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Chapter 20

Water Quality Hazard Assessment for Domestic Wastewaters

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INTRODUCTION

The effluent from a conventional secondary domestic wastewater treatment plant typically contains a complex mixture of chemicals, some of which are toxic to aquatic life at the point of discharge. In addition, industrial waste discharged to municipal sewerage systems can add a large number of contaminants that may pass through conventional secondary treatment in sufficient concentrations to increase the toxicity of the effluent to aquatic life in the receiving waters. Frequently, secondarily treated domestic wastewater effluents are chlorinated to reduce the number of fecal coliforms and, to some extent, human enteric pathogens. As discussed below, the residual chlorine normally present in municipal wastewater effluents is one of the primary aquatic life toxicants of concern. The other toxicant of concern normally present is ammonia. Further, partially nitrified effluent may contain sufficient concentrations of nitrite to cause the effluent to be toxic to aquatic life. The evaluation of the hazard that a particular municipal wastewater discharge represents to aquatic life in the receiving waters can and should be accomplished using two different approaches: (a) the classically-used approach involving measurement of the concentrations of known toxicants at the point of discharge compared to water quality criteria and standards, and (b) by hazard assessment field investigations.

With information on the flow and contaminant concentrations in the effluent and the receiving waters, it is possible to compute the potential for toxicity to aquatic life at the edge of the mixing zone by comparing the computed concentrations to the levels of contaminants known to cause toxicity. This approach works reasonably well for ammonia and residual chlorine present in municipal wastewater effluents. With additional information on the toxicity of nitrite to various forms of aquatic life, it would be possible to use this approach for that chemical as well. Although it is possible to use this approach for a wide variety of other potential toxicants, a number of factors reduce the utility of this approach for evaluating the hazard that a particular wastewater effluent represents. These factors include highly variable toxicant concentrations, the high cost associated with analyzing for the wide variety of potential toxicants and, most importantly, the fact that the toxicity information available for most potentially significant contaminants (such as heavy metals, organics, etc.) does not necessarily lend itself to direct assessment of toxicity.

This chapter describes a hazard assessment approach that may be used to evaluate, on a site-specific basis, the aquatic life hazard of secondarily treated domestic wastewater effluents. Examples of the application of this approach to several domestic wastewater systems discharging to Colorado Front Range rivers are provided.

PRINCIPLES OF HAZARD ASSESSMENT

Hazard assessment, as it is being practiced today for determining the degree of treatment needed for industrial and municipal discharges to achieve designated beneficial uses of receiving waters, is based on a coordinated site-specific evaluation of aquatic toxicology and chemistry. The basic characteristics of both aquatic toxicology and chemistry, as applied to domestic wastewater/aquatic life hazard evaluation, are discussed in the following.

Aquatic Toxicity

As shown in Figure 20.1, the toxicity of chemicals to aquatic life is a function of the concentration of available forms and the duration of exposure. As the duration of exposure decreases, the concentration that can be present without causing an adverse impact increases. There is also a concentration that is generally considered the maximum that is safe for chronic-lifetime exposure. This concentration is normally used by the U.S. EPA and many state agencies to establish water quality criteria and standards, such as presented in the July 1976 U.S. EPA Red Book [1] and the November 1980 water quality criteria released by the U.S. EPA for toxic chemicals [2].

