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Cost-Benefit Considerations in Routing Pipelines Through Offshore Fishing Grounds

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Table of Contents

Illustrations

I. Introduction

The problem of managing multiple use of our marine resources is becoming increasingly important. One of the more well known and potentially very important for the New England area has come about as a result of the possible existence of exploitable quantities of offshore oil and gas in areas which coincide with the traditionally important fishing grounds on Georges Bank. Experience in the Gulf of Mexico and the North Sea indicates that several potential conflicts may arise and not lend themselves to an easy solution.

One of the areas of major concern is the possible interaction of fishing operations, e.g., bottom trawling and scallop dredging, with submarine pipelines. This has been recognized as a problem in the Gulf of Mexico area as evidenced by OCS Order No. 9, part of which reads, "All pipelines shall be installed and maintained to be compatible with trawling operations and other uses."[29]

The major problem can be described as damage to pipelines and/or fishing gear which result in economic costs to the fisherman (mainly replacement or repair costs and lost fishing time), to the oil industry (mainly pipeline repair costs, and costs of petroleum losses and cleanup efforts if a leak or rupture occurs), and to society at large (mainly the environmental damages from a spill, which may or may not translate into economic losses, depending on where it occurs). Experience in the North Sea and Gulf of Mexico and in various studies has indicated that there are many mechanisms by which the above losses may occur, including not only the impact and/or hooking of fishing gear on pipelines, but also by interactions with the heavy anchors used in shipping and by vessels engaged in offshore construction.[4]

Virtually all offshore oil and all gas from the U.S. OCS is transported to shore via pipeline.[15] For the Georges Bank case, a find of about ½ - 1 billion barrels of oil would justify a pipeline as the preferred mode of transportation for oil (vs. tanker).[10,31] These quantities are well within the latest estimated range for the Georges Bank area.

In light of the perceived problems, a number of alternatives involving different recommendations for multiple use management have been suggested. They range from a continuation of current practice to prohibiting oil development entirely, the latter not uncommonly advocated by many fishing and environmental interests.

When instituting regulations relating to the design and installation of pipelines, society as a whole would benefit most if due consideration were given to all of the costs involved. That is, those due to the pipeline installation itself as well as potential environmental costs and potential costs which might be incurred by the fishing industry. Among the alternatives it is seldom obvious which would be best if the objective were to minimize society's total cost.

The purpose of this work is to explore the technology and economics associated with the options which might be used to transport oil from Georges Bank, with the least total cost objective in mind. The analysis should be useful in spite of several sources of uncertainty. Major sources of uncertainty include the locations of petroleum reserves, the locations of spawning areas, and the future changes to be expected in fishing usage on Georges Bank. In addition, estimates of potential spill impacts must be based on data which may be questionably applicable. The most careful analyses, e.g., that of Stewart,[24] use historic data from the Gulf of Mexico, which differs in many ways, including fishing usage (foreign and domestic), water depths, weather conditions, and at least partly in the technology which will be used by the oil industry.

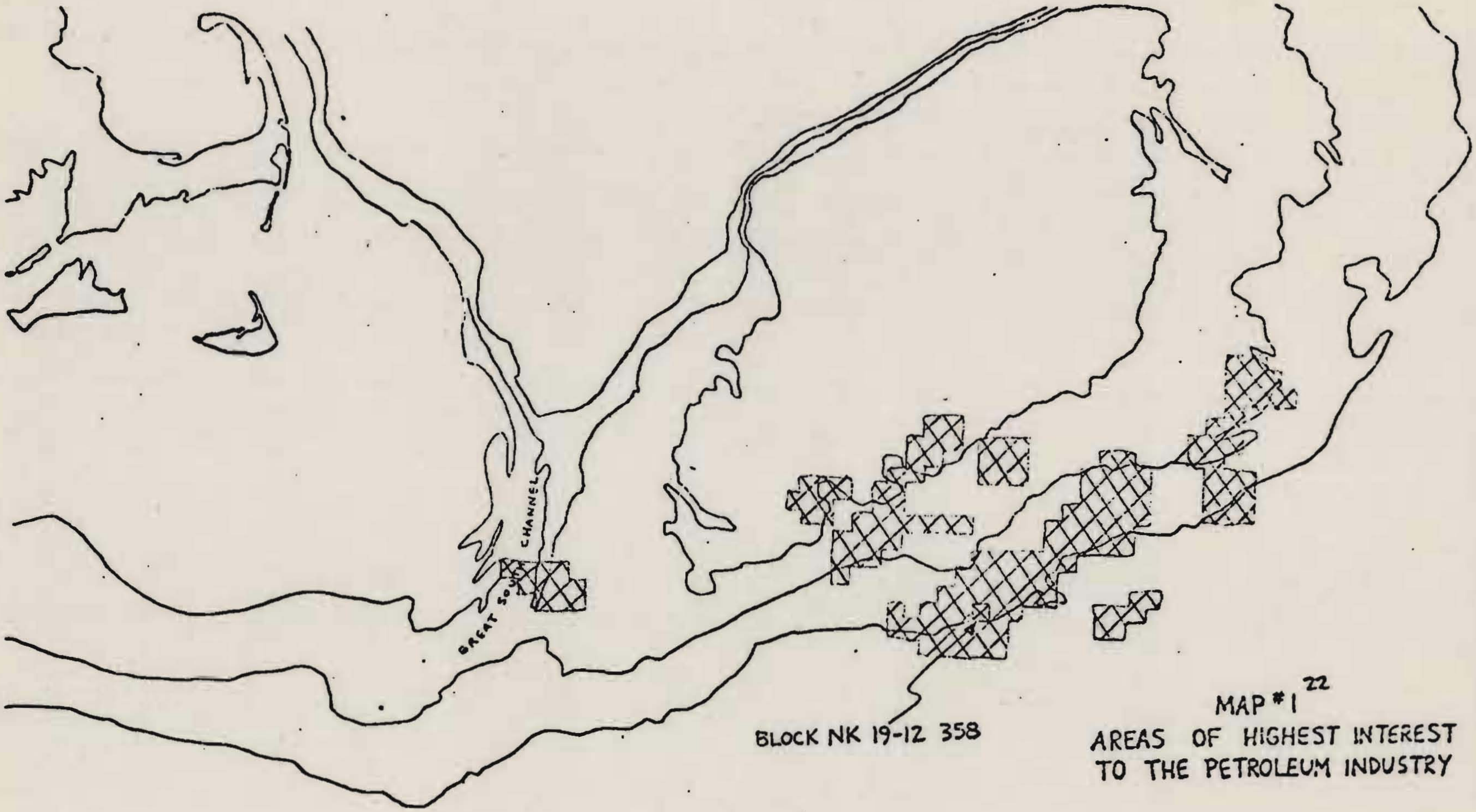
The paper is developed as follows. First, we summarize background information on the existing usage of Georges Bank by fishermen and those offshore areas of greatest interest to the oil industry. This should allow some assumptions as to likely pipeline routes and hence where high risk of interaction may be expected. From this, a consideration of various alternatives of transportation to shore and their relative costs (and benefits) should allow one to get a handle, approximate as it may be, on which might be best for society as a whole in terms of least total cost. Finally, brief mention will be made of the regulatory setting in which the multiple resource use issues raised here would be considered.

