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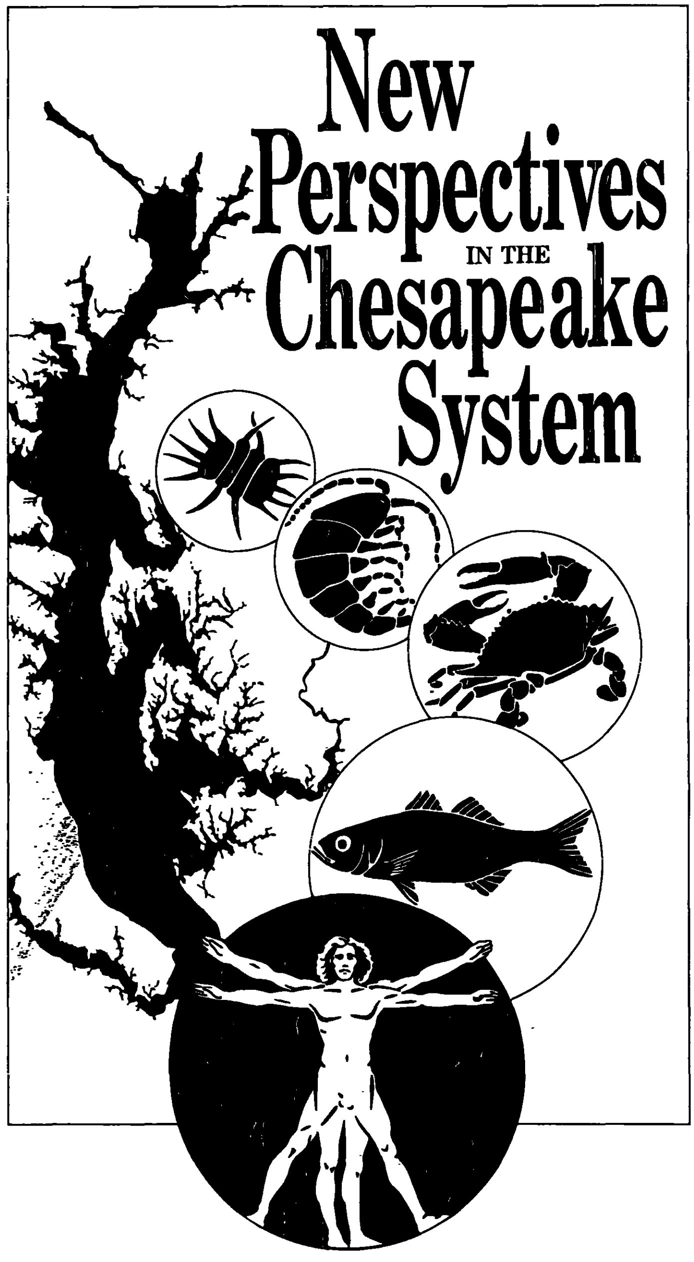

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ABSTRACT

The population of coastal counties in the United States is over six-fold higher than non-coastal counties and population density along the Atlantic coast is much greater than all other coasts in the nation. Many areas around the Chesapeake Bay watershed are participating in this growth and extensive interstate construction is planned for this region. A wide array of primary ecological risks to the Chesapeake Bay exists, and may be classified as biological, physical, or chemical. Biological risks range from physical threats to motorists and animals to genetic risks to local flora and fauna populations. Island biogeography theory can be used to predict species losses associated with highway construction and resultant limits to migration. Introduction of exotic species and loss of ecologically significant areas (e.g. wetlands) are included as biological risks. Physical risks are primarily associated with hydrology, erosion, and related water quality considerations. Chemical concerns can be described as either chronic, such as certain airborne pollutants, or acute, such as accidental or illegal discharges. Secondary risks associated with highway construction result from facilitated traffic flow. Included are a variety of effects resulting from urban sprawl, strip development, and economic development of adjacent areas. Some ecological risks have received legislative, and subsequently transportation department attention. However, most ecological risks do not affect the decision-making process.