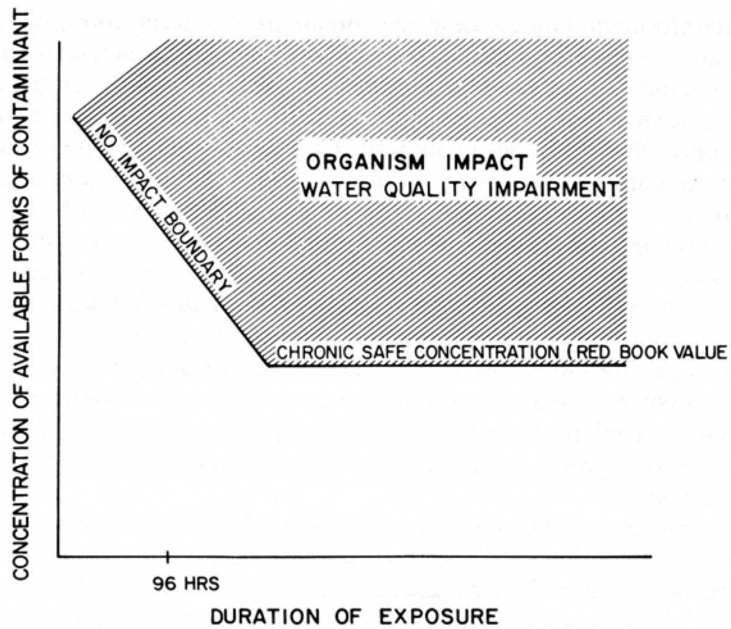


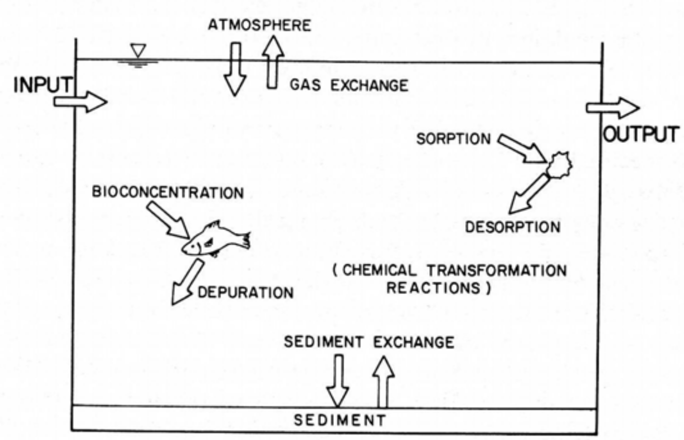
Fig. 20.1. General case for evaluating the concentration of available forms of a contaminant in relation to the duration of exposure showing a "no impact" boundary.

As a water quality standard, this level is usually protective even under the worst-case conditions of lifetime or critical life stage exposure to chemical forms that are completely available to the organisms. However, as discussed by Lee et al. [3], for many contaminants, worst-case criteria or standards are often difficult to use in evaluating the potential impact to beneficial uses of water caused by concentrations in excess of these values. This is because most organisms of concern do not receive a chronic exposure. Concentrations far in excess of the worst-case criterion values can be present for short periods of time without impairing beneficial uses. Further, the aqueous environmental chemistry of many contaminants is such that they exist in natural waters in a variety of forms, only some of which are toxic to aquatic life. This point is discussed further in a subsequent section of this chapter.

Aquatic Chemistry

The aquatic chemistry of an element or compound describes the chemical reactions that it can undergo in aquatic systems. These reactions include acid-base, precipitation, complexation, oxidation-reduction, abiotic and biotic sorption and release from particulate matter, hydrolysis, phototransformation, and exchange with the atmosphere. Each of these reactions proceeds to a certain point of equilibrium (thermodynamics) at a rate (kinetics) governed by environmental conditions. Many of these reactions can be described by mathematical relationships that can be combined to form an aquatic chemistry model for the element or compound of interest. Figure 20.2 presents a diagrammatic representation of the form of these models.

Such a model may be used to describe the occurrence and persistence-fate of the toxic forms of a particular element or compound present in a wastewater discharge. This type of information, coupled with aquatic life toxicity data for each of the forms of potential importance, provides the basis for conducting a hazard assessment of a domestic wastewater discharge—concentrations of the chemical and any of its precursors in an effluent compared with concentrations known to be harmful to aquatic organisms. These concentrations can then be used in the site-specific aquatic chemistry model to predict "concentration-duration of exposure" relationships for the receiving waters. These relationships are then compared to aquatic toxicology data and organism behavior information to determine whether the organisms in the region could be exposed to potentially hazardous concentrations for sufficient lengths of time to be adversely affected.



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

Fig. 20.2. Schematic representation of factors affecting the environmental chemistry and fate of chemical contaminants.

PROBLEMS IN IMPLEMENTING THE CONCENTRATION-CRITERIA APPROACH TO HAZARD EVALUATION

The contaminant concentration-water quality criteria approach to hazard assessment is only applicable at this time to a small number of chemical contaminants of concern in municipal and industrial wastewaters. This is a result of a number of factors, including the fact that the analytical methods normally used to measure the concentrations of contaminants in wastewaters, as well as in the receiving waters, do not necessarily measure only the toxic forms or even well-defined forms of contaminants of interest. Nor are these analytical methods sufficiently sensitive to detect criteria levels of many contaminants in waters. The importance of understanding the analytical chemistry of the methods used in water and wastewater analysis, relative to the toxic forms of chemicals, in translating laboratory-based bioassay data to field situations, has been discussed by Lee and Jones [4].

Another significant deficiency with this form of hazard evaluation is that there is almost a complete lack of information on the toxicity of various forms of most chemicals of interest in municipal and industrial wastewaters, which can also be present in natural aquatic systems. Where toxicity data do exist for a chemical, they are, almost without exception, the results of tests conducted with constant concentrations of contaminants rather than under typical environmental conditions of fluctuating concentrations. Because the exposure duration for the organisms of greatest interest (i.e., fish) is a function of a variety of factors, such as feeding habits, attraction and avoidance behavior, migratory characteristics. etc., it is necessary to investigate these characteristics on a site-specific basis. These site-specific investigations must be conducted with the fish of concern in association with the particular discharge to determine the duration of exposure to the discharge that fish (and other organisms)of the region actually receive. Information is generally lacking on how to relate worst-case criteria or standards with actual field data, especially when field concentrations are highly variable or exceed the criteria somewhat. The commonly used approach of assuming worst-case/chronic exposure is often unnecessarily restrictive and leads to the construction of more costly domestic wastewater treatment plants than needed to achieve the designated beneficial uses of the receiving waters.

