> *"And I brought you into a plentiful country, to eat the fruit thereof and the goodness thereof; but when ye entered, ye defiled my land, and made mine heritage an abomination."*
>
> *.................. (Jeremiah 2:7)*

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Ref.: portland_hills_031209_01b (17 pages)
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From: S. M. Mandaville B.E., Post-Grad Dip., Professional Lake Manage., Chairman and Volunteer Exec. Director
Date: December 08, 2003
Subject: **Stormwater runoff from road pavements, automotive areas, and other NPS pollutants- Effects on Aquatic Communities**

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Quality of stormwater runoff from road pavements (Drapper et al)

Highway runoff can contain a variety of pollutants depending upon the location, surrounding land-use, maintenance practices, type of vehicles using the roadway and volume of traffic. The motor vehicle is a major source of pollution.

Table 0007-1: Common road runoff pollutants and sources. (Drapper et al. [Source: Kobringer, N.P. 1984. Volume I. Sources and Migration of Highway Runoff Pollutants-Executive Summary. FHWA/RD-84/057. Federal Highway Administration, Rexnord, EnviroEnergy Technology Center, Milwaukee, WI])

Constituent	Primary sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance, snow/ice abrasives, sediment disturbance
Nitrogen, Phosphorus	Atmosphere, roadside fertiliser use, sediments
Lead	Leaded gasoline, tire wear, lubricating oil and grease, bearing wear, atmospheric fallout
Zinc	Tire wear, motor oil, grease
Iron	Auto body rust, steel highway structures, engine parts
Copper	Metal plating, bearing wear, engine parts, brake lining wear, fungicides and insecticides use
Cadmium	Tire wear, insecticide application
Chromium	Metal plating, engine parts, brake lining wear
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, brake lining wear, asphalt paving
Manganese	Engine parts
Bromide	Exhaust
Cyanide	Anticake compound used to keep deicing salt granular
Sodium, Calcium	De-icing slats, grease
Chloride	De-icing salts
Sulphate	Roadway beds, fuel, de-icing salts
Petroleum	Spills, leaks, blow-by motor lubricants, antifreeze, hydraulic fluids, asphalt surface leachate
PCBs, pesticides	Spraying of highway right of ways, atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria	Soil litter, bird droppings, trucks hauling livestock/stockyard waste
Rubber	Tire wear
Asbestos*	Clutch and brake lining wear

* No mineral asbestos has been identified in runoff, however some breakdown products of asbestos have been measured

Table: 0007-2: Mean pollutant concentrations (µg/l) in runoff from urban and rural highways (Drapper et al. [Source: Driscoll, E., Shelley, P.E., and Strecker, E.W. 1990. Pollutant Loadings and Impacts from Highway Stormwater Runoff. Volumes I-IV. FHWA/RD-88-006-9, Federal Highway Administration, Woodward-Clyde Consultants, Oakland, CA])

Pollutant	Urban (ADT>30,000)	Rural (ADT<30,000)
TSS (Total Suspended Solids)	142,000	41,000
VSS (Volatile Suspended Solids)	39,000	12,000
TOC (Total Organic Carbon)	25,000	8,000
COD (Chemical Oxygen Demand)	114,000	49,000
NO_3/NO_2 (Nitrate + Nitrite)	760	570
TKN (Total Kjeldahl Nitrogen)	1,830	870
Phosphorus as PO_4	400	160
Cu (Total Copper)	54	22
Pb (Total Lead)	400	80
Zn (Total Zinc)	329	80

Conclusions (Drapper et al)

The results from 21 sites across South-east Queensland have indicated that hydrocarbons, nutrients, heavy metals and suspended solids are present in measurable quantities in road runoff. The observed pollutant concentrations are above ANZECC guidelines for the protection of aquatic ecosystems, but are comparatively low against overseas data.

