petroleum compounds into the air, water column, biota and bottom sediments. Since the different compounds undergo these changes at varying rates, "weathering" also tends to change the composition, and thereby the physical and chemical properties, of the surface slick.

Evaporation is generally the primary means by which oil is removed from the slick during its first few days of existence. Somewhere between 30 and 50 per cent of the volume of most crude oils will be removed this way. Higher removal rates would be expected for lighter distillate oils and much slower amounts (perhaps 10% or less) for Bunker C oil (National Academy of Sciences, 1975). There are also several processes by which petroleum compounds may enter the subsurface regime (the water column and bottom sediments). While usually not as substantial volume-wise as evaporation, these processes are likely to be more important from an ecological viewpoint because damage from the spill depends largely on the concentrations and characteristics of the hydrocarbons in the water column and sediments. While oil is popularly considered immiscible in water, some hydrocarbons, including the most toxic ones, can dissolve. Large, less soluble molecules may form colloidal-sized particles that can be suspended or "accommodated" in water (Peake and Hodgson, 1966, 1967; Boehm and Quinn, 1973), a state that in the past has often been confused with true solution. One such mechanism for this is wave-induced dispersion — the simple tearing off of oil globules by waves.

Oil may reach the bottom by one of three paths. Probably the most important is the sediment transport route — oil globules can adhere to suspended sediments and the conglomerate, being denser than water,
will sink. Or oil may sink from its own weight, though this will occur only for the very heaviest of oils and even then only after weathering removes the lighter compounds. Finally oil may be ingested by organisms, particularly copepods (Freegarde, et al, 1971), and be carried downward in fecal pellets.

Another weathering process is the formation of water-in-oil emulsions, with water content ranging up to 80%. As water content climbs above 50% the oil takes on a sticky, greaselike, extremely viscous consistency which has been called a "mousse" after the dessert it resembles.

Finally, biodegradation and photochemical oxidation are two processes involved in the ultimate removal of oil from the environment. Both operate over the long-term (i.e., weeks to months, and even years) and change hydrocarbons into biomass or into more soluble organics, which dissolve or are further broken down, eventually to CO₂ and water.

Many of the dissipative processes, particularly evaporation and dissolution, preferentially affect the most volatile compounds, which also happen to be the lighter and less viscous ones. Hence as weathering proceeds, the slick tends to become heavier, more viscous (often by several orders of magnitude (Hellmann, 1971; Rashid, 1974)) and less susceptible to spreading. The ultimate result is breakup of the heavy oil into dense tarballs.

At the time of the Argo Merchant spill, it was a popular practice to illustrate all these pathways in one diagram full of arrows. Some examples are shown in Figure 2.3-1.
As for effects, an oil spill can have several. Generally the most noticeable is the death of seabirds after being coated by the surface slick. Oil on the surface in the water column and in the sediments may be lethal to exposed organisms. Massive mortality of benthic organisms was found after the 1969 West Falmouth spill (Blumer et al., 1970). In lesser concentrations oil can cause sublethal effects. These may weaken an organism enough to make it more susceptible to other stresses. In some cases oil can interfere with chemoreception, an organism's little-understood ability to chemically sense food or mating partners. Hence these sublethal effects may prove important in the long run. On the community level, since species vary in their susceptibility to harm from oil pollution, a spill may change the species composition of a region and will tend to reduce the species diversity. Finally, low levels of hydrocarbons in the tissues of commercially important fish, while not harming the fish themselves, may give the meat an oily taste and so reduce its economic value. Such contamination is known as tainting.

At the time of the Argo Merchant spill, ability to predict a spill's effects was extremely primitive. This stemmed from the lack of data on effects as a function of concentration — many early bioassays, for instance, did not adequately measure relevant hydrocarbon concentrations (Moore et al., 1973) — and from lack of understanding of ecosystem dynamics.

What was known is that a certain family of hydrocarbons — the aromatics — were responsible for most of the observed toxicity of oil.
Sensitivity to oil pollution varied among species and with life stage, larvae and juveniles being more sensitive than adults. Reviewing the literature in existence as of 1973, Moore et al. (1973) found that adult organisms can suffer sublethal effects when exposed to aromatic concentrations on the order of 1 ppm and lethal effects from 10-100 ppm. Most aquatic plant life is not harmed by 100 ppm aromatic levels.

Larvae are susceptible to .1 ppm and possibly even less (Rice, et al, 1977; Anderson, 1977). But the ability to go beyond that was lacking. About all that was known was that the most obviously dangerous spills were large ones of aromatic-rich No. 2 fuel oil in small enclosed areas.

Understanding of weathering was only slightly better than of effects. It was known what the processes are. And it was known what factors determine the rate of these processes. (Temperature, surface area and thickness of the oil, water turbulence and the chemical composition of the oil seem to be important for all processes. Others, such as sunlight, suspended sediment and bacterial concentrations are obviously important only for certain processes.) Finally, the relative residence times of oil in the different regimes was also known. Of importance to this report, for instance, is that oil remains in the water column only a short time before dispersing to very low concentrations, being degraded, resurfacing or evaporating. Oil remains in the sediment for far longer periods, weeks to years, with degradation limited by low light and oxygen levels.

However, still lacking was the ability to predict the magnitudes
and rates of these processes under any given condition. Rate constants for the processes (except perhaps for evaporation) were unknown and the interaction among the processes themselves and between the weathering and spreading made it a particularly difficult modeling problem. Hence, at the time of the Argo Merchant spill, no one claimed to have an adequate model for any of these processes except evaporation. There were, on the other hand, several models of spreading and surface slick growth. But these were generally not very realistic (Stolzenbach et al., 1977).

The only process that was understood well enough to be modeled in a useful manner was surface slick advection. But even here, many gaps remained. One particular problem was distinguishing the influence of winds from that of surface currents and of waves, since winds help form both the surface currents and the waves. Most modelers merely used a wind factor approach. They moved the oil at a speed equal to some percentage (usually around 3%) of the wind speed in a direction that was usually the same as the wind's direction, although some modelers deflected the oil movement a small amount (less than 45°) from the wind direction. Some modelers used this wind factor alone, hoping it accounted for wind, surface currents and waves. Others used the wind factor plus surface currents derived from drift bottle data. Some used the wind factor plus some wave-induced motion. Others used the wind to calculate a surface current by solving some equations of fluid dynamics. Some added the wind factor to this and some didn't. In addition risk assessments usually required modeling the movement of a
hypothetical spill several hundred times using some historical or synthetic wind records characteristic of the site. And there were many different approaches to handling and inputting this wind data.

To summarize, then, at the time of the Argo Merchant spill, the state of the art of risk assessments consisted of determining a probability distribution of the path of the surface oil slick. From the slick's destination, some gross estimate of its effects could be made. At least it could be determined which areas were particularly risky ones for offshore drilling platforms. Which brings us back to BLM.

2.4 BLM and Baseline Studies

In addition to risk assessments for various areas, BLM required baseline studies of environmental quality against which the effects of OCS operations could be evaluated. This in turn required development of programs detailing which data should be collected and how often for the purposes of detecting these effects. As has been mentioned, while not constituting actual post-spill study plans, such programs could serve as blueprints for post-spill studies. Hence, the BLM-sponsored projects — both risk assessments and baseline studies — began filling in the gap left by the National Contingency Plan in the ability to study offshore spills. Many of these programs first came to fruition in the months surrounding the Argo Merchant spill.

NOAA received a hefty grant from BLM and plunged more deeply into oil spill-related research. It formed an OCS task force to help design monitoring programs. The task force came out with a report (NOAA, 1976)
in February, 1976, ten months before the Argo Merchant spill. Development of various sub-programs continued. For instance, a microbiology workshop was held in October, 1976, at which the various possible microbiological tests were listed, costed and prioritized. This was two months before the spill.

Grants for extensive benchmark studies of the Georges Bank Lease Area were announced in September 1976, three months before the oil spill. EG&G and Raytheon Co., two environmental consulting firms, were to receive a total of about $4 million for physical oceanographical studies. Energy Resources Co. (ERCo.), another Boston-area consulting firm, was given almost $3 million for chemical and biological studies. The USGS was given $710,000 for geological oceanographic studies. Plans were drawn up and finalized but studies were not scheduled to begin until early 1977. This was one or two months after the spill.

2.5 NOAA and the 'Spill of Opportunity'

But the developments that most influenced the scientific response to the Argo Merchant spill were not related to the Georges Bank OCS area, in which the spill actually occurred, but to the Alaska area thousands of miles away. It is not stretching the truth to say that the initial impetus for the study of the Argo Merchant spill originated in Alaska and traveled to Nantucket Shoals via Seattle, Wash., Boulder, Colo., and Washington, D.C.

While there was concern about petroleum development on the Georges Bank and elsewhere, no place merited greater concern than Alaska, with its still largely undeveloped coastline, its fragile Arctic ecosystems.
and a treacherous climate that just seemed to invite spills. The high level of concern for Alaska was reflected in BLM's budget for OCS studies. In Fiscal Year 1975, for instance, BLM granted $4 million for studies of the Mississippi-Alabama-Florida region, $4.6 million for Southern California, $2.2 million for South Texas and $2.9 million for the mid-Atlantic area. But for Alaska it gave $28.1 million.

