them as a water source. However, because they have periodically reappeared in Port plans, it is useful to enumerate their defects here. The existing well on the Tyee Golf Course was acquired by the Port for possible low flow augmentation purposes. However, this well was not used at all for a period of years, and then was used without benefit of a water right for many more years. It is highly unlikely there is a valid water right for the well. The well was not legally constructed under state law: it exploits three different aquifers in a common casing, in contravention of state guidance on protecting upper aquifer zones.

14. Water from Seattle Public Utilities has both chemical and physical disqualifications. The scheme to use this water relied on technological inputs whose continuity could not be assured. The water would have had to be purged of drinking water conditioning chemicals such as chlorine and fluoride before release to a stream. Water from the Cedar River system is as high as 20° C for much of the time when

supplemental water is most needed, and it is too warm for use as augmentation water in a Class AA stream.

15. The Port's current concept of low flow augmentation with stored stormwater is not supported by any demonstration that a comparable scheme has been successfully implemented elsewhere. Of particular concern is the lack of demonstration that a storage vault can maintain water quality over six months of storage. Instead, the Port offers a promise to work out the details in the future. I have encountered a number of low streamflow augmentation projects in the course of more than two decades of work in the water resources field, but have not encountered any low flow augmentation plan that depended on multiple season storm water storage for a water source. All the flow augmentation plans I have encountered were formalized by state water right.

16. Ecology did not carry out its own review of the soundness of the Port's stormwater storage scheme, but instead relied on its consultant from the King County Department of Natural Resources for review and oversight of the plans for flow augmentation and low flow impact analysis (Fitzpatrick Deposition, 20; 143). This task was not part of the original scope of services for the King County reviewer however, and was added on late in the review process. Both the King County Surface Water Design Manual and the Ecology Manual are silent on the matter of low flow augmentation for affected streams.

17. The July 2001 version of the Low Streamflow Analysis/Summer Low Flow Impact Offset Facility Proposal, which was the one Ecology relied upon for 401 certification, was manifestly inadequate. It was not finished even by its own admission. Missing information was represented by dummy figure numbers. Essential appendices were missing, cross references were not functional, sections ended with the announcement "section not complete." The Port's acknowledged confusion necessitated a clarification letter two days after submittal. Clearly the need to submit something in a hurry outweighed considerations of quality.

18. The Port has not refined the concept of stormwater for flow augmentation: it is not even sure which streams will receive it. The low flow augmentation plans before December 2000 were limited to Des Moines Creek. The December 2000 Low Flow Analysis said flows would be augmented in Des Moines and Miller Creeks. The "final" (pre-401 decision) Low Streamflow Analysis/Summer Low Flow Impact Offset Facility Proposal of July 2001 showed an intention to apply augmentation flows to all three streams. The December 2001 update of the "final" (p. 3-1) plan says flow augmentation will be applied to Des Moines and Walker Creeks. The flow augmentation proposal has been and remains a draft concept, with uncertainty and questions of feasibility behind every detail. It cannot serve as a basis for reasonable

assurance that it will effectively protect the water quality of streams in the SeaTac area.

19. The hydrologic model of Des Moines Creek does not reflect observed conditions well (Low Streamflow Analysis, December 2001, p. A-32). The calibration at Des Moines Creek gauge 11C, the east branch of the stream on the Tyee Golf Course, shows simulated or modeled flows that are roughly half the concurrent observed flows. The model has a "flat-line" behavior during all the low flow months of June, July, August, and September, and appears unresponsive to hydrologic influences which are obvious in the observed stream flow. If the Port takes the modeled flows as a mitigation target, the mitigation requirements will be seriously underestimated. Modeled flows at the downstream gauge (11D) show error percentages in the range of 30 - 100% for a substantial part of the calibration record. The model does not pick up the lowest flows in the observed record, but instead shows a simulated flow of 1.5 cfs at the same time as a recorded flow of less than 0.5 cfs. If the Port takes the modeled seven day low flow for reality, it will miss actual low flows that are biologically stressful.

20. The proposal to augment streamflows in the SeaTac area by means of stored stormwater does not provide reasonable assurance that water quality standards of the

state will not be violated. Without adequate flow, there is no possibility of sustaining other water quality parameters such as temperature, dissolved oxygen, etc.

**Stormwater Quality**

21. The Port of Seattle has not furnished, nor has the Department of Ecology obtained, reasonable assurance that stormwater originating from the Port's Master Plan Update developments will not violate Washington State Water Quality Standards (WAC 173-201A).

22. The stormwater quality monitoring record indicates a history of violations of water quality standards at SeaTac Airport. Compliance with metal water quality standards is a function of matching hardness values. Hardness is defined as the sum of calcium and magnesium, expressed as calcium carbonate equivalent. Hardness renders metal ions in water less toxic by providing positively charged exchange sites for the metals to attach themselves. In the absence of hardness data, it cannot be demonstrated that specific numeric water quality standards are, or are not, being exceeded. In rare cases however, the Port has sampled and reported concurrent hardness values with the metals values. The results can be seen in the 1999 Annual Stormwater Monitoring Report, Appendix D p. 109-110 (included herewith in Attachment G). As one illustrative example, the copper data for four discharge points were pulled out and

entered in a separate spreadsheet (Attachment G). Column 1 is the sample date. Column 2 shows the sample location. Column 3 shows the hardness corresponding to the copper value. Column 4 shows the Fresh Water Acute water quality standard for the hardness value. Column 5 shows the concentration of copper (Total Recoverable) in the sample. Column 6 shows a multiple by which the sample concentration exceeds the hardness-dependent water quality standard. Column 7 shows what the dissolved concentration of metal would be if a partitioning coefficient of 0.75 applied. Column 8 shows a multiple by which the calculated dissolved metal concentration exceeds the hardness-dependent water quality standard. Columns 6 and 8 make it clear that the discharges in question are greatly in excess of water quality standards.

23. These high levels of pollutants have occurred in spite of implementation of stormwater management methods by the Port of Seattle. The Port's response to a long-standing known problem at SDS1 is that they will "continue to evaluate" waste water treatment technologies (2001 Annual Stormwater Monitoring Report, p. 54).

24. On January 28, 2002 I attended a site visit at SeaTac airport, in company with ACC consultants and attorneys and Port representatives. I assisted in taking grab samples for several water quality constituents at discharges SDS1 and SDS3. Two turbidity samples showed almost a ten-fold increase between the receiving stream and the discharge. I collected water samples for analysis for metals and concurrent

hardness. I later calculated (Attachment G hereto) specific water quality standards based on the hardness values for these samples ascertained by the laboratory (See Attachment D to Wingard Pre-filed Testimony). Based on the samples recovered from the site visit, the discharge appeared to be in violation of water quality standards for turbidity, and was discharging wastewater in excess of water quality standards for copper. The sampling regimen during the site visit was highly restricted because of limitations on access imposed by the Port of Seattle.

25. Stormwater quality problems persist at SeaTac, notwithstanding Port claims to progress in improving the situation. 35 acres of the SDS-1 catchment area have been re-routed to the Industrial Wastewater System, which has "resulted in a decrease in the levels of glycols, BOD5, copper, zinc, and lead." (SWPPP, revision Dec 01, p. 5). Yet random grab samples taken on a site visit, ACC found levels of copper and turbidity in the discharge that were in excess of  the water quality standards.

26. The Port relies heavily on biofiltration swales and filter strips for stormwater quality treatment at the airport (Comprehensive Stormwater Management Plan, Vol 1 Table 7-7). Fendt says the stormwater at the airport is treated primarily using filter strips (Declaration dated September 2001, #41). The Port insists that they are "not means of disposal," rejecting the concept that biofiltration swales and filter strips constitute permanent shallow soil disposal for long-lived pollutants (Port reply

comments to P. Willing letter of February 16, 2001). In fact the Port is intending to use them for permanent disposal. The waste load that goes into a biofiltration swale or a filter strip stays there until it is re-mobilized by a later storm flow. The King County Surface Water Design Manual describes biofiltration swales and filter strips under its Basic Water Quality Menu as "Best Management Practices" for removal of suspended solids (page 6-4). They are not adequate to remove or manage other constituents in the pollutant stream in SeaTac stormwater. Specifically, they are not intended nor designed for removal of metals such as copper and zinc. Best Management Practices that are known to be effective at removing metals are shown in the Resource Stream Protection Menu of the Manual (page 6-10). They include sand filters, stormwater wetlands, two-facility treatment trains, and leaf compost filters. With the exception of exploring leaf compost filters for the galvanized roof runoff at SDN1, the Port is not proposing these measures.

27. The Port is currently using other ineffective stormwater management practices. The Port has installed oil absorbent pads across the pipe discharge in its stormwater outfalls in such a way that they are incapable of removing oil and grease from the discharge (See photographs in Attachment C ). Even if they were installed in a low velocity pool with no short-circuiting, they offer at best a short term expedient rather than long term protection.

28. In August 2001 the Department of Ecology released the Stormwater Management Manual for Western Washington (hereinafter referred to as the Ecology Manual). This manual contains a step by step procedure for selecting treatment facilities (Vol V., p. 2-1; O'Brien Deposition, p. 12). The Port has not followed this procedure, but has limited its choice of stormwater treatment methods to the Basic Water Quality Menu in the King County Manual. As noted above, the performance goal for this menu is 80% TSS removal, not compliance with water quality standards.

29. There are several reasons why biofiltration swales and filter strips are ineffective in treating stormwater at SeaTac. One reason is that the SeaTac stormwater waste stream has relatively little suspended particulate matter (Annual Stormwater Monitoring Report, 2001, p. 28), particularly fine organic-rich colloids. Another is that it is difficult to achieve a level flow-spreading configuration in these facilities. They tend to concentrate the flow in a defined channel that meanders down the middle of a swale and does not afford the opportunity for sedimentation. A third is that the chemistry of both runoff and receiving waters tends to favor the more toxic dissolved state instead of the less toxic particulate bound state. The Basic Menu BMP's were designed to deal with residential subdivisions, but were never intended to respond to stormwater quality concerns arising from a large complex industrial facility such as SeaTac Airport.

30. The Port reports investigations of filter media for metals removal (Logan Declaration, September 2001,7; 16; Annual Stormwater Monitoring Report, 2001). Results of these investigations have not been made available to the parties to this case. Media filtration is widely known in the drinking water industry, but to be effective it serves as one component of a water treatment train that includes such steps as chemical conditioning, coagulation, and flocculation. The newly released Stormwater Management Manual for Western Washington, Volume V - Runoff Treatment BMP's, clearly expects the application of such advanced treatment technologies where removal of dissolved metals is an issue (Vol. V, p 3-5). King County's water quality specialist who reviewed the Port's plans pointed out that a storm filter cannot be a stand-alone facility but is typically the second element of a multi-facility treatment train (Kate Rhoads Deposition, p. 66). Ecology's staff writer on the new Ecology Manual said the same thing (O'Brien Deposition p. 16, 20). The 401 Certification contains no requirement for the Port to implement any stormwater treatment measures beyond the King County Basic Water Quality Menu, which is designed for sediment removal (King County Surface Water Design Manual, p. 6-4). Ecology has accepted this simplistic approach, despite the demonstrated problems of dissolved metals in the Port's stormwater discharges and the widespread recognition, including in Ecology's new manual, that means are available to address these types of pollution problems. Adoption of the Ecology Manual does not guarantee, however, that water quality standards will be met (Luster to Saunders email November 19, 1998). Further,

compliance with the technical standards of the King County Surface Water Design Manual is not intended to, nor does it, ensure compliance with water quality standards.

31. Enhanced Treatment, as described in the Ecology Manual, is required for industrial and commercial sites that discharge to fish-bearing streams (Ecology Manual Vol. V, p. 3-5). The Manual explains "Performance goal: the Enhanced Menu facility choices are intended to provide a higher rate of removal of dissolved metals than Basic Treatment facilities. Due to the sparse data available concerning dissolved metals removal in stormwater treatment facilities, a specific numeric removal efficiency goal could not be established at the time of publication. Instead, Ecology relied on available nationwide and local data, and knowledge of the pollutant removal mechanisms of treatment facilities to develop the list of options below . . ." The Port has not allowed itself to be led by this invitation to apply an appropriate selection from the enumerated treatment facilities.

32. Ecology has the authority to require appropriate water treatment practices under its WQP Policy 1-22, "Adopting Supplemental Treatment as a Best Management Practice and Defining Compliance with Water Quality Standards for Stormwater Impacts for the Water Quality and SEA Programs." (March 31, 2000). This policy states that where both a Water Quality Certification and an NPDES permit apply, the

401 Water Quality Certification may add permit requirements, including Supplemental Treatment on a case-by-case basis as needed for site and project specific requirements (i.e. 303(d) listed parameters, Endangered Species Act requirements, protection of beneficial uses, etc.). However Ecology has not elected to add such permit requirements in its 401 certification for the airport.

33. The Port claims that "by employing best management practices prior to discharging its stormwater, the Port is using all known available and reasonable remediation treatment (AKART)" (*See* Response to Comments, Port of Seattle (April 2001), CH. III, pp. 112-118). Clearly by using a BMP that may be appropriate for one problem to deal with a different problem, they have not achieved anything approaching AKART. The purpose of King County's review of the SMP was limited to whether it meets the technical requirements of the KCSWDM, and it goes no further (Exhibit A to Willing Reply Declaration, October 8, 2001). Compliance with the KCSWDM is not a guarantee of complying with water quality standards (Rhoads Deposition, 62). For each of the menus in the Manual, there is a statement of purpose for that menu. The purposes are stated in terms of percentage removal of wastewater constituents.

34. The Port has stated its intention to Ecology that its Stormwater Master Plan will meet the requirements of the 2001 Ecology Manual (Fitzpatrick Deposition p. 149).

Fendt (1st Declaration, #42) invokes the Ecology Manual, at the same time making it appear that the Basic Menu facilities are adequate for metals removal. Yet the Port's plan does not follow the step-by-step facility selection process in the Manual, and does not propose effective multi-facility treatment trains that are designed for metals removal. The Port's stormwater plan does not comply with the Ecology Manual, and thus has fallen short of AKART. Reasonable assurance of meeting water quality standards would require a rigorous application of the provisions of the Ecology Manual.

**Monitoring is Inadequate to Demonstrate Compliance**

35. The Port of Seattle and the Department of Ecology have manipulated the requirements for stormwater quality data as well as the collection and reporting procedures at SeaTac in such a way that it cannot be ascertained for most sampling dates whether the Port is in compliance with its permit or not. It is impossible for the reader to tell from the recent annual stormwater monitoring reports whether metal constituents of specific discharges comply with or violate water quality standards. The result is that the state does not have reasonable assurance that the standards will not be violated.

36. The stormwater quality data have been reported in terms of medians rather than actual values and ranges. Use of median data dilutes the results so the effect on receiving waters cannot be discerned, nor can it be established whether or not the discharges have violated water quality standards at any given time.

37. Ecology has argued that it is impossible to apply the water quality standards to a given discharge and say whether or not that discharge is violating the standards (Fitzpatrick Deposition p. 25, 26, 32, 38). Ecology maintains that the "science" is in its infancy (Fitzpatrick Deposition p. 56); and that "to try to apply these standards (WAC 173-201A-040) to a stormwater discharge is an extremely difficult process to do as opposed to trying to apply these to your standard steady state industrial discharge." He later expands the point to municipal discharges (Fitzpatrick Deposition p. 25, 38). This same specious argument was made by Logan (September 2001 Declaration p. 4). Fitzpatrick says he does not know, on the basis of Port of Seattle monitoring data, if metals in SeaTac stormwater are causing exceedances of Water Quality Standards (Deposition, 32; 40). In fact, contrary to Ecology's position, municipal and industrial discharges are not typically "steady state," but are highly variable in quantity and quality just as stormwater is. There is a well developed support industry in the field of instrumentation and equipment, and an energetic research community devoted to measuring and understanding stormwater. If Ecology pleads ignorance of these facts, it is out of choice rather than necessity.

38. Dynamic flow behavior is characteristic of the wastewater treatment industry wherever it exists. Conventional wastewater treatment plants have to deal with rapidly changing flows all the time, and do not seem to have trouble either understanding the constituents of their discharges or managing them. By way of illustration, flow hydrographs for two municipal wastewater treatment systems are included as Attachment D to this testimony. The reader will notice that flows can change dramatically in a matter of hours. The outflows from the Bellingham wastewater plant (Attachment D Figure 1) show an increase in one day from 17 to 36 million gallons per day. The Midway Sewer District treatment plant on Des Moines Creek (Attachment D Figure 2) shows a jump from 8 million to 18 million gallons in 3 hours. In the Bellingham plant the effect is more dramatic than the data show because they are daily total flows, and they are outflows that experience some attenuation in the storage basins of the plant. Even thus attenuated, they are hardly the "steady state" conditions that Mr. Fitzpatrick argues make it so much less confusing to deal with municipal and industrial discharges.

39. Readily available research results in the peer-reviewed scientific literature offer well tested protocols for sampling stormwater, and understanding the time distribution of constituents during storm runoff and the mass loading that results from it. See Glenn et al., and references cited, in Attachment E .

