A WORKSHOP REPORT

Chemical Contamination in the Chesapeake Bay

A Synthesis of Research to Date and Future Research Directions



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REPORT HIGHLIGHTS

Among the report's significant conclusions are the following:

- Monitoring has shown that contaminants emanating from diffuse sources (such as car exhaust and other air deposition, stormwater runoff, household and boating solvents and other chemicals) are becoming relatively more important than industrial sources, which have been dramatically reduced since the passage of Clean Water and Clean Air legislation.

- In addition to identified "hot spots" (Regions of Concern) evidence exists that low-levels of contaminants in the Chesapeake Bay have an impact on organisms at several major levels of the food web.

- Specifically, research shows that oysters exposed to chemical contaminants in the Bay are more vulnerable to diseases such as Dermo. This may be especially significant, given current efforts to restore oyster reefs and oyster populations in the Chesapeake.

- Exposure to trace metals and other contaminants can affect phytoplankton populations under research conditions, causing shifts in species composition, for example. Since phytoplankton form an important base of the Bay's food web, changes here could have significant impacts throughout the Bay.

- Although the consensus among researchers is that herbicides such as Atrazine and pesticides such as Dimilin do not appear to cause widespread damage to the Bay's ecosystem, experimental work has shown that both Atrazine and Dimilin can have deleterious effects in localized areas, if concentrations are high enough. Studies have also indicated that chemical preservatives, such as those used in wooden bulkheads, cause a loss of species diversity in adjacent areas.

- Because of the evidence of biological impacts - even at relatively low levels of contamination, and because diffuse sources may be more difficult to control than point sources - it is imperative that we further investigate the effects of contaminants at environmentally realistic levels, on key facets of the Bay's food web.

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EXECUTIVE SUMMARY

This report synthesizes the views of a diverse group of scientists and resource managers on the impact of chemical contaminants on the Chesapeake Bay. It is the result of a meeting - held at the Belmont Center near Baltimore, Maryland in December, 1995 - designed to reach consensus on the effects that representative contaminants have on the Bay, and to determine what scientific information we still require in order to base on-going restoration efforts on the best available technical knowledge.

Through better understanding of the behavior and, most importantly, the effects of contaminants as they move through the Bay ecosystem, managers can implement more effective prediction-based actions to safeguard the Chesapeake's living resources. Toward such ends, major research to date has focused first on determining the sources and transport of contaminants in the Bay. Much of the Chesapeake Bay Program's management efforts to reduce land-based sources of contaminants have resulted from these studies. While much remains to be learned about sources of contaminants - especially about diffuse inputs - a major research emphasis in recent years has focused on the connection between the movement of contaminants in the estuary and their varying effects on the Bay's ecological health.

Extrapolating the findings of such research can be exceedingly difficult. The dynamic effects of contaminants in an ecosystem like the Bay involve a network of elaborate feedbacks among physical, chemical and biological processes that are themselves mediated by seasonal changes in salinity, temperature, pH, oxygen, winds, tides, precipitation and other factors.

While a single contaminant may have an evident effect - creosote in the Elizabeth River, for example, has caused lesions in fish, and the spilling of Kepone in the James River caused tumors in bottom-feeders - sublethal effects of small concentrations of a contaminant may not be evident at all, at least for some time. The presence of low levels of arsenic, for instance, may have no impact on shellfish or finfish directly; however, it can significantly affect phytoplankton species composition - such changes can cascade through the food web with indirect effects on oysters and striped bass. Together with other environmental stresses, low levels of contaminants such as arsenic could have other unpredictable ecological implications.

Because of the indications of biological impacts, even at relatively low levels of contamination, and because diffuse sources may be more difficult to control than point sources, it is imperative that we further investigate the effects of contaminants, at environmentally realistic levels, on the Bay's food web at key hierarchical levels.

Sources of Contaminants | Transport of Contaminants | Biological Effects | Major Research Needs

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Primarily relying on five contaminants as "representatives" - copper, mercury, atrazine, PAHs (polycyclic aromatic hydrocarbons), and PCBs (polychlorinated biphenyls) - the scientists and managers meeting at the Belmont Center attempted to summarize what we now know about contaminants in the Chesapeake, and to give some priority to what we need to know in the areas of sources, transport and biological effects.

Sources of Contaminants

Research guided by the Chesapeake Bay Program, the Chesapeake Bay Environmental Effects Committee (CBEEC) and others, as well as related monitoring, has focused on identifying and quantifying sources of priority pollutants and on the processes that serve to transport these contaminants throughout the Chesapeake Bay. This research emphasis has led to a strong understanding and - in a number of instances - quantification of basic pathways by which contaminants reach the Bay. We now know that:

- Specific point sources of contaminants from industries and sewage treatment plants have been significantly reduced, largely in response to the Clean Water Act and the Clean Air Act.
- Increasing human population in the 64,000 square mile watershed and the even larger airshed - together with related developments such as deforestation, dredging, septic seepage and stormwater runoff - has meant that contaminants from diffuse sources account for increasingly greater inputs to the Bay ecosystem.
- Mechanisms of diffuse contaminant delivery vary widely throughout the Bay depending on the contaminant. Mercury, for example, arrives primarily from coal-fired power plants, atrazine via runoff from agricultural lands, PAHs from the burning of fuels (e.g., engine exhaust, power plan emissions), PCBs from recycling in Bay sediments.
- In the upper mainstem Bay - where river flow has more immediate influence than in the lower Bay - direct discharges, usually from urban and industrial areas, are major sources of contaminants entering the estuary. In the lower mainstem Bay, atmospheric deposition and other diffuse sources dominate.
- Contaminated Bay sediments have become potential reservoirs of toxic chemicals through recycling. Many of these buried contaminants are otherwise now heavily regulated (such as Kepone or DDT).
- How contaminants accumulate in the water and sediment depends both on the source (point or diffuse loadings) and on the areas in the Bay where contaminants arrive.
- Efforts to control diffuse inputs resulting from general patterns of land use and development, and

air deposition, have been less successful than past management efforts to reduce point source loadings of contaminants such as PCBs, DDT and TBT.

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Transport of Contaminants

Research and monitoring have demonstrated how contaminants move into and through the estuary, becoming resuspended and moving with currents and tides. We know that:

- Water circulation and sediment resuspension, recycling and movement are key processes in the transport of contaminants.
- Natural estuarine processes - physical, chemical and biological mechanisms - and human activities such as dredging redistribute both recent and historical inputs of chemical contaminants.
- Environmental conditions such as anoxia in bottom waters and sediments affect the availability, transformation and degradation of potential contaminants. During anoxic events, reducing metals such as arsenic and manganese are generally released from sediment, while non-reducing metals such as cadmium, copper and zinc tend to be fixed in sediment. When water is oxygenated, the reverse occurs: arsenic and manganese are captured by the sediment, while copper, cadmium and zinc are released from the sediment.
- Biological processes, including uptake, metabolism and transformation, can transport contaminants through the estuary. Benthic organisms, for example, may take up toxic compounds from sediments, transform and concentrate them, thus incorporating them into food web. In short, toxic substances are not inert, and as a result of biological processes their form, toxicity and availability can change dramatically.
- Recently arrived contaminants are more geochemically and biologically reactive than are historical inputs, which are more likely to be bound up in mineral phases and therefore less biologically available.
- Fisheries and fisheries management, as critical components of Bay food web dynamics, can also play an important role in the cycling of contaminants. The widespread loss of oysters, for instance, has evidently reduced the biological filtering capacity of the Bay, which has important implications for the movement of contaminants through the estuary, and for the estuarine food web.
- Nutrient enrichment has resulted in shifts in primary production that favor algal blooms over submerged aquatic plants; these shifts represent a key change in fundamental processes of metabolism and transport of chemical contaminants.

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Biological Effects

The ecological impact of chemical contaminants in the Chesapeake remains the most challenging area for scientists and managers. Demonstrating the connection between even well documented inputs of contaminants and ecosystem responses to those contaminants relies on the science of aquatic toxicology, an evolving discipline that evaluates responses at hierarchical levels, from molecules to ecosystems. Although in such ecological research there is always the question of extrapolating observations at one level (say, the level of the cell) to higher levels (such as the whole organism, or a community of organisms), scientists have nevertheless been steadily detailing relationships between specific contaminants and biological effects. We now know that:

- Contaminants can compromise the immune systems of Bay organisms. Laboratory studies of the oyster's immune system, for example, have shown that exposure of oyster cells to TBT (tributyltin) (Anderson et al. 1996), to PAHs (polycyclic aromatic hydrocarbons) (Chu and Hale 1995) or to the chemical carcinogen DEN (n-nitrosodiethylamine) (Winstead and Couch 1988) interferes with hemocytic response to the Dermo parasite, thus enabling Dermo to progress more rapidly and with more lethal results than observed in cells of unexposed oysters. Further, research on oyster feeding (Newell and Weston 1996) has shown that the oyster is more likely to take up contaminants already bound in the phytoplankton on which it feeds, in contrast to contaminants attached to sediment particles, for example.

- Chemical preservatives on wooden structures - on bulkheads for example - can harm marine life. A study on the ecological impacts of bulkheads treated with CCA (copper, chromium and arsenic) has shown that aquatic organisms grazing on green algae attached to the bulkheads ingested enough contaminants to cause death. This research also found that organisms, populations and communities in the vicinity of CCA-treated materials showed reductions in biomass and limited species composition, leading to lower biological diversity and less productivity in the area.

- Contaminants can affect phytoplankton at the base of the Bay's food web. Research in the Patuxent River, for example, has shown that phytoplankton blooms can concentrate trace metals, which are then passed to the zooplankton that graze on them.

- Unconsumed algae and other organic matter that fall to the Bay floor can decay so rapidly that the contaminants bound to that matter can remain in the water column. Whether contaminants remain longer in the water column or more quickly join bottom sediments depends on physical processes and obviously influences the kind of effects toxic compounds will have on an ecosystem like the Chesapeake Bay.

