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Project Summary

A Stress Function for Evaluating Strategies for Water Quality Management

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This investigation explores the relationship between biological communities and the physical and chemical conditions in the aquatic environment. Seasonal patterns and the duration and probability of the occurrence of chemical conditions and physical events are established by means of computer modelling. An instantaneous measure of stress is calculated by summing the decimal fractions of the 96-hr lethal concentrations (for bluegills) of each of 21 toxicants. These data are summarized as a quasi-continuous stress function calculated over 1-hr intervals. The stress function is related to five distinct biological communities ranging from the most to the least tolerant of pollution.

Data from a test watershed in northeastern Illinois yielded stress functions as follows: 0.120 to 783.7 (mean 23.02) from a site with no fish, 0.155 to 98.47 (mean 1.038) from a site with a carp population, and 0.005 to 0.279 (mean 0.116) from a site with a bass population.

A hypothetical management plan to reduce the ammonia component at the no-fish site was incorporated into the stress function. This plan limited effluent ammonia concentrations to 1.5 mg/liter during summer months and 4.0 mg/liter during the winter, eliminated combined sewer overflows, reduced sediment oxygen demand levels substantially, and increased dissolved oxygen levels moderately in treatment plant effluents. Mean stress was reduced from 23.02 to 2.12—more than an order of magnitude. This level was still significantly higher than that of the carp site, primarily because of residual chlorine in the effluents from wastewater treatment plants. These results suggest that if species other than carp are desired in the fishery, further control strategies might need to be implemented.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This report introduces the concept of the stress function as a means of expressing the interrelationships between water quality conditions and the aquatic biota. The study is based partly on the bluegill toxicity index developed by Richard E. Sparks and Kenneth S. Lubinski of the Illinois Natural History Survey. The toxicity index represents an instantaneous summation of the concentrations of up to 21 toxicants relative to their acute lethal effects on the bluegill, *Lepomis macrochirus*. The *stress function* is a *quasi-continuous* time series obtained by joining toxicity index calculations to the output of the Hydrocomp model. The stress function is constructed from the given information regarding the physical and chemical conditions of the stream (i.e., point sources, nonpoint sources, and instream physical and chemical interactions). Thus each function represents the signature of the stream reach and reflects the stress that is endured by the resident aquatic community.

Hydrocomp Nonpoint Source Model

The Hydrocomp model was developed as a tool for the evaluation and analysis of nonpoint pollution problems. The model continuously simulates hydrologic processes (including snow accumulation and melt), erosion processes, and pollutant accumulation, generation, and transport from the land surface. Sediment and sediment-like materials are used as the basic indicators of nonpoint pollutants. These erosion processes are simulated separately on both pervious and impervious areas. Pollutant loadings are determined by multiplying the resulting sediment discharge by potency factors representing the concentration of the pollutant in the sediment. The model simulates the processes that determine nonpoint pollution and is applicable to urban, agricultural, forested, and construction areas.

The Hydrocomp model is composed of three major subroutines: MAIN, LANDS, and QUAL. MAIN, the master or executive subroutine, reads model parameters and meteorologic data, initializes variables, monitors the passage of time, calls the LANDS and QUAL subroutines, and prints output summaries. LANDS, based on the Stanford Watershed Model, simulates the hydrologic response of the watershed and the process of snow accumulation and melt. The model transforms the input data into streamflow using a moisture-accounting procedure. The QUAL subroutine simulates erosion processes, sediment accumulation, pollutant transport from the land surfaces, and instream physical, chemical, and biological processes. The sources of constituents represented in the model are pervious surface washoff, impervious surface washoff, groundwater, point sources such as municipal and industrial wastewater treatment plants, and bottom sediments.

Toxicity Index

The toxicity index model was developed by Sparks and his associates to demonstrate how existing water quality monitoring data could be used to evaluate the suitability of a lake or stream for fish life, and if the water was unsuitable, to determine which factors were responsible. The bluegill sunfish was used as the reference organism because it is a panfish that is common in North America and because its sensitivity to many chemicals has been determined in the laboratory. The toxicity units were therefore called bluegill toxicity units (BGTU). For a single component, one bluegill toxicity unit (1.0 BGTU) represents the lethal pollutant dose—or that level of contaminant that would kill about 50% of the fish in 4 days. A level greater than 1.0 BGTU would kill most fish in a shorter period of time, and a level below 1.0 BGTU is considered sublethal (although a value close to 1.0 might kill a few sensitive fish over a period of days).