II. Petroleum and Fishing Interests on Georges Bank

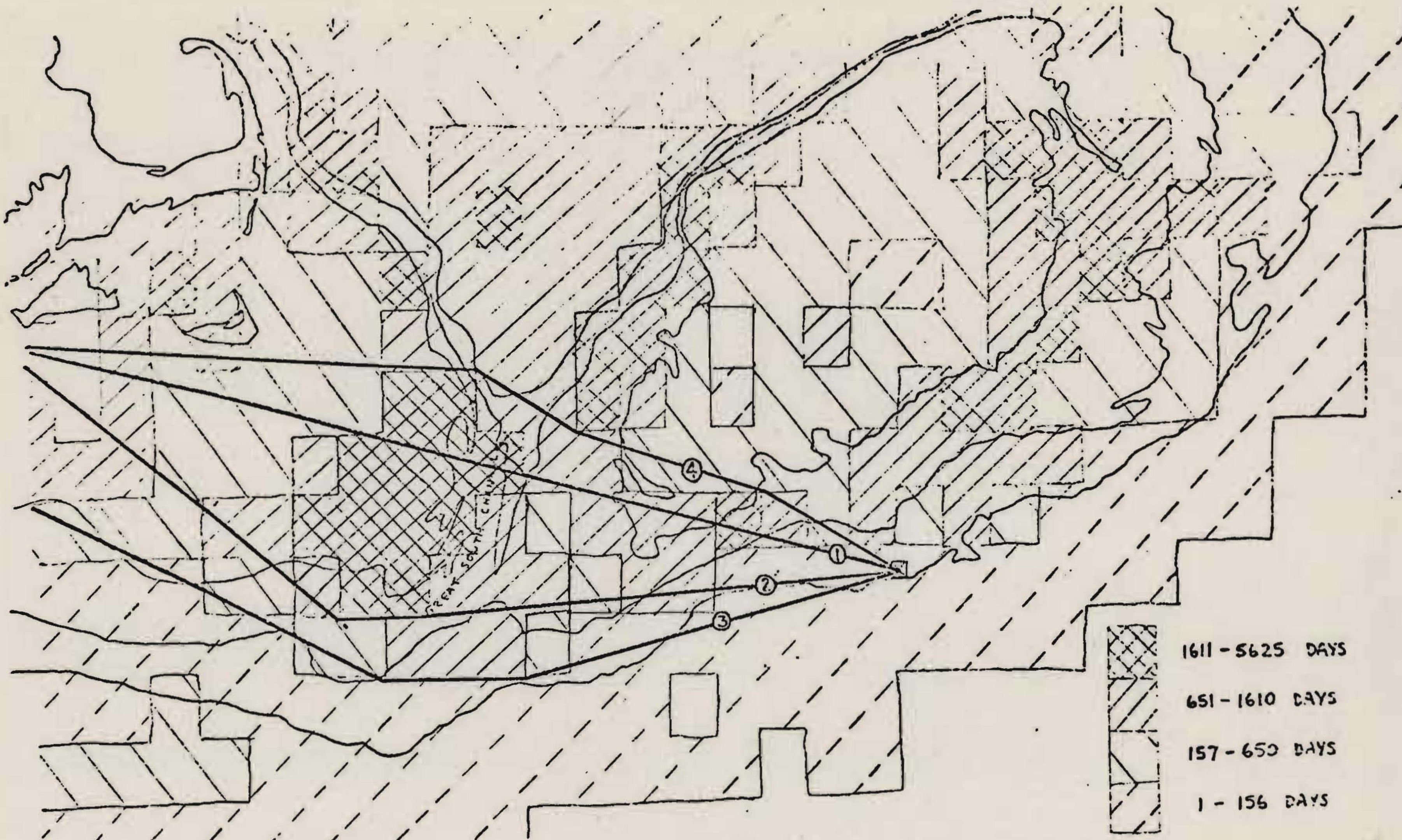
The tracts of offshore areas nominated for leasing by the oil industry are indicated on map #1.[22] In general, the areas may be characterized by depths of 150 to 300 feet, sandy bottom sediments, and frequently rugged weather conditions, especially in the winter. The areas of highest interest are on the order of 100 miles or more offshore.

Several factors must be considered when optimizing the private cost of a pipeline installation. The major factors include orthogonality to currents and wave direction, rates of change in bottom contour so as not to exceed the maximum allowable bend in the pipe, and avoiding "soft spots" and areas of probable scour to prevent pipeline instability.[17] For purposes of this analysis, however, the least cost alternative (in terms of real installation costs only) will be assumed to be a direct route to the shore terminal, which most likely would be sited in the southeast New England area in or near Rhode Island.[6,8,31] This assumption may or may not be correct, but is not critical since the focus here is on use of the offshore areas. For our purposes we are interested in encompassing the range of conditions that apply offshore and likely would be obtained for the most likely onshore facility location.

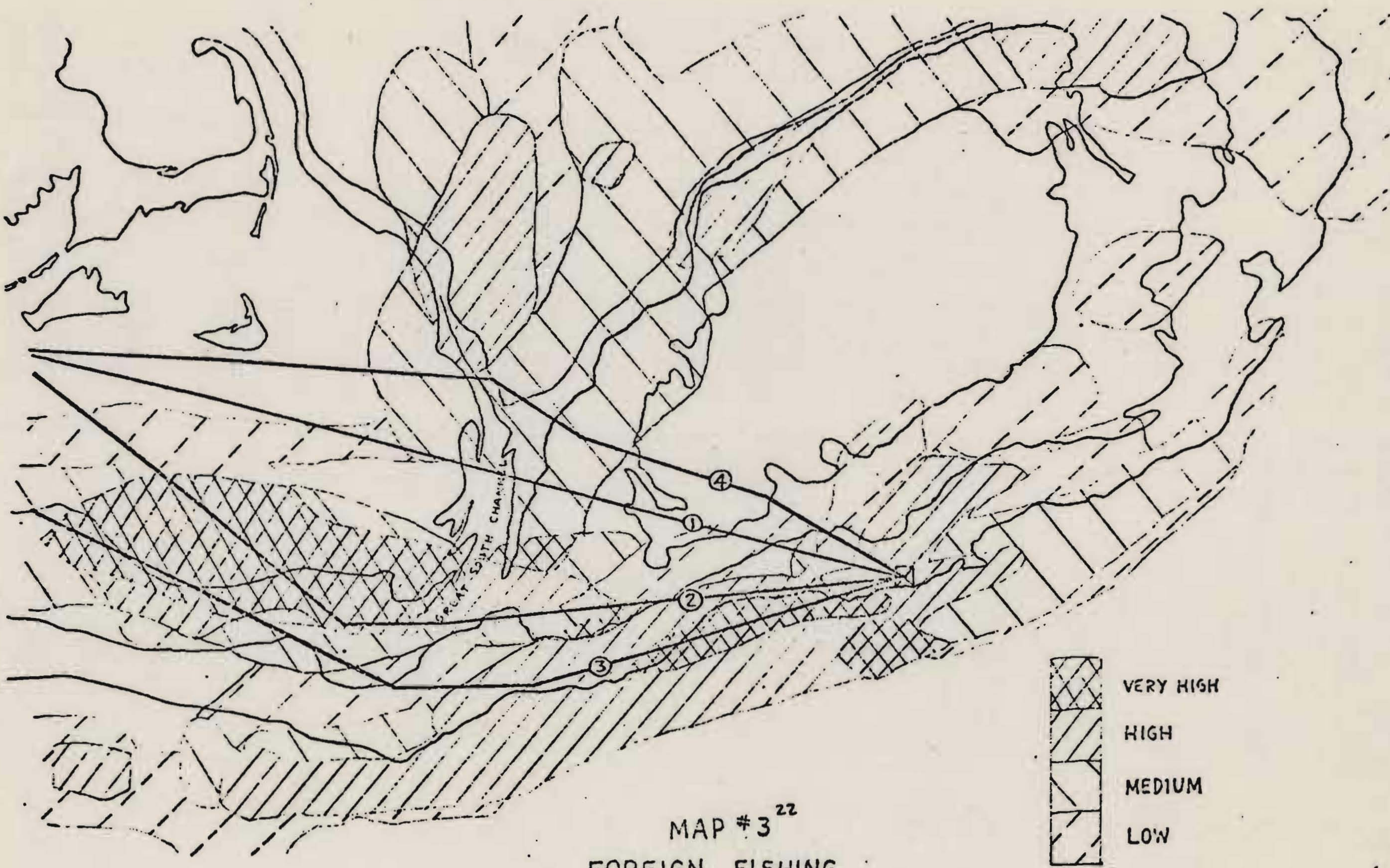
The domestic fishing usage of the area (map #2) includes such important species as cod, haddock, yellowtail and blackback flounder, whiting, and red hake.[22] Nearly all require bottom trawling



MAP #1[22]
AREAS OF HIGHEST INTEREST
TO THE PETROLEUM INDUSTRY



MAP #2[22]
DOMESTIC FISHING ACTIVITY;
DAYS FISHED 1965-1974



MAP #3[22]

FOREIGN FISHING ACTIVITY, 1974

to harvest. The fishing gear used which most affects the risk of interaction with submarine pipelines is listed in table 1.

Foreign fishing activity is of particular interest in view of the size and power of foreign fishing vessels and their gear (see table 1). However, it is unclear at present how important foreign fishing is likely to be in the future, particularly in view of extended jurisdiction. Delineation of areas of foreign fishing activity is shown on map #3.

Table 1 - Fishing vessels and gear used on Georges Bank[22]

Domestic fishing:	vessels - 65-100', 300-700 HP
	doors - rectangular, up to 8' x 12' frequently 1200 lb each
	scallop dredges - up to 16' wide up to 1½ tons each frequently towed two at a time
Foreign fishing:	vessels - up to 400', 3000+ HP
	doors - up to 2½ tons each

III. Alternate Pipeline Protection Schemes

Several alternative pipeline protection schemes might be used, and the best one in terms of minimum total cost in any given situation is not at all apparent. Considerations which must be kept in mind include technical feasibility, effectiveness, and cost.

