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About This Newsletter

Waste Management Research Report appears three times a year in order to share research from the publication's contributing institutions. Each issue focuses on one major area of waste management and highlights the institution where researchers concentrate on the featured topic. The Waste Management Institute of the Marine Sciences Research Center, State University of New York at Stony Brook, is responsible for this issue on marine pollution. The New York State Center for Hazardous Waste Management, State University of New York at Buffalo, will be responsible for the next issue which will focus on contaminated sediments.

On the Cover

The *ONRUST*, research vessel of the Marine Sciences Research Center, State University of New York at Stony Brook.

Director's Comment

Concern About Ocean Pollution Can Distort Perception Of Waste Management Issues

People flock to the sea to work, to play, and to extract its living and mineral resources. Our heritage stems from the sea and Americans have a special emotional attachment to it and its creatures. In 1990, 41 percent of the U.S. population was estimated to live within 80 kilometers (50 miles) of the coastline of marine coastal states.

Several recent events have reinforced concern about the ocean and how America uses it. The mysterious washups of dolphins along the east coast in 1987, the washups of garbage and trash including limited amounts of medical wastes along the shores of the mid-Atlantic states in 1987 and 1988, crabs with shell burn disease off of the coasts of New York, New Jersey and Rhode Island, and the *EXXON Valdez* oil spill in Prince William Sound have all been front page news. Feature articles in *Newsweek* (1 August 1988) and *Time* (1 August 1988) state that our coastal waters are at risk. But, are they any more at risk than the land or the atmosphere, the only other repositories for the residuals of our society?

Indignation and concern are appropriate responses to the problem of coastal degradation and we must strive to reduce the stress we have placed on coastal resources. However, society must not be misled when the popular press leaves the impression that the coastal ocean and even the open ocean are hopelessly degraded by pollution. The United Nations, through the Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), in fact states that "no areas of the ocean and none of its principal resources appear to be irrevocably damaged and most are still unpolluted." They admonish, however, that they "are concerned that too little is being done to correct or anticipate situations that call for action . . ."

The challenge before society is that of reducing wastes, managing the residuals and understanding the impacts of those residuals on air, land, and water. We must define the role that the oceans should and must play in a global waste management strategy. It is a mistake to believe that progress in pollution prevention, recycling, and reuse of materials is going to eliminate the requirement for waste disposal.

Given the present estimates of global population growth during the next century, increasing from about 6 billion at the beginning before possibly stabilizing according to some United Nations' estimates, at 10 billion, it is apparent that the terrestrial environment (and presumably the coastal zone) is going to be excessively stressed. Moreover, nearly 100 percent of society's drinking water and well over 90 percent of the protein consumed comes from the land. The land must be protected.

The oceans have a tremendous capacity to assimilate, dilute, neutralize, and disperse certain kinds of wastes. From the point of view of human health, it is not certain that land-based disposal technologies like composting or incineration are better than ocean disposal, particularly in areas where ground water contamination and air emissions are of concern. Highly restrictive legislation, *i.e.* the Ocean Dumping Ban Act of 1988 (P.L.100-688) or the Clean Water Act as currently written, might not be in our best long-term interests. Instead of prohibition against use of certain environmental media or technologies, greater attention should be given to encourage pretreatment or prevention of contaminants from entering the waste stream. This would produce cleaner effluents and sludges, increasing environmental acceptability of a number of disposal options. Additionally, legislation and regulations should acknowledge that coastal ocean and estuarine processes vary considerably with location and that this variability can be used advantageously to ameliorate the impacts of pollutant discharges. For example, the benefits of secondary sewage treatment on the receiving waters near Los Angeles and San Diego are small because of the



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morphology and circulation of the Southern California continental shelf. The cost of implementing secondary treatment there may be a poor investment. Public sentiment and hence public policy is easily swayed as a consequence of media focus on an environmental problem. Attention is now focusing upon the environmental hazards of air pollution and its impact on climate. With ocean disposal having been regulated as off limits, we may be backing ourselves into a terrestrial waste disposal corner — the media least regulated.

Many of us who have worked on the problems of marine pollution believe that within a decade society will be dissatisfied and perhaps even fearful of the tendency to limit our disposal of wastes to locations where we grow our food and tap our water. Consequently, while certainly wanting to conserve our ocean and coastal resources, it is important to continue to look for enlightened and acceptable ways to use the ocean as part of a waste management strategy.

However, to do this effectively, it is important to understand the cycling and impacts of contaminants in the ocean. Recently, the Waste Management Institute of SUNY Stony Brook hosted a meeting at which leading marine scientists from around the country identified the research needs and the anticipated marine pollution problems for the 1990s. The meeting was held to aid the National Oceanic and Atmospheric Administration in preparing the fifth edition of the *Federal Plan for Ocean Pollution Research, Development and Monitoring* (1992 to 1997) a requirement of P.L. 95-273. Topics discussed included Toxic Materials, Nutrients, Biological Agents, Loss or Modification of Habitat, Marine Pollution and Public Health, and Monitoring. It was an honor to be selected as the Institution to host this important National forum but also how appropriate. New York State has about 4000 kilometers (2500 miles) of coastline, much of it under stress from excessive population, poor land use planning and from an inadequate understanding of the carrying capacity of marine waters. New York State is microcosm of the waste issues confronting the world as we strive to improve air quality, protect ground water and rehabilitate Long Island Sound, the New York Bight and Lake Erie. How do we balance these admirable but competing issues?

This addition of *Waste Management Research Report* is devoted primarily to marine and Great Lakes' pollution problems. Articles are present on introduced species, oil, toxic metals and nutrient enrichment. We hope they help clarify some marine pollution issues.



"We must define the role that the oceans should and must play in a global waste management strategy."

Recent and Historical Novel Algal Blooms

Monospecific Blooms Occurred Along Northeast Coast in 1980s

By Elizabeth M. Cospers

Novel blooms of algae have been recorded since biblical times (Exodus, vii, 20.21) and the stratigraphic record indicates that they have occurred far back into geological history. Algal blooms can be usual, normal ecological events within aquatic systems such as the "winter/spring" phytoplankton bloom. They also can be unusual or novel in terms of the type of algal species, persistence over long periods of time and vast areas, potentially causing devastating effects on aquatic ecosystems. These blooms can turn the water a noticeable color (brown, green or red) but more importantly toxic substances and noxious odors can be released by the algal cells potentially harming shellfish, fish and ultimately man. If the algal bloom goes unconsumed, it will eventually decay, possibly depleting oxygen, leading to further death of animal populations. The novelty of recent blooms both locally and worldwide has led to a growing interest in understanding the causes of these unusual bloom occurrences.

Brown Tide Blooms

Several coastal embayments along the northeast coast of the USA have recently experienced novel microalgal blooms for which there is no previous record. These monospecific blooms were popularly called the "brown tide" due to the resulting water color. In the early summer of 1985 the first appearance of the "brown tide" occurred over a wide geographic range along the coast in non-contiguous bodies of water: Narragansett Bay, Rhode Island, and Long Island embayments in New York as well as Barnegat Bay in New Jersey (Cospers *et al.* 1987, Sieburth *et al.* 1988, Nuzzi and Waters 1989, Olsen 1989, Sieburth and Johnson 1989, Smayda and Villareal 1989). The extent of the blooms was restricted to these coastal bay systems; blooms did not appear to follow a pattern of spreading from one bay system to the next. This suggests that the environmental factors contributing to these "brown tide" blooms were not just localized to specific conditions in a bay system but probably were more regional, *e.g.* involving meteorologically induced changes. The blooms on Long Island markedly

reduced the extent of eelgrass (*Zostera marina*) beds because of increased light attenuation, and decimated populations of commercially valuable bay scallops (*Argopecten irradians irradians*) since the scallops were unable to graze adequately and starved to death (Cospers *et al.* 1987, Bricelj and Kuenstner 1989, Dennison *et al.* 1989). Similarly in Narragansett Bay the mussels were unable to feed and populations were severely reduced (Tracey *et al.* 1989).