INTRODUCTION

Productivity in the Chesapeake Bay, the nation's largest estuary, declined dramatically during the past decade. Increased catches of blue crab, hard clam, and possibly menhaden were more than offset by drastic declines in oyster, striped bass, and many food finfish species. Many Bay-area comercial fishermen have moved offshore for Atlantic Ocean supplies of scallops and other species (Oesterling, pers. comm.). Submerged aquatic vegetation (SAV), an ecologically important community in the shallow waters of the Bay, has shown some recovery in the lower Bay and tidal, freshwater Potomac River, but is still below 1970 levels throughout the Bay and its tributaries (Moore, pers. comm.). Tidal wetland acreage has declined slowly during the last decade, but considerable nontidal wetland loss has occurred, despite increased media attention (Tiner, 1987).

An EPA research summary for the Chesapeake Bay (EPA, 1980) prioritized the major problem areas in the Bay including SAV, eutrophication, and toxics as having the highest priority. The Chesapeake Bay receives runoff and groundwater from 64,000 mi², including over 150 rivers, streams and creeks that flow into its nearly 200 mile-long mainstem. Highways and waterways are both linear aspects of the landscape and frequently intersect. Though highways and highway construction present significant ecological risks contributing to the three ecological problems listed above, little or no direct attention has been paid to this risk in reports and goals set by the Chesapeake Executive Council, and most ecological risks, including those associated with secondary development may not be addressed by existing transportation department procedures.

Increased transportation needs associated with population growth are most evident on the Capital Beltway. "In 1976, 466,000 vehicles a day used this highway around Washington, DC; now 735,000 vehicles a day make use of this road. The average speed on the Beltway was 47 miles per hour; now this has been halved to 23 miles per hour" (Year 2020 Panel, 1988). The Baltimore, Washington, Annapolis metropolitan area ranks fourth in population nationwide, and continued, rapid growth is predicted. Proposed highways, eg. the Southeastern Expressway, would encourage growth south from Washington towards Virginia Beach through rural areas of Virginia that are already projected to increase in population ranging from 25 to 100% by 2020 (Year 2020 Panel, 1988). Other major highways are planned for the Bay's Coastal Plain Province (Hundley, Allen-Grimes, pers. comm.).

A review of assessment methods by the EPA (1988) defines ecological risk assessment as "related to actual or potential ecological effects resulting from human activities." Such risks for highways have been selected and are presented here as biological, physical, or chemical in origin. A 1990 paper regarding risk assessment development for the Chesapeake Bay (Cairns and Orvos, 1990) recommends evaluating the risk and calculating its probability before the impact. An attempt has been made to give both probability of occurrence and severity of the impact for each ecological risk (Table 1). The probability and severity of nearly all risks of highways to the Chesapeake Bay are exacerbated by secondary development following highway construction. Some of these risks are discussed near the conclusion of this chapter and are followed by a brief summary.

Biological Risks

The ecological benefits of wetlands and their importance to the restoration of the Chesapeake Bay are well established in the literature (Sather and Smith, 1984; Virginia Council on the Environment, 1987; Chesapeake Executive Council, 1988). In addition to providing habitat for a disproportionately large number of rare and endangered species, wetlands buffer erosion and flooding and reduce sediment and nutrient loading into surface waters. Virginia has more than twice the wetland acreage of any state in the Chesapeake Bay watershed, and 75% of those acres are in the Coastal Plain Province (Tiner, 1987). Furthermore, most of these wetlands occur along coastal river floodplains that, like highways, are linear aspects of the landscape and, consequently, encounters are inevitable. Unfortunately, it is in this Province that most new highways and enlargements of existing highways are planned. Wetland acreage may be lost if (a) the fill is exempted from the full permit process, or (b) the permit does not fully mitigate the loss of wetlands. Exemptions still allow loss of specific categories and sizes of wetlands. Many wetland fills do require permits, and highway construction forms the bulk of wetland fill permits in the southeastern United States (Deitz, pers. comm.). Many permits are granted that require wetland creation as mitigation for lost acreage. Most of the acres to be created in Virginia and Maryland are non-tidal forested wetlands, which are the most controversial, least studied form of wetland creation, and present several ecological risks (Atkinson et al., in prep.). While wetland creation requires the conversion of some other system, site selection is often based on direct economic considerations and may not adequately consider functions performed by the site