The technical feasibility of a particular scheme includes limitations of soil conditions (for burial), sea state and water depth (lay and/or burial equipment), etc. Effectiveness refers to the scheme's ability to reduce the frequency of interactions and/or the severity of damages resulting. Differences in costs among the alternatives are most influenced by pipe diameter, depth of burial and changes in soil type (if buried), and the depth of water - all can significantly affect the major cost elements of one or more of the alternatives. Each of the major alternatives is discussed briefly below:

1) Normal burial. A normal burial is considered to be a line which has been trenched[11] (see figure 1). Current practice in the North Sea for such an operation involves the laying of the pipe on the sea bottom, and then trenching with a bury barge. The trenching is generally done in the season (April to October) following the laying operation due to weather limitations, availability of equipment, and the time requirements of laying. The trenching operation involves the use of a high pressure water jet which displaces the soil under the laid line.[26] A time lag between laying and trenching of about one year may not be able to

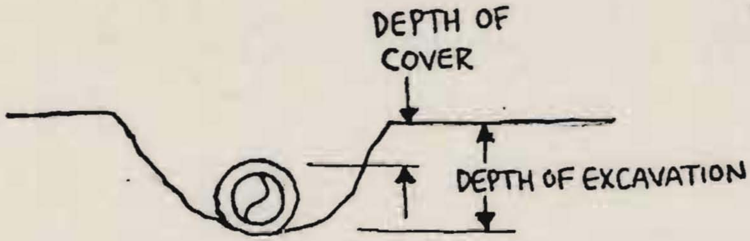


FIGURE 1 – TRENCHING

SHAPED ARMORED SECTION

ENGINEERED BACKFILL

FIGURE 2

be eliminated since pipeline owners, as a matter of procedure, ordinarily like to have a diver inspect a recently laid line for damages.[20] No backfill is usually provided - a natural backfill provided by the action of bottom currents or surface wave action can be expected to provide about as much fill as its going to in another year or so.[11,21,26]

One of the major questions which may be asked here is the effectiveness of a given depth of burial, especially on Georges Bank where the soil type of essentially the total area is sand.[22] With a soil of low shear strength, such as sand, it is highly likely that the depth of cover over a pipeline will change with time. This is primarily due to storm wave and/or bottom current erosion.* In some areas this can result in a condition known as "spanning".** It can also be caused by the phenomenon of

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* Tidal currents of up to two knots have been measured on Georges Bank. The mobility of bottom sands shown by deepening of sand levels around the legs of Texas Towers led to their abandonment and salvage in 1964.[28]

** Spanning is a condition whereby a section of pipeline is a distance above the sea bottom. It is caused by scour around the pipe or by flow conditions which produce "sand waves." Spans over 100' in length and 3' in height are not uncommon in the North Sea.[9] In addition, at a given current velocity and span length, the pipeline may become resonant and subject to a condition known as "vortex shedding," during which any of the concrete coatings now in use cannot be expected to remain intact.[5,14,22]

"floatation,"*wherein a pipeline will "float" to the water-sediment interface, or by the time lag between the digging of the trench and the placement of the pipe in the bottom of it - i.e., the stiffness of the pipe only allows a gradual lowering, so that final placement of the pipe in the trench bottom may occur on the order of two hours (for a 6' trench) after the trench digging device has passed, thus allowing partial filling in of the trench.[9]

The major considerations governing the amount of burial necessary to reduce the possibility of interaction with anchors and trawl doors to a very small amount are the depth of soil instability during storm conditions, long term soil erosion caused by currents, and the depth of penetration of anchors and trawl doors which are apt to be used in the area.[4]

Though there is always a possibility that a pipeline will become uncovered at some time, the likelihood of its doing so diminishes with depth of burial. Hence, a very deep burial, on the order of perhaps five to six feet of cover, could be considered a separate oil transportation protection alternative.

In very deep water, i.e., over about 200 feet,[4] it is unlikely that dragging anchors from ships under emergency conditions, even those in a shipping lane such as the Great South Chan-

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* Flotation may occur when a pipeline is buried in soft sediments, or the trench in which it is buried is left to fill up by natural sedimentation. A combination of very low shear strength and higher density of sediment relative to that of the pipeline can result in the pipeline literally floating to the water-sediment interface.[17]

nel (see maps), will be a problem. This is due to the limiting length of anchor line and/or the ineffectiveness of using an anchor to stop a ship in a short distance. Depths in the Great South Channel shipping lane are about 200 feet. Hence, the use of anchors is a possibility, and its risk should be considered.

2) Burial plus mechanical backfill. One may envision instances wherein fishing gear, especially trawl doors, may become wedged betwwen the pipe and the side of the trench, although this type of situation probably would arise only for particular angles of incidence of the towed gear to the pipeline's direction. A mechanical backfill would reduce the risk of this interaction. This protection system also reduces the possibility of the same type interaction with anchors and the probability of the previously mentioned floatation problem.[17]

If the backfilling procedure must necessarily be a separate operation and a time lag betwwen it and the trenching operation must also be on the order of a year, then a complete or nearly complete natural backfill will have taken place. However, the problem of floatation will not have been avoided. If a system could be engineered whereby the trenching and backfilling could be accomplished in the same pass, then a mechanical backfill may show its cost effectiveness over that of a simple trenching operation for two reasons. First, the floatation problem will have been avoided as much as possible, and secondly, the risk due to exposure between the laying and natural filling process will be eliminated. From descriptions of some of the recently designed burial equipment, this capability may not be too long in coming.[14]

3) Armored coating systems. Coatings have been developed that are better and more impact-resistant than the commonly-used concrete coatings. They are in use on some North Sea pipelines laid in areas of high fishing activity where burial was determined to be excessively costly or impossible.[4,14] A coating protection, of course, does not avoid the interactions, but lessens the damage to the pipeline which may result from gear impact,[7,14,*] and reduces the associated risk of spills. In the case of a higher quality concrete, with or without extra steel reinforcing, the risk of fishing gear damage would not be affected, but other protections which change the shape of the obstruction would affect the fishing gear damage probability. Two technically acceptable methods have been used to effect this result.

Both the shaped armored section and the engineered backfill (see figure 2) have the objective of causing an approaching anchor (or trawl door) to "walk" (deflect) over the pipeline without damage, while at the same time affording better stability to the pipeline in its environment.[4] However, the economies of concrete application in a shaped section are such that some 50 to 100% additional fabricating expense, plus large additional expense in reworking a lay barge to accept the sections, can be anticipated. The additional weight of the concrete, which is

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* A steel cage-type reinforcement used within a dense concrete coating has been shown to have better impact and fatigue (from repeated impacts) properties. The additional cost of such reinforcement over a normal coating of wire mesh plus concrete seems to be justified only in heavily fished areas.[14]

critical, may also impose too great a limitation on the water depth capability of the lay barge.[4]

Engineered backfill is used in comparatively shallow water and is very expensive. At present the technical capability of applying an engineered backfill is probably not within state-of-the-art for the depths encountered on Georges Bank.[4]

4) Rerouting around high risk areas. Another alternative would be to displace the pipeline to an area outside the high risk areas. This alternative involves several kinds of additional capital and operating costs. Taken to an extreme of increased distance, the requirement of an additional pumping/compressor intermediate station could be included. To provide some insight into the issues involved, four hypothetical routes will be considered here. All have one or more objectives (minimizing a particular type of cost(s)) in its path selection (see maps).

The objectives of the routes are:

1) minimum distance (base case)
2) avoid very high intensity domestic fishing areas
3) avoid very high and high intensity domestic fishing areas
4) avoid very high intensity domestic fishing areas and minimize (subjectively) the mileage in areas of intense foreign fishing activity

While clearly other objectives are possible, these four cover the major rerouting options that could be expected.

5) Establishment of an exclusion area around the pipeline. Under this alternative, fishing activity would be prohibited in a band around the pipeline. An effective exclusion zone on either side of the pipeline would avoid interactions from fishing operations

and anchors (other than perhaps some emergency usage in some areas). The width of zone often mentioned is 500 meters on each side of the pipeline,[5,23] which is probably about the distance a fisherman would stay clear to be reasonably assured of avoiding the pipeline.[2] Excluding fishing in the area may not be easily effected, however, especially with offshore fishermen, who almost by definition are a risky lot. If a fisherman feels he can cleverly maneuver his vessel close to a pipeline and consistently increase his catch,* he may find it to his advantage to do so even at the risk of occasionally fouling his gear. In economic terms, he will be balancing his marginal expected gains against his marginal expected costs.**

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* Some increase in catch rates when fishing near pipelines has been noted in the North Sea.[14] This could be due to some herding effect brought on by the operation of the fishing gear or temporary concentration increases present due to the pipeline itself.

