Alternative approach to assessing water quality impact of wastewater effluents

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PL 92-500, the 1972 amendments to the Federal Water Pollution Control Act, has set "zero pollutant discharge" as an ultimate goal for U. S. waters. It also set as an interim goal, the attainment by 1983 of "fishable, swimmable" waters wherever possible. The mechanism by which this interim goal is to be attained is the application of numeric water quality standards set by the states on the basis of the use classification of the waters of the state. In accordance with the provisions of PL 92-500, the U. S. Environmental Protection Agency (EPA)[1] released water quality criteria (Red Book) that are to serve as the technical foundation for the state water quality standards. These criteria are "worst case" criteria; that is they are in general, concentrations of contaminants in completely available forms that are, based on current knowledge, safe for sensitive organisms to be exposed to for their entire lifetimes or during critical life stages. While in the Foreword to the Red Book, R. Train, then EPA Administrator, indicated that guidance on the implementation of the water quality criteria would be provided in the near future, appropriate guidance has still not been provided. Some states are taking the administratively simple approach of setting their standards numerically equal to the Red Book criteria such that if the standard is exceeded in a water for the total concentration of a contaminant, a violation has been committed. As Lee and Jones[2] and Lee *et al.*[3] have indicated, this is frequently an unnecessarily restrictive approach because the physical and chemical behavior of contaminants in water, the behavior of organisms of interest, and receiving water characteristics all tend to dampen the potential impact of a chemical whose concentration in a water sample exceeds the chronic safe value (standard). An alternative to the worst case approach is therefore needed to provide a technically valid assessment of the impact, need for control, and impact of control of contaminants entering natural waters of the U. S., and as a basis for waste (contaminant) load allocation. During the past several years the authors have been involved in the development of a "hazard assessment approach" for use in assessing, on a site specific basis, the impact of a contaminant on receiving water quality.[4] The focal point of their application-evaluation of this approach has been in the determination of the impact, both in intensity and areal extent, of the ammonia and chlorine residual in domestic wastewater effluents. This paper presents discussion of the use of this approach based on the experience that has been gained in its application to domestic wastewater treatment plant effluents.

DEFINING WATER QUALITY

Before being able to assess the impact of a chemical on water quality, the terms "water quality" and "improvement in water quality" must be defined. According to PL 92-500, the characteristics of water quality that are sought are ". . . chemical, physical, and biological integrity . . ." (fishable, swimmable) wherever attainable. Because of the close tie made between these goals and water quality standards and criteria, "water quality" has unfortunately and inappropriately come to be defined in some states in terms of the comparison of a list of chemical concentrations in a water sample to Red Book water quality criteria or fixed, single-value standards. This is inappropriate because, as discussed in a subsequent section, there are a number of factors other than concentration that influence the impact of a chemical on aquatic organisms and characteristics of the water that may impact the desired uses of the water. As alluded to in the law (by requiring inclusion of the designated uses of the waters as part of water quality standards), and as classically defined, "water quality" should be tied directly to the beneficial uses of a particular waterbody by man. Potential beneficial uses include domestic, industrial, and agricultural water supplies, sport and commercial fishing, recreation, aesthetic quality as perceived by someone sitting on the bank or boating on the water, as well as others.

Selective and sequential testing is needed to assess the impact of effluent discharges.

An example of another aspect of the inappropriateness of using chemical concentration values to assess water quality is the use of orthophosphate concentrations in a water as a measure of the impact of the phosphorus load on eutrophication-related water quality. The amount of orthophosphate per se, in a waterbody is of little concern to the public; rather what is of concern is the impact that the numbers and types of algae and other aquatic plants that will be produced as a result of a particular phosphorus load will have on water quality. The public perception of the impact is highly subjective and depends on a wide variety of geographical, cultural, and socio-economic factors. A certain number and type of algae in a waterbody in the upper Midwest may elicit a completely different public response to utilization of that waterbody than the same numbers and types in another region of the country. This situation has been discussed in greater detail by Rast and Lee.[5]