There is also a lack of information on the factors governing the transformation of one form of a toxicant to another within aquatic systems. A substantial research effort is frequently necessary to develop the aqueous environmental chemistry and toxicology information needed to correctly use hazard evaluation techniques that are based on contaminant concentration comparisons with water quality criteria. In the past, there has been little impetus for undertaking such efforts because of the U.S. EPA's presumptive applicability policy, in which the agency assumed that worst-case criteria were applicable to all waters of the United States. Finally, after many years of conflict with state pollution control agency personnel, university scientists and engineers, consulting firms, etc., the U.S. EPA rescinded its presumptive applicability policy in November 1980 and is currently developing approaches that will allow site-specific water quality criteria, standards, and point source discharge limits to be developed. This approach, if carried through to is proper formulation, could be the impetus needed for municipal and industrial dischargers to demonstrate that something other than worst-case criteria and standards can be used to formulate site-specific discharge limits without sacrificing adequate protection of the beneficial uses of the receiving waters.

As discussed by Lee et al. [3], the site-specific approach currently being developed by the U.S. EPA could result in taxpayers and consumers saving hundreds of millions of dollars while still protecting beneficial uses. In order to do this, however, the U.S. EPA and state pollution control agencies must develop a philosophy of "mechanically" using worst-case criteria and standards only where site-specific studies demonstrate that they are applicable or where the discharger will not do the site-specific studies necessary to define the impact of its discharges on beneficial uses of the receiving waters. Adoption of this approach will mean that, in general, greater amounts of money will be spent in assessing impact than in the past. However, such assessments will likely prove to be highly cost-effective for the discharger, because it will be rare that the "mechanical" implementation of worst-case criteria into standards and point source discharge limits, using the 7 day, 10 year low flow (7Q10) to estimate dilution, will not be shown to be far more conservative than necessary to protect beneficial uses of the receiving waters.

APPLICATION OF HAZARD ASSESSMENT PRINCIPLES TO DOMESTIC WASTEWATER EFFLUENTS

Because of the deficiencies in the concentration-criteria approach in developing a site-specific hazard assessment, the authors and their associates developed an alternative approach for assessing the hazard that municipal wastewaters represent to the beneficial uses of several Colorado Front Range streams. As described by Lee et al. [3], this approach involves the use of site-specific field studies in which caged fish toxicity tests are used to define the acute toxicity to fish of the effluent mixed with the receiving waters. The details of cage construction and use are described by Newbry and Lee [5].

Interpretation of Instream Toxicity Data

The first step in conducting such studies is the definition of the effluent plume in the receiving river through temperature and specific conductance profiles, or with dyes injected into the effluent. It is important to note that the plume must be described both horizontally and vertically to ensure that the fish cages are placed in a part of the receiving waters that could be influenced by the effluent. The discharge plume must be defined as a function of river flow. For estuarine systems, the influence of tide stage on plume characteristics must also be considered.

In studies done by the authors and their associates, cages were placed at various locations within the effluent plume under investigation in order to detect toxicity as a function of effluent dilution in the receiving waters. The fish in the cages were inspected at periodic intervals (about four times a day during the first 2 days and twice a day thereafter, for a total of 4 days or 96 hours); dead fish were removed and samples of water from around the cage were taken for selected contaminant analysis. From these data, a plot of concentration of contaminant versus duration of exposure was developed from which the 96-h LC50 could be determined. An example of this type of plot, developed by Lee et al. [3] for the impact of the discharge of Pueblo, CO's domestic wastewaters on water quality in the Arkansas River, is presented in Figure 20.3.