All but $200,000 of this total went to NOAA, which had first been asked in May, 1974 to provide data for an environmental assessment of oil production in the Northeast Gulf of Alaska. Gradually NOAA assumed responsibility for almost the entire Alaskan OCS study and set up an Outer Continental Shelf Environmental Assessment Program (OCSEAP) within its Environmental Research Laboratory in Boulder.

Part of the NOAA effort was devoted to risk assessments, for which, it has been said, the state of the art was fairly limited. Even with regard to surface oil movement the approaches were fairly crude and there was no consensus on how to effectively include wind-induced, wave-induced and current-induced motions without counting them more than once. Jerry Galt, a physical oceanographer at NOAA's Pacific Marine Environmental Laboratory in Seattle, was in charge of the modeling for the NOAA's Alaskan OCS studies. Galt performed risk assessments using various approaches and discovered that "it makes some really startling differences which approach you use."

It was largely to help improve Galt's modeling, to help choose the best approach, that the Oil Spill Trajectory Experiment Planning Team was formed. The first formal expression of the idea was a March, 1976
draft plan prepared by Craig Hooper of the Boulder OCSEAP office. This was 9 months before the spill. The team, a joint project of NOAA and the Coast Guard Research and Development Center in Groton, Connecticut, would try to provide basic data for modeling input by conducting laboratory experiments and by observing both planned and accidental spills. But the initial emphasis was to be on observing accidental spills, since it would take time to receive the permits for a deliberate spill.

In May, 1976, James Mattson of NOAA's Center for Experimental Design and Data Analysis (CEDDA), and Elaine Chan of the Deepwater Ports Project Office, both in Washington, D.C., responded to a spill in the Florida Keys (Mattson and Chan, 1976). They made airborne measurements of current, winds and oil velocities, took photographs of the spill and dropped drift cards. Based on this effort and further discussions, details were added to the original March plan in June, again in July and finally in September. This was three months before the Argo Merchant went aground.

The September plan was much more an explicit operations plan than the March draft, which was more an expression of intent. The September plan discussed the means by which the team members were to be notified of a spill, what criteria were to be used in deciding whether or not to respond to a spill, and how the team members were to procure needed services once on-scene. It included a list of equipment. As far as the actual operations were concerned, heavy emphasis was placed on gathering data related to oil movement on the surface — weathering
and spreading data were clearly secondary. The spill was to be mapped and photographed. Wind measurements were to be made frequently, either from a plane using a smoke plume or from a ship using a hand-held anemometer. Water velocities were to be measured, hourly if possible, using either a Richardson current probe or observations with respect to a fixed marker. Oil velocities were also to be measured.

Implicit in this array of measurements was a desire to measure the slick's "leeway," the difference in speed between the oil and the surface water, expressed as a function of wind speed. This was first measured by Smith (1974), who found that oil moved faster than the surface water by an amount that was 2% of the wind speed. Determination of the leeway, it was thought, would help separate out the oil drift resulting directly from the wind from that resulting from wind acting through surface currents and waves.

The important thing to note is that the NOAA/CG Oil spill Trajectory Planning Team was the first group explicitly formed to respond to oil spills because of their scientific interest. But the objectives of the team were narrow. It was not to be concerned with providing advice to the on-scene coordinator and it was not to be concerned with biological assessment. It was interested in the spill purely as a "spill of opportunity". And even in this regard, its focus was fairly restricted to the horizontal advection of oil.

The team was an informal conglomeration of about 14 persons who worked for various NOAA departments, the Coast Guard and the State of Alaska's Department of Environmental Conservation. There were units
of the team in Seattle, Washington, D.C. and Boulder and two units in Alaska. The team was so new at the time of the Argo Merchant spill and so well camouflaged in the rest of the NOAA bureaucracy that NOAA's representative to the National Response Team had never even heard of it.

In October, 1976, the team members assembled at Santa Barbara for a two-week training session using slicks from the Channel’s natural oil seeps. This was two months before the spill. By November, the team was ready for its first spill, preferably a large one in the open ocean during cold weather, so that the findings would be more directly applicable to Alaska.

This was one month before the spill.
CHAPTER 3
BEFORE THE DELUGE

3.1 The Grounding

The Argo Merchant ran aground at 6:00 a.m. on Wednesday, December 15, 1976, and by 7:00 a.m. the Coast Guard had monitored the Mayday.

The tanker was stuck on a sandy shoal that reached to within 10 meters or so of the water's surface. The shoal was one of the Nantucket Shoals. The area was in international waters, about 29 nautical miles southeast of the island of Nantucket, Mass. The location is shown in Figure 3.1-1.

When it grounded, the Argo Merchant was carrying some 7 1/2 million gallons (about 184,000 barrels) of No. 6 fuel oil from a refinery in Puerto La Cruz, Venezuela to Salem, Mass., for the Northeast Petroleum Company. Actually, it was carrying two different varieties of No. 6 oil, 50,000 barrels of one and 134,000 barrels of the other. No. 6 fuel oil is also called "residual" oil, because when crude oil is separated into its various distillates, No. 6 is the stuff that remains at the bottom of the column. It is the highest-boiling, most viscous and the most dense part of the oil, more semi-solid than fluid. The pour points of the two Argo Merchant oils, the temperatures at which they congealed, were 10°C and 20°C. To keep it fluid, the oil was heated to about 100°C while in transit. In addition, some lighter, less viscous oil, called the cutter stock, was mixed in.
FIGURE 3.1-1: The scene of the grounding. Position of vessel is indicated by star. Where it should have been was in Boston Harbor Traffic Lane. Depth contours are in fathoms.
The ship was 195 meters long, 26 meters wide and had a maximum
draught of 10 meters (Lloyd's Register of Ships,1975-76), which is one
reason it went aground in 10 meters of water. It also had a broken
gyrocompass, which is another reason. Without the gyrocompass, the
crew had to rely on far less accurate magnetic compass and the ship
was reportedly 24 miles off its plotted course when it hit bottom.
It was also reported that the master and crew had also misinterpreted
the radio signal from Nantucket Lightship, which normally steers
vessels clear of the hazardous shoals. Instead of being dead ahead
of them, the marker was actually about 30 miles directly behind them.

Nantucket Shoals was not a particularly pleasant spot to strand a
tanker, especially in winter. Storms were frequent. The shallow
shoals forced high waves to break over the deck. Currents were
accelerated by being forced through gaps in the shoals, forming current
rips. One such rip, called Fishing Rip, was adjacent to the sandbar
on which the Argo Merchant found itself.

Nor was it a particularly opportune place to have an oil spill.
To the northwest lay the beaches of Cape Cod, Nantucket and Martha's
Vineyard. To the northeast, across the Great South Channel lay the
Georges Bank, which was the center of one of the world's most
productive fisheries for flounder, cod, squid, herring, lobster,
scallops and many other species. The northeast area centered on the
Georges Bank supported an annual catch of about one million metric
tons (NOAA, 1977; Olsen et al.,1977).

All was not well with the fishing however. Overfishing by foreign
vessels had drastically reduced the size of many commercial fish stocks.
Between 1950 and 1975, landings by native New England fishermen had dropped 54.5% (Olsen et al., 1977) as shown in Figure 3.1-2. When the Argo Merchant went aground these fishermen were looking toward the improvement in this situation they hoped would come with the declaration in March, 1977 of 200-mile sovereignty limits around the U.S. On the other flank, the prospect of petroleum drilling worried many fishermen, not to mention others. The last thing anyone needed was a massive oil spill.

It was, however, unlikely that the oil, if it spilled, would cause much direct damage to most commercial fish, which stayed below the surface and could avoid the oil. The major threat was to fish eggs and larvae, which are more sensitive to pollutants. Even though the adult fish generally lived on or near the bottom, many species released eggs that would float near the surface and gradually drop as they grew into larvae and as the larvae grew in size. It is this period near the surface — a period lasting between 2 and 10 days depending largely on water temperature — that eggs and larvae had the greatest chance of coming into contact with oil.

The area near the grounding was a spawning ground for several commercial species — cod, pollock, haddock, yellowtail flounder — and other non-commercial but ecologically important species. However, at the time of the grounding only two of the commercial species were spawning. Pollock was nearing the end of its spawning season, cod just beginning. Cod, incidentally, was a species just showing signs of recovering from overfishing (Fig. 3.1-3) (Olsen et al., 1977).

The effects of the oil would be largely determined by its fate,
FIGURE 3.1-2: The dramatic decline in New England landings owing to increased foreign fishing efforts (from Olsen et al., 1977)
FIGURE 3.1-3: Annual cod catch in New England area centered on Georges Bank (from Olsen et al., 1977).
which in turn was to be partly determined by its direction. There
were several currents that were to carry the Argo Merchant oil once it
left the tanker. Since these currents are important in what is to
come, a word about them now would be useful.