The cellular link between contaminants and biological responses allows researchers to anticipate and predict effects at higher levels, from the individual to entire ecosystems. Scientists point out that:

- Biochemical and cellular alterations are usually the first detectable, qualifiable responses to environmental stresses.
- Chemically induced changes in a biochemical system or cellular function can serve as markers of both exposure and effect.
- Alterations in these systems are often more sensitive indicators than those at higher levels of biological organization, and will underlie effects seen in whole populations.

- In aquatic organisms generally, the most confirmed linkage between toxic contaminants and physiological endpoints is as follows: carcinogens (e.g., PAHs) lead to a direct response in an organism (such as an increase in the enzyme P450) involved in the organism's attempt to detoxify environmental contaminants; this response then leads to DNA alterations and mutations, and ultimately to cancer. While the links in this chain of cause and effect can be quantified and interrelated, sublethal effects have not been quantified under varying ecological and climatic conditions. Therefore, long-term ramifications in the Bay remain uncertain.

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Major Research Needs

Future research must focus on the nature and extent of biological responses to chemical contaminants. If management of living resources is to be based on a realistic understanding of Chesapeake Bay ecology, we must detail the effects that representative contaminants (and especially combinations of contaminants and other stresses) have on the health and behavior of individuals, populations, and communities - in short, from the organism to the ecosystem level.

In particular, much greater emphasis must be placed on the following:

- Quantifying system-wide effects of low-level concentrations of contaminants on living organisms in the Bay. Researchers studying toxic chemicals in the Chesapeake have documented not only individual effects - such as lesions on fish - but also shifts in populations of benthic and planktonic communities due to contaminant concentrations at or very near ambient levels. Effects from more subtle concentrations are less well understood, though research on some organisms has shown effects, such as the suppression of immune response in oysters, noted above, at near-ambient levels.

- Building on research, including work done outside the Chesapeake Bay, that has shown direct effects from chronic, low-level toxicants, such as chemical preservatives on wooden bulkheads.

- Predicting where effects are likely to occur, given our understanding of the distribution of chemical contaminants and their behavior in the estuary. Of particular significance may be contaminant "gradients," whether spreading from a Region of Concern, or down a tributary or down the Bay. Predictions of distribution can prove difficult, especially in light of counter-intuitive data, such as unexpected spikes of sediment contamination in some otherwise unpolluted Eastern Shore tributaries.

- Determining the biological impacts of chemical contaminants in order to assess the real meaning of a "toxics-free Bay." Improved understanding of when metals or compounds - many of which are naturally occurring - become "toxic" will help clarify the balance between costly pollution removal and prevention on the one hand, and the economic benefits of commercially, recreationally and ecologically important Bay resources on the other.

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Chemical Contaminants in the Chesapeake Bay: an Introduction

Chesapeake Bay Introduction | A Focused Research Effort

The shallow Chesapeake, historically the nation's richest estuary, drains a 64,000 square mile watershed, with an extremely high ratio of land and population to volume of water, making it especially susceptible to impacts from human activities. According to one estimate, for every cubic kilometer of water in the Bay the watershed supports some 200,000 people, as contrasted with 4,000 people in the Baltic Sea watershed and only 85 in the Mediterranean Sea (Costanza 1995). Even beyond the Bay's sprawling watershed, an even larger airshed delivers nutrients and chemical contaminants from regions outside the borders of the Bay states.

A range of contaminants regularly enters the Chesapeake Bay, from land runoff, from the air, from both surface water and ground water. Even contaminants buried in sediments years ago can be resuspended both by human activities such as dredging or by natural events such as storms or the burrowing of bottom-dwelling animals. Once resuspended, these contaminants can be transported by physical processes (e.g., water circulation, tides, winds) to new locations throughout the Bay. While these contaminants would intuitively appear to be a threat, questions arise as to the extent of that threat. For example:

- What are the primary sources of contaminants in the Chesapeake Bay, and how does their importance vary in different regions of the Bay?
- How do toxic compounds move, and where do they end up?
- Can we construct the basic pathways of contaminants, including both recent and historical inputs?
- Have chemical contaminant loadings and transport processes changed as a result of management actions?
- How do chemical contaminants come in contact with the Bay's living organisms, and what effects

do they have?

- What evidence is there for effects at low concentrations of chemical contaminants?

The Chesapeake Bay Program's Executive Council, recognizing the potential threat of contaminants to the current effort to restore the Bay, adopted in 1989 the Basinwide Toxics Reduction Strategy, which was re-evaluated in 1992. In 1993, the Executive Council called for the revised strategy to focus on four areas: pollution prevention, regulatory program implementation, regional focus, and directed assessments of toxic chemicals. Specifically, the assessments were to gauge "the potential impacts on the Bay's living resources from the observed widespread low level concentrations of toxics in Bay habitats."

In 1994 the Executive Council signed the revised Toxics Reduction Strategy and set as a goal a "toxics-free Bay." Although laudable, this strategy raised a number of significant questions. How much do we know about what chemicals or compounds are truly toxic, and at what concentrations? How much do we understand about the behavior of contaminants in an estuary like the Chesapeake Bay, where salinity and other factors vary widely, and where chemical compounds may exist in changing combinations, and may be converted to numerous forms, with uncertain biological effects?

To deal with such questions, the Sea Grant programs of Maryland and Virginia, the National Oceanic and Atmospheric Administration (NOAA) Chesapeake Bay Office, and the U.S. Environmental Protection Agency launched a Toxics Research Program in 1990. It is this program that sponsored a Toxics Synthesis Workshop in December, 1995, to bring together scientists engaged in these wide-ranging toxic research studies. The workshop, which included resource managers and science program administrators, aimed at synthesizing the current state of scientific information on the impact of contaminants in Chesapeake Bay.

A Focused Research Effort

The Toxics Research Program has been guided by the Chesapeake Bay Environmental Effects Committee (CBEEC), composed of representative researchers and managers from the Bay states, from EPA and from NOAA. Initial CBEEC work, beginning in 1985, focused on dissolved oxygen dynamics in the Chesapeake, in particular those factors that led to a severe reduction of oxygen (hypoxia) or a complete depletion of oxygen (anoxia). As a result of that research, our understanding of the complex network of processes that regulate oxygen concentrations in the Bay increased dramatically.

To capture that understanding, a workshop convened in late 1991 brought together researchers active in the CBEEC oxygen research program to produce a synthesis of their findings. The resulting document, "Dissolved Oxygen in the Chesapeake Bay: A Scientific Consensus," joined a book published by Sea Grant in 1992, Oxygen Dynamics in the Chesapeake Bay. Together, these documents described current

scientific understanding of processes driving oxygen depletion in the Chesapeake.

A year earlier, in 1990, funds from NOAA were augmented by the EPA's Chesapeake Bay Program, with the recommendation that funds be redirected to study the effects of contaminants in the estuary. In response, researchers mounted a regional multi-disciplinary program aimed at increasing our understanding of how toxic contaminants affect the health and productivity of the Chesapeake Bay. The initial focus of this effort has been on the behavior and transport of contaminants in the estuary, an approach that built on the original five-year study of hypoxia and oxygen dynamics in the Bay - which also focused on Baywide physical and biological processes - and related work.

Questions surrounding the dynamics of chemical contamination in the ecosystem have proven to be considerably more complicated than the issue of oxygen dynamics. Where researchers formerly focused primarily on two nutrient compounds, nitrogen and phosphorus, the scientific analysis of chemical contaminants presents the prospect of hundreds of potentially harmful compounds, with different chemical properties and mechanisms of toxicity, some of which may join in synergies we do not yet understand.

With the EPA and others beginning to monitor the Bay for the presence of chemical contaminants beyond known areas of acute contamination such as Baltimore Harbor or the Elizabeth and Anacostia rivers, researchers concluded that an analysis of sublethal, ecological effects would prove especially valuable in revealing how even relatively low levels of chemical contaminants could affect biological communities in the Bay.

Specifically, we need to address three basic areas, around which the workshop discussions are based:


Sources: What are the levels of chemical contaminants in the estuary, and what are their points of entry into the system?


Transport: How do these contaminants behave, where do they accumulate, and are they biologically available?


Biological Effects: What are the impacts of contaminants on individual organisms, on populations, on communities?

This synthesis presents the major points of consensus from the workshop. For those interested in additional information, the Appendix lists other, related publications.

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CHEMICALS OF CONCERN

More than 75,000 commercial chemicals are on the market today, and barely 2% of them have been tested for their effects on the environment. Most chemicals are released into the air, land and water without any regulation by government, though those deemed most dangerous are regulated by the Clean Water Act, the Clean Air Act and other federal or state regulations.

Over 1,000 chemicals have been detected in the Chesapeake Bay. In an effort to focus resources on the most critical threats to the Bay, the Chesapeake Bay Program has created a list of 14 Toxics of Concern. First published in 1991, the list includes metals (cadmium, chromium, copper, lead, mercury, and tributyltin), pesticides (Atrazine and Chlordane), PAHs (benz(a)anthracene, benzo(a)pyrene, chrysene and fluoranthene), naphthalene, and PCBs. These were selected based on their concentration in the environment, fate after release, persistence, and impact on human health. The list is currently undergoing reevaluation and will be revised every three years.

In addition to the Bay Program's Toxics of Concern, the EPA and the states have myriad other lists of chemicals and pollutants. In fact, the lists get so complicated that the EPA has created a List of Lists. However, for those interested in the Chesapeake, just three lists are worth focusing on: the Toxics Release Inventory (TRI), EPA's Priority Pollutant List, and the Maryland Priority Pollutant List.

Created in 1986 as part of the Community Right to Know Act, the TRI currently lists 650 chemicals and the amounts of their releases into the environment. All the chemicals on the list are toxic, which means that in sufficient amounts they can cause disease or death. But not all toxic chemicals are on the list. In order to be listed, a chemical must cause acute or chronic health effects and be released in large volumes. The list is biased towards human health effects: no more than 25% of the listed chemicals can be ecotoxins.

The Community Right to Know Act has been acclaimed for achieving significant reductions in releases without creating excessive regulations. The Act requires that certain industries annually report their releases of the listed chemicals and make this information available to the public. This public reporting has motivated industries to reduce toxic releases to the Bay by more than 50% since 1988. Because not all users of the listed chemicals are required to report on TRI, it is not known what proportion of the total releases to the environment is reported.