40. The Department of Ecology has issued successive versions of the Port's NPDES Permit No. WA-002465-1 that have changed sample points and monitoring parameters. Some of these changes have been in response to inevitable changes in the configuration of the airport. However, the Port's new application for permit renewal (Letter of December 20, 2001 from Michael Feldman to Ed Abbasi) goes substantially beyond this purpose. It proposes a massive consolidation of nine stormwater monitoring locations into two resulting locations, downstream of most of the port's activities and much non-port activity. This will cause a further loss of accountability for the stormwater quality around the airport. Further, it will eliminate monitoring at two locations before the Port fixes the long-standing water quality problems they have shown. SDN1 has been conspicuous for high zinc levels over four years of Annual Stormwater Monitoring Reports (1998; 1999; 2000; 2001) in which the Port has promised to "continue to evaluate" the problem and possible solutions. The 2000 report showed that SDS3 had a series of problems: high hydrocarbon levels (p. 23); high biological oxygen demand ( p. 31); copper (p. 21). The 1999 report (p. 24) showed copper above comparison levels for this outfall. The Port's proposal is to monitor these discharges farther downstream, below intervening tributaries, so the monitoring data will no longer show an inconvenient problem.

41. The Water Quality Standards for metals in WAC 173-201A.040 are hardness-dependent. Hardness is a water quality parameter that is required in order to know whether a given metal concentration is above the standards or not. See Attachment G, which contains an excerpt of Ecology's spreadsheet tool TSDCALC9.XLW. This spreadsheet shows that a decrease in hardness from 56 mg/l to 24 mg/l has the effect of lowering the acute water quality criteria for copper and zinc respectively from 10 to 4μg/l, and from 70 to 34 μg/l. This change has the same effect on the chronic criteria, of lowering them to approximately half for these hardness values. Hardness is defined as the sum of calcium and magnesium, expressed as calcium carbonate equivalent. Hardness renders metal ions in water less toxic by providing positively charged exchange sites for the metals to attach themselves. Ecology has obliged the Port by not requiring that it sample for hardness concurrently with hardness-dependent constituents. Hardness is not required as a sampling parameter in any of the documents where one might expect it to turn up: the non-industrial part of the NPDES Permit, the 401 certification, the Stormwater Management Plan, and the low flow plan. Senior Ecology staff believe hardness data should be required to accompany metals data (Fitzpatrick deposition, p. 53). The prevailing practice of not reporting concurrent hardness values has resulted in a 401 certification without reasonable assurance.

42. The Port's 1999 Annual Stormwater Monitoring Report, Table 4, showed a generic hardness value of 28 mg/l, and the corresponding water quality criteria for lead, zinc, and copper. It attributed the hardness value to the Stormwater Receiving Environment Monitoring Report of June 1997, and said the value was the 10th percentile of values for the streams sampled in that report. The actual values were 23 mg/l for Miller Creek and 35.6 mg/l for Des Moines Creek. In the following year's Annual Stormwater Monitoring Report, the Port selected a different hardness value of 56 mg/l for the same table, with the explanation that it was the median of seven samples from Miller and Des Moines Creeks in 1999. By doing this, the Port voted itself a raise of 80% to 144% in the water quality criteria. The underlying data from Miller and Des Moines Creek were not made available. Values reported elsewhere, as described below, suggest that the Port's 56 mg/l for hardness is an atypical high value, and therefore is not conservative. Hardness values from stormwater discharges appear to be lower than the creeks: in 1999 SDE4 showed an average hardness of 13 mg/l; SDS1 showed an average of 24.9 mg/l. The mean storm flow hardness values reported by Herrera (2001; see Exhibit B) for Des Moines Creek fell between 30 and 40 mg/l for the first four years of their sampling program.

43. Hardness varies with meteorological conditions, sometimes over short periods of time. Seasonal variability possibly related to base flow dominance of runoff, and variability over the duration of individual storms has been observed (Glenn,

Attachment E). Groundwater flow tends to show higher hardness than rainfall, because of the opportunity for the flow to dissolve major cations from shallow sediments.

44. Metals occur in many forms, but a convenient way to differentiate biologically available forms from less toxic forms is whether the metal ions are dissolved or bound to particulate matter. Common analytical practice is to report "total recoverable" metals, which is the sum of dissolved and bound fractions. For most purposes, the Port reports total recoverable amounts. If one does not know the fraction of dissolved metals in a total recoverable sample, it is possible to resort to generic assumptions about how much is dissolved. Ecology uses a conservative partitioning coefficient that assumes 96 to 98% of the total metal is dissolved. The Port would like to use its own lower site specific partitioning coefficients, as it explains in successive Annual Stormwater reports. However, the state's use of conservative partitioning coefficients is justified. Using too low a value could lead to an unwarranted assumption of lower toxicity through "false negatives." It is also important to recognize that the partitioning between dissolved and bound forms is reversible and highly dynamic, and easily influenced by the chemical environment downstream in the receiving waters. Instead of arguing for a relaxation of the water quality standards and creating an opaque curtain of generic values, the Port should routinely analyze for both dissolved and total metal.

45. Ecology and the Port maintain that Water Quality Standards apply in receiving waters rather than at the end of a stormwater discharge pipe. The data obtained by the Port is "end of pipe" data. The Port argues that such data does not demonstrate violation of water quality standards in the receiving water body. But this is an entirely different question than the one requiring an answer before issuance of the SeaTac 401 water quality certification, which is: Is there is a reasonable assurance that the project will not violate water quality standards in project-area streams when there is a heavy load of pollutants in the discharge, and well recognized beneficial uses? There is no such reasonable assurance here.

46. State law defines appropriate mixing zones, but no mixing zones have been defined for the Port's stormwater discharges. WAC 173-201A-100 (1) says "the allowable size and location of a mixing zone and the associated effluent limits shall be established in discharge permits, general permits, or orders, as appropriate." The intent of the regulation and the implementation practice is that the discharger demonstrate that AKART has been applied to all discharges; and that under the least favorable of discharge conditions, such as low late summer flows when the discharge could equal or exceed the streamflow, beneficial uses in the receiving waters will be protected. These demonstrations are to result from a mixing zone analysis for each discharge. The only mention of a mixing zone in the NPDES permit applies to the IWS

discharge, outfall 001. The Port's NPDES permit does not authorize mixing zones at its outfalls to Des Moines, Miller, and other streams. Allowing the Port to discharge stormwater at pollutant concentrations above water quality standards is an unfounded de facto authorization of a mixing zone, because the concentrations in the end of the pipe cannot meet the standards without dilution.

47. The flows available for dilution are potentially very low in SeaTac area streams. The Low Streamflow Analysis shows low flows for Miller, Walker, and Des Moines Creeks below 0.5 cfs for extended periods of time, which provide little waste flow dilution. This means that the "first flush" of stormwater runoff in the next rainstorm will have severe water quality impacts on these already degraded streams. Discharges exceeding the water quality standards at the end of the pipe are making the problem worse, not better. WAC 173-201A-040 (1) says that "toxic substances shall not be introduced above natural background levels in waters of the state which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent on those waters, or adversely affect public health . . ." The Port and Ecology have not demonstrated that this description does not fit the Port's discharges.

48. Ecology's position on mixing zones is confusing and contradictory. On one hand, the Fact Sheet attached to the Port's NPDES, Permit, p. 29, February 20, 1998, says:

"Some amount of mixing should be allowed given that the application of BMP's satisfies the requirement for AKART. Mixing zone analysis to determine dilution factors is a very complicated modeling problem for stormwater. Assuming no mixing zone, the stormwater discharges from SeaTac Airport show reasonable potential to violate the water quality criteria for copper, lead, and zinc."

49. On the other hand, Fitzpatrick says (Declaration dated 28 September 2001, p. 3): ". . . the 401 certification does not authorize a mixing zone in violation of water quality standards. For instream and shoreline work only, the certification allows temporary exceedances of water quality standards for turbidity . . . any mixing zone . . . must be minimized . . . These conditions do not authorize mixing zones for any work other than instream and shoreline work and for no other criteria than turbidity. The 401 certification does not authorize mixing zones for stormwater discharges from the Port's STIA industrial operations." Even with dilution in a mixing zone, Port stormwater concentrations of copper and zinc are high enough to create a reasonable potential that they will violate water quality standards.

50. Instead of taking a conscientious approach to water quality sampling and analysis, offering data values above the discharge, below the discharge, and in the discharge, with concurrent hardness values that would allow all parties to know whether or not the discharges violate water quality standards, the Port of Seattle has pursued a Water

Effects Ratio study in the expectation that Ecology and the public will go along with relaxed water quality standards in the SeaTac streams.

51. The Port's Memorandum Opposing ACC's Motion for Stay (October 1, 2001) claims that "two preliminary WERS have already been conducted." Linda Logan's declaration in this case (September 2001, p.4), claims that the WER testing showed no evidence of instream or outfall toxicity. Another is the Declaration by Paul Fendt (September 2001 para. 43), wherein he claims that the 1999 WER study demonstrates the efficacy of current Best Management Practices. The first Water Effects Ratio materials that the Port released were dated February 1999, and were not submitted for inspection by Ecology or other parties until October 7, 2001, after Ecology issued both the original and modified Section 401 Water Quality Certifications.

52. Ecology has specific guidance on the subject of preparing Water Effects Ratio studies; the Port did not follow that guidance. The department's Water Quality Program Permit Writer's Manual can be summarized in relevant part as follows: " . . . Ecology believes WER studies must be conducted as rigorous scientific investigations because they are modifications of the State's water quality criteria . . . Because determining a WER requires substantial resources, the desirability of obtaining a WER should be carefully evaluated: . . . Evaluate the potential for reducing the discharge of the metal . . . Evaluate the cost-effectiveness of determining a WER . . . The Permittee

**must** (emphasis original) have examined other options for reducing the concentration of metals in the effluent such as pollution prevention and treatment. This must be reported in the form of an engineering report . . . If any technology-based option meets the cost test for reasonableness, that option must be implemented before Ecology will agree to a WER study . . . The concentrations of metals in each of the WER dilutions and in receiving water analyses must be measured as total recoverable and dissolved . . . The discharge in question must be meeting existing technology-based requirements . . ." Water Quality Program Permit Writer's Manual, Appendix 6, p 73 - 75; Ecology publication 92-109, Revised January 2001).

53. Most conspicuously, the Port's WERS activities disclosed to date have not complied with WAC 173-201A (3): ". . .The department may revise the following criteria on a state-wide or waterbody-specific basis as needed to protect aquatic life occurring in waters of the state and to increase technical accuracy of the criteria being applied. The department shall formally adopt any appropriate revised criteria as part of this chapter in accordance with the provisions established in chapter 34.05 RCW, the Administrative Procedure Act. The department shall ensure there are early opportunities for public review and comment on proposals to develop revised criteria . . ." The Port's apparent intention is to work out a relaxation of the criteria in private with Ecology, and then present the public with a fait accompli.

**Conclusion**

54. The Section 401 Water Quality Certification issued on September 21, 2001 fails to provide reasonable assurance that water quality standards of the State of Washington will not be violated. The plan to provide low flow augmentation water to SeaTac area streams is full of uncertainties and unproven assumptions. The substantive provisions for managing water quality do not take advantage of well known and eminently reasonable technology. The water quality monitoring regime at SeaTac fails to provide basic data that is required for the Department of Ecology to know whether or not the Port is violating state law. Consequently, the Department of Ecology has not provided reasonable assurance that the Port's proposed projects will not result in violations of state water quality standards.

DATED this 22nd day of February, 2002.

Peter Willing, Ph.D.

Pre-Filed Testimony
of
Dr. Peter Willing

## INDEX TO EXHIBITS

A. Curriculum Vitae of Dr. Peter Willing

B. List of Documents and Information Relied Upon in Testimony Related to 401 Water Quality Certification for Third Runway at Sea-Tac Airport

C. Two photographs taken by Dr. Willing on January 28, 2002, during Third Runway-area site visit

D. Flow Hydrographs for two wastewater treatment facilities (City of Bellingham Post Point wastewater treatment plant and Midway Sewer District treatment facility)

E. "Influence of Highway Runoff Chemistry, Hydrology and Residence Time on Non-Equilibrium Partitioning of Heavy Metals -- Implications for Treatment at the Highway Shoulder," by D. Glenn, D. Liu, and J. Sansalone

F. Letter dated March 12, 2001, from Dr. Peter Willing to Mr. Chung Yee, Dept. of Ecology, Re: NPDES Permit Major Modification

G.
- Ecology spreadsheet (excerpt from TSDCALC9.XLW);
- Stormwater Quality Data spreadsheet by Dr. Peter Willing;
- Two spreadsheets from 1998-99 POS Annual Stormwater Monitoring Report;
- Water Hardness Data spreadsheet by Dr. Peter Willing

A

**Peter Willing, Ph.D.**
*Water Resources Consulting, L.L.C.*
1903 Broadway ✦ Bellingham, Washington ✦ 98225 ✦ 360-734-1445 ✦ 360-676-1040 (fax) ✦ pwilling@telcomplus.net

## EDUCATION

B.A., University of Washington, Seattle, Washington
M.S., Ph.D., Cornell University, Ithaca, N.Y.

## PROFESSIONAL AFFILIATIONS

American Water Resources Association
American Geophysical Union

## SELECTED SPECIALIZED TRAINING

Applied Fluvial Geomorphology: Wildland Hydrology Center, Pagosa Springs, Colorado

Stormwater Treatment: Biological, Chemical, and Engineering Principles. Professional Engineering Practice Program, University of Washington

## SUMMARY

Dr. Willing is Principal in the Bellingham firm of Water Resources Consulting, L.L.C. Since founding the firm in 1989, he has carried out a wide variety of assignments for public and private clients seeking to solve water-related technical questions. Examples are: hydroelectric system design, flood frequency analysis on Northwest rivers, wellhead protection, surface water - ground water interactions, storm water management strategy, and hydrologic basis of water rights. In public sector positions, he has served as general manager of a medium sized public water system. He also served as chief environmental officer of a large municipal electric utility. Dr. Willing holds Adjunct Faculty appointments in Geology and Huxley College at Western Washington University, Bellingham.

## SELECTED PROJECT EXPERIENCE

Review of surface and ground water hydrology associated with the possible construction of a third runway at Sea-Tac Airport. Questions under investigation include permeability and water storage characteristics of imported fill materials, effectiveness of stormwater management measures, compliance with water quality provisions of the King County Surface Water Design Manual, effect of fill on wetlands and stream flows, and project effects on anadromous fish. November 1999 - February 2001.

Water supply source investigation for determination whether the source is under the influence of surface water. Project includes multi-site water quality monitoring, source intake design, microscopic particulate analysis, and a geohydrologic investigation of a complex of juxtaposed unconsolidated glacial, metamorphic, and volcanic geological systems. Client: Puget Sound Energy

Design and implementation of geohydrologic investigation for new ground water supply, with special emphasis on hydraulic continuity between ground and surface waters. Project includes securing drill and test permit, engaging driller, logging the well, overseeing a pump test, high resolution surface water flow measurements, collecting and analyzing the data, geologic mapping, and writing completion report. 1997.

**Peter Willing, Ph.D.**
*Water Resources Consulting, L.L.C.*
1903 Broadway ✦ Bellingham, Washington ✦ 98225 ✦ 360-734-1445 ✦ 360-676-1040 (fax) ✦ pwilling@telcomplus.net

Geohydrologic evaluation of Lummi Island public water supply wells in support of water rights application, including 24-hour pump test, monitoring observation wells, analysis of data, and project report. 1997.

Reconnaissance investigation of surface water storage potential of the Nooksack Basin, Washington. Project included a review of prior studies, hydrology, current water demands, and project costs. 1997.

Preparation and compliance monitoring of NPDES permits for industrial gas manufacturing facility. Responsibilities included both process wastewater and storm water permits, analysis and recommendations on process flow control, best management practices from regional surface water design manuals, and waste stream management. 1992-1997.

Alluvial fan and debris flow hazard element of Comprehensive Flood Hazard Management Plan, Lower Nooksack River, Whatcom County, Washington. This element consisted of field investigation in support of hydrologic and geomorphologic analysis of two high-gradient streams. 1995-6. Client: Whatcom County Flood Control Zone District

Assessment and expert testimony on hydrologic basis and technical adequacy of contested water rights application, San Juan Island, Washington. Case was heard by Washington Pollution Control Hearings Board as Fleming et al. v. Department of Ecology, 1994. Client: private party appellants.

Miscellaneous water rights investigations involving adequacy of water supplies, well interference, salt water intrusion potential, and hydraulic continuity between surface and ground waters. 1997. Clients: individual parties.

Hydrologic and geohydrologic data needs assessment in support of potential basinwide water rights adjudication. The preparatory work on this project is designed to support development of a hydrologic and water rights accounting model. Client: Nooksack Basin Water Users Steering Committee

Preparation of Wellhead Protection Programs for small cities and public water supplies.. Components include assessment and compilation of existing data, aquifer delineation, contaminant source inventory, storm water management design, and provision of alternative water supply. Clients: City of Everson, City of Sumas, Pole Road Water Association.

Hydrology element of Comprehensive Flood Hazard Management Plan, Lower Nooksack River, Whatcom County, Washington. This element consisted of a review of the adequacy of the stream flow record, previous flood frequency analyses, and potential error and uncertainty in flood frequency estimates. Client: Whatcom County Flood Control Zone District

Water rights review for industrial facility in Whatcom County. This assignment involved documentation of historical water use and claim to water that go back to before the turn of the century. The purpose of the effort was to position the client to advantage in the current climate of water rights regulation by the State of Washington.