The Council on Environmental Quality[6] (CEQ), in its attempt to report on the state of the current water quality of U. S. waters, chose to use what is generally recognized as an invalid approach for assessing water quality. It arbitrarily selected single value "standards" against which to compare U.S. EPA STORET computer data for several parameters in order to judge the current "health" of the nation's waters with respect to each parameter. Maps showing the U. S. waters that had concentrations above and below the arbitrary standard were presented in the annual CEQ report.[6] It was indicated in this report that the so-called "excessive" concentrations relative to the standard represented deteriorated water quality conditions. Anyone with even an elementary knowledge of how contaminants affect water quality realize that this approach is technically invalid, grossly misleading, and a complete waste of taxpayers' funds. These efforts can best be characterized as a trivial, number-crunching activity. One example of the lack of technical validity in the CEQ approach is their use of total phosphorus of 0.1 mg/l in U. S. rivers as a "standard" against which "excessive" and "permissible" phosphorus concentrations may be judged. It has been recognized for many years that this value, or for that matter, any single numeric value, is not a reliable indicator of water quality problems in rivers related to phosphorus. Similar problems occur with its standard for lead, as well as other parameters discussed in the CEQ report. It is clear that if the 1980 provisions of PL 92-500 are to be properly implemented, a more technically valid approach to assessing water quality impacts will have to be used by the CEQ as well as other governmental agencies than has been used in the latest CEQ report.[6]

Governmental agencies' taking this administratively simple (but technically invalid) approach to water quality assessment (that is, use of single numeric standards) has given rise to an increased popularity of what may be broadly referred to as "number crunchers" (modelers, statistical analysts, and so forth) in the water quality management field. It has become fashionable and in some instances mandatory that a "water quality model" be developed for particular situations. If an individual knowledgeable in how contaminants affect beneficial uses examines the "water quality models" that are in use today, he will find that most of them have been improperly labeled. Almost without exception, these models should more properly be termed "environmental chemistry-fate" models because they *do not* in any way relate the concentrations and forms of contaminants that they predict to the impairment of beneficial uses of a particular water. Water quality models, if they are properly developed, must include the coupling between a particular concentration of a chemical and its impact on a particular beneficial use of the water. This deficiency also occurs essentially universally in the work of "number crunchers" who purport to be developing water quality monitoring programs. What are called "water quality" monitoring programs should be called "contaminant" monitoring programs unless they include an appropriate component to relate concentration of the contaminant monitored to the beneficial uses by the public of a specific waterbody or part thereof.

From an overall point of view, while focusing on fixed, single value, numeric standards is administratively simple, most of these activities are of limited value in providing the public with what they want to know, namely what improvement in beneficial uses in a specific waterbody will arise from either increased taxes for a public-sponsored contaminant control program, or increased prices of goods for an industry-sponsored control program. The hazard assessment approach discussed below is designed to provide an insight into the answers to the public's question of what the improvement will be in beneficial uses of a water per dollar spent on control. As the 1980s provisions of PL 92-500 are implemented, shifting the emphasis in this country from effluent standards such as "best practicable treatment," to stream standards where attainment of swimmable-fishable waters will frequently be based on waste load allocation associated with best available treatment under water quality limited conditions, it will become necessary to abandon the single value, numeric water quality standards approach that has been used in the 1970s and adopt a hazard assessment approach.

Until such time as substantially larger amounts of money are available for research and pollution control and until techniques are available to judge much more subtle biological effects, man and his use of the water should be the focal point of all water quality considerations. During the late 1960s and early 1970s, the concept of aquatic "ecosystem quality" evolved; it is sometimes advocated that the focal point of pollution control programs should be to control contaminant input to the point at which there is no effect on the numbers, types, and functions of the various aquatic organisms that live in a particular waterbody. While this concept is in keeping with zero pollutant discharge, not only is current scientific capability to detect many such changes limited and costly, but also it is well known that the numbers and types of organisms in an aquatic system can be altered significantly—in some cases to the point of extinction of a species—with little or no impact on the overall ecosystem functioning. The public in general does not at this time seem to be willing to spend large amounts of money for water pollution control unless readily perceptible improvements in water quality will result. It is important to note that while "water quality" is being used here in its broadest sense (which can include the numbers and types of organisms), it is doubtful that large amounts of public funds are going to become available to change the number of benthic worms in a particular aquatic system sediment for example, unless there is a reasonably clear relationship between one type of worm and another in affecting the water quality components that man would perceive, such as the numbers and types of fish present in the waterbody. It is not now nor will it likely become possible in the foreseeable future, to relate subtle changes in types of aquatic organism present, especially the lower forms, to the water quality components of the system that are of greatest importance to the public in general, which are frequently the number, type, and wholesomeness of fish that they can obtain from a particular waterbody.

The hazard assessment approach can be used in helping to determine the desired beneficial uses of the water by providing the information that would enable a comparison to be made between water quality characteristics amenable to supporting various beneficial uses (such as cold water fishery versus warm water fishery versus irrigation water) and the relative cost to achieve these characteristics. Once the desired beneficial uses have been decided, this approach can be used to establish appropriate water quality standards, appropriately sized mixing zones, and contaminant load allocations, as well as to assess the improvement in beneficial uses that could be achieved if the load of certain contaminants were changed by specified amounts.