Under the Federal Clean Water Act, the EPA has created a Priority Pollutant List of 126 chemicals. The EPA has set standards for discharge of each of these chemicals into bodies of water. But these standards are not federally enforceable. Each state is free to select which chemicals they wish to regulate. Maryland's Priority Pollutant List, for instance, regulates only 28 of the 126 federally listed chemicals.

Workshop Discussion

The workshop discussions centered on questions that were organized under three major topics: sources of contaminants, their transport and their ecosystem effects. While reference is made in this report to the Toxics of Concern List (fourteen "toxic substances which represent immediate or potential threat to the Chesapeake Bay System," as adopted by the Chesapeake Executive Council), the workshop deliberations used four classes of contaminants - heavy metals (copper and mercury), organic pesticides (Atrazine), products from fossil fuels (PAHs), and complex chlorinated hydrocarbons (PCBs) - as representative. Although not all compounds in a given class behave alike (copper and mercury can behave very differently, for example, and are therefore treated separately), these five chemicals serve as general examples of classes. This synthesis report also refers to arsenic, Dimilin (the Gypsy moth treatment) and other compounds.

The rationale here is that there are thousands of different species in the Chesapeake Bay and more than a thousand potential contaminants. Researchers cannot possibly test the risk of each species from each contaminant. What they can do is assess how representative species are affected by representative contaminants.

Sources of Contaminants in the Chesapeake Bay

Question 1: What are the sources of major classes of contaminants in the Chesapeake Bay?

Loading data are available for point and diffuse sources of chemical contaminants in the Chesapeake Bay, although a great deal of uncertainty remains, especially for diffuse sources such as stormwater runoff. According to the Chesapeake Bay Basinwide Toxics Reduction Reevaluation Report (1994), the highest estimated Toxics of Concern metal loading to the Bay basin comes from urban stormwater runoff, followed by point sources and atmospheric deposition. According to that report, metal loading is highest in the Potomac, followed by the Susquehanna, West Chesapeake, James, mainstem Bay, Patuxent, Eastern Shore, York and Rappahannock basins.

Also according to that report, the highest estimated loadings of Toxics of Concern organic chemical contaminants (PAHs and PCBs) are from atmospheric deposition, followed by urban stormwater runoff

and point sources. The West Chesapeake has the highest organic chemical contaminant load, followed by the mainstem Bay, Susquehanna, Potomac, James, Eastern Shore, Patuxent, York and Rappahannock basins.

Atmospheric deposition is of relatively greater importance in the southern Chesapeake where riverine flow is less dominant than in the northern Bay. Some of these airborne materials may originate from sources hundreds of miles away, including the Ohio River Valley (cf. Airsheds and Watersheds - the Role of Atmospheric Deposition, 1995).

An additional source of chemical contaminants are Bay sediments, which have become reservoirs of toxic compounds that have settled there. In particular, compounds that do not break down easily and are now strictly controlled by regulations (e.g., Kepone and DDT) can be recycled from the sediment by biological and physical processes.

In summary, the basic pathways of representative chemical contaminants in the estuary, from source to transport to uptake and ultimate fate, are generally understood, with considerable background information available not only from the Bay but also from other ecosystems as well. While we can quantify, to a significant degree, loadings through inventories and monitoring, the effects on the ecosystem of those loadings remain unclear (as discussed in the final section of this report, under the heading of biological effects).

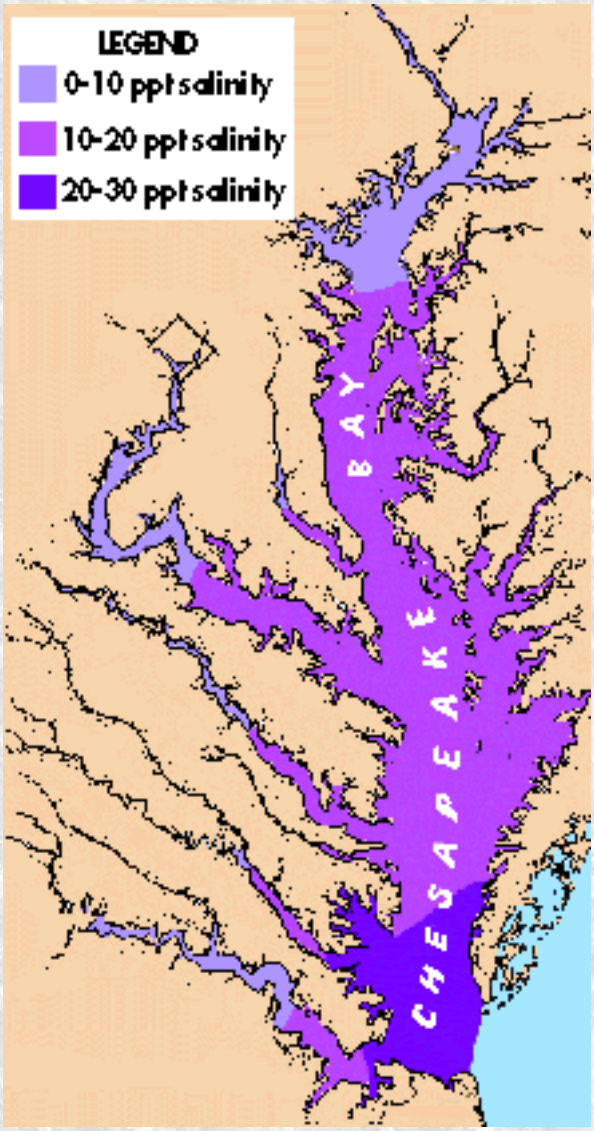
Over the past twenty years, discharges of contaminants from commercial and industrial areas have declined significantly, largely because of the Clean Water Act. At the same time, with increasing population in the Chesapeake Bay watershed, contaminants from diffuse sources in developed areas have been on the rise. An increasingly important area of investigation is the tracking of diffuse inputs, through small watersheds for example.

Question 2: How does the relative importance of the sources vary by different regions of the Bay?

Sources of contaminants vary widely throughout the Bay, even among classes - for example, while the highest loadings of PAHs are from atmospheric deposition, so are loadings of mercury. Generally, in the upper mainstem Bay, point sources - usually in urban and industrial areas - and riverine (fluvial) sources are the major sources of contaminants entering the estuary. In the lower mainstem Bay atmospheric deposition and other diffuse sources dominate. In the Bay's Regions of Concern (Baltimore harbor, Anacostia and Elizabeth rivers), the sources of toxic contaminants are in close proximity; in other areas, where "spikes" of contaminants have been detected, the sources are less clear.

Chesapeake Bay Salinity *(Autumn)*

The Chesapeake Bay may be a single ecosystem, but it comprises regions that vary in salinity, temperature and turbidity. The head of the Bay is characterized by low salinity, the lower Bay by high salinity. The large middle Bay has a moderate (mesohaline) salinity. In the upper Bay sediments will be mostly silt and clay; in the lower Bay sediments will be sandy. Differingsediment types and degrees of salinity will affect how contaminants move through the estuary, and what chemical form they are likely to take.



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Representative System Characteristics Affecting Contaminants in the Chesapeake Bay

Lower Salinity Regions

Physical Characteristics

- Mostly silt & clay sediment
- Minuimum stratification
- Strong influence of freshwater inflow, wind & tides
- High particulate input from rivers
- High sedimentation & resuspension rates

Ecosystem Characteristics

- High nutrients
- High turbidity
- Low primary production & phytoplankton density
- High bottom (benthic) abundance but low biological diversity

Contaminant Characteristics

- High influence of rivers & point sources
- High metal burial
- Moderate cycling on the Bay floor (benthos)
- Documented biological effects

Moderate Salinity Regions

Physical Characteristics

- Mostly silt & clay sediment
- High stratiification
- Strong influence of wind & tides
- High level of localized particulates
- Moderate sedimentation & resuspension rates

Ecosystem Characteristics

- High spring nutrients
- Medium turbidity
- High primary production & phytoplankton density
- Intermediate benthic abundance & low biological diversity

Contaminant Characteristics

- High influence of atmospheric & nonpoint sources
- Intermediate PCB movement (e. g., out of sedmients)
- Moderate metal burial
- Low cycling on the Bay floor (benthos)
- Biological effects uncertain

Higher Salinity Regions

Physical Characteristics

- Mostly sandy sediment
- Low stratification
- Strong influence of wind & tides
- High level of localized particulates
- Low sedimentation but high resuspension rate

Ecosystem Characteristics

- Moderate nutrients
- Medium turbidity
- Intermediate primary production & moderate phytoplankton density
- High benthic abundance & high biological diversity

Contaminant Characteristics

- High influence of atmospheric & nonpoint sources
- High PCB movement (e.g., out of sediments)
- High metal burial
- Moderate cycling on the Bay floor (benthos)
- Biological effects uncertain

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Sources of five representative contaminants:

- Copper. Loading from rivers are by far the most important, especially in the upper Bay. In the lower Bay, diffuse sources, such as atmospheric deposition and anti-fouling paint on boat hulls, are relatively more important.

- Mercury. Atmospheric deposition - largely from the burning of coal, but also from incineration, e. g., of batteries - appears to be the major source. Urban stormwater is also a significant source of this heavy metal.

- Atrazine. Runoff from farm fields is the most important source of this agricultural herbicide, used widely for control of annual broadleaf and grass weeds in corn, sorghum and other crops.

- PCBs (polychlorinated biphenyls). PCBs are persistent and appear to be widely spread throughout the Bay, although now banned from most uses. The current source for PCBs are the sediments where they are largely buried, as well as on-going recycling between air and water.

- PAHs (polycyclic aromatic hydrocarbons). Urban and industrial areas are the most significant source of these compounds. The most common vectors appear to be urban stormwater runoff and atmospheric deposition.

In short, understanding the relative importance of different sources depends upon an understanding of how varying classes of contaminants enter the estuary and how they behave.

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Transport and Fate of Contaminants

Question 1: How do different processes influence the spatial distribution of chemical contaminants within the Bay?

