Evaluating the Risks of Offshore Oil Development

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The increasing world appetite for oil and the recognition of oil as an important strategic weapon and diplomatic tool has spurred intensive efforts to develop offshore oil resources.[1] The United States Geologic Survey estimates that as much as 41 percent of the nation's undiscovered, recoverable oil lies offshore. (Dalton *et al.* 1981). Drilling offshore for oil is not new. In 1896 offshore wells were drilled from wooden piers in California's coastal waters. What is new, however, is the rapid expansion of offshore leasing activity in all types of marine environments. Currently, about one thousand new wells are drilled in the outer continental shelf (OCS) per year. (US National Research Council 1983). In many areas, especially in frontier areas such as the North Atlantic and the Alaskan continental shelf, this increased activity has given rise to concern about a variety of impacts—to the environment, to the social and economic stability of coastal communities and to public health and safety.

Prior to allowing oil exploration and development to occur in a particular OCS area, consideration is given to the potential impacts of this activity. Indeed, the National Environmental Policy Act[2] requires the Department of the Interior (DOI) to prepare an environmental impact statement prior to the Lease Sale. How the potential impacts should be considered, however, is a very difficult question to answer. Identification of the potential impacts is clearly an important first step. Estimating the probability and magnitude of a particular impact, a basic risk assessment computation, is another ingredient of an informed impact assessment.

In the following discussion the potential impacts associated with oil and gas activities on the OCS are identified and described. The discussion then focuses on risk assessment to evaluate whether this methodology might improve OCS impact assessment.

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Potential Impacts Associated with Offshore Oil Development

There are a number of activities which are undertaken during offshore oil exploration and development which pose risks to the environment. These activities can be divided into three groups: exploration activities, offshore production activities and onshore activities (See Table 1).

Table 1. The potential impacts of offshore oil and gas development

Activity	Source	Potential Impacts
Exploration Activities		
Seismic surveying	• ship traffic • sound waves • towing cable	• disruption of marine mammal migration • disturbance to fisheries • loss of fishing gear
Exploratory drilling	• drilling muds • drilling cuttings • Island construction fuel spills	• turbidity and sedimentation • creates toxicity and bioaccumulation • disruption of terrestrial environment
Production Activities		
oil discharge	• oil spills (chronic) • routine discharge	• toxicity to water column and benthic organisms • lethal and sublethal effects on seabirds • decline of tourism
Routine platform discharge	• sewage • debris	• aesthetic degradation
Production water discharge	• metals • salinity • temperature	• toxicity to benthic organisms • fish kills • reduced species diversity • chronic effects to water column organisms
transportation of oil	• pipeline construction • accidental spills	• disruption of benthic environment • disturbance of shoreline
Onshore Activities		
Construction of oil facilities	• population influx • shoreline modifications	• disruption of community stability • pressures on local services • alteration of circulation patterns, habitat

Adapted from Gilbert 1983

Exploration activities. The first step in developing oil reserves is locating the most promising hydrocarbon reservoirs. Marine geophysical surveys and exploratory drilling are the two methods used to evaluate the oil and gas potential of a marine area. A common geophysical survey technique is seismic profiling, which involves producing soundwaves under water so that the reflected waves can be recorded by hydrophones towed from a ship. The sound waves can disrupt marine life, especially breeding populations of marine mammals. In 1966, seismic surveys are said to have caused a fish kill in Georges Bank off the coast of Massachusetts (Robadue and Tippie 1980).

Seismic surveys, moreover, can directly disrupt commercial fishing. Hydrophones and cables towed by survey ships have ripped nets and detached lobster and crab trap markers. The threat of fishing gear loss has been of special concern in the North Atlantic, off the coasts of Oregon and Washington and in Alaskan waters. In 1982, for instance, the State of Washington negotiated an agreement with the Department of the Interior designed to reduce fishing gear loss by restricting offshore seismic surveys during peak fishing seasons (Washington State and US Department of Interior 1982).