In 1986 the blooms recurred throughout the summer months in the same Long Island embayments as previously. In Long Island and in Barnegat Bay, N.J. during the summers of 1987, 1988, 1989 the "brown tide" blooms returned only in diminishing levels (Cospers *et al.* 1989 *a*, 1990, Nuzzi and Waters 1989, Olsen 1989). During the summer of 1990, just as everyone was convinced that they were waning away, very brief but substantial outbreaks of the bloom were recorded in certain Long Island bay areas by the monitoring program of Suffolk County (Nuzzi 1990), indicating that the potential for these blooms to recur still exists. Since 1985, "brown tide" blooms have not returned to Narragansett Bay (Sieburth *et al.* 1988, Smayda and Villareal 1989).

The unique aspect of these blooms was the dominance of a single very small (2-3 μm in cell diameter) microalgal species in terms of cell number (greater than millions of cell/ml) which contributed greater than 80 percent of total cellular phytoplankton volume throughout most of the bloom period during the summer months (Cospers *et al.* 1987, 1989 *a*). Usually during the summer months "small form" species are dominant but as a diverse group of species with constantly varying successional patterns. During the blooms phytoplankton biomass, as indicated by chlorophyll *a* levels, was not particularly elevated for Long Island bays, in comparison to other years, since concentrations reached levels less than $30 \mu\text{g l}^{-1}$, but chlorophyll *a* was concentrated in the smaller (less than 5 μm) fraction consistent with the cellular size (Bruno *et al.* 1983, Lively *et al.* 1983, Cospers *et al.* 1987, 1989 *a*). Primary productivity levels were high but also



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were not different from pre-bloom years and estimates of carbon turnover were rapid, on the order of hours (Casper *et al.* 1989 a). Changes in inorganic nutrient levels, as nitrate, nitrite, phosphate and ammonium, were not different from pre-bloom years (Hardy 1976, Bruno *et al.* 1983, Lively *et al.* 1983). Variations in inorganic macronutrients were not correlated with variations in the productivity of the "brown tide" and there is no evidence to support increased macro-nutrient loading, such as might come from sewage treatment plants, as a cause of the blooms (Casper *et al.* 1989 a & b). These findings are consistent with similar studies in Narragansett Bay, RI (Smayda and Villareal 1989, Keller and Rice 1989).

The "brown tide" alga, *Aureococcus anophagefferens* (Sieburth *et al.* 1988), is a newly described species not previously known to cause blooms, thus, environmental conditions contributory to the blooming could in part relate to new anthropogenic influences in these bays. Physiological studies have identified certain mi-

cronutrients as conducive to the growth of this species, such as specific chelators (which have replaced phosphates in detergents), selenium and iron, and organic phosphates and nitrogen sources (Casper *et al.* 1990). Drought conditions, which elevated salinities to a level of 30 parts per thousand conducive to the growth of *A. anophagefferens*, along with pulses of rain which delivered specific nutrients to the bay waters and the restricted flushing of bay waters is believed to have set the scene for the formation of the bloom (Fig. 1) (Casper *et al.* 1990). Since this species does not appear to be very palatable to many organisms, selective grazing pressures against the "brown tide" species during the early bloom phase could have further allowed for the development of large populations (Caron *et al.* 1989). The possibility that pesticides in certain fertilizers could have killed the microconsumers in the water column, thus, allowing for the proliferation of the "brown tide" species has also been suggested (Sieburth 1989). No single environmental factor caused these blooms and research still continues to evaluate the possible role of man-made influences.

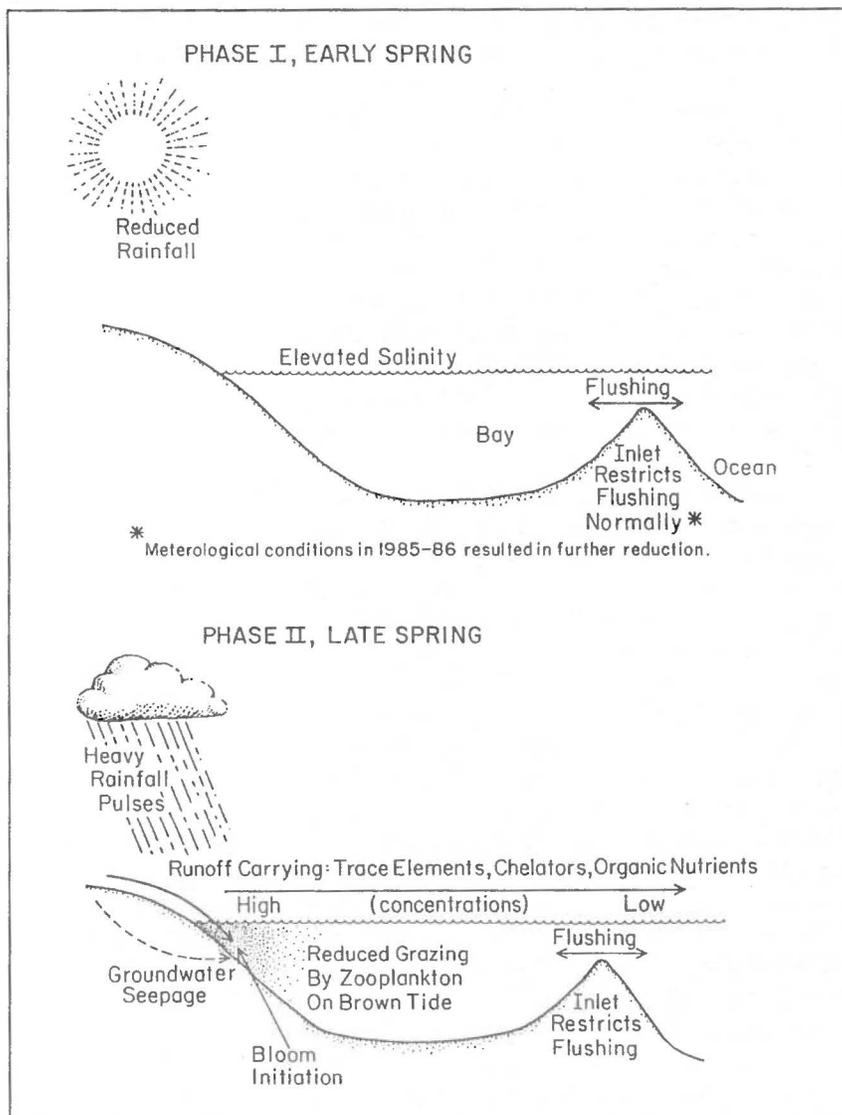
Green Tide Blooms

The "brown tide" bloom scenario had a striking similarity to the well known "green tide" blooms of the 1950's in Great South Bay which also affected the bivalve oyster populations (Ryther 1954, 1989). During the early fifties a sudden lowering of salinity selected for two estuarine ("small form") species, *Nannochloris sp.* and *Stichococcus sp.*, with a salinity of 17 parts per thousand optimal for growth. The recurrence of the "green tides" for several summers afterwards appeared to depend on the restricted circulation of the inshore bays and the overwintering of large enough seed populations to initiate the next summer's growth. Effluents from duck farms, which flowed into Great South Bay through creeks, were found to be supplying nitrogenous nutrients and promoting the growth of these two species of microalgae and these effluents were subsequently restricted. The closing and opening of Moriches Inlet and the subsequent altering of circulation patterns which would have modified the salinity and nutrient regimes in the bay were also considered contributory.

Historical Novel Bloom Records

These unusual bloom events prompted an evaluation of historical accounts of novel algal blooms for the New York/New Jersey coastal waters as well as a consideration of contributory environmental factors (Olha 1990). Unfortunately, the record is relatively incomplete until the 1950s (Fig. 2). Chlorophyte blooms of "small

Figure 1A and B.
Model depicting the two phases of conditions conducive to initiation of brown tide blooms.



forms", similar to the above described "green tides", were prevalent during the 1950s and 1960s in New Jersey waters. After the 1950 "green tide" blooms in New York, the 1960's were dominated by massive blooms of a filamentous macroalga, *Cladophora*, which filled the entire water columns of the shallow bays. In New York waters, the 1970s were characterized by a lack of blooms except for the dramatic dinoflagellate, *Ceratium tripos*, bloom in offshore shelf waters in 1976. New Jersey waters continued to be plagued by many diverse unusual blooms throughout the 1970s. "Small form" blooms returned to both states in the 1980s as the "brown tide", a new picoplankton species. Dinoflagellate blooms, causing red tides, occurred in all four decades in coastal waters of both states, although more chronically in New Jersey waters.