Tidal currents on Nantucket Shoals and Georges Bank were rotary.
Instead of going back and forth with the ebb and flood, a particle
carried by the tide would go round and round in an ellipse (Figure
3.1-4). In one tidal cycle lasting just over 12 hours, the particle
could travel between 8 and 20 miles depending on its location (Bumpus,
1976). The speed of the tidal currents could reach up to 2 knots in
general and perhaps more through the rips.

Longer-term currents of the area were not well-understood. During
the warmer parts of the year there was a clockwise gyre around the
Georges Bank, meaning that flow across the southeast part of it (and
across Great South Channel) was toward the north and west (Bumpus
1973, 1976). But in winters this gyre usually broke down and flow was
predominantly to the south and east. This was perhaps due to the
strength of the prevailing winter winds, which blew from the northwest
"Whatever the reason," noted Bumpus (1976). "the surface drift across
Georges Bank during the autumn and winter is different and contrary
to drift of other seasons." This is important. For it is this
seasonal anomaly more than anything else that was to save Massachusetts
from an onslaught of No. 6 oil.

The rapid water movement in the area kept the water well-mixed
vertically, even during warm months (Olsen, et al., 1977). This
meant that nutrients from dead organisms which sink to the bottom were

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constantly being stirred back up into the upper layers, where they were available for photosynthesis. The area had very high levels of primary productivity, which in turn could support large populations in higher trophic levels. This was one reason the region was such a productive fishery in the first place.

Beyond Georges Bank to the east and south (Fig. 3.1-1) was the edge of the continental shelf and the beginning of the slope, where 100 fathoms gave way rapidly to 1000 fathoms. Submarine canyons cut the slope at various spots and lobsters abounded all along it. Beyond the slope was the Gulf Stream, a major current carrying water from the Gulf of Mexico up the East Coast and into the North Atlantic. The positions of the slope water/shelf water interface and the Gulf Stream are shown in Fig. 3.1-5. It shows the Gulf Stream not quite 200 miles south and southeast of the stranded vessel. Such was the area, then, in which the Argo Merchant's master and crew found themselves that Wednesday morning.

The ship's master, by the way, was Greek. His name was George Papadopoulos. The crew of 38 was multi-national — Greeks, Pakistanis, Hondurans and Trinidadians, among others. The vessel was Liberian, registered under the Liberian flag, that is. Its owners were also Greek. Few people knew who they really were, but they went under the name Thebea Shipping, Inc. Actual management of the vessel was by a New York firm. The vessel had been built in Germany some 23 years before, and since then had had its share of mishaps. Between 1964 and Dec., 1976, it had been involved in 18 other accidents including 2 other groundings.
The oil in the tanker was carried in individual tanks. There were 30 of these on the Argo Merchant, arranged in 10 rows of three. Tankers have been described as ice cube trays with decks on top. The bottom and sides of the ice cube tray doubled as the hull of the tanker. Each tank was identified by a number which indicated its row (with the lowest numbers at the bow) and its position in the row, e.g., No. 4 starboard, No. 6 center, No. 10 port. Aft of all the tanks was the engine room. When the Argo Merchant ran aground at 6 a.m., on December 15, 1976, the engine room began to flood.
FIGURE 3.1-5: Map of currents and water masses prepared on day of grounding. Argo Merchant's position is shown by star.

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3.2 The Rescue

The Coast Guard's response was quick. By 8 a.m., an hour after receiving the Mayday message, Coast Guard helicopters reached the scene with dewatering pumps to help empty the engine room. Cutters were diverted to the scene and arrived later that morning. The Atlantic Strike Team, a crack Coast Guard unit especially trained to prevent and control vessel spills, was alerted. The pre-designated OSC, Captain Lynn Hein of the Marine Safety Office, departed for Cape Cod to evaluate the situation. And in Boston, Capt. Walter Folger, Chairman of the Regional Response Team, called its members to a meeting.

It was not a particularly auspicious beginning for the RRT. Only 9 persons showed up the first day, three from the army headquarters at Ft. Devens. Also in attendance were representatives from the Corps of Engineers, the Air Force, EPA, the Geological Survey and one of the secondary agencies, the Federal Disaster Assistance Administration. There was none from the U.S. Fish and Wildlife Service, none from NMFS, and none from the Navy. Worst of all, perhaps, there was no one from the State of Massachusetts. The State claimed the Coast Guard had not notified it; the Coast Guard insisted it had. This was the first of a series of events that led to somewhat ill relations between the Coast Guard and the Commonwealth. But that is another story.

By their own admission, most of the members of the RRT were not ready for the tasks awaiting them. For almost all of them it was
their first major spill. When Captain Folger had taken over the RRT in 1975, he had tried to keep it primed by having quarterly meetings, but the last one, he said, had been in May, half a year back. In addition, some of the people in attendance, including Jack Conlon of EPA and Irv Fistel of the Corps, were not the authorized representatives but their surrogates. "I think people assigned to the team were not briefed enough on what an oil spill is and what they could anticipate to be asked," commented Conlon a few months later. "A lot of people didn't realize what their functions were supposed to be down there," agreed Fistel.

While the Regional Response Team was perhaps not as knowledgeable a body as it could have been, especially since it was initially missing its biologists, its task at first was to round up equipment — tugs, barges, booms, planes. This it did with diligence, many of the members hardly returning home for six days.

From the start, the Coast Guard acted as if the spill were its responsibility. This was made clear the morning of the grounding when the first district commander denied Papadopoulos permission to dump some of his cargo in an attempt to refloat the vessel. The Coast Guard, however, had really no authority over Papadopoulos since the ship was officially in international waters. By the end of the first morning, however, the First District asked the Coast Guard Commandant's authority to invoke the Intervention on the High Seas Act, which would shift control of the salvage attempt to the Coast Guard. Authority was granted that day and intervention
officially invoked the following afternoon, December 16. In addition, the National Contingency Plan’s revolving pollution fund was activated.

Briefly, what happened between December 15 and December 21 was a futile effort to refloat the vessel or at least to prevent a major spill. The first contingent of the Atlantic Strike Team (AST) arrived on Cape Cod at 2:25 p.m. the first day. Based in Elizabeth City, North Carolina, the team handled incidents anywhere on the Eastern seaboard. It had special air-deployable booms and pumps and, before the Argo Merchant incident, claimed never to have lost a vessel in distress. Some team members were on the Argo Merchant by 8:00 that night trying to control the engine room flooding. The flooding, however, had caused the ship to lose its power and, with the heating coils thus out of commission, the oil began to congeal. Some of it leaked into the engine room and gummed up most of the pumps. Nevertheless, some progress was made, and by 1 p.m. on Thursday, December 16, the water level had been lowered 7 feet. The victory proved short-lived, however. That evening 7-foot seas and 25-knot winds battered the hull. Water began coming in all over, bulkheads started to buckle and the flooding became uncontrollable. At 9:39 p.m. on December 16, the ship was evacuated.

Strategy then shifted from emptying the engine room to trying to offload the oil, at least enough of it to allow the ship to be refloated. Barges and tugs were brought in and kept on stand-by.
On December 19, the port anchor was run out to help stabilize the ship. Huge fenders needed to cushion contact between the tanker and the lightering barges were rigged, only to be washed up on deck by the waves that night. On Dec. 20, the fenders were set again and moorings rigged for the barge.

The ship meanwhile, had developed a 15° list and waves crashed onto the sloped deck, making work difficult. Oil had started leaking from ruptured lines and was forced by water out gaps in the tank like toothpaste out of a tube. But the Navy superintendent of salvage flew over the Argo Merchant on December 18 and reported it stable, in no danger of breaking up. And as late as the evening of December 20, the Coast Guard still thought it had a chance.

3.3 Early Science

In the days immediately following the grounding, the focus was on saving the ship if possible and with insuring the safety of the crew. Little oil had yet spilled and there was little concern on the part of the Coast Guard with matters scientific. The most important things Captain Hein and the Atlantic Strike Team needed to know were the condition of the vessel and the weather forecast.

Special weather forecasts for the Fishing Rip Area were initiated the morning of the grounding and were issued several times daily for the duration of the incident to help in scheduling salvage and cleanup operations, dives and overflights.
There was still the possibility, however, that more oil would eventually spill, so very early on the Coast Guard began gearing up its scientific capability to aid in cleanup operations. Two groups within the Coast Guard were called upon to provide this scientific expertise. One was the Coast Guard's Research and Development Center, located in Groton, Conn. It had done much oil-related work before and had the capability to chemically "fingerprint" oil and to model the oil's trajectory. The other group was the Coast Guard Oceanographic Unit based in Washington D.C. It had not done much oil spill work before, being mainly concerned with general physical oceanography to aid other Coast Guard activities. One thing the Oceanographic Unit did was to fly monthly airborne radiation thermometry (ART) surveys of the Atlantic Coast to map surface temperatures using an infrared sensing technique. The data from the survey was combined with weekly satellite data to map the positions of the Gulf Stream and other currents on a weekly basis. It is the Oceanographic Unit which prepared the chart in Figure 3.1.5.

