BENEFIT-COST STUDY OF PINELLAS COUNTY ARTIFICIAL REEFS

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PREFACE

This investigation was carried out in conjunction with a cooperative investigation of biological, political and socioeconomic aspects of the Clearwater Artificial Reef. The project is headed by F. T. Manheim and H. Mathews and is jointly sponsored by Florida State University System Sea Grant and Pinellas County.

The authors wish to thank the participating agencies for a great deal of time and effort spent in providing data and explaining the mode of operation relevant for this study. Special thanks go to Jim Shinholser, Director of Mosquito Control, and Connie Fernandez, of the office staff, without whose help this report could not have been undertaken. David H. M. Holihan, Chief of Sanitation Disposal for the City of St. Petersburg, guided the authors through the intricacies of Toytown operations in general and tire burial in particular. William Burchfield, Harbor Master at the Clearwater Marina, was of great help in providing insights into fishing operations in the Tampa Bay area. The barge captain and crew were consulted numerous times on technicalities of transporting reef materials. Rhonda Shaffer produced most of the final typescript.

Two graduate assistants, Don Schug from Marine Science, and Clifford Mangano from Economics, helped a great deal in data collection and calculations. The various versions of the paper were ably criticized by F. T. Manheim, John C. Briggs and Don Schug. But naturally, the responsibility for any remaining errors and shortcomings rests with the authors.

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INTRODUCTION

Used tires are commonly thought to have few economic uses. In fact, until recently, most communities merely hauled their tires to the dumps to be buried along with other garbage and they were thought to represent just another cost attached to the modern motorized way of life. But old tires do have alternative uses. Experiments have been carried out in Pennsylvania to separate rubber from the tire base and to recycle the rubber. Old tires are seen as building blocks in fashionable patio gardens and on children's playgrounds. Until new air pollution regulations came into effect, tires were also burned in orange groves to prevent a freeze. Of particular interest in this study, tires are now used to build artificial reefs to attract algae, corals, and sponges along with fish and crustaceans that provide recreational angling and diving.

A preliminary analysis of tire disposal in the Tampa Bay area revealed that locally there are two principal ways of disposing of tires. They are dumped in public disposal grounds, such as Toytown in St. Petersburg, and provide filled land for future public parks. Or they are transported to previously barren sand bottom locations in the Gulf of Mexico to provide favored habitat for fishes and other kinds of marine life. The present study is designed to assess the benefits and costs associated with these two ways of converting old tires into public goods.

In general, a public project is deemed beneficial and worth undertaking if the present value of its estimated benefits exceed the costs, and the necessary resources to invest in the project are forthcoming. A choice between several alternative projects to be undertaken with limited or fixed resources falls upon the project whose benefit-cost ratio is the highest.

The traditional way of disposing of tires in landfills creates benefits that may or may not be deemed sufficient to cover the disposal costs. Few, if any, figures have been produced on the benefit-cost ratios of dumps taking into account their suitable long-term end uses, such as parks. For example, it takes an old city resident or an expert in the history of garbage disposal in St. Petersburg to know that the Woodlawn Recreational Complex on 16th Street North, bounded by 13th and 17th Avenues, was an old city dump. Nobody has estimated the ultimate benefits and costs.

The first task, then, is to study the dumps. To that effect, a short term and long term analysis of the Toytown sanitary landfill will be undertaken. In the short run the output of the landfill is tons of garbage buried. In the long run, garbage becomes an input into the production of acres of filled land. Appropriate demand and supply schedules will constitute the framework in terms of which the actual production, benefit, and cost figures will be evaluated.

The new way of tire disposal generates ocean bottom covered by tires (also by culvert and concrete rubble) and surface areas for marine animals to feed on and enjoy shelter. The ultimate benefits consist of personhours of fishing and diving generated by the reef. In this study, the benefits and costs of the Clearwater Reef will be assessed, since this project has the best data history. In the short run the output of the reef operations is tons of tires and culvert dropped on the ocean bottom. In the long run, these serve as inputs into the production of personhours of fishing and diving. Again appropriate demand and supply schedules will be developed to provide the framework for the quantitative assessment of production, benefits, and costs.

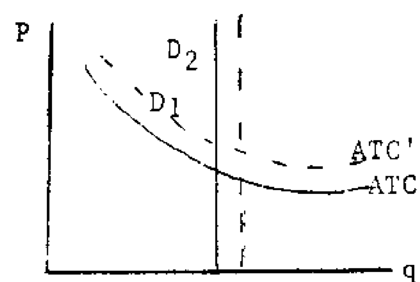
The general model in whose terms benefits and costs will be assessed will be briefly outlined next.

THE MODEL

A general model is adopted here which will allow the estimation of actual and potential benefits and costs even though the outputs of the alternative projects are subject to different pricing policies in the short and long run and vary by the type of project.

