FIRST IMPRESSIONS

The Economic Viability of
Offshore Mining of Mineral
Aggregate in the Greater New York
Metropolitan Area

Joesph Dehais
William A. Wallace
Rensselaer Polytechnic Institute
Troy, NY

New York Sea Grant Institute • 411 State Street • Albany, NY 12246

Communications
New York Sea Grant Institute
State University of New York
and Cornell University
411 State Street
Albany, New York 12246

The Economic Viability of
Offshore Mining of Mineral
Aggregate in the Greater New York
Metropolitan Area

Joesph Dehais
William A. Wallace
Rensselaer Polytechnic Institute
Troy, NY

This research was sponsored by the New York Sea Grant Institute under a grant from the Office of Sea Grant, National Oceanic and Atmospheric Administration (NOAA), US Department of Commerce.

Scope

This report is part of a New York Sea Grant research project entitled "The Impact of Offshore Sand and Gravel Mining on the Availability and Costs of Construction Minerals in the Greater New York Metropolitan Area". Our study area includes twenty-four counties in New York, New Jersey, and Connecticut. For study purposes, these counties have been combined into nine zones (Table 1). The purpose of the project has been to determine the economic conditions associated with establishing and maintaining an offshore mining industry for construction minerals in the region.

This report has two objectives: first, to replicate the earlier work of Bronitsky (3) by considering current market structure without offshore production; and second, to consider the effect of various configurations of dredging technology on the viability of offshore mining.

This report is intended to provide information for planners, coastal managers, and others involved in managing the offshore resources of the GNYMA. The first report in this series considered the offshore supply of aggregate resources in the GNYMA indicating several geologically suitable areas for offshore mining (4). The second report presented historic demand and forecasts of future demand (5). The third report considered the costs associated with the establishment and operation of an offshore mining industry in the GNYMA (7).

Utilizing data and forecasts from the previous reports, this effort matches supply and demand "optimally" to determine the economic impact of offshore mining on the future market for construction aggregates in the GNYMA.

TABLE 1

ZONES AND FINE FINE MINERAL AGGREGATE PRODUCTION
AND PROJECTED DEMAND IN THE GNYMA

ZONE

1. New York, Bronx, Queens and Kings Counties, N.Y.
2. Nassau County, N.Y.
3. Suffolk County, N.Y.
4. Rockland and Westchester Counties, N.Y.
5. Dutchess, Ulster, Orange, and Putnam Counties, N.Y.
6. Passaic, Bergen, Hudson, Essex, and Union Counties N.J., and Richmond Co., N.Y.
7. Somerset and Morris Counties, N.J.
8. Middlesex and Monmouth Counties, N.J.
9. Fairfield and New Haven Counties, Conn.
10. Extraction Point: Off N.J. Shore Surge: Zone 6
11. Extraction Point, N.Y. Harbor Surge: Zone 1
12. Extraction Point: South Shore Long Island: Surge Zone 2
13. Extraction Point: Norwalk Islands: Long Island Sound Surge: Zone 9
14. Extraction Point: Norwalk Islands: Long Island Sound Surge: Zone 2
15. Extraction Point: Off Bridgeport Connecticut: Long Island Sound: Surge Zone 9
16. Extraction Point: Off Bridgeport Connecticut: Long Island Sound: Surge: Zone 3

Introduction

The mineral aggregates industry is the largest mineral industry in the United States (1). Demand by volume for these materials (sand, gravel, and crushed stone) is greater than that for all other non-fuel and non metal resources combined.

Due to the low intrinsic value of these materials, the economics of the industry are increasingly dependent upon hauling costs. Current national estimates indicate that a hauling distance of 20 miles doubles delivered costs; hauling 40 to 60 miles prices become prohibitive (3). Longer distances are feasible by barge if a suitable route, docking, and unloading facilities exist.

Construction aggregate resources are common and plentiful within the GNYMA. Long Island, New York, alone contains resources sufficient to meet the regions present and future demands for approximately 22,000 years. However, the economic and non-economic impacts of urbanization (e.g. land use regulation, urban sprawl, increased land values, restrictive zoning) have prevented the establishment of new onshore mining operations. In addition, these impacts have forced producers to seek new extraction sites farther from sites of demand.