- This research has shown that traffic volumes appear to have minimal influence on road runoff pollutant concentrations except for total petroleum hydrocarbons.
- The levels of nitrogen, phosphorus, copper, lead and zinc in road runoff are considerably higher than ANZECC (Australia and New Zealand Environment Conservation Council) guidelines.
- Site specific features such as exit lanes, appear to influence the concentration of copper and zinc, but lead correlates strongly to levels of suspended solids.

Laser particle sizing has also indicated that a considerable proportion of the particulates in road runoff are less than 10 µm. This size fraction is difficult to capture in current stormwater pollution control devices and has been shown to contain significant quantities of heavy metals, which are of concern in aquatic ecosystems.

Quality of trapped sediments and pool water within oil-grit separators (Storm*ceptor* [Source: Schueler and Shepp, 1993])

- The quality of the water and sediments from 17 oil-grit separator (OGS) sites was assessed, based on five broad land use categories: streets, all-day parking lots, townhouses, convenience stores, and gas stations. A sump pit and stormwater pond were also monitored. Sampling was conducted at two levels: characterization of nutrient, hydrocarbon and metal concentrations within the sediment and water column of each OGS chamber, and six composite priority pollutant scans of the water column and sediments.

- Existing designs of OGS systems were demonstrated to have poor retention characteristics. The average wet volume of trapped sediments in over 100 OGS surveyed was slightly less than 12 cubic feet, within an average depth of only 2 inches. Dye tests indicated pool water residence times of less than 1/2 hour. Based on these observations of short retention, it was concluded that current design of OGS systems are not effective in trapping pollutants, and that the pollutant mass within them is largely the product of recent storm events.

- The study confirms for the first time in the Washington region that automotive areas (such as gas-stations, all-day parking lots and convenience stores) can have elevated concentrations of hydrocarbons and other priority pollutants.

- **Of concern is the impact of the PAHs, trace metals, and hydrocarbons on downstream aquatic life, when trapped sediments are resuspended, or the overlying water is displaced. In particular, automotive land use hotspots might exert a possible toxic effect on headwater streams, where dilution is relatively low and exposure is chronic.**

- Some interesting new technologies may hold some promise, such as sand filters, or off-line oil-grit separators.

Table 0007-3: List of priority Pollutants (*cf.* Storm*ceptor* [Source: Schueler and Shepp, 1993])

I. PESTICIDES:

1. Acrolein
2. Aldrin
3. α-Hexachloroclohexane (α-BRC) (Alpha)
4. β-Hexachlorocyclohexane (β-BRC) (Beta)
5. γ-Hexachlorocyclohexane (γ-BMC) (Gamma) (Lindane)
6. Δ-Hexachlorocyclohexane (Δ-BHC) (Delta)
7. Chlordane
8. DCD
9. DCE
10. DDT
11. Dieldrin
12. α-Endosulfan (Alpha)
13. β-Endosulfan (Beta)
14. Endosulfan sulfate
15. Endrin
16. Endrin aldehyde
17. Neptachlor
18. Neptachlor epoxide
19. Isophorone
20. TCBD (2,3,7,8-tetrachlorodibenzo-p-dioxin)
21. Toxaphene

II. METALS and INORGANICS:

22. Antimony
23. Arsenic
24. Asbestos
25. Beryllium
26. Cadniur
27. Chromium
28. Copper
29. Cyanide
30. Lead
31. Mercury
32. Nickel
33. Selenium
34. Silver
35. Thallium
36. Zinc

III. PCBs and RELATED COMPOUNDS:

37. PCB-1016 (Aroclor 1016)
38. PCB-1221 (Aroclor 1221)
39. PCB-1232 (Aroclor 1232)
40. PCB-1242 (Aroclor 1242)
41. PCB-1248 (Aroclor 1248)
42. PCB-1254 (Aroclor 1254)
43. PCB-1260 (Aroclor 1260)
44. 2-Chloronaphthalene