THE HAZARD ASSESSMENT APPROACH

The hazard assessment approach, discussed by Cairns *et al.*[7], Dickson *et al.*[8] and Lee *et al.*[4], has been developed to provide a technically valid basis for evaluating the impact of a contaminant on water quality. It is a sequential, selective testing scheme to provide pertinent information on the environmental chemistry-fate of the chemical in a particular aquatic system, and on the aquatic toxicology of the chemical in forms that could be encountered.

Aquatic toxicology considers the concentrations of each potentially significant form of the contaminant being considered and its transformation products that can be adverse to aquatic life. This is usually extended to include terrestrial organisms, including man, that use aquatic organisms as food. Environmental chemistry-fate considers the transport pathways and disposition of the chemical in the environment of concern, what transformations of the chemical occur and the rates of these transformations, and provides an estimate of the expected concentrations of the contaminant in the various environmental compartments. A hazard assessment is made by proceeding through a series of testing levels or tiers that develop information on the toxicology of the chemical and its environmental chemistry-fate until a decision can be made that the environmental risk associated with the discharge of the chemical is acceptable or unacceptable.

Aquatic toxicology. Chemicals affect aquatic organisms as a function of the duration of exposure of the organism. The aquatic toxicology portion of hazard assessment provides information on the response of aquatic organisms to the concentrations and forms of chemicals, and durations of exposure that may be encountered in the environment. The objective is to produce a concentration of available forms (or dilution)-duration of exposure-"no effect" relationship such as the general case shown in Figure 1. It shows that the concentration of available forms of a contaminant can often be substantially higher than the chronic safe level without causing harm to the organisms, provided that the duration of the exposure of the organisms to the chemical is sufficiently short. For any chemical, there

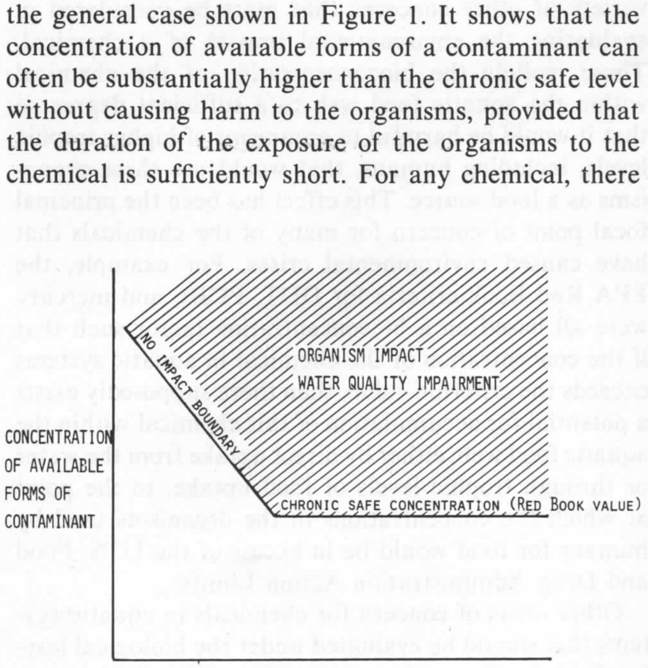


Figure 1—General case concentration of available forms—duration of exposure—"no impact" relationship.

is also a chronic exposure safe concentration for available forms below which no known impact of the chemical has been found. At concentrations of contaminants below the chronic safe concentrations, changing the duration of exposure has no effect on toxicity of the chemical to aquatic life. It is important to emphasize that the response of various organisms to various parts of the available form-duration of exposure-"no effect" relationships shown in Figure 1 will vary. In the high concentration of available form-short duration situation, such as on the left side of the diagram, the effects that are typically noted are those of acute lethality, while those on the right side of the diagram where the concentration of available forms has an impact on the aquatic organisms, the effects of the chemical on the organisms are primarily those associated with impairment of rates of growth or reproduction, alteration of behavioral patterns, and so on. Every meaningful environmental hazard assessment should include the development, even in a rudimentary way, of a concentration of available forms-duration of exposure-"no effect" relationship such as shown in Figure 1. It is evident that environmental chemistry will play a dominant role in developing this relationship because this is not only specific to a type of chemical, but also to each form of a chemical that exists within aquatic systems. A free "aquo" species of a chemical will show a different toxicological behavior in general, than a complexed, sorbed, or otherwise transformed species.