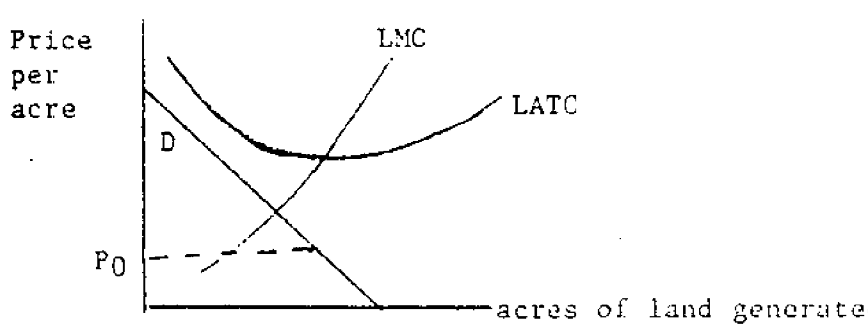
As regards Toytown, in the short run an unlimited volume of disposal services will be offered to county residents at a fixed price calculated to cover costs. From an analytical point of view, the market can be characterized by a frequently shifting vertical demand schedule for disposal and by a normally shaped average cost schedule with equilibrium occurring where the demand schedule intersects the average cost schedule. This pattern is illustrated in Figure 1.

Figure 1



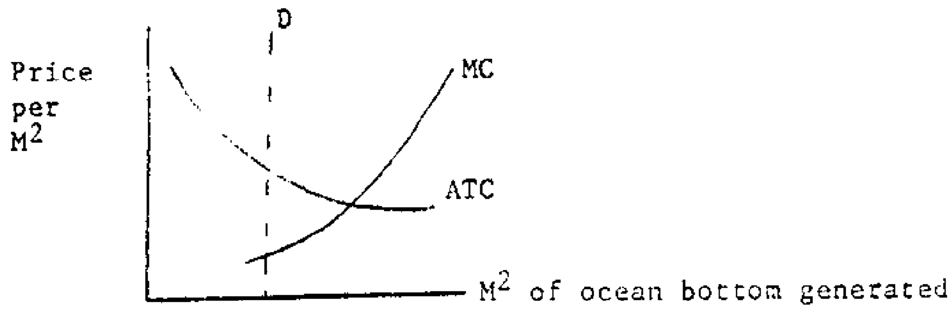
The long term output of filled land appears to sell appreciably below the marginal cost of filling land with garbage, as indicated by sales data on similar filled land adjacent to the dump. This configuration is illustrated in Figure 2.

Figure 2



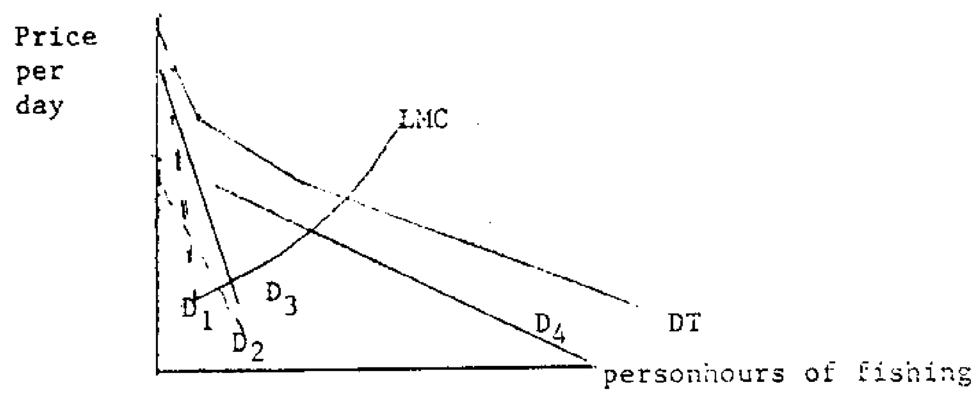
As regards the Clearwater Artificial Reef, the demand for it as a disposal site in the short run is passive, derived demand that does not depend on price, and the quantity supplied is a function of costs, given a limited, although not completely fixed budget. Demand schedule is vertical at the quantity supplied. Price is indeterminate. See Figure 3.

Figure 3



The long term output of personhours of fishing and diving is provided to a segmented market free of user charges but subject to various transportation and equipment costs to be borne by the beneficiaries. Costs are determined by the short run costs of dropping the materials plus the long run productivity of the reef. Figure 4 illustrates this case.

Figure 4



Both long run cases represent underpricing cases. It has been recently argued[1] that evaluative criteria that rely on marginal cost pricing in the case of underpriced public products do not lead to efficient resource allocation. A consistency between evaluation criteria and pricing criteria is needed. To this effect a model of efficient resource allocation in the case of underpriced public products is adopted here. It is based on models