Exploratory wells are used to determine the extent of the offshore hydrocarbon reserves. These operations are generally conducted from mobile platforms or ships and are usually short-lived (3-6 months). Exploratory drilling in the Arctic, however, is frequently conducted from artificial islands constructed from sand and gravel to prevent damage to the rig from ice movement (US Geological Survey 1981). Constructing these gravel islands poses a significant hazard to the surrounding marine and terrestrial environment. Inland extraction of gravel for construction destroys vegetation and increases erosion. Offshore gravel extraction and the construction of the island disrupts benthic organisms and may affect higher animals including whales due to heightened noise and turbidity (US Geological Survey 1981). There is a possibility, moreover, that these islands interfere with the migrations of some marine mammals.

During exploratory drilling two categories of material are regularly discharged—drilling fluids and drill cuttings.[3] The fate and effects of these discharges in the marine environment have been the subject of numerous studies and reports[4] and have generated considerable public debate.

Exploration and production drilling on the OCS is done with rotary equipment. Rotary drilling involves a rotating drill bit encased in a hollow drill stem, which contains circulating fluids. The most important function of the drilling fluid is to remove the crushed rock cuttings from around the drill bit and transport these cuttings to the surface for disposal. The drilling fluid performs other essential functions such as controlling pressure in the well and lubricating the drilling equipment. Drilling fluids contain a variety of different substances—from walnut shells to chrome lignosulfonate—according to the drilling conditions.

Both drill cuttings and drill fluids are regularly discharged during drilling operations. Cuttings are discharged continuously while drilling is in progress. The rate of discharge ranges from one to ten barrels per hour according to factors such as drilling depth. During the entire life of a well approximately 3000 to 6000 barrels of cuttings are discharged, not including the cuttings deposited directly on the ocean floor (US National Research Council 1983). Drilling fluids are replaced and discarded periodically due to changes in drilling conditions or because the fluid becomes saturated with cuttings. The volume of fluid discharged varies widely. Over the lifetime of an exploratory well, for instance, between 5000 and 30,000 barrels of fluid will be discharged (US National Research Council 1983).

As articulated in the recent National Research Council (NRC) report on drilling discharges, the two major environmental concerns associated with these discharges are: (1) the direct effects they may have on marine organisms and (2) the presence of heavy metals or organic materials in the discharges which may bioaccumulate in food chains (US National Research Council 1983).

Drilling discharges can directly disrupt marine organisms, especially benthic organisms, in a number of ways. Drill cuttings can accumulate on the ocean bottom thereby smothering the organisms residing there. Certain additives to the drill fluids, such as chrome lignosulfonate, can kill marine organisms or cause a variety of behavioral or physiological problems. (Derby and Atema 1981). The extent to which these discharges will disrupt benthic communities is largely a function of the amount of material that accumulates on the substrates, which in turn is related to the dispersive characteristics of the discharge site. In high energy environments, such as Georges Bank, fluids and cuttings from exploratory drilling have not accumulated to any extent nor has the benthic community been affected in any appreciable way (Battelle Memorial Institute/Woods Hole Oceanographic Institution 1983). In low energy environments, on the other hand, the accumulation of drilling materials around the drill site has caused reduced benthic species diversity and abundance due to smothering or chemical toxicity. For instance, studies of the effects of drilling discharges on the mid-Atlantic OCS off the coast of New Jersey, an area with low dispersive characteristics, found that the diversity and abundance of benthic organisms experienced a significant decline (US National Research Council 1983).

The other key environmental concern regarding drilling discharges is the extent to which discharge components, such as metals, accumulate in marine organisms and threaten organisms up food chains, including humans. A variety of metals are found in drilling fluids including chromium, cadmium, barium and lead. The National Research Council reviewed the recent laboratory and field studies on metal accumulation and concluded that the biological effects are minimal. The NRC review did point out, however, that there are insufficient studies on the bioaccumulation in marine food webs of metals present in drilling fluids.

Offshore production activities. While the offshore well is producing oil, there are a number of routine and accidental discharges which pose risks to the environment. Oil can enter the marine environment through both chronic low-level releases and sudden large discharges. Production water is the primary chronic discharge associated with offshore production. Removing oil and gas from the sea bottom necessitates removing a large volume of water present in the rock strata. This water, often referred to as production or formation water, has a high salinity, contains little or no oxygen and contains hydrocarbons and toxic metals. The amount of water produced varies from 20 to 150 percent of the oil output (Gilbert 1983). After passing through an oil-water separator the production water is usually discharged. Production water can cause thermal, chemical and osmotic stress to marine organisms such as plankton (Gilbert 1983). Metals in the production water, such as barium, chromium and manganese, may also pose hazards to marine life.

