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Acute Toxicity Potential of Chlorination in Estuarine Waters

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CHLORINE -

BANE OR BENEFIT?

Proceedings of a Conference on the Uses of Chlorine in Estuaries

Chesapeake Bay Foundation

Citizens Program for the Chesapeake Bay

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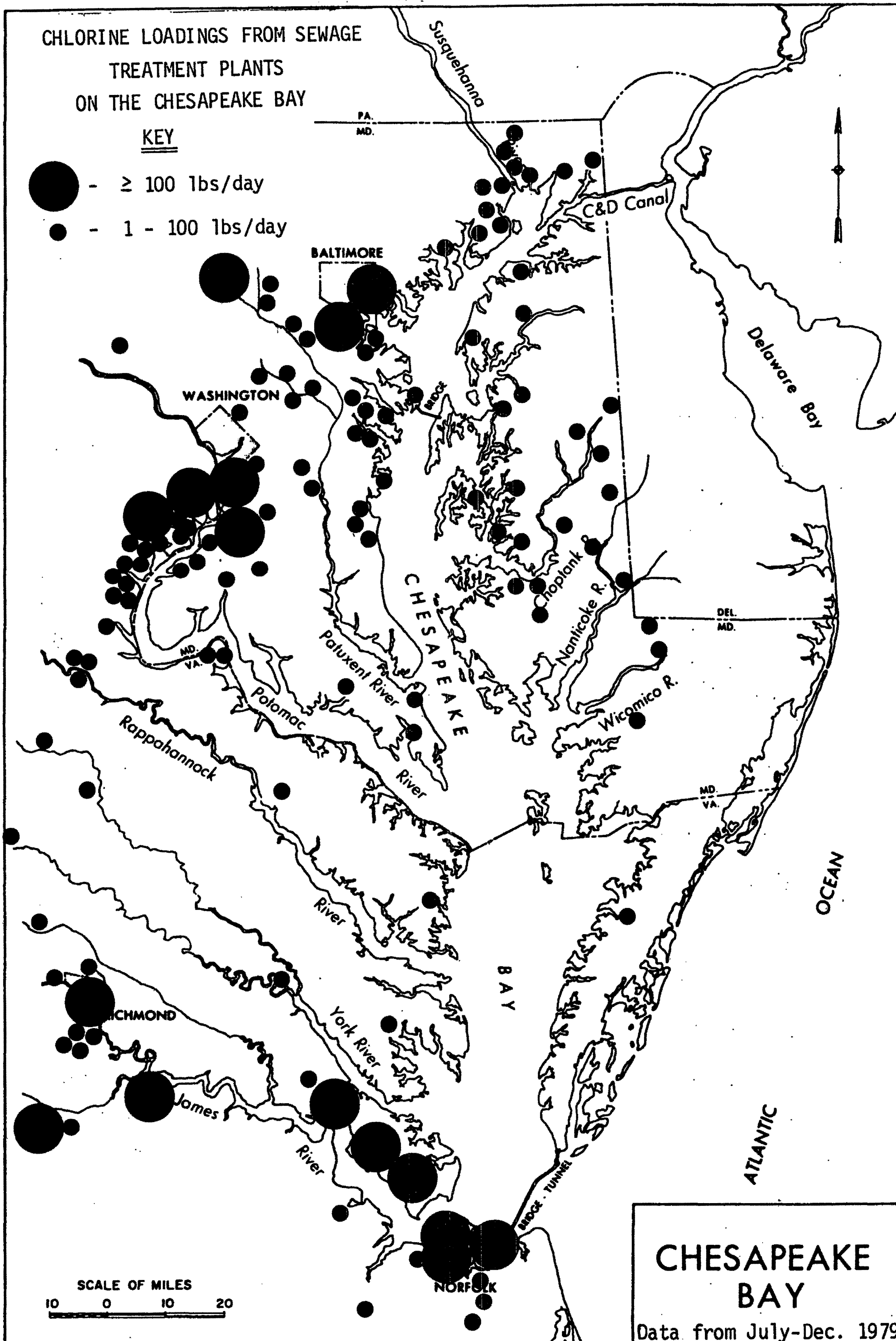

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PREFACE

The proceedings of the conference titled "Chlorine: Bane or Benefit?" are recorded in this publication. As the title implies, the purpose of the conference was to focus attention on the benefits and problems associated with a wide range of chlorine uses in the Chesapeake Bay and to investigate and assess possible alternatives to those uses of chlorine. Conference planners directed the attention of the speakers and audience toward the establishment of guidelines for chlorine use which will help to ensure the optimal protection of the Chesapeake Bay ecosystem.

