OIL SPILL RISK ASSESSMENT FOR ASSATEAGUE ISLAND

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Oil Spill

Risk Assessment

for

Assateague Island

Developed under
Dr. Terry Bashore
Barrier Island Management
December, 1991

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Abstract

The natural communities and human use areas of Assateague are reviewed to determine sensitivity to a potential oil spill. Literature was searched and investigators and park and refuge personnel were interviewed to determine distribution of species, natural resources of special concern, and sensitivity of those species and resources to oil. Maps were drawn delineating the communities of Assateague, areas of special concern, and likely sources of oil spills. This information was then brought together in a rating system which rates each community by 1) physiological susceptibility to oil, 2) recovery rate of the community subsequent to an oil spill, 3) seasonal susceptibility of the community for winter, spring, summer, and fall, 4) resource significance or economic importance of the community's resources, and 5) rarity or the number of endangered or threatened species in the community. Each community was given a rating for each ranking factor, and the ratings were then added by season. The resulting sum was combined with the maps to determine the community, the location, and the season of greatest sensitivity to a potential oil spill. The shore community was determined to be the most sensitive due to its extensive use by visitors, its use by threatened or endangered species, and the probability of oil accumulation in the event of a large spill at sea. The northern end of the island is the most sensitive portion of the shore due to its heavy use by endangered species, its proximity to Ocean City with its accumulation of marinas, and the low profile which

would permit overwash should oil be spilled by a vessel during a storm. In descending order of sensitivity, the remaining communities are the tidal flats, the bay, the ocean, the dune/swale complex, the marsh, and the forest. The marsh is low on the list despite its high productivity and economic importance, due to the fact that spills in that community are likely to be very small spills by recreational vessels. The least sensitive area of Assateague is that portion of the forest which is above the 100-year floodplain. The probability that a spill could reach this area is minimal. Maps are included delineating the communities and the resources of special concern on Assateague.

Background

The Stockholm Declaration defined marine pollution as "the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use as seawater and reduction of amenities" (M'Gonigle et al. 1979).

The deliberate or accidental discharge of petroleum and petroleum products into the ocean falls well within the terms of reference of this definition. The seepage of petroleum through parts of the ocean floor, however, is a natural geological phenomenon that has occurred continuously for perhaps several hundred thousand years: this type of discharge does not conform to the above definition and cannot be construed as pollution.

True toxic effects attributable to petroleum compounds that become incorporated into the tissues, may have contributed to the perceived declines in population size (Holmes and Cronshaw, 1977). Such effects may be of two distinct types. The extent of the effects of some compounds may be sufficient to cause death directly, while other compounds may have sublethal effects that may only threaten long term survival or reproduction. The sublethal effects are of course the most difficult to identify and until recently they have received scant attention from investigators. Nevertheless, they may represent an important aspect of the impact of oil.

Introduction

Assateague Island is a barrier island located off the coast of the Delmarva Peninsula. It stretches 37 miles from the Ocean City Inlet in Maryland south to the Chincoteague Inlet in Virginia.

In 1965 Public Law 89-195 established Assateague Island National Seashore for the purpose of "protecting and developing Assateague Island". Since that time, the Park Service has been tasked with protecting and developing natural resources as diverse as piping plover habitat and off-road vehicle areas.

Because of its proximity to the cities of Boston, Washington, Baltimore, Philadelphia, and New York, Assateague's undeveloped beaches are subjected to a recreational pressure disproportionate to its size. Any man-made disaster is likely to receive an equally disproportionate investigation by special interest groups from the power centers of Washington. Park Service response will be examined minutely and debated earnestly by all sides. Advance planning will significantly ease this review process for the Park Service.

Assateague Island is a geologically and biologically dynamic environment. Erosion rates average 7.5 feet/year, with the exception of Fishing Point, which is accreting approximately 33 feet/year (Dolan et al., 1977). Wildlife populations fluctuate markedly from season to season and year to year (Ailes, 1991). Storms sweep up the coast, bringing hurricanes in the fall and northeasters in the winter. An oil spill in this dynamic system could have severe impact; or could be relatively mild. The location and season of the spill will be critical factors.

There are two general categories of oil spill. "Operational discharges" are the routine and intentional discharges resulting from bilge water pumping, tank cleaning, and ballasting. "Accidental discharges" result from equipment malfunction, groundings, collisions, fire, and other casualties (Ehler et al., 1983).

Of the two, operational discharges are likely to be the most important source of oil in the Atlantic. Patterns of distribution of this oil depend on shipping patterns, legal constraints to normal shipboard operations, winds and tides. Approximate predictions of oil distribution require a computer model to develop and are beyond the scope of the present study. Even an accurate model would be unable to predict the changing patterns of oil deposits due to changes in shipping patterns with any future region-wide response to changing energy needs (Ehler et al., 1983).

While operational discharges result in a constant flow of small amounts of oil onto the shores of Assateague, an accidental discharge could result in a large quantity of oil washed ashore in a short period of time. While it is difficult to contrast the impact of the two sources without specifying the hypothetical quantities involved, past experience has indicated that the one-time large spill receives more media attention and hence becomes more of a management problem. For instance, the Santa Barbara oil spill of March, 1969 resulted in tremendous media interest and a sudden spurt of money for research. The fact that the same area has leaked oil into the sea for many years and continues to do so to this day is little known and receives far less research interest or funding (Stevens, 1991).

In either event, oil would be driven toward Assateague Island by winds and tides. Weathering begins to disintegrate the oil almost immediately. As the winds, currents, and solar and chemical forces work on the slick, it begins to spread into very thin layers. Eventually the film fragments and different portions of the oil disperse into the air, the water column, and into chemically altered materials. The speed of disintegration depends on weather and the distribution of hydrocarbons in the oil. Thus the amount of oil reaching Assateague beaches would depend on the chemical composition of the spill, the weather at the time, and the distance from Assateague that the spill occurred (Grose et al., 1982).

Oil is most likely to come from the sea. On the bay side, there are marinas which are probably a small, but steady, source of pollution. Exchange of bay water is about 7% (National Park Service, 1982). It is therefore unlikely that oil spilled in the bay would have a major impact on the Atlantic, or that ocean spills would affect the bay. Due to the small turnover of the bay water, spills occurring in that area would remain near the site of the spill unless blown around the bay.

Risk Assessment

"Risk assessment is the process of determining the adverse consequences that may result from the use of a technology or some other action. It typically includes three principal elements: (1) an estimate of the probability of a hazard occurring; (2) a determination of the types of a hazard posed; and (3) an estimate of the number of people, wildlife , or other environmental elements likely to be exposed to the hazard and the number likely to suffer adverse consequences." (The Conservation Foundation 1985).

The word 'risk' can be used as a general term. When in this context, it means "that we might have a problem if we do so and so" (Ellis, 1989). In this instance, the action would be a spill of oil products into the environment, whether in large quantites from a tanker sinking or grounding, or in small quantities from a recreational vessel spilling or dumping gasoline.

Assessment is a term that implies measurement. By testing the effects of our engineering endeavors on our environment, we can obtain measurements useful in assessing those effects (Ellis, 1989). There are three components of a risk assessment, each different but interrelated within the scope of risk assessments. The probability that an accident could occur is always present. Assessing that probability is first. Next, an assessment is made that predicts the effects of a possible accident on the resources that may be exposed. Lastly, an estimate is made of the amount of danger the resources are subjected to (The Conservation Foundation, 1985).

Although there is considerable information on the response to a spill event, little advance planning has historically been done. The assessment of natural resources which might be affected in the event of a possible, future oil spill remains a new science.

This assessment gives an estimate of when oil spill events might occur, based on different conditions of winds, tides, and storm events. Resources that are at risk are indexed according to specific parameters, and given numerical ratings. With information on geomorphology of the area, habits of oil, tides, wind patterns, and seasonal storm data, the amount and duration of probable exposure can be estimated.

Nature of Petroleum

The color and consistency of petroleum is highly variable. Samples taken from different parts of the world may range from pale yellow water-like liquids to black semisolid materials that can be literally cut with a knife (Hunt and O'Neal, 1967). Regardless of their wide-ranging physical appearances, the most abundant chemical components in all types of petroleum are hydrocarbons. Although no single crude oil has been completely defined chemically, all are known to be composed of an exceedingly complex mixture of different compounds, more that 98% of which are usually hydrocarbons (Hunt and O'Neal, 1967). These may range in molecular size from the simplest single carbon compound, methane, with a molecular weight of 16, to compounds containing more than 40 carbon atoms, some having molecular weights that are well above 20,000. The chemical configuration of these hydrocarbons are quite diverse, but in general they can be classified into the following groups of compounds. Saturated compounds which include straight chain alkanes, branched alkanes, and cycloalkanes, and also unsaturated compounds which include aromatics, olfins. Associated non-hydrocarbon compounds are sulphur and a variety of nitrogen-containing cyclic molecules and trace elements.

The specific physical properties and the general chemical characteristics upon which these classifications are based not only determine the commercial value of a particular crude oil or petroleum residue, but also its potential impact as an environmental pollutant.

Currents

Currents would be a major distributer of oil spilled in the ocean, and a minor distributer of oil spilled in the bay. Currents in the bay are independent of nontidal currents in the ocean (National Park Service, 1982). Bay currents thus depend on the daily and monthly tidal fluctuations and can be expected to vary almost hourly. These currents, however, are not strong.

Over the course of a year, net flow of water is to the south. During the winter, especially during storms, northeast waves prevail, with a resultant southward current (Dolan et al., 1977). Ships transporting oil or other cargo into the Delaware Bay or north to the New York area would be the most likely source of pollution.

Ocean currents are usually onshore during the summer, with a net northerly drift (Dolan et al., 1977). Thus spills occurring south of the island would be of greatest concern. Shipping to and from the Norfolk area and into the Chesapeake Bay would be the most likely source.

February sees more storms than any other month, an average of 3.0. Waves at that time come from the east 35% of the time, from the southeast 35% of the time, and from the northeast 25% of the time. Thus a spill occurring during a February storm would be likely to move west and northwest onto the beach. July, by contrast, averages 0.25 storms per month. Waves in that month are from the southeast 60% of the time. Oil spilled at sea would be likely to wash onto the beach northwest of the spill site (Dolan et al., 1977). If the spill were associated with the heavy marine traffic into the Delaware Bay or the New York area, it might miss Assateague entirely.

Sources of Contamination

Especially high levels of contamination are found in coastal areas where there are offshore drilling sites, pipelines, tanker ports, refineries, petrochemical plants, sewage outfalls and river estuaries carrying industrial and automotive wastes from inland sources.

In addition to the day-to-day operational discharges, occasional episodes of localized and sometimes severe levels of contamination occur as a result of coastal shipping accidents and blowouts from offshore oil wells (Hodgeson, 1984).

A less-well understood source of major contamination in the marine environment occurs offshore and in mid-ocean, through the regular discharge of dirty ballast water and bilge from oil tanker and dry cargo ships. Since more than 60% of the petroleum produced worldwide is transported by sea either in the form of crude oil or as one of several distillation products, it is perhaps not surprising to find that these shipping operations are estimated to account for more that one-fifth of the total petroleum discharged into the oceans worldwide (Hodgeson, 1984).

Unlike most other types of shipping, vessels engaged in petroleum transport always must make their return journeys empty of cargo. To ensure the stability of these vessels during the return journey, some of the cargo tanks are partially filled with seawater. The sides, frames, and braces of these cargo tanks, still carry a film of oil. During the course of the voyage it becomes mixed with the ballast water. Since dumping such large quantities of contaminated ballast into the harbor water of the destination port is prohibited, the water in these tanks must be replaced at some stage on the return journey. Up until the early 1960's, much of this dirty ballast was simply discharged on the high seas and the cargo tanks were refilled with clean seawater. Following the adoption of the Clan Seas Code in 1962 the majority of the tanker operators started to use the "load on top" (LOT) system in a sincere attempt to avoid the excessive dumping of petroleum on the high seas (Revelle et al, 1971). Although use of the LOT system has greatly reduced the amount of oil discharged into the sea, there still remains some serious limitations to its effectiveness.