The man who actually flew the ART survey flights was named Joe Deaver and by coincidence Joe Deaver had landed on Cape Cod the day after the grounding. At OSC Hein's request, Coast Guard headquarters authorized Deaver to stay on Cape Cod and fly oil surveillance flights. In addition, headquarters authorized both the Oceanographic Unit and the R&D Center to begin predicting the oil's trajectory. Commander Charles Morgan of the Oceanographic Unit was dispatched to the scene to begin gathering data for the unit's model and to generally
assist Captain Hein. Morgan arrived on Dec. 16 and the Oceanographic Unit had run its first prediction by December 17. The Research and Development Center was even quicker than that. So was a third group of modelers which acted independently of the Coast Guard. This was the U.S. Geological Survey's Water Resources Division in Reston, Virginia. The USGS, as has been mentioned briefly, was a contractor to the Bureau of Land Management for North Atlantic OCS studies. On the day of the grounding, BLM contacted the USGS wanting to know the chances that oil from the tanker would reach shore. BLM was no doubt worried about repercussions of a spill on its already beleaguered leasing plans for the Georges Bank. Richard Smith of the Water Resources Division had only a few months before run a risk assessment model of the North Atlantic OCS Lease Area (Smith et al., 1976). Running the model again posed no problems, and by afternoon's end, Smith and Tim Wyant estimated that oil from the Argo Merchant would have a 10 per cent chance of hitting shore.

The USGS model moved oil in response to the wind (directly downwind at 3.5% of the wind speed) and a tidally averaged long-term current. A three-hour time step was used. To generate probabilities of oil landfall, some 300 trajectories were run, each ending after 60 days or when the oil reached land.

Wind speeds and directions were generated using a lag-one Markov model, also known as a first-order auto-regressive model. For each time step the new wind speed and direction are sampled from a probability distribution that is a function of the wind in the
previous time step. The method thus has a "memory" of one time-step — it accounts for correlations in the winds of two adjacent time steps but cannot see any longer, multi-step patterns. The transition matrices needed for this method were based on 5 years of seasonal data collected by the National Weather Service at its Georges Shoals and Nantucket Shoals Weather towers. Such matrices take several days to prepare from the raw data. Had they not already been available, this technique could not have been used for quick results.

The Geological Survey had little to do with deriving the current field. That data had been fed to it by BLM in the form of polygons which spanned the lease area. Each polygon contained a vector which was the constant current inside the limits of the polygon. There was a different set of polygons and vectors for each month.

BLM, in turn, had obtained these vectors from Bumpus (1973). From 1960-1970 inclusive, Dean Bumpus, a Woods Hole oceanographer had released 165,566 surface drift bottles and 75,485 seabed drifters in a massive study of circulation on the U.S. Atlantic Shelf. His results, shown in Figure 3.3-1, were to find many uses in the Argo Merchant response.

For their first run, Smith and Wyant randomly sampled the initial winds from the seasonal distribution of winds. Subsequently, multiple trajectories were run using observed winds for the first time step. Results were quite sensitive to the initial wind. Smith and Wyant found that oil released December 16 when the winds were southeast at 10 knots would have a 24% chance of landfall.
FIGURE 3.3-1: Drift bottle survey results for December (top) and January, 1960-1970 (from Bumpus, 1973).
Oil released December 17 when Nantucket Light Ship recorded NNW winds at 20 knots would have only a 7% chance of reaching land.

The Coast Guard Research and Development Center's model was designed to forecast the oil's movement during a specific time, not to make probabilistic assessments. The day of the grounding, Ivan Lissauer drew up two sets of predictions.

-- a set of short-term predictions for the six-hour travel of patches of oil leaving the tanker at various times during the next two days.

-- a long-term prediction of the maximum area covered by a continuous spill which would start the afternoon of the grounding and continue through the weekend. During the weekend Lissauer extended the forecast for another few days.

The model moved oil at the vector sum of 3.5% of the wind speed, directly downwind, and the tidal current, with a time step of one hour. Lissauer performed the operation on a hand calculator. A two-day prediction took about 45 minutes.

For forecasted winds Lissauer relied on two sources — synoptic charts and the special forecasts for Fishing Rip made by the National Weather Service. These forecasts predicted six-hourly wind speed and direction for the coming 36-48 hours. Lissauer combined information from the forecasts and the charts into his own prediction by "intuition." The same wind would generally be used for each of the six hourly time steps. Lissauer used the model to make predictions of
the maximum (worst-case) area to be covered by the oil. An example is shown in Figure 3.3-2.

In short, both the R&D Center model and the USGS model were off-the-shelf items, either already developed and programmed or else so simple it could be drawn up quickly. The Oceanographic Unit's model was a little bit different and will be discussed later. Suffice it to say that by a few days after the grounding, before it was even a substantial spill, the Argo Merchant spill already was one of the most modeled spills in history.

3.4 The NOAA Team Arrives

NOAA/CG Oil Spill Trajectory Experiment Planning Team was notified of the grounding at about 11:30 a.m. on December 15. Gary Hufford of the Coast Guard R&D Center in Groton, being closest to the scene, departed quickly by car for Cape Cod, arriving there at 3:30. Elaine Chan arrived from Washington at 9 P.M. and the two set up headquarters at the Holiday Inn in Hyannis.

The next morning Chan and Hufford flew over the wreck in a chartered Cessna 182. They took some photos and made a current measurement using a Richardson probe, but most of the 2 1/2 hour flight was spent briefing the pilot on the nature of the team's activities and on the maneuvers he would have to perform.

Meanwhile other team members began to trickle in. Jim Mattson and Peter Grose arrived Thursday morning, followed later by Craig Hooper, the team's original leader from Boulder. Many of the team members had given up vacation plans. The team lost no time in making
FIGURE 3.3-2: Example of Coast Guard R&D Center's slick forecasts (from Grose and Mattson, 1977).
its presence known in an attempt to procure equipment and aid. It arranged almost immediately with the OSC to have the Coast Guard cutters standing by near the Argo Merchant take hourly wind readings for future trajectory studies. It conferred on December 16 with representatives from EG&G, the BLM contractor, who wanted to do some physical oceanographical work near the Argo Merchant.

It has been said that the team's plan called for concentration on studies of horizontal surface movement of oil. The team wanted to study the vertical subsurface transport of the oil as well, but needed a ship and samplers to do it. One place they thought of looking was Woods Hole Oceanographic Institution.

3.5 WHOI and Friends

The academic community began to mobilize as academic communities are wont to mobilize — by calling meetings. Simultaneous meetings were held December 17 at Woods Hole and at URI. These were the first of what was to become a fairly frequent event in the next few weeks — the massive, multi-institution coordinating sessions which sought to determine "What do we do now?" As Howard Sanders of Woods Hole Oceanographic Institution (WHOI) was later to describe it, only half exaggerating, "We had meetings going on every damned day. All sorts of people came and everyone had their own vested interests."

The meeting at Woods Hole was attended by scientists from the National Marine Fisheries Service (NMFS), the USGS and the Marine Biological Laboratory (MBL), as well as the Oceanographic Institution. Discussion largely focused on two questions — whether to do anything
and what to do specifically. According to Peter Fricke, a sociologist who was a visiting professor at WHOI at the time, about two thirds of those at the meeting were willing to get involved in the scientific effort and some felt a strong obligation to do so. The others were either pressed for time or thought it unwise to get involved. One attendee recalled that there was some discussion on whether the Argo Merchant should be the subject of a massive response or whether it would be more prudent to wait for another spill when everyone would be better prepared.

Determining what to do was even more difficult because, according to all accounts, the meeting was held in an informational vaccum. Few of those present knew much about the situation on Nantucket Shoals. No one, according to Fricke, could even draw a definitive 'X' on a map at the site of the grounding. Nor did anyone know what other researchers were doing.

"It was like a flock of birds sitting around cheeping away at each other," recalled John Farrington. "There was no leadership. No one at the meeting could tell anything about what supplies or money or analytical capability was available. The point is, no one had a plan."

To clarify matters, Jim Mattson of the NOAA/CG team was invited to the afternoon half of the meeting. "Everyone considered them the official group from Washington up to study the spill in its broadest sense," recalled George Kelly of NMFS. But as has been seen, the purpose of the team was not that at all, and while Mattson had some ideas on what could be done, he could not tell the Woods Hole group
how many samplers, ships and bottles of extract were available. For he had come to Woods Hole hoping to find these there.

3.6 URI

At URI, the response was to have a leader and was to be a team effort, because Mason Wilson wanted it that way. Wilson, chairman of the mechanical engineering department, was in charge of a three-year study for the Federal Energy Research and Development Administration (ERDA) of when, where and whether dispersants should be used to combat oil spills. The project involved oceanographers, engineers, chemists and biologists. Decisions regarding whether to use dispersants naturally require knowing what the spill would do without dispersant, and the Argo Merchant spill seemed a good opportunity to learn something about this. "We were going to do fieldwork anyway," Wilson explained. "It just came a little earlier than expected."