The economic impact of this situation has been felt in increased delivered costs, reflecting most strongly increases in hauling costs. This fact, coupled with the economies of scale associated with dredging have indicated the possibility for economically viable offshore production.

We here consider two classes of market scenarios; first, onshore production only; and second, production from both onshore and offshore sites incorporating various offshore technologies. We have matched sources of supply with areas of demand "optimally" using the methodology promulgated by

Bronitsky (2) which is similar to that used by Henderson (8) in a study of the efficiency of the coal industry.

Based upon the conclusion that the available resource in the region is fine aggregate, (4) we do not here consider the economics of the mining of coarse material or fill.

The Model

The following linear programming model was used to investigate the construction aggregates market in the GNYMA. Our objective was to consider the minimum total cost solutions to the allocation of supply to demand in a conventional transportation problem model.

$$\text{Minimize } z = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij}$$

where,

z = total yearly cost of shipments within region;

C_{ij} = unit cost of delivery, equal to the sum of unit transportation cost from the i^{th} to j^{th} zone and unit extraction cost in the i^{th} zone;

X_{ij} = quantity shipped from i^{th} to j^{th} zone in a one-year period;

m = number of consumption zones within region; and

n = number of production zones within region.

Constraints:

(1) $\sum_{i=1}^{n} X_{ij} = d_j \; (j = 1,\ldots,m)$

(2) $\sum_{j=1}^{m} X_{ij} \leq k_i \; (i = 1,\ldots,n)$

(3) $X_{ij} \geq 0$ (all i,j)

where,

d_j = yearly demand of j^{th} zone; and

k_i = yearly capacity of i^{th} zone.

The first constraint requires that demand within any zone be exactly satisfied. Due to the nature of the industry, with small and relatively stable inventory levels, this is a realistic assumption. The yearly demands are assumed to be independent of price. Since demand for construction minerals is a derived demand dependent upon the level of construction activity and the resource is not amenable to substitution this assumption is also realistic. The assumption of price inelasticity to demand also implies that demand and consumption be identical.

The second constraint requires that yearly production within a zone not exceed its yearly production capacity. These capacities are, however, assumed to be fixed.

The third constraint restricts deliveries to non-negative values. Thus a feasible solution to our transportation problem formulation will exist so long as total demand within the region is less than or equal to the regions total production capacity.

Since a least cost solution is our goal, the allocations, x_{ij}, which we will accept provide a global minimum value of the objective function. This we will consider optimal. It should be noted that this global minimum does not impose any relative parity of prices between the individual zones.

By the structure of our data, we have insured that at least one feasible solution will exist for each scenario considered. Since infeasibilities would consider the case of shortages within zones, we have not investigated this alternative although we believe that such shortages could occur in the future.

This model is characterized by ease of revision to reflect changes in costs, production, and demand. In addition we are able to undertake the analysis of the sensitivity of our solutions to perturbations in our original assumptions and parameters.

Incorporation of offshore mining within the GNYMA has been accomplished by the addition of offshore zones of production, each with a designated onshore surge point. (Table 1) These zones are considered as exactly analogous to onshore zones. Transportation costs from these zones to zones of onshore demand are considered as identical to those which would be incurred by an onshore operation in the zone in which the surge is located. Thus unit extraction costs associated with these surges, to use the designation in our model, will be assumed identical to the projected F.O.B. surge price for material mined offshore.

Description of Zones

The twenty-four counties of the GNYMA have been combined into nine zones. Each zone consists of one or more counties. When a zone consists of more than one county, these counties are contiguous. This facilitates the application of the transportation model. Offshore zones are considered in terms of the location of their designated surge. (Table 1)

The Data

Onshore Costs. Onshore unit extraction costs were obtained from reports filed by producers with the US Bureau of Mines. These reports indicate total production and total value of production by year. Average zonal costs were calculated for 1975 and adjusted by 23% for inflation to 1978 dollars. (7) (Table 2)

Transportation costs between zones were calculated by means of the least cost routes from the production center of each zone to the consumption center of each zone as determined by Bronitsky (2). This least cost route is the cheapest combination of truck and barge transportation costs between zones. (Table 3)

Barge cost data were obtained from a current user of this mode of transportation and were determined to be approximately $.02 per ton mile.