The day-to-day operation of general cargo ships is also a major source of ship-generated oil pollution. General cargo vessels lose considerable weight as their fuel stores are depleted and of course this tends to render the vessel less stable. Also, general cargo ships must often make part of their voyage with only a partial load. Under both of these circumstances, the stability of the vessels is restored by filling the empty bunker tanks with seawater. Since these vessels require the stabilizing weight until they arrive in relatively calm water, deballasting frequently occurs in coastal areas. Although these deballasting procedures are still a serious source of coastal pollution, drill cargo vessels that have been built in recent years do not need to use empty fuel tanks to store ballast water. This source of petroleum discharge should progressively diminish as the older vessels are taken out of service.

Total worldwide contamination, attributable to the combined contributions from coastal industry and shipping operations, however, may well be substantially less than the amount entering the marine environment indirectly as atmospheric fallout. Although this source of petroleum pollution is poorly understood, it is estimated that about 90 million metric tons of petroleum hydrocarbons enter the atmosphere each year. This indirect discharge of petroleum into the environment represents about forty-times the combined annual discharge from coastal installations, shipping, and rivers. Some of these atmospheric contaminants must be eventually precipitated in rainwater and in association with particulate material (Hodgeson, 1984).

Extent and Distribution of Contamination

The marine environment is undoubtedly the ultimate repository for most of the world's petroleum-based industrial contaminants. Although much has been written on the subject, there is surprisingly little information upon which the magnitude of the problem can be reliably assessed.

There has been one rather ingenious attempt to estimate petroleum discharge directly from the amounts of tar residue found on the surface of the ocean (Morris, 1971). The rationale for this method assumes that tar balls do not remain on the surface indefinitely and that the total amount of floating tar is relatively constant during a given year. If this is true, then the rate of petroleum discharge necessary to yield a sufficient influx of tar into the environment can be calculated from a exponential decay model. However, accurate estimates of two of the values needed to complete this calculation are not readily available, namely the half-life of the tar residues in the ocean and the residual tar content of the petroleum responsible for the contamination in the first place.

Although even the conservatively low estimates of direct discharge into the marine environment represent enormous quantities of petroleum, the amount may be small when compared to the quantity entering the marine environment indirectly form the atmosphere. This source of influx occurs primarily in the form of precipitated petroleum hydrocarbons that have been discharged into the atmosphere through evaporation and incomplete combustion. The total worldwide emission of petroleum hydrocarbons into the atmosphere was estimated to be about 90 million tons in 1970 (US Department of Health, Education, and Welfare, 1970, and Goldberg and Gross, 1971). There is little known regarding the fate of most of this material. Much of it may be oxidized to harmless substances and most of the balance may never reach the ocean, but if only 10% ultimately enters the marine environment it would represent much more than the total amount of direct discharge by shipping and coastal industries.

As with the estimates of total discharge, there is little quantitative information on the specific concentrations of petroleum occurring in the water column of different areas of the oceans. This is due in part to the complex nature of petroleum and to the technical difficulties encountered in distinguishing between low concentrations of petroleum and biogenic hydrocarbons in seawater and marine sediments (Ocean Affairs Board, 1975). Quantitative estimates have been restricted to measurements of total petroleum derived hydrocarbon concentrations in coastal, offshore, and deep sea sediments, estimates of the relative abundances of these compounds in the water column along major shipping routes, and very approximate determinations of tar densities on the ocean surface. A range of petroleum hydrocarbon concentrations has been found in sediment collected from different parts of the ocean floor (Monaghan et al., 1974). Very high concentrations (100 to 1,200 ppm) have been recorded in heavily polluted coastal areas, whereas in deeper water further offshore, the concentration is usually less than 100 ppm. In deep sea sediments outside the continental shelf, present on the ocean surface in different regions also reveal wide variation in the level of contamination around the world. The amounts collected range from a high value of 20 mg per m^2 recorded in the Mediterranean (Morris, 1971), to a low value of 0.0003 mg per m^2 in the South Pacific (Wong et al. 1976), while an intermediate density of 0.98 mg per m^2 has been reported for the Norwegian coastal current (Smith, 1976). Measurements of the relative abundance of petroleum derived hydrocarbons in the water column, are perhaps the most reliable index levels of contaminations occurring in the oceans. These concentrations have not been estimated in all areas, but those which are available show quite clearly that most of the contaminants occur along the major tanker shipping routes (Smith, 1976). In this regard it is of interest that since the advent of the supertanker, and the need for these ships to travel around the Cape of Good Hope, the abundance of petroleum derived hydrocarbons in the water column in the South Indian and Atlantic oceans appear to have increased significantly. Indeed it is possible to identify all of the areas where the most serious oceanic pollution is likely to occur by identifying the major international trade routes along which the world's petroleum and petroleum products are transported.

Identification of these different abundances of floating tar and petroleum derived hydrocarbons does not reveal the dynamic nature of oceanic pollution generated by industrial spillage. Immediately following its discharge into the ocean, both the physical and chemical properties of the petroleum start to change (Fay, 1971). As a result, the petroleum becomes very complex in distribution in the environment. The rate at which some of these distributional changes occur depends upon the physical properties of the crude oil, which in turn reflect its chemical composition. The boiling point, the specific gravity, and the viscosity of a particular crude oil will obviously determine the rate at which spreading, dissolution, emulsification and sedimentation are likely to occur during the period following discharge onto the ocean surface. Furthermore, as some of the chemical constituents of the petroleum leave the main mass, their relative abundance in the residual petroleum will diminish and the rates of change in distribution will be modified accordingly. Also, climatic factors will contribute to the rate at which these distribution changes occur (Hodgeson, 1984). The "pour point" of the oil, which is dependent upon the abundance of higher paraffins, will be an important factor in this regard. Other factors that will also contribute to the ultimate distribution of the petroleum, such as photo-oxidation and biodegradation, will depend to some extent on the climatic condition prevailing in the vicinity of the spillage.

Effects of Physical Contamination

Macrobenthos colonization was found to be significantly reduced by the presence of petroleum in lime drilling mud. Both the number of animals and the number of species found were reduced (Tagatz et al. 1985). The Scottish Department of Agriculture and Fisheries found drilling discharges to have suppressive effects on benthic fauna. These results were attributed to the presence of diesel oil (Leaver et al. 1987).

Fuel residues and crude oil from a North Sea oil rig (Beatric field) caused impairment of liver function and physical growth, and ultimately death of young kittiwakes, *Rissa tridactyla* (Koeth and Vaukhentzelt, 1988). Liquified coal at 0.5g/kg/day had no detectable effect on reproductive capacity or performance, and did not induce substantial systemic toxicity in Sraque-Dawley rats (Mckee et al. 1987).

Chan and Chiu (1985) reported that lower biomass is expected when petroleum exposed flora and/or fauna are compared to non-exposed controls. They nonetheless found that a low concentration of light diesel oil stimulated the growth rate, biomass yield, chlorophyll A level, and photosynthesis of the estuarine green algae (*Chlorella salina*) Cu-1, while slightly inhibiting algal respiration.

Diesel exhaust exposure has been shown to cause elevation in the rate of formation for some forms of cancers in humans (Hall and Wydner, 1984) following chronic exposure.

Fish normally harbor a variety of parasites, most of which under natural conditions cause little or no apparent harm. However, following the Alaska Exxon Valdez oil spill in Alaska, the prevalence and intensity of parasitism increased substantially (Khan, 1990). Exposure of *Puntius sophore* to different concentrations of crude oil revealed that 4,000 ppm was acutely lethal to the fish, with the minimal lethal effects occurring at > 500 ppm for a 15 day exposure (Prasad and Lumari, 1987). However, Pacific herring (*Clupea harengus pallasi*) larvae showed high mortality in a 0.09 ppm when exposed to the water soluble fraction of crude oil following 28 day exposure.

Biological Effects of Contamination

<u>Exposure Assessment</u>

Exposure assessment involves estimating the concentration of toxicants to which the organisms will be exposed and the time of exposure (NRC, 1989). This assessment is the first step in the process required to estimate potential damage to marine organisms. Once the exposure to toxic materials is known, it can be combined with laboratory measures of toxicity to obtain a hazard assessment. Exposure assessment must take into account the several factors affecting oil concentration. Untreated oil produces a certain level of exposure to surface or near surface organisms. Treatment with chemical dispersants modifies this exposure, moving the oil from the surface slick into the water column as droplets with a significant lifetime. Chemically dispersed oil thus reaches a greater volume in which organisms can be affected, but at the same time it is being diluted so that those effects will be mitigated. Measured concentrations of oil in water reported at test oil spills have frequently been regarded as representative (McAuliffe, et al. 1980; Nichols and Parker, 1985). When dispersants are used in confined areas with poor circulation, concentrations of dispersed oil in the water column will be higher than those found under open-water, experimental spills.

Since the Torrey Canyon spill in 1967, many studies of the effects of dispersed oils on marine organisms under laboratory conditions have measured toxicities and relative toxicities of various oils, oil with dispersants, and dispersants themselves (NRC, 1989). To evaluate hazards to marine organisms caused by dispersant use, the most important toxicity information needed is the comparison of chemically dispersed oil with undispersed or physically dispersed oil, under conditions approximating those in the field. The most appropriate laboratory measurement is the toxicity of the water-soluble fraction of oil or dispersed oil (NRC, 1989).

About two-thirds of the literature published prior to 1987 does not give values of oil concentration in the water phase, but instead uses the total oil per unit volume, or nominal concentration (NRC, 1989). Approximately one-third of the many tests measured the dissolved hydrocarbons that cause immediate biological toxicity (NRC, 1989). In systems where oil or dispersant forms a separate (floating layer) phase, basing toxicity on nominal concentration leads to unrealistically high LC50 values.

Swedmark et al. (1973) and Doe et al. (1978) proposed that the primary difference between untreated oil and dispersed oil under laboratory conditions was "that effective dispersants simply make more oil or its many components available to aquatic organisms" rather than causing greater-than-additive effects.

Bobra et al. (1979) recognized the importance of separating the contributions of dissolved hydrocarbons, dispersed oil particles, and dispersants in the laboratory to identify which effect dominates toxicity based on the fate of material under different aquatic conditions. This information was then incorporated into a hazard assessment of dispersed oil.

Phytoplankton

Four out of the seven studies (Chan and Chiu 1985; Hsaio et al., 1978; Lacaze and Villedon de Naide, 1976); Villedon de Naide, 1979) report that dispersed oil is more toxic than undispersed oil to phytoplankton.

One investigation (Trudel, 1984) analyzed oil concentrations in water by infrared spectroscopy, and measured response by carbon fixation. His dose-response relationship was the same in oil and 1:1 oil-dispersed oil with the dispersant present.

Another study (Fabregas et al., 1984) measured the water soluble fraction of weathered crude from the wreck of the tanker Urquiola, and concluded that the toxicity of the dispersed oil was the same as that of the dispersant (Seaklin 101-NT).

There were other observations as well. An increase in light intensity increased the toxicity of dispersed Kuwait crude oil to phytoplankton. In the presence of Corexit 8666, toxicity increased by a factor of 5 in darkness and increased by a factor of 9 in light (Lacaze and Villedon de Naid, 1976). The weathered oil mixture, when illuminated and mixed with dispersant (1:1), was the most toxic. In another study, growth of the marine diatom *Skeletonema costatum*, under the influence of dispersed oil, was the same as for oil alone, but greater than that for dispersant alone (Tokuda, 1979). Both studies demonstrated similar toxicities of oil and chemically dispersed oil to phytoplankton.