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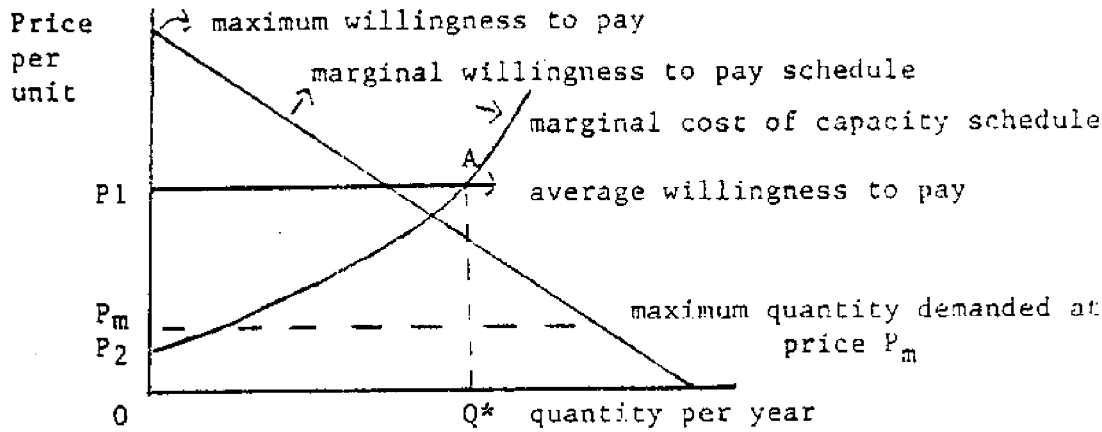
[1] G. E. Mumy and S. H. Hanke, "Public Investment Criteria for Underpriced Public Products", American Economic Review, Sept. 1975, pp. 712-719.

developed by Mumy and Hanke, and elaborated by Miller.[1] A summary is presented below.

Figure 5



Since price is not used as an allocator of demand, it is assumed that each consumption unit has an equal probability of being satisfied, and, thus, satisfaction probability is not a function of the willingness to pay, by and large. In the case of reefs and parks, delivery would presumably be on the first come, first serve basis. Expected gross benefits are not necessarily equal to the area under the demand curve but the product of the average demand price over the quantities from zero to the number of demanded consumption units satisfied and the quantity purchased. Costs are the area under the marginal cost of capacity curve up to the quantity provided (and purchased). Optimum capacity is reached, when average demand price equals marginal cost of capacity.[2]

Following Miller's recommendations[3], judgmental demand curves will be developed to calculate the average willingness to pay. The demand curves are assumed to be linear. Virtually no user demand is assumed to exist when

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[1] J. R. Miller, "On the Use of Unit Day Values in the Evaulation of Site-Specific, Water-Based Recreation Benefits". A paper presented at the Southern Economic Association Meetings in Atlanta, Nov. 1976. 18 pp.

[2] Mumy and Hanke, op. cit., pp. 714-716.

[3] Miller, op. cit., pp. 8-9. Operating costs are assumed to be zero. That is a good approximation in the cases on hand; see pp. 39.

the price of a service reaches the range of a more expensive substitute. Thus, in the case of Sunday anglers, for example, who normally either fish in their own small boats or utilize party boats, hiring a charter boat is assumed to represent such a high priced alternative. In the case of Toytown land, it is adjacent, distinctly superior but still non-residential land. Demand is at its maximum when fishing and diving sites are physically so crowded every day when weather is good enough that those who come last have no room either to fish or to dive. For Toytown, a second point on the demand schedule will be established on the basis of quantities of similar land currently sold. The marginal cost of capacity is the increase in total costs due to the expansion of public product capacity by one unit, in the present case one acre of land or one M^2 of ocean bottom. These long run marginal cost curves will be developed from budget data and from data on imputed cost components secured from other sources. Zero operating costs are assumed.

Figure 5 depicts a situation where Q* is the equilibrium quantity of the product. Benefits to consumers equal the area Op_1AQ^* and the associated costs are P_2AQ^*O. Benefit-cost ratio exceeds one. A greater quantity is produced than would be suggested by the (inefficient) marginal cost pricing principle. Less would be produced if the marginal cost of capacity schedule intersected the average willingness to pay line to the left of the demand schedule, even though the benefit-cost ratio would still be above one. If the marginal cost of capacity schedule in its entirety lies above the average willingness to pay line, costs would exceed benefits and the project would not be undertaken at all.

The above analytical framework will be applied to calculation of actual benefit-cost ratios of the two ways of disposing of tires, landfill and artificial reef. Included in the costs are the usual private cost components that any business firm would incur. But since some of the resources were secured at below opportunity cost (either below market prices or free), imputation was utilized to arrive at the full costs. The conventional breakdown of costs into fixed costs and variable costs was utilized.

CONVENTIONAL DISPOSAL OF TIRES: The Short Run

The primary disposal site of old tires in Pinellas County is the Toytown landfill, although tires are still accepted, albeit reluctantly, also in the County dump, Largo and Clearwater dumps. Companies that dispose of tires in significant numbers know that they should be brought to Toytown; they bear the cost of hauling tires to disposal sites. The county charges its dump users a flat rate of $4.00 a ton[1] no matter what the composition of the garbage. Since the county can designate the disposal sites, the users must bear whatever the costs of hauling tires to public disposal sites are, unless they find private uses at lower costs.

The present cost of operating the Toytown dump (exclusive of research and development expenditures) is $3.00 a ton (on the average).[2] Large quantities of tires brought to the dump during the last two years have been piled up outside and they await shipment to the Artificial Reef. Only tires that cannot be readily separated from other garbage are still buried. It is estimated that the current stock amounts to 40,000 tires, whereas the total number transported to the reef from the entire county since spring 1974 is 122,000. The total accumulation converts to roughly 730 tons a year, which represents only 0.2 percent of the annual 330,000 ton utilization of the Toytown dump; which in turn represents 60 percent of the tonnage of all the county dumps. A more systematic separation and accounting for tires shipped to

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[1]The minimum charge is $2.00 per one half ton.