To track contaminants, researchers generally use the concept of "partitioning" to contrast the amount of a material that is dissolved to that which is particle bound. Dissolved contaminants will stay within the water column, thus increasing the exposure to plankton and pelagic organisms. Contaminants bound to particles - either nonliving (sediment) or living (phytoplankton, bacteria, etc.) - are more likely to settle, where they may more directly impact bottom-dwelling organisms, such as oysters.

In other words, if compounds attach to particles, they will tend to follow the movement of sediments; if they do not, they will follow the water. Three major processes determine the movement of contaminants in the estuary: physical, chemical and biological.

REPRESENTATIVE CONTAMINANTS

Five chemicals can be used to represent large classes of metals, pesticides, and organic compounds. They are found on the Chesapeake Bay Program's Toxics of Concern List.

► **Copper** is ubiquitous as an alloy and a coating in products ranging from piping and electrical cable to pots and pans, pesticides, molluscicides and treatments for bulkheads and pilings. It is acutely toxic to marine plants and animals and is found in high concentrations throughout the Bay. If organisms do not excrete it, its concentration can increase dramatically at each succeeding level of the food chain. It is delivered to the upper Bay from rivers, urban runoff, and sewage treatment plant discharge. In the lower Bay, air deposition and releases from anti-fouling paints on boat hulls are significant sources of copper.

► **Mercury** is another metal that is acutely toxic to a wide range of animals and plants. It also has powerful teratogenic effects, as demonstrated by the tragic poisoning of the residents of Minamata, Japan in the 1960s. Mercury, like copper, biomagnifies through the food chain. Mercury is used in batteries, fungicides, and fluorescent light bulbs, and is a natural contaminant of coal. The largest source of mercury in the Bay comes from coal-fired power plant emissions, that is, from atmospheric deposition. Garbage incinerators are less important sources.

► **Atrazine** is the nation's and the Bay's number one herbicide in terms of pounds applied annually, thanks in part to its low cost. As Atrazine runs off fields into streams that feed Bay tributaries, concentrations may be high enough to inhibit photosynthesis and reduce plant diversity. Although not considered a major threat to the Chesapeake Bay at this time, exposure has led to changes in species composition in mesocosms at levels approaching those observed in the environment.

► **Polycyclic Aromatic Hydrocarbons (PAHs)** are a large class of chemicals generated by the burning of fuels including coal, gas, wood, charcoal, diesel and gasoline. They are generated in industrial and urban areas, where their concentration is especially high near highways. They are released from truck and auto exhaust, power plant emissions, asphalt operations, coal refuse piles, garbage incineration, residential fireplaces and backyard barbecues. Some PAHs are toxic to fresh water and marine organisms. Nearly all are suspected carcinogens or co-carcinogens.

► **Polychlorinated Biphenyls (PCBs)** are stable organic molecules that are ideal for use as electrical insulators in cables, transformers and capacitors. Unfortunately, the stability that makes them good insulators also makes them a serious peril to the environment, as they persist for many years without breaking down. At sufficient concentrations they are toxic, can prevent reproduction in mammals and birds, and are carcinogenic. PCBs are not excreted by organisms and therefore bioaccumulate through the food chain. In the 1970s, PCBs were banned from most new uses. Their presence in the Bay is due mostly to historic releases. However, because a large proportion of PCBs manufactured before 1971 are still in use, the potential exists for new releases to the environment.

Physical processes are the primary factors influencing spatial distribution of chemical contaminants in the Chesapeake Bay, with the movement of water and sediment providing the principal mechanism for transport. Winds, waves, currents, tidal actions and episodic events, such as storms and hurricanes, can cause major resuspension of bottom sediments and associated contaminants, and the frequency and intensity of these physical events will have a fundamental effect on residence time in any given area. Likewise, stratification and subsequent mixing will determine vertical, as well as horizontal, movement of toxicants, an important factor in a two-layered estuary like the Chesapeake Bay. The exact manner of sediment accumulation and contaminant flocculation will also affect how rapidly contaminants settle out and become buried.

Research (Sanford 1995) shows that the depth of erosion resulting from tidal resuspension in the mid-Bay is on the order of 0.1 to 1 mm thick. These estimated erosion depths are very similar to the thickness of the "floc layer" - the thin layer of material which has gathered on the Bay bottom and essentially lies on top of the more permanent sediment until moved or incorporated into the bottom. The movement and resuspension of sediments lengthens the time it takes for sediments to become buried, and Sanford and his colleagues estimate a burial delay time of several days to several weeks in the Chesapeake.

Winds and tides,accoding to recent studies (Sanford et al. 1995), affect the scouring of bottom sediments and the movement of contaminants. This research shows that:

- Wind and storm-generated resuspension occurs less frequently than tidal resuspension, but constitutes a much larger force than tidal resuspension.
- Stratification in the water column due to temperature or salinity gradients can limit the height to which eroded sediments can be resuspended, keeping them low in the water column.
- Resuspended bottom sediments settle quite rapdily out of tsuspension in the mid-Bay. There are, tough, some particulates that settle more slowly, and these provide a background level of suspended sediments that varies seasonally.

Sediments tend to become buried faster in areas where mixing is minimal, for instance, small coves. Near the Bay mouth, greater wave action and currents stir up the bottom, resulting in a continual "slow release" of sediment particles. Contaminants are not "sealed" in the sediments until they become buried and settle below the layer reached by burrowing organisms that can stir them up again (Swift 1995). Whether sediments serve, on average, as either sources or sinks of potentially toxic trace elements will therefore depend on their location - and on the physical, chemical and biological conditions there.

Chemical processes related to oxidation and reduction potential (redox) affect the behavior of contaminants in the Bay, for example, the sulfidic conditions in bottom waters devoid of oxygen (especially in the middle Bay). Chemical factors can affect the processes through which particles will join together (flocculation) and the rate of adsorption or desorption of dissolved compounds to either organic or inorganic surfaces. Together with oxygen levels, temperature and salinity also have

significant effects on the behavior of chemical contaminants. Other factors include photodegradation (the effect of light on PAHs, for example), hydrolysis (when a compound reacts with water), or pH (acidity/basic) or EH (oxidative reduction or redox potential). Experiments have shown that the metals most strongly influenced by anoxia are manganese, zinc, nickel and lead.

The importance of these changes is that the association of contaminants with sediments or ions greatly influences transport and biological availability and thus the exposure to different kinds of organisms. For example, the release or sequestration of metals in sediments by reduction/oxidation processes effectively determines whether those metals will be found in the water column or become tied up with sediments.

Research (e.g., Cornwell et al. 1995; Riedel et al. 1995) has shown that dissolved oxygen levels can mediate the release of metals from sediments. Rising levels of oxygen cause the release of such metals as copper and zinc, therefore causing greater contaminant exposure to organisms in the water column (i. e., plankton and fish). Decreasing levels of oxygen (hypoxia or anoxia) cause those same metals to be bound in sediments, thus increasing exposure to bottom-dwelling organisms.

Biological processes such as uptake, metabolism, biotransformation, bioaccumulation, and trophic transfer (passage of a contaminant through the food web) can all affect the movement and form of chemical compounds. Some contaminants may become more toxic once processed by microbes - for example, one experiment showed that the toxic metabolite of a chlorinated hydrocarbon proved more persistent in sediment than did its parent compound (Capone et al. 1995) Other contaminants may become less toxic, as occurs with the methylation of arsenic by phytoplankton.

Bottom-dwelling organisms can have a dramatic physical effect on the release of contaminants from sediments through such physical mechanics as burrowing, drilling, filtering, aggregating or ejecting. Contaminants can be transported and affected through microbial transformation, through uptake and transfer through the food web, and through the movement and migration of fish and other large organisms. Phytoplankton blooms, for example, have been shown to concentrate and deposit metals on the Bay floor. Eutrophication and high phytoplankton biomass could result in high uptake of chemical contaminants in the water column, but once phytoplankton settle they will eventually expose benthic environments to whatever contaminants they have taken up.

Phytoplankton bloomscan concentrate metals and deposit them on the bottom or pass them directly up the food chain. In the Chesapeake Bay the predominant grazers appear to be very small zooplankton that release small fecal pellets. Those pellets will likely remain suspended for long periods of time, carrying any particle-bound contaminants that have attached to them. Systems dominated by larger zooplankton or benthic filter feeders (as the Bay once was) favor shorter suspension times for particulate contaminants.

Schaffner and Gammish (Virginia Institute of Marine Science, unreleased video) have visually documented the release of sediment into the water column by tube worms and other benthic organisms in the York River and lower Bay, where strong tidal currents spread the material and prevent rapid settlement.

Whether contaminants remain longer in the water column or are quickly removed to the bottom sediments will obviously influence the kind of effects toxic compounds will have on the ecosystem. Some research suggests that while algae and other organic matter may fall to the Bay floor, the process of decay occurs so rapidly that any contaminants bound to them will return to the water column - leaving little of the original contaminant by the time burial finally occurs.

The sequestering of contaminants by phytoplankton is intertwined with other management issues. For example, the Chesapeake Bay Program's 40-percent nutrient reduction goal may reduce phytoplankton to 1950s levels, but unless releases of chemical contaminants into the Bay are reduced in parallel, the relative toxic exposure will not lessen, and could even increase in some parts of the ecosystem.

In summary, research has made significant strides in understanding the influence of how each of these processes influences transport within the estuary. Detailed analyses of how these processes interact are essential if we are to make informed management decisions based on expectations of how the ecosystem will interact with various contaminants.

Question 2: Can scientists construct basic pathways of representative contaminants that include introduction, transport, uptake and their ultimate fate?

Research to date has gone a long way toward documenting the basic inputs, movement and final fate (in relative terms) of representative compounds.

Entry of contaminants in the food web is often determined by chemical speciation and metabolic conversion of contaminants. Studies in the Chespeake Bay have found differential toxicities of metabolities of Atrzine and HOCs (halogenated organic compounds), and it appears likely that speciation is a moajor factor not only in food web entry but also in trophic transfer and ecological effects (Jones et al. 1984, Cappone 1995). Chespeake this certainly appears to be the case for mercury, one of the most toxic chemicals on the Chesapeake Toxics of Concern list.

