Journal of Environmental Sciences (China) Vol.4, No.1, pp. 1 – 9 , 1992 ISSN 1001-0742

Coping with the environmental effects of point-source discharges

John Cairns, Jr.* and B. R. Niederlehner

University Center for Environmental and Hazardous Materials Studies,
Virginia Polytechnic Institute and State University,
Blacksburg, Virginia 24061-0415, USA

Abstract —Current methods for assessing the environmental impact of point source discharges in the United States are reviewed. The emphasis of many assessments of damage from pollution is shifting from chemical or technological standards to biological standards, i.e., the protection of biological integrity in the receiving system. The importance of integrating information from chemical measurements, toxicity tests, and field surveys in impact assessment is re-emphasized. Ways in which environmental professionals can improve methods for assessing damage from pollution and its control are discussed.

Keywords: effluents; biological integrity; environmental assessment; toxicity tests; water pollution.

ISSUE DEFINITION

Society withdraws surface and ground waters to use as domestic, process, or cooling waters. Important users of water include steam electric power plants, chemical industries, pulp and paper processing factories, petroleum products industries, and food processing plants and so on. The water used for these purpose is often altered chemically and/or physically before being returned to the environment at one or several discrete locations (hence the term point-source discharge). In some cases, these alterations in water quality can be harmful to the environment. In such cases, the potential for substantive harm needs to be predicted before the fact or documented after discharge and appropriate steps taken to reduce the toxicity of the discharge to protect the environment. Broad-based professional judgement and scientific effort are needed to support the general goals of environmental protection as defined in current law.

IMPACTS OF POINT-SOURCE DISCHARGES

Impairment of biological integrity

At certain concentrations, point-source discharges can alter properties of organisms, communities, and ecosystems. The lifespan, fecundity, growth, visual acuity, swimming speed, equilibrium, feeding rate, spawing season, migration route, and resistance to disease or parasites of organisms can be affected. In addition, properties of communities and ecosystems, such as taxonomic composition and diversity, nutrient and energy transfer, productivity, biomass, density, stability, and connectivity, can also be altered. Not all alterations of environmental conditions are harmful. Some cause no damage; others may be valuable to human society and be favorably regarded as a subsidy(Odum, 1979); others will decrease the value of the aquatic resource. In these cases, the soundness or integrity of the biological community has been harmed (Cairns, 1977). Current law (the New Water Quality Act of 1987) calls for the restoration and maintenance of the biological integrity of the nation's waters. The continued development of efficient and accurate scientific methods to predict and document biological integrity in a variety of systems will provide the information necessary to evaluate management options and identify the most coasteffective techniques for coping with pointsource discharges.

The most convincing evidence that water quality unimpaired is the direct observation of ecological health coexisting with water use. No instrument devised by humans will measure ecological health or toxicity—only living material can be used for this purpose. This is not an attempt to deny the importance of chemical and physical characterizations of water quality, but to emphasize that when the object of protection is biological integrity, maintenance of biological integrity must be the ultimate measure used to judge success of management of point-source discharges.

The most complete assessments of the environmental effects of existing point-source discharges have three types of information: chemical data, toxicity data, and field survey data (Parkhurst, 1989).

Chemical information can confirm the presence of toxic substance in the discharge and in the affected waterway, but such information cannot assess the effects of that substance on living things. Problems with over-reliance on chemical measures include insufficient sensitivity of chemical analyses for extremely toxic materials, lack of information about what chemicals are causing the problem and, therefore, what chemicals must be analysed, wide changes in concentration and composition of the point-source discharge over time, interactions among the components of a chemically complex discharge such that their combined toxicity differs widely from the sum of their individual toxicities, and changes in biological effects with changes in environmental conditions such as water hardness, temperature, or pH (Brandes, 1985).

