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Kepone and the James River

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KEPONE AND THE JAMES RIVER

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Abstract

The James River in Virginia was contaminated by the pesticide kepone when the material entered the river as early as 1968 and continued until its discovery in 1975. The river became so contaminated that commercial fisheries were closed. In 1988, 13 years after closure, all fishing restrictions were lifted. The contaminated sediments have been diluted and covered enough by uncontaminated material that the kepone flux back into the water column has diminished. Kepone concentrations in organisms inhabitating the river are finally below the U.S. Environmental Protection Agency and Food and Drug Administration action levels. Biological, chemical, physical and geological aspects of the contamination indicate that remedial actions to remove kepone would be expensive and environmentally unwise.

Introduction

In 1988, there were no restrictions on commercial fishing in the James River. It has been more than a decade since workers at a kepone manufacturing facility in Hopewell, Virginia became ill from occupational exposure to the pesticide. The knowledge of their exposure, the fact that kepone is a mammalian carcinogen, and the subsequent determination that the adjacent river had become contaminated with the compound led Governor Mills Godwin to close the tidal portion of the James and its tributaries to commercial fishing.

Kepone (decachlorooctahydro-l, 3, 4-metheno-2H-cyclobuta[cd]-pentalen-2-one) was produced from hexachlorocyclopentadiene in the presence of sulfur trioxide. A solution of sodium hydroxide was used in the purification process (Huggert et al., 1980). The conditions used in the formulation of the compound suggest that it should be resistant to chemical degradation under natural environmental conditions, a supposition that has been verified by field observations. If kepone has degraded significantly in the river, it is not obvious even after thousands of chemical observations over 13 years.

The fishing restrictions were relaxed because the contaminated sediments were diluted and covered by uncontaminated materials. Since the kepone flux back into the water column diminished, finfish and shellfish inhabiting the river contain concentrations below action levels established by the U.S. Environmental Protection Agency (EPA) and Food and Drug Administration (FDA).

The James River

The James River extends from its mouth near Norfolk and Newport News, Virginia, to West Virginia (Figure 1). It is tidal for the first 160 km with the city of Richmond located at its fall line. The drainage basin encompasses approximately 25,600 km^2 and runoff from this area results in it being the third largest tributary of the Chesapeake Bay, delivering approximately 16 percent of the fresh water entering the system. The average discharge over the fall line at Richmond is 212 m^3/sec

The river is a coastal plain estuary for its first 60 to 80 km with the location of the freshwater-saltwater interface varying depending on rainfall in the drainage basin. Fresh water from upstream flows over more dense saline water creating a two-layer circulation pattern. As the fresh water flows to the sea, there is some mixing between layers, giving rise to a net downstream flow in the surface layer and a net upstream flow on the bottom (Pritchard, 1952). Suspended particulate matter is carried downstream in the tidal freshwater portion of the river (i.e., above the freshwater-saltwater interface) and downstream in the surface layer of the estuary. If the particles sink into the bottom layer, they are transported upstream toward the interface (Figure 2). This phenomenon is mainly responsible for the higher sedimentation rate and more turbid water in the interface region of the river, which is appropriately called the "turbidity maximum zone."

The circulation pattern and its influence on the movement of particulate matter controls the transport of kepone in the James River. The pesticide entered the river at Hopewell, associated with particulate material, and was transported downstream. Most of the kepone deposited in the turbidity maximum zone.

The Kepone Source

Allied Chemical Corporation began producing kepone in 1966 and intermittently continued until 1974. At this time, Life Science Products, Inc., began production and continued until July, 1975 (Huggett et al., 1980; Huggert and Bender, 1980). During this period over 1.5×10^{6} kg of the substance were produced (Batelle Memorial Institute, 1978). It is likely that kepone entered the James River throughout the period of production. Analyses of oysters (*Crassostrea virginica*) and bottom sediments collected as early as 1967, but analyzed in 1976, revealed that the James River was contaminated in the 1960s (Huggett et al., 1980; Huggert and Bender, 1980).