While organism toxicity is often the focal point for impact of chemicals on aquatic systems, there are a variety of other concerns that must be considered in evaluating the environmental impact of a chemical. These include the bioconcentration of the chemical within the aquatic food web to a sufficient degree so that it would be harmful to organisms of higher trophic levels, including humans, that would use these organisms as a food source. This effect has been the principal focal point of concern for many of the chemicals that have caused environmental crises. For example, the EPA Red Book criteria for DDT, PCBs, and mercury were all based on a bioconcentration factor such that if the concentration of the chemical in aquatic systems exceeds the criterion value, then there supposedly exists a potential for accumulation of this chemical within the aquatic food web, either by direct uptake from the water or through trophic levels of food uptake, to the point at which the concentrations in the organisms used by humans for food would be in excess of the U. S. Food and Drug Administration Action Limits.

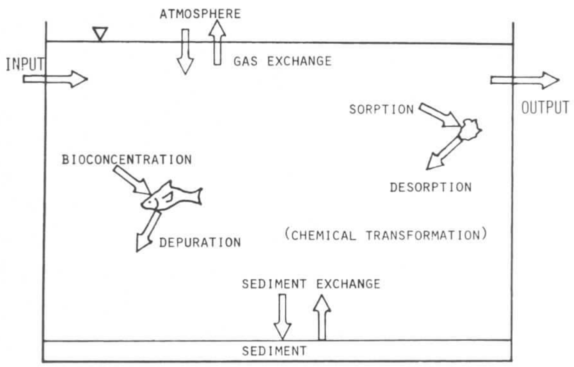
Other areas of concern for chemicals in aquatic systems that should be evaluated under the biological testing for hazard assessment include taste and odor production for domestic and industrial water supplies, stimulation of growth of excessive amounts of certain organisms such as algae by aquatic plant nutrients, as well as a host of aesthetic effects such as color, turbidity, and floating debris.

Environmental chemistry-fate. The environmental chemistry-fate part of a hazard assessment considers the transport and transformation of the chemical of concern and its potentially significant transformation products. For this, the physical processes of advection-transport and dilution-dispersion must be defined for the receiving waters. Environmental chemistry-fate also considers the chemical processes that influence the form(s) of the contaminant and its transformation products. For example, one of the transformation products of ammonia present in domestic wastewater treatment plant effluent which is of the greatest environmental significance is nitrite. Depending on receiving water conditions, the nitrite formed from ammonia could have more far-reaching impacts than the ammonia discharged. In addition to this biologically mediated reaction, major types of reactions that commonly occur in the aqueous environment are acid-base, precipitation, complexation, oxidation-reduction, hydrolysis, phototransformation, gas transfer, and biotic and abiotic sorption. Sorption reactions are among the most important in affecting the transport and toxicology of contaminants, but have not received sufficient consideration in the past. Many of the chemicals having the greatest potential hazard to the environment are highly hydrophobic and, therefore, tend to become strongly attached to particulate matter within the watercolumn and within the sediments. Some of the most important forms of this particulate matter are the hydrous metal oxides of iron and aluminum. Lee[9,10] has discussed the role of iron hydroxide in influencing the behavior of chemical contaminants in aquatic systems. Lee and Jones[11] have recently described the current state of knowledge on the factors influencing this exchange between contaminants associated with deposited sediments and the watercolumn.

The relative significance of each of the above-mentioned transformations in controlling the hazard associated with the manufacture and use of a chemical depends on the thermodynamics and kinetics of the transformations, which are in turn governed by the characteristics of the system such as temperature, light, mixing turbulence, suspended solids, and a variety of chemical properties such as pH, gross and individual organic content, and redox (oxidation-reduction) conditions. While many chemical reactions proceed rapidly, being essentially instantaneous from an environmental impact point of view, there are many reactions that are of significance in aquatic and other environmental systems, for which the rates are sufficiently slow so as to require consideration of their chemical kinetic properties.

Environmental chemistry-fate models can be developed to describe the transport and transformation of chemicals entering the environment. Development of models of this type is mandatory in order to predict, prior to manufacture and use, the hazard associated with a new chemical. For chemicals currently in use, such models are useful in predicting environmental behavior under conditions other than those under which specific studies have been conducted. Figure 2 schematically represents those factors that must be considered in environmental chemistry-fate determination or prediction and shows in general how this would be mathematically formulated. One of the greatest deficiencies in current environmental chemistry-fate modeling is in the formulation of sediment/water interactions and sediment transport. With respect to the latter, while it is relatively straightforward to predict the transport of sand-size particles in aquatic systems, it is not possible to predict with any degree of reliability, the suspension and transport of clay-size particles. Because sand generally has little or no impact on aquatic chemistry or toxicology because of its limited sorption capacity, the existing sediment transport models are essentially worthless in providing the information needed to properly evaluate the hazard of contaminants that tend to be strongly sorbed by natural water particulate matter. There is an urgent need for fundamental work on modeling of the suspension and transport of cohesive clay-size sediments in aquatic systems. Without information of this type, it is virtually impossible to predict, prior to manufacture and use, the environmental fate of contaminants that tend to become strongly associated with these types of particles.