[2]See Table 2, p. 12.

the reefs will probably double this figure. A study by the Tampa Bay Regional Planning Council[1] estimated that in 1974, 480,000 passenger car tires were discarded in Pinellas County. At 18 pounds per tire, and with a 10% allowance for reuse[2], about 3,800 tons of garbage is generated. If 90 percent of these were brought to Toytown, they would represent 1.1 percent of its annual disposal volume. A conservative figure of 0.5 percent is used here.

These figures, together with a detailed breakdown of the various costs associated with the Toytown landfill operation, allow the estimation of the total and marginal costs of dumping tires in the landfill. Annual data will be used. To obtain the aggregate costs, annual figures since 1969/70 fiscal year will be analyzed. Phase I of Toytown will end November 1977 at which time the conversion to a park will begin. This phase consists of 165 acres. Phase II - 70 acres - is estimated to end in December 1981. If resource recovery, such as extensive use of grinding machines, comes earlier, the dump may also close earlier. Here costs and benefits up to fiscal year 1980/81 will be considered.

Costs will be analyzed in three categories: land, other fixed costs, and variable costs. The fixed costs of the land fill consist of the imputed rental value of the 235 acres, in their initial condition at the time Toytown landfill was opened. Toytown opened in 1959, originally as a disposal site for brush and building materials. It was converted into a full-scale sanitary landfill in 1969. This study estimates land values since 1969.

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[1]Tampa Bay Regional Planning Council, Tampa Bay Area-Wide Solid Waste Management and Resource Recovery Study - Phase II. Technical and Management Report, St. Petersburg, Florida, February 1976, pp. 63, 74.

[2]Not all tires end up at the dump. Some 10% are reused. R. B. Stone, C. C. Buchanan, and F. W. Steinle, Jr., Scrap Tires as Artificial Reefs, U. S. Environmental Protection Agency, SW-119, 1974, p. 2.

Since Toytown is on county land, the imputed value of land was arrived at by obtaining the cost of similar, adjacent private land. According to records of real estate sales of similar land, kept in the Tax Assessor's Office, the 1969 value was estimated at $1,650 an acre. This land, without any further improvements, increased at an annual rate of 35 per cent between 1969 and 1974.[1]

Thus the initial imputed cost of land in 1969 was $387,750 for 235 acres. If the land had simply been held, instead of being converted into a land fill, and had been sold in 1974, its value would have been $1,738,684. The value of the land in intervening years was obtained by loglinear interpolation. A nine per cent return on land was imputed as the rental cost. However, additional expenditures were incurred when the land was "improved" by adding garbage to it. These expenditures were divided into fixed costs and variable costs. Fixed costs in the short run consist of the depreciation[2] of the machinery, contractual maintenance costs, insurance costs, administrative costs, environmental control costs, such as water measurements, overhead personnel costs, i.e., expenditures on equipment and personnel that would be incurred in a budget year even if there was a drastic decline in the dumping volume. Variable costs equal total costs minus fixed costs, and consist mostly of labor costs and fuel costs. Since the city had repair contracts on most of the landfill equipment, variable costs consist largely of labor

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[1] Based on a sale of a 40 acre piece 200 yards from Toytown in 1969. The same piece was resold in 1974.

[2] The City of St. Petersburg depreciated its equipment on a straight line and original cost basis except in 1974/75 and 1975/76 when estimated current costs were used.

costs. Marginal costs represent the cost of disposing each additional ton of garbage or the change in variable costs per unit of output. Since practically no overtime labor or part-time employees were used, marginal costs are equal to average costs.

The history of the three principal categories of costs for the Toytown landfill operation was traced and estimates prepared of their likely future values. Apart from the rental costs of land already discussed, budget figures were available for all components except that the costs of incinerator operations excluded in 1969/70 had to be estimated (they were available for 1970/71). Current costs were converted into constant 1974 costs by utilizing the aggregate price index of service costs and the unit costs of full-time labor paid out of the Sanitation Fund of the City of St. Petersburg in the relevant years.

The costs were projected to 1980/81 on the following conservative growth assumptions. Value of fixed costs will increase 15 per cent a year, while the service price index will increase by 8 per cent. Labor costs will increase by 10 per cent a year, of which 7 per cent represents wage increases. Land prices will increase only 9 per cent a year. When Phase I closes at the end of 1976/77 fiscal year, imputed land rental goes down by 70 per cent, but other costs are not affected.

The results of these calculations are given in Table 1. The per ton costs are given in Table 2.