Ecological risk	Probability	Severity
Biological		
Wetland loss from primary and secondary impacts	high	high
Isolating large populations	high	low
Isolating small populations	low	high
Facilitated migration of pests	medium-high	low-high
Escape of exotics	medium	low-high
Physical		
Altered wetland hydrology (upstream and downstream)	medium	medium-high
Decreased erosion and sedimentation	low	low
Increased erosion and sedimentation	high	medium
Oxygen sags/fish kills	low-medium	high
Exotic species invasion following disturbance	medium	medium-high
Chemical		
Increased nitrogen input from air pollution	high	low-medium
Increased ozone concentrations damaging vegetation	medium	low-medium
Increased trace metals in surface water (from air)	high	low-medium
Toxic spill (hydrocarbons)	medium	low-high
Toxic spill (other)	low	high

Table 1. *Probability and severity of several ecological risks associated with highways in the Chesapeake Bay watershed.*

prior to conversion. The ecological process of succession is implicitly required for mature forested wetland development in created sites. Functions dependent upon mature wetlands, eg. usage by certain avifauna, may be forfeited in the interim. Low vegetative cover during initial years following site creation may lead to erosion. Insufficient hydrology could mean that lowlying uplands were created, while excessive hydrology could mean a pond was created. In addition, the Virginia Department of Transportation (VDOT) still uses interstate loops and medians between lanes to construct wetlands designed to replace all functions, including habitat provision. Most such created wetlands have box culverts or tubes leading into them and lack fencing, thus encouraging animals to cross over highways. Ecological risks of such actions seem obvious, but such policies are currently in place. Physical risks associated with altered hydrology are discussed below.

Though wetland acres continue to be lost, at least permits are required in many cases. Such protection is seldom afforded lower profile ecosystems. Highways through areas such as uplands adjacent to wetlands, large tracts of mature forests, and floodplains can be built with minimal ecological risk assessment. With the exception of cases involving endangered species, highway placement, or alignment, rarely considers landscape ecological considerations such as dimensions of indigenous populations, and unique, non-wetland habitats.

The fact that floodplains and highways are both linear aspects of the landscape may increase risk at the landscape ecology level. Decisions to use fill and box culverts versus bridges have been based on direct cost considerations rather than ecological costs such as potential migration barrier effects (or risks to motorists resulting from animal crossings). The risks to animal populations imposed by such barriers in Southeastern bottomland forests were discussed by Harris (1989). For animals in particular, ecological risks associated with such barriers include "island" formation, isolation of populations, special risks to small populations, and loss of highway intolerant allelic forms. In the Theory of Island Biogeography, MacArthur and Wilson (1967) demonstrated the importance of immigration and emigration to the number of species an area can support. When immigration and emigration are reduced, loss of some species can be predicted. Most affected may be slow moving animals such as snails, tortoises, frogs, and snakes, which are the most likely populations to be effectively isolated by highways. Reduced immigration and emigration suggest lower numbers of pre-impact species surviving, regardless of secondary development. A variety of genetic risks are magnified by a small population size. A small population is subject to sudden extirpation by natural disaster or by direct or indirect effects of highway construction. Increased expression of deleterious alleles through increased inbreeding is likely for small populations. Loss of demes within meta populations limits genetic diversity and further contributes to viability of a small population (Wallace, 1981). For any species affected by a highway, there is a risk that highway impact-intolerant allelic forms may be lost. For example, if juvenile migration is genetically based and is selected against by highway traffic, nonmigrants will be selected for. This may eventually put the population at risk.

Whereas highways may act as migration barriers to certain animal species, they can also facilitate migration for certain r- selected plant species and associated animals. Many of the ecosystems traversed by highways previously acted as barriers to invasive plant species and to animals considered to be pests. For example, forests in the Bay's watershed are at greater risk to gypsy moth invasion as a result of accidental transport by vehicles such as those traveling along the Blue Ridge Parkway. Plants may use highways as corridors and, through pollinator or other relationships, may facilitate migration of animals such as insects. The result can be breakdowns in natural isolation, loss of diversity of pre-impact species, and even radical changes in community composition. The later case could occur when animal pests utilize a monoculture at flowering to spread, eventually adapting to utilize related species of plants in new areas. Ditches are believed to provide a means of dispersal for some species, including *Juncus arbortivus*, the only Virginia record for which is ditches in Isle of Wight County (Porter and Wieboldt, in press).

Monocultures may have other risks for ecosystems. Whether planted or simply resulting from differential survivorship, monocultures can be deleterious as a result of seasonal characteristics, loss to disease and resultant erosion, and the risk that non-native, or exotic, species might be used. Seasonal characteristics include the potential for timing of vegetative cover production, which would result in erosion and reduced fertility. Monocultures that are more supceptible to disease and vulnerable to its spread, could again lead to inadequate cover. The use of exotics, such as kudzu (*Pueraria lobata*) for erosion control, and certain aquatic and wetland species associated with mitigation, could risk community composition and normal ecosystem function.