In order to assess environmental effects in the field, a field survey typically examines selected biological properties in the river, lake, estuary, or stream to determine whether or not these measurements are consistent with environmental health. The characterization of environmental health can be based on comparisons to similar measures in the same system before exposure to the point-source discharge, in upstream sites, or in reference systems. Conditions in the ambient receiving system are the most relevant and convincing measure of the adequacy of pollution control activities. However, field surveys alone cannot establish a causal link between a point-source discharge and a decline in biological integrity; changes in natural systems could be due to habitat alteration or other changes rather than changes in water quality due to the point-source discharge (Hurlbert, 1984).

Toxicity tests are the experimental exposure of some living things to two or more concentrations of waste, holding other factors constant. Because of the ability to design and replicate these studies, toxicity tests can be used to demonstrate a link between biological effects and the presence of a discharge. But toxicity tests alone lack the complexity of the real world and may not accurately anticipate the magnitude and significance of changes in biological integrity in the field, or may miss the response that will be the most important determinant of biological integrity in the natural system. For example, avoidance of a discharge by fish is not routinely measured but can be the mechanism by which biological integrity is harmed in a stream (Geckler, 1976).

To establish a causal chain from the point-source discharge to a decline in biological integrity in the environment, all three types of information are necessary. (1) A field survey that identified areas with impaired biological integrity suggests a possible problem with water quality. (2) Chemical measurements link the point-source discharge with the affected area. (3) Toxicity tests link the biological impairment with the presence of the waste. It is also necessary to choose endpoints used to characterize biological integrity in both the field and the laboratory with care.

Test endpoints

The responses or endpoints choosen to characterize biological integrity in both field surveys and toxicity tests must be carefully chosen to address management goals effectively (Suter, 1989). Desirable characteristics for endpoints include a quantitative nature, easy interpretation, a logical relationship to the decision at hand, ecological significance, sensitivity, low cost, and measureability. An array of information is always more valuable than a single test. Ideally, a suite of endpoints reflecting both structural and functional changes at various levels of biological organization, i.e., cell, organism, population, community, and ecosystem would be measured in order to assure maintenance of biological integrity at all levels. However, cost is always a factor, and the study team director must exercise extraodinary judgement in seeing that the most useful information for a particular management decision is obtained in the most efficient manner.

Historically, an inventory of the species present in some subsample of the community (fish, algae, macroinvertebrates and so on) has often been used as the endpoint in field surveys. More recent measures developed for efficient determination of biological integrity incorporate both structural and functional characterizations of the community, as well as habitat characterization (Karr, 1986; Plafkin, 1989). Another important feature of these methods is that they base judgements of biological integrity on regionally appropriate norms for intact systems. Other endpoints can also be important for particular systems. Recruitment rates of important species and some estimates of important energe transfer functions such as productivity or detrital processing can be used. Biomarkers, sub-organismal indicators of stress such as levels of enzymes used to detoxify specific pollutants, can also be used (McCarthy, 1990).

The most commonly used endpoint in toxicity tests is death or impairment of reproduction in a laboratory population. Such tests are well developed and are efficient tools for studies of the relative sensitivity of organisms to a specific waste, or relative toxicity of wastes or conditions to a specific organism, or effects on population level responses (such as growth or reproduction) of an important species under specified environmental conditions. Other important endpoints can also be assessed in toxicity tests. Properties of communities, such as competitive success, taxonomic diversity, productivity, and detrital processing, have been used in microcosm or mesocosm toxicity tests (Odum, 1984; Cairns, 1985; 1986a; Kimball, 1985). These tests use more complex systems that simulate one or more important ecosystem processes or atributes and evaluate the effects of a toxicant on these properties. Although methods are not as well developed for these types of tests as for single species toxicity tests, inclusion of community or ecosystem level endpoints in an assessment is becoming increasingly common, and specific methods have been developed for pesticide registration (Touart, 1989) and premanufacture testing under the Toxic Substances Control Act (USEPA, 1987). Initial concerns about excessive cost and difficulty in interpretation of results for microcosm and mesocosm toxicity tests have been resolved for several test methods (Cairns, 1985; 1986a).