The existing models for contaminants such as PCBs, which tend to strongly interact with natural water particulate matter, have little or no predictive capability in ascertaining the impact of altering the conditions on the environmental significance of the chemical. An example of problems created by using such models to predict contaminant behavior is provided by the New York State Department of Environmental Conservation's proposal for hot spot dredging of the sediments of the Upper Hudson River that contain elevated concentrations of PCBs derived from the General Electric Company's manufacturing operations. In a court settlement, $7 million has been made available to correct the problems associated with PCB discharges. The New York State Department of Environmental Conservation has had a number of studies conducted which had as their purpose developing models to predict the long-term fate of PCBs in the sediment and aquatic organisms near and downstream from the General Electric Company's former PCB discharge. Based on this modeling effort, it has been decided to proceed with hot spot dredging. However, examination of the approach used in formulating the sediment/water exchange portion of the model shows that it was improperly done. It was assumed that all sediment in the Upper Hudson River that contained PCBs held the PCBs with equal tenacity and that the only factor governing the release of PCBs from the sediment was the concentration of PCBs within the sediment. It has been known for many years that the concentration of contaminants in sediments is a very poor indicator of the tendency for contaminant release. Further, it is also well established that aquatic system sediments tend to be heterogeneous with respect to their composition and most importantly their tendency for sorption and release of contaminants. It is very likely that the sediments in the PCB hot spot areas of the Upper Hudson River have elevated PCB concentrations because of their greater tenacity for PCBs compared with sediments of adjacent areas; therefore, they will not release PCBs to the overlying water in direct proportion to their concentrations. Because the purpose of the hot spot dredging is to reduce the PCB concentration in the fish of the area, proceeding with hot spot dredging without properly evaluating sediment/water exchange could result in the expenditure of $7 million for PCB control without lowering the PCB content of the fish to the point that they would be acceptable for use as human food.



$$\frac{D(\text{AVAIL. FORM})}{DT} = K_1(\text{GAS EXCHANGE}) + K_2(\text{BIOCONCENTRATION}) + K_3(\text{SORPTION}) + K_4(\text{CHEMICAL TRANSFORMATIONS}) + K_5(\text{ETC.})\ldots$$

Figure 2—Schematic representation of factors affecting the environmental chemistry-fate of chemical contaminants.

Typical point-source contaminant discharge situation. Figure 3 illustrates a commonly encountered general situation that exists in the vicinity of point-source discharges of contaminants to a river, lake, estuary, or ocean, and demonstrates the need for using a hazard assessment approach rather than fixed, single value standards for assessing water quality impacts. As discussed by Lee and Jones[2], associated with most discharges is an area in which the effluent becomes completely mixed with receiving waters, labeled in Figure 3 as the Zone of Mixing. Contaminant concentrations there are higher than in surrounding waters and for some discharges can cause acute lethal toxicity if or-

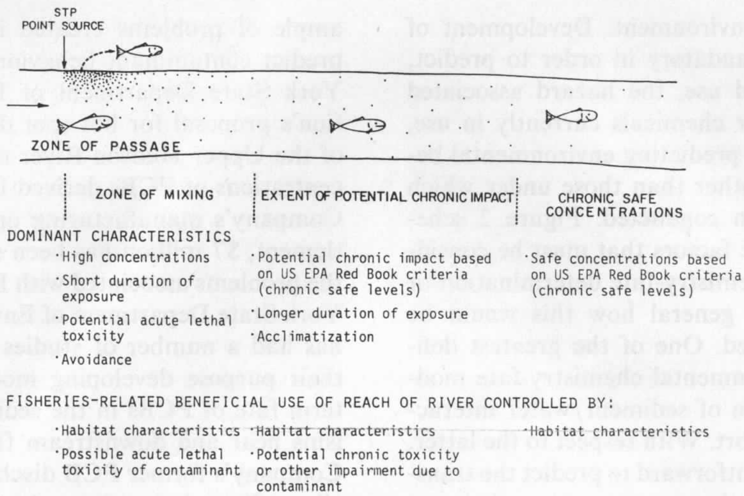


Figure 3—Schematic representation of potential impact of non-persistent chemicals discharged in wastewater effluent.