Physical Risks

Hydrologic alterations, soil disturbance, and dredging are physical impacts with potential ecological risks. Hydrologic concerns include altered flow rates and increased runoff. Upstream effects associated with altered flow rates include unmitigated alteration of wetlands resulting from increased flooding. Flooding may be caused by reduced subsurface flow following compaction by fill material, inadequate positioning of culverts, and failure of culvert size estimates to account for increased watershed runoff following secondary development and increased cover of impervious surfaces. Increased flooding duration can reduce forested wetland productivity (Odum, 1978), increase sedimentation rates, and lead to extensive tree mortality. Downstream impacts associated with altered flow rates include subsequent diminished sediment nourishment and potential erosion, increased temperatures and potential loss of intolerant species, and altered flooding patterns with potential effects similar to those listed for upstream impact.

Soil disturbance can lead to erosion and sedimentation and invasion by opportunistic plant species. Little or no erosion controls were used up to the last 15 years, and current practices are frequently insufficient. Direct sources are often difficult to determine because development indirectly associated with the highway construction may contribute to this pollution. Phosphorus loading is often associated with sediment runoff, and eutrophic effects that result can be extreme, often adversely affecting oxygen content of the water. Altered community composition and fish kills may result. Affected systems include the Bay, its tributaries, and water reserviors (Dr. C. Randall pers. comm.). An example of plant invasion following disturbance is provided by the reed phragmites (*Phragmites communis*). An excellent competitor in disturbed sites such as roadsides, mud waves, and created wetlands, phragmites grows in near monotypic stands of minimal ecological value. Phragmites is an invador throughout the Bay's watershed, and eradication techniques are expensive and controversial.

Another physical risk associated with bridge construction involves the use of barges. The average depth of the Bay is 20 feet, and dredging is often necessary to allow barges to reach shallow portions of a crossing. Ecological risks include increased suspended sediments, nutrients, and toxics and lead to loss of habitat. The dredging process itself can increase suspended sediments and mobilize any nutrients and toxics previously buried in those sediments. Disposal sites for dredge material are limited, and shallow areas nearby are likely sites. Loss of the shallow water habitat is likely, and erosion and transport of unstabilized material is possible. A myriad of adverse environmental impacts are associated with both dredging and disposal and are discussed in dozens of publications produced by the Waterways Experimental Station of the Corps of Engineers.

Chemical Risks

Most chemical risks can be classified as either chronic or acute. Chronic risks include certain atmospheric pollutants as well as substances routinely applied to highways. The mainstem of the

Bay lies to the east of major population centers within the watershed. Since the primary wind direction is westerly, transport and deposition of airborne pollutants into the Bay are serious concerns. Automobile exhausts are the primary source of atmospheric nitrogen oxides (Chevone, pers. comm.), and chronic deposition may contribute to the already over-enriched waters (Moore, pers. comm.). Burning fossil fuels elevates ozone concentrations and may threaten sensitive vegetation. Randall et al. (1978) studied the contribution of several atmospheric pollutants to storm water quality near commuter routes into Washington, DC. Significant impacts to surface water quality were found following both rain and snow precipitation events. Significant concentrations of several trace metals have been found in detention basins receiving highway runoff (Wigington et al., 1983), but capacity for long-term retention of metals was not determined. Routine applications of chemicals including salt, herbicides, and fertilizers may be accumulated and reach harmful levels.

Chemical risks may also be acute, taking the form of accidental releases and illegal dumping. Toxic liquids may remain in surface soils with some potential for recovery, or may enter sub-soil and groundwater compartments where recovery may be precluded. Once reaching Bay waters, these toxics may be transported out of the Bay in surface flow, transported up the Bay along the bottom, or deposited in the sediment. Fate and effects of toxics is dependent upon the chemical species involved.

Accidental release of toxic gases incurs ecological risks such as direct toxicity via uptake or indirect risk through surface water deposition. Remediation of atmosphere distributed pollutants may not be feasible. Illegal dumping of toxic material ranges from thoughtless discard of partially empty containers to disposal of known carcinogens along highways for profit. Unlike accidental releases, many illegal discharges may be concealed to avoid detection.