Truck cost data were originally determined from tariff notifications filed with the New York State Department of Transportation. These were found to indicate a cost of approximately $.24 per ton mile. By discussion with a carrier in the area, it was determined that these tariffs do not represent the actual costs incurred by a producer under current practice. A more appropriate figure of $.08 per ton mile has therefore been used in our formulation.

TABLE 2

INFLATED ONSHORE UNIT EXTRACTION COSTS
($ PER TON)

Zone 1	-----
Zone 2	3.78
Zone 3	1.91
Zone 4	2.83
Zone 5	2.53
Zone 6	4.40
Zone 7	2.96
Zone 8	2.58
Zone 9	2.53

TABLE 3

INTERZONAL TRANSPORTATION COSTS
($ PER TON)

From Zone \ To Zone	1	2	3	4	5	6	7	8	9
1	.60	.69	1.17	2.80	2.09	2.24	2.23	.78	1.97
2	.69	.80	1.28	1.30	2.37	1.08	2.76	2.09	.99
3	1.17	1.60	.96	1.78	2.85	1.56	3.24	2.57	.72
4	2.80	2.36	3.00	.96	2.67	1.80	3.48	2.89	2.61
5	2.09	2.87	3.51	2.11	.72	2.31	3.91	3.40	3.12
6	2.24	3.00	3.64	1.44	3.62	1.28	2.56	3.20	2.96
7	2.23	3.24	3.88	2.84	3.91	1.60	.96	2.56	3.06
8	.78	1.76	2.40	1.48	2.55	1.92	2.56	1.12	1.70
9	1.97	1.82	1.71	2.38	3.45	2.15	3.83	3.31	1.28

Offshore Costs. Offshore extraction and movement to surge costs were determined for eight configurations of technology. These are:

1. Small hydraulic dredge (16"); transportation to shore by barge.
2. Small hydraulic dredge (16"); transportation to shore by a submerged pipeline.
3. Medium hydraulic dredge (20"); transportation to shore by barge.
4. Medium hydraulic dredge (20"); transportation to shore by submerged pipeline.
5. Large hydraulic dredge (27"); transportation to shore by barge.
6. Large hydraulic dredge (27"); transportation to shore by submerged pipeline.
7. Representative dipper dredge (1585 yd^3 per hour); transportation to shore by barge.
8. Representative clamshell dredge (800 yd^3 per hour); transportation to shore by barge.

The data used to obtain these costs were obtained from a previous report in this series (7). An operating time of 500 hours per month was assumed as well as a conversion factor of 1.5 tons per yd^3. No explicit account of winter lay up time was taken. (Table 4) All data are in 1978 dollars.

Extraction costs were computed based upon the capital and operating costs associated with the operation of a particular barge. Transportation costs to shore were calculated incrementally based upon additional equipment and operating personnel required. These costs were calculated for ranges of distance from shore in mileage increments dictated by the technology involved. The maximum cost within the range was used as representing the entire range (i.e., maximum hauling or pumping distance). (Table 4) Pipeline distances of greater than 15 miles were not considered. This was done for two reasons:

TABLE 4

EXTRACTION AND TRANSPORTATION COSTS TO
SHORE BY TECHNOLOGICAL CONFIGURATION
($ PER TON)

	Extraction Cost	Transportation Cost (Incremental) By Distance From Shore 0-5	5-10	10-15	15-20	20-25	25-30
Small Hydraulic Barge	1.32	0	0	.05	.05	.10	.10
Small Hydraulic Pipeline	1.32	.23	.65	1.07	---	---	---
Medium Hydraulic Barge	.64	0	0	.02	.02	.05	.05
Medium Hydraulic Pipeline	.64	.13	.37	.60	---	---	---
Large Hydraulic Barge	.50	0	0	.02	.02	.04	.04
Large Hydraulic Pipeline	.50	.09	.28	.47	---	---	---
Dipper Barge	.28	0	0	.03	.03	.06	.06
Clamshell Barge	.44	0	0	.03	.03	.06	.06

first, pipeline distances of more than 15 miles are not within current industry practice; and second, each five mile increment in pipeline length requires the use of an additional booster pump. Each such pump reduces total production by approximately 20% thereby increasing cost per ton proportionately (7).

Onshore processing costs at the surge were assumed to be $.80 per ton for all surges. This value was obtained by consultation with our consultants (6). The figure is considered to accurately portray the capital and operating costs of a surge but does not include the cost of the land upon which a surge might be located.