A new team was formed that day -- the Oil Spill Response Team -- with the ERDA team as its core and additional chemists and biologists thrown in. Eva Hoffman, a chemical oceanographer, was hired to head the team and work full-time on the URI spill response. The team was given its own headquarters, complete with phones, marine radios and charts, in two former storerooms of the Marine Technical Building on the Narragansett Bay campus of the Graduate School of Oceanography. Some modeling work was also begun in the days following the grounding.

A smaller group of WHOI scientists met again the following day and decided to call in the Oceanus, the Institute's research vessel, and prepare it for an Argo Merchant cruise. It was also decided that
the aim of the cruise would be to collect water column, sediment, and benthic baseline data for later comparison with contaminated areas.

On December 20th, URI scientists met again and decided to likewise commit their brand new research vessel, the Endeavor. But with only one exception, to be discussed shortly, no academic scientists did any actual cruising, sampling or analyzing until after dark on Dec. 20. Between Dec. 17 and Dec. 20, scientific activity was almost the exclusive preserve of two groups — the NOAA/CG team and the Coast Guard Oceanographic Unit. A symbiotic relationship quickly developed between the two groups.

3.7 The NOAA Team Takes Charge

When the NOAA/CG team had first arrived in Hyannis it had requested flight time in Coast Guard planes and helicopters. All available planes were being used in the salvage and rescue effort and, in any case, Hein had never heard of the team. In this regard, the team's link to the Coast Guard R&D Center was a big help in proving the team's legitimacy to Capt. Hein. By December 17, with the Argo Merchant already evacuated, the team was able to abandon its chartered plane and fly with the Coast Guard in its planes and helicopters.

Of course, the NOAA/CG team was not the only group vying for Hein's attention. In the days immediately following the grounding the OSC was besieged by requests for information and flight time from scientists, the press and others. Capt. Hein had neither the time nor, in some cases, the technical knowledge to deal with all of
these, so when Cmdr. Morgan of Oceanographic Unit arrived from Washington on Dec. 16, Hein made him his liaison with the scientific community. Morgan found, however, that the NOAA team was even better suited for this role. It had a broader knowledge of oil's fates and effects than did Morgan, a physical oceanographer. It also had better ties to other agencies and to the academic community. So the NOAA team, in effect, became Morgan's liaison with the rest of the scientific community. From then on, when Hein received requests of a scientific nature, he would refer the caller to Morgan who would in turn generally refer him to the NOAA team. Within a few days after the grounding, the formerly unheard of NOAA/CG team had become a major resource for the Coast Guard.

Morgan's reliance on the NOAA team served to push it further into the center of the scientific response, a place the team did not necessarily want to be. "All of a sudden we became the coordination center," recalled Gary Hufford, the team's only member from the Coast Guard. "It grew so quickly it hindered our purpose in being there." Somewhere along the way, as if to reflect its broader role, the "Oil Spill Trajectory Experiment Planning Team" became simply the "Spilled Oil Research (SOR)" team, a name it has kept since.

Several factors made the SOR team the likely candidate for the coordination role. It was an interdisciplinary team with a broad knowledge of oil pollution. It was a government organization which was looked to for guidance and funding by the academic and commercial institutions, and it was affiliated with both NOAA and the Coast Guard.
But most important, it had gotten there first and had a plan. It knew what it wanted to do, at least for starters, while others were still floundering around. As sociologist Fricke put it, "Mattson was the only one with an ongoing idea of what was going on."

During this period the two groups concentrated on what they had come to do. The Oceanographic Unit concerned itself mainly with getting its model into working order. The SOR team concentrated on measurements of oil leeway. Two such measurements were made December 19 and one on December 20. A fourth was made December 22. The measurements were made by dropping a line of dye markers downwind of a pancake and observing how quickly the pancake caught up to the dye markers. Measurements were made from either a helicopter or a fixed wing aircraft, using both time-lapse photography or directly using a Coast Guard viewfinder. The difference in speed was then expressed as a percentage of on-scene winds, measured by the Cutter Vigilant.

Many current measurements were taken or attempted during this period. The SOR team made several Richardson probe measurements in addition to those made in conjunction with leeway experiments. The technique involves measuring the separation of timed dye patch releases. Being very short-term measurements (a few minutes) they reflected mainly the area's strong tidal currents. On December 18th and 19th, John Fornshell of the Oceanographic Unit tried to obtain some measurements with a current meter deployed off the side of the Vigilant. His intention was to take measurements at 3 depths per site, for about 15 or 20 minutes at each depth, according to Commander.
Morgan, and then move on to a new location. Those measurements too would be tidally dominated, but it was hoped they could give at least some indication of the mean, tidally averaged flow for input into the Oceanographic Unit's model. Unfortunately, Fornshell's current meter did not work.

A variety of surface drifters were also deployed during this period. On December 18, 19, and 20, the SOR team dropped polypropylene drift cards in batches of 25 near the wreck. If the drift cards did indeed simulate oil movement, which their use in the Florida Keys spill had seemed to indicate, they would be useful in helping spot the oil from the air.

The Oceanographic Unit also deployed some drifters to follow the oil and give some indication of the long-term current. One drifter was a datum marker buoy, a device commonly used by the Coast Guard in search and rescue operations. The buoy emits a radio signal which permits it to be tracked for about 3 days. This particular buoy, released near the Argo on December 18, was spotted 3 times, the last being on December 20 at 10:23 a.m.

The Oceanographic Unit also had the Vigilant deploy 3 plywood sheets as drifters. The sheets were 4 feet by 4 feet, 1/4-inch thick and painted light yellow. Each was numbered on each side with a huge black numeral stretching the entire length of the board. Each was also liberally striped with reflective tape to make it easier to spot on the water. Each time a Coast Guard vessel spotted one of these drifters, it was to report the drifter's number and position.
The effort proved ill-fated from the start. The sheets were dropped off the Vigilant on December 18. As they hit the water, the reflective tape peeled off. Only one of the boards was ever seen again, and that one only one time, and that time on February 2.

During this period, the SOR team took only one sample of oil with a bucket from a helicopter on December 19. Concerned about whether the oil would sink, the team took the oil back to the Holiday Inn and ran it under hot and cold tap water. The oil did not sink in its fresh water bath.

That, then, was the extent of the scientific effort from the grounding through December 20 — many meetings, many phone calls, attempts to marshall equipment. Active operations were confined mainly to modeling, to mapping, and to measuring wind, water and oil velocities. Except for the modeling, these investigations were carried out mainly by the Coast Guard Oceanographic Unit and the SOR team, which had reached a modus vivendi. The six-day period before December 21 was, essentially, a period of preparation for scientists.

It was also a period of preparation for the spill. Oil started escaping from the vessel the day of the grounding, but for a few days discharges were intermittent, growing gradually larger as the condition of the vessel worsened. On December 17 the trail of oil was reported running 2 miles north thence to 2 1/2 miles west thence back to ship. On December 18 it was estimated that 100,000 gallons had spilled, officially classifying the Argo Merchant as a
"major spill" according to National Contingency Plan guidelines. How was this volume estimated? There really was no good way, according to Captain Hein, who said all early estimates of spill rates and volumes were "guesstimates" made on the basis of whatever information was available on the surface slick and on the conditions and contents of the ship's tanks. "At one point," he recalled, referring to the particular estimate above, "I said, 'Oh hell, it's got to be 100,000 barrels by now,' to make it a major spill."

That estimate was increased by an order of magnitude to 1.5 million barrels by the next day, based on SOR team observations.

3.8 Jerry Milgram Takes a Sample

The one exception to the lack of early participation by the academic community was Jerome Milgram of MIT's Department of Ocean Engineering. Milgram, a naval architect, had been a Coast Guard contractor on various projects since 1968. At the time of the Argo Merchant, he was involved as a principal investigator on one project to study the dispersion of oil by breaking waves, and as a consultant on two others. In dealing with the Coast Guard, Milgram had stressed the importance of observing actual ocean spills and had elicited a promise that he would be allowed to do so in the future. So when the Argo Merchant ran aground, Milgram went straight to Coast Guard headquarters in Washington, skirting the OSC, to cash in on that promise. The result was a ringside seat for 3 days on a Coast Guard cutter near the Argo Merchant and for a time on the tanker itself. At 4:25 p.m. on December 16, the cutter Bittersweet delivered Milgram and Ed Kern, an associate,
to the Argo Merchant along with 4 Atlantic Strike Team members and an additional pumping system. The Intervention Convention had been invoked 1 1/2 hours earlier and attempts were being made to control flooding in the engine room.

Milgram's main concern was observing the dispersion of oil by breaking waves. He and Kern made careful observations, took many photos, and even made a movie of the slick and the ship. He observed, he said, that the 6-7 ft. waves present in the area at the time would not break in thickly oiled areas and would break only rarely in thin sheens. He also observed that the edge of breakers would often "bite off" a piece of oil and send it dispersed as globules into the water column.