Secondary Risks

Secondary development often follows highway construction. Loss of wetlands, over-enrichment, loss of SAV, and lower water quality are major threats to Bay ecology and may all be impacted when construction occurs in the watershed. Filling of wetlands, erosion and sedimentation, and poor land use practices can accompany secondary development. The resultant increase of sediments and nutrients find their way downstream with well known ecological and economic consequences.

Secondary impacts associated with highway construction may present even greater ecological risk than the direct effects of both highways and highway construction. Not only are all risks of direct effects still valid for secondary development, enforcement of existing environmental legislation may not be as vigorous. Departments of transportation meet regularly with agencies having wetland regulatory responsibilities, but secondary development may be less conspicuous. In the case of wetlands, once an area is exposed to development by a new or enlarged highway, wetland losses occur either from unpermitted fills or from permitted activities when "no alternatives" are shown to exist. Unpermitted fills may have severe cummulative effects as incremental losses occur associated with repeated small fills. In many cases, local landowners are uninformed regarding evolving wetland legislation and may fill wetlands somewhat accidentally.

The "no alternatives" provision of the Federal Water Pollution Control Act, Section 404 is of key importance to secondary impacts and wetland legislation. Following enhanced transportation, industry and increasing population size place greater demands on limited resources, such as groundwater and fresh surface water supplies in the region. Water reserviors are often the least expensive measure to meet the new demands. Hundreds of wetland acres can be lost as a direct result of reservior construction, if no practiceable alternatives can be found to the reservior. Not considered in such cases, or in decisions to build box culverts, is the risk associated with reduced sediment conveyance by the impounded waterway. Thousands of tidal wetland acres could be lost if sediment nourishment is precluded and these wetlands fail to keep pace with rising sea-level. A water reservior on Ware Creek in James City County, Virginia, was planned in order to meet the predicted population and industrial needs. The County received a Corps permit to fill over 400 acres of wetlands, but the permit was subsequently vetoed by the EPA. This particular issue remains unresolved since a suit successfully challenged the EPA veto and an appeal is possible. Surely, pressure to create other reserviors, shopping centers, and housing developments can be expected to grow with facilitated transportation and population growth. Virginia Coastal Plain county populations have predicted increases ranging from 25 to 100% by the year 2020.

The Washington Bypass proposed by the Virginia and Maryland departments of transportation has received considerable opposition at the draft environmental impact statement (DEIS) stage. A four-page resolution adopted by the Chesapeake Bay Commission (1990) was highly critical of the DEIS, primarily because of a lack of "comprehensive analysis of the environmental impacts of the secondary development that would be expected..." A detailed review of the DEIS is in production by the Chesapeake Bay Foundation, and the effects of the proposed bypass on land use patterns are a major concern (S. Hillyer, pers. comm.). The lack of coordination throughout the watershed was characterized by the 2020 Panel (1988): "The panel is dismayed by the lack of growth management and planning, particularly on a state and regional level."

SUMMARY

Ecological risks to the Chesapeake Bay resulting from highways can be classified as biological, physical, or chemical. Biological risks from highways are often a result of the fact that both highways and rivers, with their associated floodplains, are linear aspects of the landscape. Ecological risks are magnified in these areas because both wetlands and large, continuous stands of floodplain forests are found along the approximately 150 streams in the Bay's dendritic drainage basin. Permitted wetland loss, unpermitted wetland impacts, and isolation of populations may result when highways and floodplains intersect. Bridges, rather than box culverts, would greatly deminish these risks.

Physical risks include erosion and sedimentation. These naturally occurring processes may be impeded, but are often intensified by highways. Both cases incur ecological risks, primarily water quality concerns. Over-enrichment of water reserviors, rivers, and the mainstem of the Bay may lead to phytoplankton blooms, low light penetration, submerged aquatic grass dieback, and inadequate oxygen supply. Another physical risk, altered hydrology, is highly significant to floodplain ecological processes.

Chemical risks can be classified as either chronic or acute. Chronic input of atmospheric pollutants can harm vegetation directly or can reach surface water during precipitation events. Chronic input of nitrogenous compounds may confound nutrient abatement attempts in the Bay. Acute chemical risks may be lower in frequency, but are surprisingly regular in occurrence and can be catastrophic in extent. Even rapid responses cannot guarantee prevention of groundwater and surface water transport of toxics. Circulation models indicate a limited capability to flush either nutrients or toxics out of the Bay.