These calculations yield costs per ton that average $2.51 over the life of the dump. The conservative cost estimates projected for 1976/77 - 1980/81 produce declining costs per ton, whereas up to 1975/76 per ton costs increased in every year except 1970/71 and 1972/73. These costs underestimate the ultimate costs of garbage disposal also, for another reason. The dump requires

TABLE 1. ANNUAL COSTS OF TOYTOWN SANITARY LANDFILL OPERATIONS

	FIXED COSTS,[3] excl. LAND			LABOR COSTS[4]			LAND "RENTAL"			TOTAL COSTS		
Fiscal Year	Current Value	Price Index	In Constant Prices	Current Value	Price Index	In Constant Prices	Imputed Rent	Price Index	In Constant Prices	Current Price	Price Index	In Constant Prices
1969/70[1]	$284,898	79.9	$285,970	$ 80,415	58.9	$136,528	$ 34,897	30.1	$156,481	$255,312	54.5	$578,979
1970/71[1]	143,110	84.4	169,560	116,934	61.3	190,757	47,112	40.6	156,481	307,156	59.4	516,798
1971/72	256,134	87.6	292,390	114,866	70.0	206,951	63,600	54.9	156,481	464,600	70.8	655,822
1972/73[2]	229,865	91.5	251,220	213,734	77.9	274,370	85,861	74.1	156,481	529,460	77.6	682,071
1973/74[2]	348,144	100.0	348,144	232,896	100.0	232,896	115,912	100.0	156,481	696,952	94.5	737,521
1974/75[2]	400,132	109.5	365,417	277,950	102.2	271,967	156,481	109.0	156,481	834,563	105.1	793,865
1975/76[2]	569,685	118.2	481,967	378,342	114.1	331,588	170,565	118.8	156,481	1,118,592	115.4	970,036
1976/77	655,138	127.7	513,029	412,176	120.3	342,623	185,916	129.5	156,481	1,253,230	123.9	1,012,133
1977/78	753,408	137.9	546,344	449,394	124.2	361,831	60,644	141.2	43,000	1,263,446	132.8	951,175
1978/79	866,420	148.9	581,880	490,333	128.2	382,475	66,266	153.9	43,000	1,423,619	141.3	1,007,355
1979/80	996,383	160.8	619,641	545,366	132.3	412,219	72,230	167.7	43,000	1,603,980	149.2	1,074,860
1980/81	1,145,840	173.7	659,666	584,903	136.7	427,873	78,730	182.6	43,000	1,809,473	160.0	1,130,539

[1] Excludes incinerator costs, includes costs of operating the compost and the open dump.

[2] Excludes costs of recycling operations.

[3] 12% of the entire budget added as administrative and insurance costs.

[4] Includes the wages of Emergency Jobs personnel assigned to the landfill in 1975/76 and assumed to continue.

Source: Annual Budgets of the City of St. Petersburg.

TABLE 2. TOTAL DISPOSAL COSTS PER TON IN 1974 PRICES

	Total Costs	Tonnage	Costs per Ton	Estimated Tire Burial Costs
1969/70	$ 578,979	156,300	$3.70	$ 3,184
1970/71	516,798	250,369	2.06	2,842
1971/72	655,822	286,040	2.29	3,607
1972/73	682,071	322,695	2.11	3,750
1973/74	737,521	314,305	2.35	4,057
1974/75	793,865	313,486	2.53	4,370
1975/76	970,036	325,661	2.98	5,335
1976/77	1,012,133	360,000	2.81	5,567
1977/78	951,175	400,000	2.38	5,232
1978/79	1,007,355	434,000	2.32	5,541
1979/80	1,074,860	471,000	2.28	5,911
1980/81	1,130,539	511,000	2.21	6,218
	$10,111,154	4,144,856	———	$56,614
"Scrap value" of land in 1977	297,635			1,488
Aggregate Costs	$10,408,789		2.51	$57,102

continuous maintenance even after it is closed because of odor problems, rodent problems, methane gas problems and mosquito breeding problems. The costs of burying tires are above average for two reasons. When there are heavy rainfalls that wash away sand, all materials but especially tires have to be covered up a second time. In 1974, these additional costs were estimated to represent about 13 per cent of the variable costs. The costs of tire burial are also higher than those of other garbage because tires work their way up to the top of the fills far easier than any other components and need to be covered more than once even in the absence of heavy rainfalls. Tires also produce a "spongy" land surface in later years. A 10 per cent adjustment was made to the unit costs on account of these factors.

LONG-RUN BENEFITS AND COSTS OF TIRE DISPOSAL IN TOYTOWN

Tires were assumed to represent 0.5% of the annual tonnage at Toytown. If tires had continued to be buried there, these costs would thus have increased from about $2,600 in 1969/70 to $6,200 in 1980/81 yielding an aggregate cost figure of $57,102.

Assuming an interest rate of seven per cent[1], the 1969/70-72/73 tire burial expenditures were compounded at that annual rate and the 1974/75-80/81 expenditures were discounted at the same rate to arrive at the 1974 present value of all expenditures on tires. They came to a total of $50,177. Since the tire tonnage handled was estimated at 19,800, this yields a present value cost of $2.53 per ton on tires. Assuming tires weigh 18 lbs. each, this represents 2.2 million tires, a cost of two cents per tire.

Tire volume and weight remain the same for an indefinite time, whereas other types of refuse would probably be reduced by 50% in weight and volume in 10 years.[2] Therefore, tire volume at the closing of the dump was assumed to represent twice as high a percentage of total volume as at dumping time, or 1.0 per cent of the total of 235 acres, or 1.70 acres in 1976/77 and .70 acres in 1980/81. The alternative cost principle was utilized to estimate the benefits of this land. This kind of filled land now exists near the land fill and currently sells anywhere from $800 to $1500 an acre and has, for all intents and purposes, not changed in value since 1952.[3] Most of this filled land dates back to the land boom of the 1920s and the subsequent depression in which the county acquired the land in tax foreclosures.