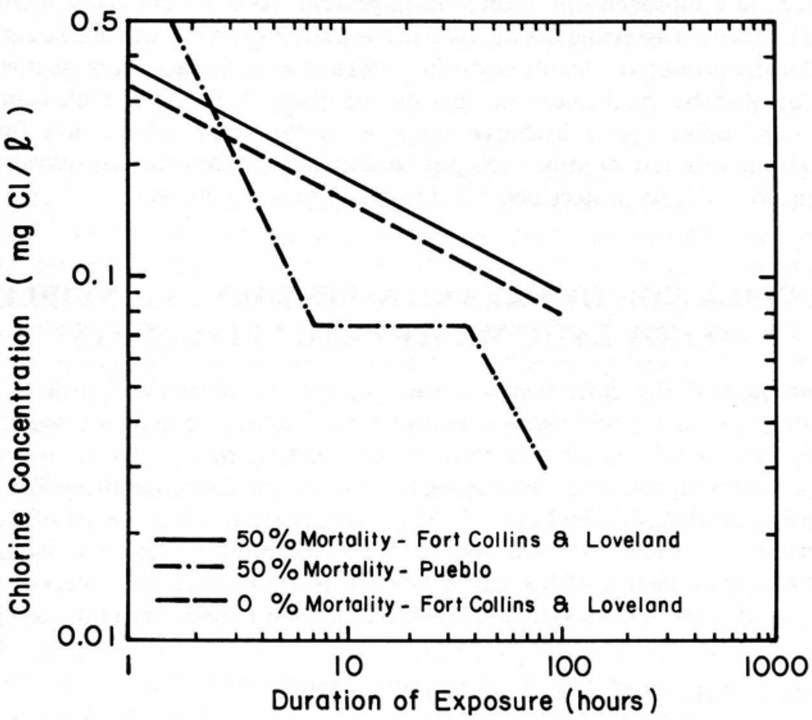


Fig. 20.3. Chlorine concentration versus duration of exposure for 50% mortality relationships in caged fish exposed to wastewater discharge.

In formulating Figure 20.3, it was necessary to make some assumptions about the concentration-exposure duration relationships that existed within the cages. First, it was necessary to select the toxicant that was most likely causing the death of the test species (in this study, fathead minnows, *Pimephales promelas*). A comparison of the literature 96-h LC50 data for various potential toxicants in the effluent with the toxicity data generated in this study showed very good agreement between the literature-indicated toxicity of chloramines and the toxicity found in this study. A comparison to other measured contaminant toxicities, such as un-ionized ammonia, showed that ammonia would not likely have been responsible for much of the toxicity observed. It also showed that the potential role of other toxicants in causing the death of the fathead minnows, either synergistically or individually, was likely to have been small.

The probability that an unidentified toxicant(s)—also present in the same concentrations in the wastewater effluents from other cities that have been investigated in the literature—was causing the toxicity in the Pueblo domestic wastewater effluent is remote. Such an unidentified toxicant(s) would have to have had a fairly high acute toxicity to aquatic life at low concentrations. And such a toxicant has not been detected in any of the studies that have taken place thus far on the toxicity of domestic wastewater effluents to aquatic life. Further, some of the other studies on the toxicity of domestic wastewaters (see Newbry [7] for review of literature on this topic) have shown that when the effluents under study have been dechlorinated, the toxicity was lost. Therefore, an unidentified toxicant must also have reacted with dechlorinating agents in much the same way that chlorine does. Because it is highly unlikely that all of these conditions were fulfilled, it is reasonable to assume that the toxicity of the Pueblo domestic wastewater discharges at the time of the Lee et al. studies [6, 8] was due primarily to chloramines formed by the reaction between chlorine added for wastewater disinfection and ammonia present in the effluent. It should also be noted that in similar studies conducted by the authors on the Fort Collins, Loveland, and Colorado Springs domestic wastewater effluents [9-11], similar degrees of toxicity were found for the residual chlorine present in the effluents.

In order to construct Figure 20.3, it was necessary to estimate the concentrations of toxicant (chlorine) to which the fish were exposed. This was done by summing the area under the curve of the concentration-time plot. This approach is in error to the extent that there is not a linear relationship between the area of a concentration-time function and the toxicity of chloramines to fish. Although it is almost certain that this relationship is not linear, its exact function remains unknown at this time. Further, the linear function appears to be a reasonably good first approximation, based on the fact that the computed LC50 values matched literature-derived data for constant-concentration toxicity reasonably well.

The caged fish toxicity tests provided a relatively simple method for estimating acute toxicity of domestic wastewater effluent to aquatic life. The chronic safe level for an effluent can be estimated by several means. For specifically identified toxicants, an acute-chronic ratio approach could be used to determine downstream toxicity-concentration relationships that exist in the receiving waters. If the acute-chronic ratio for a toxicant is not known, it may be estimated from the range of ratios that are usually found for chemicals. It now appears that many chemicals have acute-chronic ratios on the order of 10 with a few, especially pesticides, on the order of 100. Therefore, unless the chemical of concern were a pesticide, it would be rare that a 10- to 50-fold decrease in the concentration of the chemical would not be chronically safe to downstream aquatic organisms.

The other approach to estimating chronic safe levels is the direct measurement of chronic toxicity using either side-stream or instream toxicity tests. The caged fish bioassays were extended to a 6-month period by the authors in the study of the Fort Collins Wastewater Treatment Plant No. 1 effluent with no deaths of fish in the upstream control cages. Although this type of test is not a true chronic test, it does demonstrate the survivability of adult fish with continued exposure to the toxicants over several seasons.

One of the most promising approaches for determining chronic safe levels for complex effluents is a short-term cladoceran test being developed by D. Mount of the U.S. EPA Duluth Laboratory. This organism produces three broods in a 7-day period. Work is currently underway on this organism *(Ceriodaphnia reticulata)* by Mount and Norberg [12] to determine its sensitivity to a wide variety of toxicants. Once this type of information is available, it should be possible to estimate the chronic toxicity of a complex mixture of chemicals to aquatic life based on relatively short-term tests.

