USE OF BIOTOXICITY TESTS FOR ESTIMATING IMPACT OF STORMWATERS ON AQUATIC LIFE

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ABSTRACT

A test protocol was evaluated for estimating the acute toxicity of urban stormwater runoff to aquatic life. Potential deleterious effects of storm flows on the aquatic community of small artificial impoundments were examined by application of short-term bioassays. Definitive, static renewal, acute toxicity tests were performed using the fathead minnow, Pimephales promelas, and the crustacean, Daphnia magna. The feasibility study indicated that short-term bioassays may provide an alternative to individual chemical constituent measurements and comparisons to numerical water quality criteria for protection of aquatic life. Biotoxicity tests may identify synergistic interactions to chemicals which individually meet specific water quality criteria but collectively lead to toxicity.

INTRODUCTION

Background

Urban lakes are found throughout metropolitan areas. They are often designed as stormwater retention structures to meet runoff management requirements. When stormwater runoff enters these impoundments it transports metallic and organic pollutants originating from automobile oil and wear metals deposited on streets and parking areas (Mance and Harman 1978, Galvin and Moore 1982, Athayde et al. 1983, Fletcher et al. 1983, Milligan et al. 1984, Hoffman et al. 1985, Novotny et al. 1985, Pitt 1985, Amalfi 1988), pesticide and herbicide residues from residential yards and community parks (Cole et al. 1984), and other toxicants improperly disposed on streets and vacant lots.

Conventional physical and chemical analyses are usually conducted to assess the impact of stormwater runoff on aquatic organisms in the receiving stream. Individual constituent concentrations are compared to numerical standards (USEPA 1986) to determine the potential toxicity of the water to aquatic species at different concentrations of the specific constituent. Numerical standards exist for physical characteristics such as temperature and dissolved and suspended solids; inorganic chemicals as heavy metals, ammonia, oxygen, and sulfides; and organic chemicals including chlorinated and aromatic solvents. Although these water quality criteria appear to cover most compounds that could be expected to be present in urban stormwater runoff, comparison of constituent concentrations does not permit evaluation of synergistic or antagonistic effects between the stormwater components.

The USEPA (1985a, 1985b) has developed bioassay test procedures designed to assess the toxicity of wastewater effluents on aquatic organisms in the receiving stream. Sensitive aquatic species are exposed to various concentrations of the discharge water for a fixed time period. Organisms response is measured as growth, reproduction, or mortality. These procedures are advantageous because they: (a) evaluate actual organism response, (b) allow for manipulation of physical variables (time, temperature, pH, etc.), (c) provide a definitive effect concentration, (d) permit use of a variety of test organisms including resident species, (e) eliminate the need for expensive chemical tests, (f) allow assessment of receiving water quality impact on toxic response through use of ambient or synthetic waters, and (g) account for synergistic and antagonistic effects between pollutants.

Objective

A study was conducted to determine the feasibility of using acute biotoxicity screening tests for assessing the toxicity of stormwater runoff on aquatic organisms in urban lakes. The fathead minnow, Pimephales promelas, and the water flea, Daphnia magna, were selected as representative test organisms. Fathead minnows show sensitivity to metallic pollutants and dissolved gases such as ammonia and sulfides, while Daphnids are more sensitive to organic contaminants. Should toxicity be observed in stormwater runoff samples, the relative responses of the two species could shed light on the general class of compounds responsible for the detrimental effect.

PROCEDURES

Field Methods

Stormwater runoff samples collected at two sites were evaluated. Grab samples of stagnant stormwater runoff was collected from a large stormwater conveyance structure using pre-cleaned, non-toxic, plastic carboys. This type of water, consisting of highway and commercial property runoff, could eventually be discharged into urban impoundments during a major storm event. A second grab sample was collected from a discharging stormpipe which terminates at a small, recreational urban impoundment. The first-flush sample was collected in containers as described above. This sample was assumed to represent stormwater runoff from a residential area, and a worst-case scenario in which a maximum contaminant load would be present in the initial stormwater discharge.

Samples were transferred to insulated chests and held at 4°C during transport and storage.

Laboratory Methods

Test procedures were in general accordance with those published by USEPA (1985a) for static renewal, acute toxicity screens and are summarized in Table 1. Mortality was selected as the effect response, with the LC50 (concentration at which 50 percent of the organisms are affected) acting as the end point of the test.

