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Regional Highway Stormwater Runoff Characteristics in California

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by

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ABSTRACT

The California Department of Transportation (Caltrans) is engaged in a multi-year program of monitoring storm water runoff from highways. As part of this ongoing program and permit requirements specified by the National Pollution Discharge Elimination System (NPDES) a total of ten representative highway sites were selected within five Caltrans Districts for comprehensive stormwater monitoring and characterization study. Parameters monitored include: (1) conventional pollutants, (2) metals and inorganics, (3) nutrients, (4) organics and pesticides, (5) selected microbes, and (6) toxicity. Results obtained during 1997-98 and 1998-99 NPDES monitoring seasons are discussed in this paper.

INTRODUCTION

With the passage of the Clean Water Act (CWA) in 1972, the federal government has placed a priority on protecting the quality of our nation's waters. The stated objective of the CWA is to restore and maintain the chemical, physical, biological integrity of the Nation's waters. The CWA prohibits point source discharge of pollutants into waters of the U.S. without a National Pollutant Discharge Elimination System Elimination (NPDES) permit. In the 1987 amendments to the CWA, Congress directed EPA to establish a permitting framework under the NPDES program to address storm water discharges associated with urban areas and certain industrial activities.

In California, administration of the federal NPDES program has been delegated by the EPA to the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCB). The SWRQCB uses statewide general NPDES permits for construction sites and industrial activities. The RWQCBs issue and enforce individual municipal permits and take the lead in enforcing the general permits within their respective regions.

Prior to 1999, each of the twelve Caltrans geographical Districts obtained individual, District-specific NPDES permits and developed individual stormwater quality management programs. As of May 1999, Caltrans has refined its statewide stormwater management goals and objectives and obtained a single NPDES stormwater permit. A comprehensive and consistent stormwater management plan (SWMP) was found to be the most effective approach to addressing its activities statewide.

Presently, Caltrans is engaged in a multi-year program of monitoring and research on the environmental effects of stormwater runoff from highways. The questions addressed run from the fundamental, such as the contents and receiving water effects of highway runoff, to the practical, such as the performance of various best management practice (BMP) technologies in meeting water quality standards. Part of this multi-year program relates to the monitoring and characterization of highway runoff. The information presented in this paper was developed in a two-year NPDES highway stormwater runoff characterization study that was undertaken during the 1997-98 and 1998-99 winter seasons.

METHODOLOGY

Sites Selection

A total of ten sites were selected as part of the NPDES stormwater monitoring program. The selected sites are shown in Figure 1.

Storm Event Monitoring

The storm events were monitored according to the Caltrans "Guidance Manual: Storm Water Monitoring Protocols," (Caltrans Environmental Program, 1997) and the requirements of the individual NPDES permits applicable to the specific Caltrans Districts. Detailed monitoring specifications were described in comprehensive Storm Water Monitoring Plans developed for each District (Caltrans Environmental Program, 1997-98 and 1998-99). Depending on the site location, two to four storm events were monitored during each of the 1997-98 and 1998-99 wet seasons.

The minimum criteria used to consider each storm event as a representative event were as follows :

- Depth of storm rainfall must be greater than 0.1 inch accumulation,
- At least 4 hours of runoff (District 7 only),
- At least 72 hours must have elapsed since the last storm (5 days in District 7), and
- Where feasible, the rainfall depth and duration should be within 50 percent of the median values for the sampling location.

Samples Collection

Grab and composite samples were collected manually or using automated samplers, depending on the site configuration. Automated samplers were only used at the three District 7 sites. Three types of samples were collected:

1. *First-flush Sample*: A set of grab samples that were collected for specified constituents shortly after runoff began.

2. *Peak Flow Grab Sample*: A set of grab samples that were collected for specified constituents when rainfall and runoff were estimated to be representative near the midpoint of the sample collection.

3. *Composite Sample*: A composite sample was prepared by collecting sample aliquots over the duration of the rainfall event, up to a maximum of 8 hours, and flow-weighting those aliquots based on the flow rate at the time of sample collection (except for District 10 where compositing was based on rainfall depth).

Rainwater samples were also collected at each monitoring station, and a temporary rain gauge was installed at each site to measure rainfall during the sampling period.