** As a hypothetical example, assume there is a 10% chance/day of fouling one's gear by fishing up to 100 feet instead of 500 meters of the pipeline location. In addition, there is approximately equal probability that an accident will be a serious (costing $4000) or a minor (costing $200) incident. Hence, the expected costs associated with observing a 100' zone would be:

$$EV(100') = .90\ (0) + .05\ (4000) + .05\ (200) = \$210/\text{day}$$

Now, unless the expected gains from increased catches are greater than $210/day, a "rational" fisherman would not fish as close as 100 feet.

The availability of compensation for possible damages to fishing gear should influence the behavior of fishermen. As long as no compensation is guaranteed and there seems to be more than just a little chance that his gear can be lost, an exclusion zone may not be necessary.

6) Tankers vs. pipeline. One may also be willing to forego the use of a pipeline altogether and instead accept the increased cost associated with transportation by tanker, plus increased spill probabilities, etc., in return for the benefits expected from no pipeline in high risk areas. Ideally, one could represent this alternative in the form of a graph such as that of figure 3. The size find where a pipeline transportation system would become favored over the use of tankers would be the intersection of the two cost curves. Whether this switchover to pipeline use would occur at a higher or lower size find when the additional external costs to the fishing industry and other competing usage, onshore impacts, etc., are considered, depends on the relative external costs associated with each alternative. If the additional costs associated with a pipeline are higher than those for tanker usage, then the changeover to pipeline use would occur at a higher size find (Q_2 vs. Q_1 in figure 3).

Since accurate figures on the range of external costs that would need to be considered to estimate the relations in figure 3 are unavailable and extremely difficult to estimate, no attempt will be made to compare this alternative with the others considered.

7) Combinations. A final alternative involves some combination

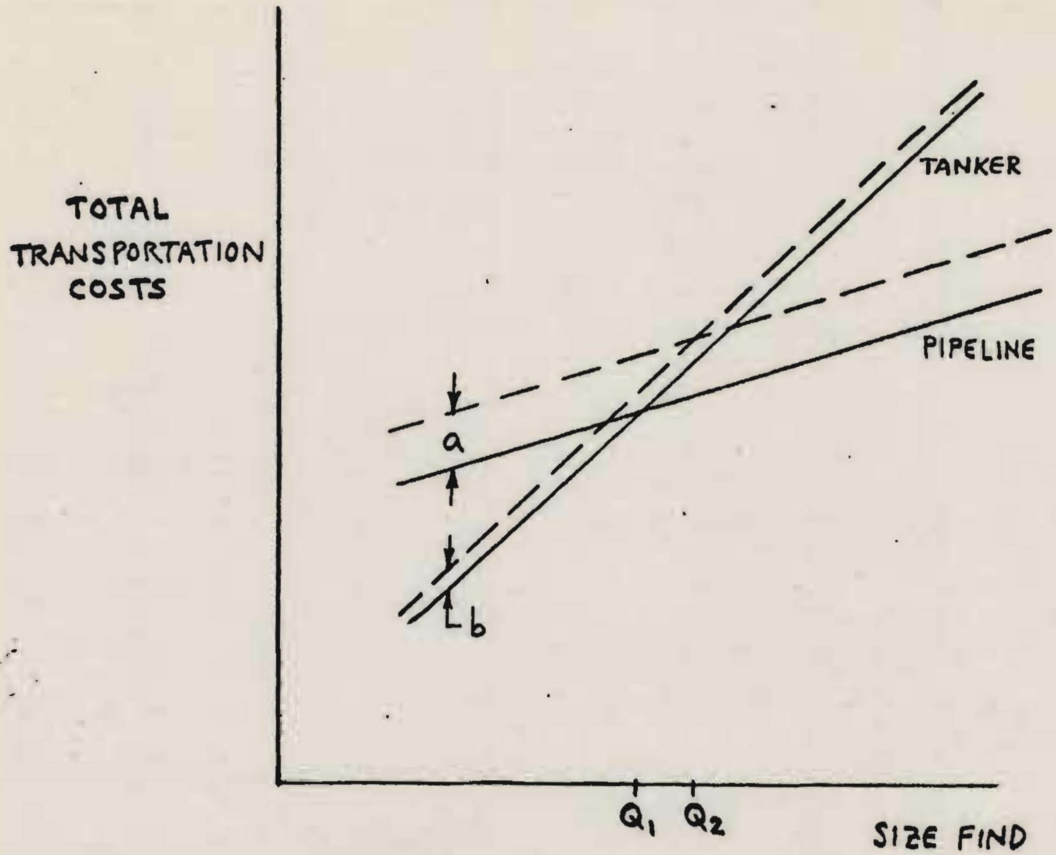

Figure 3 - Total transportation costs vs. size find
for a tanker and a pipeline transportation mode

a hypothetical external costs associated with pipeline usage

b hypothetical external costs associated with tanker usage of the other individual schemes, and minimizes some costs in only certain areas along a hypothetical route. Four possibilities encompassing variations of the major options are considered here. They are:

1) bury the line in only the areas of very high domestic fishing usage

2) #1 plus an exclusion zone for the areas of high, medium, and low intensity domestic fishing

3) bury the line in only the areas of very high and high intensity domestic fishing

4) #3 plus an exclusion zone for the areas of medium and low intensity domestic fishing

IV. Costs of pipeline alternatives to the oil industry

To quantify differences in costs among the alternatives described above, a comparison will be made between the additional costs of each alternative over that of the least expensive system which will adequately do the job in the absence of other uses of the area. Almost any base case installation could be used since only the differences must be considered.

Here the base case pipeline is taken to be a common carrier oil line* which extends from block NK 19 - 12 358 (see route #1 on map #2), which is a central point in the largest area of highest oil industry interest, in a direct line to a point 3 miles south of the island of Martha's Vineyard (to keep the pipeline under federal jurisdiction). The most probable pipe diameter would be about 16" - this assumes recoverable reserves of about 200 million barrels of oil and a 20 year field life.**

It should be noted that all of the following calculations and the conclusions drawn from them are only applicable to a common carrier trunk line on Georges Bank and do not necessarily apply to gathering or other flow lines within the field develop-

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* The case of an oil pipeline will be made here since it would have a large potential environmental cost; other costs are quite similar for a gas pipeline

** The capacity of the pipeline in the peak year is assumed to be 10% of recoverable reserves, or 20 million bbls/yr, or 60,000 bbls/day. This requires a pipeline diameter of 14 to 16".

ment.

A summary of the approximate costs for each of the alternatives is shown in table 2. The values represent a breakdown of the various additional costs. All operating costs have been discounted to their present value equivalents so that they may be compared equally with capital costs. The discount rate of five percent attaches a larger present value to future costs relative to initial costs than would a larger discount rate. Since a large part of the oil industry costs are initial capital expenses, the results are biased to the benefit of the fishing industry.

The last two columns of table 2 are the most important. They contain totals of the additional capital and operating costs, plus a subjective assessment of the composite risk of additional cost due to damages resulting from fishing gear and anchor interactions. There is often a major difference in costs that is unappreciated among the alternatives. Those alternatives most costly to the oil industry involve deep burial and the special armored section and engineered backfill protection systems. The exclusion zone around the base case installation is the least costly. Slight alterations in routing, e.g., alternative route #4, or a specific combination of alternatives, e.g., combination #2, may be attractive since they involve comparatively less additional expense than most others.

The desirability of any one system over another may depend on the value assigned to each system's risk. For example, route #4 avoids very high intensity domestic fishing areas and costs

Table 2 - Costs to the oil industry over the base case installation and evaluation of subjective risk ($ million, 1974)

alternative	capital costs: mat'ls + coating	capital costs: laying	capital costs: burial	capital costs: int. plat	operating costs: maint, insp & op line	operating costs: pump sta op & maint	subjective damage probabilities: anchors	subjective damage probabilities: dom. fishing	subjective damage probabilities: foreign fishing	total cost	subj. composite risk
Normal burial	-	-	$21[a]	-	-	-	M	M	M	$21	M
Deeper burial (5' cover)	-	-	50[b]	-	-	-	L	L	L	50	L
Burial plus backfill	-	-	~30[c]	-	-	-	M-L	M-L	M-L	~30	M-L
Protection systems:											
high quality concrete	$4-9[3]	-	-	-	-	-	M	L	M	4-9	M-L
shaped sections	34-67[3]	large[3]	-	-	-	-	L	L	L	34-67	L
engineered backfill	-	very large[d]	-	-	-	-	L	L	L	~∞	L
Rerouting:											
1) minimum distance	-	-	-	-	-	-	H	H	L	0	H
2) avoid VH domestic	1.9[e]	$1.5[f]	-	$.1[g]	$2.1[h]	$.5[i]	H	M	H	6.1	M-H
3) avoid {VH, H} domestic	3.9	3.2	-	.1	3.6	.9	H	L	H	11.7	M
4) {avoid VH domestic, avoid foreign}	.7	.6	-	.02	.6	.2	H	M	L	2.1	M
Exclusion zone	-	-	-	-	-	-	L	L	L	0	L
Combinations:											
1) bury VH domestic[j]	-	-	4.3	-	-	-	M-H	M-H	H	4.3	M-H
2) {bury VH domestic, excl zone for H,M,L}	-	-	4.3	-	-	-	L	L	L	4.3	L
3) bury {VH, H} domestic	-	-	10.1	-	-	-	M	M	H	10.1	M-H
4) {bury {VH, H} domestic, excl zone for M,L}	-	-	10.1	-	-	-	L	L	L	10.1	L