Milgram also took the first slick samples on December 17. Using a bucket, Milgram scooped up a sample of oil from a thick part of the floating slick and one from the thin part. He transferred the oil, which by his estimate had been afloat 12-48 hours, to 1-liter wide-mouthed jars and closed the jars with screw caps. He obtained 2 more slick samples — one thick and one thin — on December 19.

More importantly, while hovering over the wreck in a helicopter on December 19, Milgram lowered a 1-liter bottle down to an Atlantic Strike Team member on board who dipped it into the number 4 port tank and filled it with oil. This was the only sample of unweathered cargo taken during the entire incident.

On December 19, Milgram returned to MIT and measured the physical properties of both the cargo and the December 19 slick samples —
the viscosity, surface tension, pour point and specific gravity. He also performed a distillation analysis and found that 25% of the oil boiled off below 120°C. This portion was largely the "cutter" stock of light oil and it was this oil that Milgram assumed would quickly evaporate after the spill. Significantly, the residue above 210°C had the same specific gravity as the cargo sample and as the thick slick sample — 0.96, an indication that the oil would not weather and sink of its own accord.

In the coming months, the lack of adequate reference samples was to become a problem. Milgram's small sample, while sufficient for chemical analysis, was insufficient for all the uses to which such a sample might be put — bioassays, weathering studies, etc. It was also not enough to go around to all the labs needing reference samples for chemical analyses. Finally, there were two No. 6 oils in the tanker anyway, so Milgram's sample was not sufficient. The need for reference samples eventually prompted efforts to obtain samples of both No. 6 oils and the cutter stock from Venezuela, an attempt that got tangled in international red tape.*

As was mentioned in Chapter II, the on-scene coordinator has the responsibility to obtain cargo and spill samples; in fact, it is just about the only thing scientific required of him. Captain Hein, who did not go out to the Argo Merchant himself, said he did not forget this responsibility. "I asked people to get samples," he said.

*On February 5, Peter Fricke of WHOI did manage to obtain from a tanker in Boston 5 gallons of oil from the same refinery as the Argo Merchant oil. Both oils were said to have been refined the same way.
referring to the Atlantic Strike Team. "But in the heat of the battle out there, sampling is the one thing you don't think about."

Had there been other scientists like Milgram with access to the grounded tanker, more samples would have surely been taken, because it is such an obvious and essential task. But Milgram and Kern were the only independent investigators ever to board the Argo Merchant, and here's why.
CHAPTER 4

THE BREAKUP

4.1 The Argo Merchant Gives Up

Because at 8:45 a.m. on December 21, six days after running aground, the Argo Merchant split apart and proceeded to dump most of its remaining cargo into the sea. The break was just aft of the kingpost and 100 feet aft of the bridge. The bow and stern sections gnashed together as the stern began to sink.

Any groups which until now had held back, hoping for the best, held back no more, at least on expressions of concern and outrage. Those who had been worried and active all along, worried and acted even more. With 5.5 million gallons of oil in the water, the threat of massive damage was very real indeed.

Russell Train, EPA administrator, flew over the spill that day and called it "the biggest oil spill disaster on the American Coast in our history." He told EPA to get busy.

The state of Massachusetts' Dept. of Fisheries and Wildlife met with several other groups to establish a bird-cleaning operation. Other state agencies began to assemble volunteer groups to clean up the beaches should the oil reach them.

The Coast Guard, too, seemed to shift from concern over the tanker to concern over the environment. The day of the breakup, the Coast Guard hired Coastal Services and Jetline Services to deploy equipment to protect Nantucket from oil. The state of Massachusetts had first hired Coastal Services several days before. Coast Guard headquarters
in Washington also ordered the R/V Evergreen, the research vessel of
the CG R&D Center, to make a survey of the area to determine environ-
mental harm from the spill.

Of course, the Coast Guard's business on the ship was not finished
yet. While the stern section was lost, the Coast Guard thought it
might still be possible to tow the bow section, thought to contain
as much as 2 million gallons, out to sea and sink it. That after-
noon Coast Guard headquarters sent a message to Boston requesting
advice on where the bow could be towed to minimize the effects on the
fisheries. Headquarters had its own suggestion — the vicinity of
39° N, 68° W, 135 miles southeast of the wreck site and 70 miles beyond
the 1000-fathom line, the end of the continental slope. This choice,
it said, was based on consideration of currents and of the proximity
of lobster and yellowtail flounder.

District 1 consulted the Oceanographic Unit, which in turn consul-
ted a group at Woods Hole. According to Cmdr. Morgan of the Ocean-
ographic Unit, advice from both groups was somewhat general — avoid
submarine canyons, avoid the Gulf Stream and eddies, and put a trans-
ponder on the bow so it could be relocated if necessary. A position
(39°30'N, 68°20'W) was recommended in headquarters' suggested area.

The bow was never towed anywhere, however. It itself split into
two pieces the next day at 3:40 p.m. and oil poured out of the number 3
port tank at an estimated 500 g.p.h. With the towing idea abandoned,
Capt. Hein next suggested that the bow section (actually the forward
part of the original bow section) be sunk in place with gunfire to
secure its position. This, he argued, would make it easier to monitor
any further pollution emanating from it. In making his request, Hein noted that the #2 tanks and the #1 center might still contain oil, since all the breaks had occurred behind these tanks.

The request to sink the bow was denied by the district commander on December 23.

4.2 The First Research Cruise

The Oceanus, a WHOI research vessel, left Woods Hole late on December 20 on the first post-spill research cruise. The following morning inclement weather and turbulent seas — the same weather and seas that finally overcame the Argo Merchant — forced the cruise to be cut short. Strictly speaking, the Oceanus did get to sea and take some samples before the tanker split apart, and thus might make a claim to being put in the previous chapter. But for purposes of historical analysis, it is much more akin to the activities which were to take place in the next phase of the response from December 20 to, say, December 31. This phase, though no one ever planned the response in phases, was the short-term investigations of the immediate fate and effects of the spill.

The purpose of the cruise was to obtain baseline data on levels of hydrocarbons in the water and sediments. The data so collected before the oil's arrival would be necessary to determine the increase in concentrations following contamination. The crew consisted mainly of Woods Hole people, but also included Jerry Galt, the SOR team's modeler from Seattle, Richard Jadamec, a chemist from the Coast Guard R&D Center, and Dave Folger of the USGS.
Sediment samples were taken at two stations using a 1/25 m² Van Veen grab mounted on a circular frame to insure perpendicular penetration. Half of each sample was placed in glass jars with foil-lined caps and frozen for later hydrocarbon analysis. The other half was preserved with formalin for biological tests.

Surface, mid-depth and near bottom water column samples were also taken and extracted on board using methylene chloride. The crew acknowledged in its subsequent report that the equipment used for the water column sampling was not well-suited for its task but was all that was available on short notice. The 30-liter bottle, John Farrington explained in an interview, entered and emerged from the water with its top open. The presence of oil on the surface would thus contaminate the samples. Also, trace concentrations of naturally-occurring surface-active organics tend to concentrate in the surface micro-layer and could contaminate the samples. In addition, Farrington said, the bottles were plastic, which might also leach petroleum-type substances into the sample. This latter contamination would be barely detectable were the samples contaminated with oil. But it could be significant in measuring unpolluted samples for trace concentrations of hydrocarbons.

That was all there was to the first research cruise — some baseline sampling cut short by the weather — but we will not let it go at that. Being the first cruise, there were many activities that could have been undertaken but were not. The Oceanus could have, for instance, also taken oil samples, or water column samples of contamina-
ted areas, as the SOR team no doubt would have liked. It could have
taken plankton tows instead of only benthic samples. And it could
have gone in many other directions besides or instead of the place
it did go. As a mini-case study of the factors that enter into
quick-response cruise planning, then, let us take a closer look at
why the Oceanus did what it did.

THE OBJECTIVE: The desire to collect baseline data was clearly a
preference of the Woods Hole researchers from the start, back on
December 17. A case can easily be made that this was the wisest
decision possible, inasmuch as the Oceanus was the first ship out
and had sailed before the tanker split apart. Later cruises might
not have a chance to get this data, and, it has been pointed out,
lack of background data has hindered many post-spill assessments in
the past.

However, this cannot have been the only reason Woods Hole went
after baseline data, because it also did this on its second cruise,
December 28, after all the oil had already spilled. Nor does this
explain why the Oceanus did not do more than collect baseline data.
The reason for this, the main reason Woods Hole scientists collected
baseline data, was that they did not want to get oil on the Oceanus,
which was frequently used for surveys of trace hydrocarbon levels
in the oceans and sediments. A contaminated vessel is not suitable for
such analyses (Farrington, 1974) and it would have been expensive to
clean the Oceanus had it passed through large slicks from the Argo
Merchant.
THE ACTIVITIES: Concentrating on hydrocarbons in the water and sediment and on benthos (as opposed to other biological habitats) largely reflected the interests and capabilities of the chief investigators — Farrington, John Teal and Howard Sanders. Benthos are about the easiest organisms to test for impact since they do not move and there is thus less doubt which organisms were exposed to oil and which weren't. The particular gear used, as had been said, largely reflected what was available.