An enumeration of these documented unusual blooms indicates that there is no evidence for an increase in novel blooms in the last 40 years in either New York or New Jersey (Table 1). In evaluating the areas of occurrence, the blooms were much more likely to occur in estuarine areas rather than in coastal or shelf waters in both states (Table 1). Overall New Jersey waters had two to three times the number of documented novel blooms as New York. Multiple environmental variables appear to contribute to any single novel bloom and it is impossible to attribute the blooms to any unique set of variables (Table 2). The environmental variables cited the most often as contributory were residence time of water, nutrients and runoff. However, this analysis must be considered semi-quantitative since much of the documentation for the involvement of certain factors can be

WATER MASS	1950s		1960s		1970s		1980s		TOTAL	
BAY/ESTUARY	7	6	28	9	17	0	4	8	56	23
COASTAL	0	1	1	1	3	0	4	0	8	2
NEW YORK BIGHT	0		0		1		0		1	
TOTAL	7	7	29	10	21	0	8	8	65	25
		14		39		21		16		90

more conjecture than definitive proof. In fact, the obvious trend in the data is for an increase over the decades in factors considered causative, perhaps indicating the increasing awareness that many environmental variables in concert lead to blooms. Understanding the underlying causes of these unusual algal blooms and, thus, ultimately achieving the ability to predict and perhaps prevent their occurrence still depends on a better definition of environmental variability and the role of anthropogenic inputs such as macro- and micro-nutrients in fueling the growth of specific algal species. Another consideration which must be addressed is the role of toxic chemical effluents which can alter the nature and magnitude of the consumer populations in coastal waters, potentially uncoupling production from consumption, and thus unbalancing the ecosystem.

Table 1., above, shows number of novel blooms by water mass type in New York and New Jersey between 1950 and 1988. (N.J. blooms appear in upper left corners and N.Y. blooms in upper right corners.)

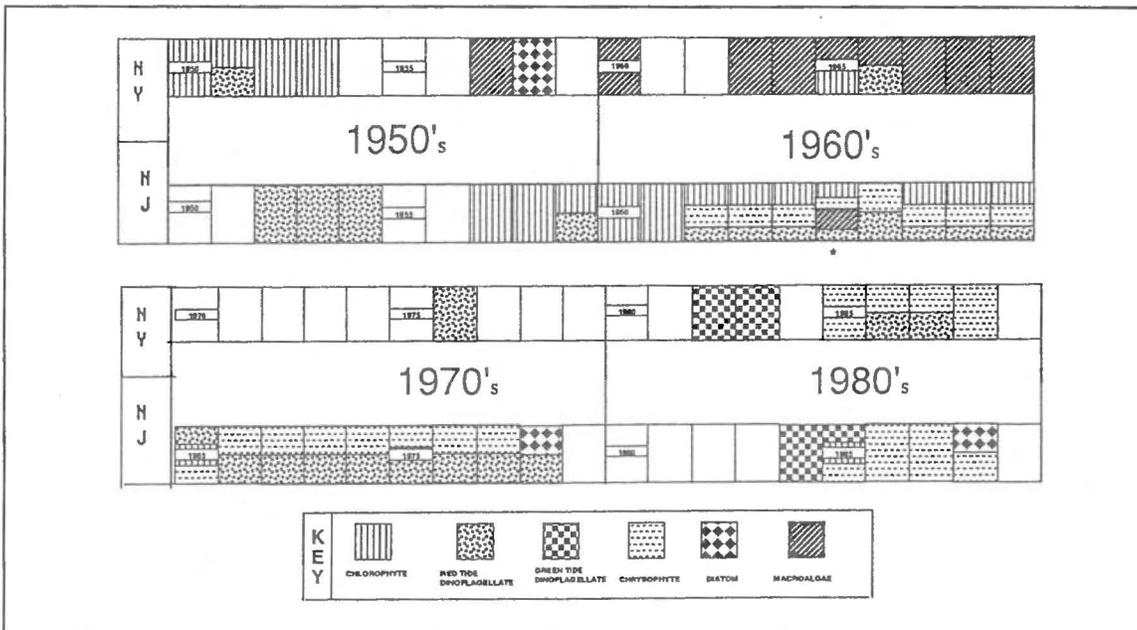


Figure 2. Records of novel algal blooms in the New York/New Jersey area between 1950 and 1988 (There were four blooms in 1965.)

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Table 2, below, shows instances within a decade when a particular environmental variable was considered partly responsible for a novel bloom occurrence.

FACTOR	location	1950's	1960's	1970's	1980's	TOTAL
winds	NY	5	8	1	0	21
	NJ	3	0	1	3	
salinity	NY	5	1	0	4	19
	NJ	3	2	0	4	
rainfall	NY	1	2	0	4	16
	NJ	3	2	0	4	
runoff	NY	4	2	1	4	22
	NJ	3	1	1	6	
nutrients	NY	5	0	0	6	28
	NJ	3	6	0	8	
residence time	NY	5	8	0	6	29
	NJ	3	6	0	1	
stratification	NY	0	0	1	2	8
	NJ	1	1	1	2	
grazing	NY	0	0	1	2	15
	NJ	3	6	1	2	
temperature	NY	1	1	1	2	13
	NJ	3	1	1	3	
oceanic transport	NY	1	0	1	1	7
	NJ	0	1	1	2	
TOTAL		52	48	12	66	180

Metal Bioaccumulation in Marine Phytoplankton and Zooplankton

By Nicholas S. Fisher

The fate of pollutants entering the oceans at the surface (that is, atmospherically delivered pollutants, many river-borne contaminants, etc.) is strongly influenced by the resident biota in the receiving waters. Contaminants are accumulated by organisms to varying degrees, depending upon the type of organism and the speciation of the contaminant in the water. The latter is, in turn, affected by characteristics of the receiving water, with salinity and dissolved organic carbon content being particularly important. Once contaminants are accumulated in organisms, they can remain in the organism, be transferred from one trophic level to another (that is, an animal can eat the contaminated organism and consequently acquire the contaminant), or package the contaminant into rapidly sinking biogenic debris, so that the contaminant is effectively removed from surface waters.

Particular attention has been paid to the interactions of contaminants with planktonic organisms -- primarily phytoplankton and macrozooplankton -- since these organisms lie at the base of most marine food webs and can serve to introduce the contaminants into food chains, potentially leading to man. Moreover, the plankton can be extremely sensitive to some contaminants, and toxic effects on these organisms can have far reaching effects on marine communities since pollutant-induced changes in the species composition of plankton communities can result in shifts in higher trophic levels due to selective feeding and/or digestion among resident animals. However, pollutants can not exert toxic action to an organism if they are not somehow associated with that organism. Put another way, organisms do not care about contaminants outside them--only in or on them. Thus, it becomes imperative in the first instance to understand the bioaccumulation of contaminants in marine organisms at the bottom of the food chain and assess the degree to which they can be transferred to the next trophic level.

Toward this end, a research program has been established to quantify the potential extent of contaminant accumulation in marine plankton by identifying and quantifying the rates and routes of contaminant accumulation and depuration in marine organisms. This work in-

cludes studying the fate of contaminants associated with planktonic debris, which is believed to be the principal means by which contaminants are vertically transported out of surface waters to deep waters and sediments. The focus of this program has been on the behavior of specific metals and metalloids, although many of the mechanisms and principles governing the fate of the metals are applicable to organic contaminants as well.

Metal Accumulation in Phytoplankton

Previous reports have compiled data on the accumulation of diverse metals by marine phytoplankton (Bewers et al., 1985; Fisher, 1986). It has always been assumed that the source term for metal uptake by phytoplankton is the "dissolved" pool of metal. The question of what is really dissolved, however, is very much an open one, and is commonly defined operationally. Typically, material passing through membrane filters with pore sizes ranging from 0.2 to 0.4 μm has been included in the dissolved (as opposed to particulate) fraction. However, recent studies suggest, largely on the basis of metal uptake kinetics by marine particles, that many metals may be associated with colloidal material in seawater and that uptake of the metal onto particles may be via colloid-particle interactions (Honeyman and Santschi, 1989). The extent to which metals, including those which are considered to be toxic when present at high concentrations in contaminated inshore waters (e.g., Ag, Cu, Pb, Hg, Zn, etc.), are bound to marine colloidal material is largely unstudied, although recent work with Fe and Th indicate the presence of colloidal association of these metals.