Toxicity Testing of Effluent

It should be pointed out that toxicity testing of effluent in portable trailers, as is frequently advocated today, in which fish or other test organisms are exposed to dilutions of the effluents achieved by mixing the effluent with upstream waters, is often not an appropriate approach to assess toxicity in the receiving waters. The basic problem with this approach is that it assumes that the only change that occurs downstream of the point of effluent discharge is a dilution of the effluent with upstream water, that is, that the chemicals in the effluent and the river are conservative and do not react. It is very rare that this situation occurs. An example of a potential problem with basing hazard assessments on effluent toxicity testing could occur with a wastewater containing a heavy metal sulfide in which little or no toxicity would be found in the effluent, because the heavy metal sulfide itself is nontoxic. However, downstream, dissolved oxygen would oxidize the sulfide, releasing the heavy metal from the sulfide precipitate so that it could then be toxic to aquatic life.

Another example of this kind of situation occurred in the authors' study of the impact of domestic wastewater discharges on Colorado Front Range streams. The problem centered around the conversion of ammonia to nitrite. Per unit concentration of nitrogen, nitrite is more toxic to many forms of aquatic life than is ammonia. An unnitrified domestic wastewater effluent can contain 20 to 30 mg N/L of ammonia. The authors have found concentrations of nitrite from a few tenths to several mg N/L in several Colorado streams below domestic wastewater discharges. For cold water fish such as trout, the chronic safe level of nitrite is on the order of a few hundredths of a mg N/L. Although the chronic safe level of nitrite for other cold and warm water fish, in general, is not known at this time, it is likely to be on the order of a few tenths of a mg N/L or less. Thus, a low temperature, low pH domestic wastewater effluent and receiving water could contain 10 to 20 mgN/L total ammonia and be nontoxic to aquatic life at the point of discharge. However, the conversion of ammonia to nitrite downstream of the discharge point could result in sufficient concentrations of nitrite in the river to be chronically, and in some cases acutely, toxic to fish and other aquatic life.

It is important to note that the concept which is widely held in the water pollution control field, that nitrite is highly unstable in an aqueous environment, is incorrect. The authors and others have found that, at 10ºC or less, the rate of conversion of ammonia to nitrite in some domestic wastewater treatment plant effluents, as well as in natural waters, is such that nitrite is present in sufficient concentrations to represent a hazard to aquatic life. The authors have observed nitrite concentrations in some secondary treatment plant effluents approaching 10 mg N/L, especially in the fall or spring when the operations are going in or out of nitrification. Under these conditions, it would take appreciable dilution of the effluent in the receiving water to develop a nontoxic situation for aquatic life downstream of the discharge.

Because of the potential importance of nitrite as a toxicant in domestic wastewaters, and downstream from the discharge of unnitrified effluents, it is important for wastewater treatment plant laboratories to monitor the concentrations of nitrite in the effluent on at least a weekly basis. Further, any time unnitrified effluent is being discharged to a river such that the dilution of the effluent with the river water could result in nitrite concentrations above a few hundredths of a mg N/L, then the treatment plant laboratory personnel should conduct downstream studies to determine the amount of nitrite build-up in the receiving waters. This is especially important during low temperature conditions. The downstream monitoring studies should be conducted in such a way as to ascertain the fate of the ammonia and nitrite discharged in the effluent. Because of denitrification actions that occur at the sediment/water interface and gas exchange of ammonia with the atmosphere, it is rare that a mass balance can be quantified between ammonia discharged and nitrite-nitrate in the receiving waters. But attempts should be made to formulate this kind of balance.

Another situation in which dilutions of the effluent may not be toxic, but in which appreciable downstream toxicity can occur, is when the treatment plant operator deliberately lowers the pH of the effluent through the addition of sulfuric acid in order to meet un-ionized ammonia discharge limits. This approach must be carefully evaluated because, although it may achieve its objective at the point at which the effluent is first mixed with the receiving waters, it could readily result in a more adverse situation downstream due to the fact that the sulfuric acid addition results in a reduction of the buffer capacity of the effluent/receiving water mixture. The changes in water pH due to algal or other aquatic plant photosynthesis downstream would then be more dramatic, which would, in turn, result in more un-ionized ammonia downstream than would have been present if the sulfuric acid had not been added.