Both the probability for occurrence and severity of impacts of all ecological risks considered in this paper are greatly increased by secondary development. Highways are known to attract development, yet such impacts are seldom given sufficient weight in highway planning or construction. A policy of considering alternatives to highways, landscape ecology issues, and creative zoning restrictions on development are needed to adequately address ecological risks associated with highway construction near the Chesapeake Bay and its watershed.

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Ecological Risk Assessment for the Chesapeake Bay

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ABSTRACT
Although agricultural pesticide use is suspected of being a major contributor to the risk of toxic contamination of the Chesapeake Bay, there is little information on the total use of pesticides in the drainage basin and the total risk implied by that use. Such information is essential, however, for setting pesticide risk management priorities and for designing policies to reduce the risk of toxic pollution from agricultural sources.

A procedure for estimating agricultural pesticide risk is developed for Virginia's Chesapeake Bay Region, using both available data and the results of specially conducted surveys. Information generated includes: an inventory of which chemicals are used; where they are used; estimates of aggregate chemical use for counties and sub-regions; and the potential adverse environmental effects of that use. Environmentally relevant characteristics of the pesticides (toxicity, persistence, mobility, etc.) are used to divide aggregate pesticide use according to the different levels of environmental risk associated with that use. An assessment of both current (1990) and future (2000) pesticide risk is provided.

Three determinants of pesticide risk are considered in the procedure: (1) acreage in crops treated with pesticides; (2) pesticide application rates per acre; and (3) the toxicity characteristics of the applied pesticides. In the future, all three will surely change, but due to the rapid urbanization of portions of the Chesapeake Bay region, it is likely that changes in the amount of land devoted to crop production will be the dominant determinant of pesticide risk. Therefore, estimating changes in agricultural land use is given greatest weight in projecting to the year 2000.

The policy implications of this modeling are then explored. Particular attention is paid to the potential for targeting of pesticide risk management programs at chemicals, sub-regions, or production systems (i.e. crops) that represent the greatest risk of toxic contamination of the Chesapeake Bay.

INTRODUCTION

The world's population growth along with increased individual expectations for improved quality of life have vastly increased the pressures upon natural resources. As a consequence, resources such as the Chesapeake Bay may eventually be unsuitable for use. An estimated Bay region population growth of 20% by the year 2020 will place additional burdens on this watershed.

Finally, the Chesapeake Bay is simultaneously used for a variety of purposes, frequently with one use conflicting or competing with another. Ecological risks to the Bay will come from a variety of sources, both natural and anthropogenic, and these risks may be minor or catastrophic. Participants at a symposium on ecoaccidents (Cairns, 1984) agreed that a sizable number of accidents were due to human operator failures because of alcohol, drugs, fatigue, failure to read or understand instructions, and a variety of other human frailties. These incidents may increase as fiscal constraints grow; even if the frequency of such major accidents is only once in 50 to 100 years, the risk to the Bay ecosystem is enormous and, therefore, predictions of and planning for such an incident are essential.

The development of protocols for assessing ecological and human health risk has escalated in recent years such that an accurate assessment of risk from a particular event in a local area can often be made. However, development of protocols for use on larger, regional ecosystems has not evolved as rapidly. Effective management of regions such as the Chesapeake Bay cannot be carried out in the current fragmented fashion. Integrated resource management, relevant research directives, and proper risk assessment are essential.

Risk, the probability of harm from an actual or predicted concentration of a chemical in the environment, has been determined in various ways. Prior to 1977, potential environmental damage was assessed by considering effects only (SETAC, 1987). Coupling effects assessment with exposure gave rise to hazard assessment, a process that has found its way into many federal regulations. Environmental risk assessment is still a developing field and has been defined in different ways. A National Research Council Committee (1983) defines environmental risk assessment as "the characterization of the potential adverse health effects of human exposure to environmental hazards." An Environmental Protection Agency (EPA) review of assessment methods (1988) defines ecological risk assessment as any "assessment related to actual or potential ecological effects resulting from human activities." Risk assessment should be a scientific endeavor, depending on scientific data and judgment that provide benefits to the scientist as well as the public, business, and regulatory sectors (SETAC, 1987). Risk management, however, is a process of determining how to deal with the risk; by definition, it includes scientific, political, and socioeconomic facets (Cairns, 1980). Even though human impacts from environmental alterations are obviously important, this discussion concentrates on only ecological risk assessment using the EPA definition; however, this point of view differs from the EPA definition because both human and non-human activities affect Bay integrity (Bonner, 1988) and are considered.