**Peter Willing, Ph.D.**
*Water Resources Consulting, L.L.C.*
1903 Broadway ✦ Bellingham, Washington ✦ 98225 ✦ 360-734-1445 ✦ 360-676-1040 (fax) ✦ pwilling@telcomplus.net

Snoqualmie River Shallow Aquifer Evaluation. This project consists of a two-year investigation of hydraulic continuity between the pool behind Snoqualmie Falls and the local shallow aquifer. Key questions are effect of river stage on sewer inflow, wetlands, building foundations, and construction conditions. Client: Puget Sound Power & Light.

Primary technical witness in siting of industrial landfill in Whatcom County. This project consisted of an independent review of the geohydrology report submitted by the landfill applicant in support of the application for the landfill, and expert testimony on that review. Client: Private landowner.

Hydrogeologic evaluations of sand and gravel mining and landfill proposals in glacial outwash deposits on the margins of the Nooksack River in Whatcom County, Washington. These investigations have established local gradients and flow directions in the vicinity of gravel mining operations. Different projects have been completed, both for gravel mining clients and others who perceived themselves to be affected.

Review of rainfall and runoff hydrology in support of design of small hydroelectric installation on Baranof Island, Alaska. Project involved use of HEC-1, HEC-2, WaterWorks, and other hydrologic models. Client: City and Borough of Sitka.

Principal investigator for low flow frequency and water supply risk study on the Nooksack River, Whatcom County, Washington. Client: Whatcom County Public Utility District #1.

Consultant for aquifer recharge area delineation, Whatcom County, Washington. Project undertaken in support of Critical Areas Ordinance to be adopted pursuant to the Washington State Growth Management Act.

Project manager and surface water hydrology investigator for groundwater resource evaluation, for Lummi Indian Business Council, Whatcom County, Washington.

Project manager for review of power operations plan and fish and wildlife mitigation plan for Kerr Dam, Flathead River, Montana. Client: Bureau of Indian Affairs.

Preparation of Initiating Memorandum and preliminary scope of work for US $3M investigation of Southern African river basins. The project is designed to provide water resources focus to major World Bank grant-in-aid program.

Project manager and client liaison for runoff forecast model development project, for the Cedar and South Fork Tolt Rivers, King County, Washington. Work carried out for the Seattle Water Department.

Project manager for hydroelectric power plant efficiency improvements for Puget Sound Power and Light Company's White River plant. Project consists of application of linear and dynamic programming and optimization techniques to interactions between hydraulics, energy value, and hardware.

Analyst for hydrologic and environmental screening of 1,200 potential small-scale hydroelectric sites in British Columbia, on behalf of independent power producer with interests in B C Hydro's resource acquisition program.

**Peter Willing, Ph.D.**
*Water Resources Consulting, L.L.C.*
1903 Broadway ✦ Bellingham, Washington ✦ 98225 ✦ 360-734-1445 ✦ 360-676-1040 (fax) ✦ pwilling@telcomplus.net

System planning, operations efficiency, and source evaluation for water supply and hydroelectric facilities.

Contributor to Coordinated Water Supply System Plan for six-utility area with 250,000 population. Project elements consisted of demand projections, evaluation of existing and planned capacity expansion, and evaluation of alternatives for meeting projected demand.

Researcher for assessment of U.S. groundwater management strategies and their suitability for the Puget Sound lowland.

Participant in oversight of lake restoration program for Lake Whatcom, Whatcom County, Washington. Reviewed water quality sampling regime, interim findings, and final analysis and interpretation. Participated in steering committee deliberations, final drafting of Watershed Management Plan, and presentation to local government.

Chief administrative officer for water and sewer utility, which included responsibility for raw surface water source monitoring and protection. Devised watershed management policies and documented land use - water quality interactions.

Expert witness in litigation concerning adequacy of Environmental Impact Statements prepared under Washington State Environmental Policy Act. Witness before the Pacific Northwest Power Planning Council on fish and wildlife aspects of implementing the Pacific Northwest Electric Power Planning and Conservation Act.

Visiting Lecturer, upper division courses in surface water hydrology and water resources policy; Department of Geology and Huxley College, Western Washington University.

Investigator for design and implementation of an analysis of the interactions between watershed land use and receiving lake water quality for a 205-square-mile lake basin in Cayuga County, New York. Participated in water quality sampling and analysis program. The lake in question is the water source for the City of Auburn.

Principal researcher for report on costs of fish and wildlife mitigation and enhancement measures in the Columbia River Basin.

Team participant in multi-national effort to research and recommend coal transportation environmental standards for Pacific Rim developing countries.

Responsible official for preparation of Environmental Impact Statement on Copper Creek Dam, Skagit County, Washington. Important issues included anadromous fisheries, riparian habitat, power generation, hydrologic effects, and water rights.

Team manager for preparation of environmental documents in support of FERC application for a hydroelectric installation on the South Fork Tolt River, King County, Washington.

Supervisor of analysis of environmental aspects of rehabilitating the Cedar Falls hydroelectric project, King County, Washington.

B

**List of Documents and Information Relied upon in testimony relating to 401 Water Quality Certification for Third Runway at SeaTac Airport**

Peter Willing, Ph.D.


Glenn, D.W., Liu, D. and Sansalone, J.J., "Influence of Highway Runoff Chemistry, Hydrology and Residence Time on Non-Equilibrium Partitioning of Heavy Metals – Implications for Treatment at the Highway Shoulder", ***J. of Transportation Research Record***, 1775, 129-140, November 2001.

APHA-AWWA-WPCF, 1989. Standard Methods for the Examination of Water and Wastewater. 17th Ed.

Sansalone, J.J. and Buchberger, 1997. Partitioning and first flush of metals in urban roadway stormwater. Jour. Environ. Eng. Vol 123 (2).

Kadlec, R.H. and R.L.Knight, 1996. Treatment Wetlands. Lewis Publishers. 893 p.

Washington State Department of Ecology, 2001. Water Quality Program Permit Writer's Manual. Publication 92-109. Revised January 2001.

Washington State Department of Ecology, 2001. Guidelines for preparing quality assurance project plans for environmental studies. Publication 01-03-003; Revision of publication 91-16.

American Public Works Association, Washington Chapter, Stormwater Managers Committee. 1999. Protocol for the aceptance of unappproved stormwater treatment technologies for use in the Puget Sound watershed.

Washington State Department of Ecology, 2000. Water Quality and Shorelands and Environmental Assistance Programs Joint Policy. Adopting Supplemental Treatment as a Best Management Practice etc.

Adolfson Associates, 1995. Pilot Evaluation, Subsurface Stormwater Disposal Facilities, Clover/Chambers Creek Basin. Final Report to Tacoma-Pierce County Health Department.

Claytor, R.A and T.R. Schueler, 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection, Silver Spring, MD. Supplemental funding by USEPA Region 5.

EPA, 1999. Preliminary Data Summary of Urban Stormwater Best Management Practices. EPA-821-R-99-012.

HNTB, 2001. Memorandum from Alan Black to Michael Cheyne, April 26, 2001. Yellow D6 version.

Strecker, E., Quigley, M.M., and Urbonas, B.R.. Undated. Determining Urban Stormwater BMP Effectiveness. URS Greiner Woodward Clyde, Portland, Oregon.

Herrera Environmental Consultants, 2001. City of Des Moines Water Quality Monitoring Program, Five year project report. Prepared for City of Des Moines Surface Water Management Utility.

Moore, J.W. 1991. Inorganic Contaminants of Surface Water. Springer Verlag. 326 p.

Maidment, D.R. 1993. Handbook of Hydrology. McGraw Hill.

Des Moines Creek Basin Committee, 1997. Des Moines Creek Basin Plan.

Port of Seattle, 1997. Stormwater Receiving Environment Monitoring Report for NPDES Permit No. WA-002465-1. Vol. 1, Report. 83 pp.

Port of Seattle, 1999. Procedure Manual for Stormwater Monitoring at Sea Tac International Airport in compliance with NPDES Permit No. WA-002465-1. Revision 6.

Port of Seattle, 1998. Annual Stormwater Monitoring Report for Sea Tac International Airport.

Port of Seattle, 1999. Annual Stormwater Monitoring Report for Sea Tac International Airport.

Port of Seattle, 2000. Annual Stormwater Monitoring Report for Sea Tac International Airport.

Port of Seattle, 2001. Annual Stormwater Monitoring Report for Sea Tac International Airport.

Port of Seattle, 2001. Application for Permit to Discharge Stormwater. Sea Tac International Airport.December 19, 2001.

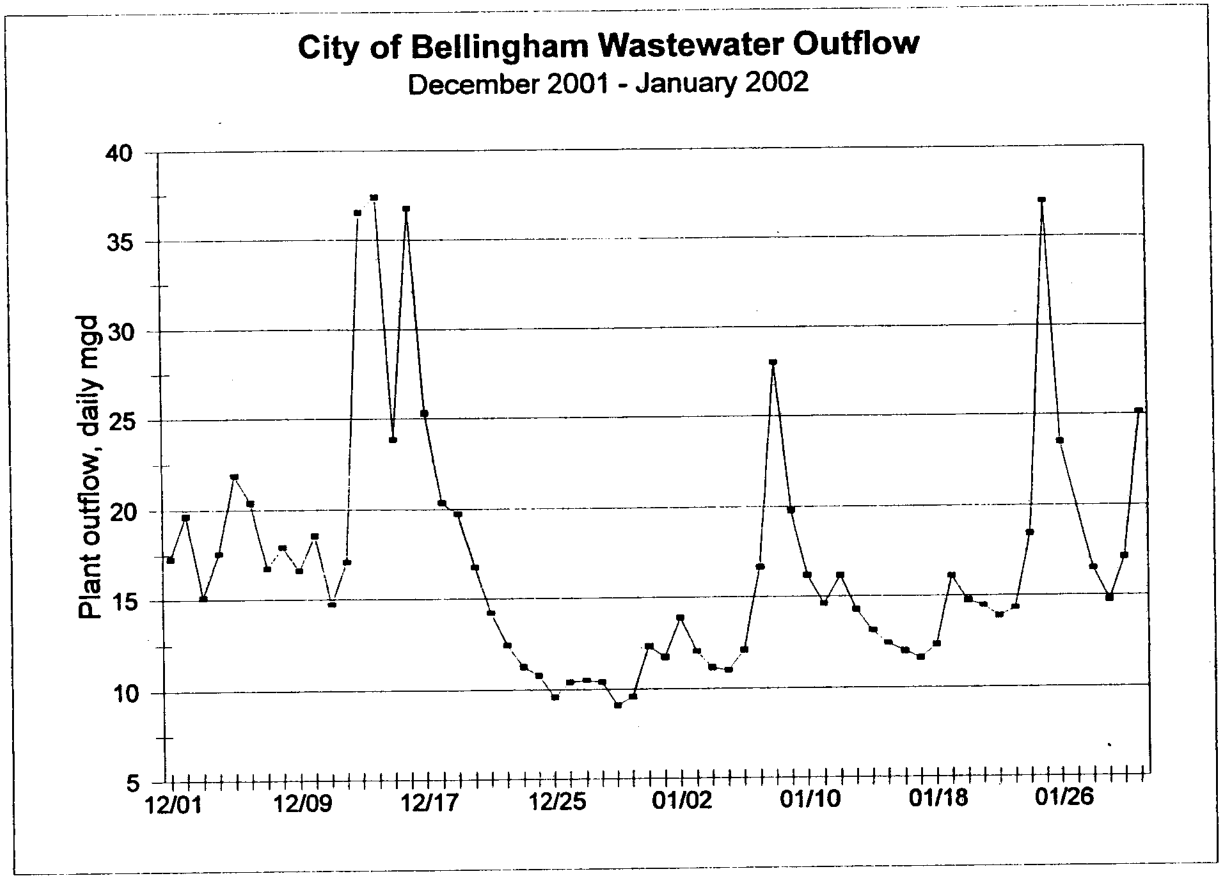
Parametrix, Inc. 1999. Water Effect Ratio Screening Study at Seattle Tacoma International Airport: Toxicity Evaluation of Site Water. Prepared for Port of Seattle. 4pp. Appendices.

C

Figure 1. Absorbent boom in stream below SDS1 outfall. Photo taken by P. Willing, January 28, 2002.

Figure 2. Absorbent boom in stream below SDS1 outfall. Note turbid effluent. Photo taken by P. Willing, January 28, 2002.

D




Water Resources Consulting LLC

Figure 1. Outflow hydrograph of City of Bellingham Post Point wastewater treatment plant. Outflow figures include peak flow attenuation due to storage in the plant. Values are daily flows and do not show hourly variation.

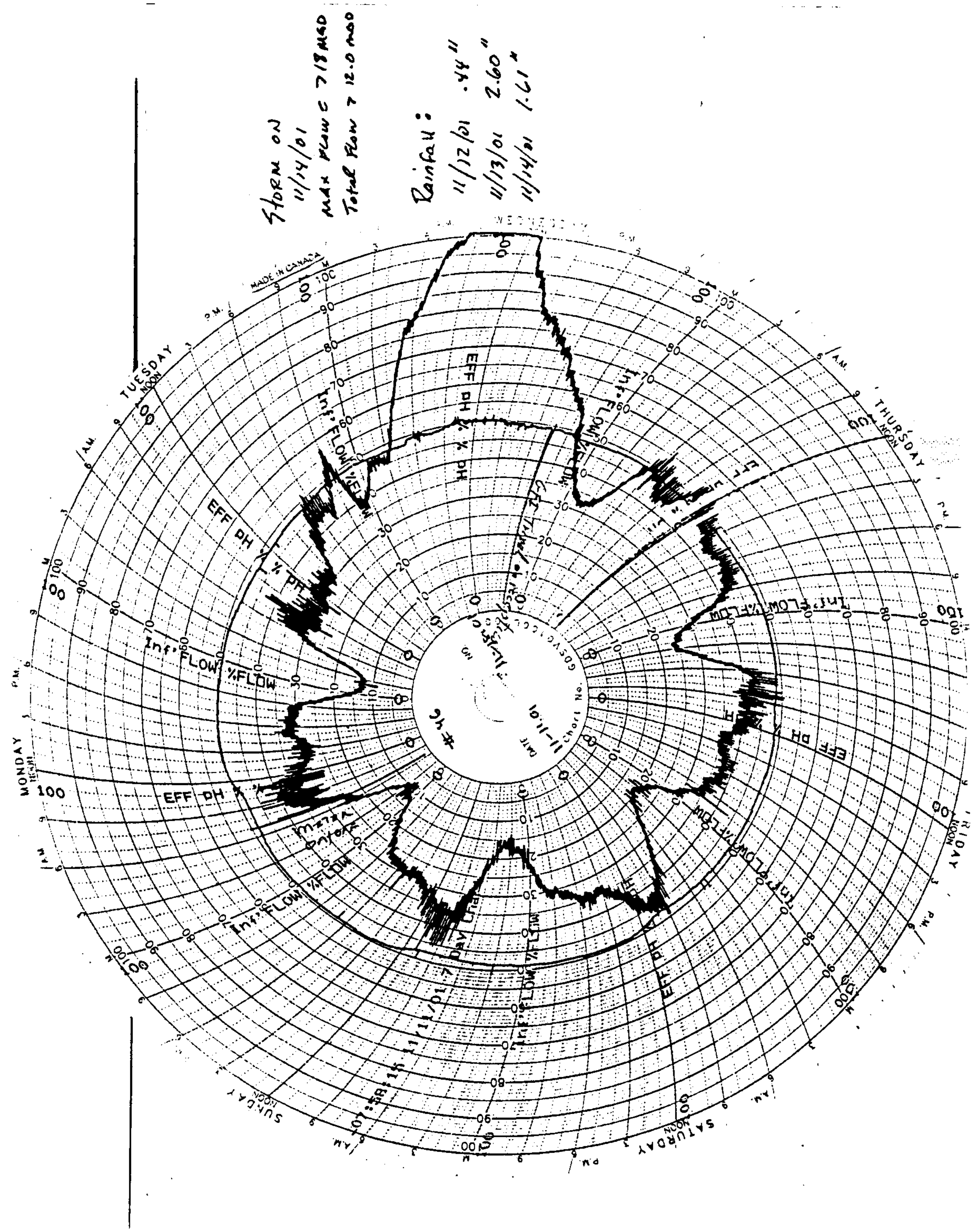



Figure 2. Flow recorder chart from Midway Sewer District treatment facility. Scale is percent of maximum hydraulic capacity (18 million gallons per day). Storm on November 14, 2001 resulted in a flow at the plant that increased from 8 to 18 mgd in 3 hours.

E

## Influence of Highway Runoff Chemistry, Hydrology and Residence Time on Non-Equilibrium Partitioning of Heavy Metals – Implications for Treatment at the Highway Shoulder

Donald W. Glenn III[1], Dingfang Liu[1], and John J. Sansalone, Ph.D., P.E.[2] (corresponding author)

[1]Louisiana State University, Department of Civil and Environmental Engineering, 3502 CEBA Building, Baton Rouge, Louisiana 70803-6405; 225.578.8652 (fax)
[2]Louisiana State University, Department of Civil and Environmental Engineering, 3502 CEBA Building, Baton Rouge, Louisiana 70803-6405; 225.578.6047 (office); 225.578.8652 (fax)

Word Count: 5000 text and 2500 for tables and figures

**ABSTRACT**

The control and treatment of highway pavement storm water at the edge of the highway shoulder pose unique challenges due to the unsteady nature of processes including rainfall runoff, mobilization and partitioning of heavy metals, variations in storm water chemistry, residence time on the pavement and delivery of particulate mass. This study presents heavy metal partitioning results as influenced by pavement runoff chemistry and hydrologic parameters from a series of eight rainfall runoff events over a two-year period. Water quality characteristics such as low alkalinity, low hardness and short pavement residence times results in a majority of the heavy metal mass remaining in solution at the edge of the pavement with partitioning coefficients only approaching equilibrium conditions towards the end of the event as heavy metals partition to entrained solids.