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[1]This rate is approximately what has recently been recommended for the evaluation of Federal public projects.

[2]Estimates by D. M. M. Holihan, Chief of Sanitation Disposal in St. Petersburg.

[3]Mr. Bumiller, County Engineering Office, estimated that lots of ¼ to ½ acres have been selling for $200 to $400 since 1952. These lots have no access; neither would the closed dump.

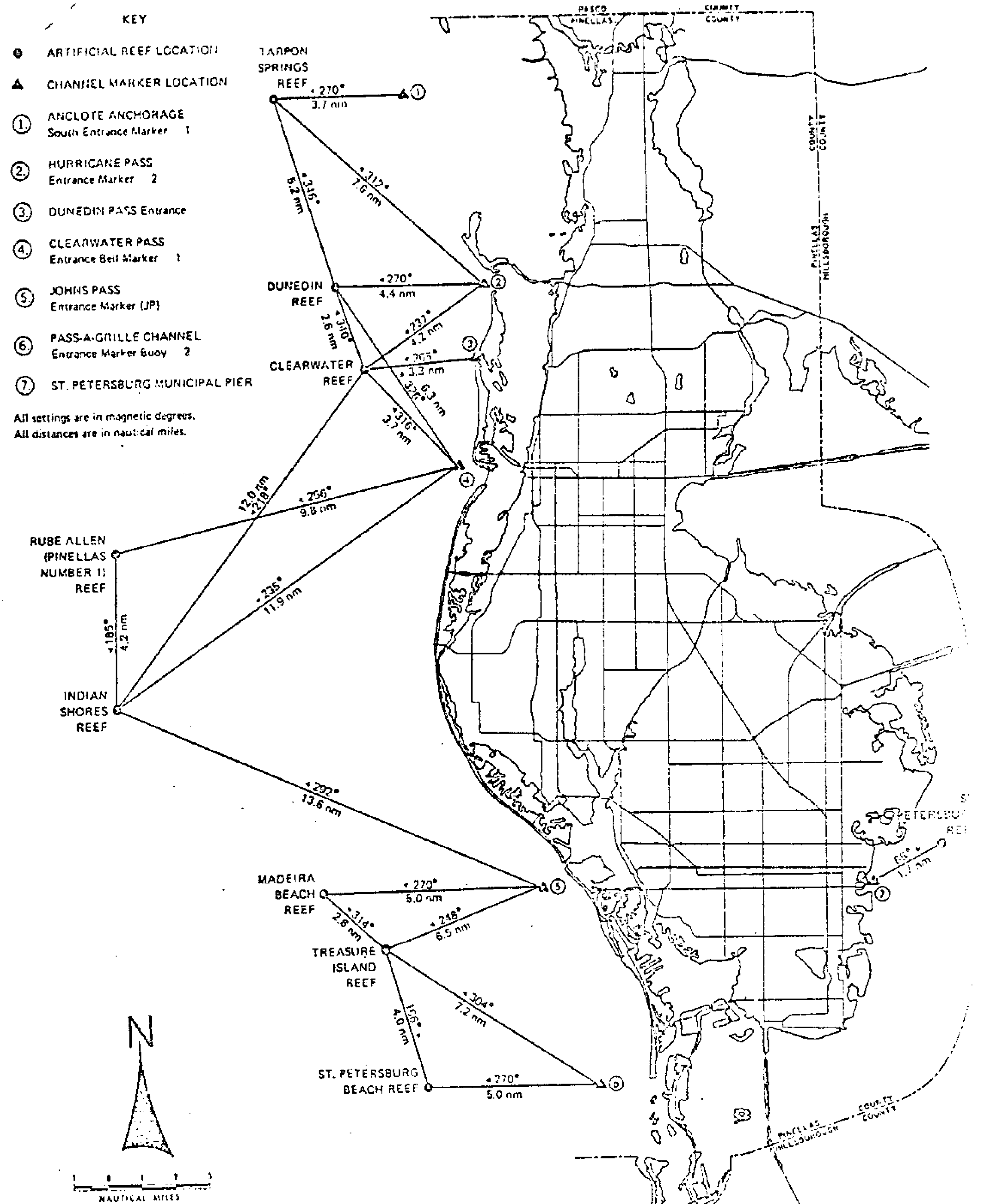
All sales of such land in the area for the last three years were surveyed to estimate that 6.5 acres is the quantity demanded annually at the market price of $1,400 per acre. This information was utilized to establish one point on the judgmental demand schedule. The highest price considered acceptable to the buyers was set equal to $6,000, the price of distinctly superior land in Evergreen Acres that was still not good enough to erect any type of permanent structure (none can be erected on the filled dump land). 2.4 acres were thus estimated to confer total benefits of $3,964.

The benefit-cost ratio is thus $3,964/50,177 or 0.079. Clearly, tires should not be buried if there are any more economical methods of disposing of them.