ganisms were to spend sufficient time in the area. Concentrations in the Zone of Mixing are decreased by dilution and, to some extent depending on the chemical, by chemical reactions such as those discussed previously. Not infrequently, the shape of the discharge plume will create a Zone of Passage in which fish and other mobile organisms can avoid being exposed to the higher concentrations in the Zone of Mixing; many organisms tend to avoid, if possible, elevated concentrations of certain contaminants. Even though concentrations in the Zone of Mixing can be acutely toxic, typical pelagic organism exposure would be expected to be short, minimizing potential adverse effects of the contaminant at higher concentrations. However, there is a possibility that fish would be attracted to the discharge area such as can occur in the winter when the effluent has an elevated temperature compared to the surrounding waters. The fisheries-related beneficial uses of this portion of the reach of the river would in general be limited by potential toxicity and/or habitat characteristics (that is, stream flow, velocity, bed and bank shape and composition, stream depth, and temperature, as well as other factors). It is important to note that the "Zone of Mixing" discussed herein is not necessarily synonymous with the "Mixing Zone" at the edge of which water quality standards are to be applied. The legally defined "Mixing Zone" can be smaller than the Zone of Mixing, however, normally it would be appropriate to have the Mixing Zone larger than the Zone of Mixing when single value, chronic safe (worst case) concentrations are used as standards, because the total concentrations of contaminants can exceed chronic worst case standards without significant impairment of beneficial uses of a water.

After dilution and reaction have reduced the contaminant to concentrations below the acute lethal level, there is an area in which there is a potential for chronic toxicity based on chronic safe levels (Red Book criteria). It would be expected that this area would be larger than the Zone of Mixing, extending until reactions of the contaminant and potential further dilution arising from additional water inputs caused its concentration to be decreased to chronic safe levels. Organism exposure here could be longer than in the Zone of Mixing, but the impact would still be controlled by the concentration of available forms—duration of exposure coupling. It is also possible that fish could become acclimated to some degree and hence may be able to tolerate the potentially chronically toxic concentrations without adverse effects. Fisheries-related beneficial uses of this area would be limited by potential chronic toxicity as well as habitat characteristics.

The third zone begins where contaminant concentrations have been decreased to chronic safe levels based on Red Book criteria. Here, only the habitat characteristics limit fisheries-related beneficial uses of the water.

Not illustrated in Figure 3, but nonetheless an important consideration is the fact that the sizes/shapes of these zones continually change depending on factors such as water flow through the region, contaminant source discharge rate, contaminant concentration, and at times other factors, such as temperature of the discharge and the receiving water. The concentration at any one point in the discharge plume can show large variations over short periods of time. The studies conducted by the authors and their associates, however, on the ammonia released in domestic wastewater treatment plant effluent indicate that the zone in which concentrations are sufficiently high to cause acute lethality to fish residing in the area continuously for 4 days extends for a few hundred meters downstream (with a

Zone of Passage), while the area in which chronic sublethal impacts could occur given sufficient exposure can extend several kilometers downstream of the discharge. It is important to note that the demarcation between the Zone of Mixing and Zone of Potential Chronic Impact in Figure 3 does not necessarily coincide with the extent of the potential acute lethal toxicity.

Given the above considerations and the fact that for some chemicals, concentrations cannot be reliably measured at the Red Book criteria levels, it is inappropriate to use a chronic safe concentration as a water quality standard, especially if exceeding the standard in any sample collected constitutes a standards violation. Instead, if there is question about the potential impact of a discharge on water quality, the hazard assessment approach should be used to estimate the characteristics of the particular system to help determine if the hazard is acceptable in light of the beneficial uses and other limiting factors (such as habitat characteristics, public accessibility). It is only by using such a site-specific approach, considering the characteristics of the chemical, receiving waters, and beneficial uses, that technically valid, cost-effective, yet environmentally protective standards and contaminant control programs can be developed.

TIERED TESTING FOR IMPACT OF DOMESTIC WASTEWATER EFFLUENTS

A hazard assessment should be conducted in a series of levels or tiers of increasing sophistication and detail with a decision point at the end of each tier. This is done to eliminate as much as possible, both unnecessary testing and overlooking unacceptable risk to water quality. In each tier an assessment is made of some aspect of environmental chemistry-fate and aquatic toxicology; the information is compared to make a decision as to the environmental impact. Decision choices at the end of each tier's testing based only on technical input would be:

- Do not discharge effluent containing the substance evaluated because of undesirable impact;
- Restrict discharge to the waterbody, that is, require a specified degree of treatment, in order to reduce environmental hazard to an acceptable level;
- Allow unrestricted discharge as the environmental impact is acceptable; and
- Continue testing to better define the extent and degree of impact. The actual decision should be made by the residents-users of the water in light of the beneficial uses desired for the water.