Macroscopic Algae and Vascular Plants

As with phytoplankton, three of the five papers reviewed on macroscopic plants employ nominal concentrations and conclude, without convincing evidence, that dispersant-oil mixtures are more toxic than oil alone (Ganning and Billing, 1974; Hsiao et al., 1978; Thelin, 1981). The other two studies employed gas chromatographic analysis of the water-soluble fraction.

Zooplankton

Protozoa

Little work has been conducted with protozoa and dispersed oils. Goldacre (1968) was the first to describe the narcotic effects of hydrocarbons and some non-ionic dispersants on the cell membrane of amoebae, but no oil-dispersant mixtures were evaluated (NRC, 1989).

Rogerson and Berger (1981) determined the toxicity of oil-dispersant mixtures to ciliates, *Tetrahymena pyriformis* and *Colpidium campylum*, on the basis of growth rate.

They concluded that Corexit 9527 concentrations above 1 ppm were acutely toxic. The protozoa grew better in dispersed oil tests than in oil alone. This was attributed to the more rapid volatilization of the more toxic, aromatic fraction of the oil from the dispersed oil mixtures. After oil had weathered, the dispersant was apparently the primary toxicant.

Polychaetes

Polychaetes are known to be tolerant of oil and are often the first species to colonize the benthic community after an oil spill (NRC 1985). The acute toxicity (1-day LC50s) of Corexit 7664 to Spionid larvae was 889 ppm for the dispersant and 222 ppm for an Iraq crude oil-dispersant mixture (Latiff, 1969). Likewise, 48-hr LC50s for Corexit 7664 with the polychaete *Opphryotrocha* were extremely high: 35,000 ppm for males, 30,000 ppm for females, and 12,000 ppm for larvae (Akesson, 1975). With oil in a ratio 1:2, the toxicities became 580 and 420 ppm, respectively. Even though the data from these experiments were analyzed using nominal concentrations, Akesson concluded correctly that the oil-dispersant mixture was more toxic than the dispersant alone.

Echinoderms

A number of studies have been conducted exposing sea urchin eggs, embryos, and larvae to oil-dispersant mixtures (Falk-Petersen, 1979; Falk-Petersen and Lonning, 1984; Lonning and Hagstrom, 1975, 1976). Experiments were conducted with Kuwait and Ekofisk crudes, a range of dispersants, especially Corexit 9527, and a number of sensitive sublethal embryological responses.

Fish

Iran crude oil (1,000 ppm nominal concentration) and Corexit 7664 (100 ppm) produced narcosis or lethality in 1-day-old herring larvae (Kuhnhold, 1972). After 2 days in static laboratory conditions, the physically dispersed oil had lost its toxicity, but the chemically dispersed oil had retained or increased its toxicity.

Another early study considered the effects of Russian crude oil and dispersants on the eggs and larvae of northern pike, *Esox lucius* (Hakkila and Niemi, 1973). The study's main finding was a description of the comparative sensitivities of the life stages to oil dispersions. More than 60 ppm oil plus dispersant caused some egg mortality and 300 ppm caused complete mortality; this is high compared to other results. Larval tests gave 2-day LC50s of 66 ppm (stage II) and 4.4 ppm (stage III). The aytoxicity of the oil-dispersant mixture was greater than the oil, but the same as the dispersant alone; and was attributed to the dispersant since it was a nonionic surfactant in an aromatic solvent.

Linden (1975, 1976) studied the effects of Venezuelan crude plus dispersant (BP1100X, Finasol SC, and Finasol OSR-2) on the ontogenetic development (i.e., embryonic movement and heart rates, morphology, and length of larvae) of the Baltic herring, *Cluppea harengus*. Both arcuate and sublethal effects of the oil increased 2 to 3 orders of magnitude if the oils were dispersed by the least toxic dispersant (BP1100X), and 3 to 4 orders of magnitude with a highly toxic dispersant formulation, such as finasol SC.

Two studies of oil-dispersant mixtures were conducted by Mori et al. (1983, 1984). They found that the tolerance of common sea bass eggs is greater than those of parrotfish and flounder (Mori et al., 1983), and that oil-dispersant mixtures were more toxic than oil alone for the young of sea bream and Japanese flounder and the larvae of stone flounder (Mori et al., 1984). The results of these experiments are questionable because that water-soluble fraction of the oil was not measured, and toxicities were based on nominal concentrations.

Borseth et al. (1986) conducted a comparison of in vivo and in situ exposure of plaic (*Pleuronectes platessa*) eggs to the water-soluble fraction of Statfjord A + B crude oil topped at 150°C and mixture with Finasol OSR-5. To cause significant mortalities (98 percent) required the full strength WSF of the oil-dispersant mixture. In contrast, 10 percent mortality occurred with the maximum WSF concentration for the topped crude. AT 1:1 dilutions, of both WSFs, mortalities were equivalent.

Salmon have been studied because of their highly developed chemical sense, which might be disturbed by low concentration of petroleum hydrocarbons (NRC, 1989). The effects of untreated and chemically dispersed Prudhoe Bay crude oil on the homing of salmon were measured in two experiments (Brannon et al., 1986; Nakatani et al., 1983, 1985; Nevissi et al., 1987). In the first study, 24 adult chinook salmon (*Oncorhynchus tshawytscha*) were caught in a freshwater pond, anesthetized, tagged, and divided among four tanks (Nakatani et al., 1983):

. An untreated control group;

. A tank with untreated Prudhoe Bay crude oil as a 0.5 mm thick slick

. A tank containing 105 ppm of chemically diapered crude oil (10:1 oil to dispersant); and

. A tank containing 10.5 ppm of freshwater chemical dispersant.

After one hour exposure the salmon were removed from the exposure tanks, held overnight in a raceway, trucked 9 km downstream, and released. Of the 215 fish released, 154 (72 percent) returned to the pond where they were caught. There was no significant difference in the percentage of return among the four groups, nor in the time it took the fish to return.

Tests with coho salmon (*O. kisutch*) produced similar results. The methods used were the same, except that seawater was used instead of freshwater in holding and exposure tanks, and the tanks were outdoors, not indoors. Again, there was no statistically significant difference in the percentage of returns of time to return.

However, oil avoidance was observed in these studies. Before the untreated oil was added to the exposure tank, the salmon swam throughout the tank. After oil was added, the fish swam to the bottom of the tank and remained there during the one hour exposure.

Chemical senses are considered essential to homing in salmon, but these studies concluded that the olfactory systems were not impaired enough from a one hour exposure to interfere with homing. Histopathological analysis of the olfactory organs of the salmon showed no anomalies. Thus, while adult salmon might avoid oil (Weber et al., 1981), forced brief exposure to whole Prudhoe Bay crude oil or chemically dispersed oil at high concentrations did not prevent or delay homing.

Mollusca

Pelecypod and gastropod mollusks, with many species in the littoral and shallow sublittoral zones, are particularly susceptible to oiling (NRC, 1985). With bivalves, studies with measured concentrations showed equivalent toxicities or lowered toxicities between the dispersed oil and the oil (or its WSF) alone. Studies with nominal concentrations showed grated exposures were unknown for all compared treatments. Physiological, behavioral, and recovery experiments predominated with the bivalve research and illustrate differential sensitivities and often the capacity to recover from exposures (NRC, 1989).

For gastropods, all studies used nominal concentrations, thus invalidating conclusions abut the comparative effects of dispersed oils to oil alone, but showed that respiratory and behavioral responses were quite sensitive to oil or dispersant exposures.

The only reported study on molluskan plankton deals with the gametes, embryos, and larvae of two oysters (*Crassostrea angulata* and *Crassostrea gigas*) and the mussel *Mytilus galloprovincialis* (Renzoni, 1973). Only very high nominal concentrations of hydrocarbons in water, with and without dispersants, were toxic, producing responses with the eggs and embryos. Oil-dispersant mixtures (1 to 1,000 ppm) were toxic to fertilization. The toxicity of oil and oil-dispersant mixtures at high concentrations were similar, although the analytical method using nominal concentration is incorrect.

Crustaceans

More work with diapered oil has been conducted on crustaceans than any other type of organism, due to their ecological and commercial importance and the relative ease with which many species can be studied (NRC, 1989). The sensitivity of many crustaceans, particularly in young and molting stages to dissolved and physically dispersed hydrocarbons as well as to dispersant formulations has been well documented (NRC, 1985; Sprague et al. 1982).

Copepoda

Lipid metabolism, swimming behavior, respiration, and survival of the copepoda *Acartia* sp. and *Cyclops* sp. were used as indicators of toxicity in the early work of Gyllenberg and Lundquist (1976). A number of potential sublethal effects were identified with the dispersal of oil by Finasol OSR-2 and Finasol SC, but comparisons were not reliable because only nominal concentration were used.

Percy (1977) reported on the effects of sublethal exposure to dispersed oils on the respiratory metabolism of an arctic marine amphipol, *Onisimus (Boekisimus) affinis*. The relative magnitude of the change in respiration rate was less in oil-dispersant mixtures than in oil alone, but in both cases, reversal of respiratory depression was influenced by oil type. Low concentrations (13 to 21 ppm initial measured concentration) significantly depressed respiration rates, whereas increased hydrocarbon concentrations (268 to 800 ppm initial measured concentration) reversed depression, and respiration rates reached and even exceeded the controls (Wells and Percy, 1985).

<u>Birds</u>

The few studies of direct toxicity of oil and dispersants to seabirds show that dispersant and crude oil reduce hatching success and lower resistance to infection to about the same extent as oil alone (NRC, 1989). Studies have been primarily on avian reproduction and physiology. The effects of oil alone on embryos and early development are well known, and the effects of oil-dispersant mixtures have been studied at various stages of the reproductive cycle.

Work with other species, such as mallard ducks and herring gulls also show a wide range of sensitivities, particularly with duck eggs. Akesson (1979) tested Prudhoe Bay crude oil, Corexit 9527, and mixtures (5:1 and 30:1) on the hatchability of mallard eggs (*Anas platyrhynchos*) over 6 to 23 days. All produced diminished hatchability at the 20 μl dose level per egg (external surface). The oil, dispersant, and 5:1 mixture had similar effects, but the 30:1 mixture was significantly less toxic. At reduced dosage, only the Corexit mixture caused significant effect.

A field study with Leach's storm petrels (Butler et al., 1988) showed no effects of internal dosing with Prudhoe Bay crude oil or mixtures with corexit 9527 (10:1), but the highest dose of externally applied dispersant-oil mixture (1.5 ml per bird) significantly increased the percentage of brooding birds deserting the nesting burrow. No significant effects were seen with oil alone. Hatching success was decreased to the same extent with both oil and dispersant-oil treatment.

Other studies have examined the toxicity of dispersed oils to seabirds; these include Butler et al. (1979, 1982, 1988), Albers (1980), Lambert and Peakall (1981), Miller et al. (1981, 1982), Peakall and Miller (1981), Butler and Peakall (1982), Trudel (1984), and Ekker and Jenssen (1986). Collectively these studies, including those by Peakall et al. (1982), show the range of responses of birds to oil and dispersed oils, the similarity in response to oil and dispersed oils, and the obvious need to reduce surface oiling for bird protection.

Marine Mammals

Effects of oil spills on marine mammals include physical fouling, thermal and compensatory imbalance due to oil coatings, uptake, storage and depuration of hydrocarbons, changes in enzymatic activity in the skin, interferences with swimming, occasional mortalities, eye irritation and lesions, and oiling of young (Engelhartdt, 1985).