BUILDING AN ARTIFICIAL REEF WITH TIRES AND CULVERT: The Short Run

Pinellas County entered a new phase of service activity in March 1974 when it assumed responsibility for reef building in the adjacent coastal waters. The City of Clearwater had been engaged in the same activity on a smaller scale for about two years previously. But in Spring 1974 a large barge was purchased jointly by the county and eight coastal cities. The City of Clearwater had been building the Clearwater Reef about 3 miles off Clearwater Beach. This site was the first target of the county project also, but in subsequent years other sites have been developed from Tarpon Springs to St. Pete Beach and into Tampa Bay. These reef sites are located off the main municipalities of Pinellas County on sand bottoms that were formerly barren of productive marine life. The enclosed map shows all the actual and planned locations to date.

The project was assigned to the Mosquito Control Division as a separate activity, although the funds came initially from the General Fund of the county. In subsequent years the project has had a budget of its own, but a substantial



ARTIFICIAL REEF LOCATION MAP

amount of resources has been drawn from other county government agencies. The present study will attempt to analyze all the costs incurred to obtain costs per square meter of ocean bottom covered.

Volume of Materials Handled

When the Reef project was initiated by the City of Clearwater, only tires were used as the building material. At first, individual tires were laid, but soon a bundle of four tires became the standard unit. More recently, tires have been split and bundled to stacks of 30 split tires in each one of the two forks of a forklift, and, further, three of these loads tied together to a 6 times 30 split halves per drop. Concrete culvert was not dropped until 1973/74 when the county took over the project. At that time concrete culvert had become available from local construction projects. Concrete rubble came from three sources: old Gandy Bridge, the old Corey Causeway Bridge and the old Courtney Campbell Bridge. The Clearwater Reef was the destination of rubble from the Courtney Campbell Causeway Bridge. In addition, some construction companies made occasional donations to the county of old pipe and culvert for the reef. Such donations qualify as bona fide charitable contributions and are tax deductible.

Overall the following quantities of materials have been hauled to the different reefs.[1]

TABLE 3. QUANTITIES OF TIRES AND PIPE HAULED TO THE REEFS

Fiscal Year	Tires, Number	Concrete Pipe, Tons	Steel Pipe, Tons
1973/74	5,798[2]	31	30
1974/75	42,796	1665	32
1975/76	74,173	1756	28

Source: Budget Preparation Data, Mosquito Control

[1] Unfortunately, the rubble was so widely scattered at the sea bottom as to be of little value as shelter for aquatic life.

[2] About 72,000 tires deposited before the county program started.

The Physical Facilities and Equipment

As soon as the decision was made to acquire a barge for transporting tires and other materials off shore to the reef, no more tires were buried in the Toytown or other sanitary landfills of the county. Three areas have been set aside for accumulating the tires and culvert: an acre site at the entrance to Toytown landfill, established in 1974; a 75' x 300' staging area in Clearwater behind the Seminole Street boat launch site, originally established by the City of Clearwater in 1972 and leased to Pinellas county in 1974; and a 75' x 265' staging area in the Southwest corner of the Corey Causeway to St. Petersburg Beach right behind the St. Petersburg municipal water treatment plant, established in Fall 1975.

The two staging sites receive tires, culvert and concrete rubble not only from the various dumps but also directly from interested individuals, companies, and public agencies. A barge was acquired for transporting the materials. Initially, materials were loaded onto the barge exclusively from the Clearwater staging area. In Fall 1975, a new dock of 10 ton capacity was built at the St. Pete site and it now offers considerably better facilities. A major advantage is deep enough water so that loading does not have to await a high tide as in Clearwater. The barge is berthed at the Clearwater Marina and usually makes one-day trips to the Clearwater site.[1] When taking materials from the St. Pete site, the barge is berthed at the dock, making one trip a day. It takes longer to load tires at the St. Pete site because of the limitations of dock space; at the Clearwater site, the entire seawall serves as a loading area. There is no appreciable difference on loading times for culvert.

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[1]Under ideal tide and weather conditions, only one trip in a 10 hour day is possible from the Clearwater site to the nearest reef, the Clearwater reef. A round-trip to Clearwater Reef takes 2.5 hours, plus fuel and salaries. An average roundtrip to all reefs takes 4.5 hours. Trips from the South staging area require longer travel and loading times, exclusive of loading and unloading, which takes another 3 hours and the total costs come to $150.

At each one of these sites, tires are either punched or split, and bundled ready for lifting into the barge. Up until Fall 1974, punching was used exclusively. Punching holes in the tires takes longer, and the bundles require ballast; split tires require no ballast. Splitting enables more concise packing of the tires and thus easier transportation. Punching is now used as a back-up system only. The normal rate of splitting is about 500-600 tires per day per machine, although 800 a day could be reached with better utilization of equipment and more efficient labor. (In fact, the manufacturer claims a capacity of 125 tires per hour.) The punching rate is 700 a day.

The tires and culvert are loaded with a large crane aboard the barge from the two staging sites. Mosquito Control provided the crane in spring 1974 from its surplus stock. It was fully depreciated and no longer served a useful purpose as a piece of mobile equipment at Mosquito Control because of the poor condition of its undercarriage. But in stationary use on the barge maintenance costs are acceptable.

Other equipment besides tire splitters and a tire punch, includes two fork lifts for moving the tire bundles in the staging areas, a Lo-Boy heavy duty vehicle for transporting culvert, one truck for moving the tires from Toytown to the other sites, and one pick-up truck.[1] Most tires are still delivered to Toytown, although some dealers and salvage companies are delivering them directly to the staging sites. They are offered an incentive to do this: unlike delivering to Toytown, there is no service charge per ton.