An example of a tiered hazard assessment scheme for potentially toxic components of domestic wastewater effluent discharged into a river is presented below. It was developed as part of a study recently completed by Lee *et al.*[12]

Tier 1 testing might include examining wastewater treatment plant data on chlorine residual and ammonia concentrations and their discharge rates, dissolved oxygen, existing flow records for 7-day, 10-year low flow, and any chemical data on the receiving waters. With knowledge of pH and temperature of the receiving waters, this would allow a conservative estimation to be made of the concentrations of un-ionized ammonia and chlorine residual that would be present at the point at which the effluent and receiving waters are completely mixed, because no transformation would be accounted for.

Tier 2 could involve the measurement of temperature, dissolved oxygen, and specific conductance with depth along transects of the river downstream from the discharge to determine mixing patterns. This will allow an estimate to be made of where the effluent was completely mixed with the river, approximate concentrations of the contaminant in various areas based on dilution volumes, and the existence of a Zone of Passage. The pH should also be measured. Part of Tier 2 could also be to obtain, through electroshocking or other means, a fish census (numbers and types of fish) above the discharge and below it both within and outside the area of expected impact. The literature summaries in the Red Book[1] and much more recent literature including American Fisheries Society (AFS)[13], could be used to help evaluate the potential significance of the presence of the calculated concentrations of ammonia and chlorine to the types of fish present. If nitrite is not measured in the wastewater treatment plant effluent, this should be done because of its relatively high toxicity to some types of fish and because of its persistence in receiving waters under winter conditions. Evaluation should also be made of the rate of ammonia conversion to nitrite in the receiving water.

In Tier 3, one or more field studies should be conducted under worst case conditions in which ammonia, nitrite, chlorine residual, and dissolved oxygen are determined in the effluent and in the river upstream and downstream of the discharge. Because the purpose of chlorination of domestic wastewaters is to reduce the number of human enteric pathogens, it would be appropriate to also determine the concentrations of fecal coliforms upstream and downstream of the discharge. Based on the mixing pattern determined, and estimated and measured contaminant concentrations, in-stream fish bioassays should be conducted to determine the areal extent of potential acute and chronic sublethal toxicity. Lee *et al.*[12] discuss how these studies should be conducted and present the results of such a study conducted in the Arkansas River near Pueblo, Colo.

Tier 4 should involve some estimate, where indicated, of the potential for fish avoidance of or attraction to the areas of potential concern. At this time, however, established techniques are not available for this. In this or the subsequent tier, studies should be conducted to develop and field calibrate an environmental chemistry-fate model for predicting fate-persistence of the chemical of concern for conditions not specifically studied or for altered contaminant loads which might be encountered. Additional electroshocking should be conducted at this level of testing to define for various times of the year, the numbers and types of the fish present relative to the persistence of the chemical contaminants of concern. As discussed previously, the testing can be terminated after any tier once sufficient information has been gathered to make a decision regarding the potential hazard. For some situations, the decision can be made after the first or second tier of testing, while for others, testing through the fifth level may be necessary.

Once the hazard has been defined to the degree desired, an evaluation should also be made of habitat characteristics to assess what types and number of fish could be present, stream bed and bank characteristics, as well as flow rates and variability. This information will indicate the potential fishery that could exist if there were no contaminant discharged to the water. Further, an assessment should be made of the accessibility of the area of potential impact to the public. This may have some bearing on the decisions regarding degree of treatment desirable. Cost of treatment to achieve various degrees of contaminant removal should also be determined. It could be determined as it was for a Fort Collins, Colo., domestic wastewater treatment facility, that it is quite possible that little or no perceptible improvement in the fisheries-related beneficial use of downstream waters would result from spending the $20 million necessary to remove ammonia, not only because the zone of potential impact is limited, but also because of habitat characteristics and the lack of public access to the waters. These other pieces of information assist in determining the acceptability of the determined risk for the receiving water.

The above-mentioned hazard assessment scheme is largely directed toward fisheries-related uses. A similar approach would be followed with different analytical focal points, if the primary concern were for drinking water or other beneficial uses.