The water quality parameters were divided into three categories: limiting factors, modifying factors, and toxicants. The limiting factors are temperature, pH, and dissolved oxygen, which must be within a certain range to permit fish to survive. The model includes both a wide range (within which bluegills can survive for several days) and a narrower range (within which bluegills can survive indefinitely as well as carry on normal functions such as growth and reproduction). Temperature, pH, and dissolved oxygen also are modifying factors in that they modify the toxicity of some chemicals by changing the chemical equilibria in the water or the sensitivity of the fish. Calcium is also a modifying factor because the greater its concentration in water, the less sensitive the bluegills and other fish are to certain toxicants such as heavy metals. Twenty toxicants have been tested for toxic effects on bluegills and were used in computing toxicity indices.

The joint toxicity of all the chemicals present at a particular water quality sampling station at a particular sampling time was estimated by adding the toxicities contributed by the individual chemicals. This estimate of the joint toxicity is the toxicity index, and the toxicity contributed by any particular chemical is defined as a component toxicity. The water quality parameters considered are: ammonia, arsenic, boron, cadmium, chlorine, chromium, copper, cyanide, dissolved oxygen, fluoride, hardness, pH, iron, LAS, lead, manganese, mercury, nickel, nitrate and nitrite, phenol, silver, temperature, and zinc.

Test Watershed

The DuPage River basin in northeastern Illinois was selected as the test watershed to develop the concept of the stress function. The drainage system contained 30 Illinois EPA water quality sites whose records served as sources of water quality data. All available information regarding the fish of the basin is summarized in Table 1 under the three headings (bass, carp, and no fish) corresponding to communities now characteristic of that reach of the river.

Computer Simulations

To perform simulations of water quality and to generate time series stress functions, one representative site at each of the three existing habitat types was selected. Computer simulation of the stress function was performed for a 3-year period for the three study sites. The following were included as component toxicities in the calculation of the total stress at each site because these items were known to be present in significant concentrations in at least one of the sites: ammonia, cyanide, lead, zinc, copper, LAS, and residual chlorine.

Stress functions for each site and component toxicities are given in Table 2. Inspection of the mean total stress at each site reveals that the levels are quite high at the no-fish site, significantly lower at the bass site, and intermediate at the carp site. These results are in line with initial predictions.

The extremely high mean stress value at the no-fish site is due to relatively high levels of ammonia, LAS, and residual chlorine, combined with very low dissolved oxygen concentrations—particularly during the summer months. Municipal wastewater treatment plants located upstream of the no-fish site are the primary cause of the significant levels of ammonia, residual chlorine, and LAS toxicity. Because of lower ammonia levels and improved dissolved oxygen concentrations, the mean ammonia stress contribution at the carp site was substantially lower than at the no-fish site. The bass site typically had such higher dissolved oxygen and lower ammonia concentrations in the summer months, so its ammonia component was very much lower than that of the no-fish site. The bass site also received a smaller contribution from the treat-

Table 1. *Fish Known or Likely to Occur at Three Sites in the DuPage River Basin Before 1908, Since 1950, and in 1976*