Samples and dilution water were brought to test temperature (18-22°C). Each sample was diluted with synthetic soft water for the P. promelas assays and synthetic moderately hard water for the D. magna assays (Table 2) to produce concentrations of 10, 25, and 50 percent stormwater. Undiluted stormwaters served as the 100 percent concentrations and synthetic water acted as the control. A 750-mL aliquot of each soft water dilution was transferred to individual 1-L glass vessels. A total of ten, randomly-selected fathead minnows (nine-day old) were loaded into each vessel. A 50mL aliquot of each moderately hard stormwater dilution was also added to individual 75-mL glass jars. Ten, randomly-selected Daphnids (less than 24-hr old neonates) were placed in each vessel. All test organisms were obtained from laboratory-reared organisms to assure that no exposure to contaminants had occurred for multiple generations.

Stormwater dilutions were analyzed for temperature, dissolved oxygen, pH, alkalinity, total chlorine, and specific conductance as specified in the test protocols using standard laboratory procedures (APHA 1989). Measurements were conducted to assure that no significant change in basic water chemistry, which might affect organism survival, occurred during the exposure period. Accordingly, because of rapid oxygen depletion during the initial exposure period and potential for mortality due to oxygen deprivation (<40 percent saturation), all sample vessels were aerated at a rate of 100 bubbles per minute using an oil-less diaphragm pump.

The solution in each test vessel was renewed with freshly-prepared dilutions of the appropriate composition at the end of each 24-hr period. Organisms and a small portion of the sample were carefully removed from the test vessels prior to sample renewal and then immediately returned to the vessels. The number of dead organisms in each test vessel was determined and recorded at this time. The total exposure period was 96 hours for P. promelas and 48 hours for D. magna.

Data Analysis

Mortality data were evaluated by Probit Analysis using a computer-driven statistical package provided by the USEPA Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

RESULTS

No mortality occurred in tests involving dilutions of both stormwater sources with Daphnia magna as the test organism. Because of the absence of toxicity, statistical analysis of the test data was not warranted.

Considerable mortality was observed for Pimephales promelas in the various concentrations of both stormwater sources. Ninety-percent mortality occurred in the 100-percent stagnant stormwater and 100-percent mortality occurred in the 25-percent first-flush stormwater. Mortality data and results of the Probit analyses are presented in Tables 3 and 4. The computed LC50 for the stagnant stormwater was 22.3 percent, with a 95-percent confidence interval of 7.0 to 40.5 percent. An LC50 of 12.6 percent was computed for the first-flush stormwater, with a 95-percent confidence interval of 7.5 to 27.0 percent.

DISCUSSION

Biotoxicity tests can be used to assess toxicity of stormwater runoff to aquatic life. The procedure may account for synergistic and antagonistic effects of contaminants which may not be apparent by chemical analysis and comparison to numeric water quality standards. It is possible that stormwater contaminants, which individually meet water quality criteria for aquatic life protection, may interact in the the stormwater discharge or with chemicals in the receiving stream to render a cumulative toxic effect on sensitive species. Conversely, chemical interactions in the stormwater or receiving impoundment may transform the pollutants to non-toxic forms.

Initial data indicate that stormwater runoff contributions of 10 to 40 percent of lake volume may be toxic to early life stages of sensitive aquatic species. Based on the response of P. promelas, metals are a likely cause of the toxicity. Although D. magna exhibited no toxic response to the stormwaters of the screening tests, aeration of the test vessels may have negated toxic effects of volatile organic compounds. The runoff samples collected had observable oil sheens on the surface. The data do indicate that non-volatile organics are not a likely source of toxicity in urban runoff samples. These conclusions are in general agreement with previous priority pollutant analyses conducted on urban stormwater runoff entering several urban impoundments in the same geographic location (Amalfi 1988). Few extractable organic compounds and no volatile organic priority pollutants were detectable in urban runoff collected at five sites during the referenced study. However, metals including cadmium, nickel, copper, chromium, and zinc were found in nearly all samples.

Future feasibility studies should utilize ambient receiving water as the dilution water in the bioassays. The procedure would account for physical and chemical characteristics of the impounded water which may affect the environmental fate, longevity, and bioactivity of the stormwater runoff contaminants.