Recent studies at Stony Brook (Fisher, unpublished results) have shown that for a number of metals, the fraction that would have been previously characterized as dissolved contains substantial amounts of colloidal metal. This is true for americium, cerium, lead, polonium, and tin. Zinc exhibits a modest association with colloidal matter, and barium, cadmium, manganese, selenium, and silver display essentially no colloidal association. Moreover, for those metals which are associated with colloidal material (primarily in the 1-50 kilodalton size range), the



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uptake of metal by natural marine particulate assemblages, including phytoplankton, is mostly via particle-particle interactions. That is, the uptake appears to proceed by colloidal association with larger particles, perhaps driven by Brownian motion, as described elsewhere (Honeyman and Santschi, 1989).

At the same time, the cellular distribution of these various metals (and other elements: C, P, S) in marine phytoplankton cells has been determined. The results show that those metals which have no association with marine colloidal material do penetrate to varying degrees into the cytoplasm of these algal cells and do associate with algal protein. On the other hand, those metals which associate with the phytoplankton via colloidal intermediates are almost entirely (typically > 95%) associated only with the surface (cell walls and/or plasmalemmae) of the phytoplankton cells and show little evidence of protein association.

Metal Accumulation in Zooplankton

Subsequent experiments have been conducted to determine the efficiency with which marine zooplankton, grazing upon metal-containing phytoplankton cells, can accumulate the metals they ingest. Zooplankton, like any marine animals, can obtain metal from both dissolved and food sources. The efficiency with which metals are trophically transferred has been little studied to date, although this information is critical to understanding and predicting the build-up of contaminants in marine food chains, potentially leading to man. To perform these trophic transfer experi-

ments, phytoplankton cells radiolabeled with radioactive isotopes of specific elements were fed to marine copepods (an important component of the zooplankton community) collected from Long Island coastal waters. The results (Figure 1) showed that elements (including metals) associated with cell surfaces were not assimilated in the copepods, while elements in the cytoplasm of the algal cells were assimilated in direct proportion to the extent to which they were contained in the cytoplasm (Reinfelder and Fisher, 1991). It appears that the animals have developed a digestive strategy (perhaps involving the gut lining of these animals) which permits them to assimilate only soluble cytoplasmic material.

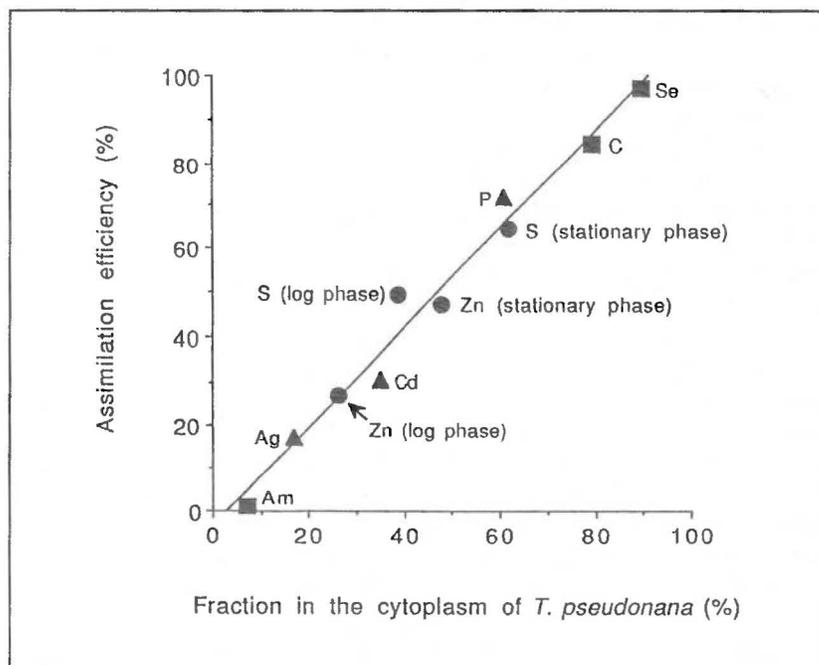
Therefore, metals which associate with phytoplankton cells via colloidal attachment to cells and which do not penetrate into the algal cytoplasm are not assimilated by the animals. Instead, these metals are packaged into fecal pellets which sink rapidly out of the surface waters of the oceans. Thus, the animals serve to depurate the surface waters of these non-assimilated metals. By contrast, those metals which do not associate with colloidal matter and do penetrate into the algal cytoplasm are assimilated in zooplankton. These assimilated metals enter into the organic cycle in the sea, are transferrable to larger animals which eat the zooplankton, and have much longer residence times in ocean surface waters (Whitfield and Turner, 1987). Further, the assimilated metals have greater potential to exert toxic action to the animals because they can be accumulated from the food as well as the water.

Thus, it appears that the extent to which metals are associated with colloidal matter in seawater is directly related to the cellular localization of metals in phytoplankton, the assimilability of ingested metals in zooplankton, and the oceanic residence times of metals.

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Figure 1. Assimilation efficiency (in percent) of ingested elements in copepods fed radiolabeled diatom cells (*Thalassiosira pseudonana*) as a function of the cytoplasmic fraction (percent of the total cell content) of these elements in the phytoplankton cells. (■) *Acartia tonsa*, (●) *Acartia hudsonica*, (▲) *Temora longicornis*. $y + 1.131x - 3.503$. For sulphur and zinc labeled cells, log and stationary growth phase cells were compared. (From Reinfelder and Fisher, 1991)



SUNY-Buffalo Researchers Study Chlorine Control of Zebra Mussels

By John Van Benschoten and James N. Jensen

Introduction

The introduction of zebra mussels (*Dreissena polymorpha*) into the Great Lakes and their inevitable spread to other North American waters have resulted in an intensive search for methods of controlling this unwelcome invader. Zebra mussels have spread throughout Lake Erie, parts of Lake Ontario, and have been identified in the St. Lawrence River, the New York State Barge Canal, and isolated locations in Lakes Huron and Michigan.

In engineered structures such as water treatment plants, power plants, and water intake pipelines, zebra mussel colonization can result in losses in hydraulic capacity, clogging of strainers and filters, obstruction of valves, increased odors, and nuisance problems associated with the decay of proteinaceous flesh and removal of shells.

Chlorination is one of the most common chemical control methods for microorganisms, slimes and attached biota. In virtually all water treatment plants, for example, chlorine is added to the treated water for disinfection. Many power plants have used chlorine for control of biofouling, although in recent years the use of chlorine has been greatly reduced due to environmental concerns. It is known from European experiences that chlorine is effective for controlling zebra mussels. The combination of proven effectiveness with familiarity in applying chlorine both in water treatment plants and power installations has resulted in the widespread use of this chemical for zebra mussel control.

While chlorine is and will probably continue for at least the short term to be used for zebra mussel control, mechanisms of inactivation of zebra mussels by chlorine are not well understood. Consequently, current application strategies may not be optimal in terms of effectiveness or in minimizing chlorine use. In once through cooling systems, at least four different chemical addition strategies are being used. These include: 1. intermittent dosing at high concentrations during the breeding season, 2. low level continuous application during the breeding season, 3. short term (2-3 weeks) continuous, high level treatment several times during the breeding season, and 4. short term (2-3

weeks) continuous high level treatment at the end of the season. Chlorine doses used in practice range from < 0.5 mg/L to about 2 mg/L. In water treatment plants, application strategies are not fully developed.

A complicating factor for water treatment plants is that in addition to effectiveness in killing zebra mussels, dosing strategies must meet the goals of minimizing both taste and odor problems and the formation of chlorinated byproducts. Chlorination of the raw water as it enters the treatment facility would increase the contact time between naturally occurring organics and chlorine. This in turn would likely increase the formation of chlorinated organics, including regulated compounds such as trihalomethanes (THM's). In fact, many treatment facilities recently have eliminated pre-chlorination in order to better comply with limitations on THM production.

Meeting the twin goals of adequate zebra mussel control and minimization of disinfection by-product formation will require careful selection of chlorine doses and contact times. It is perhaps fortunate that the zebra mussel has appeared in waters (*i.e.*, the Great Lakes) which typically produce relatively low levels of THM's upon chlorination. This makes chlorination a more reasonable short-term method for zebra mussel control in the Great Lakes basin.