The unintentional, uncontrolled release of oil—a blowout—is a significant source of both perceived and actual risk to the marine environment. Major spills are actually quite rare. The blowout rate is estimated to be less than one for every 500 wells drilled. Only a few of these blowouts result in major spills. Although the probability of a major accident is low, the magnitude of damages associated with the spill is potentially enormous (US National Oceanographic and Atmospheric Administration 1983). Nevertheless, increases in the level of offshore oil development can be expected to result in an increased incidence of oil spills (Stewart and Devanney 1978).

Human error and severe environmental conditions are two causes of oil spills. The largest oil spill to date, for instance, the IXTOC I blowout, was caused by an error in judgment in changing a drill bit (Ross *et al.* 1979). In June 1979 this exploratory well spilled over 450,000 tons of oil off the coast of Campeche, Mexico.

Geological hazards also increase the risk of spills. Rigs placed on steep slopes are subject to damage from unstable sea floor conditions. Earthquakes can also cause damage to offshore structures resulting in an oil spill (Gilbert 1983). Although no oil was spilled, the tragic loss of the drilling platform Ocean Ranger and its crew in a storm off Nova Scotia in 1982 exemplifies the threat posed by storms. Oil is transported to shore either via pipeline or by tanker. Ship transportation from offshore fields or refineries accounts for the largest portion of spilled oil in the entire exploration and development process. A 1975 study by the National Academy of Science (NAS) estimated spill that transportation accidents account for a volume of spilled oil four times greater than the amount released by accidents during offshore production. One of the most spectacular accidents occurred in March 1979 when the supertanker *Amoco Cadiz* ran aground off the coast of Brittany, France spilling some 220,000 tons of oil. This spill was roughly twenty times the size of the Santa Barbara blowout spill in 1969 (US National Oceanographic and Atmospheric

Administration 1983). Spills from an oil pipeline can arise from a number of sources such as erosion, seabed instability and fishing snags.

Pipeline and other types of construction related to oil production can also disrupt the marine and nearshore environments. The sea floor is often disrupted by dredging relating to laying underwater pipelines. The location and manner in which the underwater pipes are brought to shore can cause environmental harm, especially in estuaries where dredging and filling can alter drainage patterns and increase erosion. In the Arctic, offshore terminals will be necessary to accommodate deep draft tankers because Arctic nearshore waters are quite shallow. These offshore terminals may be disruptive to whales during migration or summer feeding.

Onshore production-related activities. Onshore activities in support of drilling and exploration offshore can be the source of benefits as well as environmental, social and economic costs to coastal communities. The number and nature of required onshore facilities are directly related to the level of offshore activity. During exploration a temporary service base is usually the only industrial facility necessary. If no commercially exploitable quantities of oil are found, no other facilities need be built. However, a number of onshore facilities are necessary for production, including service facilities for shipping equipment and personnel to offshore sites, facilities for the repair and maintenance of vessels and for the installation of pipelines, processing complexes to separate the oil, gas and impurities, and shipping facilities.

Large amounts of land and water may be necessary to support the construction and operation of such facilities, and competition for scarce harbor space may work to the detriment of such traditional activities as commercial fishing. The support facilities, moreover, may require a variety of improvements or additions to existing transportation systems.

Offshore oil production, especially in frontier areas, often necessitates the influx of a large labor force. On the North Slope of Alaska, for instance, the non-native population quintupled between 1970 and 1979 as a result of offshore oil activites (US Geological Survey 1981). This population influx can overwhelm schools, available housing and the infrastructure throughout the host community. In some instances in Alaska these developments caused major shifts in the community social structure by shifting the local economy from a subsistence to a cash economy.

The Effect on Resources

A wide variety of marine and coastal resources are at risk as a result of offshore oil development. These include such ecological resources as benthic communities and sea birds and such social resources as the tourist industry and the continued integrity of coastal communities.