Reviews by Geraci and St. Aubin (1980), Smiley (1982), Engelhardt (1983, 1985), and NRC (1985) describe the effects of oiling on the fur of sensitive marine mammals (sea otters), based on laboratory and mesocosm toxicology experiments and observation of oiled animals in the field. More than a twofold increase in thermal conductance (over baseline), and therefore a 50 percent reduction in insulating capacity, has been reported for polar bears (Hurst and Oritsland, 1982), sea otter pups and fur seals (Kooyman et al., 1977).

Dispersants have been used experimentally like "shampoos" to remove crude oil from marine mammal fur, but such attempts removed natural skin oils along with the crude oil, thus destroying the fur's water-repellency (Williams, 1978). Surface-active agents, such as those used in dispersants, can increase the wettability of fur or feathers, which in turn allows cold water to penetrate and increase the thermal conductance of the pelt. This is particularly dangerous to animals that are buoyed or insulated by their fur or features. In the cold water leaks through the fur and against the skin, causing fatal chilling. If the animal grooms excessively, it can scratch away large amounts of underfur, further complicating the restoration of body insulation (McEwan et al., 1974).

Community Effects of Oil

Marine and Estuarine communities

Studies of temperate subtidal habitats, like the mesocosm studies of microbes and plankton, indicate that oil concentration and length of exposure to oil constituents appear to be the controlling factors, not whether the oil is dispersed.

Wells and Keizer (1975) tested the effect of oil and oil plus Oilsperse 43 on sea urchin (*Stronghlocentrotus droebachiensis*) populations exposed to samples of water from two shore-based mesocosms (8,000 liters). After 30 days, no mortality was caused by 4-day exposures to water from the mesocosm treated with oil alone, at 40 ppb total extractable organic (by fluorescence). Because of the high concentration in the dispersed oil mesocosm (250 ppm oil, up to 125 ppm dispersant), greater than 50 percent mortality resulted. Oil plus dispersant was also observed to reduce mobility of the urchins, as measured by the percentage climbing the walls of the test tanks. Such oil and dispersant concentrations could be reached in inshore applications of dispersant to actual oil spills, but would be unlikely to remain so high for a month (Gordon et al., 1976).

In these tests, 50 percent of dispersed oil and 24 percent of undispersed oil was lost by day 22 from the mesocosm. The dispersant itself was well above the acute lethal threshold for urchins (125 ppm), and was considered to be the major cause of mortality.

Mortality, larval settling, spawning, and octopus predation on littleneck clams (*Protothaca staminea*) were examined in small outdoor tanks and in field quadrates (0.5

m^2) using Trans-Mountain Western crude oil and Corexit 9527, at 1,000 ppm oil plus 100 ppm dispersant in seawater (Hartwick et al., 1979, Hartwick, 1982). Seven liters of this mixture were purged onto the field plots daily for five days. The stock mixture in the tank was allowed to weather naturally outdoors during this period so that each successive application was with a more weathered oil. This experimental design may simulate a usually high and repeated exposure of an intertidal environment to dispersed oil, and repeated exposure of an intertidal environment to dispersed oil, as might occur in an estuary where a large oil spill was diapered but not diluted rapidly by water circulation (Hartwick et al., 1979, Hartwick, 1982).

Reduced siphon activity was apparent on the first day, significant mortality occurred with the dispersed oil after 4 days, but mixing the dispersant with fresh water prior to use reduced mortality. No mortality occurred after 10 days with oil alone. Settlement of larval clams were low at highest concentrations of oil plus dispersant clams was lowest at highest concentrations of oil plus dispersant (1,000 ppm oil plus 100 ppm dispersants). Octopus predation was substantially reduced when clams were tainted with oil (Hartwick et al , 1979, Hartwick, 1982).

The effects of oil on blue mussels (*Mytilus edulis*) were studied in a mesoscale experiment simulating the Baltic Archipelago (Linden et al., 1985, 1987). In the dispersed oil tank, oil concentration in the mussels increased more rapidly than in the mussels exposed to oil only. However, by the end of the experiment, the dispersed-oil mussels had added about twice as much shell length as the oil-only mussels, while controls had added three times as much. Mussels exposed to oil plus dispersant exhibited reduced byssal thread production and spawning activity for the first four days, but recovered by day 12. With exposure to oil alone, spawning was still abnormal after 12 days (Carr and Linden, 1984).

A three month study in large-scale, flow-through exposure tanks of sublethal responses of invertebrates (i.e., lobster, scallops, clams, mussels) to nominal 50 ppm light Arabian crude, with and without Corexit 9527, maximum measured concentrations were 1 to 2.2 ppm for six hours for oil alone, and 12.7 to 19.4 ppm for six hours for oil plus dispersant. No mortalities occurred, however, clams (*Mya* sp.) exhibit some reversible changes and reduced shell adductor muscle (Carr et al., 1985, 1986). Other transient sublethal effects were observed in both oil and oil-dispersant treatments. For example, mud snails tried to avoid oil alone and were narcotized in oil-dispersant treatments. Hydrocarbon concentration were initially elevated in sediments and mussel tissues in the dispersant-treated tanks, with alkylated dibenzothiophenes present in tissue after 21 days.

Eelgrass (*Zostera noltii*) cover decreased when oil alone, dispersant alone, and oil plus dispersant were applied (Baker et al. 1984). The sand and mud flat experiments showed rapid dispersion of both oil and dispersed oil, with little effect on the meiofauna. However dispersant led to greater retention of oil in the upper sediment layer and reduced abundance of the tube worm *Arenicola* sp. (Rowland et al., 1981). Submerged aquatics are most abundant in the Tingles Island and Pope Bay areas (Anderson, 1970).

Shore communities

Biological effects of North Sea crude oil and BP1100WD were studied by Crothers (1983). The experiment simulates a situation in which dispersed oil washed ashore. Oil was sprayed onto 2 m^2 plots during ebb tide, and dispersant was sprayed on the flood tide. Shores covered with seaweed (Fucus spp.) were unaffected, and recovery was rapid. As above, limpets and small periwinkles were most affected in the short term, while barnacles showed long-term effects. Of all treatment, oil plus dispersant was most harmful, oil alone had moderate effect, and dispersant alone was not toxic compared with controls.

A major study in the United kingdom compared effects of oil and dispersant for a variety of intertidal rocky shore, salt marsh, seagrass, sand, and mud flat habitats. Experimental plots were treated with oil dispersant (BP1100WD, BP1100Z, Corexit 8667, and Croexit 7664), oil plus dispersant, premixed oil plus dispersant, and no treatment (control) (Baker, 1976; Baker et al., 1984; Rowland et al., 1981). Major effects were confined to limpets and periwinkles which were reduced in population number for several months.

Marsh communities

The dispersant BP1100WD was ineffective in cleaning an oiled salt marsh in the United Kingdom (Baker et al., 1984). Long-term (one to two years) reduction in *Spartina anglica* density and short-term loss of *Salicornia* spp. was noted with both oil and dispersed oil. *Salicornia* recovered after two years. In contrast, in Louisiana, *Spartina* salt marsh recovered much more rapidly (Smith et al., 1984). Short-term effects on meiofuna were observed, but by five to ten weeks after oiling there were no significant difference between the test plots and the control.

Although dispersant applied directly to Louisiana salt marsh plants prior to oiling caused reduced biomass by the end of the growing season (Delaune et al., 1984), little evidence of oil or dispersant caused mortality among the meiofauna was found. The general conclusion was that the Louisiana salt marsh exhibited a low sensitivity to oiling.

Studies of an Atlantic Coast salt marsh exposed to weathered crude oil and Corexit 9527 provided additional information on the extent of damage and recovery of affected marsh vegetation in three vegetation zones (Lane et al., 1987). Sensitivities of marsh zones ranged from midmarsh (high) to high marsh (low). Both the mid marsh and creek-edge vegetation communities were most sensitive to the oil plus dispersant applications based on a range of morphological, growth, and plant stress parameters; oil alone had the least impact, and dispersant effects were similar to dispersed oil.

Salt marshes are most likely to be subjected to small gasoline spills from recreational vessels or fishing vessels. Winds and tides could drive the oil into the marsh, where the plants would trap the pollution.

<u>Tidal flat community</u>

Artificial intertidal mudflats were treated with forties crude oil and Finasol SR-5 dispersant, and monitored for 10 months (Dekker and van Moorsel, 1987) Dispersant plus oil had more severe short term effects than oil alone: high mortality in cockles (*Cerastoderma edule*), clams (*Macoma balthica*), and polychaetes (*Arenicola marina*). In both treated areas, *C. edule* was more vulnerable to frost that in the control areas.

Dispersant used directly on oiled intertidal and subtidal environments, ranging from mud flats to marshes and seagrass beds, may facilitate the penetration of oil into the sediments and thereby increase ecological damage without decreasing the time necessary for recovery.

Methods and Materials

Wind Speed and Direction

Weather data was obtained for the period (January 1981 to November 1991) from the National Oceanic and Atmospheric Administration at Wallops Island, Virginia. Wallops is the island located immediately south of Assateague Island.

Both average annual wind speed and average annual wind direction were determined for two parameters on a monthly basis. Daily average values were taken from each day's average wind speed. These speeds were averaged for each month. This value was then averaged over the ten-year period for each month of the year to obtain the daily average for that month. Wind direction was likewise averaged for each month from the average daily direction, then the monthly values averaged over ten years for the final daily average.

Average monthly maximum values were calculated by averaging the maximum wind speed for each month over the ten-year period. Average monthly maximum wind direction was calculated using the wind direction of the highest wind in each month. Thus average monthly maximums reflect the highest winds in each month, whereas daily averages reflect the average winds in each day.

Averages for wind speed were computed directly from the speed of the wind in miles per hour. Wind directions were assigned a numeric value for computational purposes. North was assigned a value of 1, northeast 3, east 5, southeast 7, south 9, southwest 11, west 13, and northwest 15.

Physical Inventory

A physical inventory was performed by off-road vehicle in October to secure photo documentation of areas likely to be impacted by a possible oil spill. Documentation was also taken of possible sources of oil pollution. Since ocean-going ships are most likely to experience trouble during a storm event, storm tides could carry oil into parts of the island which would normally be beyond the reach of tides. Storm impact on Assateague Island was therefore documented.

Assessment Parameters

Risk was documented by biological community. The communities of Assateague were defined to be the off-shore waters (designated on the maps with an "O"), the shore ("S"), the dune/swale complex ("D"), the barrier flat (maritime forest) ("F"), the *Spartina* marshes ("M"), the tidal flats ("T"), and the bay ("B") (adapted from Leatherman, 1988).

Each parameter describes the resources' or community's susceptibility or significance towards exposure to oil. Scores of 1, 3, or 5 were given to the resource under each of the parameters. A score of 1 signifies low susceptibility or significance, 3 signifies moderate susceptibility or significance, and 5 signifies high susceptibility or significance. These scores were tallied and used as an index of importance for each resource.

Scores were based on information in the literature, on assumptions based on that information, and on information collected from researchers or managers. The resulting scores are subjective estimations based on a synthesis of the best information available.

Physiological susceptibility:

A measure of the community's physiological response to exposure to oiling. This score is based mainly on the response of the community's organisms to oil and/or dispersants which normally would foul a community during an oil spill. Known response of related organisms was often used to approximate the response of untested organisms. Where organisms with varying susceptibility occurred together, the more important economically or in the food chain or the more sensitive of these important species was used to determine susceptibility of the community.

Score:

5 - community shows high susceptibility upon exposure

3 - community shows moderate susceptibility upon exposure

1 - community shows little susceptibility upon exposure

Recovery Rate:

The rate at which a resource or a community can recover within an amount of time after exposure to oiling. Known recovery rates were used to approximate unknown rates. An organism basic to the integrity of the community was given greater weight than less vital organisms (e.g. *Spartina* recovery rates are a major factor in marsh recovery, while economically important marsh species will determine the public perception of marsh recovery). Probability of oil removal or breakdown, both natural and articial, was also considered.