Kepone entered the river at Hopewell via a number of routes. The most significant was the discharge of the local municipal sewage system. Kepone-laden industrial waste entered the sewage treatment plant and the pesticide exited with little or no degradation. Other sources

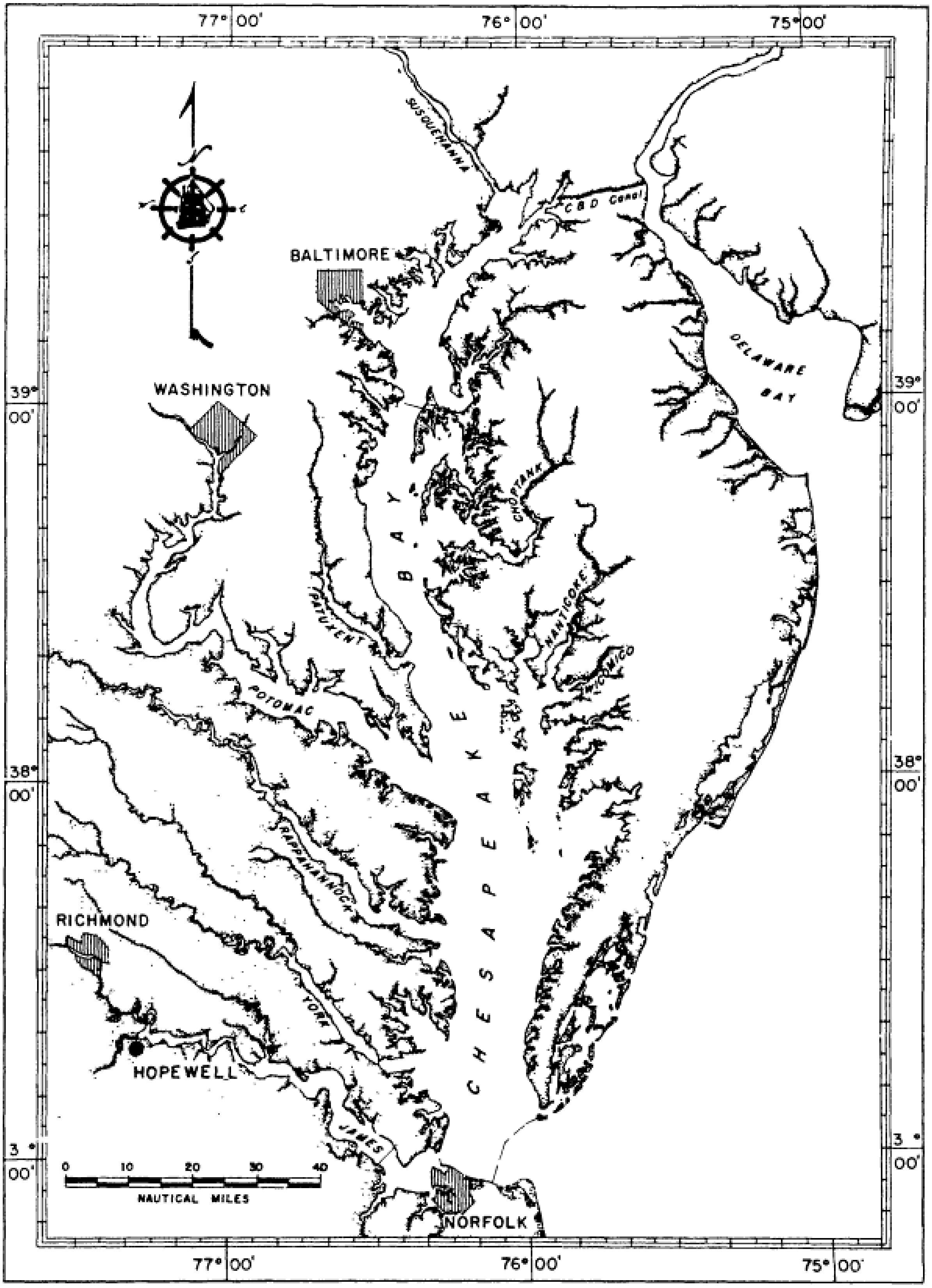

Figure 1
Map of the Chesapeake Bay showing the tidal James River.

included runoff from contaminated soils near the manufacturing facilities and solid waste dumped into a freshwater marsh on a small tributary of the James River (Huggert et al., 1980). The material entered the river either as particulates or in solution. In the latter case, it rapidly sorbed to bottom and suspended solids to be transported by the river's currents.