It is evident from the above discussion that the commonly practiced approach of domestic wastewater treatment plant operators examining only the characteristics of their effluents could give a highly inaccurate assessment of the hazard that an effluent represents to aquatic life-related beneficial uses of the downstream waters. In conducting a hazard assessment of an industrial or domestic wastewater containing heavy metal sulfides, ammonia, etc., the investigator must determine the aqueous environmental chemistry of the potential toxicant (i.e., the heavy metal, nitrite, etc.) in the receiving waters under downstream conditions. This situation illustrates the importance of the use of both aquatic toxicology and aquatic chemistry in hazard assessment evaluations. Simply examining the toxicity of the effluent can give a completely erroneous picture of the hazards that an effluent represents to aquatic life in the receiving waters. Most properly conducted hazard assessments of industrial or domestic wastewaters will require either instream or side stream toxicity tests downstream of the discharge point to determine whether the aqueous environmental chemistry of toxicants present in the effluent is such that they would be adverse to aquatic life downstream of the point of discharge.

It is important in making this assessment not to simply determine that a potential toxicant in the effluent can be converted to a toxic form in downstream waters. Because few toxicants remain in water in a toxic form for long periods of time, it is important to consider the relative rates of toxicant formation and detoxification downstream, in order to determine whether the toxicant concentration may build up in the receiving waters sufficiently to affect aquatic life. An example of this type of situation occurs with the photodecay of iron cyanides. An effluent from a refinery, steel mill, metal plating operation, etc., could be found to be nontoxic at the point of discharge. However, downstream, this effluent could have a devastating effect on aquatic life if the rate of photodecay of iron cyanide to free cyanide in that particular water were much greater than the rate of free cyanide decay to nontoxic products. The authors are aware of situations in which some non-toxic effluents become toxic downstream due to free cyanide formation, whereas in other situations the same effluent concentrations of iron cyanides do not cause the same degree of downstream toxicity. At this time, the factors governing these situations are poorly understood and site-specific evaluations must be conducted.

Impairment Assessment

The approach developed by Lee and associates [3] to detect significant impairment of beneficial uses due to a wastewater discharge involves a combination of instream flow techniques for habitat assessment and fish census studies. The instream flow techniques [13, 14] involve determination of the physical habitat characteristics of the stream such as water depth, velocity, bottom type, etc., that have been found to influence the numbers and types of fish present. Figure 20.4 diagrammatically presents the overall situation found in the vicinity of many discharges and illustrates the importance of proper habitat evaluation in a hazard assessment. If, for a given stream it is found that habitat characteristics above or below the discharge are the

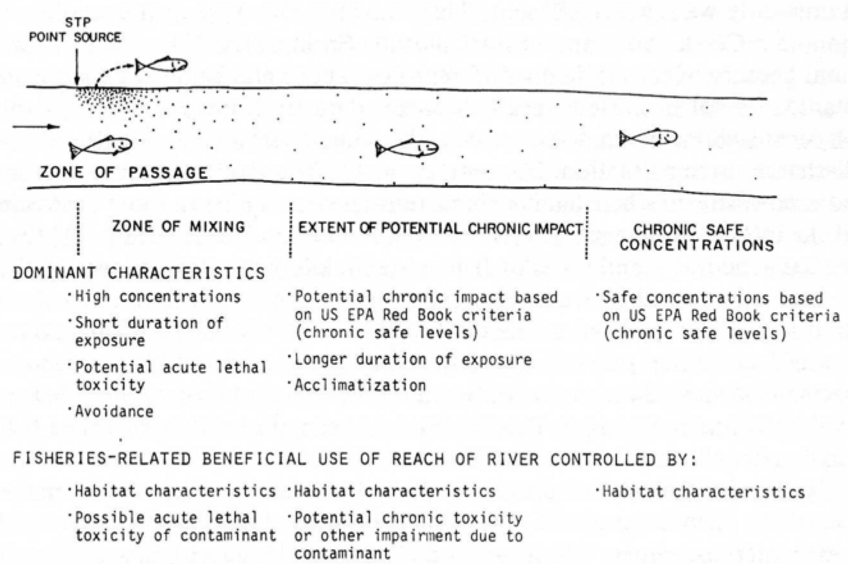


Fig. 20.4. Schematic representation of the potential impact of nonpersistent chemicals discharged in wastewater effluent.

same as those within the zone of potential impact, as shown in this figure, then it can be reasonably assumed that, if the numbers and types of fish found above or below and within the zone of potential impact were similar, it would be highly likely that the effluent would not be significantly affecting the beneficial uses of the river. If, however, a stream is a trout stream above the wastewater discharge and has the same habitat characteristics above and below the discharge, it is reasonable to suppose that, if no trout existed downstream of the discharge, the effluent contains chemicals that are adverse to trout.

Fish census techniques can range all the way from relatively simple visual observations through seining and electroshocking techniques. The Western Division of the American Fisheries Society recently held a symposium discussing these techniques. At this symposium, Lee and Jones [15] discussed how those conducting physical habitat studies may determine whether numbers and types of fish present at a particular location are being affected by chemicals present in the stream.