Score:

5 - community shows little to no chance of recovery. Future generations may be affected.

3 - community shows chance of recovery. Future generations may be affected.

1 - community shows immediate recovery. Future generations will not be affected.

Seasonal susceptibility:

A measure of a community's seasonal susceptibility from exposure to oiling because of migrational, feeding, or reproductive habits of species within that community or seasonal probability of oil spill. Sources of oil, patterns of human use, and wind and current directions were used to determine probability of oil contamination. Biological activity of economically, biologically, or legally important species was used to determine sensitivity to oil during each season. Probability of contamination and sensitivity to its effects were combined to give a seasonal score.

Score:

5 - community highly sensitive during season considered.

3 - community moderately sensitive during season considered.

1 - community not sensitive during season considered.

Resource significance:

The significance of the resource as an economic (food source) or tourist attraction. Factors considered included direct value of the resource to the economy and indirect support of an economically important resource. Community values were based on the overall value of the resources of that community.

Score:

5 - community resources are economically important.

3 - community resources indirectly economically important (food source for economically important organisms).

1 - community resources do not hold economic importance.

Rarity:

The number of species within the community which are rare or have legal status. Species considered rare or of special interest were determined from the literature and from park and refuge personnel. Species with legal status were determined from the federal list and from lists for Virginia and Maryland.

Score:

5 - More than 3 listed or rare species in the community.

3 - Less than 3 listed or rare species in the community.

1 - No listed or rare species in the community.

Resources considered included recreational resources such as bathing beaches and off-road vehicle use areas. Water resources included fresh and brackish waters on the bay side of the island. Biological resources included marine and estuarine vegetation, any terrestrial vegetation which might be impacted by an oil spill, and terrestrial, estuarine, marine, and benthic fauna at risk from a spill. Species lists from the Refuge and Park Service and from the literature were used to determine species present (Conant et al., 1990; Stalter and Lamont, 1990; Kirkpatrick, 1991, 1991b; Counts, 1991; Dumsor, n.d.). Biological rarity, where specified, was based on literature or interviews. Legal status was based on lists received from the states of Maryland and Virginia, and on 50 CFR 17 (U.S. Dept. Interior, 1990).

Maps were prepared designating the communities, resources of special concern, and source points for possible oil spills. The maps, and the risk factors assigned to each community, were then used to determine an accumulated number of risk points for each area. By this method the areas which are most at risk in each season were delineated.

Results and Discussion

Wind Speed and Direction

Figures 1 and 2 give the wind direction and wind speed, respectively. Daily averages are depicted separately from the average monthly maxima. Figure 3 gives the wind rose from Bartberger (1973).

Daily average wind speeds peak in March (10.3 mph), with a secondary peak in November (9.2 mph). Highest wind speed of the month also peaks in March/April (46.9 mph) and again in November (47.0 mph). If an oil spill occurs as a result of strong winds, these are the months when the spill would be most likely to occur. During these months, the winds are likely to be southerly (9.1 in March. 9.2 in November). Storm events in these months, however, tend to come from the southwest (12.6 in March, 9.5 in April, 11.9 in November). Thus a spill occurring during high winds is most likely to result in oil being blown out to sea instead of toward the land. Murphy's law would predict opposite results.

Easterly winds occur most often in the spring (May) and again in the fall months (August, September, October). These are the months when an oil spill at sea is most likely to result in the pollution being blown ashore.

Hurricanes strike Assateague with a probability of 2% annually. Peak season is the fall; peak month September (U.S. Dept. Int., 1988). Due to the destructive nature of these storms, oil stored near the coastline can be washed into the sea and spread along miles of coast.

The annual wind rose (Fig. 3) (Bartberger, 1973) indicates that the majority of winds, and the strongest winds, come from the south and south-southwest. This roughly agrees with Table 1, which shows the average wind direction as 8.9, or southerly. The average direction for the highest winds was 10.0, or south-southwest. Thus on an annual basis a spill occurring south of Assateague will present the greatest danger. Since the industrial centers are to the north, the winds are likely to be an ally in the event of a spill at sea.

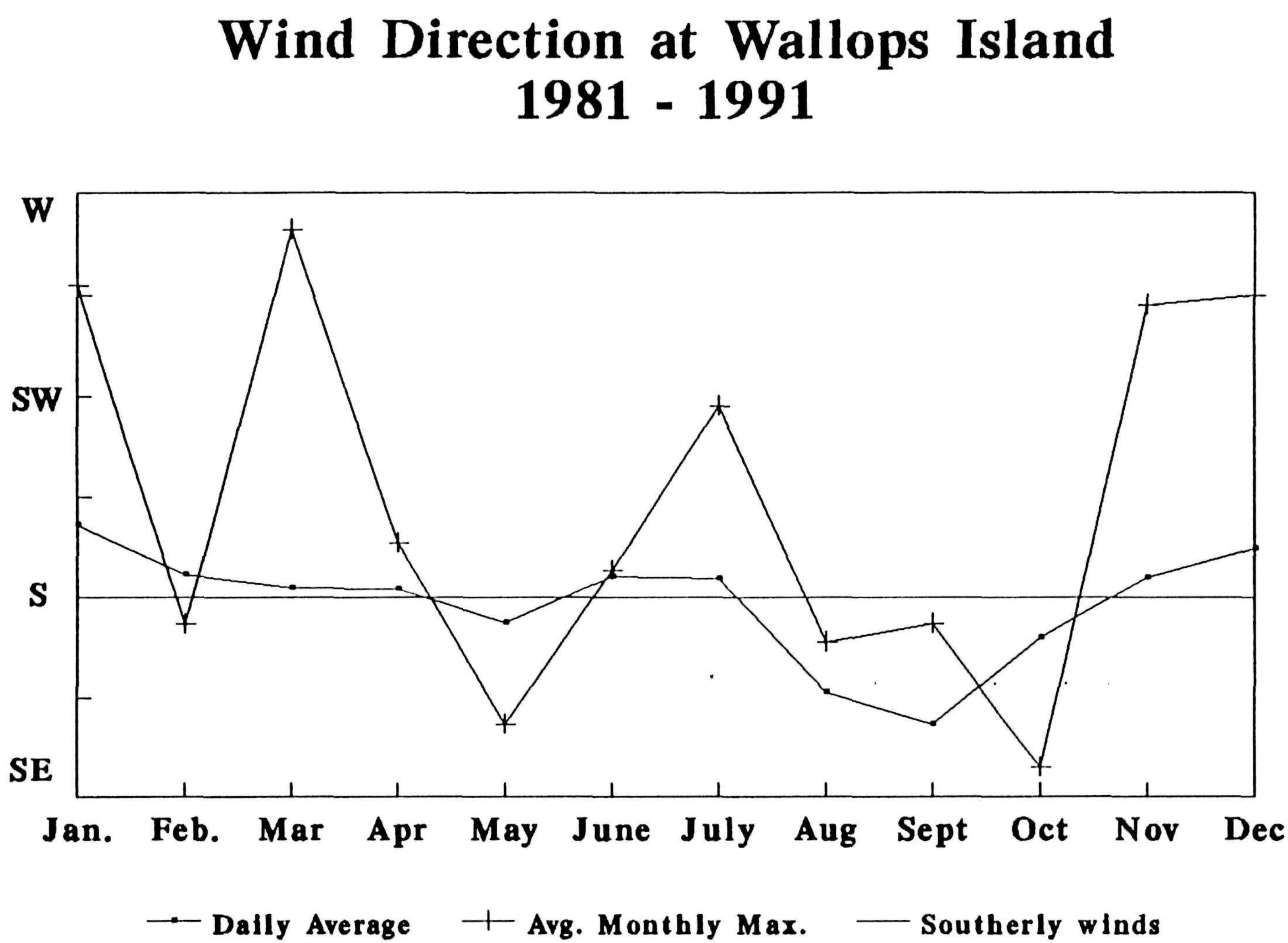

Figure 1. Wind Direction at Wallops Island, Virginia, 1981-1991. Computed from daily averages and monthly maxima. Data from National Aeronautics and Space Administration, Wallops Flight Facility.

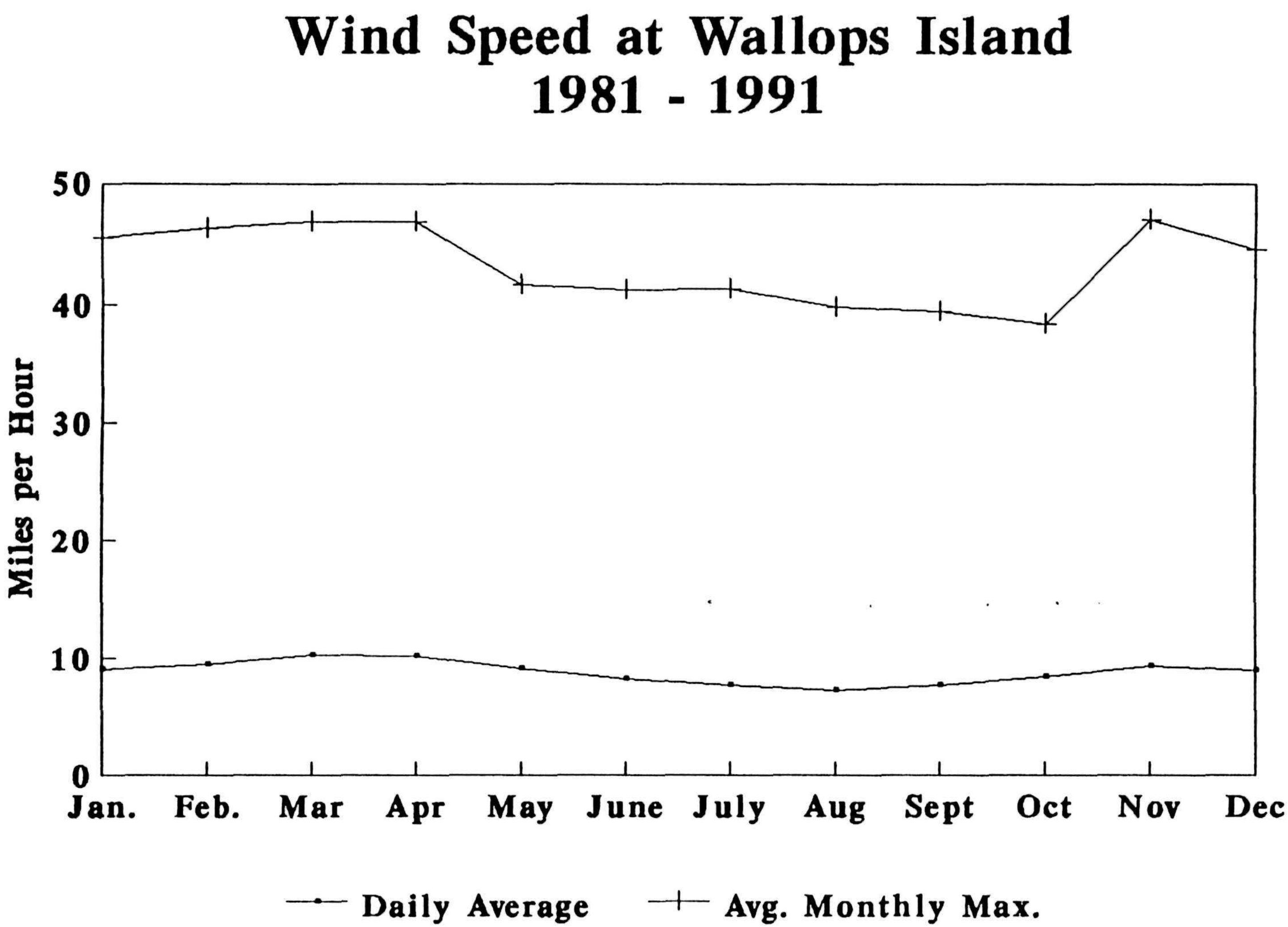

Figure 2. Wind speed at Wallops Island, Virginia, 1981 - 1991. Computed from daily averages and monthly maxima. Data from National Aeronautics and Space Administration, Wallops Flight Facility.