There are two primary implications when considering the application of typical best management practices (BMPs) for highway runoff within the right-of-way. The first implication is to utilize a BMP such as a detention basin or roadside swale to detain runoff and produce sufficient residence time so that partitioning to the entrained solids occurs. The second implication is to utilize a BMP such as an engineered infiltration trench to provide surface complexation for dissolved metals and filtration mechanisms for the particulate bound metals. While no simple solutions exist for the removal of a heavy metal or particle once released in the highway environment, knowledge of the dynamic processes in highway runoff can provide insights for the proper selection of BMPs depending on the conditions at the highway site. A design should be based on the concept that BMPs, to be effective, are essentially garbage cans for heavy metals and solids and as such must be emptied and maintained.

**Keywords:** heavy metals, partitioning, highway storm water, alkalinity, in-situ treatment

**INTRODUCTION**

Storm water runoff, impacted by both urban transportation activities and associated urban transportation infrastructure, transports significant loads of dissolved, colloidal and suspended solids in a complex heterogeneous mixture that includes heavy metals, inorganic and organic compounds. Compared to drinking water and domestic wastewater, storm water treatment continues to pose uniquely difficult challenges due to the unsteady and stochastic nature of processes including traffic, rainfall-runoff, heavy metal partitioning and transport of entrained solids. Heavy metals from these sources are not degraded in the environment and constitute an important class of acute and chronic contaminants. Highway storm water levels of Zn, Cu, Cd, Pb, Cr and Ni can be above ambient background levels, and for heavily traveled highways often exceed surface water discharge criteria on an event basis for both dissolved and particulate-bound fractions. Storm water transports a wide gradation of particulate matter ranging in size from smaller than 1-μm to greater than 10,000-μm. From a treatment perspective, entrained solids or engineered media having reactive sites and large surface-to-volume ratios mediate partitioning and transport of heavy metals while serving as reservoirs for reactive constituents.

Since passage of the 1972 Clean Water Act, storm water non-point pollution has advanced from being a problem that was understood only well enough to realize the difficulties associated with application of conventional treatment process design, to now becoming our most recent water treatment challenge. Since the National Pollution Discharge Elimination System (NPDES) Storm Water Phase I permitting regulations in the 1980s, there has been a proliferation of suggested in-situ storm water "best management practices", BMPs. However, experience over the last decade has demonstrated that there continues to be a significant gap in knowledge between conventional in-situ BMP design/analysis and design based on the actual physical and chemical characteristics of storm water loadings. Such an understanding of these physical and chemical characteristics of storm water loadings at the point of treatment, such as the edge of the highway shoulder, is critical to the success of a new generation of storm water treatment systems that will develop in response to the new February 2000 Phase II Storm Water Final Rule. This knowledge will require an understanding of temporal storm water chemistry, temporal heavy metal partitioning between solid and solution phases, physico-chemical characteristics of transported particulate matter, and highway hydrology as influenced by traffic and pavement conditions.

**STUDY OBJECTIVES**

There were three objectives of this study. These objectives were carried out at an instrumented experimental site on inter state 75 in urban Cincinnati for eight fully analyzed rainfall runoff events over two years. The goal of the paper is to demonstrate that an understanding of heavy metal partitioning and pavement hydrology at the edge of the pavement shoulder is a critical prerequisite for in-situ BMP design focused on heavy metal capture. As a result, there are three objectives of this paper. The first is to demonstrate that despite relatively low alkalinity and essentially neutral pH values, heavy metal mass can be predominately dissolved at the edge of the highway shoulder. The second objective is to demonstrate the role of residence time and hydrology on delivery of heavy metals at the edge of the highway shoulder. The final objective is to examine the trends in non-equilibrium heavy metal partitioning in terms of temporal heavy metal partitioning coefficients and delivered suspended solids at the edge of the highway shoulder. Finally, the paper will discuss implications of these findings for the selection, design and efficacy of in-situ BMPs loaded by highway pavement sheet flow.

**PREVIOUS WORK**

Storm water runoff from roadways transports significant event and annual loads of heavy metals and a wide gradation of particulate matter to receiving waters (*1*). In urban environments, heavy metals are generated primarily from the abrasion of metal-containing vehicular parts, including the abrasive interaction of tires against pavement, leaching of metal elements from infrastructure, and oil and grease leakage (*2-5*). Storm water from urban and transportation land uses is a complex physico-chemical heterogeneous mixture of heavy metals, particulate matter, inorganic and organic compounds with variations in flow, concentrations and mass loadings that sometimes vary by orders of magnitude during a single hydrologic event. This complexity has made storm water very difficult to treat. For example, two years of research results from data collected on an instrumented urban transportation roadway site located at the edge of the highway shoulder on inter state 75 in urban Cincinnati demonstrates the variation in magnitude of event mean concentration (EMC) values between discrete hydrologic events. For total Zn, EMCs ranged from 15,244 to 459-μg/L, total Cu from 325 to 43-μg/L, total Pb from 88 to 33-μg/L, total Cr from 35 to 13-μg/L, and total Cd from 11 to 5-μg/L (*6*).

From urban inter state highway pavement alone, annual heavy metal, total suspended solids (TSS), chemical oxygen demand (COD) loadings and storm water flows have been shown to equal or exceed annual loadings and flows from untreated domestic wastewater for a given urban area (*7*). The urban inter state and major arterial pavement area typically constitutes less than a factor of 10 of the total pavement area for an urban area while generating a disproportionate pollutant load especially with respect to heavy metals. In fact, it was been reported in the literature as early as 1974 that storm water runoff from urban pavement represented a greater pollutant loading to receiving water than point source wastewater discharges from that same urban area (*8*).

**BACKGROUND**

Heavy metal partitioning between the dissolved and particulate-bound fractions in storm water is a dynamic process. This partitioning, which varies significantly between hydrologic events and traffic patterns, is a function of pH, alkalinity, residence time, mixing and solids characteristics (*6*). As a result of very low rainfall alkalinity, low rainfall pH (4 to 5.5) and low pavement residence time, urban roadway runoff can be of moderate to low alkalinity (< 50 mg/L as $CaCO_3$) with slightly acidic to neutral runoff pH. This results in dissolution of finely abraded metallic particles generated from traffic activities, and therefore metal mass partitions predominately to the dissolved fraction for short residence times. Understanding the kinetics of this non-equilibrium partitioning is critical for proper monitoring, conceptual design and viability of unit operations and processes that may be applied as in-situ or source control treatment.

For sampling and monitoring, previous results indicate for such pH and alkalinity conditions that the originally dissolved Cu mass partitions to the particulate-bound fraction within 6 hours of transport from the pavement. Additionally, in the presence of suspended or entrained solids, a resulting change in the partitioning coefficient, $K_d$ as a function of time for Pb, Cu, Cd and Zn during the passage of the rainfall runoff event, can occur. Knowledge of the partitioning kinetics and the relative fractions of dissolved ($f_d$) and particulate-bound ($f_p$) mass delivered for treatment are of fundamental importance for in-situ treatments where residence times on the urban surface or in the urban drainage system in the presence of entrained particulate matter are less than several hours.

With respect to partitioning, the edge of the highway shoulder receives a mixture of aqueous heavy metals and entrained particulate matter. Therefore, there will be a competitive process of partitioning. Even for the complexities of the highway environment, trends predicted by theory can be used to explain actual competitive partitioning results.

Under conditions where a number of heavy metals are present in solution, the competitive order of partitioning (sorption) can be compared to bonding preferences as predicted using covalent theory, electrostatics or the tendency of a metal element to undergo hydrolysis followed by sorption. Electronegativity is an important factor in determining which heavy metal will complex to a hydrated inorganic surface, such as an iron oxide surface, with the highest preference. The more electronegative heavy metals form the strongest covalent bonds with the oxygen atoms of the surface hydroxyl groups. According to covalent theory for divalent metal ions, the predicted order of bonding preference would be (*9*):

$$Cu > Ni > Co > Pb > Cd > Zn > Mg > Sr \quad (1)$$

However, based on electrostatics, bonding preference is for the metals with the greatest charge-to-radius ratio, producing a different order of preference for this group of divalent metals (*9*):

$$Ni > Mg > Cu > Co > Zn > Cd > Sr > Pb \quad (2)$$

Electrostatics would also predict that trivalent metal ions such as $Cr^{3+}$ would have a greater bonding preference to all divalent metal ions. Finally, based on the tendency to hydrolyze, the bonding preference of selected metal ions to iron oxides would be (*9*):

$$Pb > Cu > Zn > Co > Ni > Cd > Mn \quad (3)$$

## METHODOLOGY

### Experimental Site

An experimental facility, utilized since 1995, was designed to sample and analyze representative lateral pavement sheet flow ($q_{sf}$) at the edge of the highway shoulder. The focus on $q_{sf}$ is a departure from work of other researchers who sampled flow as an aggregation of sheet flow, gutter flow and pipe flows (*10, 11*). Measurements of $q_{sf}$ are critical for design of in-situ treatment systems such as BMPs loaded by such flow. At the site, the downstream edge of the pavement section was saw-cut and removed to allow the construction of a 15-m wide instrumented sampling facility. The drainage area to the site was a well defined 15-m wide by 20-m long (across the super-elevated four lanes of pavement) asphalt pavement drainage area. Details of the sampling and instrumentation configuration are provided elsewhere (*6*). Figure 1 illustrates the location of the experimental facility with respect to the Millcreek Expressway portion of inter state 75 approximately 3-km north of downtown Cincinnati. Figure 2 provides details of the geometry of the experimental facility and the relative location of experimental appurtenances.

**Sampling and Field Data Collection**

During 1996 and 1997, eight rainfall runoff events were sampled and analyzed at the experimental site. Samples were obtained using an automated sampler programmed to acquire discrete 1-liter samples at timed intervals of between 2 to 10 minutes for the duration of the runoff. Hydrologic and water quality field data were collected during all sampled events at the experimental site. The rain events varied in duration, intensity, inter-arrival times and generated flows (ranging from the low-flow to high-flow capacity of the flume). Samples were analyzed for trace metals, solids and water quality parameters for all events. Details of hydrology, sampling, the various laboratory methodologies and analyses as well as the experimental protocols are provided elsewhere (*6, 7*).

**Heavy Metal and Water Quality Protocols**

After the completion of a runoff event, the samples were immediately transported to the nearby laboratory. Metal partitioning between the dissolved and particulate-bound phases is a dynamic process. Therefore, samples were fractionated between dissolved and particulate-bound heavy metals and acidified within hours of being logged at the laboratory.

The dissolved fraction is defined as heavy metals of an unacidified sample that pass through a 0.45-μm membrane filter (*12*). Each one-liter sample was mixed on a magnetic stirrer, and a 50-ml sample was passed through a membrane filter. The 50-ml dissolved fraction was immediately acidified with 2.5 ml of trace-metal $HNO_3$. The particulate-bound heavy metal fraction, retained in the membrane filter, was subsequently digested using a microwave-assisted procedure based on SW-846 Method 3015 (*13*). Heavy metal analyses conducted on a Perkin-Elmer Optima 3000 Inductively Coupled Plasma Spectrometer included scans for Cr, Mn, Fe, Ni, Cu, Zn, Cd, and Pb.

In addition to heavy metal analyses, standard water quality measurements were carried out for the purposes of this study. These measurements included pH, redox, alkalinity and various suspended solids fractions including total and volatile suspended, and total and volatile dissolved solids (TSS, VSS, TDS, VDS) for all samples. All analyses quality assurance and quality control procedures were employed in the field and laboratory.

**Partitioning and Heavy Metal Mass Indices**

Whether in pavement runoff, urban storm water or any aqueous system, there is a temporal partitioning between heavy metals in solution and solids whether these solids are in suspension (TSS, VSS) or as settleable solids that may be part of a fixed or mobile bed load. This partitioning includes specific mass transfer mechanisms of sorption, ion exchange and surface complexation with both organic and inorganic sites on the solid matter. These partitioning reactions are generally non-linearly reversible between the solid-phase and soluble phase concentrations. Total concentration of a heavy metal is therefore the sum of the dissolved ($c_d$) and the particulate-bound concentrations ($c_p$) where:

$$c_T = c_d + c_p \quad (4)$$

Operationally, the soluble or dissolved fraction is that fraction that passes the 0.45-micrometer membrane filter and therefore contains both the dissolved and part of the colloidal-bound heavy metals. The solid phase concentration, $c_p$ is defined as the product of the heavy metal concentration on the solid phase, $c_s$ in terms of mass/mass of solids and the concentration of the adsorbing solid material in the aqueous system, m typically measured as either TS or TSS in terms of mass/volume of aqueous solution:

$$c_p = (c_s)(m) \quad (5)$$

When the rate of sorption and de-sorption are equal, concentration equilibrium exists between the dissolved and solid-phase concentrations of a heavy metal. The ratio of these phases is referred to as the partitioning coefficient, $K_d$ for a particular heavy metal at a particular pH and redox level:

$$K_d = c_p/c_d \quad (6)$$

Substitution of equation (5) and (6) into equation (4) yields the dissolved fraction ($f_d$) and the particulate-bound fraction ($f_p$) is defined as:

$$f_d = D/(D+P) = c_d/c_T = 1/[1+K_d(m)] \quad (7)$$

$$f_p = P/(D+P) = c_p/c_T = [(K_d)(m)]/[1+K_d(m)] \quad (8)$$

where, D is the dissolved mass of a heavy metal (mg) and P is the particulate-bound mass of a heavy metal (mg). For $f_d > 0.5$, the heavy metal mass is mainly in dissolved form. The product of $(K_d)(m)$ is dimensionless and $K_d$ is usually expressed as liters per kilogram (L/kg). The larger the $K_d$ value the greater the partitioning of a heavy metal to the solid phase. Heavy metals in pavement runoff have $K_d$ values that range from $10^1$ to $10^5$ in rainfall runoff. The greater the dissolved fraction, or the more soluble the heavy metal, the lower the $K_d$ value. Because of much longer residence times in the presence of highway solids, the dissolved fractions of heavy metals can be very low (*6*). In comparison, $K_d$ values for snowmelt are typically in the range of $10^3$ to $10^6$.

For each discrete sample obtained, dissolved and particulate heavy metal concentrations were obtained after sample preparation and digestion through Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES) analysis. Each respective sample concentration ($c_i$) (dissolved or particulate) was multiplied by the $q_{sf}$ volume ($v_i$) representative of the discrete time increment to determine heavy metal or solids mass ($m_i$) as shown in equation 9.

$$m_i = (c_i)(v_i) \quad (9)$$

To evaluate the study objectives, these data ($m_i$) were evaluated for both dissolved fraction and for Kd for Zn, Cd, Cu and Pb as a function of time for each event.

## RESULTS

### Alkalinity and pH

While pH is a measured water quality parameter that is readily measured, understood and documented by many researchers examining highway runoff with an interest in heavy metals, alkalinity can also be an important parameter with respect to partitioning, speciation and toxicity of heavy metals, albeit a parameter that is not as easily measured and less documented than pH. Higher alkalinities drive heavy metal partitioning towards the particulate-bound phase, reduce the ionic concentration of a heavy metal species and in addition to providing buffering capacity for pH also provides protection for aquatic species against toxic effects of dissolved heavy metals. Alkalinities above 200-mg/L as $CaCO_3$ provide sufficient protection for most fresh and salt-water fish (*14*). There are many situations where highway right-of-ways are in direct hydrologic communication with receiving waters, such as along waterways or for elevated roadway infrastructure over shallow receiving waters such as estuaries, bayous, shallow lakes, reservoirs or source waters for drinking water supply. Figure 3 presents both alkalinity and pH trends for each rainfall runoff event.

Despite wide variability in event hydrology, pavement sheet flow alkalinity at the edge of the paved shoulder stabilized at or below 50-mg/L relatively rapidly within the initial third of the event runoff duration for most events. Although pH results were somewhat more variable, pH values stayed within a range of 6.5 to less than 8 for most of the storm event and were relatively stable during the latter half of each event.

**Pavement Hydrographs and Delivery of Suspended Solids**

Using the format of Figure 3, the delivery of suspended solids as the ratio of TSS/VSS is plotted in Figure 4 along with the pavement hydrograph, $q_{sf}$ as measured at the edge of the paved shoulder. Results clearly indicate that TSS dominates VSS and in particular this ratio increases as a function of flow indicating the increased mobility of the denser inorganic fraction as a response to increased flow. Results demonstrate that the mass delivery of suspended material is driven by flow as have been reported elsewhere for this site (*7*). The entrainment and delivery of suspended solids concentration, as well as total mass fractions shown in Table 1, have an impact on heavy metal partitioning as will be discussed shortly. In addition, pavement hydrographs rapidly respond to variations in rainfall intensity with little intervening lag time. This can be discerned from the APRT (average pavement residence time) values for $q_{sf}$ tabulated in Table 2 for each event.

**Dissolved Mass Fraction of Pb, Cu, Cd and Zn**

For each event, the variation in the dissolved mass fraction for Pb, Cu, Cd and Zn are plotted as a function of elapsed time in Figure 5. These results indicate that the dissolved mass dominates the particulate-bound mass at the edge of the highway shoulder even for relatively insoluble heavy metals such as Pb. While the signature of the hydrograph can be clearly discerned in the dissolved heavy metal mass results, it is somewhat less pronounced than the delivery signature for the suspended solids. The major peaks of the hydrograph generally correspond to decreases in the dissolved heavy metal mass fraction as a result of partitioning to increased entrained solids mobilized by the higher flow.