Marine habitats and organisms vary widely in their vulnerability to damage by spilled oil. In a recent review of the ecological effects of oil spills, Teal and Howarth (1984) summarized studies of oil spills conducted since the 1975 NAS report, including spills from platform Bravo in the North Sea and IXTOC I. These studies show that petroleum hydrocarbons can reach subtidal marine sediments and remain in the water column in concentrations great enough to affect the benthic and planktonic communities. Under some conditions, long-term effects can occur in benthic communities, especially in soft sediments in shallow protected waters. In addition, rates of weathering and detoxification of oil are now known to be highly variable. In some cases rates of recovery have been much slower than previously believed, in others, recovery has been relatively rapid and damage minimal. Table 2 indicates the range of vulnerability for intertidal communities.

Teal and Howarth emphasized that even the "best" studies of oil spills in the environment are extremely limited in their scope and that natural variability makes firm conclusions very difficult. This review indicates that for some communities, especially planktonic, the complexity of this system makes research so difficult that it is unlikely that all effects of oil will ever be detected. They emphasize, however, that this does not mean the effects are not occurring.

There are a number of ways that benthic organisms can be affected during offshore oil development. Some fractions of spilled oil have been shown to be acutely toxic to certain benthic organisms (Nunes and Benville 1978). Hydrocarbons tend to accumulate in the sediment and become a source of chronic exposure for marine organisms living there. Some hydrocarbon derivatives, such as the metabolic intermediates of polynuclear aromatic hydrocarbons are highly carcinogenic, mutagenic or teratogenic (Menzie 1982). Reduced abundance and species diversity of benthic organisms has been observed around production platforms (Menzie 1982). As discussed earlier these impacts are caused by the discharge of drilling fluids and cuttings.

Benthic organisms are of concern in OCS risk assessment and impact studies for several reasons. First, many of the most valuable commercial fishery resources of the continental shelf are epibenthic organisms. These include such species as scallops, razor clams and Dungeness, king and Tanner crabs in Alaskan waters; lobsters, scallops, surf clams and ocean quahogs in the North and Mid-Atlantic; and abalones, corals and spiny lobsters in Southern California. Second, benthic infaunal organisms, such as polychaete worms and amphipods, are an important food source for demersal fish and California gray whales. Third, since benthic organisms are relatively stationary and include many suspension and deposit feeders, they are particularly sensitive to pollutants in sediments and in the sediment-water interface. Many benthic organisms have a propensity to accumulate toxins in their tissues, thus making them critical links in pathways with the potential to pass toxicants on to humans.

Table 2. Proposed environmental classifications in order of increasing vulnerability to oil spill damage

Relative Vulnerability	Shoreline type	Comments
1	Exposed rocky headlands	Wave reflection keeps most of the oil offshore. Clean-up frequently unnecessary.
2	Eroding wave-cut platforms	Wave-swept. Most oil removed by natural processes within weeks.
3	Fine-grained sand beaches	Oil does not usually penetrate far into sediment, facilitating mechanical removal if necessary. Otherwise, oil may persist several months. (Recent evidence suggests that water table movements in sediments are a factor affecting degree of penetration.)
4	Coarse-grained sand beaches	Oil may sink and/or be buried rapidly making clean-up difficult. Under moderate to high energy conditions, oil will be removed naturally within months from most of of the beachface.
5	Exposed, compacted tidal flats	Most oil will not adhere to, nor penetrate into the compacted tidal flat. Clean-up is usually unnecessary, except to prevent the oil from going elsewhere.
6	Mixed sand and gravel beaches	Oil may undergo rapid penetration and burial. Under moderate to low energy conditions, oil may persist for years.
7	Gravel beaches	Same as above. Clean-up should concentrate on high-tide swash area. A solid asphalt pavement may form under heavy oil accumulations.
8	Shelterd rocky coasts	Areas of reduced wave action. Oil may persist for many years. Clean-up is not recommended unless oil concentration is very heavy.
9	Sheltered tidal flats	Areas of low wave energy and high biological productivity. Clean-up is not recommended unless oil accumulation is very heavy. These areas should receive priority protection by using booms or oil sorbent materials.
10	Saltmarshes and mangroves	Most productive of aquative environments. Oil may persist for years. Cleaning of saltmarshes by burning, cutting or stripping should be undertaken only if heavily oiled. Mangroves should not be altered. Protection of these environments by booms or sorbent material should receive first priority.