The objectives of ecological risk assessment are (1) to evaluate actual or potential risk from an environmental impact, (2) to determine the probability that the impact may, in fact, adversely affect the environment, and (3) to predict potential risk prior to the actual impact. These are feasible when the impact and its affected area are well defined, but become far more difficult to achieve when either the impact or the affected area become larger and more nebulous, as is the case of the Chesapeake Bay.

The concept of localized risk assessment has been well documented and refined in recent years. Using environmental impact assessments (EIA) to predict and assess environmental and human health risks has been mandated by federal, state, and local statutes for some time. Although these procedures are liable to bias, they have been useful for predicting localized impact from specific sources.

Conversely, the success of regional risk assessment has not been convincingly demonstrated. Few studies have addressed the concept and additional investigation is warranted (Levenson & Stearns, 1980; SETAC, 1987). A good approach to regional risk assessment to date is offered by Hunsaker et al. (1989). A regional risk assessment from ozone of the Adirondack region of New York and subsequent insect outbreaks that affected water quality as well as wildlife habitat are described. The authors concluded that ozone did have a regional effect, particularly on landscape pattern.

Assigning a probability to a risk, termed quantitative risk assessment (NRC, 1983), is difficult even in ideal situations because of the inherent variability of both the environment and the testing procedures used to evaluate the hazard. This is further complicated when the region affected is larger and diverse. Also difficult is delineating absolutely which adverse effect is produced by a particular impact. Of course, exceptions exist when the impact is well characterized, but potential synergistic reactions between various anthropogenic and "natural" pollutants, such as sediment and salinity, are not well understood.

The risk assessment process involves many judgements, including the dilemmas of determining which impacts are important to assess, defining what is to be protected, and, finally, deciding how to measure impact on those parameters chosen as important. The process of ascertaining which impacts are important may be of research interest only but, more likely, will be of regulatory concern. Impacts applicable to the Chesapeake Bay include sediment, nutrients, and toxic chemicals in water and sediments (Mackiernan, 1985; Wright & Phillips, 1988; EPA, 1987).

Defining what is to be protected is an important aspect of the strategy process; it is subjective and incorporates political and socioeconomic factors. If this is not defined, then the risk assessment process will be ambiguous. In fact, priorities change with time and administrations. Yet, without establishing what resources to protect, subsequent development of strategy, testing procedures, and model development may be worthless. While prioritizing resources is beyond the scope of scientific research, examples for consideration might include commercial and recreational fishing and boating, industrial water users, and other effluent dischargers.

Once areas of importance are defined, then end points for measuring the effect of stresses upon these important areas may be selected. Several groups of end points have been proposed, including assessment and measurement end points (Hunsaker et al., 1989) and chronic and acute end points (Dickson & Rodgers, 1986).

While characterizing and analyzing risk is a scientific pursuit, deciding whether that risk is acceptable to society is not. Such decisions are made by politicans and managers using cost-benefit analyses and integrated management with a highly subjective nonquantifiable component. While these individuals use scientific data, they also incorporate various political and socioeconomic components. Scientists, in the past, have often failed to realize this and often do not enter the decisionmaking process; however, this process is a vital component of the risk management process. If scientific data are not properly used by public officials, then the scientist must ensure that they are. This is especially true when regulators call for additional data and data reviews just to sway a particular regulatory decision. Even though many risk assessment methods exist, most assess potential for risk or perceived risk in a particular ecosystem.

Another factor for consideration in strategy development is the extremes of acute versus episodic releases of hazardous substances, sediment, or nutrients. Acute spills are infrequent, arouse negative public opinion, and may result in subsequent legislation, such as Bhopal and the Alaskan oil spill (Hann & Cairns, 1975). Chronic releases, often far more damaging, are less likely to attract public attention. Both of these extremes require creation and/or modification of risk assessment schemes and different management approaches for their resolution.

Estimates of uncertainty in risk assessment may be immense and confusing. Some reviews exist (EPA, 1988; Hunsaker et al., 1989), so only the topic of pertinence will be discussed here. Uncertainty is inherent in the risk assessment process. Application or safety factors are often used in assessment approaches to deal with this uncertainty; these are sometimes, but not always, based on scientific data. Some other techniques used to include uncertainty in the actual assessment and modeling are statistical confidence limits, Monte Carlo simulation, sensitivity analysis, and field validation (EPA, 1988).