IV. HALOGENATED ALIPRATICS:

45. Methane, bromo- (Methyl bromide)
46. Methane, chloro- (Methyl chloride)
47. Methane, dichloro- (Methylene chloride)
48. Methane, chlorodibromo--
49. Methane, dichlorobromo-
50. Methane, tribromom- (bromoform)
51. Methane, trichloro- (chloroform)
52. Methane, tetrachloro- (carbon tetrachloride)
53. Methane, trichlorofluoro-
54. Methane, dichlorodifluoro- (Freon-12)
55. Ethane, chloro-
56. Ethane, 1,1-dichloro-
57. Ethane, 1,2-dichloro-
58. Ethane, 1,1,1-trichloro-
59. Ethane, 1,1,2-trichloro-
60. Ethane, 1,1,2,2-tetrachloro-
61. Ethane, hexachloro-
62. Ethane, chloro- (vinyl chloride)
63. Ethane, 1,1-dichloro-
64. Ethane, 1,2-trans-dichloro-
65. Ethane, trichloro-
66. Ethane, tetrachloro-
67. Propane, 1,2-dichloro-
68. Propane, 1,3-dichloro-
69. Butadiene, hexachloro-
70. Cyclopentadiene, hexachloro-

V. ETHERS:

71. Ether, bis(chloromethyl)
72. Ether, bis(2-chloroethyl)
73. Ether, bis(2-chloroisopropyl)
74. Ether, 2-chloroethyl vinyl
75. Ether, 4-bromophenyl phenyl
76. Ether, 4-chlorophenyl phenyl
77. Bis(2-chloroethoxy) methane

VI. MONOCYCLIC AROMATICS (excluding PHENOLS, CRESOLS, PHTHALATES):

78. Benzene
79. Benzene, chloro-
80. Benzene, 1,2-dichloro-
81. Benzen, 1,3-dichloro-
82. Benzene, 1,4-dichloro-
83. Benzene, 1.2.4-trichloro-
84. Benzene, hexachloro-
85. Benzene, ethyl-
86. Benzene, nitro-
87. Toluene
88. Toluene, 2,4-dinitro-
89. Toluene, 2,6dinitro-

VII. PHENOLS and CRESOLS:

90. Phenol
91. Phenol, 2-chloro-
92. Phenol, 2,4- ichloro-
93. Phenol, 2,4,6- trichloro-
94. Phenol, pentachloro-
95. Phenol, 2-nitro-
96. Phenol, 4-nitro-
97. Phenol, 2,4-dinitro-
98. Phenol, 2,4-dimethyl-
99. a-Cresol, p-chloro-
100. o-Cresol, 4,6-dinitro-

VIII. PHTHALATE ESTERS:

101. Phthalate, dimethyl
102. Phthalate, diethyl
103. Phthalate, di-n-butyl
104. Phthalate, di-n-octyl
105. Phthalate, bis(2-ethylnexyl)
106. Phthalate, butyl benzyl

IX. POLYCYCLIC AROMATIC HYDROCARBONS:

107. Acenaphthene
108. Acenaphthylene
109. Anthracene
110. Benzo (a) anthracene
111. Benzo (b) fluoranthene
112. Benzo (k) fluoranthene
113. Benzo (g,h,i) perylene
114. Benzo (a) pyrene
115. Chrysene
116. Dibenzo (a,h) anthracene
117. Fluoranthene
118. Fluorene
119. Indeno(1,2,3-c, d) pyrene
120. Naphthalene
121. Phenanthrene
122. Pyrene

X. NITROSAMINES and other NITROGEN-containing compounds:

123. Nitrosamine, dimethyl (DMX)
124. Nitrosamine, diphenyl
125. Nitrosamine, di-n-propyl
126. Benzidine
127. Benzidine, 3,3'-dichloro-