Techniques used in managing point-source discharges

1. Existing discharges

For existing discharges, biological monitoring is the primary tool to insure that water quality becomes and/or remains biologically acceptable. Although the term "biological monitoring" has been used to describe any information gathered to assess environmental effects, useful distinctions can be made between one time studies and continuous biological monitoring as a part of a quality control plan. Hellawell (1978) uses the following definitions:

Survey An exercise in which a set of standardized observations (or replicate samples) is taken from a station (or stations) within a short period of time to furnish quantitative or qualitative descriptive data.

Surveillance A continued programme of surveys systematically undertaken to provide a series of observations in time.

Monitoring Surveillance undertaken to ensure that previously formulated standards are being met.

These previously formulated standards are generally based on a definition of a normal operating range for biological conditions at the site of interest and at some similar control area without the point-source discharge: upstream, pre-exposure, or in a reference system. If comparisons of biological conditions to the normal operating range suggest that there is no impairment of biological integrity, one continues surveillance, perhaps with less frequency. Alternately, if these comparisons suggest that biological integrity is damaged at the point-source discharge, this information serves as a feedback control in an established biological monitoring plan. Evidence of impairment in biological integrity automatically initiate more intensive study and, perhaps, remedial action. Examples of remedial actions include changes in the processes or treatment producing the discharge (Mount, 1989) or changes in dispersal or flow of the discharge into the receiving system to reduce the toxicity of the discharge. Continued surveillance after these changes will document the success of efforts to improve the discharge and will document the degree of rehabilitation achieved (Gameso, 1977; Seagle, 1980).

Although biological monitoring often relies on field survey, it is not the only tool used in biological monitoring. Reliance on field survey is complicated when the point-source discharge enters an already degraded system. In many cases, field syrvey cannot distinguish which of several sources of pollution is causing impairment in biological integrity. These conditions force an increased reliance on toxicity testing in clean water to sort out toxic and non-toxic discharges. Existing discharges can be monitored at various places along the waste flow. When toxicity is monitored before the discharge is released to the receiving system, high toxicity can be ameliorated before discharge. These early warning systems provide a means of preventing damage to the environment before it occurs.

2. Proposed discharges

When evaluating proposed rather than existing discharges, there are different possibilities and problems. Biological data can be incorporated into the earliest stages of planning and design of facilities producing point-source discharges. Studies of alternate sites can identify systems less vulnerable to damage from pollution because resident communities are more able to resist damage from pollution and/or to return in a reasonable amount of time to some approximation of original condition following damage. Other factors considered in siting a facility include the uniqueness and value of the intact natural resource and complications from other sources of pollution in the watershed. Initial environmental impact assessments will address some of these concerns. In addition, by evaluating biological response to pilot or simulated effluents, processes and treatment can be designed to minimize toxicity.

Since a proposed discharge has not yet been released to a river, lake, or stream, no field survey of biological effects or chemical concentrations in the real world is possible.

Environmental concentrations and effects must be predicted rather than observed directly, and the validation of these predictions becomes important.

The prediction of environmetal effects before the fact is the purpose of hazard evaluation protocols. Hazard evaluations consist of determining the probability of harm from a predicted concentration of a chemical in the aquatic environment (Cairns, 1978). The hazard assessment process estimates an acceptable concentration of a discharge, i. e., a concentration for which there is no observable damage to biological integrity, and relates this to an independent estimate of the expected environmental concentration (Cairns, 1980). The accuracy of the predictions of environmental effects will depend on : (1) the amount of information available to estimate both acceptable concentrations and environmental concentrations; (2) the degree of variability in the quality and/or quantity of the point-source discharge; (3) the degree of variability in flow and water quality in the receiving system; and (4) the proximity of the waste concentration, after mixture with the receiving water, to the concentration producing a significant adverse biological response.