Some scientists have suggested that mercury concentration in fish is a direct consequence of the environmental factors determining the species of mercury (Mason and Morgan 1996). In the estuary, mercury is converted in part to methylmercury through sulfate-reducing bacteria. Uptake appears to be determined by the amount of mercury in uncharged lipid soluble forms, particularly forms combined with chloride. Both pH and salinity appear important in speciation and accumulation.

Studies elsewhere have also demonstrated that methylated forms of mercury were more toxic than inorganic mercury to certain marine diatoms, supporting the hypothesis that methylmercury is more easily taken up and is therefore more toxic to marine organisms. The critical step in accumulation of mercury occurs at the base of the food web (e.g., through phytoplankton).

The ways in which contaminants enter the food web will depend to a large extent on the level of the food web or the feeding mechanism. For example, experiments have shown that arsenic is more readily accumulated by an omnivore like grass shrimp feeding on plant material than by another omnivore like the mummichog feeding at higher levels in the food chain - the mummichog is apparently exposed to less readily available forms of arsenic (Sanders 1995).

That same research (Sanders 1995) also suggests that direct physical contact between fish and sediment during low tide apparently contributed to the uptake of contaminants (by mummichogs). Other recent studies have shown that the oyster is more likely to take up contaminants that are already bound in the phytoplankton on which it feeds, as opposed to contaminants bound to sediment particles, for example (Newell and Weston 1995).

Question 3: Are the biologically available chemical contaminants due to recent inputs or historical sources? What are the relative percentages of these sources?

Whether a contaminant threat is historical (e.g., compounds buried in the sediment) or recent will depend on the compound itself. For example, new inputs of lead have gone down dramatically, as a result of lead-free paints and lead-free gasoline. Similarly, with the significant decline of steel production and tighter controls on direct discharge over the last two decades, inputs of some heavy metals have also declined. Furthermore, DDT, a polychlorinated pesticide banned in the U.S. since 1972, primarily re-enters the Bay's ecosystem from sediments where it persists, though some atmospheric deposition also still occurs.

Other contaminants have become more prevalent since World War II, such as agricultural herbicides,

pesticides and fertilizers, though in some cases their forms are less persistent. The early pesticides DDT and chlordane (as well as other compounds, such as the wood preservative penta-chlorophenol) proved to be resistant to degradation, with unanticipated effects on non-targeted organisms and ecosystems. Newer pesticides such as glyphosate degrade more rapidly with less effect on non-target species. Unfortunately, recent studies show that the chemical Dimilin, used to control Gypsy moth infestations, can have harmful effects on certain crustacea, such as copepods.

Though difficult to measure, household chemicals, from solvents and cleaners to garden pesticides and herbicides, have also increased dramatically along with rapid population growth in the region. Larger populations also mean more combustion products arrive in Bay waters from automobile and truck engines (even though cleaner burning) and from boats, lawnmowers and machines using two-cycle engines, which are relatively inefficient in the combustion of fuel.

At the ecosystem level, the sources and relative significance of historical versus recent contaminant inputs depend upon a number of factors, such as location (upper Bay versus lower Bay, urban versus rural areas) and mode of delivery (atmospheric versus riverine, point source versus diffuse source). Overall, it appears that in the Chesapeake Bay regulatory controls have reduced the importance of point sources relative to nonpoint sources. Ultimately, the significance to the Bay's ecosystem and food web is determined by the biological niche and the feeding mechanisms and behaviors of individual organisms and communities of organisms.

Question 4: What is the chemical contaminant memory - the "residence time" of toxicants - in the Bay?

How long will contaminants remain potentially active or available, once they have settled in the Bay? In other words, what is their residence time? The answer is that residence time depends on a number of factors, including:

- Location and removal rates from burial, degradation, dilution and mixing.
- Chemical structure of the toxic compound.
- Chemical characteristics of the surrounding environment (e.g., oxygenated or anoxic waters and sediments).
- Natural mechanisms such as storm events, hurricanes and strong currents, snow melt and precipitation.
- Exporting of contaminants into the Atlantic as a result of net movement of low-salinity river water; or importing of contaminants due to intrusion of dense, high-salinity ocean water.
- Anthropogenic activities, including dredging (where timing and controlling depth will be

important variables), and natural activities of benthic organisms burrowing in sediments, which can contribute to the resuspension and regeneration of contaminants. Only beneath levels affected by these physical forces will contaminants be considered "permanently" buried.

Contaminants will obviously "disappear" from the ecosystem more quickly if they degrade relatively rapidly. Some contaminants - PCBs are notorious examples - persist, while others such as Atrazine are designed to degrade once in the open environment. Compounds can also be considered "removed" when they join to form more stable complexes. There are diagenic reactions that can tie up inorganics; and there are similar reactions that occur with organic compounds as well.

Question 5: What have been the effects of management actions on chemical contaminant loadings and transport processes in the Chesapeake Bay?

Federal and state laws have served as the basis for reducing point-source discharges of numerous chemical contaminants and metals, among them, PCBs, DDT and lead. Tributyltin (TBT) concentrations in the Bay, for example, have dropped dramatically since TBT's use as an antifoulant was restricted in the late 1980s. The annual reporting by industry of direct discharges and the publication of Toxic Reduction Inventories (TRIs) have helped to document these declines. Of course nutrients have likewise been targeted in the Bay: phosphorus discharges from waste treatment plants, for example, have decreased as a result of banning phosphorus-based detergents, while nitrogen discharges have essentially been held constant because of targeted facilities upgrades.

Even with regulation, however, reducing contaminant loading (and nutrients as well) from diffuse sources continues to have mixed success. On the one hand, traces of lead from automobile combustion have decreased significantly, as monitored in sediments; on the other hand, hydrocarbons such as PAHs have increased because of growing population and inputs of hydrocarbons from fossil fuel combustion - from automobile exhaust, for example.

Management actions have been addressing the wide-ranging effects of increased human population in the watershed and airshed, with their concomitant deforestation, dredging, sewage effluent and stormwater runoff - all of which increase contaminant inputs to the estuary. Each of these factors has a strong role in the transport of toxics:

- Deforestation increases the flow of sediments into the estuary and leads to more pronounced stratification as stronger pulses of freshwater pour over heavier saltier waters.

- Dramatic declines in underwater grasses and the reduction of natural wetlands have had profound effects on the way the ecosystem traps and processes toxic compounds.

- Dredging of channels resuspends potential contaminants but also changes physical circulation patterns in the Bay, often with unknown effects.

- Impervious surfaces, from roofs to roads to parking lots, gather and propel rain water and snow melt into gutters and storm drains. This storm water carries contaminants - such as hydrocarbons, pesticides and metals - directly to the Bay's tributaries.

Management actions in many parts of the watershed have led to improvements in controlling vast pulses of stormwater, though a significant problem remains throughout the Chesapeake watershed, especially in developed areas constructed before the advent of new stormwater retention technologies. Retrofitting of outdated systems poses a major engineering anf inancial challenge for the region's municipalities.

Agricultural practices can play a significant role in the transport of soil and contaminants into the estuary. While soil conservation and Best Management Practices (BMPs) are helping to decrease the movement of animal wastes and soil - which becomes sediment - into the Bay, different practices affect not only rates of input of contaminants bound to sediment particles, but also rates of burial (by new sediment) on the Bay bottom. For instance, farming practices that are beneficial for one purpose may have negative tradeoffs - as an example, no-till farming may decrease surface runoff in one area, but could also lead to more contaminants seeping into ground water, since no-till farming depends on the use of such herbicides as Atrazine and Simazine to control weed growth. BMPs may need to be assessed on a region by region basis to optimize their benefits.

Carbon cycling in the Bay, clearly affected by the input of nutrients into the Bay from farm fields or waste treatment plants, has a significant impact on the transfer of contaminants. Overnutrification has led to an enhancement of phytoplankton, and perhaps a shunting from higher organisms to microbial production, which alters the flow of energy or carbon. This carbon flow in turn affects the way contaminants are cycled in the Bay, especially as food webs shift, varying pathways through which may travel.

Because of the importance of the Bay's food web to the cycling of both nutrients and toxic chemicals, ecosysem-based fisheries management also becomes important. The loss of the Bay's oyster population, for example, appears to have had a significant effect on the ecosystem's ability to filter large populations of phytoplankton from the water column. In this sense, oysters are not merely resources but habitat itself. Just what the large-scale effecrs of the loss of this habitat has meant for benthic populations and the cascading network of food web relationshipd is mostly a matter of speculation, though studies are now underway to sort through these effects. Currently, the relation between fisheries and natural resources management and the behavior of contaminants in the Bay remains unclear, since many specifics about interactions between toxic compounds and estuarine organisms are still not known.

To understand such relationships between land use and impacts to the Bay, research will need to continue to uncover the ways that living organisms mediate toxic contaminants. With increasing knowledge in this area, managers will know more precisely what actions could potentially modify the

current pathways that contaminants follow through the ecosystem. This issue presents a series of difficult scientific challenges, as described in the following section.

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Biological Effects of Contaminant Exposure

Question 1: What factors influence the bioavailability of chemical contaminants?

A number of conditions affect bioavailability of contaminants, though four in particular are extremely important:

- chemical species or form (often affected by environment)
- environment (e.g., salinity, pH, dissolved oxygen concentration)
- physiology of the organism
- ecological structure (e.g., whether benthic or pelagic)

Chemical species of a compound will determine whether it is more or less available for uptake by living organisms. For example, copper used in antifouling paint is Cu2+; it is very reactive and highly toxic to many living organisms, hence its effectiveness against fouling communities; other forms of copper may be less toxic.

Some organics such as PCBs have molecular compositions and structures that remain stable and resistant to enzymatic action under a range of environmental conditions. These compounds are therefore extremely persistent and will accumulate in fatty tissues of organisms, with possible genetic and carcinogenic effects.

Furthermore, the source of a chemical contaminant - for example, whether it is "pyrogenic," resulting from the combustion of fossil fuels, or "petrogenic," resulting from unburned petroleum products - will affect its form and therefore its toxicity. Generally PAHs from combustion are bound within soot or fly ash particles and are, in effect, biologically less available. Petrogenic PAHs, on the other hand, are more likely found on the surface of particles and are therefore potentially more available.