	128.	Hydrazine, 1,2-diphenyl
	129.	Acrylonitrile

Table 0007-4: Toxicants found in Priority Pollutant Scans (*cf.* Storm*ceptor* [Source: Schueler and Shepp, 1993])

Key:

* = Found in water column also

** = Observed only in water column samples

(S) = Suspected (a result of gas chromatography testing)

(G) = Observed predominantly in gas station sampling

(NG) = Observed predominantly in non-gas station sampling

(AS) = Observed in both sampling

Potential Toxicant	Typical Use	Probable Pathway to Oil-Grit Separator (OGS)
	-------------------- **Sediment Samples** --------------------	
Semi-volatile Organics Naphthalene*	Component of gasoline, fossil fuel.	Incomplete combustion of fossil fuels. Atmospheric deposition of the vapours, Gasoline spillage, crankcase motor oil drippings. (G)
2-Methylnaphthalene*	“ “	“ “
Acenapthene	“ “	“ “
Fluorene	“ “	“ “
Phenanthrene	“ “	“ “
Pyrene	“ “	“ “
Chrysene*	“ “	“ “
Benzo (b) fluoranthene	“ “	“ “
Indeno (123-cd) pyrene	“ “	“ “
Benzo (g,h,i) perylene	“ “	“ “
Di-nbutyl phthalate	Plasticizer- component of plastics, polymeric substances.	Leaches from plastic products such as garden hoses, floor tiles, plastic containers and food packaging. (NG) May leach into motor oils and other automotive fluids from their plastic containers. (G) Motor oil is a suspected source of compound of OGS. (AS)
Butylbenzyl phthalate	“ “	“ “
Bis (2-Ethylhexyl) phthalate*	“ “	“ “
Di-n-cotyle-phthalate	“ “	“ “
Volatile Organics Toluene*	Used as solvent and in chemical synthesis.	Improper disposal of industrial waste. Atmospheric deposition of vapours resulting from incomplete combustion of fuels. (AS)
Ethylbenzene*	Intermediate in chemical synthesis, solvent component of antifreeze.	Antifreeze spillings. (AS)
Total Xylenes*	“ “	“ “
Methylene Chloride	Used as refrigerant. Component of PVC.	Improper disposal of industrial waste. Refrigerant leakage. (S) Car air conditioners, coolants. (S)

(Table 0007-4 contd.)

Potential Toxicant	Typical Use	Probable Pathway to Oil-Grit Separator (OGS)
	-------------------- **Sediment Samples** --------------------	
Pesticides/PCBs		
Aldrin	Pesticide	Used in farming, gardening and landscaping.
4,4-DDT	Pesticide	“ “
Metals		
Antimony	Component of lead alloys, rubber, matches, ceramics, enamel, paints, lacquers and textiles.	Leaches from painted and rubber waste articles. Household and industrial waste erosion from rocks and soils. (G)
Arsenic*	Component of fossil fuel, insecticide, food preservatives. Used in treatment of leukemia and as a tonic.	Product of incomplete combustion of fossil fuels and incomplete atmospheric deposition of vapours. (AS)
Beryllium*	Used to manufacture non-sparking alloys for tools, nuclear reactors and lightweight alloys.	Erosion from rocks and soils. (AS)
Cadmium*	Used in manufacture of batteries, paints and plastics. Used to plate iron products such as nuts and bolts for corrosion prevention.	Waste from plating processes. Motor vehicle exhaust. Leached from galvanized copper and plastic pipes. (G)
Chromium*	Used to make alloys, catalysts and refractories. Used in plating processes. Used in paints, leather tanning, plastics.	Improper disposal of industrial waste. Corrosion of alloys and plated surfaces. (AS) Spillage of brake fluid.
Copper*	Used as alloy component. Sulphate salt used as algicide in water supply reservoirs. Component of fungicide. Used in electroplating industry. Found in coolant, brake fluid, motor oil, gasoline.	Corrosion of copper pipes and fittings. Improper disposal of waste from industry. Algicide. (AS) Spillage of listed automobile products.
Lead*	Used as an additive to gasoline, motor oil, brake fluid and coolant. Component of pipes, paints and dyes. Used in manufacture of batteries, insecticide.	Atmospheric deposition of motor vehicle exhaust. Gasoline, motor oil, brake fluid and coolant leakage. Leaching from paints, stains, plastics. Improper disposal of batteries and insecticides.
Nickel	Used in electroplating, food processing (gelatin, baking powder). Present in gasoline, transmission fluid, motor oil, brake fluid, coolants.	Wastewater from electroplating operations. Product of incomplete combustion of fossil fuels and atmospheric deposition. Gasoline leakage, coolant, motor oil and brake fluid spillage. (AS)
Silver	Used in electroplating industry. Silver halides are used in photography. Component of germicide, antiseptic and astringent. Found in diesel fuel.	Improper disposal of industrial waste. (AS)
Zinc*	Used in electroplating industry. Component of bronze, rubber, enamel, glass and paper. Component of automobile tires, road salt and paint.	Wastewater from electroplating operations. Weathering and abrasion of galvanized iron and steel. Leaching from road salt, automobile tires. (AS)