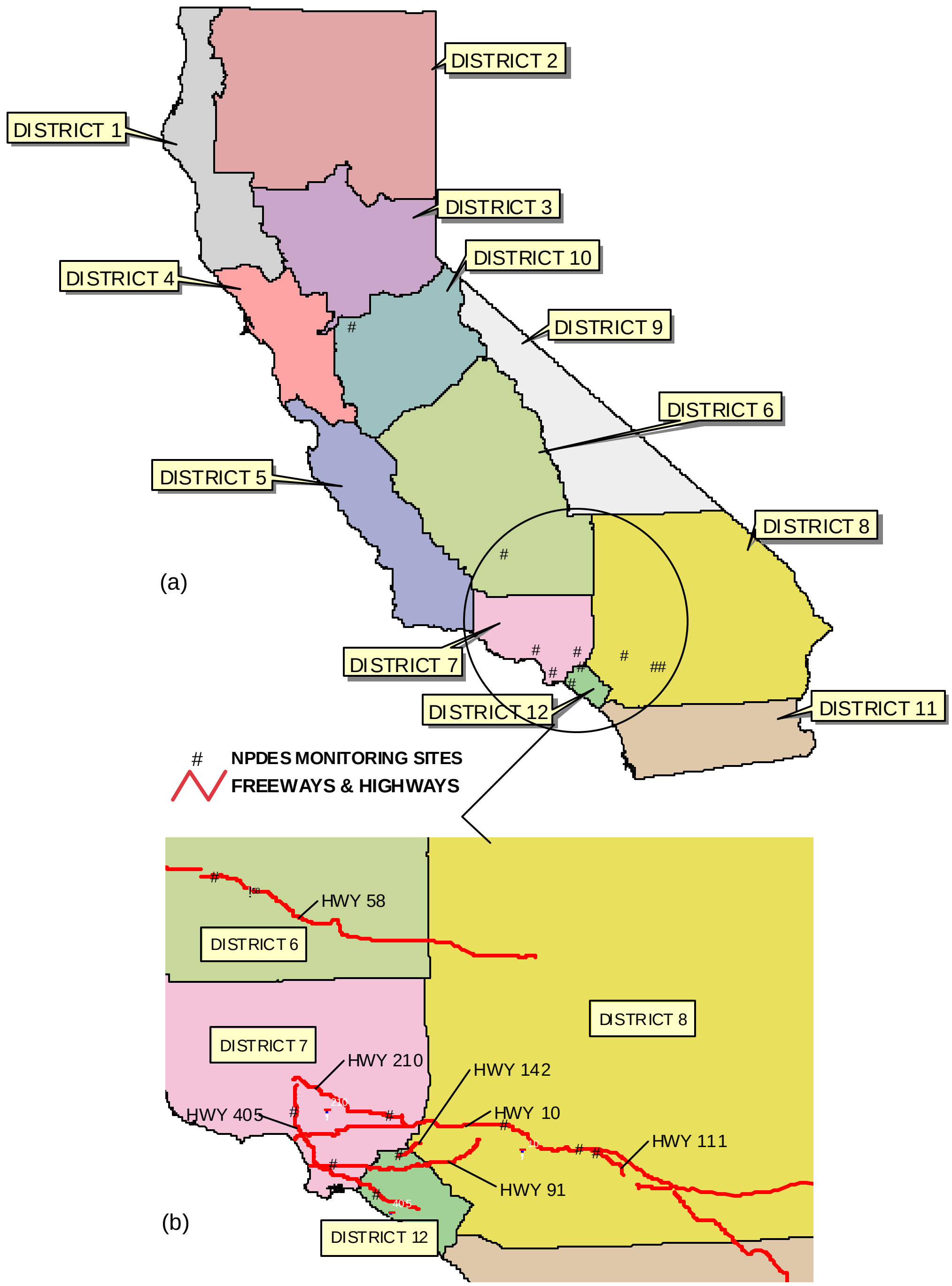

Figure 1
Locations of the NPDES Monitoring Sites: (a) with respect to Caltrans Districts, (b) with respect to Caltrans highways

Samples Analysis

Constituents used for sample analysis were organized in six major groups: (1) conventionals, (2) metals (total and dissolved) and inorganics, (3) nutrients and minerals, (4) microbiological, (5) toxicity, and (6) organics and pesticides. All laboratory analyses were conducted according to the *Standard Methods* and the USEPA analytical methods specified in the Monitoring Plans (Caltrans Environmental Program, 1997-98 and 1998-99). Standard lab QA/QC procedures were followed as indicated in the monitoring plan (Caltrans Environmental Program, 1997-98, 1998-99). Analytical results were qualified as necessary based on the results of the QA/QC evaluations.