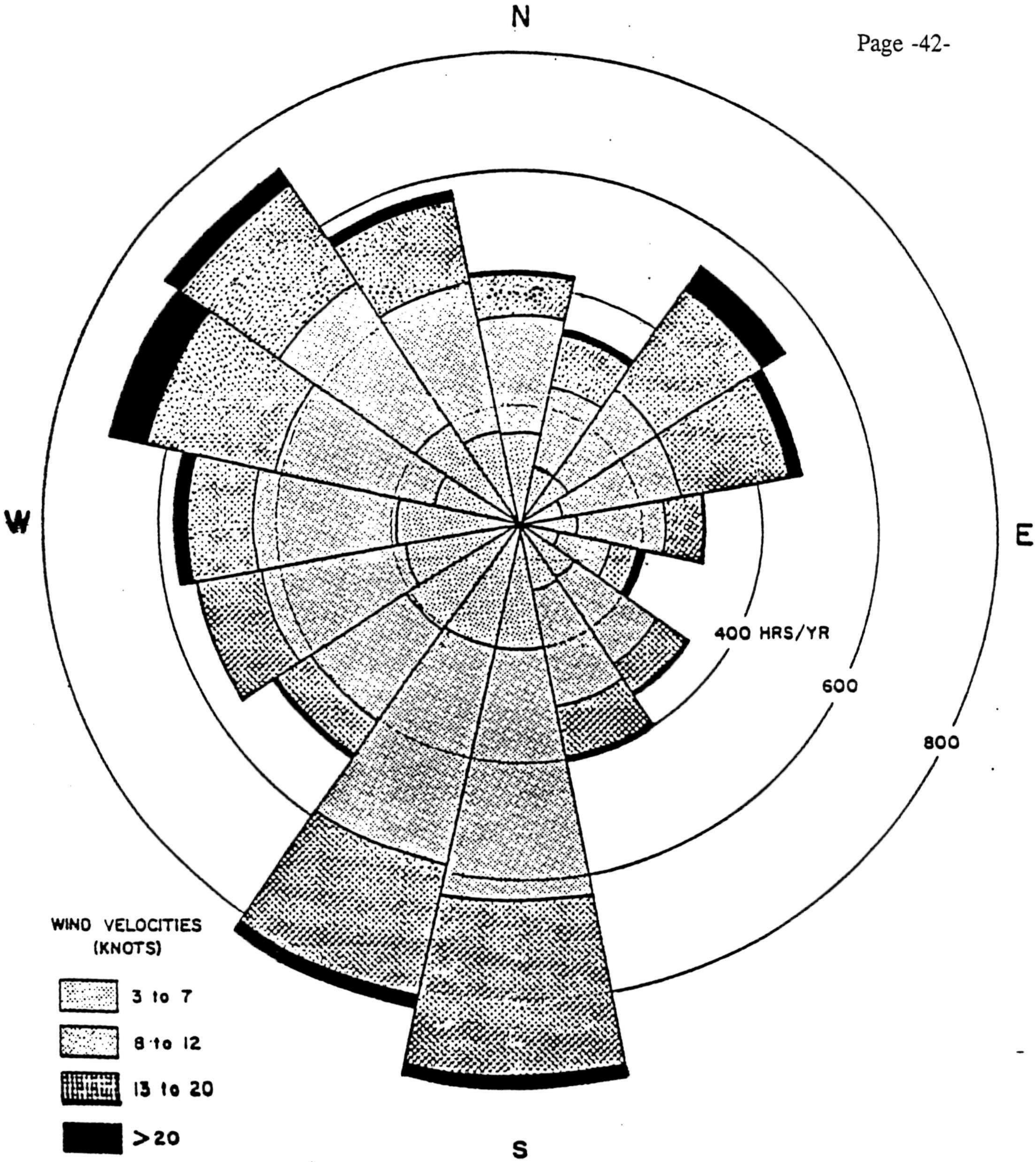

Figure 3. Wind rose for Wallops Island, Virginia, located directly southwest of Chincoteague Inlet. Duration of wind velocities expressed in hours per year averaged from data of National Weather Service, March, 1945 to June, 1957 (Bartberger, 1973).

Community Descriptions

Ocean

The ocean habitat is defined here to be that area up to mean low tide. There is no deep-water boundary for the purposes of this study. At Assateague, the ocean is used for fishing offshore, for migrating by numerous birds, for feeding by many species including brown pelicans, and as a nursery by immature sea turtles. Large oil spills are most likely to occur in this community, either as a result of vessel malfunction or as a result of sinking or grounding of ships due to storm events. Dispersants would also affect this community significantly.

Physiological Susceptibility - 3

The physiological susceptibility is given a 3 because many species can move away from a polluted area. Wave action would break up a spill and winds and currents would move it into other areas.

Recovery Rate - 1

Currents and winds usually cleanse a spill in the ocean within a few years (Hodgeson, 1984).

Seasonal susceptibility -

Winter - 3

In winter the ocean is not heavily used by many marine species, but the sea ducks are present and would be heavily impacted by an oil spill. January is the month when sea duck populations peak (Kirkpatrick, 1991b). Winds and currents would drive spills from a large area toward Assateague.

Spring - 5

Spawning season for many marine animals occurs in the spring. At this season winds and tides are high.

Summer - 1

Spawning activity is much less, and winds and tides are less likely to drive oil toward Assateague.

Fall - 3

Although winds and tides are high, there is little activity in the ocean in the fall.

Resource significance - 5

Fishing is a major factor in the economies of Accomack and Worcester Counties. For instance, surf clams brought in at Ocean City represented 13% of the national catch in 1968 (Boynton, 1970).

Rarity - 5

Balaenoptera physalus and *Megaptera novaeangliae*, Finback and humpback whales; *Eretmochelys imbricata*, hawksbill sea turtle; *Lepidochelys kempii*, Ridley sea turtle; *Dermochelys coriacea*, Leatherback sea turtle; *Caretta caretta*, loggerhead sea turtle, *Pelecanus occidentalis*, brown pelican.

Shore

The shore community is that area between mean low tide and mean high tide on the ocean side of the island. The shore is used heavily by summer visitors for sunbathing, fishing, off-road vehicle driving, and swimming. Shorebirds use the shore for feeding. Large spills are most likely to wash ashore in this community, accumulating along the high tide line.

Physiological susceptibility - 5

Animals which burrow in the sand would be heavily affected by oil, both physically and chemically.

Recovery rate - 5

Oil washed ashore is difficult to clean up. Once buried in the sand, it can remain in the system, washing inland and reburying with each storm or high tide.

Seasonal susceptibility -

Winter - 3

Currents and winds may drive any oil spill onto the beach, but most lifeforms are not highly susceptible at this time.

Spring - 5

Winds and currents are likely to drive oil ashore. In addition, many beach species are reproducing or are using the beach during migration. Shorebird migration peaks in mid May (Ailes, 1991).

Summer - 5

This is the season when the beach is most heavily used by tourists. The economic importance of the resource is highest, even though winds and tides make an oil spill less likely. Shorebird flights also increase in mid-August, peaking late in the month (Ailes, 1991).

Fall - 5

Winds and currents are likely to drive oil ashore. Although few species are reproducing at this time, the fall flights of raptors and shorebirds make the area biologically important. Raptor flights peak in the first week of October; shorebirds in late August but lasting until the first week of October (Ailes, 1991).

Resource significance - 5

Tourism supports a major industry in both Accomack and Worcester counties.

Rarity - 5

Charadrius melodus, piping plover (Cross, 1991; MacIvor, 1991); *Falco peregrinus*, peregrine falcon (Seegar, 1991); *Cicindela* sp., tiger beetle (Knisley, 1991).

Dune/Swale Complex

The dune/swale complex is the area from the primary dune extending back toward the bay until either the barrier flats or the bay is encountered. This area is unlikely to be exposed to an oil spill except during a storm. The entire community is subject to overwash, which could include oil if there were a slick on the ocean during the storm. Overwash areas and the flats are especially susceptible because the oil could ride in on a high tide and spread over a large area (Figure 4).

Physiological susceptibility - 3

Many dune/swale species can burrow beneath an oil spill or reproduce readily.

Recovery rate - 3

Because of the dynamic nature of the community, recovery would occur but may be prolonged.

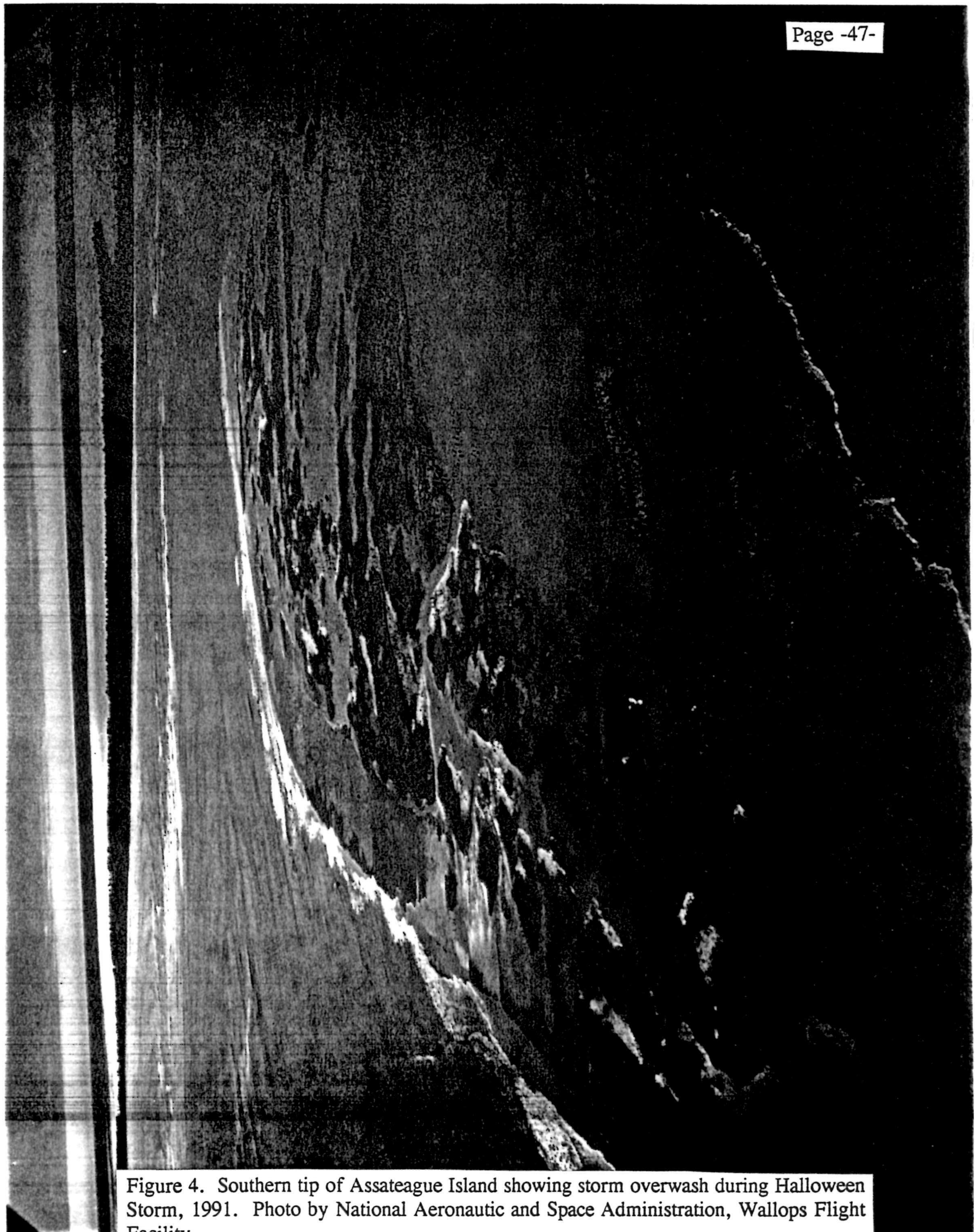

Figure 4. Southern tip of Assateague Island showing storm overwash during Halloween Storm, 1991. Photo by National Aeronautic and Space Administration, Wallops Flight Facility.