(Table 0007-4 contd.)

Potential Toxicant	**Typical Use**	**Probable Pathway to Oil-Grit Separator (OGS)**
-------------------- Sediment Samples --------------------		
Cyanide/Phenols Phenol*	Product of plating operations. Anticaking ingredient in road salts. Intermediate in production resins.	Waste from coal coking and refinery operations. Leaching from road salt. (AS)

-------------------- Water Column Samples --------------------**

Semi-volatile Organics Benzyl alcohol	Component of gasoline, fossil fuel.	Incomplete combustion of fossil fuel and atmospheric deposition of vapours. (G)
2-Methylphenol	“ “	“ “
3-4-Methylphenol	“ “	“ “
2,4-Demithylphenol	“ “	“ “
Volatile Organics Acetone	Used as gasoline additive. Solvent for paints, resins, lacquers and plastics.	Leaching of paints and plastics. Automobile product, motor oil leakage.
2-Butanone	“ “	“ “
Benzene	“ “	“ “

Key:

* = Found in water column also

** = Observed only in water column samples

(S) = Suspected (a result of gas chromatography testing)

(G) = Observed predominantly in gas station sampling

(NG) = Observed predominantly in non-gas station sampling

(AS) = Observed in both sampling

Table 0007-5: Street Surface Pollutants associated with various particle sizes (USEPA, 1976 [Source: Sartor and Boyd, 1972])

Measured Pollutant	Particle Size		
	< 43μ	43μ-246μ	> 246μ
	(% by weight)		
TS	5.9	37.5	56.5
BOD_5	24.3	32.5	43.2
COD	22.7	57.4	19.9
VS	25.6	34.0	40.4
Phosphates	56.2	36.0	7.8
Nitrates	31.9	45.1	23.0
Kjeldahl Nitrogen	18.7	39.8	41.5
All heavy metals	51.2	48.7	
All pesticides	73	27	
PCB	34	66	

Caution (Ball and Abustan):

It is emphasized that the above survey was based on the accumulation of particulates on street surfaces, and thus represents only a portion of the pollution in urban stormwater. Other sources are erosion from pervious and non-street impervious areas, deposited material in the conveyance system (dry-weather deposition), and atmospheric washout. In addition, dry weather samples from street surfaces which are collected by sweeping, vacuuming or flushing techniques, may not result in the same particulate proportions as the storm washoff due to different processes. Therefore, sampling through the end-of-pipe principle gives a more representative estimate of the constituents transported during the storm event. For example, phosphorus in certain areas may be sorbed (adsorbed/absorbed) to particles in the clay fraction (<1 μ) or could be mostly in a dissolved form.