a favorable burying conditions assumed throughout the 198 mile length; burial cost \$106,000/mile[13]

b taken from diagram, p. 25

c assumes additional backfill operation to cost on the order of half of a trenching operation

d the cost of an engineered backfill is considered to be so large as to be technically infeasible - this is primarily due to lack of control of the operation in deep water[3]

e basic material plus coating costs are \$170,000/mile[13]

f laying cost ≅ \$140,000/mile[13]

g additional equipment cost to pump longer distances ≅ \$6200/mile[12]

h additional pipeline maintenance costs ≅ \$12400/yr/mile[12]

$$\sum_{i=1}^{20} \frac{12400}{(1.05)^i} = \$155{,}000\text{/mile for the first 20 years}$$

i additional operating expenses at an intermediate pumping station = \$3020/yr/mile[12]

$$\sum_{i=1}^{20} \frac{3020}{(1.05)^i} = \$37{,}700\text{/mile for the first 20 years}$$

j assumes 2 extra days (@ \$200,000/day[13]) for each mobilization to separate areas for burial

∴ additional cost ≅ 37 mi. x 106,000 + 400,000 = \$4.3 million

k additional cost ≅ (37 + 55) x 106,000 + 400,000 = \$10.1 million

l damage probabilities were estimated from their susceptibility to interaction for a given alternative; composite risk is an average of the 3 types, with more weight given to the risk from domestic fishing operations; besides the pipeline repair costs, other potential costs include the value of oil lost & cleanup expenses; the cost of repair may run several million dollars, as could the value of oil lost & cleanup, but an expected value of the cost is not accurately estimable without an extensive and applicable data base to predict an expected frequency of occurrence

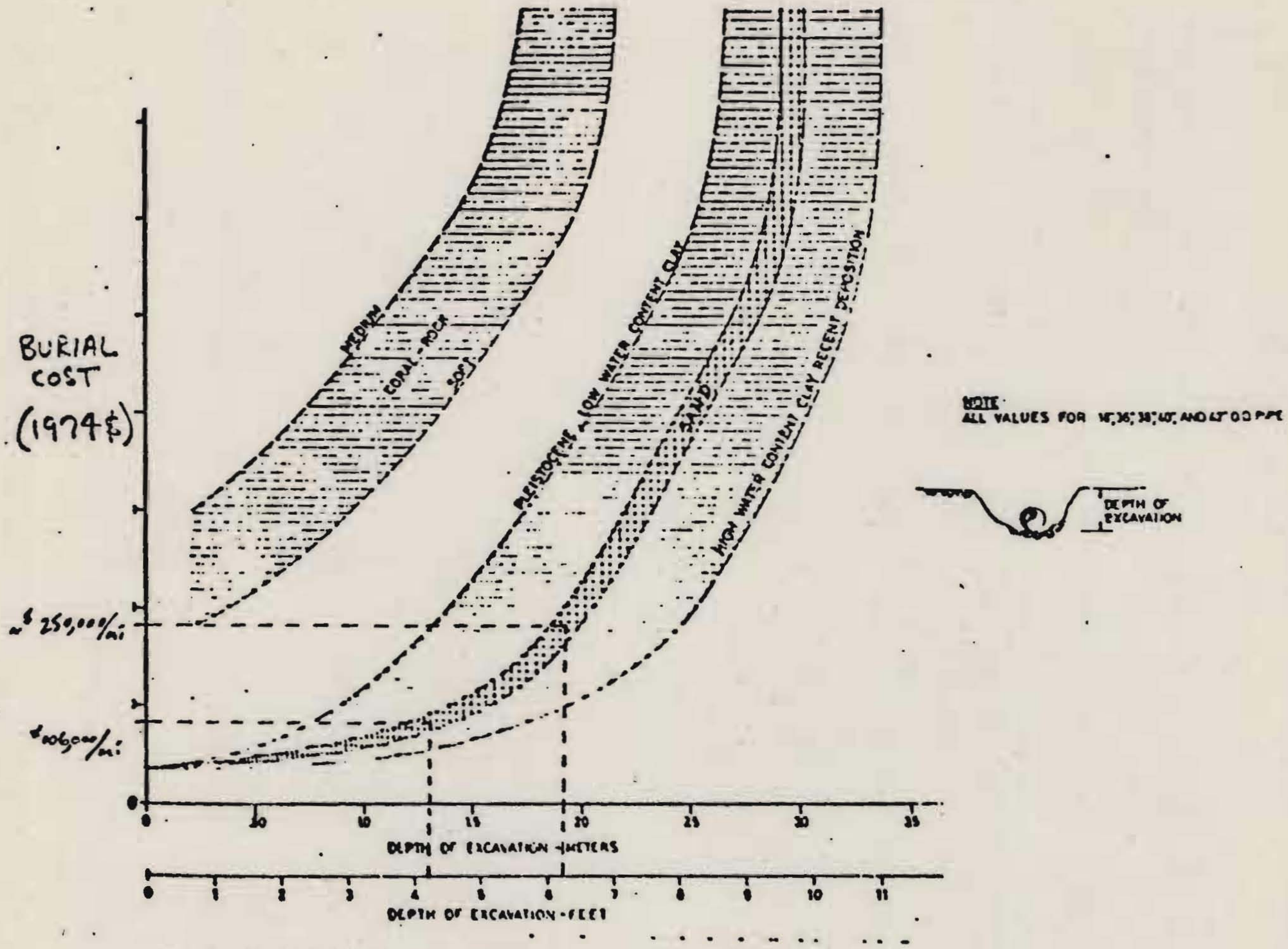

Figure 4 - Burial cost as a function of burial depth[5,13]

less but has higher risk than combination #2, which buries the line through the same category of fishing area.

V. Costs of pipeline alternative to the domestic fishing industry and the rest of society

Many factors will influence the impact of any pipeline installation on the fishing industry and the rest of society. As mentioned previously, quantifying these impacts is a major problem. However, a discussion of the more important factors is useful in that it provides insight into their potential and probable importance.

Likely result of an interaction of fishing gear with a pipeline. Depending on the specific type of gear used (see table 1), the vessel's horsepower and towing speed, the angle of incidence to and exposure of the pipeline, and the pipeline's previous history of interactions, a number of types of damage to the pipeline and the fishing gear may result. Damages to the pipeline include cracking and spalling off of the coating, denting the pipe, and leaks or ruptures. The economic damages as a result of a spill on Georges Bank are extremely speculative, ranging from the industry-born cleanup costs (see table 3) to the additional possible social costs associated with biological impacts and various onshore effects, including property damages, reduction in property values, adverse effects on tourism and recreational opportunities for the resident population, and aesthetic degradation.

A look at the past record of pipeline spills (see table 4) shows only one very large spill of 7 million gallons in the last 10 years. All other pipeline spills have been considerably smaller. In addition, even a very large spill only covers a very small percentage of the total Georges Bank area.* In view of the lack of highly aggregated populations or spawning grounds local to the route alternatives considered here,[22] the writer feels that an offshore spill probably should not be a large cost factor in terms of yearly expected value to fishing operations. The potential cost to society of cleanup of a large offshore spill should be more significant, however. This cost would be born by the oil industry, but indirectly born by society. This would come in the form of lower bids for tracts in the future in anticipation of having to pay for spill cleanup costs which may occur.