SITE SELECTION: This is perhaps the most interesting decision of all. Of all the possible choices, why go to an area 40 miles northeast of the tanker?

The main reason, all those interviewed agreed, was that the particular area was one with fine-grained sediments. Such fine sediments only accumulate in areas where the water turbulence is low enough to allow them to settle out of suspension. Also, fine grained muds and silts hold oil better than sand. Such areas were thought by the Woods Hole scientists to be likely resting places for oil-sediment globules. A similar site was also chosen for the second Oceanus cruise.

Further, of all the areas with fine-grained sediment, this seemed to be the one the oil was heading for at the time. Jerry Galt said he guided the Oceanus to these stations based on the slick map for December 20, shown in Figure 4.2-1, which he received barely half an hour before the cruise departed. It is indeed true that winds on December 20 had been mainly from the south and that the oil was
FIGURE 4.2-1: Sampling stations of Oceanus cruise. On Dec. 20 (top) oil appears headed toward the stations. But sudden wind change diverts it to southeast by Dec. 21 (bottom). Also shown are forecast slick limits (-----) for times indicated.
heading toward the Oceanus' stations. Figure 4.2-1(a) also shows the Oceanographic Unit's forecasts for December 21 (which were apparently not used in station selection), which predicted that the oil would pass over the stations a few hours after the Oceanus had been there.

The Woods Hole scientists, then, were trying to take baseline data in an area that was likely to be contaminated later. They were implying, (and agreed explicitly in subsequent interviews) that the best use of baseline data is for before-after studies of the same site. Baseline data can also be used as indicative of general background levels over the whole wider region, but its value in this case is a notch lower. Using background data from one area to compare to contaminated levels from another area introduces an additional element of uncertainty, in that spatial differences are not accounted for.

Now consider the following: Just after midnight, probably just about the time the Oceanus was enroute from Station 1 to Station 2, the wind shifted and started blowing the oil to the east and southeast. By the time daylight came, the day's overflight showed no oil in the vicinity of the sampling station, and none apparently ever passed that way again. It is unknown whether in the dark oil actually did reach as far as the Oceanus' stations or, instead, turned right before getting there, but this question is somewhat moot. Even if oil

*Grose and Mattson (1977, p. 126) report: "Surface oil was never observed north of 41°21'." This latitude is south of the WHOI stations.
did reach the area it stayed only a short while. The fact that the area sampled was at best the northeast extremity of the oiled area did not bode well for the chances of oil accumulating in the sediments, especially since the predominant bottom currents were thought to be in precisely the opposite direction — to the southwest. And while some oil might have entered the water column, dissolved and dispersed, oil does not remain that way for long. It either coagulates and resurfaces, evaporates (Frankenfeld, 1973) or is diluted to very low levels (McAuliffe, 1977). Large subsurface concentrations of oil are likely to persist only in areas continually covered by oil or in areas in which dispersants are used. Hence, to perform a before-after study on water column hydrocarbon concentrations would have required returning to the Oceanus sampling sites while the oil was still there (if it was) or within a few hours of its departure. The only vessel close enough to do this was the Oceanus itself, and it had no intention of going back into an oiled area.

The upshot of all of this is the following: Owing to a shift in wind, the value of the baseline data collected was diminished greatly. In fact, the samples could not even be considered representative of the region as a whole since the sites were chosen precisely because they were atypical. Sure enough, the baseline hydrocarbon levels in the Oceanus samples were higher than those found in subsequent samples, almost as high as in some samples judged to be contaminated.

Which brings us to the next question — Could this have been anticipated and the sampling differently planned? The answer is yes and
and no.

The Oceanographic Unit's forecast, as we have already seen, would have led the Oceanus to the same location, since it was based on erroneous wind forecasts. But the probabilistic models might have helped. These showed very high odds that the winds would eventually take the oil to the southeast of the wreck site. And Bumpus' data showed bottom currents were predominantly to the south and west. A case could be made that the Woods Hole group should have played the long-term odds and gone either to the southeast or to the west (they did go to the west on the next cruise, so we will not consider that further). Several of those involved were asked why this wasn't done.

John Teal suggested one answer. The region to the southeast, he said, was not as biologically interesting as other areas, which points up an interesting dilemma. Does one sample where the oil is most likely (but not certain) to go, even if the oil's reaching there would not have as significant an effect as if it went elsewhere? In other words, should one sample the oil or the location? Teal sided with the sampling the most sensitive area. Jerry Galt suggested an answer that was similar to Teal's but somewhat more cynical. He said that the researchers did not care where the oil was going and merely wanted to sample their favorite areas.

Teal and Sanders suggested perhaps the most important reason — the southeast was too far. The Oceanus, after all, had to reach the site before the oil got there. Looking back, because the wind shifted when it did and because the tanker broke up when it did, the research
vessel might not have been able to cut across the slick's path. (It could have, however, at a risk of contamination, sampled at the side of the ever-widening slick). Even if it could have beaten the oil, however, the Oceanus still would not have gone there, said Teal and Sanders, because it would have taken too long. Pressed for time by their own research projects, the researchers did not want to spend more than two days on the cruise, Teal said. Sanders pointed out that the distance factor would also make follow-up studies difficult.

No matter whom one believes, our case-study-within-a-case-study has pointed out the many factors that go into designing a cruise plan quickly and under uncertainty. It shows how the scientific value of the cruise was greatly diminished by a change in winds. More than that, however, it shows that this could have been anticipated and planned for. It wasn't, for a number of factors, some scientific, but many logistical and even personal. Things might have been different had the ship been able to sail into oil, had it been out a day earlier, and had the crew been willing to devote more time to it.

Few would deny that the first Oceanus cruise could have been more valuable. The fact that it wasn't has generally been attributed to the rough weather and stormy seas.

4.3 Sink or Swim?

The fear of damage from the oil spill also spread to Rhode Island on the day of the break-up. One thing the governor's office did was to ask URI's department of ocean engineering what the chances were that oil would wash ashore on Rhode Island. The URI group had not had a
risk assessment model ready to use at the time of the grounding. But Malcolm Spaulding, Chris Noll and Peter Cornillon had developed two of them quickly— one for surface movement and one for bottom movement.

The surface model moved oil at 3.5% of the wind speed with no deflection angle. Tides were added in later runs. Winds were picked at random from a Monte Carlo matrix containing 8 directions and 6 speed ranges, based on 10 years of monthly data for the "Summary of Synoptic Meteorological Observations for North American Coastal Marine Areas" (U.S. Naval Weather Service Command, 1970). Unlike the USCG model, this model had no memory— each 3-hour time step was independent. The model took about a day to develop and was used to generate a probability distribution of the position of the slick's leading edge 5, 10, 15, 20, 25, and 30 days after the release of oil. An example is shown in Figure 4.3-1.

To predict the chances that oil would reach their state, the URI modelers also thought it necessary to model the path of oil that might reach the bottom. The fear that oil would reach the bottom sediments was surpassed in magnitude only by the fear that the surface slick would head directly for Cape Cod or the Georges Bank. Oil in the bottom sediments could be expected to biodegrade very slowly, over a period of years, owing to oxygen limitation. It thus might cause long-term damage to bottom-dwelling organisms, which served as food for commercially important groundfish. In addition, what little evidence there was indicated that whereas the winter surface currents moved offshore with the wind, the bottom currents flowed landward.
FIGURE 4.3-1: URI's 30-day Monte Carlo prediction of position of leading edge of oil (from Noll et al., 1977).
There are, as has been mentioned, three ways for oil to reach the bottom — by weathering and sinking from its own weight, by adhering to sediment particles, and by being ingested and then excreted by copepods. The copepod route was not thought likely to be important but the other two paths were considered by many scientists to be possible, even likely routes for the Argo Merchant oil. The sediment adhesion route was thought likely because the wreck occurred in a highly turbulent and sandy region. The turbulence could be expected to stir up the sand from the shallow bottom and promote its mixing with the oil. It was also known that the water was not thermally stratified and there therefore was no thermocline to impede mixing and the oil's descent.

The sinking route was thought likely because No. 6 oils were known to have specific gravities between 0.9 and 1.0 which could climb above seawater's 1.025 once the lighter components evaporated.

No one in the world at the time of the Argo Merchant spill could have predicted how much oil would be carried down by sticking to sediments. It was beyond scientific capability. Whether the oil would sink from its own weight, however, could have been determined fairly easily, by weighing it after first boiling off the compounds likely to evaporate. This is what Milgram had done the day before the Governor called on URI. But his work, which indicated the oil would not sink this way, was not known to the URI group. What the URI group did have was an erroneous value of specific gravity it had obtained from a contact at the Coast Guard Research and Development
Center. That figure put the oil's specific gravity at .996 instead of Milgram's .96, adding to the URI group's belief that sinking would be very likely indeed.