Species	Bass			Carp			No Fish		
	1908	1950	1976	1908	1950	1976	1908	1950	1976
Grass pickerel	x	-	-	x	-	-	-	-	-
Northern pike	x	-	-	x	-	-	-	-	-
Stoneroller	x	x	x	x	x	-	x	-	-
Goldfish	-	-	-	-	x	-	-	-	-
Carp	-	x	x	-	x	x	-	-	-
Hornyhead chub	x	x	x	x	-	-	x	-	-
Golden shiner	-	x	x	-	-	-	-	-	-
Emerald shiner	x	x	x	x	-	-	-	-	-
Striped shiner	x	x	x	x	-	-	x	-	-
Bigmouth shiner	-	x	x	-	x	-	-	-	-
Blackchin shiner	x	-	-	x	-	-	-	-	-
Blacknose shiner	x	-	-	x	-	-	x	-	-
Spotfin shiner	-	x	x	-	x	-	-	-	-
Sand shiner	-	x	x	-	x	x	-	-	-
Redfin shiner	x	x	-	x	x	-	-	-	-
Bluntnose minnow	x	x	x	x	x	x	x	-	-
Fathead minnow	-	x	x	-	x	-	-	-	-
Creek chub	x	x	x	x	-	x	x	-	-
White sucker	x	x	x	-	-	x	-	-	-
Creek chubsucker	x	-	-	x	-	-	-	-	-
Northern hog sucker	x	-	-	x	-	-	-	-	-
Golden redhorse	x	-	-	x	-	-	-	-	-
Black bullhead	x	x	x	x	-	-	x	-	-
Yellow bullhead	x	-	-	x	-	-	x	-	-
Stonecat	-	x	-	-	x	-	-	-	-
Tadpole madtom	x	-	-	x	-	-	-	-	-
Blackstripe topminnow	x	-	-	x	-	-	x	-	-
Starhead topminnow	x	-	-	x	-	-	x	-	-
Brook silverside	x	-	-	x	-	-	-	-	-
Rock bass	x	x	-	x	x	-	-	-	-
Green sunfish	-	x	x	-	x	x	-	-	-
Pumpkinseed	-	x	-	-	x	-	-	-	-
Bluegill	-	x	x	-	x	-	-	-	-
Smallmouth bass	x	-	-	x	-	-	-	-	-
Black crappie	x	x	x	-	-	-	-	-	-
Mud darter	x	-	-	x	-	-	-	-	-
Rainbow darter	x	-	-	x	-	-	-	-	-
Least darter	x	-	-	x	-	-	-	-	-
Johnny darter	x	-	-	x	-	-	x	-	-
Banded darter	x	-	-	x	-	-	-	-	-
Slenderhead darter	x	-	-	x	-	-	-	-	-
Total species	31	21	17	28	14	6	12	0	0

ment plant, so the residual chlorine and LAS toxicities were lower as well.

After results were examined for the basic stress function, it was tested for sensitivity to dissolved oxygen, hardness, temperature, and pH. In addition, a hypothetical management plan to reduce the ammonia component at the no-fish site was developed and incorporated into the stress function. The plan involved several strategies: (1) Limit wastewater treatment plant effluent ammonia concentrations to 1.5 mg/liter during the summer and 4.0 mg/liter during the winter, (2) eliminate combined sewer overflows, (3) reduce sediment oxygen demand substantially, and (4) moderately increase dissolved oxygen concentrations in wastewater treatment plant effluents. Table 3 summarizes the results of this management test. The overall mean stress was reduced from 23.02 to 2.12 BGTU—more than an order of magnitude. Ammonia toxicity, which was the principal target of the management strategy, was reduced by nearly three orders of magnitude. Inspection of the component toxicities showed that residual chlorine from the wastewater treatment plant effluents was the principal component of stress (1.935).

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Table 2. *Stress Function and Component Toxicities at Three Sites in the DuPage River Basin (in Bluegill Toxicity Units)*

Item	No-fish site	Carp site	Bass site
Total Stress:			
Maximum	783.7	98.47	0.279
Minimum	.120	.155	.005
Mean	23.024	1.039	.115
Component toxicity:			
Ammonia	20.18	.116	.014
Cyanide	.088	.081	.000
Lead	.023	.016	.000
Zinc	.004	.046	.003
Copper	.020	.020	.008
LAS	.772	.107	.030
Residual chlorine	1.937	.653	.060

Table 3. *Impact of a Hypothetical Water Quality Management Plan on the Stress Function at the No-Fish Site (in Bluegill Toxicity Units)*

Item	Unaltered run	Altered run
Total stress:		
Maximum	783.7	51.48
Minimum	.120	.118
Mean	23.024	2.121
Component toxicity:		
Ammonia	20.18	.023
Cyanide	.088	.079
Lead	.023	.000
Zinc	.004	.003
Copper	.020	.008
LAS	.772	.073
Residual chlorine	1.937	1.935

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The complete report, entitled "A Stress Function for Evaluating Strategies for Water Quality Management," (Order No. PB 82-109 828; Cost: $11.00, subject to change) will be available only from:
National Technical Information Service
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