Adapted from Baker 1983 after Gundlach and Hayes 1978

Organisms in the water column, such as phytoplankton, zooplankton and fish eggs, can be seriously affected by spilled oil and other discharges. Studies suggest that spilled oil can cause significant demersal fish egg mortality (Hufford 1971 *et al.* 1971) Generally, larval stages of various organisms ar 10 to 100 times more sensitive toward spilled oil than adults (Moore *et al.* 1974).

In addition, there may be indirect effects that are more difficult to document. In one case, the 1977 *Tsesis* spill in the Baltic Sea, the hatching success of herring eggs was 29.5 percent lower in the oil-affected area studied than at control sites. While direct oil contamination of the eggs was a possible cause, it was more probable that an oil-induced kill of gammarid amphipods was at fault. These benthic crustaceans are known to graze on the fungi which infect herring eggs, thus keeping the eggs clean and the hatching success relatively high (Nellbring *et al.* 1980).

Coastal habitats, such as tidal flats, marshes and estuaries, are important breeding, nursery and feeding grounds for finfish, shellfish and shore birds. Marshes and estuaries also serve as sediment and nutrient traps, storm barriers and aquifer recharge areas. These resources and functions can be seriously degraded by oil development activities. A long term study of an oil spill in an estuarine area of Massachusetts, for instance, found that it caused very significant long-term ecological changes (Sanders *et al.* 1980). Dredge and fill operations associated with pipeline and onshore facility construction can also pose a major threat to coastal resources. The Council on Environmental Quality determined that dredge and fill activities in the Gulf of Mexico associated with pipeline construction caused more damage to wetlands than did oil pollution (US Council on Environmental Quality 1974).

Marine mammals are an integral biological resource which have significant social and cultural value. Bowhead whales, for instance, are an important subsistence resource to Arctic natives. Whales and other marine mammals may be adversely affected by oil development in a number of ways. Discharges may diminish food supplies by degrading the quality and quantity of water column organisms. Increased activity and noise from ships, aircraft, seismic surveys and gravel islands may cause 1) pronounced short-term changes in behavior, 2) temporary displacement of whales and pinnipeds on land, and 3) limited disruption of acoustic communication. For the most part long-term effects and the biological significance of both long and short-term impacts are not known, although some pinniped deaths from stampeding have occurred from low air flights over haul-out sites where they are most easily disrupted during the breeding and pupping season (Richardson *et al.*1983).

The direct impacts of spilled oil on cetaceans are very poorly understood, but the few observed effects have appeared to be minor or short-lived. Hair seals and walruses, which, like whales, depend on blubber for thermoregulation, appear to suffer few serious effects from light to medium contact with oil unless under additional stress or of sub-adult age. In contrast, fur seals, sea lions, sea otters and polar bears are all especially vulnerable to being oiled since their fur can become matted, resulting in loss of heat and ingestion of oil during attempted cleaning (Richardson *et al.* 1983).

Pelagic and marine birds are especially intolerant of oil pollution. The oil damages the waterproofing and insulating properties of the feathers thus increasing the susceptibility to hypothermia and pneumonia and reducing the ability to feed or fly (Vermeer and Vermeer 1975). Seabirds, like many marine mammals, are particularly vulnerable to large spills during their breeding seasons. There is also concern about the sublethal effects from both large spills and chronic pollution on birds living under natural or human-induced stress, particularly in the Arctic (Levy 1983).

Fishery resources, both finfish and shellfish, are jeopardized by offshore oil production in a variety of ways. Spilled oil can cause a significant loss of eggs and juveniles thorugh both lethal and sublethal biochemical toxification. Sublethal effects on adults can lead to reduced reproductive success and lowered survivorship among larvae and juveniles. After the IXTOC I Spill, for example, the harvest of Campeche shrimp within Mexico reportedly decreased by 50 percent (Caron 1983). Oil development may also hamper the fishermen themselves because of loss of fishing grounds to drilling platforms, oil tanker transit and pipelines. Littering the ocean floor with unwanted material dumped from platforms can result in significant gear loss (Grant 1978).

Diminished fish catches, such as a reported decline in fish catch per unit effort in the Gulf of Mexico, are notoriously difficult to link to offshore activity. Nevertheless, some scientists point to the destruction of marshland for oil barge canals as the primary reason for the fishery decline in the Gulf (Jackson 1981).