The important point is that the dissolved mass fractions at the edge of the highway shoulder are typically greater than 80% for Zn and Cd, approximately 70% for Cu and approximately 60% for Pb. While the incremental values show some variability, dissolved fractions remain relatively high throughout each event. These results have important implications for design of in-situ treatment BMPs within the highway right-of-way.

**Generation of Storm Water Hardness**

For each event, the variation of hardness is plotted as a function of elapsed time in Figure 6. Hardness is the sum of the calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$) ions. With regard to toxicity, hardness is similar to alkalinity in that the higher the hardness the lesser the toxicity effect for heavy metals discharged to receiving waters (*15*). Since hardness is measured in terms of a concentration, it rapidly diminishes for all events to approximately 50-mg/L with the exception of the 7 July 1996 event where hardness is driven by the event hydrology. Many states, such as Ohio have numerical outside and inside zone mixing criteria for heavy metals, and these criteria are based in part on hardness. To provide a sense for 50-mg/L as $CaCO_3$ hardness levels, the Ohio criteria start at a minimum hardness of 100-mg/L as $CaCO_3$.

**Non-Equilibrium Partitioning – Heavy Metal $K_d$ Values**

Water quality parameters such as alkalinity, pH, suspended solids and hardness play a role in partitioning of heavy metals in highway storm water. While each of these parameters influences partitioning and $K_d$ values, TSS (as a mass concentration) has a direct influence on heavy metal $K_d$ values. Plots of $K_d$ values for Pb, Cu, Cd and Zn as a function of elapsed time are presented in Figure 7. There are a number of important results portrayed in these figures. First, $K_d$ values vary in a discernible trend across several orders of magnitude and sometimes more for many events. Second, an equilibrium $K_d$ condition in the range of $10^4$ to $10^5$ L/kg appears to be approached as elapsed time increases given that all other conditions, such as TSS and flow remain relatively constant. In fact, $K_d$ values in the range of $10^4$ to $10^5$ L/kg are typical for rivers and large lakes where the residence time is in terms of days and conditions such as TSS and flow are constant. Finally, the variations in flow and TSS are mirrored shortly afterwards by resulting changes in $K_d$. This can be clearly discerned for the 18 June 1996 event. Finally, the variation in the relative magnitude of $K_d$ for Zn, Cd, Cu and Pb tends to follow similar trends that can be explained by covalent bonding theory or tendency of the heavy metal to undergo hydrolysis.

## CONCLUSIONS

This study presented heavy metal partitioning results from a series of eight rainfall runoff events over a two-year period loading a 300-$m^2$ instrumented asphalt pavement drainage area located on inter state 75 in urban Cincinnati. This study excluded snowmelt, which is addressed in a separate study. With respect to in-situ treatment for heavy metals at or near the edge of the highway pavement, a number of conclusions are important to State DOTs. As a result of recent regulations, State DOTs are increasingly focusing their resources to addressing challenging and expensive issues of in-situ treatment. The goal of this study was to demonstrate that heavy metals in pavement storm runoff could be predominately dissolved. Any treatment or BMP loaded by pavement sheet flow must be designed to provide the appropriate removal mechanisms for dissolved metals. Effective treatment will require a mechanism to either sorb heavy metals onto engineered sorptive filter media or onto entrained particulate matter that can subsequently be removed through liquid/solid separation processes such as filtration or sedimentation.

Water quality characteristics such as low alkalinity, low hardness and short pavement residence times for heavy metals entrained with pavement runoff TSS results in a majority of the heavy metal mass remaining in solution at the edge of the pavement. This high degree of dissolved heavy metal mass occurs despite pH values at the edge of the shoulder that range from 6.5 to 8. These same water quality issues present toxicity concerns for highway conditions where there are direct discharges to receiving waters that also have poor buffering capacity. One common example is elevated roadway infrastructure over shallow and limited volume receiving water that has a poor buffering capacity. This highway runoff chemistry, results in heavy metal $K_d$ values that can vary by several orders of magnitude or more across a storm event. These $K_d$, for all heavy metals, only approach equilibrium partitioning conditions towards the end of each event. This can be seen for relatively lengthy 17 October 1996 event (Figure 7).

## IMPLICATIONS FOR BMP DESIGN

The conclusions identify important water quality and hydrologic highway runoff parameters that have significant implications for non-equilibrium heavy metal partitioning and also toxicity. These parameters have a direct influence on the treatment selection of in-situ treatment design for BMPs. Each of the results reported have an important effect on initial selection and then on the details of treatment design for the selected in-situ BMPs.

Unlike the treatment of wastewater or source water for drinking water, storm water runoff at the edge of the pavement has not reached equilibrium conditions. A pavement storm water residence time of 15 minutes or less provides an indication of this when compared to a wastewater delivery residence time in term of hours to days and source waters with significantly longer residence times. As shown in Figure 7, as a result of low residence times and dynamic water chemistry, parameters such as $K_d$ can vary by orders of magnitude in less than an hour. High intensity runoff events such as 18 June 1996 and 7 July 1996 provide a clear indication of this. For these events, partitioning rate coefficients are large for all heavy metals.

There are two primary implications when considering the application of typical BMPs in the highway right-of-way, such as those shown in Figure 8, that are loaded by direct runoff from the edge of the paved shoulder. The first implication is to utilize a BMP, such as a detention basin or roadside swale as shown in parts b and c, to detain runoff and produce sufficient residence time so that heavy metal partitioning to the entrained solids fraction occurs. This requires the proper chemistry and mixing. Alkalinity and pH values must increase above runoff levels, which can occur where there are situations of overland flow, $q_{of}$. There must be sufficient suspension of entrained solids initially, to which the heavy metals will partition, while still settling within the BMP during the detention time. The benthic zone must remain sufficiently aerobic in order that the heavy metals partition to settled solids and therefore not released back into the water column. Such BMPs require land area, a valuable commodity within the highway right-of-way. In addition, while many DOTs utilize basins at selected sites within the right-of-way, there are issues of sufficient drainage relief and safety that must be addressed for each application which may preclude their use despite favorable water chemistry conditions. While maintenance and disposal issues are in terms of years, State DOT must deal with these real issues.

The second implication is to utilize a BMP, such as an engineered infiltration trench as shown in part d of Figure 8, designed to provide surface complexation mechanisms for the dissolved fraction and filtration mechanisms for the particulate bound fraction of a heavy metal. There are a number of variations for infiltration trench design, including designs that also function as an underdrain, intercepting subgrade interflow, $q_i$ as well as lateral pavement sheet flow, $q_{sf}$. These designs are loaded by lateral sheet flow, not concentrated flow, directly off the edge of the paved shoulder. The engineered media is designed to provide an ion exchange or adsorption mechanism for removal of dissolved heavy metals while at the same time functioning as a filter media for separation of incoming particulate material. While efficiencies can be high, greater than 90%, such efficiency comes with costs associated with BMP maintenance to prevent issues such as clogging and the eventual recovery/disposal of trapped heavy metals and solids.

There are no simple solutions for the removal of a heavy metal or particle once released in the highway environment, and there are BMPs that can be misapplied for the intended purpose, unfortunately at a significant cost. BMPs for heavy metals and solids are essentially garbage cans and as such must be emptied and cleaned occasionally. The purpose of design is to provide effective capture, reasonable time between disposal and an optimal cost between treatment alternatives.

**ACKNOWLEDGMENTS**

The authors acknowledge the support and research funding from the Ohio Department of Transportation (ODOT), through grant No. 8773 as well as the insights of Dr. Steven Buchberger. ICP-AES support and access was provided by Ms. Linda Rieser. Field sampling, laboratory analysis and data QA/QC were provided by Mr. Joseph Koran, Mr. Joseph Smithson, Mr. Scott Schulte and Ms. Janet Anno. The Hamilton County section of ODOT - District 8 provided crack and joint sealing traffic control.

**REFERENCES**

1. Hamilton, R.S., and R.M. Harrison. *Highway Pollution*. Elsevier Science Publishing Company Inc., New York, 1991, pp. 350.

2. Armstrong, L.J. *Contribution of Heavy Metals to Storm Water from Automotive Disc Brake Pad Wear*. Report for Santa Clara Valley Nonpoint Source Pollution Control Program, Woodward-Clyde Consultants, 1994, pp. 1-37.

3. Ball, D., Hamilton, R., and R. Harrison. *The Influence of Highway-Related Pollutants on Environmental Quality*. R. Hamilton and R. Harrison, eds., Highway Pollution, Elsevier Science Publishing Company, Inc., New York, NY., 1991, pp. 1-47.

4. Lygren, E., Gjessing, E., and L. Berglind. Pollution Transport from a Highway. *The Science of the Total Environment*, Vol. 33, 1984, pp. 147-159.

5. Muschack, W. Pollution of Street Run-Off by Traffic and Local Conditions. *The Science of the Total Environment*, Vol. 93, 1990, pp. 419-431.

6. Sansalone, J.J., and S.G. Buchberger. Partitioning and First Flush of Metals and Solids in Urban Highway Runoff. *J. Envir. Engrg. Div.* ASCE, Vol. 123, No. 2, 1997, pp. 134-143.

7. Sansalone, J.J., Koran, J.M., Smithson, J.A., and S.G. Buchberger. Physical Characteristics of Urban Roadway Solids Transported during Rain Events. *Journal of Environmental Engineering*, ASCE, Vol. 124, No. 5, 1998, pp. 427-440.

8. Klein, L.A., Lang, M., Nash, N., and S.L. Kirschner. Sources of metals in New York City wastewater. *J. Water Pollution Control Federation*, Vol. 46, No. 12, 1974, pp. 2653-2662.

9. McBride, M. *Environmental Chemistry of Soils*. Oxford University Press, New York, 1994, pp. 406.

10. Morrison, G., Revitt, D., Ellis, J., Svensson, G., and P. Balmer. Variation of Dissolved and Suspended Solid Heavy Metals Through an Urban Hydrograph. *Environmental Technology Letters*, Vol. 7, 1984, pp. 313-318.

11. Harrison, R., and S. Wilson. The Chemical Composition of Highway Drainage Waters I. Major Ions and Selected Metals. *Science of the Total Environment*, Vol. 43, 1985, pp. 63-77.

12. American Public Health Association. *Standard Methods for Water and Wastewater,* 18th edition. A. Greenberg, L. Clesceri, and A. Eaton, eds., Washington, D.C., 1992, pp. 823.

13. USEPA. *Test Methods for Evaluating Solid Waste.* Physical/Chemical Methods, SW 846, 3rd edition, final update, Washington, D.C., 1990, pp. 312.

14. Loyless, J.C., and R.F. Malone. A sodium bicarbonate dosing methodology for pH management in freshwater-recirculating aquaculture systems. *The Progressive Fish-Culturist*, Vol. 59, 1997, pp. 198-205.

15. Cusimano, R.F., Brakke, D.F., and G.A. Chapman. Effects of pH on the toxicities of cadmium, copper, and zinc to steelhead trout (*Salmo gairdneri*). *Can. J. Fish. Aquat. Sci.*, Vol. 43, 1986, pp. 1497-1503.

**LIST OF TABLES**



**LIST OF FIGURES**

**TABLE 1 Dissolved and Particulate Solids Mass for Each Event**

| Event Measured | TS Mass (g)[c] | TSS Mass (g)[d] | VSS Mass (g)[e] | TDS Mass (g)[f] | VDS Mass (g)[g] |
|---|---|---|---|---|---|
| 21 May 1996 | 52.3 | 17.5 | 4.7 | 34.8 | 16.0 |
| 18 June 1996 | 362.5 | 257.7 | 66.1 | 104.8 | 34.8 |
| 7 July 1996 | 454.9 | 275.6 | 137.7 | 210.5 | 121.6 |
| 8 August 1996 | 804.3 | 637.5 | 147.1 | 166.8 | 148.3 |
| 17 October 1996 | 854.6 | 400.5 | 156.9 | 454.1 | 192.1 |
| 25 November 1996 | 87.2 | 39.7 | 12.6 | 47.5 | 8.4 |
| 16 December 1996 | 97.4 | 37.9 | 12.7 | 59.6 | 11.1 |
| 12 June 1997 | 93.1 | 32.9 | 15.1 | 60.2 | 26.7 |
| All events mean | 350.8 | 212.4 | 69.1 | 142.3 | 69.9 |
| All events median | 230.0 | 148.7 | 40.6 | 82.5 | 30.8 |
| All events SD[a] | 329.4 | 224.4 | 67.6 | 140.4 | 72.7 |
| All events RSD[b] (%) | 93.9 | 105.7 | 97.7 | 98.7 | 104.0 |

[a]standard deviation
[b]relative standard deviation
[c]total solids
[d]total suspended solids
[e]volatile suspended solids
[f]total dissolved solids
[g]volatile dissolved solids

**TABLE 2 Hydrologic Indices and Residence Time Data for Each Event**

| Event Measured | Rainfall Duration (min) | Rain Depth (mm) | Runoff Volume (L) | IPRT (min)[c] | APRT (min)[d] | LEMF (L/min·m)[e] | LPF (L/min·m)[f] |
|---|---|---|---|---|---|---|---|
| 21 May 1996 | 35 | 0.9 | 97 | 4 | 6 | 0.05 | 0.92 |
| 18 June 1996 | 63 | 11.3 | 2779 | 5 | 2 | 2.29 | 16.3 |
| 7 July 1996 | 50 | 40.4 | 9644 | 4 | 2 | 11.08 | 21.50 |
| 8 August 1996 | 51 | 14.1 | 3877 | 7 | 3 | 4.31 | 26.10 |
| 17 October 1996 | 616 | 29.1 | 3693 | 5 | 7 | 0.40 | 2.95 |
| 25 November 1996 | 150 | 3.1 | 216 | 8 | 10 | 0.09 | 0.61 |
| 16 December 1996 | 340 | 3.4 | 268 | 14 | 15 | 0.05 | 0.24 |
| 12 June 1997 | 20 | 2.0 | 464 | 3 | 5 | 0.52 | 5.14 |
| All events mean | 165.6 | 13.0 | 2629.8 | 6.3 | 6.3 | 2.3 | 9.2 |
| All events median | 57.0 | 7.4 | 1621.5 | 5.0 | 5.5 | 0.5 | 4.0 |
| All events SD[a] | 210.0 | 14.5 | 3260.5 | 3.5 | 4.5 | 3.8 | 10.5 |
| All events RSD[b] (%) | 126.8 | 111.2 | 124.0 | 56.6 | 71.4 | 163.2 | 113.4 |

[a]standard deviation
[b]relative standard deviation
[c]initial pavement residence time
[d]average pavement residence time
[e]lateral event mean flow
[f]lateral peak flow

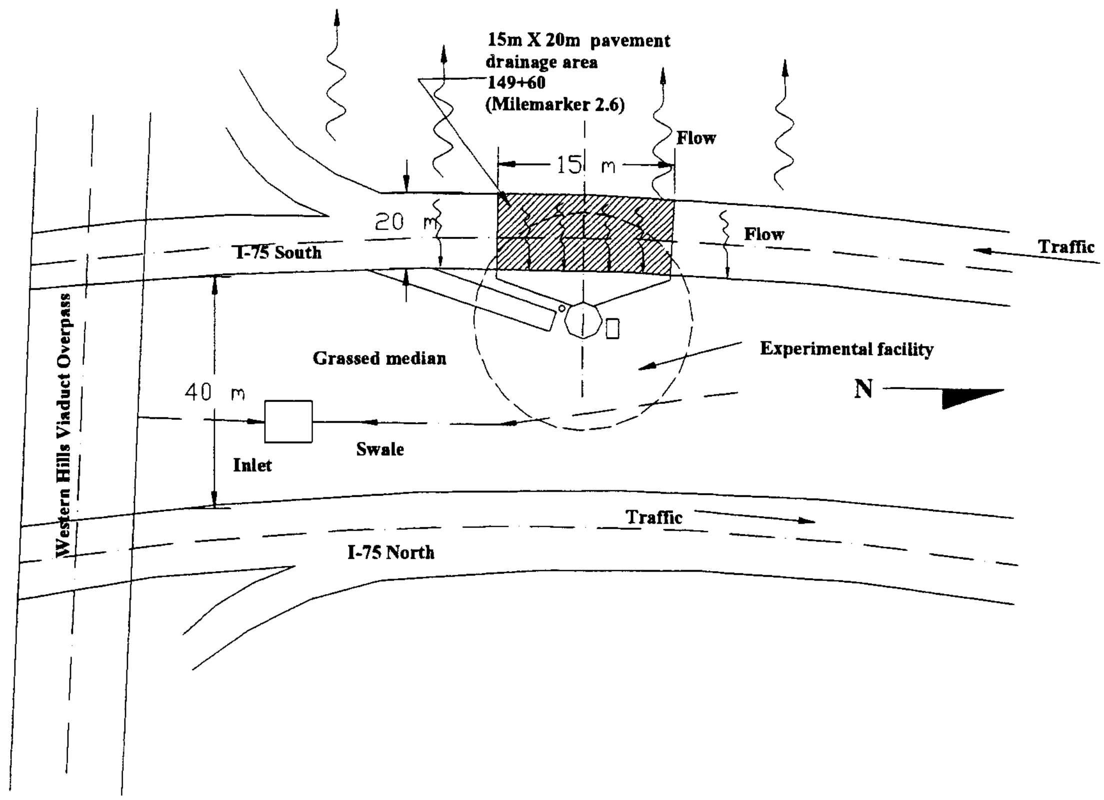



FIGURE 1 Location of site in SW Ohio and in Cincinnati.