In determining the offshore extraction sites to be considered in our economic evaluation of offshore mining, we relied upon a previous report in this series (4). From available data it appears that the following sites may be suitable (from a geologic perspective) for offshore mining:

1. Offshore New Jersey, east of Red Bank.
2. South Shore Long Island, south of Jones Beach.
3. New York Harbor.
4. The Norwalk Island Shoals, in Long Island Sound.
5. Off Bridgeport, Connecticut, in Long Island Sound.

For each of these sites a designated surge was established to be in the nearest onshore zone. For the offshore sites in Long Island Sound, two designated surges were established for each; one in Connecticut and the second on Long Island. F.O.B. surge prices for each surge were calculated from the data in Table 4 and are shown in Table 5. Reduced production levels associated with the addition of boosters in pipeline transportation to shore were incorporated.

TABLE 5

F.O.B. SURGE PRICE
($ PER TON)

Technology	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16
Small Hydraulic Barge	2.12	2.12	2.12	2.12	2.22	2.12	2.17
Small Hydraulic Pipeline	3.26	3.26	3.26	2.35	---	3.26	4.54
Medium Hydraulic Barge	1.44	1.44	1.44	1.44	1.49	1.44	1.46
Medium Hydraulic Pipeline	2.06	2.06	2.06	1.57	---	2.06	2.74
Large Hydraulic Barge	1.30	1.30	1.30	1.30	1.34	1.30	1.32
Large Hydraulic Pipeline	1.78	1.78	1.78	1.39	---	1.78	2.31
Clamshell	1.24	1.24	1.24	1.24	1.30	1.24	1.27
Dipper	1.08	1.08	1.08	1.88	1.14	1.08	1.11

Transportation costs from surge to zones of demand were considered to be identical to those incurred by onshore producers. We recognize that in practice, this involves some double counting of transportation costs. For example, if Manhattan were to be served by an offshore mining operation in Long Island Sound, it would be cheaper to transport material directly to a surge closer to Manhattan by barge than to bring it to shore, process it, and then to transport it to Manhattan by barge. We have, however, uniquely associated our offshore production sites with surges.

Supply

Onshore supply was set at the maximum production level for each zone for the period 1970 - 1975. (Table 6) Offshore supply was assumed to be limited by the size of onshore surges. We concluded that a surge capacity of 2,000,000 tons per year was appropriate.

For a consideration of the optimal location of an initial offshore mining operation, a series of analyses were done assuming that the capacity of the surge would be unlimited.

Demand

Three levels of demand were considered. The historical demands for the years 1972 and 1975 were used to represent maximal and minimal levels of demand. In addition, the projected future demand for the period 1980-2000 was also considered. The values of these demands, by zone were obtained from a previous report in this series (5) and are shown in Table 6.

TABLE 6

PRODUCTION AND DEMAND
BY ONSHORE ZONE

Zone	Production (Maximum 1970-75)	Demand 1972	1975	1980-2000
	Tons x 10^3	Tons x 10^3		
1	0	4167	1096	2630
2	4600	491	338	550
3	5900	1514	712	1550
4	400	1356	716	1190
5	5300	1348	560	760
6	900	2456	1508	2590
7	3300	1336	508	1130
8	2800	1585	660	1580
9	1800	1664	966	1420

Procedure

Thirty-six separate optimal solutions were obtained for our formulation using the IBM MPS/360 programming package (9). These were divided into four classes dependent upon supply and demand scenarios. The classes are: (A) for 1972 demand with surge capacities set at 2,000,000 tons per year: (B) for 1975 demand with surge capacities set at 2,000,000 tons per year; (C) for projected demand (1980-2000) with surge capacities set at 2,000,000 tons per year; and (D) for projected demand (1980-2000) with unlimited surge capacities.

Within each class nine solutions were obtained; one incorporating no offshore mining and one each for the technological configurations under study.

Results

Results for all runs are shown in tables 7A, 7B, 7C, and 7D. Each column corresponds to one run. Total cost and shipments, in tons, from each of the nine onshore supply zones and seven surges are shown. Subtotals of onshore and offshore supply are given.

Conclusions

From our results, it appears that offshore mining of fine construction aggregate is currently viable economically. Comparison of the offshore subtotals from tables 7A, 7B, and 7C indicates that this economic viability would not be jeopardized by fluctuations in annual demand.