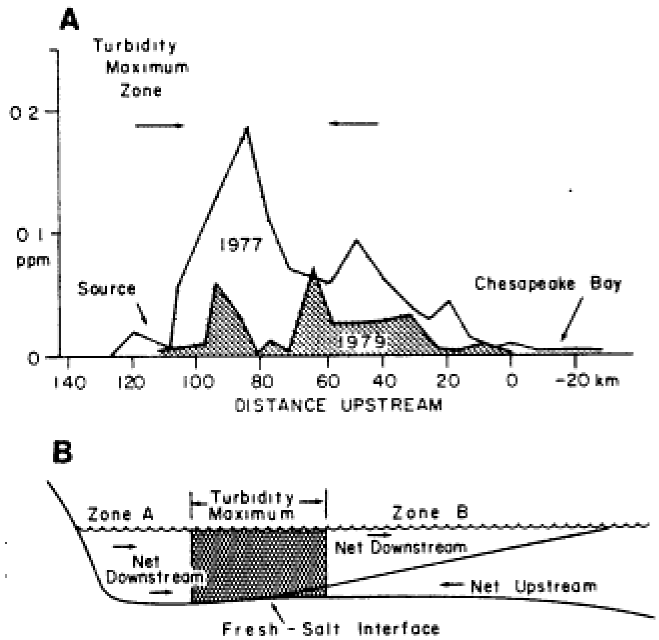

Figure 2
A. Kepone in the top 2 cm of channel bottom sediments from the James River. B. Hypothetical coastal plain estuary with two-layered circulation and turbidity maximum. Source: Huggett and Bender (1980), reprinted with permission from the American Chemical Society.

Contaminated Sediments

Kepone readily partitions from solution to solids. Dawson (Batelle Memorial Institute, 1978) suggested that a sediment-water partitioning coefficient of 10^4 to 10^5 be used. Other laboratory experiments as well as measurements of kepone in suspended sediments and associated waters from the James indicate that the value is between 1.6×10^{3} and 7.7×10^3 (Huggert et al., 1980; Strobel et al., 1981). The partitioning coefficient, as derived in the laboratory, does not appear to be affected by changes in salinity from 0 to °/oo or by pH values from 6 to 9 (Huggett et al., 1980). These span both the salinity and pH ranges normally found in the contaminated portion of the river. Field investigations verify these findings (Strobel et al., 1981).

The bottom sediments of the James River are contaminated with kepone to varying degrees. The main factors governing the concentrations appear to be the makeup of the sediments and the currents of the overlying water. These two factors, in combination, distribute kepone in a nonuniform pattern over an area of approximately 500 km^2 (Huggett and Bender, 1980, 1982).

Kepone associates more with the organic portion of the bottom sediments (Huggert et al., 1980). Sandy or coarse-grained sediments generally contain less kepone than fine-grained sediments. This is due to the ordinarily high organic content of the latter. The organic content of the sediments can have a dramatic influence on kepone distribution. For instance, the highest sediment concentrations found (except within several kilometers of the Hopewell source) were near the outfall of a sewage treatment facility 75 km downstream (Huggett and Bender, 1982). The organic content of this sediment was approximately 20 percent. There was no indication that kepone had ever been disposed of by this treatment plant.

The distributions of the pesticide in the top 2 cm of bottom sediments in the channel of the river in 1977 and 1979 are given in Figure 2. The highest concentrations in 1977 were found in the vicinity of the turbidity maximum zone. The mass of kepone in the sediments at that time was estimated to be between 1×10^4 kg and 3×10^4 kg (Huggett and Bender, 1980). The range was due to the large area contaminated (500 km^2) and the relatively few samples analyzed at the time.

By 1979, surface sediment concentrations were greatly diminished. Analyses of sediment cores with depth showed that kepone was becoming diluted and buried by newly deposited material rather than being transported away or decomposing. This trend has continued, but in areas where the sedimentation rate is low, kepone is most concentrated near the surface. Where the sedimentation rates are high, concentrations increase with depth (Figure 3) (Helz and Huggett, 1987).

As mentioned previously, most of the kepone is deposited in the James' turbidity maximum zone, which has a high sedimentation rate. This has resulted in a continual reduction in the pesticide's concentration in surface sediment (Figure 3). This reduction is reflected in the residue concentrations in edible tissues of male blue crabs (*Callinectes sapidus*) and oysters (*Crassostrea virginica*)

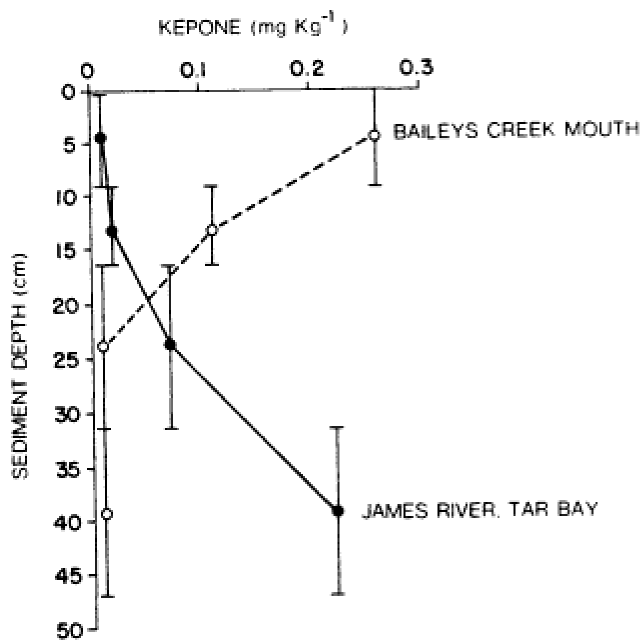

Figure 3
Kepone concentrations in sediment cores from the James River. Bars indicate the depth interval of the sediments analyzed. Source: Reprinted with permission from Majumdar et al., 1987.