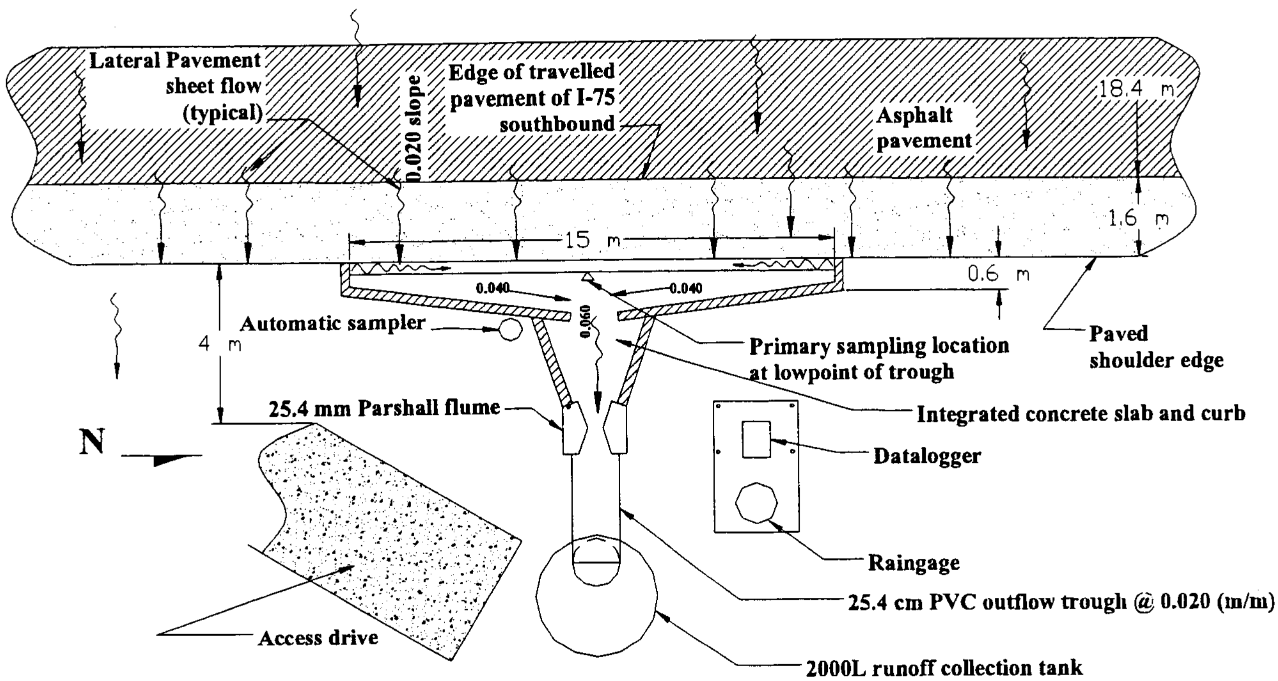



**FIGURE 2 Experimental facility capturing highway shoulder runoff.**

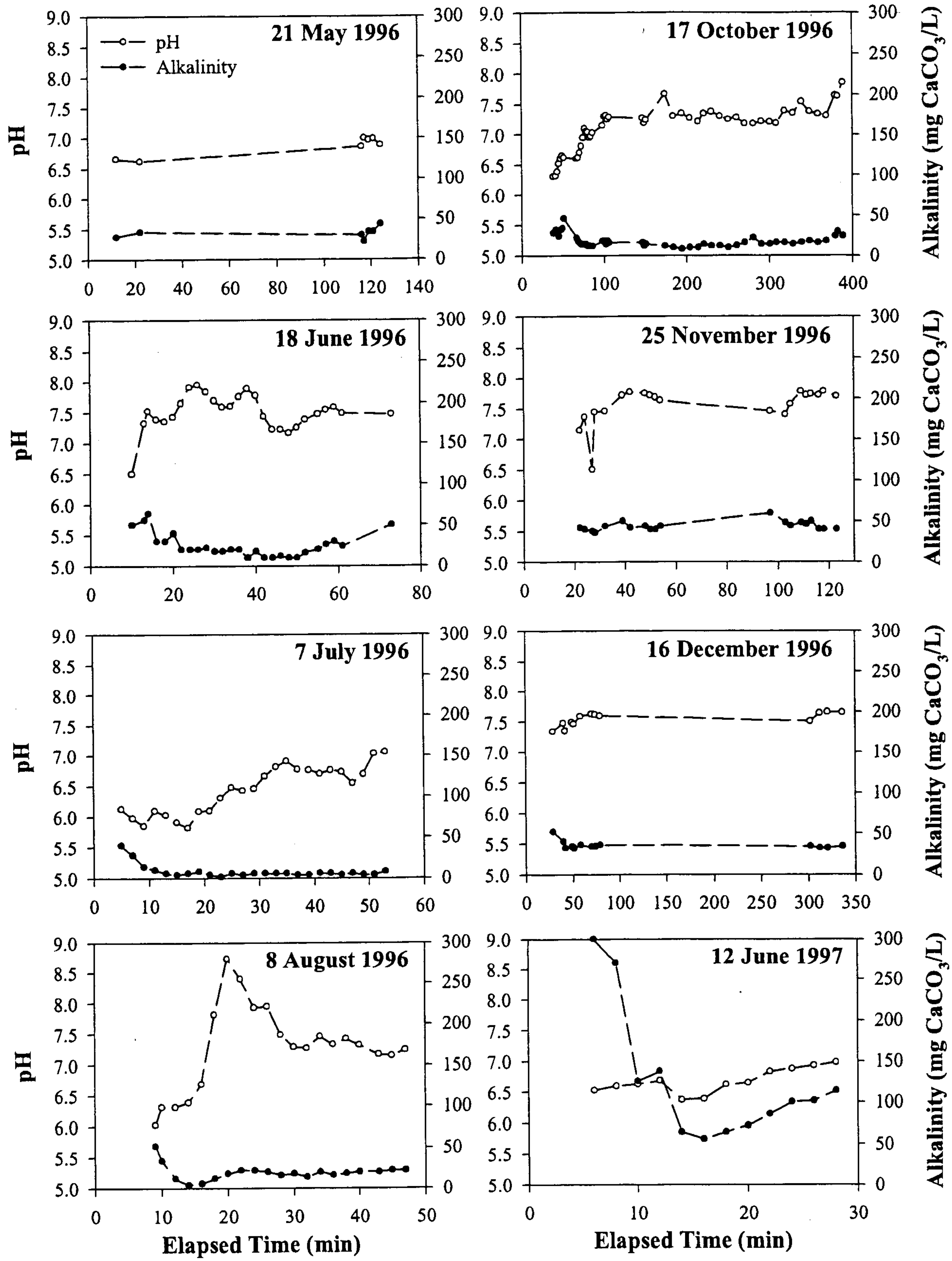



**FIGURE 3 pH and alkalinity for all rainfall events at I-75 site.**

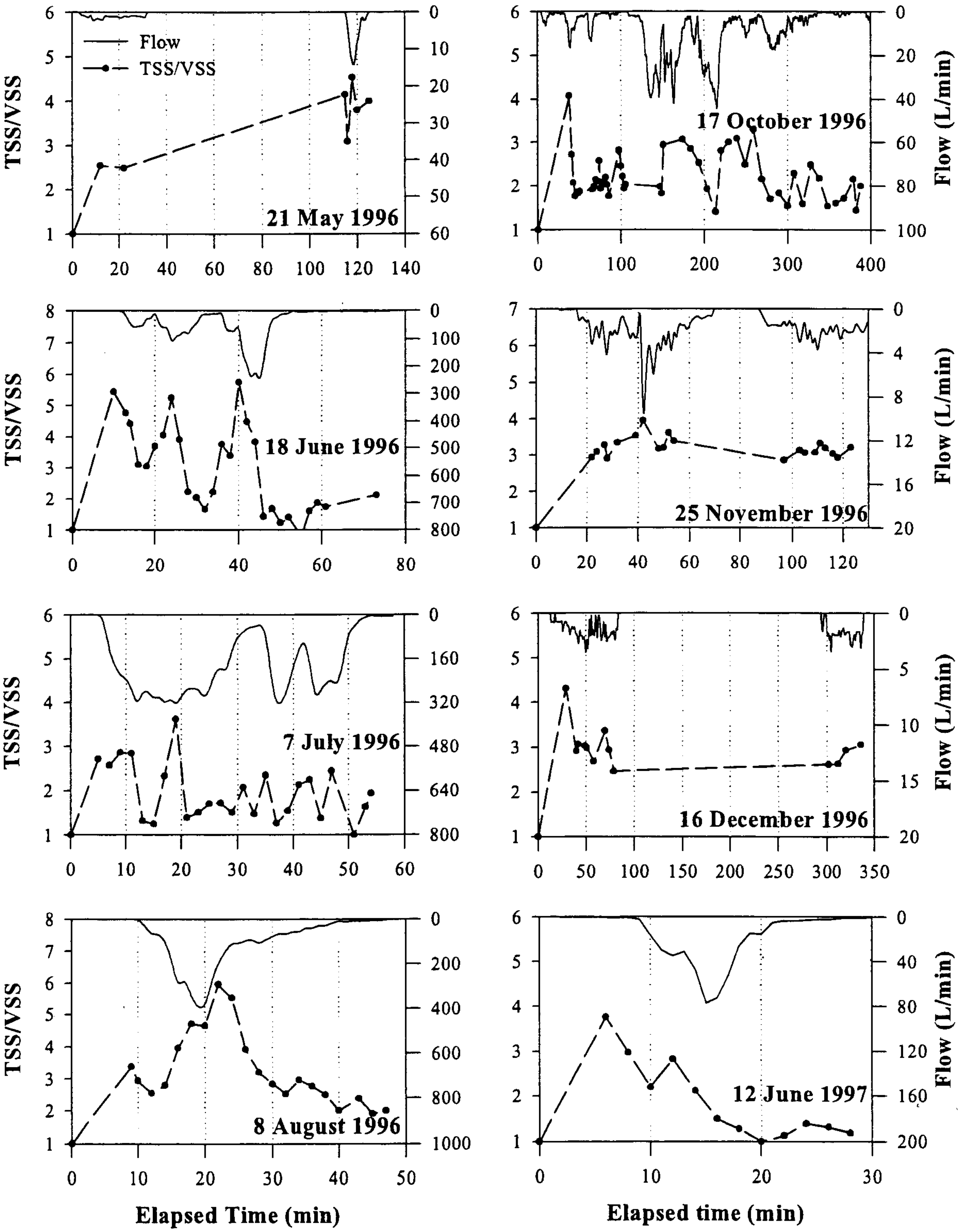



**FIGURE 4 The ratio of TSS/VSS compared to hydrology for each event.**

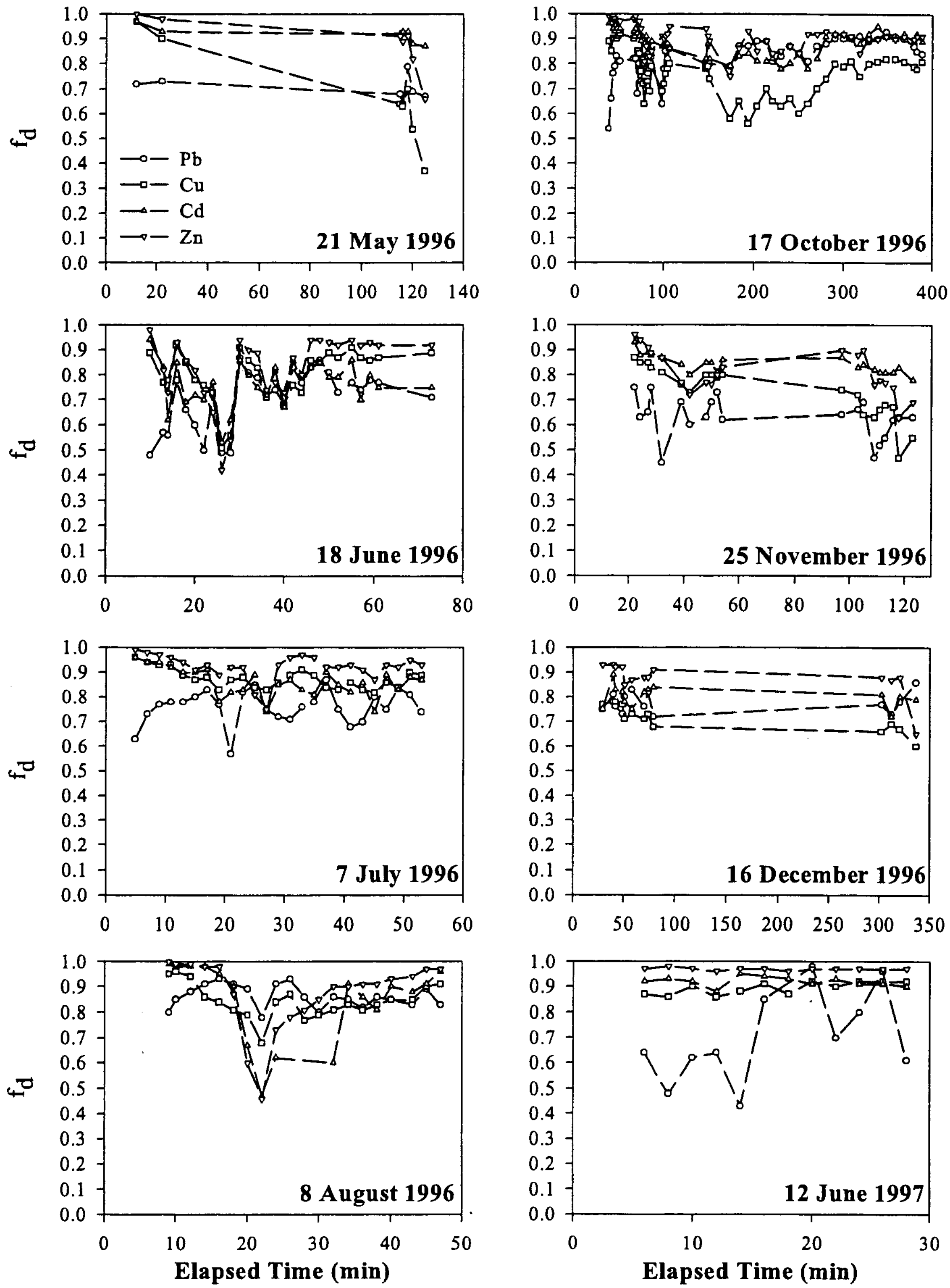



**FIGURE 5 Temporal variations of dissolved fraction ($f_d$) with respect to Pb, Cu, Cd and Zn.**

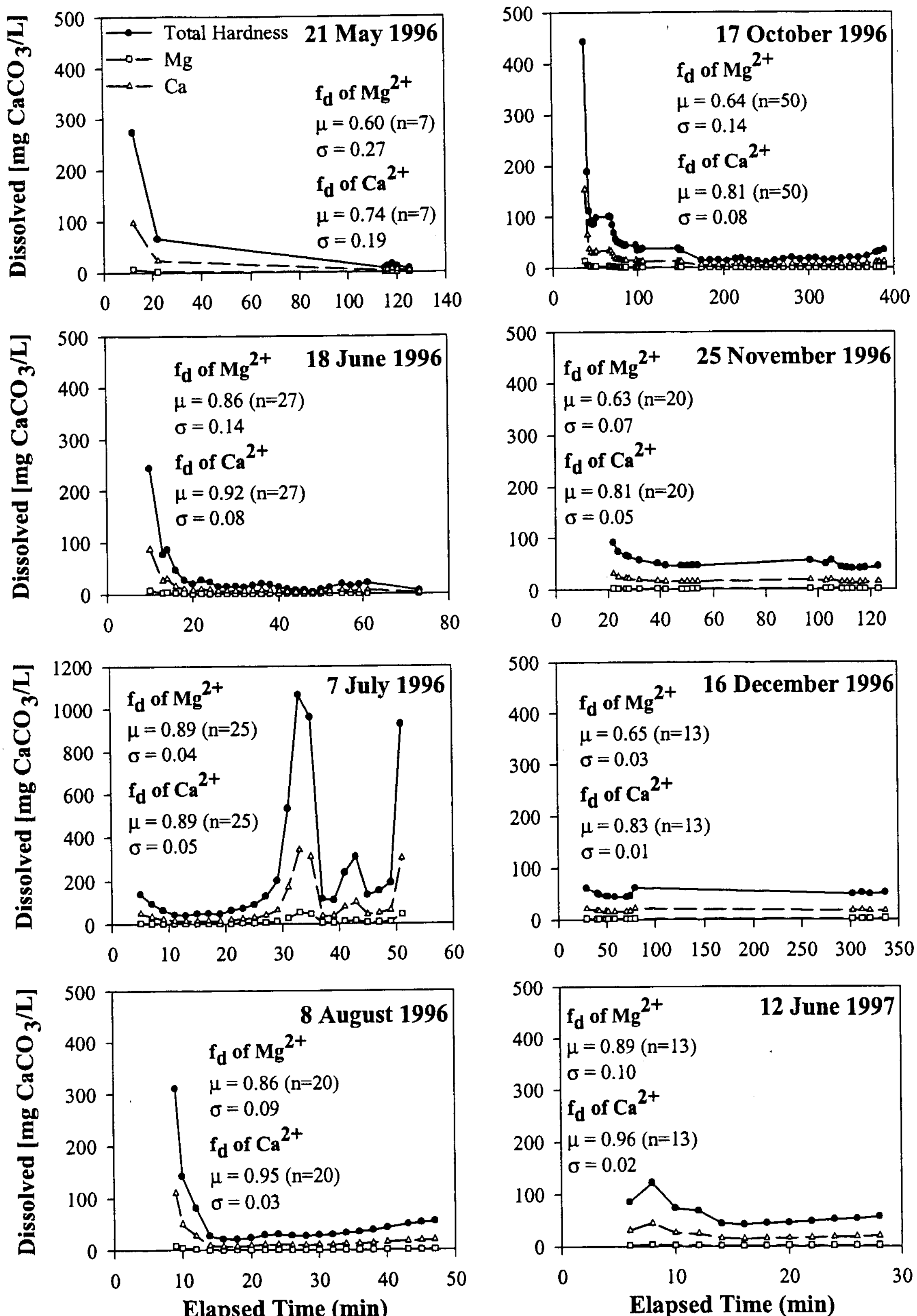



**FIGURE 6 Total hardness (hardness = 2.497[$Ca^{2+}$, mg/L] + 4.118[$Mg^{2+}$, mg/L]) with respect to Mg and Ca for each rainfall event.**