<u>Seasonal susceptibility</u>

Winter - 3

Most species are hibernating, migrated, or dormant. This is the season when overwash during storm events is most likely. Geese and swans on the wash flats area would be most susceptible during this season (Kirkpatrick, 1991).

Spring - 3

The dune/swale environment is most sensitive biologically at this season, but the likelihood of a storm event is low.

Summer - 1

Biological sensitivity remains moderately high, but the probability of a storm event is very low.

Fall - 3

The presence of migrating raptors increases biological sensitivity, while the probability of storm events is very high.

<u>Resource significance - 3</u>

Support structures for beach use are located in the dune/swale environment.

<u>Rarity - 5</u>

Charadrius melodus, piping plover (Cross, 1991; MacIvor, 1991); *Falco peregrinus*, peregrine falcon (Seegar, 1991); *Cicindela* sp., tiger beetle (Knisley, 1991); *Haliaeetus leucocephalus*, Bald eagles are known to feed over the flats.

Forest

The forest is located on and includes the barrier flats. Vegetation varies from myrtle thickets to maritime forest. Most parts of the forest are beyond the reach of a probable oil spill (Dolan et al., 1977). Portions of the forest near the lighthouse are above the 100-year floodplain, and very unlikely to be affected by an oil spill (Federal Emergency Management Agency, 1984). In contrast, fingers of forest reach into bay and marsh environments where small spills from recreational vessels are likely. Storm tides could wash such spills into forest communities.

Physiological susceptibility - 1

Because of the improbability of oil spill in the forest little is known of susceptibility. Oil spills are likely to be small and easily absorbed by the community.

Recovery rate - 1

Size of spills is likely to be small. Plants tend to be perennial, with firmly rooted soils. The community could probably recover from a spill fairly quickly.

Seasonal susceptibility

Winter - 3

Winter storms could conceivably force an oil spill into some forest areas.

Spring - 1

Oil is unlikely to reach the forest during this season except through very small spills due to tourist use.

Summer - 1

Oil is unlikely to reach the forest during this season except through very small spills due to tourist use.

Fall - 3

Storms could conceivably force an oil spill into some forest areas.

Resource significance - 1

The area is used by tourists for bird study and other nonconsumptive recreation.

Rarity - 3

Sciurus niger cinereus, Delmarva Fox Squirrel (U.S. Fish & Wildlife Service, 1991).

Salt Marshes

Marshes are the area on the bay side whose vegetation is composed predominantly of either *Spartina alterniflora* or *Spartina patens*. The two vegetative types were considered together for the purpose of this study. Since these marshes are on the bay side of Assateague, their most likely source of oil contamination is from small spills of gasoline products from recreational or small watermen's vessels.

Physiological susceptibility - 3

Spills which cover the entire *Spartina* plant produce a high susceptibility (Alexander and Webb, 1985). The probability of a spill of that magnitude in the salt marshes is small, since there are no major sources of oil within the bays.

Recovery rate - 3

There is a long-term reduction in *Spartina* densities, and short term reduction in *Salicornia* densities. After one to two years, the marsh recovers well. (Smith et al., 1984; Baker et al., 1984). Some species may take longer to reach pre-spill levels.

Seasonal susceptibility

Winter - 1

Due to low tourist levels during the winter, the probability of a spill approaches zero. Most marsh plants show low susceptibility due to decreased growth during the dormant season (Watton, 1985). Dabbling ducks reach their winter peaks in December (black duck, pintail) or November (mallard, wigeon, teal, shoveler) (Kirkpatrick, 1991b).

Spring - 3

Spring tourist use is still low. The marsh does not green fully until late spring or summer. Spawning fish and non-vertebrates show high susceptibility to oil at this season. Breeding ducks are the gadwall, teal, mallard, and smaller numbers of black duck (Kirkpatrick, 1991b).

Summer - 5

Due to the heavy influx of tourists, this is the season when numerous small spills can be expected. Biological activity in the marshes is also at its peak.

Fall - 1

Biological activity is returning to dormant levels. Except for hunting parties, tourist activity has also dropped off.

<u>Resource significance - 5</u>

A major portion of the fisheries industry depends on species which breed on the marsh or use marshes as a nursery.

<u>Rarity - 1</u>

Tidal Flats

Tidal flats are those bayside areas covered by daily high tides but exposed at low tides. Spills in the tidal flats are likely to be wind- or tide-driven spills from small vessels.

<u>Physiological susceptibility - 5</u>

The large proportion of filter feeders in the tidal flats are highly susceptible to oil pollution. An oil spill can be spread thinly over a large area on these flat, shallow areas.

<u>Recovery rate - 5</u>

Currents are not strong enough in these areas to remove pollution. Oil is likely to sink into the marsh soils, where it will remain indefinitely.

<u>Seasonal susceptibility -</u>

Winter - 3

Many filter feeders remain present, though sometimes buried.

Spring - 5

Biological activity levels are high, and many species are highly sensitive.

Summer - 5

Biological activity remains high, but tourist activity increases the probability of spills. The threatened piping plover is using the tidal flats at the end of this season (Cross, 1991).

Fall - 3

Biological activity is lower; tourists are mostly gone.

Resource significance - 5

A major portion of the fisheries industry is dependent upon species which breed in the tidal flats or use them as a nursery.

Rarity - 3

Charadrius melodus, piping plover (Cross, 1991; MacIvor, 1991) feed on the tidal flats in late summer.

Bay

The bay is the area between the island and the mainland which is underwater at all times. Spills are most likely to come from recreational vessels, from the marinas that serve them, or from larger vessels passing through to harbor at Chincoteague or Ocean City. Spills are likely to be gasolines in relatively small quantities.

Physiological susceptibility - 5

Neritic organisms are highly susceptible to oil in the shallow bays (Kuhnhold, 1972).

Recovery rate - 3

The exchange rate between the bays and the ocean is roughly 7.5% of the total bay volume daily (Pritchard, 1960). Due to the low exchange rate of the water in the bays (Dolan et al., 1977), the oil is likely to settle into the sediments on the floor of the bays, affecting benthic life. Pollution is thus likely to remain present for an extended period of time. Quantity of pollution, however, is likely to be low. Sedimentation can be expected to cover the pollution very slowly; average sedimentation rate is 0.3 mm/year (Bartberger, 1976). Over time the levels of contamination can be expected to drop below toxic levels except in the affected stratum of bottom deposits (Holmes, 1988).

Seasonal susceptibility

Winter - 1

Both biological activity and tourist activity are low. Bay ducks peak in December (Kirkpatrick, 1991b) and would be affected, but in most cases the spill would affect only a small area and the birds could move to unaffected areas. The most likely source of oil contamination would be by currents drawing a local spill into the bay.

Spring - 5

Biological activity levels are high, and many species are highly sensitive.

Summer - 5

Biological activity remains high, but tourist activity increases the probability of spills.

Fall - 3

Biological activity is lower; tourists are mostly gone.

Resource significance - 5

Many species of economic importance either breed or raise their young in the bays. 92% of Maryland's total hard clam catch is from the Chincoteague Bay (Boynton, 1970). The blue crab is most abundant near the state line (Leber and Lippson, 1970).

Rarity - 3

Haliaeetus leucocephalus, Bald eagles are known to feed over the bays, especially near the Tom's Cove area.

Conclusions

The shore community has the highest overall risk assessment total (Table 2). The north end of Assateague, opposite Ocean City, is the most sensitive area of the shore. This area is used by summer visitors as well as by wildlife. The piping plover, peregrine falcon, and tiger beetle all occur on the north end. In addition, the marinas are concentrated in the Ocean City Inlet area, greatly increasing the risk of spill in that area. The shore community retains its highest ranking throughout the year.

The next most sensitive overall and in each season is the tidal flats. The extensive flats across from Snug Harbor are the most likely to be affected due to the activity at the marinas in the area.

The bay has the third highest overall rating. In winter, however, the dune/swale and ocean communities have the same score. At that time there is a very small chance of spill in the bay as recreational activity drops almost to nothing. At the same time, the winter storms greatly increase the probability of pollution in the dune/swale and ocean areas due to overwash and storms. The northern bays nearest Ocean City are the most likely to be exposed to an oil spill, though many of the bays further south are more productive.

The fourth highest rating overall is the ocean. In summer the marsh is higher due to the high biological activity and the likelihood of small spills from recreational vessels.

The dune/swale complex receives the fifth overall rating. In winter it equals the ocean and bay, where biological activity is high, due to the importance of the tourist industry and the presence of several species of special concern. In fall and summer the ocean and dune/swale receive the same rating. Low dune areas on the south and north ends, where artificial dunes have not been erected, are more susceptible to overwash because of their low profile and more sensitive due to biological importance.

The sixth highest rating overall is the marsh, except in the summer when biological and recreational activity both peak. Although marshes are a highly productive system, their location on the west side of the island means that the most likely source of oil is spills from recreational vessels. These spills are likely to be small in volume. The marshes along the Assateague Channel are the most sensitive due to their extent, their proximity to Chincoteague's marinas, and the lack of extensive tidal flats in that area.

The least sensitive community throughout the year is the forest. It is unlikely that this community will be exposed to an oil spill except during storm events. Of these, the forests near Black Duck Marsh are most at risk due to their low topography, their high visitor use, and the presence of the Delmarva Fox Squirrel.

It can be assumed that in the future, better information will become available. Better integration of existing information should become available through geographic information systems. Modeling of oil movements in the Atlantic should give a better picture of oil concentrations, both under normal conditions and in the event of a major spill. As this information becomes available, scores may be changed to better reflect Assateague's sensitivity.

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Average speeds and directions of winds at Wallops, VA.