Environmental conditions such as salinity, pH, redox potential and other ambient factors, will also affect the bioavailability of toxic compounds, but in ways that cannot easily be generalized. Salinity, for example, reacts with contaminants in several different ways. First, it acts to complex metals, making them less available for uptake by Bay organisms - this is why copper becomes less available in the water column as one moves from the head of the Bay toward its mouth. Second, salinity can affect various physiological mechanisms in an organism (movement across cell membranes, for example); and it can affect an organism's biological functioning, influencing how it may respond to the presence of

contaminants.

Complexation of contaminants by carbon compounds represents an important "sequestering" process in the estuary. In general, this complexation dramatically reduces the bioavailability of metals for uptake by organisms, and reduces many organic contaminants as well, although the data are not clear cut. For example, well over 90 percent of the copper and 60-70 percent of the cadium in the Chesapeake Bay (Donat 1995) are complexed by naturally occuring organics.

Some research (Wright 1996) has shown that mercury toxicity is reduced with increasing salinity, and other experiments (Reidel 1988) have found that chromium, which is highly toxic at low salinities, is less toxic at 5-10 ppt salinities of the middle Patuxent River. One mechanism for this mitigating effect of salinity is the presence of sulfate, a major component or saline waters, which often interferes with and slows the uptake of chromium by phytoplankton.

In oysters, higher salinities "improve" physiological functioning, such as increased feeding rates, thus affecting the rate of metal uptake. Some studies have indicated that oysters can take in and then expel contaminants - in pseudofeces, for example, by gathering chemicals in the gametes and then expelling them during spawning. Precisely how oysters in any particular location will be affected by contaminants under varying environmental conditions will depend on an interaction of factors, such as those described above.

Physiological differences of specific organisms can amplify environmental effects. For example, mussels and oysters will take up metals at different rates, even after accounting for differing filtration capacity. In addition to feeding rates, the rate at which organisms metabolize chemical contaminants also affects toxicity, as does the distribution of a metal or toxicant within the body of an organism. PCBs are sequestered in the fatty tissue of fish, for example, potentially making the fish unsafe to eat, but not necessarily causing direct illness or mortality in the fish itself. Likewise, the binding of metals to metal-binding proteins or within granules in the tissues of organisms can serve as an effective defense against a contaminant's toxicity.

Ecological structure affects how contaminants move through the food web remains key to understanding how some compounds behave in particular parts of the carbon cycle. As mentioned earlier, dissolved contaminants tend to stay in the water column, thus increasing the exposure to plankton and pelagic organisms. Contaminants bound to particles are more likely to settle, where they can more directly impact bottom-dwelling organisms.

Question 2: Can researchers quantify transfers of chemical contaminants through the food web - both in the water column (planktonic) and along the Bay bottom (benthic)?

Scientists have been developing the ability to quantify the transfer of toxic compounds through Bay food webs. Such measurements are important because they can demonstrate how contaminants accumulate at

different trophic levels in the food chain. Studies of phytoplankton blooms in the Patuxent River, for example, have indicated rates at which copper uptake by phytoplankton is transferred to copepods that graze on them (Sanders and Sellner 1995).

Grazing by copepods and other zooplankton is extremely important in the Chesapeake for several reasons: at certain times of the year the zooplankton community removes the bulk of phytoplankton production; at the same time, zooplankton serve as prey for other organisms, including anchovies, which are prey to a variety of food fish, among them, striped bass. Knowing the transfer rates of contaminants as they are processed through food webs and in recycling processes could make possible more effective risk-based predictions of the toxicity of contaminants in the Chesapeake.

Contaminants transfers through the food web have been documented by a number of recent studies.

- Rates at which copper appears to be transferred fromtoh phytoplankton to the copepods that graze on them have been determined (Sanders ans Sellers 1995). These studies also suggest that some elements such as cadmium are more likely to be absorbed by grazers directly from the water.
- Oysters accumulate metals in varying amounts, according to changes in environmental conditions (Roesijadi 1996). Concentrations of metals are influenced by such environmental and biological factors as temperature, salinity and changes in tissue composition as a function of season and stage of reproductive cycle.

- Mercury uptake, transfer and bioaccumulation occur in the water column, with uptake by phytoplankton and transfer to copepods a key step in entering the food web (Wright 1996).

Quantifying the movement of contaminants through the food web thus depends on models that can enumerate important components of the Bay's ecosystem. For example, the Chesapeake Bay is dominated by small zooplankton, which excrete dissolved or very fine particles. These waste products can remain suspended for long periods of time, and easily re-enter the food web. In systems dominated by large zooplankton copepods, waste products may take the form of heavier fecal pellets that settle out of the water column. Likewise, systems dominated by large filter feeders such as oysters also concentrate waste products that are more likely to settle out of suspension.

Quantification of contaminants in the bottom (benthic) community likewise depends on understanding transfer mechanisms. Research on phytoplankton uptake of trace elements in the Patuxent River found increased levels of some elements on the river bottom that had apparently settled out of blooms (Sanders and Sellner 1995). With studies by Harding and others (1992) that have documented the timing and location of phytoplankton blooms and of certain hydrologic events (e.g., the spring freshet and the fall "turnover" of the Bay) we can begin to quantify the delivery of phytoplankton potentially ladened with contaminants to the benthos.

Question 3: What evidence is there that chemical contaminants at concentrations observed in the designated "Regions of Concern" impact living resources?

Acute and sublethal biological effects of contaminants have been observed in the field and in laboratory experiments. In the Anacostia and Elizabeth rivers and Baltimore harbor, for instance, fish and other organisms have exhibited lesions and cancers due to toxic concentrations of contaminants. In the Patapsco River, shifts have occurred in populations and in community structures of organisms there.

For some time we have known that oysters can serve as sensitive indicators of metal contamination in a region, and more than thirty years ago Galtsoff (1964) observed higher concentrations of copper, lead and iron in oysters located near areas of industrialization. Researchers have now shown that contaminants can impact oysters in subtle ways. Laboratory studies on Crassostrea virginica's vulnerability to Dermo disease (Perkisus marinus) give strong indications that the oyster's immune system is impaired by chemical contaminants. In the Elizabeth River, for example, scientists (Chu et al. 1995) demonstrated that PAHs (polycyclic aromatic hydrocarbons) rendered oysters more vulnerable to Dermo. Scientists studying the effects of chemicals such as TBT (tributyltin) (Anderson et al. 1995) and the chemical carcinogen DEN (n-nitrosodiethylamine) (Winstead and Couch 1988) have found similar reactions. Although these findings are generally based on laboratory studies, contaminant concentrations employed in these experiments are environmentally realistic, especially within the Regions of Concern, but also elsewhere in the Bay (see below).

Question 4: What evidence is there that chemical contaminants at low concentrations impact living resources?

A number of reports have documented the biological effects of ambient toxicity in waters of the Chesapeake Bay; they include shellfish (Bender and Huggett 1987), striped bass (Hall et al. 1985 and 1989), blue back herring and the American shad (Klauda et al. 1988). Studies conducted by Lenwood Hall et al. (1995) used larval sheepshead minnow, larval grass shrimp, a copepod and the coot clam to test water from nine ambient stations in the Chesapeake over a two-year period. Results showed toxic effects at most stations, including reduced growth or mortality of sheepshead minnow or copepods during one year. Minimal effects were observed during the subsequent year of testing, suggesting that ambient effects are subject to considerable annual as well as spatial variation.

A number of research studies have uncovered measurable biological reaction to low concentrations of contaminants - as previously discussed, trace levels of arsenic can cause a shift toward species of smaller phytoplankton, along with uptake and transfer into the food web. While the trophic effects of these transfers remain to be determined, clearly the potential exists for accumulation through the food chain.

Changes in phytoplankton community structure and changes in size of dominant phytoplankton species can have a profound effect on aquatic ecosystems. One classic study, for example, in Great South Bay (Ryther et al. 1954) documented a shift in phytoplankton size toward smaller cells (nannoplankton) as a result of eutrophication. These small plankton were not suitable food for filter feeders and resulted in a decline of the oyster populations there.

Sublethal effects, then, do not necessarily reveal themselves to the eye or even to the microscope - a

contaminant or multiple contaminants can affect organisms at the cellular level, can lead to molecular deterioration of a species' immune system or, with other factors, can affect gene mutation in another species' reproductive system. By the time sublethal effects do become evident, it is because their impacts have already cascaded through the food web.

Using molecular biological methods, researchers (Kramer et al. 1995) are now exploring new ways to identify subtle sublethal effects. By developing DNA probes, these scientists hope to find genetic signals that will reveal whether or not an organism (such as phytoplankton) has been exposed to metals. They will do this by tracking genes responsible for triggering the production of metalothienin - a clear signal that an organism's genetic mechanism is mounting a response to metals in the environment.

Question 5: Given the observed spatial distribution of chemical contaminants and our understanding of the influence of processes on contaminant distribution and fate, are there regions of the Bay where (1) we can predict that effects are likely to occur and (2) we should focus research efforts?

Clearly there are regions of the Bay where we can predict that contaminants are likely to have biological effects:

- Most obvious are the identified Regions of Concern (Baltimore Harbor, Anacostia River and Elizabeth River). As previously emphasized in this report, organisms in these regions have shown demonstrable effects, such as lesions or tumors, and more indirect effects, such as shifts in benthic community composition.

- Resource managers already target certain areas as being at risk, given some knowledge of the vulnerability of particular organisms to particular toxicants. One example is the management of chlorine discharges from waste treatment plants in fish spawning areas.

More difficult to define are other target areas where contaminants could pose serious, if less obvious problems:

- Studies on areas outside the Regions of Concern - specifically as reflected in the Ambient Toxicity Study supported by the Chesapeake Bay Program - have revealed unexpected levels of ambient toxicity. While highly suggestive of potential problems, these results require additional analysis to determine their precise replicability and the full significance of detected levels.