STORMWATER RUNOFF CHARACTERISTICS

Average composite concentrations for selected constituents of highway stormwater runoff during 1997-98 and 1998-99 for each Caltrans District are summarized in Table 1. Representative conventional parameters (TSS, TDS, COD), nutrients (TKN, total phosphorus, ortho-phosphorus), metals (total and dissolved copper, lead and zinc), oil and grease, pesticides (chlorpyrifos and diazinon), fecal coliform, and bioassays provide an overview of characteristic water quality conditions for the highway runoff samples. Although additional constituents were analyzed, these constituents are reported for their primary importance in water quality and for the availability of similar data in the literature for comparison purposes.

DISCUSSION

The results are discussed based on the important findings of composite and first flush sample, rainwater analysis, influence of sample size on pollutant concentration, and comparison of the California highway stormwater runoff with those data found elsewhere in the nation.

Composite Samples

As indicated in Table 1, the average composite concentrations are fairly consistent among the monitoring sites between the two wet seasons for most constituents, including nutrients, dissolved metals, oil and grease, and pesticides. The other constituents vary, with some constituents having higher 1997-98 concentrations and others having higher 1998-99 concentrations. No clear trend could be found throughout the sites. However, on average, the concentration of constituents for all districts during the 1998-99 monitoring season was slightly lower than the values obtained during the 1997-98 monitoring season (see Table 1). This difference in concentrations is believed to be attributed to variability in storm conditions, site conditions and sampling randomness, rather than to any fundamental change in runoff water quality.

Bioassay tests in District 6 showed toxicity in first flush and peak flow grab samples collected from both 1998-99 storms. Chlorpyrifos and diazinon concentrations averaged 0.146 ug/l and 0.352 ug/l, respectively, in 1998-99 composite samples. The somewhat high diazinon concentration may be partially responsible for the storm water toxicity. Dissolved copper, lead and zinc tend to be higher at this site than at other Caltrans highway sites under this NPDES monitored program, and could be contributing to storm water toxicity. None to mild toxicity were observed on some composite samples from Districts 10 and 8/12 during 1998-99 winter season. Low toxicity in District 10 can be explained by lack of adequate storm sample (storm event did not generate adequate representative sample) during the January-February period when pesticide spraying is prevalent in the Central Valley.

The extensive organic constituent analyses detected only a few constituents throughout the monitoring season. Organic constituents that were consistently detected were chlorpyrifos and diazinon. These two constituents were analyzed by the ALISA method using low detection limit. Acetone was another organic constituent that was frequently detected. Other organic constituents such as Fecal sterol (coprostanol), Glyphosphate, Oxadiazon, Bis (2-ethylhexyl) phthalate, aniline, bromacil, 4-Methylphenol (p-Cresol,

Table 1
Average value for selected constituents found in highway stormwater runoff from different Caltrans Districts during 1997-98 and 1998-99 monitori

		Average Value for Composite Samples*												
		District 6		District 7		District 8		District 10		District 12		All Districts		
Constituent	Units	1997-98	1998-99	1997-98	1998-99	1997-98	1998-99	1997-98	1998-99	1997-98	1998-99	1997-98	1998-99	1997-99
TDS	mg/L	275	180	52.0	96.5	89.5	170	56	155	130.3	68.3	120.6	134	127.3
TSS	mg/L	805	480	359.6	237.9	1256	69	730	148	593.3	84.3	748.8	203.8	476.3
COD	mg/L	266.5	165	48.2	120.8	217.5	135	263.5	66.5	107.2	76.8	180.6	112.8	146.7
TKN	mg/L	8.1	8.1	1.7	4.6	5.1	4.8	7.5	7.1	2.4	2.9	5.0	5.5	5.2
TP	mg/L	2.3	1.2	0.4	0.3	0.4	0.3	0.6	0.6	0.3	0.1	0.8	0.5	0.7
Ortho-P	mg/L	0.7	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.2	0.1	0.3	0.2	0.2
Oil&Grease	mg/L	5.5	5.9	5.5	6.3	6.1	3.8	3.0	3	1.0	3.1	4.2	4.4	4.3
Cu (Total)	µg/L	69	68	53.7	72.4	39.5	40.9	37.0	10.4	17.2	16	43.3	41.5	42.4
Cu (Dissolved	µg/L	46	11	12.5	15.2	23.3	20.8	4.8	5.3	12	12.4	19.7	12.9	16.3
Pb (Total)	µg/L	117	138	129.3	189.6	50.0	39.6	182.0	15.5	16	14	98.9	79.3	89.1
Pb (Dissolved	µg/L	81	1	5.3	1.8	2.3	2	1.1	0.5	5.3	1.9	19.0	1.3	10.2
Zn (Total)	µg/L	515	475	255.0	376.7	236.0	313.0	365	72.5	99.3	85.5	294.1	264.5	279.3
Zn (Dissolved	µg/L	346	23	93.0	47.2	101.7	211.5	30	21.5	50.5	44	124.2	69.4	96.8
Toxicity**	%Survival	100	0.0	NA	NA	98.0	100	47	97.0	NA	NA	82	65	73.5
Fecal Coliform	MPN/100 m	>1600	500	2975	4478	NA	NA	>1600	19	9083	3250	>3051	1649	>2350
Chlorpyrifos	µg/L	0.2	0.1	0.8	0.2	0.1	0.1	0.8	0.1	0.1	0.1	0.4	0.1	0.3
Diazinon	µg/L	0.1	0.4	0.8	0.3	0.1	0.2	0.6	0.1	0.1	0.1	0.3	0.2	0.3