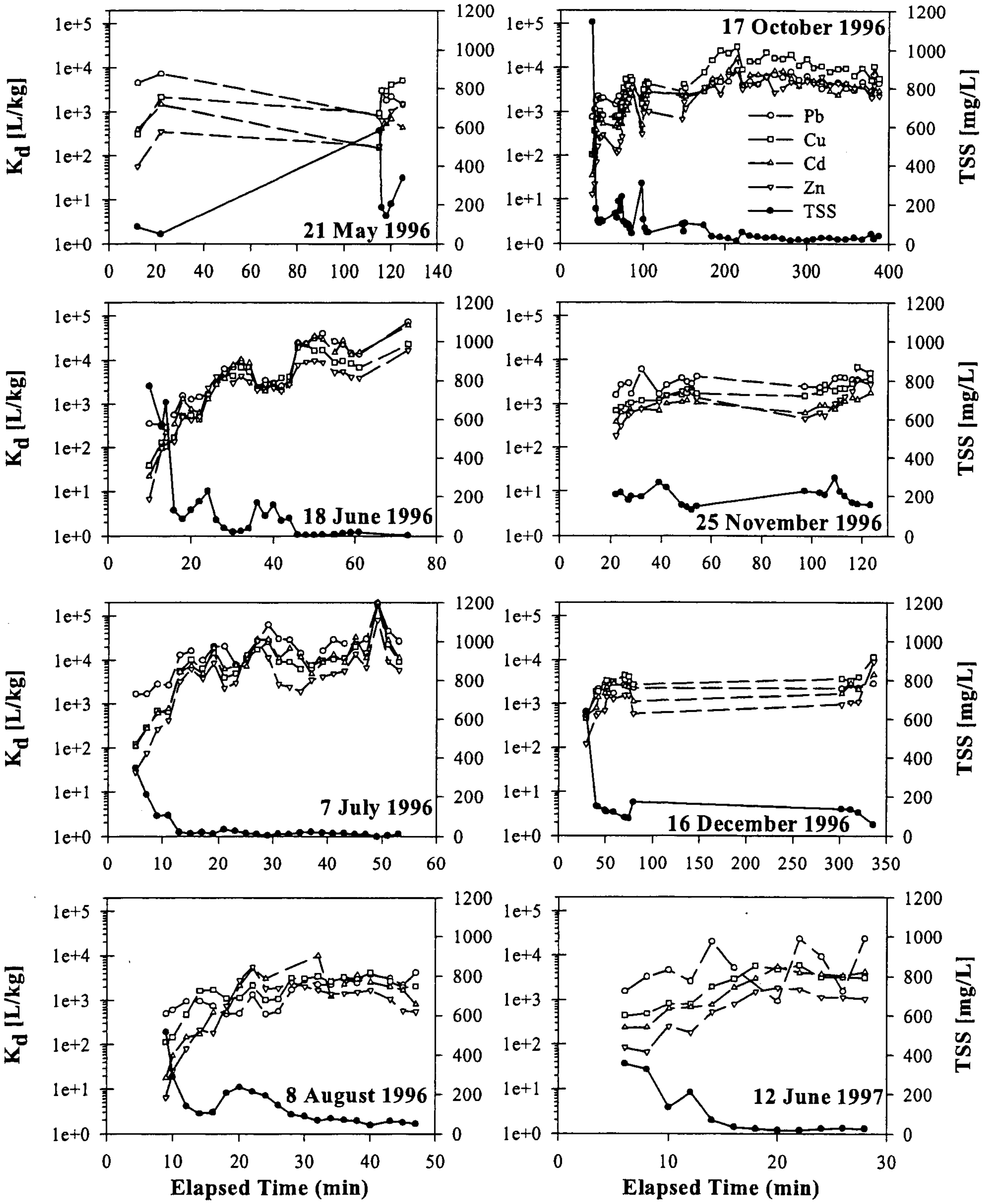
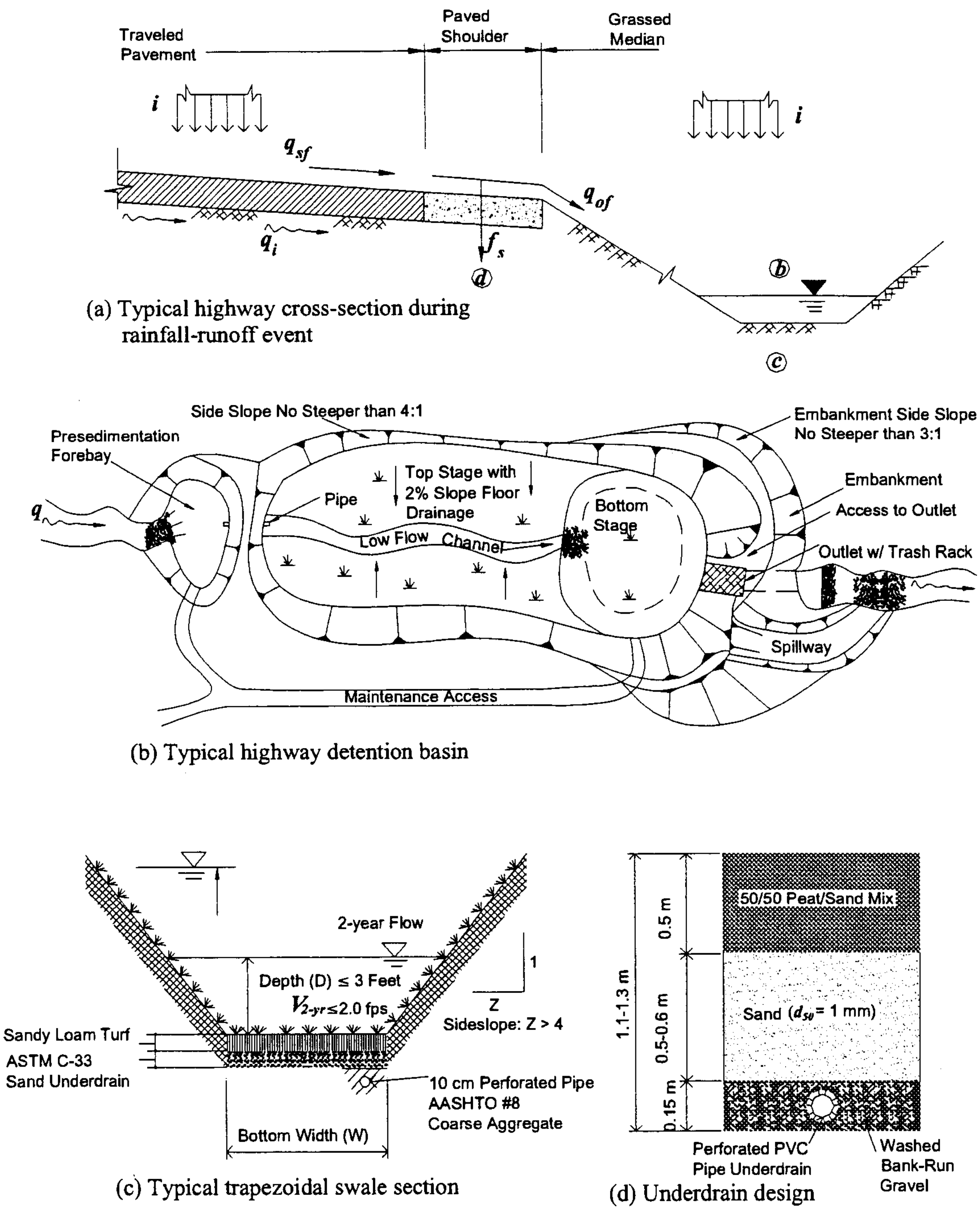



**FIGURE 7 Temporal variations of TSS and $K_d$ values with respect to Pb, Cu, Cd and Zn.**




(a) Typical highway cross-section during rainfall-runoff event

(b) Typical highway detention basin

(c) Typical trapezoidal swale section

(d) Underdrain design

**FIGURE 8 A typical highway shoulder section with several common in-situ treatment (as BMPs) alternatives.**

F

**Water Resources Consulting L.L.C.**
Peter Willing, Ph.D.

March 12, 2001

Mr. Chung Yee
Washington State Department of Ecology
3190 160th Ave. S.E.
Bellevue, Washington 98008-5452

RE: NPDES Permit Major Modification

Dear Mr. Yee,

The following comments on the proposed draft NPDES permit no. WA-002465-1 for SeaTac Airport are submitted to you on behalf of the Airport Communities Coalition. This letter makes two main points:

- The draft permit offers a blank check approval of future discharges at unknown locations. Such a permit would allow the Port to pollute the state's waters with impunity, and would deprive the State and its citizens the vital knowledge of where and how the Port's discharges will affect State waters.
- The reporting requirements of the permit must be revised to require the data needed to interpret dissolved metals concentrations.

The Port of Seattle has requested a permit that allows the discharge of unknown pollutants, in unknown amounts, at unspecified locations, into unspecified receiving waters, at unknown times in the future. This request is obviously desirable for the Port's purposes, but it serves the people of Washington State very badly and must not be granted. It allows the Port to cause harm through pollution to beneficial uses of waters of the State, at any time, in any place where the Port chooses to operate. The modified permit should be specific as to the character of discharged pollutants, the exact locations where discharges will be allowed, and the exact premises which are intended to be covered by the discharge permit modification. The State must not abdicate its access to information, its oversight responsibility, and its citizens' opportunity for informed review of the Port's discharge practices.

Neither the existing permit nor the proposed permit require the permittee to collect or report water quality data that are necessary to ascertain whether a given concentration of metals is in compliance with water quality criteria. Numeric water quality criteria for metal pollutants are a function of hardness (WAC 173-201A-040). Hardness data should be reported on the monthly DMR's (Discharge Monitoring Reports) as follows: 1) they should be based on samples taken concurrently with and from the same source as the metals samples; 2) they should be reported on the same page as the metals concentrations; 3) the meaning of the data should not be obscured by the use of median values or other summary statistics. To bring this result about, the modified permit, Monitoring Requirements, section S2. A, Stormwater, should be amended by insertion of an extra line for hardness in the accompanying table. Note c should be amplified to include point 1) above. Hardness should be analyzed either by calculation based on calcium and magnesium concentrations, or by the EDTA method; the reported results should say which method was used.

1903 Broadway
Bellingham, Washington
[illegible]

Telephone 360-734-1445
FAX: 360-676-1040

The Port of Seattle's Annual Stormwater Monitoring Reports for SeaTac Airport have the same problem as the DMR's. The annual reports are intended to "present the analytical data, the Port's conclusions as to what is being learned from the data, and any new initiatives to be undertaken as part of the Stormwater Pollution Prevention Plan . . ." (Draft Permit, Section S2.E). The most recent Annual Stormwater Monitoring Report for July 1999 through June 2000 defeats this purpose by submerging the airport monitoring data in a sea of irrelevant data from other jurisdictions. It also makes the metals concentrations impossible to interpret by separating them from the hardness data. Instead of showing hardness data that corresponds with the metal sampling sources, it substitutes an across-the-board hardness value of 56 mg/l which purportedly is the median of seven samples collected in 1999 – data for which are not shown. Using median values dilutes the observations downward and dilutes the criterion upward, in both cases hiding water quality violations. 56 mg/l is higher than any hardness values the Port has reported before: the median of 12 values reported in the previous Annual Monitoring Report is 14 mg/l. Under the State Water Quality Standards, if one accepted the 14 mg/l median as valid, all of the five values shown in Appendix B are in violation, by up to 9 times the chronic toxicity standard for copper, and 7 times for lead. The effect of this distorted and selective "cooking" of the data is to make it look as though the metals concentrations comply with the water quality standards, when in fact they constitute a significant contribution to the violation of those standards. This interpretive sleight of hand could be dispensed with if the monitoring requirements were written so as to require straightforward reporting of relevant data.

The proposed NPDES Permit modification requires revision. The Department of Ecology must not issue it until all discharge locations, discharge sources, and receiving waters are identified in the permit, with appropriate opportunity for public comment.

Thank you for considering these comments on the Major Modification of the Port of Seattle's NPDES Permit for SeaTac Airport.

Sincerely,

Peter Willing, Ph.D.

G

SPREADSHEET CREATED BY D. NUNNALLEE, REV 1-92 BY G. SHERVEY
Last revision date 3/00
FACILITY: Hypothetical stream near SeaTac International Airport

FILENAME:
RUN DATE: 2/12/2002
PREPARED BY:

WATER QUALITY CRITERIA (in ug/L unless otherwise noted)

| Pollutant, CAS No. & Application Ref. No. | PRIORITY PLTNT | CARCIN GEN? | Water Quality Criteria Fresh acute | Fresh chronic | Marine acute | Marine chronic | Human Health Criteria Fresh | Marine | Organoleptic Effects | Source and Comments | Metals Translators Freshwater Acute | Freshwater Chronic | Marine Acute | Marine Chronic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COPPER - 744058 6M Hardness dependent | Y | N | 4.44 | 3.35 | 4.80 | 3.10 | | | 1000.00 | WAC 173-201A | 1.000 | 1.000 | 0.83 | 0.83 |
| ZINC- 7440666 13M hardness dependent | Y | N | 34.16 | 31.19 | 90.00 | 81.00 | | | 5000.00 | WAC 173-201A, | 0.993 | 0.993 | 0.946 | 0.946 |

This spreadsheet is split so that you can copy substances of interest into the top portion of the spreadsheet and obtain a printout of just the pollutants of interest. Updated the formulas and values to match with WAC 173-201A in December of 1992. Enter the hardness value for the receiving water for hardness dependent metals in B200 and TSS values in B199.
Spreadsheet updated with human health criteria by Gary Bailey in March 1995 and checked by G. Shervey
Metal criteria changed to those announced in FR Vol. 60 No.86 5/4/95 (10/95)
Metal translators added 6/96 (based on work by Pelletier and FR Vol 60, No.86 5/4/95)

WATER QUALITY CRITERIA (in ug/L unless otherwise noted)

| Pollutant, CAS No. & Application Ref. No. | PRIORITY PLTNT | CARCIN GEN? | Water Quality Criteria Fresh acute | Fresh chronic | Marine acute | Marine chronic | Human Health Criteria Fresh | Marine | Organoleptic Effects | Source and Comments | Metals Translators Freshwater Acute | Freshwater Chronic | Marine Acute | Marine Chronic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENTER RECEIVING WATER TSS (IF UNKNOWN LEAVE BLANK) > | 5 | | | | | | | | | | | | | |
| NUAL DATA INSERT A, OR IF FROM CRITICAL PERIOD INSERT S> | S | | | | | | | | | | | | | |
| ENTER HARDNESS>>>>>>>>> | 24 | | | | | | | | | | | | | |

SPREADSHEET CREATED BY D. NUNNALLEE, REV. 1-92 BY G. SHERVEY
Last revision date 3/00
FACILITY: Hypothetical stream near SeaTac International Airport

FILENAME: tsdcalc9.xlw
RUN DATE: 2/12/2002
PREPARED BY: P. Willing

WATER QUALITY CRITERIA (in ug/L unless otherwise noted)

| Pollutant, CAS No. & Application Ref. No. | PRIORITY PLTNT | CARCIN GEN? | Water Quality Criteria Fresh acute | Fresh chronic | Marine acute | Marine chronic | Human Health Criteria Fresh | Marine | Organoleptic Effects | Source and Comments | Metals Translators Freshwater Acute | Freshwater Chronic | Marine Acute | Marine Chronic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COPPER - 744058 6M Hardness dependent | Y | N | 9.85 | 6.92 | 4.80 | 3.10 | | | 1000.00 | WAC 173-201A | 1.000 | 1.000 | 0.83 | 0.83 |
| ZINC- 7440666 13M hardness dependent | Y | N | 70.02 | 63.94 | 90.00 | 81.00 | | | 5000.00 | WAC 173-201A, | 0.993 | 0.993 | 0.946 | 0.946 |