The sponsoring organizations found a useful common cause in this effort to broaden public understanding and improve future management decisions. The Chesapeake Bay Foundation is a private, non-profit public interest organization dedicated to promoting the sound management of Chesapeake Bay's natural resources, principally through environmental education and resource representation. The Chesapeake Research Consortium is a planning and coordination center for research on the Bay among the University of Maryland, The Johns Hopkins University, the Smithsonian Institution and the Virginia Institute of Marine Science. The Citizens Program for Chesapeake Bay is a private, non-profit organization of organizations dedicated to citizen participation in decisions affecting use and management of the Bay's resources.

In addition to financial support from the sponsoring organizations, contributions were received from the U.S. Environmental Protection Agency, the Maryland Association of Bay Pilots, and the German Marshall Fund. The Office of Environmental Programs of the Maryland Department of Health and Mental Hygiene generously arranged for printing of these Proceedings. A ten dollar registration fee was also received from each of the 150 audience participants.

The Conference Committee appreciates the essential contributions of the speakers and participants to the conference. The committee would also like to thank Mary Brady, Mary Tod Winchester, Kitty Cox, Jennifer Young, Helen Collins, the administration of Mary Washington College and the staff members of the three sponsoring organizations for their dedicated work.

Conference Committee
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ACUTE TOXICITY POTENTIAL OF CHLORINATION IN ESTUARINE WATERS*

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Two primary uses of chlorination in estuarine systems are disinfection of sewage effluent and fouling control in condensor tubes of electric power generating plants. The intent in both uses is to apply sufficient chlorine to kill certain target organisms. At the same time, however, efforts are made to control both the application rate and effluent release so that non-target species in the receiving waters are not affected. To accomplish such control, the effluent is usually retained, which permits the decay of the residual chlorine and rapid dilution with ambient water to reduce further the residual. The residual concentration continues to decay in the ambient water through a series of reactions outlined in Dr. Helz's paper. If all goes well, no adverse impacts can be expected in the receiving waters.

However, at least two disquieting instances of chlorination's possible impact in the Chesapeake Bay have been observed. First, in 1966 a significant depression in primary production was noted in the effluent mixing zone of the Chalk Point power plant in Maryland, especially during periods of chlorination (Morgan and Stross, 1969; Hamilton et al., 1970). The second observation was a massive fish kill in the lower James River during the spring of 1974. A series of quickly developed tests strongly implicated chlorination at a sewage treatment plant as the principal cause (Bellanca and Bailey, 1977). These observations and ones elsewhere stimulated extensive research in the 1970's into the effects of chlorination. This paper addresses such observed acute effects.

Acutely toxic concentrations (LC 50s) are, by definition, those concentrations which cause the death of fifty percent of a population of aquatic organisms in a specified time span, ranging from moments to hours to a few days. Early researchers studying the effects of chlorination selected methodologies and test durations which suited their specific environmental concerns. For example, testing the effects of chlorination on

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organisms contained in cooling water passing through a power plant requires only a few minutes exposure to high chlorine concentrations and high temperature. On the other hand, testing the effects of chlorinated sewage on organisms in receiving water requires prolonged exposure of several days. Additionally, the experimental design should include treated sewage because sewage affects the chemical species present to which the organisms are responding.

The acute effects of chlorine on various estuarine animals are summarized in "Figure 1". Rather than including every data point available, this figure presents only recent data to determine whether results of these studies change general conclusions about chlorination's effects. Further data is contained in Mattice and Zittel's (1976) excellent paper summarizing data through about 1974.