Table 0007-6: Rate of settling in pure, still water (Welch, 1935)

(temp=10^{o}C, sp. gravity of particles=2.65, shape of particles=spherical)

Material	Diameter (mm)	Hydraulic subsiding value (mm/sec)	Time required to settle 1 ft.
Gravel	10.0	1000.0	0.3 sec
Coarse sand	1.0	100.0	3.0 sec
Fine sand	0.1	8.0	38.0 sec
Silt	0.01	0.154	33.0 min
Bacteria	0.001	0.00154	55.0 hr
Clay	0.0001	0.0000154	230.0 days
colloidal particles	0.00001	0.000000154	63 years

Effect on Aquatic Communities (http://lakes.chebucto.org/ZOOBENTH/BENTHOS/ii.html)

Introduction (Mackie, 1998)

Aquatic communities downstream of many municipalities change due to the effects of urban stormwater runoff and solid waste disposal. Stormwater runoff has similar constituents as highway runoff, with road salt, tars, oils, gasoline, metals and rubber tire derivatives entering streams as a broth of contaminants. Runoff from asphalt also has a significantly higher water temperature, often resulting in greater than a 10^{o}C increase in stream temperature immediately below the outfall. Silt loads are also high so that the runoff is hot and turbid. Much of the effluent results in increases in sediment concentrations of total hydrocarbons, aromatic hydrocarbons (both in lubricating oils and fuels), and heavy metals (e.g. lead in fuel, copper in brake linings, zinc and cadmium in tires, and chromium and copper in de-icing salts).

The toxicity of this "broth" of contaminants in the water and sediments is complex, with synergistic and antagonistic effects. Benthic and fish communities respond accordingly, but over the long term, fish may be eliminated and the benthos are dominated by pollution tolerant forms like tubificid worms and chironomid larvae.

In general, the type and size of the receiving water, the potential for dispersion, the size of the surrounding catchment area, and the biological diversity of the ecosystem are some of the factors determining the importance of runoff effects.

Effect on macroinvertebrates (Maltby et al, 1995)

Road-vehicle-related activities produce a number of potentially toxic substances including oil and tar products, dioxins, oxygenated compounds, halogenated phenols, metals, deicing salts, and asbestos. These contaminants are derived from a wide range of sources. For example, hydrocarbons are present in lubricating oils and fuels, whereas metals are present in fuel (e.g., lead), brake linings (e.g., copper), vehicle tires (e.g., zinc and cadmium), and road deicing salts (e.g., copper and chromium).

Contaminants from roads can enter river systems via runoff or atmospheric deposition, the relative importance of these two routes being dependent on the particular contaminant in question. Whereas low-molecular-weight polycyclic aromatic hydrocarbons (PAHs) are emitted mainly in the gas phase and are therefore dispersed in the atmosphere, higher-molecular-weight compounds are emitted in particulate form and are deposited on or near the road. Other contaminants may be associated with crankcase oil and leak directly onto the road surface where they become associated with particulate material.

Road runoff therefore contains a complex mixture of potential toxicants that are discharged, untreated, into receiving waters. The potential impact of road runoff on receiving water quality will be dependent on several factors, including volume of traffic, rainfall, and size of receiving water.

Many of the contaminants in road runoff are associated with particulate material and accumulate in the sediments of receiving waters where they may reach concentrations orders of magnitude greater than those present in the overlying water.

The organisms most at risk, therefore, will be members of the benthic community as they are exposed to both dissolved and deposited contaminants. Although several different groups of benthic organisms may be used to assess water and sediment quality, most studies have concentrated on macroinvertebrates. These play an important role in energy flow and nutrient processing in freshwaters, as well as providing prey for vertebrates such as fish and birds.