To develop efficient and effective control strategies for zebra mussels, a more fundamental understanding of the factors affecting inactivation of zebra mussels by chlorine is needed. The objectives of this paper are threefold: 1. to review the aqueous chemistry of chlorine in terms of zebra mussel control, 2. to illustrate study results for the chlorination of zebra mussels, and 3. to discuss zebra mussel chlorination in terms of traditional disinfection kinetics.

Chlorine Chemistry

In aqueous solution, molecular chlorine, Cl_2 , hydrolyzes according to the following reaction:



Because the kinetics of this reaction are rapid, and with a disproportionation constant of $10^{4.5}$ (15°C), molecular chlorine is virtually absent



John Van Benschoten

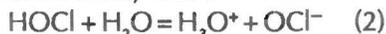


James N. Jensen

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when chlorine is added to most natural waters.

Hypochlorous acid, HOCl, is a weak acid which dissociates to form the hypochlorite ion, OCl⁻.



The acidity constant for the above reaction is defined as:

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{OCl}^-]}{[\text{HOCl}]} = 2.5 \times 10^{-8} \text{ at } 25^\circ\text{C} \quad (3)$$

Figure 1, below left, shows the effect of temperature on zebra mussel mortality using chlorine. Free residual chlorine at 0.5 mg/L. Figure 2, right below, shows the effect of chlorine concentration on zebra mussel mortality.

Temperature ranges from 12 to 15° C. (Jenner and Janssen-Mommen, 1988). Figure 3, left, facing page, shows characteristic disinfection survival curves. See text for explanation of curves. Figure 4, right, facing page, shows survival curves for chlorination of zebra mussels, indicating an increase in mortality with time.

(Adapted from Jenner and Janssen-Mommen, 1988, 2nd International Conference on the Zebra Mussel in the Great Lakes, Rochester, NY.)

As indicated in equations 1 to 3, aqueous chlorine species consist of hypochlorous acid and the hypochlorite ion with the distribution between these species being pH dependent. In addition, the acidity constant for hypochlorous acid is temperature dependent, ranging from 1.5×10^{-8} at 0°C to 2.7×10^{-8} at 25°C.

What does the aqueous chemistry of chlorine suggest for zebra mussel control?

First, it is of no chemical significance whether chlorine is added in gaseous form or as hypochlorite ion. In either case, the acid/base reaction kinetics are fast and the pH and temperature of the water will determine the final distribution of HOCl and OCl⁻.

Second, the use of chlorine for zebra mussel control in the Great Lakes (pH approximately 8) results in a predominance of the hypochlorite ion compared to hypochlorous acid. At pH 8 and 25°C, the [OCl⁻]:[HOCl] ratio is 2.7:1. The significance of this in terms of zebra mussel control is unknown, but in the disinfection of bacteria and viruses, HOCl is known to be about 100 times more effective than OCl⁻. It is plausible that zebra mussels may be more sensitive to one of the chlorine species than the other.

Third, because of the dependence of K_a on temperature, the application of a constant dose of chlorine at constant pH would result in a different chlorine species distribution if applied at differ-

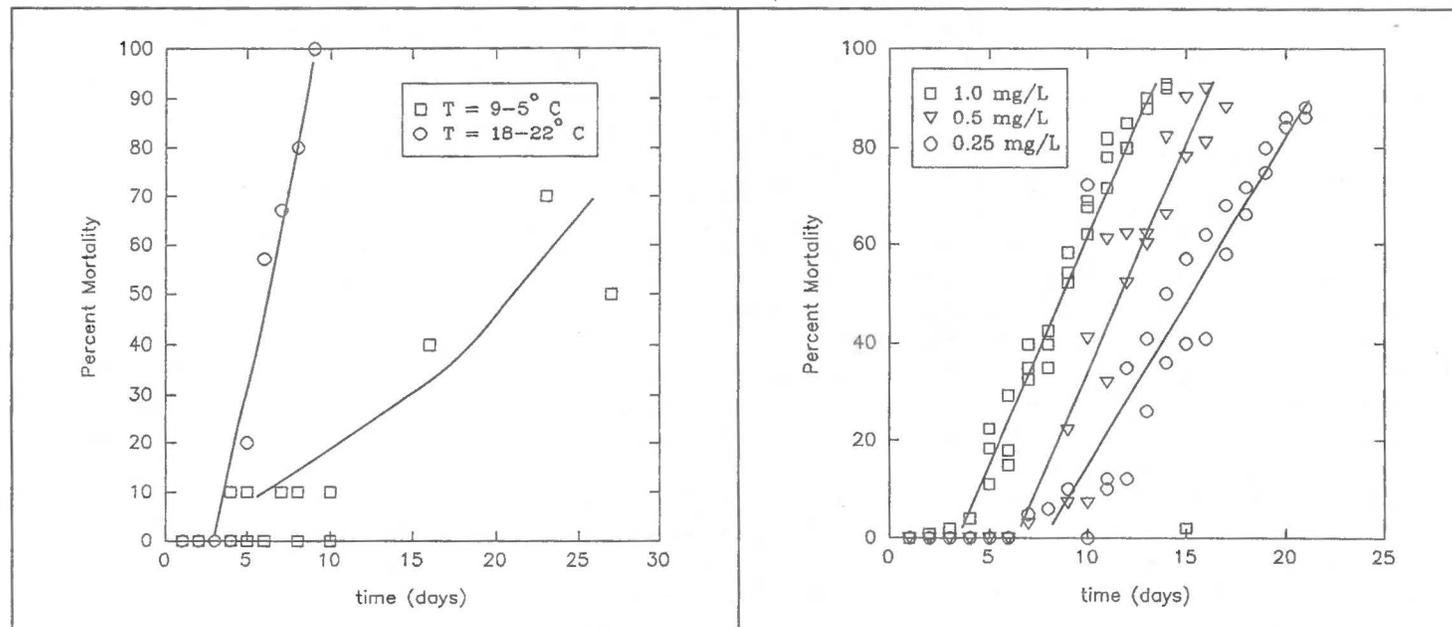
ent temperatures. For example, the application of chlorine at 0°C would result in a ratio of [OCl⁻]:[HOCl] = 1:1 compared to a ratio of 2.7:1 at 25°C.

Chlorination of Zebra Mussels

When chlorine is applied to control zebra mussels, the response of the mussel is to immediately withdraw its siphon and cease all apparent metabolic activity. This behavior is observed even at low chlorine doses. The result of this acute sensitivity to chlorine (as well as other oxidants) results in a considerable lag period between the time of oxidant introduction and the onset of mussel mortality.

The effectiveness of chlorination of zebra mussels is also known to be quite sensitive to variations in temperature, with higher mortalities being observed at warmer temperatures for a given dose and contact time. The effect of temperature is illustrated in Figure 1. The results shown in Figure 1 are for a free chlorine residual of 0.5 mg/L. Studies were conducted in a continuous flow system using Niagara River water. The time for 50 percent mortality increases from about six days at the warmer temperature to nearly three weeks with a temperature reduction of approximately 10°C.

Chlorine concentration also is observed to affect zebra mussel mortality as shown in Figure 2 (Jenner and Janssen-Mommen, 1988, 2nd Intn'l Conf. on the Zebra Mussel in the Great



Lakes, Rochester, NY). It is seen that an increase in concentration results in a reduction in contact time needed to achieve a given mortality. For example, the time for 50 percent mortality decreases from 15 days at 0.25 mg/L to about nine days at 1.0 mg/L total residual chlorine.

The results shown in Figures 1 and 2 are for continuous chlorination of adult zebra mussels. The effectiveness of intermittent applications of chlorine are unknown. Except for temperature, the effects of water quality variables on chlorination effectiveness also are unknown.

Kinetics of Inactivation

Knowledge of the effectiveness of chlorine (and other oxidants) for controlling zebra mussels has been gained from studies that are site specific and empirical. One objective of the work being undertaken at the University at Buffalo is to interpret study data on a more fundamental and global basis.

An initial step to accomplish this objective is to attempt to interpret zebra mussel mortality data according to the disinfection models that have been widely and successfully used for bacterial and viral inactivation. From such models, mechanisms of inactivation possibly may be inferred.