This spreadsheet is split so that you can copy substances of interest into the top portion of the spreadsheet and obtain a printout of just the pollutants of interest. Updated the formulas and values to match with WAC 173-201A in December of 1992. Enter the hardness value for the receiving water for hardness dependent metals in B200 and TSS values in B199.
Spreadsheet updated with human health criteria by Gary Bailey in March 1995 and checked by G. Shervey
Metal criteria changed to those announced in FR Vol. 60 No.86 5/4/95 (10/95)
Metal translators added 6/96 (based on work by Pelletier and FR Vol 60, No.86 5/4/95)

WATER QUALITY CRITERIA (in ug/L unless otherwise noted)

| Pollutant, CAS No. & Application Ref. No. | PRIORITY PLTNT | CARCIN GEN? | Water Quality Criteria Fresh acute | Fresh chronic | Marine acute | Marine chronic | Human Health Criteria Fresh | Marine | Organoleptic Effects | Source and Comments | Metals Translators Freshwater Acute | Freshwater Chronic | Marine Acute | Marine Chronic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENTER RECEIVING WATER TSS (IF UNKNOWN LEAVE BLANK) > | 5 | | | | | | | | | | | | | |
| NUAL DATA INSERT A, OR IF FROM CRITICAL PERIOD INSERT S> | S | | | | | | | | | | | | | |
| ENTER HARDNESS>>>>>>>>> | 56 | | | | | | | | | | | | | |

AR 015214

Stormwater Quality Data from SeaTac Airport

| Sample Date1 | Outfall1 | Hardness 2 | FW Acute WQS for Copper 3, 4 | TR Copper Sampled 2, 4 | Sample as multiple of Acute WQS | Dissolved assuming p.c = .75 | Diss Frac as multiple of Acute WQS |
|---|---|---|---|---|---|---|---|
| 11/19/98 | SDE4 | 16 | 3.0 | 32 | 11 | 24 | 8 |
| 01/20/99 | SDE4 | 14.5 | 2.8 | 22 | 8 | 16.5 | 6 |
| 02/22/99 | SDE4 | 10 | 1.9 | 15 | 8 | 11.25 | 6 |
| 03/24/99 | SDE4 | 10 | 1.9 | 20 | 10 | 15 | 8 |
| 07/02/99 | SDE4 | 14 | 2.7 | 26 | 10 | 19.5 | 7 |
| 11/13/98 | SDS3 | 24 | 4.4 | 22 | 5 | 16.5 | 4 |
| 01/13/99 | SDS3 | 20 | 3.7 | 23 | 6 | 17.25 | 5 |
| 11/11/98 | SDN1 | 16 | 3.0 | 24 | 8 | 18 | 6 |
| 01/13/99 | SDN1 | 8 | 1.6 | 24 | 15 | 18 | 11 |
| 03/24/99 | SDN1 | 16 | 3.0 | 15 | 5 | 11.25 | 4 |
| 05/11/99 | SDN1 | 14.2 | 2.7 | 46 | 17 | 34.5 | 13 |
| 07/02/99 | SDN1 | 10 | 1.9 | 38 | 20 | 28.5 | 15 |
| 11/13/98 | SDN4 | 24 | 4.4 | 25 | 6 | 18.75 | 4 |
| 01/13/99 | SDN4 | 28 | 5.1 | 20 | 4 | 15 | 3 |

1. Some of these data reported in 2000 Annual Monitoring Report
2. From 1999 Annual Stormwater Monitoring Report, Appendix D p. 109
3. Calculated in accordance with WAC 173-201A-040.
4. Values stated in micrograms per liter.

p.c. = partitioning coefficient

# Annual Stormwater Monitoring Report

for

## Seattle-Tacoma International Airport

*for the period July 1, 1998 through June 30, 1999*

*Port of Seattle*

**September 1999**

## 1998-99 WET Testing Sample Data

| SDE4 | sample | storm characteristics | | | | | | | concentration, mg/l | | | | | | | | | | | | | | | WET, % survival | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | type | depth rep | rain | dur | maxint | 48hr ai | dryant | pH | TSS | Turb | BOD | NH3 | Surf | glycols | TRCu | TRPb | TRZn | Dcu | DPb | DZn | Hard | cond | avg rank | daphnid | fathead | Comment |
| 11/19/98 | SMC | 0.40 | 2.34 | 66 | 0 | 0 | 73 | 8.1 | 66 | 52 | 6.8 | 0.5 | n/a | 2 | 0.032 | 0.0314 | 0.163 | | not analyzed | | 16 | 37 | | 90 | 100 | |
| % rank | | | | | | | | | 82% | 88% | 54% | | | | 64% | 81% | 58% | | | | | | 71% | | | |
| 1/20/99 | EMC | 0.35 | 0.42 | 28 | 0 | 0.95 | 22 | 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* | 1 |
| % rank | | | | | | | | | 98% | 88% | 41% | | | | 35% | 28% | 61% | 0.25 | 0.08 | 0.07 | | | 58% | | | |
| 2/22/99 | EMC | 0.55 | 0.56 | 34 | 0 | 0.04 | 9 | 7.2 | 53 | 44 | 2 | 0.5 | n/a | 2 | 0.015 | 0.022 | 0.108 | 0.004 | 0.001 | 0.042 | 10 | 36 | | 95 | 63 | |
| % rank | | | | | | | | | 60% | 81% | 0% | | | | 19% | 52% | 22% | 0.29 | 0.05 | 0.39 | | | 39% | | | |
| 3/24/99 | EMC | 0.28 | 0.28 | 19 | 0 | 0.15 | 40 | 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% | | | | | | 43% | | | |
| 7/2/99 | EMC | 0.27 | 0.30 | 6 | 0 | 0 | 103 | 6.2 | 45 | 39 | 6.8 | 1 | n/a | n/a | 0.028 | 0.013 | 0.141 | | not analyzed | | 14 | 41 | | 100 | 70* | 2 |
| % rank | | | | | | | | | 46% | 76% | 55% | | | | 47% | 29% | 46% | | | | | | 50% | | | |
| | average | | | | | | average result | 7.1 | 59 | 44 | 5 | 0.5 | 0.2 | 2 | 0.023 | 0.019 | 0.143 | 0.005 | 0.001 | 0.027 | 13 | 36 | | 96 | 87 | |
| | | | | | | | average % rank | | 63% | 81% | 39% | | | | 38% | 46% | 46% | | | | | | 52% | | | |
| | | | | | | | count | | 29 | 28 | 32 | | | 31 | 32 | 33 | 32 | | | | | | | | | |
| | | | SDE4 | | Historical data (7/94-6/99) | | max | | 131 | 57 | 29 | | | 49 | 0.078 | 0.076 | 0.337 | | | | | | | | | |
| | | | | | | | min | | 8.8 | 1.5 | 2.0 | | | 2.0 | 0.003 | 0.001 | 0.003 | | | | | | | | | |
| | | | | | | | median | | 49 | 27 | 6.4 | | | 2.0 | 0.028 | 0.021 | 0.150 | | | | | | | | | |

| SDS3 | sample | storm characteristics | | | | | | | concentration, mg/l | | | | | | | | | | | | | | | WET, % survival | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | type | depth rep | rain | dur | maxint | 48hr ai | dryant | pH | TSS | Turb | BOD | NH3 | Surf | glycols | TRCu | TRPb | TRZn | Dcu | DPb | DZn | Hard | cond | avg rank | daphnid | fathead | Comment |
| 11/13/98 | SMC | 0.52 | 0.98 | 62 | 0.15 | 0.05 | 31 | 7.5 | 24 | 29 | 17.6 | 0.5 | n/a | 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% | 0.61 | 0.25 | 0.20 | | | 79% | | | |
| 1/13/99 | EMC | 0.85 | 1.07 | 22 | 0.16 | 0 | 85 | 6.8 | 22 | 16 | 7.8 | 0.5 | n/a | 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% | 0.55 | 0.26 | 0.40 | | | 58% | | | |
| | average | | | | | | average | 7.1 | 23 | 23 | 13 | 0.5 | | 11 | 0.023 | 0.004 | 0.110 | 0.013 | 0.001 | 0.025 | 22 | 61 | | 85 | 97 | |
| | | | | | | | count | | 33 | 33 | 36 | | | 25 | 37 | 39 | 37 | | | | | | | | | |
| | | | SDS3 | | Historical data (7/94-6/99) | | max | | 33 | 42 | 38 | | | 32 | 0.087 | 0.016 | 0.134 | | | | | | | | | |
| | | | | | | | min | | 1 | 1 | 2 | | | 2 | 0.004 | 0.001 | 0.003 | | | | | | | | | |
| | | | | | | | median | | 7 | 6 | 8 | | | 5 | 0.032 | 0.002 | 0.045 | | | | | | | | | |

| SDN1 | sample | storm characteristics | | | | | | | concentration, mg/l | | | | | | | | | | | | | | | WET, % survival | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | type | depth rep | rain | dur | maxint | 48hr ai | dryant | pH | TSS | Turb | BOD | NH3 | Surf | glycols | TRCu | TRPb | TRZn | Dcu | DPb | DZn | Hard | cond | avg rank | daphnid | fathead | Comment |
| 11/13/98 | EMC | 0.81 | 0.98 | 62 | 0.15 | 0.05 | 31 | 8.0 | 53 | 46 | 2 | 0.5 | n/a | n/a | 0.024 | 0.0253 | 0.487 | 0.006 | 0.001 | 0.110 | 16 | 20 | | 80 | 40 | |
| % rank | | | | | | | | | 63% | 100% | 0% | | | | 87% | 79% | 94% | 0.23 | 0.04 | 0.23 | | | 67% | | | |
| 1/13/99 | EMC | 0.85 | 1.07 | 22 | 0.16 | 0 | 85 | 7.0 | 78 | 31 | 2 | 0.5 | n/a | n/a | 0.024 | 0.048 | 0.182 | 0.005 | 0.001 | 0.033 | 8 | 22 | | 30 | 78 | |
| % rank | | | | | | | | | 94% | 75% | 0% | | | | 81% | 100% | 33% | 0.19 | 0.02 | 0.18 | | | 61% | | | |
| 3/24/99 | EMC | 0.28 | 0.28 | 19 | 0.08 | 0.15 | 40 | 6.6 | 61 | 40 | 4.86 | 1 | n/a | n/a | 0.015 | 0.010 | 0.175 | | not analyzed | | 16 | 22 | | 10 | 83 | |
| % rank | | | | | | | | | 69% | 88% | 53% | | | | 30% | 44% | 28% | | | | | | 52% | | | |
| 5/11/99 | EMC | 0.13 | 0.14 | 10 | 0.08 | 0 | 50 | 7.1 | | 28 | | 0.238 | 0.25 | n/a | 0.046 | 0.004 | 0.276 | 0.043 | 0.001 | 0.117 | 14.2 | | | 5 | | 4 |
| % rank | | | | | | | | | | 53% | | | | | 86% | 10% | 74% | 0.94 | 0.29 | 0.42 | | | 56% | | | |
| 7/2/99 | EMC | 0.30 | 0.30 | 6 | 0.11 | 0 | 103 | 8.1 | 69 | 25 | 4.28 | 0.3 | n/a | n/a | 0.038 | 0.009 | 0.238 | | not analyzed | | 10 | 21 | | not tested | 33* | 2, 3 |
| % rank | | | | | | | | | 83% | 52% | 36% | | | | 83% | 32% | 69% | | | | | | 59% | | | |
| | average | | | | | | average | 6.9 | 65 | 36 | 3 | 0.6 | | | 0.025 | 0.023 | 0.271 | 0.005 | 0.001 | 0.072 | 13 | 21 | | 40 | 80 | |
| | | | | | | | average rank | | 77% | 79% | 22% | | | | 60% | 64% | 56% | | | | | | 60% | | | |
| | | | | | | | count | | 17 | 17 | 18 | | | | 19 | 20 | 19 | | | | | | | | | |
| | | | SDN1 | | Historical data (1/97-6/99) | | max | | 85 | 46 | 29 | | | | 0.062 | 0.048 | 0.540 | | | | | | | | | |
| | | | | | | | min | | 9.7 | 6.4 | 2 | | | | 0.003 | 0.001 | 0.066 | | | | | | | | | |
| | | | | | | | median | | 43 | 24 | 5 | | | | 0.019 | 0.011 | 0.218 | | | | | | | | | |



AR 015217

1998-99 WET Testing Sample Data

| SDN4 | sample type | storm characteristics: depth rep | rain | dur | maxint | 48hr | ai dryant | pH | TSS | Turb | BOD | NH3 | Surf | glycols | concentration, mg/l: TRCu | TRPb | TRZn | Dcu | DPb | DZn | Hard | cond | avg rank | WET, % survival: daphnid | fathead | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/17/98 | EMC | 0.80 | 0.68 | 62 | 0.15 | 0.05 | 31 | 7.5 | 22 | 15 | 2 | 1 | n/a | 2 | 0.025 | 0.0012 | 0.127 | 0.021 | 0.001 | 0.049 | 24 | 75 | | 75 | 100 | |
| % rank | | | | | | | | | 94% | 89% | 0% | | | | 23% | 81% | 100% | 0.8379 | 0.83 | 0.39 | | | 65% | | | |
| 1/13/99 | EMC | 0.85 | 1.07 | 22 | 0.16 | 0 | 85 | 6.8 | 7 | 9.2 | 2 | 0.5 | n/a | 2 | 0.020 | 0.001 | 0.034 | 0.014 | 0.001 | 0.027 | 28 | 56 | | 100 | 100 | |
| % rank | | | | | | | | | 57% | 78% | 0% | | | | 9% | 27% | 77% | 0.7065 | n/a | 0.79 | | | 41% | | | |
| | average | | | | | | average | 7.1 | 15 | 12 | 2 | 0.8 | | 2 | 0.023 | 0.001 | 0.081 | 0.018 | 0.001 | 0.038 | 26 | 66 | | 88 | 100 | |
| | | | | SDN4 | | Historical data (7/94-6/99) | | count | 20 | 20 | 22 | | | 16 | 22 | 23 | 23 | | | | | | | | | |
| | | | | | | | | max | 27 | 23 | 38 | | | 34 | 0.091 | 0.003 | 0.127 | | | | | | | | | |
| | | | | | | | | min | 2 | 2 | 2 | | | 2 | 0.015 | 0.001 | 0.014 | | | | | | | | | |
| | | | | | | | | median | 4 | 5 | 4 | | | 2 | 0.035 | 0.001 | 0.025 | | | | | | | | | |

comments
1 SDE4 Jan 20, 1999 sample lab error on fathead test was 48-hr instead of 96-hr
2 July 2, 1999 samples control failed at 72.5% survival (criterion is >90%)
3 July 2, 1999 SDN1 sample insufficient # of organisms to start daphnid test
4 May 11, 1999 SDN1 sample taken for source tracing (was a non-storm) only, not to explicitly satisfy permit condition S10

<MDL, value shown is 1/2 MDL
exceeds single value and/or average criterion for survival

notes
1 pH, ammonia, hardness and conductivity measured at Parametrix toxicology lab
2 Dissolved metals not routinely analyzed, therefore, no summary statistics provided
3 Summary statistics for each outfall are relative trimmed data set July 1994 through June 30, 1999
4 All data for SDN1 are from "up" station located in manhole SDN1-22
5 Ammonia values <1 analyzed at Aquatic Research unless shown as shaded in table

AR 015218

Effect of increasing hardness on Fresh Water Acute Water Quality Standards (Revised)
Reference: WAC 173.201A.040

Copper – Fresh water Acute

| | Exp -> (.9422) | Hardness, mg/l | [ln hardness] | - .1.464) | <- Exp | e^x | WQC @ this hardness (ug/l) |
|---|---|---|---|---|---|---|---|
| 0.96 | 0.9422 | 16 | 2.772588722 | 1.464 | 1.148333 | 3.152933 | 3.0 |
| 0.96 | 0.9422 | 19 | 2.944438979 | 1.464 | 1.31025 | 3.707102 | 3.6 |
| 0.96 | 0.9422 | 42 | 3.737669618 | 1.464 | 2.057632 | 7.827415 | 7.5 |
| 0.96 | 0.9422 | 47 | 3.850147602 | 1.464 | 2.163609 | 8.702489 | 8.4 |
| 0.96 | 0.9422 | 48 | 3.871201011 | 1.464 | 2.183446 | 8.87684 | 8.5 |
| 0.96 | 0.9422 | 110 | 4.700480366 | 1.464 | 2.964793 | 19.39068 | 18.6 |
| 0.96 | 0.9422 | 122 | 4.804021045 | 1.464 | 3.062349 | 21.37771 | 20.5 |

Zinc - Fresh water Acute

| | Exp -> | Hardness, mg/l | ln hardness | | <- Exp | e^x | WQC@this hardness, ug/l |
|---|---|---|---|---|---|---|---|
| 0.978 | 0.8473 | 16 | 2.772588722 | 0.8604 | 3.209614 | 24.76953 | 24.2 |
| 0.978 | 0.8473 | 19 | 2.944438979 | 0.8604 | 3.355223 | 28.652 | 28.0 |
| 0.978 | 0.8473 | 42 | 3.737669618 | 0.8604 | 4.027327 | 56.11075 | 54.9 |
| 0.978 | 0.8473 | 47 | 3.850147602 | 0.8604 | 4.12263 | 61.72136 | 60.4 |
| 0.978 | 0.8473 | 48 | 3.871201011 | 0.8604 | 4.140469 | 62.83226 | 61.4 |
| 0.978 | 0.8473 | 110 | 4.700480366 | 0.8604 | 4.843117 | 126.8642 | 124.1 |
| 0.978 | 0.8473 | 122 | 4.804021045 | 0.8604 | 4.930847 | 138.4968 | 135.4 |