A summary of cost estimates of various cleanup methods can be found in table 3. The range of possible costs for a given spill size is not large, but the cost differences between sizes of spill can cover several orders of magnitude. The value for potential cost which should be used here is difficult to esti-

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* A 1 million gallon spill would cover about 3 mi^2 after 12 hours and about 10 mi^2 after 4 days. Only about 1% of the larvae of the species with relatively concentrated spawning periods and grounds might come in contact with the spill. Toxic effects predominate in only about the first 4 days. In this period the spills movement can be expected to cover about 400 mi^2, or about 3% of the Georges Bank area. To find the actual area covered, this figure would have to be reduced to account for repetition of the same area due to repeated tidal excursions. Thus, the effect on succeeding generations is unlikely to be noticable.[31]

Table 3 - Cost estimates for oil spill cleanup offshore[15]

method	"small" spill (100,000 gal.) direct[a]	capital[b]	"large" spill (10 million gal.) direct[a]	capital[b]
Chem. dispersion	80,000	51,600	6,200,000	862,500
Absorption (straw)	113,000	79,300(579,300)	8,625,000	1,405,000(6,405,000)
Sinking	64,900	56,600	4,505,000	1,385,000
Combustion	82,200	49,500	6,171,000	675,000

a for a specific spill including material and operating expenses

b initial equipment and warehouse costs; number in parentheses includes equipment to collect spent materials

Table 4 - Spills over 1000 barrels from pipelines in OCS[24]

(1964-74)

Date	Gulf of Mexico Area, Block No.	Amount (gals.)	Cause
10-15-67	West Delta, 73	6,746,838	Anchor dragging
3-12-68	South Timbalier, 131	252,000	Anchor dragging
2-11-69	Main Pass, 299	316,344	Leak
5-12-73	West Delta, 73	210,000	Leak, corrosion
8-2-73	Avco "C" South Pass, 60	43,000	Leak
4-17-74	Eugene Island, 317	832,986	Anchor dragging
9-9-74	Main Pass, 73	92,946	Hurricane

mate, but probably should be on the order of $1 million.

The most significant costs to society from a spill will more likely come in a nearshore area where the chance of coming ashore is greater and the time to get there shorter. In the present case, the most likely sites for onshore impact are Cape Cod and Long Island,[6] which are all highly dependent upon tourism and recreational uses of the coastal zone. Social costs generated by a spill here could be comparable to those of the Santa Barbara spill, which were estimated in 1969 at several million dollars over and above that of the $10.6 million cost to Union Oil Company.[19]

Hence, considerably more weight should be placed on measures to avoid spills in areas of high fishing activity in nearshore areas, e.g., the high intensity fishing areas just south of Martha's Vineyard and Nantucket Islands (see map #2).

Although foreign fishing has been important in recent years, the potential risk to pipelines associated with foreign fishing activity in the future is uncertain. Should an incident occur, it seems highly likely that the resulting damages would be serious, considering the size of the fishing gear and the power of the vessels (see table 1). Map #3 is an estimate of the areas of foreign fishing activity. Regulations prohibit bottom trawling in some parts of Georges Bank. With the implementation of extended jurisdiction, this may be more easily effected in the future. However, even though the frequency of incidence may be very low, serious consideration is justified by a high percentage of incidents which will probably result in serious damages. In addition, a resulting spill could raise international legal/liability issues. Possibilities of this situation arising in the Gulf of Mexico area was lacking since no foreign vessels operate in the area, and hence the Gulf experience offers no insight into this problem. In the total analysis this factor will be carried through as an unquantified potential risk.

Studies have shown that a previous history of repeated impacts can significantly influence a pipeline's ability to withstand future impacts.[4,11] This possibility would only be likely to occur on Georges Bank if impacts were concentrated at specific locations, e.g., at points where a pipeline crossed LORAN lines. This condition depends on how the fishermen set their towing tracts. From a questionnaire sent out to many of those who fish regularly on Georges Bank, it can be said that, in practice, LORAN lines, compass bearings, depth contours, and random towing patterns are all used by nearly all of the fishermen at different times.[2] Hence, the conclusion may be drawn that some areas will probably be more subject to impacts than others, but not by much and certainly not by as much as an order of magnitude.

The severity of damage to fishing gear is mainly determined by the type of interaction, i.e., impact or hooking the door under the pipe,[11] and the fisherman's ability to get his gear back, if possible. As long as there is an adequate safety factor in the strength of his towing warps and connected gear, it is difficult to believe apriori that a fisherman's gear will be lost or significantly damaged by an impact. The available literature suggests that hooking under a spanned section of pipeline or wedging between a pipeline and trench wall (and perhaps eventually under the pipe - see figure 1) would offer the greatest chances of losing one's gear. This type of interaction does not depend on the particular species sought in bottom trawling and has been noted to be the biggest problem to the fishing industry associated with pipelines in the North Sea.[2]

Assuming an incident did occur, some rough calculations will serve to indicate the approximate loss which may be incurred by a fishing operation. Assume the accident occurs half way through a fishing trip and the loss requires steaming back to port for repairs. The approximate loss associated with lost income, boat expenses, and opportunity cost for the vessel would total $1-2000, depending on the vessel.* The

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* Assume the loss occurs half way through the trip and three days are required to steam back to port, unload fish, obtain and install new gear, etc., The major elements of cost would include:

opportunity cost of vessel, $\frac{3}{365}$x.15x$150,000 (vessel valued at $150,000; return to capital = 15%)	= $200
normal crew wages, 8 crew x $40/day x 3 days	= 1000
running expenses of vessel (fuel, etc.)	= 300
	$1500

replacement cost of the gear can range from $1-4000(exclusive of the towing warps), depending on how much of the gear is lost.[30]

<u>Fishing area precluded</u>. One concern of fishermen is that extensive offshore development may preclude fishing activity on sections of Georges Bank. While this problem may be more serious with platforms and gathering lines, it also arises in connection with common carrier pipelines. As noted before, how close a fisherman will fish to a pipeline depends on his estimate of the risk involved with respect to the potential losses he might incur, the potential gains he feels may be had by fishing closer to the pipeline, whether or not a compensation fund is available if his gear is lost or damaged, and whether an exclusion zone is established or not.

Assuming that an exclusion zone of 500 meters on either side of the pipeline is established and/or the risk/gain considerations are sufficient so as to preclude fishing from the same zone, what does this mean to the fishing industry in terms of lost income? Although we cannot hope to derive a precise estimate, the process is useful in indicating the considerations that apply and the kinds of assumptions that must be used. A reasonable estimate here depends on the productivity of the precluded area, the availability of alternate areas, the disruption of desirable fishing tow patterns, and perhaps the effect of the pipeline's presence on catch rates in adjacent areas.

Table 5 shows the approximate length and corresponding area precluded for very high, high, medium, and low intensity categories of domestic and foreign fishing for each of four

Table 5 - Approximate length, area precluded, & route objectives for 4 alternate pipeline routes

(derived from information in reference 17, plates 3 & 7)

route	objective	total mileage	mileage in domestic grounds VH	H	M	L	mileage in foreign grounds VH	H	M	L
1 (base case)	minimum distance	198	37	55	57	18	0	11	34	41
2	avoid VH intensity domestic grounds	209	0	96	48	36	80	53	18	23
3	avoid VH & H intensity domestic grounds	221	0	0	67	109	87	43	28	21
4	avoid VH domestic & minimize mileage in foreign grounds	202	0	78	86	9	0	11	48	11

hypothetical pipeline routes. Each of the alternative routes has a different objective in its route slection, as previously described on page 16. Ideally, one would like to know the value of each area in order to estimate its net worth to the fishing industry. The approach adopted here is based on available data and makes use of an empirically derived "value coefficient," assigned to each unit area of each category of fishing intensity in terms of dollars per square mile per year. To arrive at a final net worth for an area, its value coefficient would be multiplied times the area in square miles and then summed over the desired time span (20 years here), with an appropriate discount rate. As long as any other factors can be shown to be negligible or can be estimated independently, this method should offer an advantage in its simplicity.

In all of the cases considered here, generous estimates, i.e., high estimates of the costs to the fishing industry, are used. Thus, if there is a bias to the figures, it is to the benefit of the fishing industry by figuring for the maximum reasonable potential loss which fishermen may incur.

The procedure followed in estimating the value coefficients is as follows:

1) Estimate the total potential value of the Georges Bank fishery resources to the domestic fishermen in terms of personal income.

2) Next, an estimate is made of the values of individual areas based on the categories very high, high, medium, and low (VH, H, M, L) fishing intensity in the Georges Bank/Nantucket Shoals area.

3) We assume the ratios of the value coefficients between areas of different fishing intensity is the

same as the ratios of the median number of days fished in each of the different areas* as drawn up by Olsen and Saila.[22] Thus, if the median number of days fished in two different areas is 200 and 100, the value coefficients should also be in the ratio of 2:1.

4) Finally, the value found in step one is set equal to the sum of the products of the areas of a particular intensity times the value coefficient assigned to that area, i.e.,

$$V = \sum_{i} \alpha_i A_i$$

where: V = total potential income value to fishermen

α_i = value coefficient for i-level fishing intensity area

A_i = total area of i-level fishing intensity

i = fishing intensity levels, VH, H, M, L

A simple method was used to estimate the total potential income in step one. A maximum sustainable yield (MSY) of 420,000 metric tons for the Georges Bank area has been estimated to have a gross value of $142 million (1974 dollars)[22] - this corresponds to about 8¢/lb. Typically about half, or $71 million, is the payment to labor, and the rest is boat expenses, including a return on investment. In the calculations it is assumed that there is a zero opportunity cost of the labor to society. The social rate of return is therefore assumed to be higher than that earned by the vessel owner. In keeping with our intent of

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* To account for the fact that much of the landings are low valued species, days fished was considered to be more of an indicator of value to the fisherman than total landings.

biasing the results to the benefit of the fishing industry, we will use the maximum of $71 million as the value of Georges Bank to the fishing industry.