TABLE 1

TEST CONDITIONS FOR ACUTE TOXICITY ANALYSES WITH PIMEPHALES PROMELAS AND DAPHNIA MAGNA

	P. promelas	*D. magna*
Temperature	20°C +/- 2°C	20°C +/- 2°C
Light quality	50-100 ft c	50-100 ft c
Photoperiod	8-16 hr light/24 hr	8-16 hr light/24 hr
Test vessel size	1 L	125 mL
Test solution vol.	0.75 L	50 mL
Age of organisms	1-90 days	< 24 hours
No. organisms/vol	10 max	10 max
Feeding	not required	not required
Aeration	none unless < 40% satn	none unless < 40 satn
Dilution water	soft synthetic	moderately hard synth
Test duration	96 hr	48 hr
Effect measured	mortality	mortality

TABLE 2

SYNTHETIC DILUTION WATER SPECIFICATIONS

	Final Water Quality	
	Soft	Mod. Hard
pH, SU	7.2-7.6	7.4-7.8
Hardness, mg/L as CaCO3	40-48	80-100
Alkalinity, mg/L as CaCO3	30-35	60-70

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TABLE 3.  P. PROMELAS ACUTE TOXICITY SCREEN WITH STAGNANT STORMWATER

                                       Observed   Adjusted   Predicted
           Number     Number          Proportion Proportion Proportion
Conc.      Exposed   Responding       Responding Responding Responding

 10.0000     10          3              0.3000     0.3000     0.2721
 25.0000     10          5              0.5000     0.5000     0.5338
 50.0000     10          7              0.7000     0.7000     0.7283
100.0000     10          9              0.9000     0.9000     0.8709


Chi - Square Heterogeneity    =    0.201

Mu       =   1.349155
Sigma    =   0.575753

Parameter    Estimate    Std. Err.    95% Confidence Limits
-----------------------------------------------------------
Intercept    2.656714    0.935480    (0.823173,     4.490255)
Slope        1.736855    0.613504    (0.534388,     2.939322)

Theoretical Spontaneous Response Rate    =    0.0000


              Estimated EC Values and Confidence Limits

                                                 Lower        Upper
    Point              Conc.                  95% Confidence Limits

    EC  1.00          1.0228                  0.0005         4.3816
    EC  5.00          2.5240                  0.0085         7.6508
    EC 10.00          4.0857                  0.0398        10.3838
    EC 15.00          5.6551                  0.1123        12.8414
    EC 50.00         22.3437                  6.9681        40.5240
    EC 85.00         88.2806                  6.9681        40.5240
    EC 90.00        122.1913                 46.7703      1182.6928
    EC 95.00        197.7932                 81.6863     15010.6406
    EC 99.00        488.1235                144.6551    272359.5000
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                            Version 1.4

TABLE 4.  P. PROMELAS ACUTE TOXICITY SCREEN WITH FIRST-FLUSH STORMWATER

                                      Observed   Adjusted   Predicted
          Number     Number          Proportion Proportion Proportion
 Conc.    Exposed   Responding       Responding Responding Responding

 Control    10          1              0.1000     0.0000     0.1000
 10.0000    10          3              0.3000     0.2222     0.2222
 25.0000    10         10              0.9900     0.9889     0.9889
 50.0000    10         10              1.0000     1.0000     1.0000
100.0000    10         10              1.0000     1.0000     1.0000


Chi - Square Heterogeneity     =    0.201

Mu      =    1.099727
Sigma   =    0.130407

Parameter     Estimate    Std. Err.    95% Confidence Limits
--------------------------------------------------------------
Intercept    -3.433084   3.616706    (-10.521751,     3.655736)
Slope         7.668274   3.349074    (  1.104089,    14.232460)

Spontaneous   0.100001   0.094868    ( -0.085939,     0.285942)
Response Rate


               Estimated EC Values and Confidence Limits

                                               Lower        Upper
    Point              Conc.               95% Confidence Limits

    EC  1.00          6.2569               0.1179          9.2512
    EC  5.00          7.6775               0.4699         10.7310
    EC 10.00          8.5624               0.9667         11.8013
    EC 15.00          9.2166               1.5527         12.7479
    EC 50.00         12.5813               7.5413         26.9519
    EC 85.00         17.1744              12.4484        167.6621
    EC 90.00         18.4866              13.2713        272.8644
    EC 95.00         20.6174              14.4328        567.6545
    EC 99.00         25.2984              16.5812       2284.8472
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