It is important to note that the instream flow techniques used by the authors [3] are a relative assessment of habitat and fish populations within the same geographical region on the same stream under essentially the same flow regimes. Therefore, these techniques are less susceptible to the problems that confront the physical habitat work of many fishery biologists, because the only variable that is different is the presence of the effluent. Some of the Colorado streams studied by Lee and his associates flow only during certain times of the year; the stream flow during other times of the year is predominantly wastewater effluent. This was especially true in the studies of Fountain Creek above and below Colorado Springs, CO [11]. In this situation because of the markedly different flow above and below the treatment plant, it is not possible to use fish census data from upstream even if the physical habitat characteristics were the same both above and below the discharge. In this situation, fish censuses had to be conducted at several locations downstream where habitat characteristics were similar to those upstream of the effluent discharge. It was found in the Lee and Jones study [11] that the same numbers and types of fish existed a kilometer downstream of the discharge as existed above it. However, this was not true within a few hundred meters downstream of the discharge, that is, within the mixing zone. It was decided that this was due to the chlorine, which would have been expected to be acutely toxic to fish within a few hours, based on the concentrations found in the river. This is what had been observed in the caged fish bioassay conducted by Lee and Jones and their associates.

The hazard assessment approach used by Lee et al. [3] relies heavily on the use of fish as an integrator of water quality impacts of domestic and industrial wastewater discharges. This is justified from several points of view. First and foremost, fish are the aquatic organism of greatest concern to the public in fresh water systems. Second, the greatest body of technical information on the effects of chemicals on aquatic organisms is for fish and certain zooplankton organisms, such as *Daphnia*, which are recognized as key fish food organisms. It is sometimes suggested that lower trophic level organisms such as algae be used for toxicity testing and hazard evaluation. It is the experience of the authors, and it is generally becoming recognized in the field, that toxicity testing with algae yields results that are uninterpretable in terms of environmental effects of chemicals. The relatively short generation times of these and related organisms create a situation in which any adverse effect on their population would usually be of short duration and of limited areal extent.

SUMMARY OF HAZARD ASSESSMENT STUDIES ON DOMESTIC WASTEWATER DISCHARGES

The studies conducted by the authors and their associates on the water quality impacts of domestic wastewater discharges for the cities of Fort Collins, Loveland, Colorado Springs, and Pueblo, CO, which served as a basis for developing the hazard assessment techniques described in this chapter, have a number of common features and results. First, although it should have been obvious, but did not appear to be generally recognized, the effluents from the Fort Collins, Colorado Springs, and Pueblo domestic wastewater treatment plants are highly toxic to aquatic life at their points of discharge. This is due to the presence of approximately 0.5 mg/L residual chlorine (chloramines) in these effluents. This situation was also true during the studies of the Loveland effluent (although under normal operating conditions, Loveland practices partial dechlorination). During the course of these studies, the state of Colorado agreed to allow the Loveland wastewater treatment plant to stop the dechlorination of the effluent. It is important to point out that, in general, the authors conducted the hazard assessment studies during low-flow summer and low-flow winter conditions, which would represent worst-case situations for the chemicals of greatest concern (ammonia, nitrite, and residual chlorine).

As described by Newbry et al. [16], the instream toxicity data for the various treatment plant effluents and rivers studied showed that all of the effluents had about the same toxicity to fathead minnows. As discussed by Newbry [16], there is a relatively small area in the effluent plume associated with each of the treatment plant discharges in which fish would be expected to die within 4 days of continuous exposure. The loss of acute toxicity outside of this region is due primarily to the dilution of the effluent with the receiving waters. It should be noted, however, that the authors and their associates did not find that the region of the stream, in which 96-h acute lethal toxicity to fish existed, was devoid of fish. Minnows of various types were repeatedly observed foraging in the zone of 96-h acute lethal toxicity. Resident fathead minnows were seined from the stream and placed in cages. They displayed the same concentration-exposure duration relationships as the test species, indicating that the fish had not adapted to the toxicants in the effluent but were foraging in the region in such a manner as to apparently avoid acute toxicity due to these chemicals.

The size and configuration of the zone of potential chronic toxicity was between the edge of the zone of mixing and the point at which the chlorine concentrations are considered to be chronically safe for fish (Fig. 20.4). This zone of potential chronic toxicity was, as expected, highly dependent on site-specific characteristics of the effluent and the receiving waters. Heinemann et al. [17] were able to develop models that could be used to readily predict, under various flow and temperature regimes, the fate-persistence of chlorine in each of the systems investigated. Thus, they were able to define the zones of potential acute and chronic toxicity. These models are based on estimates of rates of photodecay, volatilization, and chlorine demand, that is, reactions with organics within the water.

Table 20.1 presents a summary of the results of the Heinemann et al. [17] modeling of chlorine residual persistence in the Colorado Front Range rivers studied. The river reaches with potential chronic toxicity are defined as the distance below the domestic wastewater discharge where the residual chlorine concentration would be above the Colorado water quality standard of 0.003 mg/L Cl. It is evident that there are appreciable reaches of the waterbodies investigated that could be toxic to aquatic life based on the chronic exposure criteria-standards developed by the U.S. EPA and the state of Colorado for chlorine.