- If areas and times of predictable "pulses" (e.g., resulting from the seasonal application of herbicides or pesticides) can be identified, then it may be possible to describe "danger zones" and "danger times" for some species and some contaminants. Dimilin, shown to affect survival and reproduction of crustaceans, especially at lower salinities, is an example - its application could potentially be better managed to reduce its impact on species that are especially vulnerable.

To apply predictive principles on a much broader basis, managers would need to know such factors as:

- Depositional rates, especially of fine-grained sediments, and to identify areas where there are high flux rates. Considerable information is already available for some regions of the Bay.

  The effects of multiple contaminants are difficult to track. Much of what we know about the ecological impacts of toxic compounds is based on observing responses or organisms to acute exposure of sinlge contaminant. Tracking sublethal responses of an organism to mulitple contaminants is more complicated because of the network of physical, chemical and biological interactions; impacts at higher trophis levels may be obscured by the passge of a contaminant (or range of contaminants) through hierarchal levels of the ecosystem. The most difficult scientific challenge will therefore be to understand the extent and nature of interactions between contaminants -- singly and combined -- and the various physical and chemical components of the environment.

- The relation between the effects of single contaminants (which are more easily tracked) and the effects of contaminants in possible combinations - where synergies could result in toxic impacts on organisms.

- Other broad interactions, such as those at the air/water interface.

The next steps for determining which regions (or zones, such as depositional areas or areas of high productivity) include learning how low-level contaminants may have system-wide effects on living organisms in various parts of the Bay at hierarchical levels. Specifically, future research must:

- Continue to focus on learning to predict where effects are likely to occur, given our understanding of the distribution of chemical contaminants and their behavior in the estuary. Such prediction can be difficult, especially in light of counter-intuitive data, for instance, the unexpected sediment contamination spikes in some relatively clean Eastern Shore tributaries.

- Build on research that has shown direct effects on benthic communities from chronic, low-level toxicants, such as wood preservatives.

- Develop methodologies to apply findings from other estuarine systems, especially in the mid-Atlantic - for example, in the Hudson River, Raritan Bay, Delaware Bay, and Pamlico Sound - to local situations.

It will be important to evaluate a range of distinct ecosystems in the Bay to determine if specific keystone species are missing or impacted. These keystone species play a central role in the healthy functioning of a food web. Already, research has documented changes in phytoplankton communities that could profoundly influence organisms higher up the food chain. Further research should help clarify just how significant these changes, brought about by metals and other contaminants, relate to the

ecological functioning of the Chesapeake Bay.

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TWO ORGANICS: ATRAZINE AND DIMILIN

Among the numerous organic compounds of potential concern in the Chesapeake Bay are Atrazine and Dimilin, each engineered for a very different purpose, and each an interesting case of how toxicants can enter the estuary and how they behave.

Atrazine. Atrazine is a broad spectrum herbicide used widely in the cultivation of corn and sorghum. It has been estimated that about 1% of Atrazine applied to the Chesapeake Bay watershed reaches the aquatic environment (Kemp et al. 1981; Wu, 1980) and although Atrazine levels sufficient to inhibit various species of submerged aquatic vegetation do occur in localized areas, it does not appear that Atrazine has been the major cause of SAV decline in the Chesapeake. In fact, Solomon et al. (1996) conclude in an extensive review that Atrazine does not pose a signigicant risk to the aquatic environment, although transient inhibitory effects may occur in phytoplankton and aquatic vegetation in areas suseptible to agricultural runoff.

There are, however, reasons to be concerned. For example, Atrazine has a differential effect on varying species of submerged grasses, and could perhaps shift species composition in areas where it reaches the Bay or its tributaries in significant quantities. Research has shown, for example, that water milfoil (Myriophyllum spicatum)‹ a less desirable grass than, say, wild celery, which is important food for diving ducks ‹ proved more resistant to Atrazine than several other species of Bay grass (specifically, Potomageton perfoliatus, Ruppia maritima, and Zannichellia palustris) (Jones et al. 1984).

Atrazine also has the potential to enter the Bay in pulses, arriving in spring, when applied to farm fields, and when Bay grasses are beginning their spring growth. Atrazine may also reach the Bay in rural, otherwise pristine areas that could be important habitat, for molting blue crabs, for example.

Finally, there is the potential for interaction with environmental variables, resulting, for example, in the formation of various metabolites (such as deethylated, deisopropylated and hydroxyatrazine metabolites). These metabolites, which result from biological breakdown and conversion occurring after application of the herbicide, may have increased or reduced toxicity, depending on their chemical structure. We know that Atrazine and its metabolites, if they enter the water in sufficient quantities, can have a deleterious effect on underwater grasses, and could therefore be important components of the chronic toxics burden in the Chesapeake ‹ whose combined effects we are just beginning to understand.

Dimilin. Dimilin is a pesticide (a growth inhibitor) used in parts of the Chesapeake region to control the gypsy moth. Dimilin's mechanism of action is to inhibit the insect molting process through impairment of chitin incorporation. Because of its specificity, Dimilin is not a concern to organisms that do not have a chitinous exoskeleton. Crustaceans, however, also have such exoskeletons, and Dimilin appears to affect them in the same way it affects insects. Studies conducted by Savitz et al., (1994), demonstrate that Dimilin is toxic to the copepod Eurytemora affinis at low, environmentally realistic concentrations. Crustaceans are important and abundant components of the Chesapeake food web

including, in addition to copepod species, amphipods, shrimp and crabs -- including the commercially important blue crab.

Dimilin also offers an example of how an organic contaminant might interact with environmental variables. Wright and Dawson (1995) show that survival of E. affinis exposed to Dimilin concentrations up to 1 ug/ liter was enhanced at higher (15 ppt) salinities. These observations suggest that Dimilin toxicity to crustaceans is of greater concern in the upper, low-salinity portions of the Bay and the low-salinity portions of the tributaries of the lower Chesapeake, which includes major finfish nursery areas where copepods are importand food for juvenile fish. As with other organic contaminants, Dimilin is also converted into various metabolites through biological, physical or chemical activity. Dimilin's breakdown products include 4-chlorophenylurea, 2,6-difluorobenzoic acid, and 4-chloroaniline.

Dimilin use appears most likely to occur later in the season than Atrazine, which is applied early in spring. But like Atrazine, Dimilin, which is released in dissolved or particulate form from forests treated for gypsy moth infestation, has the potential to be released in strong pulses in response to rainfall.

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Summary

The goal of scientific research on contaminants in the Chesapeake Bay is to develop measures of ecosystem functioning that decisionmakers can use for better managing the Bay's living resources. Major tools that managers increasingly rely on are conceptual and mathematical models for predicting risk-based effects of alternative control strategies.

While such models can mimic, to some extent, basic food web relationships and predict ecological responses to various management strategies, those models - when it comes to contaminant effects on ecological processes - are limited. That is because a model's value is only as good as the data it relies on - and for the many ways in which contaminants can affect an aquatic ecosystem, the data are often ambiguous or simply not available. A major conclusion of the workhop is that research on biological effects of contaminants is especially important if science is to contribute to the kind of predictive measures that decisionmaking requires.

What We Know

In the last decade, research on contaminants - especially on the sources and transport of contaminants in the Bay - has made major strides. This research has gone a long way toward developing what we now understand as accepted fact, though scientists and managers still question how well measured values reflect various physical and chemical processes, which may affect the toxicity of chemical compounds once they enter the Bay. Despite such reservations, research and monitoring have made significant contributions to what we now know a good deal about:

- Major sources of chemical contaminants in the estuary and their general location and movement in identified contaminated areas - in the sediments of Baltimore and Norfolk harbors, for example, and in the Anacostia River
- How organic contaminants, e.g., PAHs, and metals (such as copper, cadmium and mercury), generally behave in the Chesapeake Bay and in other marine and estuarine ecosystems, though quantitative information is still limited.
- How the presence or absence of oxygen affects the behavior of heavy metals and organic compounds like PCBs and their movement between sediments and the overlying water column.
- How the uptake of specific contaminants by phytoplankton can serve as the entry of contaminants into the food web, though again quantitative information on transfers is limited.

In addition, researchers can:

- Describe the general physical transport - mediated by chemical and biological factors - of contaminants throughout the estuary, and document the effects of specific contaminants on particular organisms.
- Observe the uptake of contaminants by grazers (e.g., zooplankton) and begin to extrapolate how toxic compounds may be moving through the estuarine food web. However, because of the complexity of estuarine ecosystems, there is enormous potential for interaction among different levels of the food chain under varying environmental conditions, so our basic understanding, along with predictive tools for management, rapidly reaches its limits.

- Demonstrate numerous ways in which parts of the ecosystem are affected by chemical contaminants - whether at the surface microlayer, or in biofilms covering submerged surfaces, or in areas of dense algal blooms where trace elements become concentrated. Though these scientific findings suggest the potential for broad systemic effects, we lack adequate data, information and experiential observation to feel fully confident of the true scale of toxic impacts in the estuary.

What We Need to Know

Though research over these last five years has made fundamental discoveries about the diverse ways contaminants impact ecological functioning at different levels of organization, large gaps remain in our understanding of ecosystem effects. To date that research has helped to clarify the kinds of questions we must answer, answers that will be especially important as population in the Bay watershed increases - since population growth means development, and development inevitably brings with it increasing contaminant discharges and runoff.

As this report has made clear, we now understand, to a significant degree, the fundamental mechanisms of contaminant entry and movement through the Chesapeake Bay, though some major issues concerning contaminant sources and transport remain. For instance:

- What are the dynamics of transport for different classes of compounds from the contaminant-heavy Regions of Concern to regions which demonstrate sporadically high measures of particular contaminants?

- How well are we tracking diffuse sources of contaminants - for example household cleaners and other wastes - and their entry into the Bay - through septic tanks and groundwater seepage, for example?

As also emphasized, biological effects of low concentrations of contaminants found within the Bay remain the biggest area of uncertainty, especially in relation to species that are important both commercially and ecologically. We need to answer a number of important questions:

- How are genetic, molecular and cellular responses to representative contaminants that scientists

generally measure in the laboratory related to the organism and to community structure in the estuarine environment?