collected from 1976 to 1985 (Figure 4). The data are interesting in that they show similar rates of concentration decrease for both species although crabs obtain most of their kepone from food, while oysters obtain kepone both from solution and from suspended particles (Schimmel and Wilson, 1977; Morales-Alamo and Haven, 1983; Bender and Huggert, 1987). Apparently the equilibration times between sediments and water, sediments and food are relatively short.

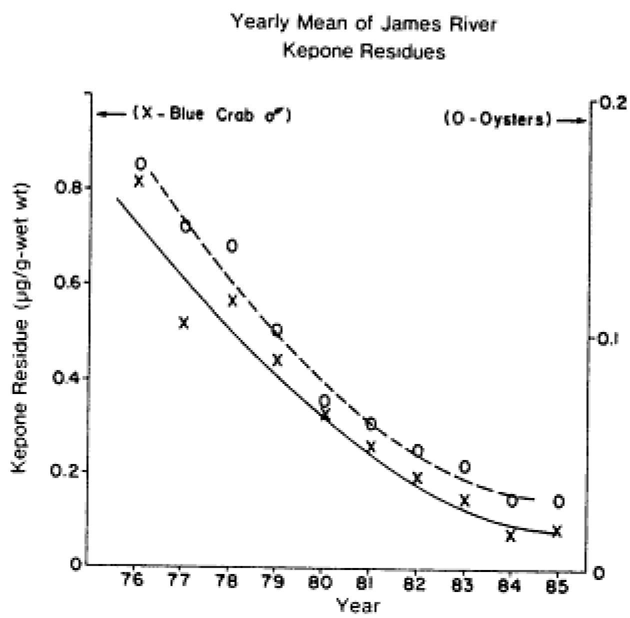

Figure 4
Kepone concentrations in blue crabs and oysters.
Source: Majumdar et al., 1987.

Discussion and Conclusion

Kepone concentrations in the James River are much lower now than in the past, therefore the biota are at less risk from the toxicant now than during the period of production. A comparison of existing toxicity data and kepone concentrations in solution or in tissues of the biota indicates that there has been little or no biological impact due to the contamination (Bender and Huggert, 1984). The impact has been economic; commercial fishermen couldn't harvest the seafood and consumers couldn't buy it.

Any consideration of mitigation must balance the benefits of cleanup, which would be solely economic, with the costs, which are not only economic (e.g., the cost of dredging) but also ecological. *Any cleanup effort* will have detrimental biological impact relative to doing nothing. Natural forces, such as sedimentation, are cleansing the river and the time frame for this cleanup is on the order of decades.

Studies have been conducted, however, to assess the feasibility of mitigating the kepone contamination of the James (Batelle Memorial Institute, 1978). Options ranged from dredging, at an estimated cost of $\$3 \times 10^9$ not including the cost of disposal, to stabilizing the sediments with molten sulfur (often called "the Yellow Brick Road theory"). None of these options were feasible, either economically or environmentally; therefore, nothing has been done.

Kepone concentrations in finfish and shellfish are now low enough to again allow commercial harvesting in the river. The pesticide is buried under a veneer of clean sediments. A major hurricane could stir up these sediments and recontaminate the river (Huggert and Bender, 1980). Such a storm has not occurred in the area since the 1950s. Another complicating factor is that the channels of the James River will need to be dredged in the near future. In the past, dredged material was disposed by placing it on the flanks of the river, adjacent to the channel being dredged. Such a practice now would place buried kepone-contaminated sediments back on the surface. The biota would again be exposed to the pesticide. The resulting body burdens could result in fisheries closures.

Given the uncertainties involved in predicting the transport and fate of kepone under the conditions mentioned above, deciding whether or not to dredge the James River will be difficult. The benefits of continued shipping on the James River by allowing dredging will have to be compared to the potential costs of fisheries closures due to kepone contamination. One solution to the dilemma may be to bear the expense of upland disposal and containment of the dredged materials rather than pumping them back overboard. (VIMS Publication Number 1502.)

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