One of the oldest and most widely used disinfection models is the Chick-Watson model. According to this model, the kinetics of disinfection are first order

yielding a relationship for survivorship given as:

$$\ln(N/N_0) = -AC^n t \quad (4)$$

Where:

- N** = number of organisms at time *t*
- N₀** = number of organisms initially
- A** = coefficient of specific lethality
- C** = disinfectant concentration
- n** = coefficient of dilution
- t** = time

The value of *n* in equation 4 depends on the type of disinfectant and pH. The coefficient of specific lethality depends on the relative disinfectant potency. From equation 4, a plot of $\ln(N/N_0)$ versus time should yield a linear relationship. In practice, curvilinear relationships are often observed.

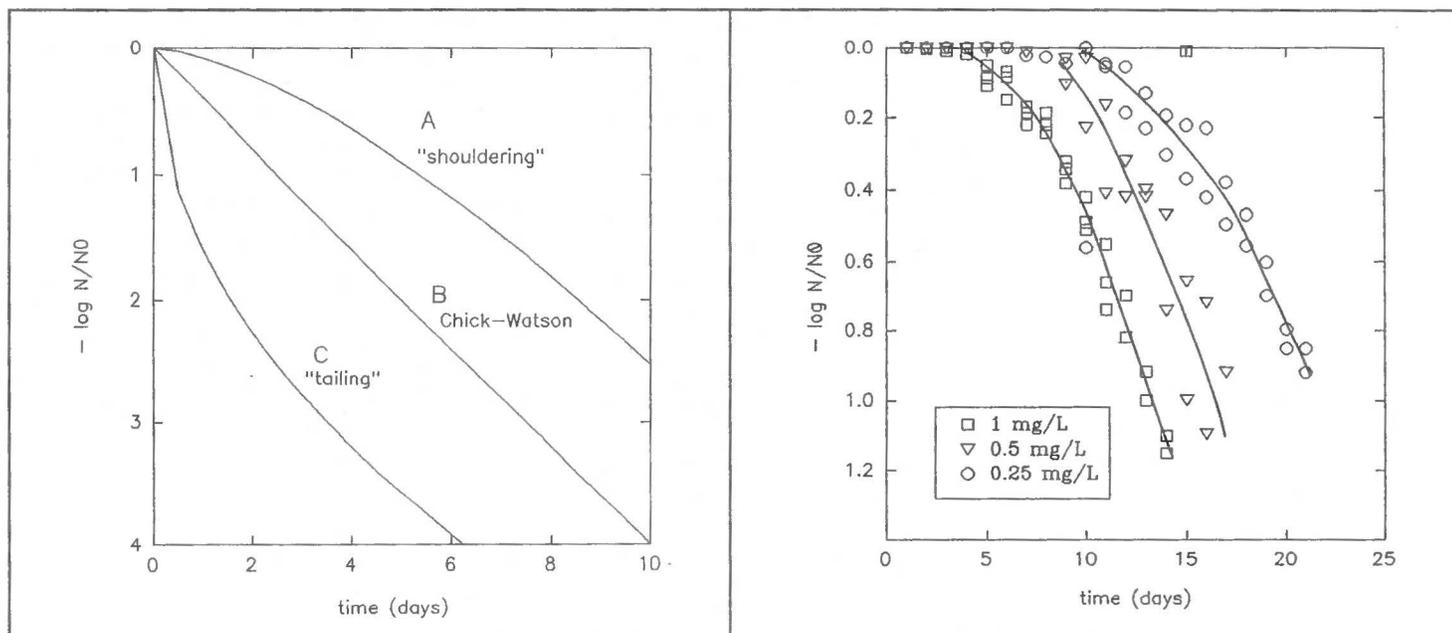
The types of curves observed in practice are shown in Figure 3. Curve A represents an increase in the rate of kill with time and is common for multicellular organisms. Curve B is in conformance with the Chick-Watson model. Curve C indicates a decreasing rate of kill over time.

In addition, an initial lag time during which no organism kill occurs often is observed in practice. For an initial lag period the curves in Figure 3 would be offset to the right a distance equal to the initial lag period. In the disinfection literature, various explanations have been offered to account for this phenomenon. Based on observations of zebra mussels during chlorination, it appears a lag period may be explained by the sensitivity of the mussel to chlo-

rine and the cessation in metabolic activity that follows introduction of the oxidant.

To illustrate the disinfection kinetics of zebra mussels, the data in Figure 2 are replotted in Figure 4 according to the Chick-Watson model. Two observations are noteworthy. First, an initial lag period is observed and appears to be correlated with chlorine concentration. That is, mortality is observed sooner at 1 mg/L chlorine than at the lower concentrations. Second, the curves are not linear but indicate an increase in the rate of kill with time. The presence of curves with "shoulders" as observed in Figure 4 are often accounted for by assuming that multiple targets within each organism must be damaged by independent disinfectant molecules before mortality occurs. Models that account for this phenomenon are defined as "multihit."

Several aspects of a model for the disinfection kinetics of zebra mussels can be identified. From experimental observations, it is clear that models must account for the effects of concentration, temperature, and contact time. Also, some type of multihit model may be necessary. Work is in progress at the University at Buffalo to develop zebra mussel disinfection models for oxidants such as chlorine and ozone. The development of such models should provide useful tools for assessing the effectiveness of oxidant dosing strategies or for comparing the effectiveness of alternative oxidants.



Regular Spills and Chronic Pollution Add to Deterioration of Ocean Life

By Robert W. Howarth and Roxanne Marino

Oil pollution can have serious effects on life in the oceans, and many parts of the world's oceans are being degraded by chronic oil pollution and by regular oil spills. Unfortunately, uncertainty about the magnitude and extent of the effects of oil pollution is great. The variability of life in the oceans and the wide range of insults occurring (other forms of pollution, over-fishing, climate change) make it extremely difficult to know how much of the deterioration of life in the oceans — now widely apparent — is due to oil pollution. Oil pollution is clearly part of the problem, however, and society clearly can and should do more to minimize the problem.

Tanker spills, although dramatic, highly visible, and certainly a contributor to the problem, are not the main source of oil entering the marine environment. Rather, non-point and intentional, chronic discharges are the largest sources. Over the last decade, the world has taken steps to help control some of the chronic pollution associated with tanker operations. Although there is much more that can be done, such as requiring segregated ballast tankers and better controlling tanker loading operations, the effort seems to have helped. There has been a shift from marine transportation as the single largest contributor to the world total input of petroleum hydrocarbons, (estimated in 1981), to its becoming the second largest source, (estimated in 1989), now exceeded by oil inputs in municipal and industrial wastes and runoff.

Because our world uses oil in large quantities and is dependent upon this use, and because oil by its nature is difficult to transport, oil spills cannot be completely prevented. Also, for societies so addicted to oil consumption, some chronic leakage of oil during normal operations is inevitable. Therefore, perhaps a first step in dealing with the oil pollution problem is to recognize the need to develop energy alternatives and to make the maximum use of conservation. The world will not be fueled by oil forever, and the sooner we develop these other approaches to energy use, the less harm will be done by careless use of oil.

Beyond this, we can do much. We probably can greatly reduce chronic pollution, and we definitely can do more to minimize the like-

lihood of oil spills. However, the remaining largest sources of oil pollution — municipal and industrial sources — remain poorly studied and quantified. We need to know much more about the sources of oil coming from urban areas in order to better control them. For example, are the aromatic hydrocarbons in municipal wastes coming principally from volatiles released in industrial operations and from filling car gasoline tanks, which later rain-out and become street runoff, or are poorly disposed-of waste oils more the problem? No one knows, and in fact much of what is known about oil inputs from municipal and industrial sources comes from studies in southern California. Are the sources and input frequencies similar in Singapore? or Amsterdam? or Buenos Aires? No one knows, and it will be difficult to take meaningful steps to reduce the problem until the sources are better defined.

Pollution from offshore oil development has grown to make up five percent of the total input to the world's oceans, with much of this going into previously pristine waters. The chronic oil releases from offshore oil development can be better controlled. Oil-contaminated drill cuttings need not be dumped wherever wells are drilled. They can be contained and disposed of in environments of lower sensitivity. Oil-contaminated formation waters can be re-injected into oil formations rather than released into the oceans. Although formation waters are treated before release, large amounts of toxic aromatic hydrocarbons are still released. At the very least, monitoring of these releases should be improved so as to accurately measure the aromatic hydrocarbons, which can be underestimated by current methods. Better measurement of hydrocarbon discharges and monitoring of ecological impacts are also needed around oil refineries and oil-loading ports. And for both offshore and shore-based oil facilities, society needs to give more thought as to location. Some areas are clearly more sensitive than others, and yet this rarely enters into siting decisions. Some locations are too sensitive even to consider as sites of oil facilities.