The major energy sources in small streams are benthic algae and detritus, coarse particulate organic matter (CPOM, e.g., leaf litter) being the dominant energy input in wooded streams. The breakdown of CPOM is brought about by a combination of microbial decomposition, macroinvertebrate feeding, chemical leaching, and physical abrasion. Studies have shown that conditioning of leaf material by fungi increases its palatability to macroinvertebrate shredders and that aquatic hyphomycetes (*Fungi Imperfecti*), in particular, play an important role in the microbial decomposition of leaf material. The processing of CPOM by microorganisms and shredders produces fine particulate organic matter (FPOM), which is consumed by filter feeders and collector-gatherers. The latter are in turn consumed by invertebrate and vertebrate predators. Hence, efficient decomposition is key to the energy budget (and therefore the integrity) of many stream ecosystems. A major rate-limiting step in the incorporation of CPOM into the freshwater food web is the conversion of detrital material into fungal and macroinvertebrate biomass.

1. Field Study- Abstract: The effects of motorway runoff on the water quality, sediment quality, and biota of small streams were investigated over a 12-month period. Downstream of motorway runoff discharges there was an increase in the sediment concentrations of total hydrocarbons, aromatic hydrocarbons, and heavy metals and an increase in the water concentrations of heavy metals and selected anions. Hydrocarbon contamination of sediments was positively correlated with potential contaminant loading (i.e., length of road drained/stream size). The greatest effect was observed at Pigeon Bridge Brook, a small stream receiving drainage from a 1,500-m stretch of the M1 motorway. The dominant

PAHs in contaminated sediment at this site were phenanthrene, pyrene, and fluoranthene, whereas the dominant metals were zinc, cadmium, chromium, and lead. Differences between the station upstream and downstream of discharges in the diversity and composition of the macroinvertebrate assemblages were detected in four out of the seven streams surveyed. However, there was no evidence of an effect on either the diversity or abundance of epilithic algae. The diversity of the aquatic hyphomycete assemblage was only affected at the most impacted site. Reductions in macroinvertebrate diversity were associated with reductions in the processing of leaf litter and a change from an assemblage based on benthic algae and coarse particulate organic matter to one dependent upon fine particulate organic matter.

2. Identifying major toxicants- Abstract: Previous studies have provided prima facie evidence that runoff from the M1 motorway, UK, affects both the quality of the receiving water and the biota living there, in sites short distances from point sources- i.e., possible worst-case situations. Because discharges contain a wide variety of contaminants, both the identification of toxicants and the establishment of causal relationships between observed changes in water/sediment quality and biology are often difficult. In this particular case, the problem was addressed by conducting a series of toxicity tests using the benthic amphipod *Gammarus pulex*. The abundance of this species was greatly reduced downstream of the point where motorway runoff entered the stream. Stream water contaminated with motorway runoff was not toxic to *G. pulex*. However, exposure to contaminated sediments resulted in a slight reduction in survival over 14 d, and sediment manipulation experiments identified hydrocarbons, copper, and zinc as potential toxicants. Spiking experiments confirmed the importance of hydrocarbons, and fractionation studies indicated that most of the observed toxicity was due to the fraction containing polycyclic aromatic hydrocarbons. Animals exposed to contaminated sediments and water spiked with sediment extract accumulated aromatic hydrocarbons in direct proportion to exposure concentrations.

Urbanization, an overview (Williams and Feltmate, 1992)

Two major effects of urbanization on aquatic systems and insects are, (a) increases in sediment loads during construction phases, and (b) post-storm increases in the discharge of streams and rivers downstream from developments.

- Higher levels of sedimentation can affect aquatic insects by altering biochemical conditions, food resources, respiratory diffusion gradients, and habitat space.
- In a laboratory stream, several species of mayfly, stonefly and caddisfly, when given a choice between sedimented and unsedimented regions, all selected unsedimented substrate.
  - Avoidance of sedimented regions was due to the loss of interstitial space between stones, and behavioural observations revealed that the insects would not excavate fine particles.