* All non-detect measurement were substituted with the detection limit for computing the average values

**Toxicity test was conducted based on the USEPA standard species of Ceriodaphnia dubia

NA = Not Analyzed

Benzyl Alcohol, diuron, and 2-Butamone (methyl ethyl ketone) were occasionally detected that appear to be sporadic.

Factors such as urban development, percent paved area, traffic lanes, and daily traffic are among parameters that can influence pollutant generation (Driscoll et al., 1990; Barrett et al., 1998). For instance, in comparing results for the three monitoring sites along Highways 405, 10, and 142 the Highway 405 site generated the highest constituent concentrations. Of the 16 constituents, 10 showed their highest average composite concentrations at the Highway 405 site. Five constituents showed their highest average composite concentrations at the Highway 10 site, and only one (chlorpyrifos) was highest at the Highway 142 site. This ranking is in direct proportion to the freeway width, intensity of use, and level of urban development associated with the various sites. Similarly, fecal coliform counts at these three sites are found to be higher than at sites monitored in Districts 6 and 10, which are in less urban locations.

First Flush Samples

First flush samples were analyzed based on the individual first flush and seasonal first flush. In general, a weak or moderate first flush effect was found on individual storms in the 19997-99 data. The strongest effect is seen for nutrient constituents. The presence of a seasonal first flush effect was investigated by comparing composite concentrations in the first storm of the season with later storms. A relative value of first flush compared to composite samples for selected highway runoff constituents during 1997-99 monitoring season is shown in Figure 2. In general, a seasonal first flush effect is supported by the data. The following power relationship was developed to correlate the concentration of seasonal first flush with composite samples.

$$FF = 1.5 \times C^{0.95} \qquad R^2 = 0.99$$

Where,
FF= Seasonal first flush concentration, mg/L (except bioassay and fecal coliform)
C = Composite concentration, mg/L (except bioassay and fecal coliform)

Rainwater Analysis

Table 2 presents the rainwater characterization data and compares them to average storm water composite concentrations over the same period for different Caltrans Districts. As can be seen the large number of non-detect measurements in the rainwater samples makes direct comparison with storm water concentrations difficult. Data gathered under this NPDES monitoring program indicate that, except for nitrate, TKN, and diazinon, rainwater contributes only a small fraction of the constituents found in highway runoff. Arsenic, nickel and nitrite were not detected at all in the rainwater. On the other hand high concentrations of nitrate, TKN, and diazinon in rainwater represented significant airborne contributions to the stormwater runoff pollutant concentrations recorded at Districts 6, 7 and 8. Toxic organic compounds such as diazinon and chloropyriphos in rainwater may be contributing to highway runoff toxicity. It is important to note that with this limited data its is too early to tell if materials dissolved in the rain are always significant. Addition data is needed to verify this finding.

Comparison of Highway Runoff Characteristics

Representative concentration of pollutants in California highway stormwater runoff are compared with values reported for other highways around the nation in Table 3. In general, the pollutant concentrations for nutrients, metals, oil and grease, and bacteria from California highways are within the range of values reported elsewhere. However, several conventional pollutants are reported higher for California. In general, site characteristics and environmental conditions play a major role on pollutant concentration. As noticed, most California monitoring studies where conducted in southern California where there are more industrial activities, higher traffic, more asphalt surface per drainage area, and less grassy swale. The connection between these characteristics and higher COD and TSS are not clear.