What about oil spills? Locally, they can certainly be disastrous. And cumulatively, oil spills can cause widespread and long lasting

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harm. Human error and structural failures cause most oil spills, and as tankers and pipelines age, more accidents can be expected. We can and should insist that oil spills not be the first sign of the need to replace aging tankers and pipelines. We can also do much more to prevent catastrophic damage when accidents occur, as in insisting that tankers be of double-hull design. In double-hulled tankers, the hull consists of two complete layers of metal between the oil and water. This greatly diminishes the odds of catastrophic accidents, since both hulls must be punctured or torn. A double-hulled tanker tore away some 40 percent of its outer hull in an accidental grounding in Japan without spilling any of its cargo.

Double-hulled tankers have been in use for over 20 years, but less than one-fifth of the world's tankers have double hulls, according to Arthur Mackenzie of the Tanker Advisory Center in New York. Before the Alaska pipeline from Prudhoe Bay to Valdez in Prince William Sound was built, Congress was assured by Secretary of Interior Rogers Morton that all tankers used to haul oil from the terminal through Prince William Sound would be required to have double hulls. Unfortunately, heavy lobbying from the oil industry resulted in the dropping of this requirement, so that the *Exxon Valdez* had no extra protective layer. Had the requirement been upheld, the the *Exxon Valdez* oil spill may never have occurred.

We also need better checks and controls on the movement of tankers through sensitive areas and through waters treacherous for navigation. It is easy to blame a tanker accident on a captain who has been drinking, but the movement of such large vessels carrying toxic cargo through sensitive marine habitats should not be left to the control of any one individual. The movement of vessels can be monitored through the use of radar, and "traffic lanes" which keep vessels apart can be enforced. Radar tracking of tankers existed in Prince William Sound, but the U. S. Coast Guard had reduced their use of radar there before the grounding of the *Exxon Valdez* in response to budget constraints. After the accident, the shortsightedness of this cut is apparent to all. Cutbacks on staffing on the tanker itself may also have contributed to the accident through crew fatigue. Tankers can also be accompanied by escort tugs through sensitive areas.

In many waters, tanker traffic is reasonably regulated. However, problems exist even in some of these waters because non-tanker traffic is often not included in regulations. For instance, in the Hudson River, tankers moving up and down the river between New York City and

Albany require an experienced river pilot on board. Yet tug boats can push and pull barges full of oil and oil products without any requirement for a pilot. These tugs and their barges frequently run aground and are the major source of oil spills for much of the Hudson River.

As part of realistically dealing with oil spills, the world needs to understand that large oil spills have never been cleaned up to any significant extent, and they are unlikely ever to be cleaned up. Small spills sometimes can be cleaned up, although they usually are not, and sensitive habitats sometimes can be protected from large spills. Planning for oil spills should be directed toward these achievable objectives, and the public should not be misled about rosy prospects for clean-up.

Realistic spill contingency plans for oil transport facilities should be developed and periodically reviewed and updated. Such contingency plans should require that adequate and reliable equipment, along with well-trained response teams who understand which technologies are best used under a given set of conditions, are available for rapid response to any spill. However, even the best response system will be limited in its ability to clean up a major oil spill. Generally, efforts are best spent in minimizing the likelihood of spills.

Society needs to recognize the risks of oil pollution, and environmental needs must be given their proper weight relative to economic and energy concerns. Governments of nations around the world should develop sane and diverse energy policies and encourage conservation to reduce our planet's dependency on fossil fuel. The longer such planning is put off, the more difficult and expensive the transition — both to the economy and to the environment. Developing and industrialized countries alike need to do more to protect their ocean resources from oil pollution. Finally, we need to recognize that acts of war can be a major source of oil spills. Much more must be done to encourage world peace and cooperation in dealing with the limited oil resources available to the world.

*The above article is from the summary, **Oil in the Oceans**, a 1991 review written for Greenpeace. (References deleted)*

Cornell Institute to Sponsor Workshop

The Cornell Waste Management Institute will sponsor a workshop, "Commercial and Institutional Waste Reduction," Nov. 14 at the Genesee Plaza Holiday Inn, Rochester, NY, in conjunction with the New York State Department of Environmental Conservation Recycling Conference Nov. 12 and 13.

Dewatering Facilities Under Construction

New York City Agrees to End Dumping Of Sludge in Ocean By June 30, 1992

By John H. Martin Jr.

On 10 August 1989, the City of New York entered into a consent decree and enforcement agreement with the U.S. Environmental Protection Agency (US EPA), that should terminate all ocean dumping of the City's sewage sludge by 30 June 1992. This will end a practice that New York City has used for more than 50 years to dispose of the sludge generated at the 14 wastewater treatment facilities located in the City.

It also should end all ocean disposal of New York State sewage sludge, because similar consent decrees and enforcement agreements are in place for the 10 other New York State wastewater treatment facilities, located in Nassau and Westchester Counties, that also use ocean dumping for sludge disposal. The sludge generated at these 24 facilities represents, on a dry matter basis, more than 40 percent of the total sewage sludge produced in New York State.

Although the practice of sewage sludge disposal by ocean dumping had been employed by coastal cities for many years, it became the subject of considerable debate in the 1970's. This led to an initial attempt by Congress in 1977 to ban ocean dumping through amendments (PL 95-153) to the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532). These amendments required the EPA to establish a deadline for the termination of all ocean disposal of sewage sludge. That date was 31 December 1981. While many coastal communities developed sewage sludge disposal alternatives that resulted in the termination of ocean dumping, New York City and several other affected communities sought judicial relief in federal court, and obtained injunctions that permitted continued dumping pending promulgation of revised regulations.

In 1985, the EPA, under statutory authority of the Marine Protection, Research, and Sanctuaries Act of 1972 as amended, designated a new location for the ocean disposal of sewage sludge from the New York metropolitan area. This new location, known as the 106 mile site, was designated as an interim site until a final determination could be reached on the question of ocean disposal of sewage sludge. It replaced the location, known as the 12 mile site, that had been used by New York City since 1938. Sludge dis-

posal at the 106 mile site began in 1986. By 15 December 1987, the phasing out of sludge dumping at the 12-mile site had been completed as mandated by the Clean Water Act Amendments of 1987.

As a condition of New York City's permit for use of the 106 mile site, the US EPA required a comprehensive study of other sludge disposal alternatives. This study was in progress when the Ocean Dumping Ban Act of 1988 (PL 100-688) was enacted. This legislation amended the Marine Protection, Research, and Sanctuaries Act of 1972 by prohibiting all disposal of sewage sludge and also industrial wastes by ocean dumping after 31 December 1991. In addition, ocean disposal of sludge and industrial wastes was prohibited in the interim without a permit issued by the US EPA, and no permit could be issued unless an agreement with a plan and time schedule for the cessation of ocean dumping was in place. If schedule negotiated does not provide for the cessation of ocean dumping by 31 December 1991, the agreement requires the payment of penalties beginning with \$600 per dry ton for 1992.

The consent decree and enforcement agreement that New York City entered into with the US EPA as a condition for a permit to continue use of the 106 mile site for sludge disposal contains a detailed plan and schedule for the termination of ocean disposal of sludge by the City. New York City currently is in the process of executing this plan which includes construction of dewatering facilities to reduce sludge volume, contractual agreements with the private sector for interim sludge disposal, and finally development and implementation of a long-term sludge management plan.

The consent decree and enforcement agreement require that the sludge dewatering facilities be in operation by 30 June 1992, and also that all ocean disposal of sewage sludge cease by that date. It also requires full implementation of a long-term sludge management plan by 30 June 1998. To date, New York City has met all deadlines set forth in the consent decree. Although remarkable progress has been made, much remains to be accomplished.

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Ralph Rumer Receives Excellence Award

Dr. Ralph R. Rumer, executive director of the New York State Center for Hazardous Waste Management at State University of New York at Buffalo and a professor of civil engineering at the university, recently received a 1991 New York State/United University Professions Award for Excellence. Award recipients are elected by their peers. SUNY Chancellor D. Bruce Johnstone must approve each election.