The ratios of median number of days fished for the very high, high, and medium intensity areas relative to the areas of low intensity usage are 46.4, 14.5, and 5.2, respectively. Hence, the ratios of the value coefficients between the same areas is assumed to be 46.4, 14.5, and 5.2, respectively.

The three equations expressing these ratios, plus the previous equation, $V = \sum \alpha_i A_i$, yields four equations with four unknowns which may be solved simultaneously. The solution and the actual areas of each use level (step 2) can be found in the Appendix.

Adjustments to coefficients based solely on the commercial productivity of the area may have to be made upon consideration of the assumptions behind the productivity, and also upon consideration of other factors. These are taken up below.

The future productivity of the Georges Bank area clearly depends importantly on fisheries management efforts and their effectiveness, including the management of extended jurisdiction. The effect of each is uncertain and so for simplicity, and in keeping with our bias, the calculations which follow are based on a maximum worth to the fishing industry - a total MSY of 420,000 metric tons.* It is also assumed that little

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* An assuption of maximum worth based on net income should actually be based on the maximum economic yield (MEY), in

competition from foreign fishing for the domestically sought species will exist.

Among the other factors which are considered, two are likely to have minimal influence, at least in the case of a common carrier pipeline. Significant disruption of desirable fishing tow patterns would tend to add to the value of a precluded area since it would work to lower the value of adjacent areas to fishermen. The adjacent areas are lowered in value since some of the possible towing patterns a fisherman might want to make would have to be altered or would not be possible. These include all those patterns which might otherwise enter or cross the precluded pipeline zone. This would seem to be a significant factor only in areas where a comparatively high density of gathering lines would tend to significantly reduce the maneuverability of gear or the fishable area to an extent that adjacent areas are hardly worth the trouble of setting a trawl.

It is also possible that the presence of an exposed pipeline may disrupt migration patterns, spawning, etc., and hence could affect catch rates in adjacent areas. However, studies wherein obstacles were placed in such a way as to impede the movement or activity of the fish have shown that, in general, only temporary delays in migration or behavior are effected by such obstacles.[23] Hence, this effect is also considered to be

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which the catch is slightly less than the MSY. However, the difference in catch levels is small and the corresponding difference in net worth to the fishing industry even smaller. Hence, for simplicity, the MSY level will be used.

negligible.

Another factor is the effect of the mobility of fish stocks on concentrations in different areas. If fish concentrations were temporarily reduced adjacent to an exclusion zone by fishing, the fish within the zone would tend to buffer the effect, thereby reducing the absolute value of precluded fishing in the exclusion zone. This is a very significant factor, especially since most species are highly migratory.[22] Here again it is very difficult to make a precise estimate of the effect. In the interests of being consistent with the objective of determining the maximum reasonable value to be expected of precluded areas to the fishing industry, the reduction in value will be a conservative 50%.*

In summary, the only factor of significance is the latter. The final coefficients are 50% of those calculated by the procedure described on pages 35 and 36. This is almost certainly an upper bound of the value which might reasonably be assumed for the expected costs to the fishing industry as a result of the implementation of an exclusion zone. Hence, the adjusted value coefficients to be used in the analysis are $4650, 1450, 520, and 100/mi^2/year for the very high, high, medium, and low intensity domestic fishing areas.

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* If future fishing is beyond the MSY, as it has in the recent past, it could be imagined that an exclusion zone may be beneficial to fishermen in the long run by arguing that the zone could serve as an area analogous to a wildlife conservation area or preserve.

<u>Life of the pipeline.</u> Since the area value calculations were made on the basis of a single year, the life of the pipeline must be considered to get the total value over time of area preclusion. If not removed, the pipeline will remain as an obstruction indefinitely, even though the exclusion zone may no longer exist (by regulation anyway). Thus, the maximum total cost would be the summation of the maximum yearly costs, discounted to present value, over a time period from the present to infinity.

The cost after year 20 could be born by the owners of the pipeline if the pipeline were removed at the end of the field life. The cost of doing this is by no means accurately estimable from experience since very few offshore areas are near the end of their economic life and in a position where other uses of the area would demand consideration of its removal. Would removal of the pipeline at the end of the life of the field be cost effective?

Assuming the cost of removal is the same as the cost of laying the pipeline, the present value of removal cost in the final year is $\frac{\$140,000}{(1.05)^{20}}$ = \$53,000 per mile (1974 dollars). This is a one-time-only-cost. Now, should the pipeline not be removed, any interference with fishing would occur over an extended period of time. Assuming the interference takes place in the area of highest (VH above) fishing intensity, that the period of concern is from year 20 to infinity, and that the discount rate is five percent, the maximum present value of losses to the fishing industry as a result of indefinite preclusion is \$20,000/mi.*

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* $\$4650/\text{mi}^2/\text{yr} \times \frac{1000 \text{ m}}{1609 \text{ m/mi}} = \$2900/\text{mi/yr}, \quad \sum_{20}^{\infty} \frac{2900}{(1.05)^t} = \$20,000$

The assumption of a five percent discount rate here biases the calculation to the fishermen's favor since losses in the later years take on a larger present value than with a higher discount rate. Hence, the conclusion is that removal is probably not cost-effective for even the most heavily fished areas, and so calculations of fishing costs (table 6, p. 42) assume that the pipeline is not removed.

Table 6 indicates that those alternatives resulting in the highest cost of $3.3 million to the fishing industry are the three systems with an unburied pipeline: in an exclusion zone, with a high quality concrete coating, and with no special protection of any sort (the base case system).

The reason all three systems result in a maximum cost of $3.3million is because all are based on the maximum width exclusion zone. Whether an exclusion zone is established or not, if the losses in terms of gear damage were greater than the marginal gains of fishing closer than 500 meters to a pipeline, the fisherman would impose an exclusion zone upon himself to avoid the excessive losses (see footnote, p. 17). Hence, the maximum loss in all three cases is the loss from a 500 meter exclusion zone.

Those systems resulting in the least cost to the fishing industry are those previously found to involve the greatest cost to the oil industry, i.e., deeper burial, shaped armored sections, and an engineered backfill. The most striking contrast between the costs here and those in table 2 is that, in general, both the magnitude and the range of costs to the fishing industry for most alternatives is not nearly as great as the oil industry costs for the same alternatives.

Table 6 - Costs to the fishing industry & the rest of society

($ million, 1974)

alternative	maximum cost based on precluded area	subjective assessment of damage probability to fishing operations & the rest of society[f]
Normal burial	$1.6[b]	M
Deeper burial (5' cover)	~0	L
Burial plus backfill	1.4[c]	M
Protection systems:		
high quality concrete	3.3	L
shaped sections	~0	L
engineered backfill	~0	L
Rerouting[a]:		
1) minimum distance	3.3	VH
2) avoid VH domestic	1.9	H
3) avoid {VH, H} domestic	.6	M
4) {avoid VH domestic, avoid foreign}	1.8	M
Exclusion zone	3.3	L
Combinations		
1) bury VH domestic	2.3[d]	H
2) {bury VH domestic, excl. zone for H,M,L}	2.3	M-H
3) bury {VH, H} domestic	1.8[e]	L
4) {bury {VH, H} domestic, excl. zone for M,L}	1.8	L

a maximum present value of a particular route,

$$PV = \left(\sum_{t=1}^{\infty} \frac{1}{(1+r)^t}\right)\left(\sum \alpha_i A_i\right)$$

where: $r = .05$ (a discount rate of 5% biases the results to the favor of fishermen)

i = VH, H, M, L activity levels

A_i = area of i-type activity precluded $= \frac{1000}{1609} \times \text{mileage}_i$

α_i = value coefficient for i-type activity areas

$$\sum_{t=1}^{\infty} \frac{1}{(1.05)^t} = 18.7$$

for route #1:

$$18.7 \left[(23\ mi^2)(\$4650/mi^2/yr) + (34\ mi^2)(\$1450/mi^2/yr) + (35\ mi^2)(\$520/mi^2/yr) + (11\ mi^2)(\$100/mi^2/yr)\right] = \$3.3\ m$$

for route #2:

$$18.7 \left[(60)(1450) + (30)(520) + (22)(100)\right] = \$2.0\ m$$

for route #3:

$$18.7 \left[(42)(520) + (68)(100)\right] = \$\ .5\ m$$

for route #4:

$$18.7 \left[(48)(1450) + (53)(520) + (6)(100)\right] = \$1.8\ m$$

b normal burial would allow a high risk exposure until naturally backfilled and thereafter only if uncovering occurs, which places the cost between 0 and \$3.3 million; since uncovering should be as likely as covering deeper, the cost here should be something less than ½ of \$3.3 million, or \$1.6 million as a maximum

c a backfill operation done simultaneously with a trenching operation would save, at most, the expected cost of the first year's risky exposure, or $\frac{3.3}{18.7}$ = \$ .2 million

d as in note a, the cost should be that of route #1 minus the expected cost from VH intensity areas plus something less than ½ of the same cost, or, as a maximum figure:

$$\$3.3\ m - 18.7(23)(4650) + \tfrac{1}{2}(18.7)(23)(4650) = \$2.3\ m$$

e similar to note d, $3.3\ m - \tfrac{1}{2}(18.7)\ (23)(4650) + (34)(1450) = \$1.8\ m$

f includes damages to fishing gear and potential biological impacts on future harvesting resulting from spills as costs to the fishing industry, and potential onshore impact and other environmental damages to the rest of society

VI. Summary and Conclusions

In this study consideration was given to several major pipeline transportation options that could characterize a Georges Bank petroleum development. The study assumes that the transportation of Georges Bank oil is by a pipeline corridor to shore, and the analysis necessarily involved numerous sumplifications.