- For a 3rd order stream through the city of Edmonton, it was found that although the density of insects was higher within the city (e.g. chironomids and tubificid worms), diversity and richness (number of species and individuals) of the fauna was much lower than that were found in the portion of the same stream upstream of the city.
- In several other cases elsewhere, reductions in densities of aquatic insects in areas of stream exposed to heavy siltation were related to increases in catastrophic and behavioural drift (Rosenberg and Wiens, 1978).

Chironomid mouthpart deformity frequencies as an indicator of community health (Diggins and Stewart, 1998)

Benthic community metrics can be very useful in ranking the health of specific sites, but this study shows that more detailed metrics (e.g., taxonomically detailed chironomid data, *Chironomus* mouthpart deformity frequencies) provide additional information on community health that justifies the extra effort required for their assessment.

- The mean density of the family Chironomidae decreased (R^2=0.41, p=0.01) with increasing factor scores (i.e., higher trace element concentrations, As, Cd, Cu, Fe, Hg, Mn, Ni, Pb, and Zn).

- Mean richness and diversity of the chironomid community were strongly negatively associated with factor scores (R^2=0.77 and 0.76, respectively, p<0.001), while the prevalence of the tolerant genera *Procladius* and *Chironomus* increased with trace element levels (R^2=0.55, p=0.002).

- Mouthpart deformities in larvae of *Chironomus thummi* group also increased with higher trace element levels (R^2=0.72, p<0.001). Mouthpart deformities of *Chironomus* larvae (mostly *thummi* species group) were assessed, and were reported as the % of larvae in each sample displaying distinct aberrations within the mentum. Deformities included missing or extra mentum teeth, fused or misshapen teeth, gaps within the mentum, and notable asymmetry.

- Chironomid larvae are known to bioconcentrate a number of contaminants, and there is some evidence associating deformities with bioconcentration. Higher tissue concentrations of polycyclic aromatic hydrocarbons (PAHs) in deformed vs normal larvae of *Chironomus anthracinus* in the Welland River, Ontario were noted by Dickman et al (1992). Janssens de Bisthoven et al (1992) measured higher levels of Cu and Pb, but not Cd or Zn, in deformed vs normal larvae of *Chironomus thummi* in the Dyle River, Belgium.

Sublethal parameters in morphologically deformed *Chironomus* larvae (Janssens de Bisthoven et al., 1998)

- Parameters of condition between normal and deformed fourth instar larvae of *Chironomus* gr. *thummi* were compared in four populations: one reference (PE) and two metal-polluted sites (NP and SCH) in the River Dommel, and one site polluted by domestic sewage and copper in the River Ijse (NEI).

- The site PE ranked lowest for metal body burdens, deformities, mortalities and emergence duration, while SCH and NEI ranked highest.

- Deformed and non-deformed larvae most often did not differ in length and weight (*in situ* end-points for growth); when differences occurred, deformed larvae tended to be smaller.

- The energy content and dry weights in one population (NEI) were lower in normal larvae than in the weakly deformed ones. The percentage of ash-free dry weight was lower in deformed larvae of the polluted Dommel sites, compared to the normal ones.

- The *in vitro* emergence rate (end-point for development of fourth instars) for the reference population PE, both in its own sediment and in artificial cellulose substrate, was better than for the other sites. In two populations (NEI, SCH) the development of deformed larvae in their own sediment was slower, with higher mortality, than for the normal larvae. In one population (NP), normal and deformed larvae survived and developed equally well. The emergence rates of the respective populations were similarly ranked when the larvae were raised in an artificial cellulose substrate.

- Elution peaks of alleged metal-binding proteins were lower in deformed larvae from SCH and NEI, but higher in deformed larvae from NP, than in normal larvae.

- A different development rate and mortality of deformed larvae in non-adapted populations and the possibility of metal adaptation, as in site NP, may modulate the final outcome of deformity frequencies, thus having an impact on the biomarker value of deformities in benthic midge larvae.

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