As expected, these tables indicated the increasing economies of scale associated with progressively larger mining operations. In all classes, the largest hydraulic dredge was "less expensive" than competing smaller hydraulic dredges. Also, movement to shore by barge was found to produce lower total costs than movement by pipeline.

1972 DEMAND; SURGE CAPACITY 2,000,000 TONS/YR

	Technological Configuration								
	1	2	3	4	5	6	7	8	9
Total Cost ($ x 10^3)	56,901	48,337	55,595	40,275	49,859	38,414	47,939	37,683	35,541
Shipped From (Tons x 10^3)									
Zone 1	---	---	---	---	---	---	---	---	---
Zone 2	---	---	---	---	---	---	---	---	---
Zone 3	5,900	5,233	5,900	1,421	5,900	1,421	5,900	1,178	1,178
Zone 4	400	---	400	---	---	---	---	---	---
Zone 5	2,304	1,348	1,481	1,348	1,348	1,348	1,348	1,348	1,348
Zone 6	---	---	---	---	---	---	---	---	---
Zone 7	3,300	---	1,336	---	1,336	---	1,336	---	---
Zone 8	2,800	---	2,800	---	---	---	---	---	---
Zone 9	1,213	---	---	---	---	---	---	---	---
Total Onshore	15,917	6,581	11,917	2,769	8,584	2,769	8,584	2,526	2,526
Zone 10		2,000	---	2,000	2,000	2,000	2,000	2,000	2,000
Zone 11		2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Zone 12		2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Zone 13		1,336	---	2,000	1,333	2,000	1,333	1,391	1,391
Zone 14		2,000	---	2,000	---	2,000	---	2,000	2,000
Zone 15		---	---	1,148	---	1,148	---	2,000	2,000
Zone 16		---	---	2,000	---	2,000	---	2,000	2,000
Total Offshore		9,336	6,000	13,148	7,333	13,148	7,333	13,391	13,391

1975 DEMAND; SURGE CAPACITY 2,000,000 TONS/YR

	Technological Configuration								
	1	2	3	4	5	6	7	8	9
Total Cost ($ x 10^3)	23,244	21,129	23,244	17,348	21,278	16,436	20,069	16,065	15,013
Shipped From (Tons x 10^3)									
Zone 1									
Zone 2									
Zone 3	5,336	1,678	5,336		1,678		1,678		
Zone 4									
Zone 5	560	560	560	560	560	560	560	560	
Zone 6									
Zone 7	508		508		508		508		
Zone 8	660		660						
Zone 9									
Total Onshore	7,064	2,238	7,064	560	3,146	560	2,746	560	
Zone 10		224		224	318	224	318	224	224
Zone 11		2,000		2,000	2,000	2,000	2,000	2,000	2,000
Zone 12		2,000		2,000	2,000	2,000	2,000	2,000	2,000
Zone 13				508		508		508	508
Zone 14		94		94		94		94	654
Zone 15		508							
Zone 16				1,678		1,678		1,678	1,678
Total Offshore	-0-	4,826	-0-	6,504	4,318	6,504	4,318	6,504	7,064

TABLE 7C

FUTURE DEMAND; SURGE CAPACITY 2,000,000 TONS/YR

	Technological Configuration								
	1	2	3	4	5	6	7	8	9
Total Cost ($ x 10^3)	47,031	40,553	46,146	33,234	41,640	31,580	39,960	30,939	29,034
Shipped From (Tons x 10^3)									
Zone 1									
Zone 2									
Zone 3	5,900	3,510	5,900	970	5,510	970	5,510	970	
Zone 4	400		400						
Zone 5	1,550	760	760	760	760	760	760	760	760
Zone 6									
Zone 7	2,200		1,130		1,130		1,130		
Zone 8	2,800		2,800						
Zone 9	550								
Total Onshore	13,400	4,270	10,990	1,730	7,400	1,730	7,400	1,730	760
Zone 10		2,000		2,000	2,000	2,000	2,000	2,000	2,000
Zone 11		2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Zone 12		2,000	410	2,000	2,000	2,000	2,000	2,000	2,000
Zone 13						540		540	1,510
Zone 14		2,000		2,000		2,000		2,000	2,000
Zone 15		1,130		1,670		1,130		1.130	1,130
Zone 16				2,000		2,000		2,000	2,000
Total Offshore	-0-	9,130	2,410	11,670	6,000	11,670	6,000	11,670	12,640