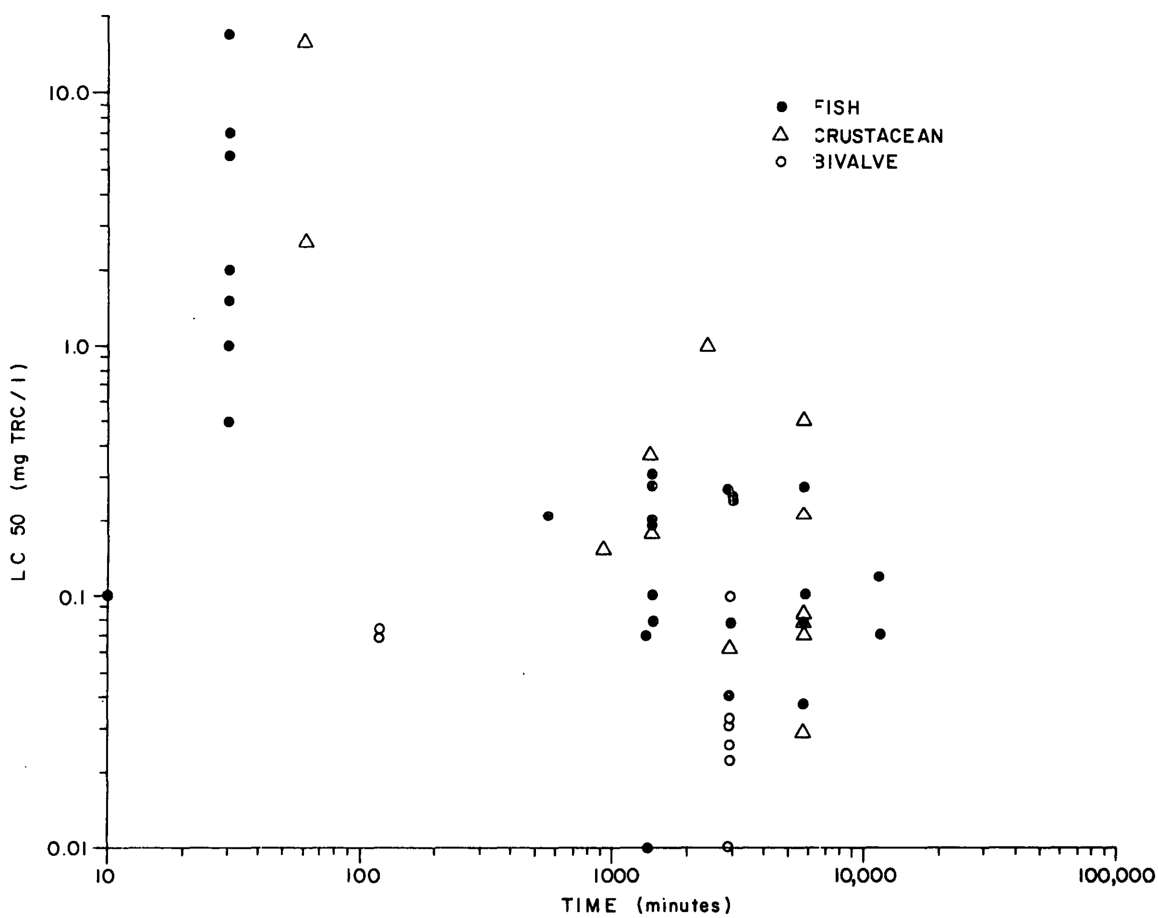

Figure 1. Summary of Acute Toxicity of Total Chlorine Residuals to Estuarine Fishes, Crustacea and Mollusks Independent of Life Stage.

Several things are apparent in Figure 1. Clearly, bivalves are generally more sensitive to chlorine residuals than either fishes or crustaceans. Life stages are not distinguished in this figure, but almost all data points for bivalves were obtained using embryos or larval stages. For fishes and crustaceans data are shown in this figure for larval and adults. Second, the LC50 is higher for short exposures than long exposures since both time and concentration play a role in the acute response of an organism to a toxic substance. From a practical standpoint, however, the operator of a power plant which produces high chlorine residuals for only brief periods might apply chlorine at somewhat higher rates than the operator of a sewage plant in which chlorination is continuous. Third, if the exposure lasts two to eight days, most organisms tested can tolerate a concentration of 0.02 mg/l, which agrees with the conclusion of Mattice and Zittel (1976). In one test on striped bass (Morone saxatilis) eggs, the 48 hour LC50 was approximately 0.01 mg/l. Similarly, the 48 hour LC50 for coot clam (Mulinia lateralis) embryos ranged between 0.01 and 0.1 mg/l in different larval batches. Thus the 0.02 mg/l concentration which Mattice suggested as an upper limit for chlorine in saline water does not totally protect against acute toxicity.