Table 2

Average Rainwater Characteristics Compared with Composite Stormwater Characteristics within each District that for 1997-98 and 1998-99 Wet Seasons

		District 6		District 7		District 8		District 10		District 12		All Districts	
Constituent	Units	Average Rain Water	Rain Water % of Storm Composite	Average Rain Water	Rain Water % of Storm Composite	Average Rain Water	Rain Water % of Storm Composite	Average Rain Water	Rain Water % of Storm Composite	Average Rain Water	Rain Water % of Storm Composite	Average Rain Water	Rain Water % of Storm Composite
Arsenic (total)	µg/L	ND	N/A	ND	N/A	ND	N/A	<1.3	<22	NA	N/A	N/A	N/A
Copper (total)	µg/L	3.5	5	<5.80	5	<2.80	<24	<4.	<16	2.46	<12	<3.71	<9
Nickel (total)	µg/L	ND	N/A	ND	N/A	ND	N/A	ND	N/A	ND	N/A	ND	N/A
Lead (total)	µg/L	3	2	<6.60	2	<0.90	<2	3.3	3.3	<2.73	<13	<3.3	<4.
Zinc (total)	µg/L	34.00	5	<51.90	3	15.5	5	34	12	100.7	<62	<47	<17
TKN	mg/l	<1.03	<13	<0.76	<15.00	<1.00	<19	1.06	14	<0.85	<28	<0.94	<18
NO2	mg/l	ND	N/A	ND	N/A	ND	N/A	ND	N/A	ND	N/A	ND	N/A
NO3	mg/l	0.56	24	<.02	16	0.33	10.5	0.87	72.1	<1.98	<99	<0.79	<44
Phosphorus	mg/l	0.03	2	0.04	9	<0.02	<8	0.11	18.2	<0.05	<19	<0.05	<7
Chlorpyrifos	µg/l	0.07	35	0.02	7	0.01	9.13	0.87	16.4	0.04	62	0.2	80
Diazinon	µg/l	0.09	48	0.09	22	0.03	15.8	0.65	147.4	0.15	102	0.2	67

ND = Not Detected (Detection limit for: Arsenic = 1 µg/L, Nickel = 5 µg/L, and Nitrate = 0.1 mg/L)