Acceptable concentrations have most often been estimated from acute and chronic toxicity tests with single species (Homing, 1985; Weber, 1988). Because the sensitivity of organisms to chemicals can vary widely (Kenaga, 1987), and the same species are not consistently the most sensitive to all toxicants (Mayer, 1986), it is important to test more than one species, especially if the management objective is to protect more than just that species. It is theoretically possible to protect the whole environment based on a single test by testing the effects of a waste on the most sensitive response of the most sensitive species. However, this is impossible in practice because wc do not know which of the thousands of species in a natural system will be most sensitive to a particular waste or which of their responses will be most affected (Cairns, 1987). Added to this is the likelihood that test methods would not be available for that most sensitive species. The number of commonly tested aquatic species is probably under 50, yet the number of species in a mid-sized river will be in the thousands and the number of species worldwide has been estimated at 5 to 50 million (Wilson, 1988). But , we can test an array of species and observe a range of sensitivities of tested organisms, then extrapolate with error to untested organisms, untested conditions, and untested responses found in the river, lake, or stream (Stephan, 1985; Brandes, 1985).

We can also test for the effects of wastes on endpoints that integrate effects over many individual species. Microcosm and mesocosm toxicity tests often measure endpoints that are the object of protective management and identical to those used in field survey, i.e., species diversity (Cairns, 1985; 1986a). This similarity in endpoints makes prediction of field effects from laboratory tests somewhat simpler because there is no need to extrapolate from one test endpoint to a different characteristic that is the object of protection. However, prediction of actual events in the field still requires extrapolation because of differences in such things as: (1) species and age class compositon of laboratory and field communities; (2) energy import and export fluxes; and (3) biological recruitment.

An array of data will provide the best basis for prediction of acceptable concentrations and that array can include many types of endpoints that are importants in a particular system, e.g., survival and reproduction of an important species, the range of sensitivities of aquatic organisms in general, and effects on important ecosystem processes such as productivity or detrital processing. Information from these separate toxicity determinations could be combined into a single index for use in hazard analyses in the same way different field survey endpoints are combined in protocols for assessment of biological integrity (Karr, 1986; Plafkin, 1989).

Expected environmental concentrations are estimated from predictions of release, fate, and transport of pollutants. Data are collected to characterize probable effluent compositon, dilution, flow and other transport rates, chemical transformation, biotransformation, degradation, recombination, partitioning and so on (Burns, 1985).

Because hazard assessments are carried out before wastes are discharged, there is no immediate opportunity to directly confirm our predictions in the real world; consequently, the question remains: how well do laboratory tests predict ecosystem responses? This question is answered through validation studies that compare predictions from hazard assessments to real world effects (Cairns, 1986b; Sanders, 1985). There is controversy over the adequacy of existing predictive techniques. Estimates of the precision and accuracy with which current laboratory test methods predict environmental concentrations associated with biological impairment vary. One review suggests that an array of toxicity tests with individual organisms or a single micro-or mescosm test can predict an acceptable concentration within an order of magnitude of the actual waste concentration that protects biological integrity in larger test systems or the real world (Cairns, 1987). This level of predictive accuracy can probably be improved with no substantial increase in cost through further validation studies and continuing evaluation of relative merits of various test endpoints in predicting environmental outcome.

NEEDED ACTIONS

Biological parameters should be recognized as the ultimate evidence for whether the goal of protecting biological integrity of the nation's water is being met. Again, no instrument devised by humans will measure toxicity— only living material can be used for this purpose. The trend towards increased use of biological information by regulatory agencies (USEPA, 1984) should be supported by providing the necessary scientific background and methods. Professional societies, representing individuals from diverse groups (industry, academia, government, and conservation groups), can provide a broad-based perspective and are an excellent vehicle for affirming the value and facilitating the application of the biological approach to pollution control over the long term.

To facilitate the use of biological information in the management of point-source discharges, AFS members can contribute by: (1) affirming the value of biological information in all stages of planning and regulating point-source discharges; (2) identifying the biological endpoints that are most useful in protecting aquatic communities through comparative laboratory and field validation studies; (3) developing standard methods and procedures best suited to measure useful endpoints; (4) developing indices incorporating both structural and functional measures into integrated indicators of biological integrity for all taxonomic levels and spatial and temporal scales, and (5) certifying individuals qualified to make these determinations.

Acknowledgements — I greatly appreciate the editorial assistance of Darla Donald in the preparation of this manuscript. Much of the manuscript was prepared at the Rocky Mountain Biological Laboratory.

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(Received May 13, 1991)