Rumer's award cites his work on the Coriolis force in large lakes as "a unique contribution to the understanding of Lakes Erie and Ontario and the mitigation of environmental problems." (The Coriolis force, named for Gaspard G. Coriolis, a 19th Century French mathematician, is an inertial effect of the earth's rotation. It deflects moving bodies above the earth's surface to the right in the Northern Hemisphere and counterclockwise in the Southern.)

The New York State Center for Hazardous Waste management, which Rumer directs and helped to develop, is a \$4 million research and development program that involves 10 universities and colleges in the state. The Great Lakes Program at Buffalo, which began as an information clearing house and center for policy studies, now supports science and technology research and collaborates with Canadian and New York State research facilities as a result of Rumer's efforts.

He has served on National Academy of Sciences panels, National Science Foundation fellowship review panels, and, closer to home, advised Town of Amherst officials and the Buffalo Mayor's Committee on engineering issues.

NYS Center for Hazardous Waste Management

Project Summary Reports Available

The New York State Center for Hazardous Waste Management supports research aimed at the development of new and improved technologies and methods for: reducing the generation of hazardous waste, recovery and reuse of hazardous substances, treating hazardous waste so that it can be disposed of safely, and cleaning up environmental sites contaminated with hazardous substances. The Center also conducts workshops and roundtables that address important hazardous waste management issues. To

make the findings from its research and workshop activities available to those interested, the Center provides summary reports (about 10 pages in length) for a nominal cost. The following recent summary reports are now available from the Center (see complete listing of Center publications at end of this article).

Development of Oxides of Iron as Sorbents for the Control, Separation, and Recovery of Inorganic Hazardous Waste Components.
Thomas L. Theis, Clarkson University

Granular iron oxides were used to adsorb trace and hazardous inorganic substances from aqueous solution. Solutes investigated included: arsenite, selenate, selenite, vanadate, humic acids, cadmium, lead, arsenate, and chromate. Granular iron oxides can be used in a variety of treatment settings, including waste site remediation, end-of-pipe controls, industrial process in-line recycling-recovery, and purification of water to meet maximum allowable contaminant levels.

Use of Metal Adsorbing Compounds to Mitigate Heavy Metal Toxicity in Suspended Growth Biological Treatment Systems: Part II.
Mark R. Matsumoto, State University of New York at Buffalo

Powdered compounds having a high metal adsorbing capacity were added to a suspended growth biological treatment process to mitigate toxic upsets caused by heavy metals. After screen-

Buffalo Center Offers Questionnaire on Source Reduction

The New York State Center for Hazardous Waste Management sponsors a project to identify research needs related to source reduction of hazardous waste. In conjunction with this project, a short, confidential questionnaire has been developed to help identify and target specific research project areas. If you are interested in this area, your response to the survey would be greatly appreciated. To receive the questionnaire, please contact: Professor Michael E. Ryan, New York State Center for Hazardous Waste Management, State University of New York at Buffalo, 207 Jarvis Hall, Buffalo, NY 14260 Telephone (716) 636-3446, FAX (716) 636-3667.

ing available sorbents, a selected metal adsorbing compound was found to mitigate process upsets caused by soluble nickel in the influent waste.

Air Stripper Offgas Adsorption for Hazardous Waste Sites and Contaminated Groundwater. James A. Mueller, Manhattan College

A mathematical framework needed to predict multicomponent offgas adsorption was developed that will allow successful design of gas phase adsorber systems treating

multicomponent volatile organics from hazardous waste sites or any contaminated groundwater using air stripping technology for removal from the liquid phase.

Nonaqueous Enzymatic Conversion of Recalcitrant Polyaromatic Hydrocarbons to Readily Biodegradable Substrates. Alexander A. Friedman and James E. Smith, Syracuse University

A feasibility study was conducted using immobilized iron-sulfur enzymes to degrade fused-ring PAHs. Biological enzymes associated with soil bacteria were covalently linked to fiberglass pads, dried, and exposed to PAHs and azo dyes dissolved in toluene and cyclohexane. Azo dyes and the single ring control compound p-anisidine were degraded under low moisture conditions by the enzymes.

Electrocoagulation for Hazardous Waste Management: Fundamental Aspects, Applications and Economic Feasibility. James N. Jensen and John E. VanBenschoten, State University of New York at Buffalo

Study results identify the mechanisms responsible for contaminant removal by electrocoagulation, determine the treatability of specific hazardous wastes by this method, and evaluate the associated economic advantages.

Anaerobic Biological Activated Carbon Treatment of Multicomponent Hazardous Wastes, A. Scott Weber, State University of New York at Buffalo

A process model based on a mechanistic understanding of the anaerobic biological activated carbon process was constructed and tested. During steady-state operation, greater than 99 percent removal of acetate and phenol was achieved. Even at high loading rates, near stoichiometric methane generation was observed, suggesting that biodegradation is the primary removal mechanism with the carbon serving simply as a biofilm support structure.

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The Cornell Waste Management Institute has published its newest series of **Fact Sheets** and **Viewpoints**. Fact Sheet 4, "Waste Prevention: What, Why and How," and Viewpoint 4, "Options for Waste Prevention," are available from the Institute, (607) 255-7535.

Guest Comment

Marine Pollution Nothing New In Annals of Human History

By Harold Berger

This issue of *Waste Management Research Report*, dedicated to marine pollution, highlights important concerns. Oil spills, hypoxia, floatable debris, ocean dumping, phytoplankton blooms, introduced species, water diversion, and sewage disposal are ever-present marine pollution problems in New York State. The problems are economic as well as environmental. Research into many of these issues is discussed in this *Report*.

Pollution has had an impact upon much of New York's 4,000-kilometer coastline. On July 6, 1988, medical debris was found on Lido Beach, Long Island. The discovery was the beginning of "the beach washup event of 1988" that resulted in an estimated \$2 billion in lost tourist revenues for Long Island that summer. While the amount of actual medical waste found on Long Island beaches during July and August of 1988 was small, filling approximately two shopping bags, public perception was that the beaches were covered with needles, surgical tubes, and miscellaneous hospital waste.

Concerns about marine pollution and its effects on our beaches, on the habitat and edibility of fish, on the safety of our waters for swimming, and on the aesthetics of our shores did not begin with the events of the 1988 summer season on Long Island. Historical records show that European royalty expressed concern about the discharge of waste into marine waters because they were afraid that garbage would block the passage of ships. In 1388, the English Parliament banned the disposal of waste into public waterways and ditches for that reason. In Naples in 1597, the breakwater that sheltered moored vessels became so clogged that city leaders contemplated building a new breakwater instead of repairing the existing one. In 1880, nine percent of all cities in the United States disposed of municipal waste by dumping it into bodies of water.

The concerns of the public, and of sanitary engineers, may have given Col. George E. Waring Jr., often called "the father of modern waste management," incentive to invent the dual system that channels raw sewage and storm water into separate piping. Today, we ascribe many of the pollution problems found in New York's coastal waters to the combined overflows of New York City's sewers. On Long Island, however, the greatest threat to the most productive, certified shellfish growing waters comes from non-point source pollution, particularly in the form of storm water runoff. Of the 1.2 million acres of tidal and subtidal land in New York State, approximately 195,000 acres (15 percent) are uncertified for shellfish harvest because they exceed coliform standards. The situation has a significant impact upon the livelihood of the 200 full-time baymen on Long Island.

Oil spills, both local and in other waterways, have become commonplace. Hypoxia affects many semi-enclosed bodies of water. Floatable wastes blemish our beaches, and plankton blooms have become more than a mere nuisance. The many insults to our marine environment, both actual and perceived, result from an affluent society's attempts to dispose of its wastes. While it appears that the immediate answer is to reduce those wastes, an ever-increasing population makes waste reduction a losing battle.

Marine pollution, like pollution of land and air, is a symptom of civilization. As our civilization develops and our population continues to rise, we stress the capacity of the planet's natural processes to store and degrade our wastes. We need to reduce the size of the waste stream, optimize natural systems to decompose waste safely, develop innovative technologies to speed natural processes, and reuse materials in the waste stream. The Waste Management Institute of the Marine Sciences Research Center at SUNY-Stony Brook, the New York State Center for Hazardous Waste Management at SUNY-Buffalo, and the Cornell Waste Management Institute and New York State Solid Waste Combustion Institute at Cornell University are important to the state's future because their researchers strive to find solutions to our ever-increasing waste disposal dilemmas.



Harold Berger

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Aerial view of Setauket Harbor,
North Shore of Long Island

By R.G. Rowland