Risk Assessment Strategy Development

Strategy development must consider which testing procedures or end points will be used to ascertain and predict environmental impact, as well as how much exposure individuals will receive from the impact. Obviously, the choice of end points and biological markers must be relevant to the environment being assessed but will be under the influence of regulators and other groups. Stress will have varied impacts on different ecosystems, but the majority of state-of-the-art biological tests for hazard assessment use single species as stress indicators. However, there are questions about the adequacy of approach (Cairns, 1983).

Potential structural end points for localized use in the Bay include species diversity and range, recruitment, biomass, mortality, trophic structure, and fecundity. Extreme care must be used when selecting species for examination since spatial distribution, stress susceptibility, and economic or ecological relevance must be considered. Biota, such as submerged aquatic vegetation, oysters, plankton, benthic communities, and gamefish, should be used in the Bay and adjoining wetlands. Fish have often been used because of their economic and recreational importance, even though they may serve only "minor" ecological roles. While examining the effects of chronic toxics exposure to fish, Suter et al. (1987) found the most sensitive effect was a reduction in fecundity and not effects on early life stages as is now being proposed by some regulators.

End points are not available to delineate selected parameter impacts when two or more stresses are present. In such cases, laboratory/microcosm tests must be used to isolate the stresses and individually ascertain their effect.

No pertinent regional assessment schemes for estuarine areas could be found for this review. While significant research needs to be completed to reduce uncertainty in estuarine risk assessment, schemes developed for other ecotypes may be applied to estuarine areas as long as unique factors are considered. While additional research is needed to complete the estuarine risk assessment process, development of methodology that will facilitate satisfactory risk assessment must continue.

However, present risk assessment methods applied to estuarine areas are often flawed for several reasons. Environmental decisions are often made in a fragmented, uncoordinated fashion, one case at a time, as is seen with effluent discharge permits. In addition, much effort has gone into establishing quality control conditions for discharges, but not quality control conditions for the ecosystem itself. Predictions of no-adverse-biological effects are being based on single species, short-term toxicity tests low in environmental realism in the more complex, highly variable natural systems or surrogates thereof. This failure to validate predictions is one of the major weaknesses of the present risk assessment system.

Ecological Risk Assessment for the Bay

Factors affecting the Bay that must be considered in the assessment process, regardless of what stress is being evaluated, include sediment influx and transfer, nutrient input, and toxicants. One of the main problems presently facing the Bay is a decrease in its primary production rate, already acknowledged to be among the highest of estuarine systems (Wright & Phillips, 1988). The presence of these stresses and their subsequent effects upon submerged aquatic vegetation and other components of the food chain have resulted in combined resultant losses in habitat for both the Bay, its tributaries, and adjoining wetlands.

Present procedures for regulating inputs into the Bay and assessing risk are primarily administered by the States of Maryland and Virginia under mandates from federal and state law and with the assistance of the Chesapeake Bay Program of the EPA. However, these management procedures have been criticized, especially those concerning future growth and development.

Parameters that are important to monitor on a regional scale must be decided before proposing a regional risk assessment; these decisions are both subjective and political. Promising examples on a regional scale for the Bay include assessing primary production via satellite, using computerized geographical data bases to predict effects of adjacent terrestrial areas, and monitoring submerged aquatic vegetation. Other methods, such as infrared monitoring and using DNA, antibodies, and other biomarkers, may also eventually be applicable to the Bay as will the use of computer-based risk assessment models.

Present and future research must address the need for improved analytical methods for toxicant and nutrient detection, increased use of biological markers (EPA, 1988a), and questionable continued use of single species, rather than multispecies, toxicity tests in predicting environmental harm (Cairns, 1982, 1988d; Kimball & Levin, 1985). Integrated approaches using all of these techniques must be developed. If we are to ever develop the "ideal" risk assessment strategy, relevant risk end points must be defined, data gaps identified, and relevant research to address those gaps conducted. Central issues in risk assessment remain: whether risk is significant, who is responsible for proving that significance, how to eliminate tension between component groups in the risk assessment process, and how much risk is acceptable. Hopefully, this discussion will increase the awareness of the reader to the methods and limitations of risk assessment. Only through cooperation will these questions be answered.