- How are sublethal impacts of contaminants at different levels of biological organization transferred through trophic networks?

We also need to address the following issues:

- Since it will prove impossible to study the effects of all compounds on all organisms, we must continue to focus, systematically, on representative estuarine species and representative contaminants, such as those described in this report.

- While we understand much about the behavior of specific contaminants, we know little about combined toxic effects on organisms, let alone entire communities, under different physico-chemical factors (e.g., pH, temperature, redox potential). We do not yet understand fully the effects of the total suite of contaminants on the Bay's whole complex and integrated ecosystem.

Scientific research on contaminants in the Chesapeake Bay, while its goals are a fundamental understanding of how the Bay functions, is guided by the need to identify critical issues that will best serve resource management goals - namely protecting the integrity and health of the ecosystem itself. Towards these ends, research efforts over this last decade, including those supported by CBEEC, have been working to provide the answers that influence decision making. While science will continue to pose new questions, these questions arise from research findings that contribute the kind of knowledge that can only lead to more effective management. The linkages between science, management and policymaking are critical - and only by continuing to expand our knowledge of chemical contaminant behavior and effects in the Chesapeake will we be able to make the decisions necessary to ensure a healthier Bay for the future.

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TOXIC EFFECTS OF BULKHEADING

Protection of eroding shorelines is a major priority in the Chesapeake Bay, where islands have virtually disappeared in a matter of decades. But bulkheading involves the use of protective coatings that use chemical compounds such as chromium, copper and arsenic. These chemicals, designed to prevent decomposition of wood by fungi and bacteria and retard consumption by wood-eating invertebrates, can leach from wood and cause changes in benthic community structure, according to recent research in New York, New Jersey, Florida and more recently in the Chesapeake Bay (Weis and Weis 1992).

The Weis's have studied the impacts of leached toxic preservatives from lumber in bulkheads treated with chromated copper arsenate (CCA). Lumber used in bulkheading is typically pressure-treated yellow pine at 1.5-2.5 lb/ft^3 of CCA. The CCA treatment usually consists of oxides of chromium, copper and arsenic at 47.5, 18.5 and 34%, respectively. The high concentration of metals in the wood as a result of pressure treatment ensures that even at low leaching rates environmental levels result that can be toxic to adjacent organisms. All three metals are EPA priority pollutants listed among the top ten inorganic contaminants.

From these initial studies come compelling indications of the biological impact of CCA. Laboratory studies showed somewhat higher than ambient concentrations of leachate from CCA treated wood were toxic to different estuarine organisms including algae, crabs, snails and reproductive stages including fish embryos and sea urchin gametes. Early field studies showed that metals from treated wood concentrated in attached organisms including algae and barnacles. The attached community also had a lower species diversity, indicating that toxicity had eliminated more sensitive species. The transfer of contaminants from the attached community to predators observed in subsequent studies suggested that leaching of metals from CCA-treated lumber might pose a potential threat to the food web. Impacts of metals from treated wood extend beyond the surface communities as well. Benthic communities adjacent to bulkheads in Florida had lower species diversity than control sites. Preliminary studies in the Chesapeake Bay also show reduced diversity in benthic communities adjacent to bulkheads.

These studies reinforce the need to consider varying management options for controlling shoreline erosion, which is also a key issue in the Chesapeake — and will continue to be, given current projections of rising sea levels. In some areas, for example, treated wooden bulkheads may be the best (and perhaps only feasible) option. In other areas, methods that do not require chemical preservatives, such as rip rap, rocky gabions or shoreline stabilization by marsh restoration, may be preferred. If research continues to show probable links between preservatives like CCA and degraded biodiversity in adjacent areas, the choice of erosion control mechanisms could become an especially important issue.

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Glossary

Airshed - The area from which most airborne particles emanate. The Chesapeake Bay's airshed extends west as far as Ohio.

Algae - A group of non-vascular aquatic plants, most of which have chlorophyll; often referred to interchangeably as phytoplankton.

Anoxia - A complete depletion of oxygen in the aquatic environment. Anoxia occurs in the Bay's deepest waters, especially during summer.

Anthropogenic - Referring to the influence of human beings on the environment.

Atrazine - An organic herbicide, used widely in the cultivation of corn and sorghum, that can have deleterious effects on some species of underwater grasses.

Benthic organisms - Refers to organisms that live in or on the bottom of the aquatic environment (e.g., bacteria, rooted grasses, worms, oysters, clams). Referred to collectively as members of the benthos.

Bioavailibility - Describes whether a contaminant is available for uptake by living organisms.

CBEEC - Chesapeake Bay Environmental Effects Committee, the committee which oversees the Toxics Research Program, funded by the National Oceanic and Atmospheric Administration (NOAA).

CCA - A compound containing copper, chromium and arsenic (chromated copper arsenate) that is used to treat wood, including wooden bulkheads.

Chlordane - A powerful pesticide once used to treat termites and other insects, but now banned. Highly resistant to degradation.

Complexation - The joining of elements (e.g., chemical contaminants) with other elements or compounds, generally rendering them less available for uptake by living organisms.

Copepods - A small planktonic crustacean vital to the food web in the Chesapeake.

DDT - Dichlorodiphenyltrichloroethane, a polychlorinated pesticide banned in the U.S. since 1972.

DEN - Also called DENA, n-nitrosodiethylamine is a well known mammalian carcinogen; it has been shown to increase an oyster's susceptibility to Dermo disease (Perkinsus marinus).

Dermo - A parasitic disease agent, Perkinsus marinus, that has caused extensive mortality on Chesapeake Bay oyster reefs and elsewhere.

Diagenesis - A term for characterizing the physical and chemical processes that alter sediments during the interval between deposition and final lithification.

Diffuse sources - Sources of contaminants to an aquatic environment that are not derived from a single, discrete (point) source, but are derived from multiple sources such as storm drains, groundwater seepage and septic tanks.

Dimilin - An organic pesticide, diflubenzuron, that acts as a growth inhibitor. Dimilin is used in parts of the Chesapeake region to control the Gypsy moth and adversely affects crustaceans (e.g., copepods, amphipods, shrimps, crabs).

Ecotoxin - Toxicants that adversely impact ecosystems.

EH - Redox potential. See oxygen reduction.

EPA - Environmental Protection Agency

Eutrophication - The process of nutrient overenrichment in aquatic ecosystems. In the Chesapeake, eutrophication and a resulting increase of phytoplankton biomass has contributed to oxygen depletion.

Flocculation - The physical process whereby particles such as sediments are joined together.

Food web - Refers to the flow of energy through an ecosystem via successive steps or trophic levels.

HOCs - Halogenated organic compounds.

Hydrolysis - Occurs when a compound reacts with water, essentially the chemical breakdown by the addition of water to replace a covalent bond.

Hypoxia - The presence of very low dissolved oxygen in the aquatic environment, usually considered to be dissolved oxygen concentrations ranging between 2 to 0 mgO2 L-1.

Kepone - A potent pesticide, well known because of a large spill by the Allied Chemical Company into the James River.

NOAA - National Oceanic and Atmospheric Administration.

Oxygen reduction - Often referred to as "redox potential." This is a measure of reducing or oxidizing

capacity of sediments, etc.

PAHs - Polycyclic aromatic hydrocarbons, a large class of chemicals generated by the burning of fuels such as coal, gas, wood, charcoal, gasoline and diesel.

PCBs - Polychlorinated biphenyls, a type of complex chlorinated hydrocarbon which is very stable and highly persistent in the environment; although now outlawed they are widely distributed and were extensively used in manufacturing industries.

Pelagic organisms - Organisms that live within the water column of aquatic environments (e.g., phytoplankton, zooplankton, fish) in contrast to those live on the bottom (benthic).

Penta-chlorophenol - A chemical used as a wood preservative. A halogenated ring structure that like of PCBs, PPT and Chlordane, it is highly resistant to degradation.

Petrogenic - A contaminant produced from unburned petroleum products.

pH - A measure of acid or base, as determined by the hydrogen ion concentration.

Plankton (phytoplankton and zooplankton) - A diverse group of minute animals (zooplankton) and plants (phytoplankton) that freely drift in the water.

Point source - A single direct source of a contaminant such as an oil spill or sewage outfall. Contrasts with diffuse source.

Pyrogenic - A contaminant produced from the combustion of fossil fuels.

Redox (or redox potential) - See oxygen reduction.

Regions of Concern - Areas in the Chesapeake Bay with acute toxic contamination such as the Baltimore Harbor, Elizabeth River and Anacostia River.

SAV - Submerged aquatic vegetation, important but badly degraded bottom habitat in the Chesapeake Bay and its tributaries.

Simazine -Like Atrazine, one of the s-triazine herbicides used in agriculture; its mechanism of toxicity is based on photosynthesis inhibition.

Speciation - The form or "species" taken by a metal. Metals such as copper can appear in numerous forms in the Chesapeake Bay, some far more toxic than others.

TBT - Tributyltin, a potent anti-fouling paint largely banned because of its toxicity, but with some exemptions (e.g., for military vessels).

TRI - Toxics Release Inventory, a list of 650 chemicals used by industry and an annual accounting of their releases into the environment; created in 1986 as part of the Community Right To Know Act.

Watershed - The drainage basin of a creek, stream, river or bay. The watershed of the Chesapeake Bay covers 64,000 square miles in six states.

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Credits and Acknowledgments

This report was prepared by Jack Greer and Dan Terlizzi, Maryland Sea Grant and Maryland Sea Grant Extension. It was designed by Sandy Rodgers.

This report represent a broad synthesis based on direct input from the scientific community, as well as selected resource managers and others, to outline what we know and what we need to know about the impact of contaminants on the Chesapeake Bay.

Among those participating in this synthesis were representatives from the following institutions and agencies: National Oceanic and Atmospheric Administration Chesapeake Bay Office and Office of Oceanic and Atmospheric Research, University System of Maryland Center for Environmental Studies, and Sea Grant College, Academy of Natural Sciences Benedict Estuarine Research Center, Virginia Institute of Marine Science, Virginia Sea Grant Program, Maryland Department of Natural Resources, U. S. Environmental Protection Agency, and others.

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