In making any hazard assessment, deciding on an acceptable risk, and considering stricter discharge requirements, it should be noted that in general the closer the allowable concentration in the stream is to the chronic safe concentration of a contaminant, the less the improvements in beneficial uses of waterbodies obtained per dollar spent in pollution control will be. Figure 4 illustrates this concept as it shows the substantial increases in cost for achieving lower and lower concentrations (to the chronic safe levels) of available forms of contaminants. At the same time, the impacts of the further reduction of contaminant concentrations on water quality—beneficial uses—become less. This is especially true in light of the way in which the worst case standards are applied, that is, to the total concentration of the contaminant rather than to the available forms. Because of the factors discussed previously (such as reactivity and duration of exposure), however, it is not necessary in all cases to reduce contaminant concentrations to chronic safe levels in order to provide protection of beneficial uses of the water of concern. It is crucial with the current inflation and energy problems that funds available for pollution control be spent in such a way as to gain the most benefit per dollar spent. While it is generally believed that the majority of the public would strongly support the kind of control programs which would prevent the death of fish, it still remains to be seen whether or not the public in general wishes to pay the enormous costs, either through their taxes or increased price of goods, for the control of contaminants to the point of eliminating the potential of chronic toxicity manifested in decreased rates of growth, slightly less healthy fish, a somewhat impaired reproduction rate, etc. While there may be considerable sympathy for control of contaminants to prevent acute lethal toxicity, contaminant control programs to provide

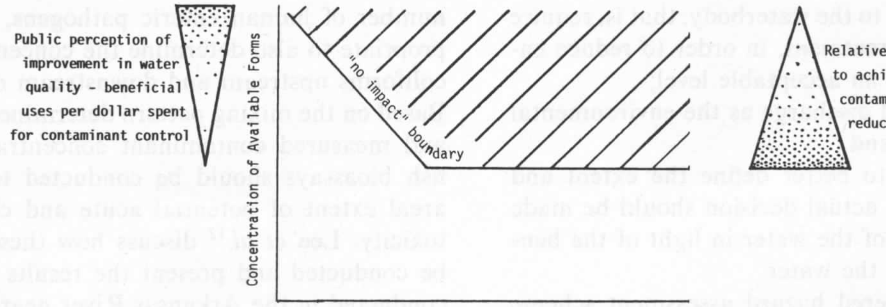


Figure 4—Relationships among potential impact of contaminants on water quality—beneficial uses of the water, relative costs to achieve various degrees of water quality improvement, and perceptibility of various degrees of improvement in water quality to the public.

the ultimate, based on amount of suitable habitat, in fisheries for a particular waterbody is another matter. It is important that the public be informed as to the potential benefits that will be derived from controlling contaminants to the degree necessary to achieve Red Book criteria at the edge of the mixing zone.

SUMMARY AND CONCLUSIONS

In summary, water quality should be judged based on the impacts of contaminants on beneficial uses of the water by man; it should not be assessed by the total concentrations of contaminants in a water sample. Just because the concentration of a contaminant in a water sample exceeds a worst-case water quality criterion such as those in the EPA Red Book, does not mean that water quality deterioration is occurring or that the water quality is unacceptable. Water quality control programs should be directed first toward improving gross water quality deterioration that is readily discernible and deemed to be undesirable by the public. Only after these problems have been eliminated in a particular region should control efforts and funding be directed toward the more subtle effects of contaminants such as impairment of reproduction, changes in fish behavior, and "ecosystem quality" impacts. These impacts should be controlled to the degree desired by the users of the water and in accord with funds made available to do so.

In light of the fact that there may be very little relationship between exceeding water quality standards numerically equal to Red Book criteria and water quality, it is reasonable to ask how pollution control agencies, municipalities, and others should proceed to achieve the goals of PL 92-500 for swimmable-fishable waters throughout the U. S. within the financial and resource constraints that exist today, constraints which will most certainly become more severe in the future. Rather than arbitrarily assuming that worst case conditions exist (as is assumed when Red Book criteria values are used to judge water quality), it should be possible for governmental agencies, industry, and others responsible for the source of contaminants to determine the potential zones and magnitude of impact of a particular contaminant or combination of contaminants on given aspects of water quality. Basically what is needed is an assessment of the contaminant load-water quality response relationships which could be used to inform the public of the water quality benefits that will be achieved as the result of providing certain degrees of contaminant control, for certain amounts of their money. The hazard assessment approach provides a framework by which these types of assessments can be made. By using this approach, technically valid, cost-effective, yet environmentally protective contaminant control programs can be implemented.

AUTHORS' NOTE

After preparation of this paper, the EPA changed its presumptive applicability policy with regard to its Red Book and subsequent water quality criteria. Therefore water quality standards no longer have to be at least as stringent as the worst case, chronic safe level criteria, but can take into account receiving water characteristics as discussed in this paper. At this time it is not clear exactly what the new EPA policy will require with respect to site-specific water quality standards development.

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