TABLE [illegible]

FUTURE DEMAND; UNLIMITED SURGE CAPACITY

	Technological Configuration								
	1	2	3	4	5	6	7	8	9
Total Cost ($ x 10^3)	47,031	39,772	46,132	32,215	40,141	30,446	37,750	29,702	27,619
Shipped From (Tons x 10^3)									
Zone 1									
Zone 2									
Zone 3	5,900	2,970	5,900		2,970		2,970		
Zone 4	500		400						
Zone 5	1,550	760	760	760	760	760	760	760	
Zone 6									
Zone 7	2,200		1,130		1,130		1.130		
Zone 8	2,800		2,800						
Zone 9	550								
Total Onshore	13,400	3,730	10,990	760	4,860	760	4,860	760	-0-
Zone 10									
Zone 11		4,760	2,410	4,760	4,760	4,760	4,760	4,760	5,520
Zone 12		3,780		5,200	3,780	5,200	3,780	5,200	5,200
Zone 13				1,130				1,130	
Zone 14									
Zone 15		1,130				1,130			1,130
Zone 16				1,550		1,550		1,550	1,550
Total Offshore		9,670	2,410	12,640	8,540	12,640	8,540	12,640	13,400

The cheapest alternatives were the two mechanical dredging configurations considered, with the clamshell dredge always less expensive than the dipper.

Consideration of Table 7D indicates that the most desirable sites for the establishment of an offshore mining operation are in New York Harbor (zone 11) and off south shore Long Island (zone 12). With the single exception of a small dredge and pipeline technology, future demand from such operations ranges from 8,540,000 tons per year to 10,720,000 tons per year for the period 1980-2000. This amounts to 64% and 80% of total projected regional demand annually.

Comparison of Table 7C with Table 7D indicates that the utilization of other offshore sites and associated surges is forced by the limitation of capacity at surges 11 and 12. Thus increases in production from south shore Long Island and New York Harbor would reduce or eliminate the viability of other offshore mining operations, especially those off the New Jersey shore (zone 10) and off the Norwalk Islands in Long Island Sound with a surge on Long Island (zone 14). These two surges would operate at capacity if such capacity is limited, but should be considered as secondary alternatives to extraction from zones 11 and 12.

The potential annual savings, for each class considered, associated with the establishment of the indicated least cost offshore industry are: (A) $21,360,000; (B) $8,231,000; (C) $17,997,000; and (D) $19,412,000. These figures represent a savings, as opposed to the alternative of no offshore mining, of 38%, 35%, 38%, and 41% respectively.

BIBLIOGRAPHY

1. Ahearn, V.P., Jr. Land Use Planning and the Sand and Gravel Producer. Silver Springs, Maryland: The National Sand and Gravel Association, 1964.

2. Bronitsky, L., The Economics of Construction Mineral Aggregates with an Analysis of the Industry in the Greater New York Metropolitan Area, (Doctoral Thesis) Rensselaer Polytechnic Institute, 1973.

3. Bronitsky, L. and W.A. Wallace, "The Economic Impact of Urbanization on the Mineral Aggregate Industry," Economic Geography, Vol. 50, No. 2, p. 130-140, April 1974.

4. Carlisle, D. and Wallace, W.A., "Sand and Gravel in the Greater New York Metropolitan Area", New York State Sea Grant Program, 1978, NYSSGP-RS-78-13.

5. Courtney, K., DeHais, J. and W.A. Wallace, "The Demand for Construction Minerals in the Greater New York Metropolitan Area", New York State Sea Grant Program, 1979.

6. Dunn, J.R., Dunn Geoscience Inc, Latham, New York; Personal Conversations, October, 1978.

7. Guyette, P.L. and Wallace, W.A., "A Cost Analysis of Offshore Mining and Dumping Operations in the Greater New York Metropolitan Area", New York State Sea Grant Program, 1979.

8. Henderson, J.M., The Efficiency of the Coal Industry: An Application of Linear Programming. Cambridge: Harvard University Press, 1958.

9. Mathematical Programming System/360 (360A-CO-14X): Applications Description (H20-029-3), International Business Machines Corporation, White Plains, New York, 1967.