The URI bottom drift model relied exclusively on Bumpus' (1973) seabed drifter data. His arrows were redrawn and the location and direction of each were digitized. In his seabed study, unlike in his surface study, Bumpus had not assigned magnitudes to the arrows, so the URI group used a constant speed of .7 n.m./day. A dot representing the oil was moved for a period of a day under the influence of the nearest arrow. The array was then searched again for the new nearest arrow, which was used for the next day. To account for the possibility that oil would drift on the surface before sinking, various starting points were used — some along the probable path of the surface slick, some along a north-south transect.

The oil sinking near the wreck was predicted to travel west, then turn north to surface after 30-120 days on Martha's Vineyard. Oil sinking further offshore headed toward Rhode Island. One imaginary subsurface patch did not go anywhere. It got trapped by the digitizing scheme and oscillated indefinitely between two opposing arrows.

4.4 Slick Tracking, Search-and-Rescue Style

By the time the Argo Merchant split apart, the on-line forecasting effort by the Coast Guard Oceanographic Unit was in full swing. The aim of the forecasting was to predict the outer limits of the oil-contaminated areas of the ocean and to warn of landfall. Information from slick overflights was used to correct and update the forecasts on
a daily basis.

In contrast to the other groups modeling the Argo Merchant spill, the Oceanographic Unit had never done an oil spill model before, but it was in the process of developing one. What it did have was a search-and-rescue model designed to predict the drift of lifeboats and debris from a vessel in distress. When asked to model the oil spill, the Oceanographic Unit first ran this model, treating the oil as a life raft with zero draught. At the same time, it hastened the development of its on-line oil spill model. Within a couple of days the new model was computerized, the bugs worked out and a routine established.

The new model computed oil advection as the vector sum of four forces — tides, a wind-induced surface current, additional wind-induced motion on top of the current (the leeway), and a long-term or residual current.

The model did not include weathering or spreading. Yet it did given some indication of the shape and width of the slick by treating the spill not as a single dot, but as a whole array of dots. The dots corresponded to the leading edge of the slick, to specific pancakes within the slick, to bends and corners on the slick's perimeter, and to little peninsulas of oil jutting out from the main body of the slick. The positions of these features were determined by Joe Deaver's overflights. In addition, a new dot was generated at the position of the wreck every 12 hours. Adverting each dot separately under the influence of spatially varying currents achieved the effect of
dispersing the slick. In addition, it provided the capability of forecasting the position of individual features of interest, such as particular pancakes or thin sheen areas. An example of the Oceanographic Unit's forecasts is shown in Figure 4.4-1.

Tides were taken from standard tide table (Haight, 1942), with several roses used for different areas. The figure used for leeway was 1.2% as suggested by the SOR team's measurements. The forecasted winds used were the NWS special forecasts for Fishing Rip. As the area covered by the oil grew, however, two other wind forecasts — both by the U.S. Navy Fleet Numerical in Norfolk, Virginia — were also used, one for the area far to the east of the wreck and one for the region far to the south. Spatially varying surface currents were computed using an Ekman-type model. The actual formulation was that of Jelesnianski (1970).

Determining the residual current proved the knottiest problem, there being little to base it on. Initially it had been decided to try to backfit it. For the first few days this was tried on a one-day basis. The slick's position was hindcast using observed winds for the day just past and the results compared with that day's map. The difference was attributed to the residual current and this current was then used for the next day's forecast. Morgan would call Dean Bumpus at WHOI frequently to check if the values so derived were reasonable. But one day proved too short a period for determining the long-term currents, and this approach was soon abandoned.

The next approach, the one used through the rest of December, was
Figure 4.4-1: An actual hot-off-the-presses hand-drawn slick forecast by Coast Guard Oceanographic Unit showing dots used to define shape, and the polygon used as the outer forecast limits.
to run the model using no residual current at all and to correct the forecast by hand based on the latest weather and oil observations, ART survey data, or just plain intuition. Eventually, sometime in the first half of January, the whole spill was hindcast and a current of .25 knot to the northeast found to work best.

As can easily be seen, this model was more complicated than the other models and required far more data. It used several tidal roses and, for a time at least, 3 wind fields. It required not only forecasted winds but observed winds for several days previous. And it required observations of the oil's actual position for updating and backfitting. Moreover, it needed this information in a timely fashion and the model had to be run frequently enough to be of use. All this was complicated by the fact that the prototype model was continually being refined throughout the course of the spill and by the fact that the modeling was being done in Washington, D.C. "Information flow was a big bugaboo in the Argo Merchant case," said Lt. David Frydenlund, who did the computer work in Washington. "The big problem was getting the input data and sending out the results." Commander Morgan agreed, saying, "Half the problem was making a system out of the thing."

Gradually, however, a system had evolved which operated fairly smoothly during the period when the bulk of the oil was still trackable — the last 10 days of December. The system, which closely tied in the modeling to the slick overflights, worked this way:

The oil spill overflights would generally end by late afternoon or early evening, and by the time he landed Joe Deaver would have his
map drawn. Morgan would compare the map to the day's forecast and to the previous day's map. Some of the pancakes, peninsulas, and turning points that had been modeled as dots the day before would have moved to new positions, which Morgan noted. Others, however, would not be apparent on the new map. They had either dissipated, melted back into the main body of the slick or been missed by the mapper. At the same time, new patches, new bulges, and new corners would have formed to take their place. Morgan would number these new dots and cancel the obsolete ones and would telephone this information to Frydenlund in Washington the next morning, usually at around 10 a.m.

Frydenlund would assume the dots represented the position of the oil at 1 p.m., the day before, corresponding roughly to the mid-point of the overflight. He would then run the model from that time to the present time using observed winds. Then he would forecast ahead until 1 p.m. the next day using forecast winds. Here too, the 1 p.m. time was chosen to represent the midpoint of the overflight, which could last eight hours or more. This was to minimize the distortions arising from the fact that the overflight could not take an instantaneous snapshot of the oil.

When the system was working well, then, it can be seen that the model was on a "leash," so to speak. It could not run more than 48 hours ahead of verified slick positions and errors were thus not allowed to propagate. For the first 20-24 hours the model moved oil in response to observed winds. Any deviation between the actual and the forecasted slick position at the end of this period would be attributable
solely to the model formulation. For the second 24 hours or so, errors could result both from the model's inability and from errors in the wind forecast. The leash "broke" on days when there was no overflight. In such cases, the model was corrected for forecasted wind errors only.

After receiving Morgan's call, it would take Frydenlund 2 to 3 hours to run the model and come up with the next day's forecast. He would phone the forecast to Morgan in the form of the numbered dots and positions. No computer plotting or facsimile transmission here, just your basic, slow, error-prone phone communication. Morgan would plot the dots and, if necessary, correct their positions in some way to account for the residual current. He would draw the slick outline around the dots and around the outline would draw a polygon, leaving about 5 miles between the polygon and the oil boundary as a safety margin. The coordinates of the corners of this polygon were then disseminated as the "forecasted slick limits" for a given date. All surface oil was supposed to lie within these limits.

Morgan would give a copy of the limits to Joe Deaver who would use it to plan the next day's overflight. Deaver would lay a rectangular grid, with nodes spaced 10 miles apart, over a map of the area and plan the flight to cover the grid points which fell inside the forecasted limits.

Flights would be flown in a zig-zag pattern along parallel tracklines spaced 10 miles apart, as shown in Figure 4.4-2. From an altitude of 500 feet, it was easy to see five miles to either side, so the whole
FIGURE 4.4-2: The December 25 mapping flight showing zig-zag pattern, forecast slick limits (---) and the slick map made on the flight.
area between tracklines could be covered. The return route would be used to try to more accurately trace a side of the slick's perimeter. In addition, before starting the zig-zag the flight would check for oil landward of the Argo Merchant. The flights were thus deliberate, methodical scans, based largely on the method used for ART surveys and (like so many other of the Oceanographic Unit’s operations) on search-and-rescue procedure.

Deaver himself was not the pilot but an oil observer. Flights generally had a crew of 8, he said, two of whom were observers, one on each side. The other observer would signal Deaver by hand to indicate the presence of oil and its quantity (e.g. heavy coverage, sparse coverage, thin sheen). Deaver would occasionally check to calibrate his partner's interpretation of these terms with his own.

Deaver would indicate the oil boundaries, pancake locations and sizes, mammal sightings and grid points on the same strip chart used for the ART surveys. Assuming the plane flew at a constant speed between grid points, the position on the strip chart would accurately indicate the position of the sighting. This could be readily transferred in flight to a gridded map.

Usually the oil was not in the form of one continuous slick but consisted at least partly of discrete and dispersed patches. Estimation of the percentage of the surface covered by oil was extremely difficult, as was estimating pancake sizes. While still over land, Deaver would sometimes try to fly over a parking lot. The sizes of autos would help calibrate size estimates of oil patches, and the