Under some conditions offshore oil development may cause a public health hazard. A blowout off the coast of Nigeria in 1980 polluted the Niger Delta and ruined drinking water and food supplies (Caron 1983).

The social and environmental integrity of the host coastal communities is another resource which may be at risk from development associated with offshore oil. Onshore construction of facilities for oil development as well as increased construction of roads, and other infrastructure to accommodate the population influx could degrade some environmental amenities of the host community.

The economy of the host community may also be subject to destabilizing growth patterns. In the "boom-bust cycle," rapid economic development and large influxes of outsiders can alter the social and cultural condition of a community, especially communities in the Arctic which are based on a subsistence economy. Some of the social and cultural effects are: increased incidence of alcoholism and drug abuse, the emergence of social stratification in communities moving from a subsistence economy to a cash economy and loss of community cohesion. However it must also be pointed out that many communities or groups of actors within them stand to benefit economically from OCS development. The very high *per capita* income in Alaska as a result of Prudoe Bay development is a case in point.

Oil and gas development may also have an adverse affect on the coastal tourist industry. For instance, the *Amoco Cadiz* oil spill off the coast of Brittany, one of the most popular summer vacation areas in France, caused a significant reduction in tourism. A comprehensive study of the social costs resulting from this spill recently completed by the National Oceanic and Atmospheric Administration (NOAA) estimated that approximately 245 thousand tourists did not come to visit Brittany in 1978 because of the spill. This decline in tourism translated into estimated economic losses of between 28 and 60 million dollars (US National Oceanic and Atmospheric Administration 1983).

OCS Risk Assessment

Not all risks are equal. Indeed, it is difficult to compare the risk of increased alcoholism among native Alaskans and the risk of decreased species diversity in marine benthic communities. Yet both types of risks should be considered by offshore oil development decision makers. How should such risks be considered and balanced? The OCS environmental impact assessment process has, to date, emphasized the identification of hazards and the estimation of impacts rather than the assessment of risk *per se*. The nature of many controversies surrounding OCS development in frontier areas has, however, brought into focus a need to consider further the possibilities of risk assessment and risk management strategies.

When discussing the risks associated with offshore development, it is important to consider how risks are estimated in formal assessments. Decision makers weighing the relative importance of various types of risk often find, however, that the perceptions held by affected parties of the seriousness of some risks differ significantly from what quantitive assessments may indicate. The judgments individuals and groups make about risk may depend on personal biases and interpretations of consequence made with reference to highly personal sets of beliefs (Thomas 1981). For example, the possibility of catastrophic effects, however remote, appears to profoundly influence some people's attitudes and actions. Quanitititative risk assessments, though seemingly more objective, may also depend on a variety of subjective judgments on the part of the analyst. Most often this subjectivity is introduced because there is more than one way to incorporate technical information into the assessment (Smalley 1980).

To assess quantitatively the risk posed by a hazardous undertaking, a two-part computation is required. First, since it is not certain that calamity will occur, the probability of occurrence must be estimated. Second, even if catastrophe does occur it is not certain how great the damages will be. Thus the likely impacts must also be estimated. Ideally, "the expected value" of the risk is then the product of these two estimates (Smalley 1980). When probabilities are conditional, such as when a so-called fault-tree analysis is performed, a complex calculus of probabilities must also be brought into play. The problem of estimating impacts and probabilities is further complicated by the fact that we have little experience with activities such as offshore development in harsh environments, leaving little empirical evidence upon which to base analysis.

Ultimately, the question of the "acceptability" of the risks associated with offshore development is one phrased best in terms of the acceptability of particular development alternatives with particular sets of risks, costs and benefits associated with them (Derby and Keeney 1981). There is much evidence to suggest that real human decisions about risky enterprises are seldom made without at least implicit reference to the benefit side of the risk-benefit equation. Thus it is not surprising that wide disagreements exist over the appropriateness of present offshore development policies, and that development strategies deemed acceptable in one OCS region may find little acceptance in another (See e.g. Pagan 1980).