Many of the factors considered in a study of this nature are extremely difficult if not impossible to quantify fully, thus necessitating the introduction of several unavoidable sources of uncertainty. Nonetheless, the results are useful in at least indicating the range of costs associated with the different major oil transportation options. The enormous range of costs associated with the alternatives indicates the danger of making hasty judgements in choosing among the alternatives.

In light of the necessary uncertainties introduced, some adjustments in the figures may have to be made as more knowledge about the offshore area or the field development becomes known.

On the basis of the analysis (see table 7, p.45),, the alternative with the least additional total cost and lowest risk involved is that of applying an exclusion zone around a pipeline which has been laid at minimum installation cost. The additional cost involved in effecting any of the other schemes considered is probably at least on the order of several million dollars more. In other words, the loss to commercial fishing of the area taken up by a pipeline corridor is considerably less than the cost to alter the installation scheme to partially or fully reduce the

Table 7 - Total costs over base case

($ millions, 1974)

alternative	cost to oil ind.	risk	cost to fishing industry & rest of society	risk	total cost	risk
Normal burial	$21	M	$1.6	M	$23	M
Deeper burial (5' cover)	50	L	0	L	50	L
Burial plus backfill	~30	M	1.4	M	~31	M
Protection systems: high quality concrete	4-9	L	3.3	H	7-12	M-L
shaped sections	40-50	L	0	L	40-50	L
engineered backfill	~∞	L	0	L	∞	L
Rerouting: 1) minimum distance	0	H	3.3	VH	3.3	H
2) avoid VH domestic	6.1	M-H	2.0	H	8.1	M-H
3) avoid {VH, H} domestic	11.7	M	.5	M	12.2	M
4) {avoid VH domestic, avoid foreign}	2.1	M	1.8	M	3.9	M
Exclusion zone	0	L	3.3	L	3.3	L
Combination: 1) bury VH domestic	4.3	M-H	2.3	H	6.6	M-H
2) {bury VH domestic, excl zone for H,M,L}	4.3	M-H	2.3	M-H	6.6	M-H
3) bury {VH, H} domestic	10.1	L	1.8	L	11.9	L
4) {bury {VH, H} domestic, excl zone for M,L}	10.1	L	1.8	L	11.9	L

interactions and external costs. This is especially true of the existing regulation to bury all lines in water depths of less than 200 feet to a depth of three feet (unless the operator can show that the area is prone to self-burial).[16] Here the difference in cost is almost an order of magnitude. A major benefit of burial, however, is the lowering of the risk of the high social costs of a spill. To the extent that higher cost alternatives are imposed on oil companies, their corresponding bids for tracts will be lowered, thus passing on the cost to the rest of society.

However, since not all possible schemes were examined and since the base case installation was hypothetical, some variation from an exclusion zone setup may result in a lower total cost. The most likely possibilities where this may be true include:

1. higher quality concrete pipe coating and no exclusion zone, at least in areas of high fishing acitivity

2. slight variations in routing to avoid areas of very high domestic or foreign trawling

In addition, the more speculative variables, such as the risk due to foreign fishing, possibly should have more importance attached to it. Of course, damage to fishing gear and other external costs imposed on the fishing industry are only one component of social costs. The private and social costs of a spill - particularly nearshore spills - could far outweigh these losses and may justify a protection scheme.

The usage of a tanker with offshore storage must be considered an option open to planners and policy makers. However, it cannot be adequately compared with the other alternatives considered here. The external costs created by the tanker option are not well-known or accurately estimable by the techniques used in this study. Only qualitative statements about some of the factors contributing to the total external cost can be made. For example, based on past experience the probability of having large spills (over 1000 barrels) is higher with tanker usage, but the possibility of having extremely large spills (over 240,000 barrels) is higher with pipelines.[6] Thus, if the very large spills are the main concern, pipelines may have a higher environmental cost - otherwise the environmental cost of tankers should be higher. The lack of data on which to base necessary judgements of this nature should exclude the tanker option from direct comparison with the other alternatives in this study.

The distribution of the cost, in addition to the amount of total cost, is also important. The best alternative in terms of reducing society's total cost places the total additional cost on the fishing industry. A more equitable distribution of the burden could be effected by the use of some sort of compensation scheme. This could be used for a general fund for fishermen incurring losses - similar to that administered by an inter-industry group in the United Kingdom, or by the fishing industry itself.

An example to illustrate how the distribution of costs, as well as the amount to total cost, could be considered to further the least cost objective and benefit the private interest groups involved would be helpful. If the pipeline is to be installed by burial of the line at a cost of $21 million, as may presently be required by existing regulation, the oil industry would theoretically prefer to pay out any amount less than $21 million to get the job done. If the least total cost system is in fact the exclusion zone at a cost of $3.3 million to the fishing industry, the fishing industry would theoretically prefer receipt of any amount greater than $3.3 million plus the exclusion zone installation rather than some other system involving absolutely no additional cost to them. Thus, if the exclusion zone system were used and the oil industry were to give the fishing industry an amount of money greater than $3.3 million and less than $21 million, both industries would theoretically be better off than if the burial option were effected. Obviously, there are may practical impediments to implementing a compensation scheme of this sort.

Another possibility for the redistribution of costs to effect the exclusion zone option, and one which should be highly recommended, is to finance the changeover to the use of oval trawl doors instead of the rectangular doors now in common use by Georges Bank fishermen. This should have two beneficial effects:

1. the efficiency of the trawling operation would be somewhat improved since an oval door will spread the same net to the same extent with less towing power applied than a rectangular door,[11] and,

2. many of the impacts with rectangular doors would be reduced to "glancing blows" with oval doors, thereby lessening the probable resulting damages, if any.

Any recommendation towards institution of the findings of this study should be in the form of further study to reduce the uncertainty in the data and assumptions. the largest sources of uncertainity are: the location of the petroleum development, the location of spawning areas, the future fishing usage of Georges Bank, and the expected value of environmental damage (its probability of occurrance and potential impact if it did occur).

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Appendix

Table A-1 - Total areas & coefficient calculations

fishing intensity	range of days fished	median no. days fished	ratios used	total no. blocks[a] delineated on map #2
VH	1611-5625	3618	46.4	38
H	651-1610	1131	14.5	$80\frac{1}{2}$
M	157-650	404	5.2	118
L	1-156	78	1.0	121

a area of "blocks" used by Olsen & Saila[22] $\cong 100\ mi^2$

area of VH intensity usage;
$100\ mi^2/block \times 38\ blocks = 3800\ mi^2$

area of H intensity usage;
$100 \times 80\frac{1}{2} = 8050\ mi^2$

area of M intensity usage;
$100 \times 118 = 11{,}800\ mi^2$

area of L intensity usage;
$100 \times 121 = 12{,}100\ mi^2$

now solve
$$\begin{cases} \$71\ m = \alpha_{VH}(3800) + \alpha_H(8050) + \alpha_M(11{,}800) + \alpha_L(12{,}100) \\ \dfrac{\alpha_{VH}}{46.4} = \dfrac{\alpha_H}{14.5} = \dfrac{\alpha_M}{5.2} = \dfrac{\alpha_L}{1.0} \end{cases}$$

resulting values;
$$\left.\begin{aligned} \alpha_L &= \$200/mi^2/yr \\ \alpha_M &= \$1040/mi^2/yr \\ \alpha_H &= \$2900/mi^2/yr \\ \alpha_{VH} &= \$9300/mi^2/yr \end{aligned}\right\}$$

note; these values are to be adjusted by a 50% reduction - see text, p.39