The significance of the apparently excessive concentrations of chlorine on beneficial uses of the rivers was evaluated by the fish habitat-census approach described above. In each case, except near the point of discharge for Colorado Springs wastewater, no

Table 20.1. River Reaches of Potential Chronic Toxicity Under Near Worst-Case Conditions.[a]

Waste water treatment plant	Estimated length of river reach (km)
Fort Collins No. 1	6.1
Fort Collins No. 2	3.0
Loveland	3.2
Pueblo	14.7
Colorado Springs	41.5

[a]After Newbry et al. [16].

readily discernible difference was observed between the numbers and types of fish in the zone of potential chronic toxicity and the numbers and types outside of this zone. This was likely due to several factors, the most important of which was the character of the habitats in the streams studied, which, in general, would be considered as relatively poor for optimum fisheries development. The bottoms of the streams are principally sand, the channels are meandering, there are few under-cut banks, and little vegetation along the shorelines. Further, irrigation diversions of water from the rivers create situations where flows in the rivers at certain times of the year are quite low, making it difficult to establish a warm water game fishery.

Although the outcome from use of the hazard assessment approach to determine the degree of treatment necessary to protect beneficial uses still remains to be resolved, it appears from the actions taken thus far by regulatory agencies that this work has been influential in obtaining a different permitted discharge for ammonia than was originally proposed for these plants. If the current, tentatively approved approaches continue to be followed, a savings of several tens of millions of dollars in reduced treatment plant construction and operating costs could result, due to the elimination of the need for the proposed nitrification of effluents. It is clear from these studies that the construction and operation of nitrification facilities at each of these treatment plants will have little or no impact on the beneficial uses as perceived by the public. It is important to note that this situation will not necessarily always occur at other locations. A site-specific hazard assessment will have to be made to determine the benefits in improved fisheries that could develop as a result of installing nitrification facilities at other locations.

With respect to the discharge of chlorine, it does not appear at this time that the dechlorination of the wastewaters before discharge, which is being adopted in Colorado, is a justifiable expense in terms of increased protection of aquatic life in the receiving waters for the Fort Collins, Loveland, Colorado Springs, and Pueblo wastewater discharges. These cities, however, are not making any significant effort to try to obtain permits that would eliminate the need for dechlorination, because they consider costs of dechlorination "small" and not requiring any major capital expenditures.

Table 20.2 presents the potential costs of dechlorinating domestic wastewater effluents to eliminate acute and chronic toxicity to fish in the receiving waters. It is important to note that this approach of cost-benefit assessment does not try to place a dollar value on fish, but instead provides the opportunity for the public to assess the cost of achieving additional fisheries of a certain type as a result of dechlorinating the effluent. The cost in dollars per square meter of stream bottom per year can be related to the fisheries potential that exists in regions in which the habitat is the same but the chlorine residual does not exist at potentially acute or chronic concentrations.

Lee and Jones [18] questioned the advisability of removal of chlorine from domestic wastewaters in situations where no readily discernible impact on fish or aquatic life

Table 20.2. Costs for Chlorine Removal Per Unit Area of Potential Toxicity Eliminated.[a,b]

Waste water treatment plant	Estimated cost ($\$/m^2/yr$) for reduction of: Potential acute toxicity area	Potential chronic toxicity area
Fort Collins No. 1	2.1	0.3
Fort Collins No. 2	15.0	1.2
Loveland	10.8	1.1
Pueblo	5.2	0.1

[a]Based on dechlorination cost of $\$0.003/m^3$ water treated.

[b]After Newbry et al. [16].

would be expected. Their position was based on the fact that the chlorine would tend to keep fish and other aquatic life from congregating near the wastewater outfall and thereby being exposed to the greatest concentrations of a wide variety of contaminants that could bioconcentrate within the fish tissue and render the fish unsuitable for use as human food. Further work needs to be done on a site-specific basis to determine the hazards that non-readily identifiable carcinogens and other contaminants in domestic wastewater effluents represent to man through bioaccumulation. The chlorine normally present in domestic wastewaters as a result of the disinfection could be a valuable asset in reducing the public health hazard of eating the fish and, at the same time, reduce the cost of domestic wastewater treatment.

Obviously, in situations where the domestic wastewaters are discharged to a highly prized sports fishery, and it is shown through hazard assessment techniques of the type described here that this fishery either is or will be impaired by continued discharge, then steps should be taken to dechlorinate the effluent to some extent to reduce the area of chlorine hazard to fish. If ammonia is present in sufficient concentrations to either be toxic in its own right, or to create sufficient concentrations of nitrite to be toxic to aquatic life, then nitrification to nitrate should be considered as an appropriate advanced wastewater treatment process to eliminate the toxicity of the effluent to fish and other aquatic life in the receiving waters.

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