To place these values in perspective, some knowledge of the chlorine concentrations actually produced in ambient waters is needed. For example, during the 1974 fish kill in the James River, two samples were found to contain 2.0 mg/l and several others contained more than 0.2 mg/l. When the chlorination rate was reduced, ambient levels declined below detectable limits as the fish kills ceased. Today at the same plant, it is extremely rare to observe even 0.01-0.02 mg/l except in the immediate vicinity of the outfall. Thus, proper management at this plant has greatly reduced the potential for producing acutely toxic residuals. In waters receiving power plant effluents, reported residuals are generally below 0.01-0.02 mg/l (Fox and Moyer, 1975), which is the approximate limit detectable by most field methods. These findings suggest that, given present practice, the residuals that can be expected in the environment are below but close to levels which are acutely toxic to the most sensitive species.

Early life stages are generally more sensitive to toxicants than juveniles or adults. The 48 four LC50 for oyster embryos (two to six hours after fertilization) was 0.025 mg/l (Roberts & Gleeson, 1978), whereas the 48 hour LC50 for straight hinge larvae was 0.3 mg/l (Rooseburg et al., 1980). Prediveligers are even more tolerant; extrapolating the data of Roosenburg and his colleagues, this later stage has a 48 hour LC50 of perhaps 0.5 mg/l. Adult oysters exhibit reduced shell growth when exposed to chlorine at concentrations of only 0.023 mg/l (Roberts and Gleeson, 1978), but do not die when exposed to concentrations as high as 0.5-1.0 mg/l even after 96 hours. Similar relationships between life stage and sensitivity to chlorine can be shown for fishes and crustaceans.

Dechlorination, the chemical reduction of chlorine residuals with a suitable reducing agent, can eliminate the acutely lethal effects of chlorine on both freshwater and estuarine species (Esvelt et al., 1973; Ward et al., 1977; Roberts, 1980). One study showed that chlorination followed by dechlorination actually reduced toxicity below that of unchlorinated effluent (Esvelt et al., 1973). In addition, a moderate excess of the reducing agents has no demonstrable adverse effect on those species tested to date. Dechlorination has been recommended at new sewage treatment plants in Tidewater Virginia to reduce the possibility of acutely adverse effects of chlorination, should present management control measures fail (Douglas, 1979).

In all of the studies reviewed for this paper, there is great uncertainty about the exact chemical species causing the observed responses. Thus, the mix of active chemicals which probably was not the same in all studies, may contribute to the variability in response shown in Figure 1.

Various halogenated organic compounds have been observed to be formed by chlorination of either sewage or natural waters (Jolley, 1973; Jolley, 1974; Glaze and Henderson, 1975; Jenkins et al., 1978; Rook, 1974). The most ubiquitous organohalogens which appeared in the highest concentrations in the effluent of a Virginia sewage treatment plant were the trihalomethanes, chloroform or bromoform (Roberts et al., 1980). Concentrations up to 0.6 µg/l chloroform and 7.2 µg/l bromoform have been reported in the vicinity of both power plant and sewage effluents in Virginia and Maryland (Bieri et al., 1980). These are compounds known to be hazardous in some environments. At present, however, there is limited data on the acute effects of these compounds on freshwater animals and apparently no data for estuarine animals. Therefore, it is impossible to fairly assess the potential environmental significance of the observed concentrations of haloforms or to evaluate the need for time-consuming and expensive studies of chronic effects.

In summary, chlorine residuals are toxic when present in sufficient concentration. Present chlorination practices produce residuals approximating the acutely toxic concentration, especially for early life history stages. The technology is available, however, to remove the chlorine residual from effluents, thus reducing or eliminating the potential for acute lethal effects.

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