NA = Not Analyzed

N/A = Not Applicable

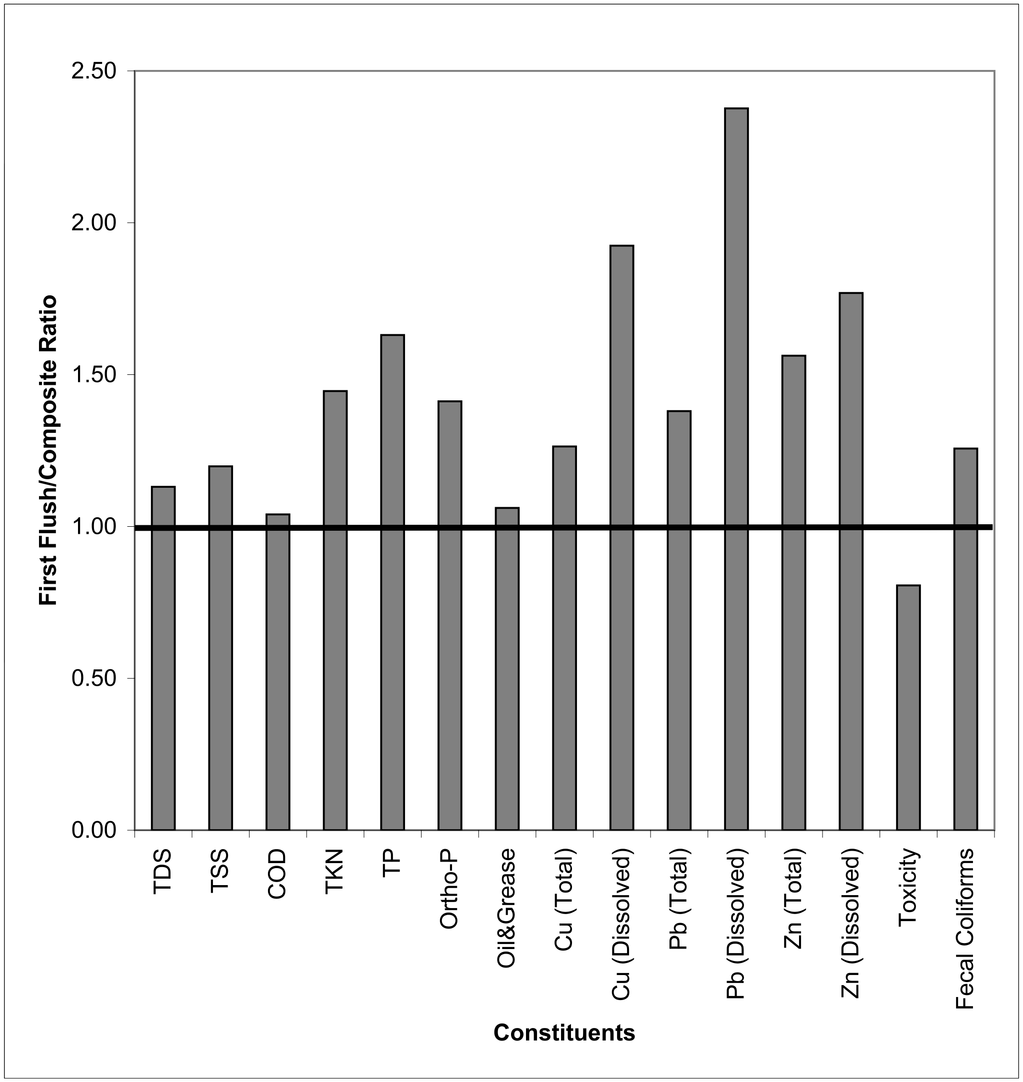

Figure 2

Relative Values of Seasonal First Flush Compared to Composite Samples for Selected Highway Runoff Constituents

During 1997-98 and 1998-99 Monitoring Season

Table 3

Average Representative California Highway Stormwater Runoff Constituent Characteristics Compared to Those Values Reporetd Nationwide

Constituent	Unit	National and International Highways Runoff Characteristics					California
		Barrett et al., 1995	Wu et al., 1998	Driscoll et al, 1990	Wanielista and Yousef, 1993	Germany Stotz 1987	Caltrans 1997-99
COD	mg/L	59.0	35.0	114.0	14.7	45.0	146.7
TDS	mg/L	158.0	87.0				127.3
TSS	mg/L	90.0	105.0	142.0	261.0	68.0	476.3
TKN	mg/L	1.2	1.0	1.8	3.0		5.2
NH3-N	mg/L		0.6		1.2	0.3	1.9
NO3-N	mg/L	0.7	0.2	0.8	1.1		1.8
Soluble P	mg/L	0.1	0.2	0.4	0.6		0.2
Total P	mg/L	0.2	0.3		0.8	0.1	0.7
Oil and Grease	mg/L		1.9		6.2		4.3
Cadmium, Cd	µg/L		2.5	20.0	4.0	0.4	1.1
Chromium, Cr	µg/L		3.8		4.0	1.2	11.5
Copper, Cu	µg/L	11.0	9.8	54.0	10.3	6.7	42.4
Lead, Pb	µg/L	11.0	11.3	400.0	96.0	97.0	89.1
Nickel, Ni	µg/L	25.0	4.7		9.9		13.8
Zinc, Zn	µg/L			399.0	410.0		279.3
Fecal Coliform	MPN/100 mL	50,333		27,255			>2350
Total Coliform	MPN/100 mL	86,000		46,000			22,347

SUMMARY

1. Fairly consistent stormwater runoff characteristics were found at most California highway sites over the 1997-99 monitoring period. It appears that highway sites with more lanes, more intense use, and with more urban influences have a tendency to produce more pollutants.
2. Compared to composite samples, a higher pollutant concentration were noticed in first-flush samples.
3. Besides chlorpyrifos, diazinon and acetone, organic compounds were very rarely found at concentrations exceeding detection limits from highway sites.
4. Toxicity results demonstrate widely varying toxicity (0 to 100 percent survival rate of *Ceriodaphnia*) in highway runoff. Sources of toxicity have not been investigated, though pesticides which are present in rainwater, are suspected causes.
5. Rainwater contributed a significant fraction of the stormwater runoff organic pesticide load. Contributions varied substantially by site and storm.
6. California highway stormwater runoff characteristics are generally similar to highway runoff characteristics reported elsewhere in the nation.

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