Risk assessments in the strict sense have been conducted for a number of years by the US Geological Survey (USGS) for pending OCS lease sales. The USGS Oil Spill Trajectory Model (Lanfear *et al.* 1979) has been used to assess the probabilities and likely trajectories of spills with respect to vulnerable resources in proposed OCS lease sales. Still, the role of such assessments in leasing decisions remains unclear (see Stedman in this issue).

The use and interpretation of risk assessments has several times become involved in OCS ligitation. In the mid 1970's assessments conducted for Long Island communities became persuasive bargaining instruments in disputes with the Department of Interior over leasing in the North and Mid-Atlantic (Koppelman and Robbins 1980). More recently, the issuance by the Environmental Protection Agency (EPA) of permits for the construction and operation of the Pittston refinery in Eastport, Maine was voided pending additional quantitative analysis of the probability of tanker spills in channels near the refinery site (*Roosevelt Campobello International Park Commission v. EPA*, 17 ERC 2023). In a recent Alaskan case, however, the federal circuit court declined to require DOI to conduct extensive quantitative assessments of oil spill risks at the pre-lease sale stage (*Village of False Pass v. Watt*, 18 ERC 2129 and 20 ERC 1705).

It is clear that many potential serious impacts do not lead themselves to formal risk assessments, even though quantitative assessments have proved useful where appropriate. Considerations of risks can be incorporated into OCS oil and gas decisions in a number of ways (Smalley 1980). Improved assessment capabilities can improve management decisions, but simple "automated" decision-making schemes are unlikely to replace the complex interplay among competing interests which now typifies OCS leasing decisions. Nevertheless, the purely informal approach to questions of risk, which Smalley equates with the make-it-as-safe-as-possible approach, is increasingly difficult to justify, because it fails to provide any direct way to compare the reduction in risk achieved to the costs of risk reduction.

Risk Management. Risk reduction, which can work either by impact reduction or by reduction of the probabilities of misfortune, is an important tool of risk management. Efforts to reduce the uncertainties in estimates of the magnitude of potential impacts, or in estimates of the probabilities of accidents, have proved costly and difficult. Yet measures to reduce risks, or to compensate those who must bear it, can be developed fairly easily. Such measures often emerge from the debate over OCS leasing decisions, whether in the courts or through formal and informal bargaining among federal agencies, between federal agencies and the states, or among other affected interests (See Charter, and Hirsch and Scott, in this issue). OCS leasing and development has proceeded, albeit at a slower rate than many would like, in large measure because such bargains have been struck.

The OCS regulatory program has incorporated a variety of risk management measures. The Environmental Studies Program sponsored by the Bureau of Land Management has in many instances made the prediction of impacts a much more tractable problem. Monitoring programs like those developed for the North and Mid-Atlantic and Eastern Gulf of Mexico have allowed exploration to proceed in the face of uncertainties about potential impacts. Improved standards for tanker and pipeline construction and operation have reduced the risk of accidents which release oil into the environment. The Coastal Energy Impact Program, administered under NOAA's Coastal Zone Management Program, has made offshore development more palatable by compensating communities for some of the costs they bear in supporting onshore activities.

In total, measures like these, if they allow OCS development to proceed, constitute a rough measure of societal willingness to pay for oil development offshore. As in other technologically intensive endeavors, risk cannot be reduced to zero and deleterious impacts cannot be eliminated. At the same time, public apprehensions about environmental harm cannot be judged "wrong" when they differ from quantitative assessments of risk. Such perceptions can and do change with the contextual framework in which judgments are made about the acceptability of activities like OCS development. Unavoidably, however, OCS development carries risks and costs as well as benefits.

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Notes

1. "Offshore" refers to both state and federal submerged lands; "OCS" refers to federal lands only, in other words, lands between the state's offshore boundry, typically three miles offshore, and the limits of US jurisdiction.
2. 45 UCS §4321-70 (1969)
3. Drilling fluid is also commonly referred to as drilling mud.
4. There are a number of comprehensive, and in some cases, critical reviews of the articles and reports on the fate and effects of drilling discharges:
   - National Research Council. 1983. Drilling Discharges in the Marine Environment. Washington, DC: US National Research Council.
   - IMCO Services. 1982. Environmental Aspects of Drilling Fluids: A Biography. 3d Ed. Technical Bulletin. Houston, Texas: IMCO Services.
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