	Jan.		Feb.		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.
1981	10.1	11.5	10.7	9.9	11.9	11.5	11.9	9.8	10.7	8.5	7.7	10.9	7.1	9.2	7.5	6.5	7.9	9.2	10.2	8.9	11.8	9.9	9.5	10.7
1982	10.0	10.9	9.3	9.2	7.9	8.2	10.1	9.6	6.9	7.9	7.1	8.7	6.0	8.1	6.2	9.0	7.2	6.5	7.4	8.5	8.3	8.4	8.9	7.7
1983	9.7	9.6	10.9	6.6	12.6	7.8	11.2	10.3	9.3	10.1	8.1	8.2	7.7	10.1	7.2	8.0	9.0	6.7	9.9	7.1	8.8	10.7	10.5	10.5
1984	7.8	7.0	9.5	11.1	10.4	9.8	8.7	9.1	9.2	10.2	7.2	9.1	8.0	9.8	5.6	9.7	7.8	7.3	7.3	7.3	8.1	8.2	7.0	9.5
1985	8.3	10.6	8.9	10.1	9.6	9.4	8.6	8.6	9.6	7.9	8.2	9.7	8.3	9.1	7.2	6.7	6.3	7.0	7.7	7.3	9.5	7.1	8.2	9.2
1986	8.5	10.0	8.4	9.1	9.8	7.9	8.6	7.8	8.8	9.7	8.8	8.0	7.0	9.5	7.3	8.4	6.2	6.9	7.0	9.8	6.7	7.3	7.2	7.0
1987	8.6	8.5	7.7	7.6	8.6	7.3	11.2	8.6	8.5	7.3	7.1	9.8	5.9	9.5	6.6	7.4	6.3	8.3	7.2	8.1	10.5	8.9	8.5	11.1
1988	8.1	9.9	9.6	9.1	9.8	10.5	11.2	9.3	7.7	8.1	10.3	9.8	9.0	10.9	9.3	8.9	8.1	8.1	8.7	10.5	9.7	9.6	9.4	11.5
1989	9.2	10.4	9.2	9.1	12.1	8.1	9.8	8.5	9.8	8.8	8.5	10.0	8.3	9.0	7.3	7.9	9.8	7.5	8.3	9.3	9.9	11.1	9.7	8.2
1990	9.0	10.5	10.1	10.6	9.6	8.8	9.4	9.5	10.0	8.7	8.9	9.3	9.2	8.2	7.6	8.1	7.7	9.4	9.9	9.2	10.0	10.3	10.2	9.6
1991	9.6	8.1	9.3	9.2	10.7	10.7	10.9	8.8	10.2	9.0	8.7	7.8	8.4	7.8	8.3	8.0	8.7	8.2	8.1	7.3	9.4	9.7		

N=1, NNE=2 NE=3, ENE=4, E=5, ESE=6, SE=7, SSE=8, S=9, SSW=10, SW=11, WSW=12, W=13, WNW=14, NW=15, NNW=16

Averages:

	Jan.	Feb.	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Average
Speed	9.0	9.4	10.3	10.1	9.2	8.2	7.7	7.3	7.7	8.3	9.3	8.9	8.8
Direction	9.7	9.2	9.1	9.1	8.7	9.2	9.2	8.1	7.7	8.5	9.2	9.5	8.9

Highest monthly speeds and directions of winds at Wallops, VA.

	Jan.		Feb.		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.
1981	46	15	66	10	52	16	50	13	37	8	47	6	44	7	39	3	33	9	40	16	41	14	41	14
1982	50	9	41	3	35	14	54	15	39	10	40	9	39	14	36	13	40	8	50	3	51	16	45	9
1983	47	2	61	11	49	8	50	9	47	10	32	9	40	14	53	10	44	2	39	6	51	15	53	15
1984	41	15	44	12	50	15	38	14	52	13	32	10	35	10	29	9	30	3	36	1	41	10	35	8
1985	46	14	42	14	44	14	45	13	43	4	37	14	37	11	39	13	70	14	37	4	53	4	46	11
1986	36	14	37	2	49	11	41	2	35	15	39	15	49	1	60	4	32	12	31	2	34	11	34	4
1987	63	4	44	1	47	3	50	2	36	3	34	10	34	12	39	15	33	9	33	15	60	14	43	14
1988	37	15	43	15	42	15	50	2	34	2	69	13	40	13	38	9	33	12	31	9	40	15	56	15
1989	43	16	41	1	68	13	54	3	52	9	49	12	37	9	35	3	43	9	39	4	56	15	48	14
1990	41	14	46	14	37	16	37	16	42	8	39	1	47	13	30	14	41	15	48	13	42	14	45	16
1991	51	15	45	13	43	14	47	16	41	3	35	3	52	16	40	1	35	3	38	3	48	3		

Averages:

	Jan.	Feb.	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Average
Speed	45.5	46.4	46.9	46.9	41.6	41.2	41.3	39.8	39.5	38.4	47.0	44.6	43.3
Direction	12.1	8.7	12.6	9.5	7.7	9.3	10.9	8.5	8.7	6.9	11.9	12.0	9.9

Appendix II

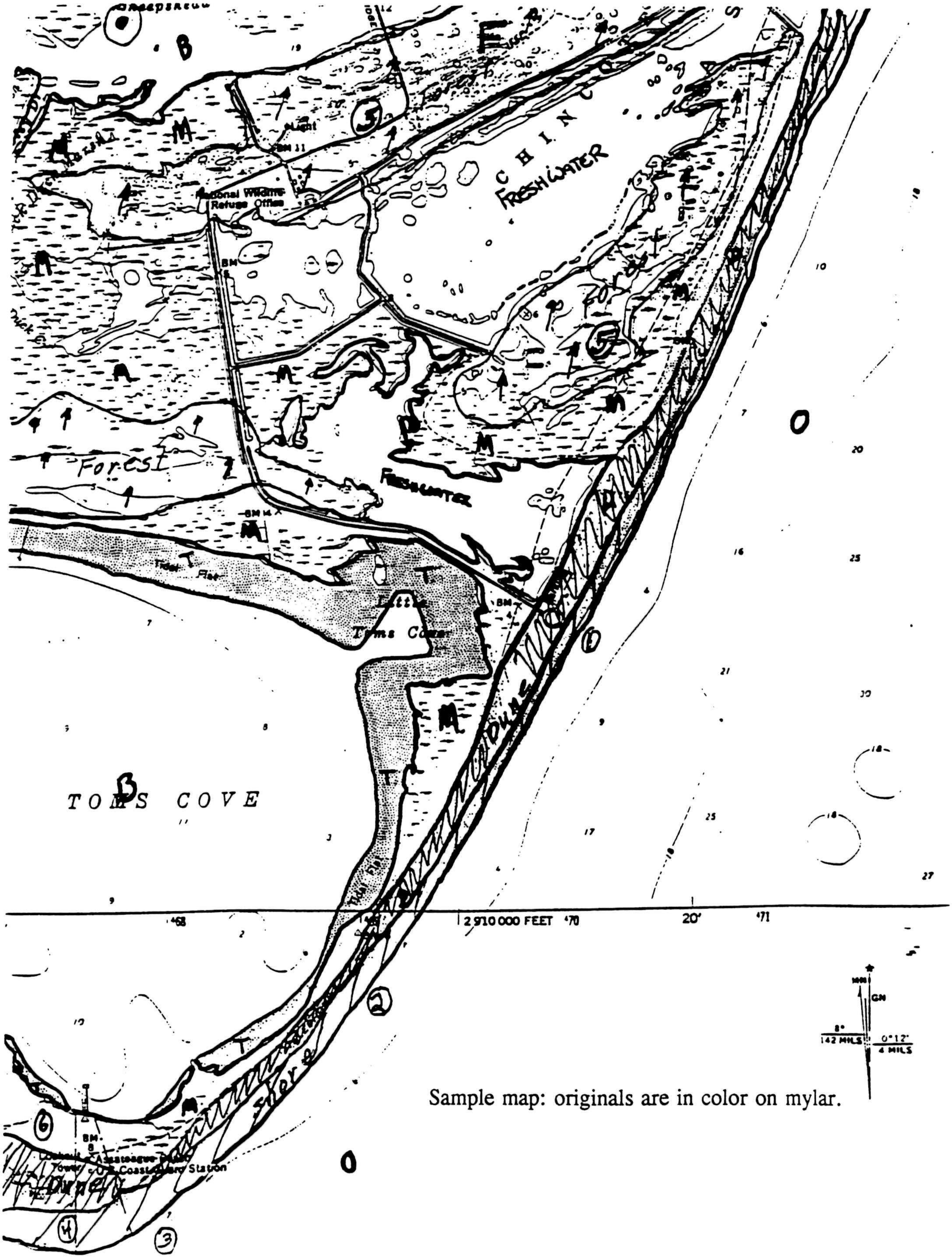
Risk Assessment Parameters

TABLE 2.

of parameters and indices assigned to each of the communities throughout the Totals represent the importance of the communities resources if a spill effects a unity.

	ocean	shore	dune/ swale	forest	marsh	tidal flats	bay
	3	5	3	1	3	5	5
	1	5	3	1	3	5	3
	3	3	3	3	1	3	1
	5	5	3	1	3	5	5
	1	5	1	1	5	5	5
	3	5	3	3	1	3	3
	5	5	3	1	5	5	5
	5	5	5	3	1	3	3
	26	38	24	14	22	34	30

': p.s. = physiological susceptibility; r.r. = recovery rate; s.s. = seasonal susceptibility (win = winter, spr = spring, mmer, fall = fall); r.s. = resource significance; rari. = rarity



Sample map: originals are in color on mylar.

Appendix IV

Photographs[1]

1 - Ocean community. Many birds migrate over the ocean along the shoreline.
2 - Ocean community. Brown pelicans are returning to Assateague Island after a precipitous population drop. Their recovery continues to be followed closely. These birds feed and rest just beyond the breakers.
3 - Shore community. The broad expanse of beach is used heavily during the summer months for recreational purposes. In addition, species such as the piping plover require the shore community for nesting and feeding.
4 - Shore community. The ghost crab population would be heavily affected by oil on the beach.
5 - Dune/Swale community. The peregrine falcon tower is located in the dune/swale environment. Piping plovers also nest here, and many migrants move along the dunes.
6 - Dune/Swale community. Washover areas in the dune/swale environment are more susceptible than the adjoining dune areas. Oil washed ashore, especially on a storm tide, would coat the washover areas first.
7 - Dune/Swale community. Low areas between the dunes can develop into freshwater wetlands. These wetlands can be a vital source of fresh water.
8 - Dune/Swale community. Goldenrods along the dune can be a primary resting place for monarchs on their migration.
9 - Dune/Swale community. Myrtle bushes provide a vital source of energy to tree swallows, whose migrating numbers can darken the skies of early October.
10 - Barrier flat community. The forest community serves as a nesting and feeding site for many species which also use adjacent communities. Oil spilled into these adjacent communities could indirectly affect the forest community as well.
11 - Barrier flat community. The forest can occur as a thin strip of trees adjacent to marshes or dunes. Although the forest is least likely to suffer from an oil spill, the possibility can not be dismissed.
12 - Barrier flat community. The forest can also occur adjacent to the open marsh. Spills in the marsh are less likely to penetrate into the forest due to the filtering action of the *Spartina* grasses.
13 - Marsh community. The flat, open marsh where water normally moves less vigorously than it does in the ocean offers less probability of an oil spill, but less probability of cleansing afterward.
14 - Marsh community. Quiet bays where people come to fish, crab, or just relax are a possible location for spills of gasoline products. These bays could not cleanse themselves naturally as quickly as the ocean could.

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[1] Slides are bound with the copy of this report on file at the Assateague National Seashore office.

15 - Tidal flat community. These flats are usually found between the marsh and the bay. Clams and oysters draw both watermen and recreational visitors. Spills could occur both on the flats themselves, and on the nearby bay. Winds would probably drive spills on the bay either onto the flats or into the marsh.

16 - Bay community. The number of recreational vessels, often under the control of people unaccustomed to their crafts, increases the chances of an oil spill in summer.

17 - Bay community. A number of waterfowl migrate along the bays.

18 - Specific concerns. Fishing vessels carry more petroleum products than do most recreational vessels. Points of primary concern are the northern and southern extremities of Assateague Island.

19 - Specific concerns. There are a number of small marinas located opposite Assateague either on the mainland or on Chincoteague. The refueling of pleasure boats, the lack of experience of many of the operators, and the numbers of vessels on these restricted waters in the summer greatly increase the probability of small spills.

20 - Specific concerns. Overwash during a storm event can destroy fuel containers either in homes, offices, or in cars. Oils accumulated on parking lots over a summer can be washed into the bay or onto the shore.

21 - Specific concerns. During storm events navigational aids can be dislocated or may malfunction. Ships are more likely to experience a variety of difficulties, including groundings and sinkings. Oil in large quantities can be released from some of the larger vessels offshore. Winds and currents could drive the oil onshore.

22 - Specific concerns. Washover points could be badly tarred during a storm in which a vessel was releasing pollution.

23 - Specific concerns. Tarring of the shore could prevent the normal rearrangement of sand by currents, tides, and winds.

24 - Specific concerns. A large spill could cover large areas during a washover event in some of the flats on Assateague.