The barge itself is equipped with two 150 horsepower engines and complete navigational equipment. Its capacity is 63 short tons, net. Average load in seas of less than four feet is 34-40 tons of tires; culvert can be

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[1] Some small tools and equipment are also included in variable costs.

carried only in seas of less than three feet. In addition, there is a considerable amount of diving equipment aboard for use in delivery, reef sight surveys and maintenance.

Estimating Fixed Costs

Fixed costs consist of two categories: the wear and tear of equipment over time as measured by depreciation, and other costs not related to the volume of operations, mainly overhead labor costs, insurance, land rental and office expenses.[1] In cases where the Artificial Reef Project purchased equipment, expert estimates of the life of each piece of equipment were obtained and depreciation schedules were established on a straight line and original cost basis. In the case of rented equipment or equipment carried in other than the basic budgets, similar information was gathered. If rental charges were judged not to reflect the full costs, imputation was resorted to. Purchase price and life of similar equipment or sites were used to represent the opportunity cost concerned. The following figures were obtained.[2]

TABLE 4. FIXED COSTS OF ARTIFICIAL REEF CONSTRUCTION

	1973/74	1974/75	1975/76
Barge	$ 2,143	$ 2,143	$ 2,143
Docks	1,452	1,452	2,290
Equipment on barge	460	559	599
Sites	7,413	7,642	14,694
Heavy equipment	208	743	3,252
Tire cutting equipment	--	348	660
Diving equipment	138	328	393
Overhead labor costs	13,590	13,905	11,390
Insurance	1,790	1,990	2,115
Telephone fixed charge	138	331	662
Total	27,332	29,441	38,198
Of which: in other budgets	9.646	10,904	11,999
imputed	11,998	12,098	16,466
Artificial Reef Budget	5,688	6.439	9,733

[1]None of the equipment is on service contract, unlike Toytown equipment.

[2]The annual capital expenditures from which these fixed costs are allocated

It appears that a relatively small portion of the fixed costs of the Artificial Reef Project are found in the Reef Budget itself. Many of the equipment costs and overhead labor costs are in other budgets, whereas no rental was paid for most of the sites and a rental cost of nine per cent of the estimated 1974 value of the sites was imputed.[1] Sites, labor, insurance and telephone fixed costs are calculated in 1974 prices; capital equipment costs are not so adjusted, but most of them were actually purchased in 1974.

Estimated Variable Costs

Variable costs consist mainly of equipment maintenance and operation, and labor costs. The major maintenance of the equipment was provided by the motor pool and the dry dock at what appear to be close to market prices. They charged for materials and labor. Mileage charges on rented equipment fell considerably short of the average running costs per mile by equipment category as estimated by the county. Therefore, the latter were used as imputed values. Detailed operating costs were available for all purchased equipment; estimates from other budgets were obtained for rented equipment.

Labor costs cover personnel budgeted by a number of different departments: the Department of Mosquito Control, the Artificial Reef Project, and Emergency Jobs Program. Mosquito Control personnel initially operated the tire cutter at Toytown, the tire trucks and the dragline for the barge. Since Fall 1975, Emergency Jobs personnel, funded by the Federal Government, have taken over the duties of preparing the tires and operating a truck. A total of seven is currently employed. Only the rest of the personnel, especially the barge operator and three divers are paid out of the budget of the Artificial Reef proper.

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[1]This figure could be improved by estimating appreciation of land since 1974.

TABLE 5. VARIABLE COSTS OF ARTIFICIAL REEF CONSTRUCTION

	1973/74	1974/75	1975/76
Wages (incl. fringe benefits), contract services, commissions and fees	$13,359	$57,768	$107,884
Supplies, small tools and communications[1]	1,371	4,086	6,645
Travel	2,997	--	245
Equipment maintenance & operation	7,619	20,615	26,224
Total	25,346	82,465	140,992
Of which: in other budgets	3,772	33,557	77,401
imputed	--	--	--
Artificial Reef Budget	21,574	48,912	63,597
In 1974 prices	25,346	80,690	123,569

Costs of Creating a M^2 of Reef Bottom

The simplest short run output measure of reef construction is taken to be M^2 of Reef bottom covered by tires, culvert and other reef material.[2] Accordingly, unit cost figures given in Table 6 were obtained.

TABLE 6. AVERAGE AND MARGINAL COSTS OF REEF BOTTOM GENERATION PER M^2 CLEARWATER REEF, CONSTANT PRICES

	M^2 of Reef Bottom Generated	Total Costs	Average Total Costs per M^2	Marginal Costs Per M^2
1973/74	923	52,678	57.07	26.56
1974/75	2,963	106,859	36.06	18.78
1975/76	5,928	162,535	27.42	26.93
1976/77	7,257	198,319	27.33	

If punched tires had been the sole source of reef materials, or if split tires only had been used, and the costs of dropping each type of treated tire are assumed identical, then the entire annual reef generation would have required the following quantities of "raw" tires and would have resulted in unit costs shown in Table 7.

[1]No adjustment was made for free telephone calls to Tampa.

[2]For a fuller discussion, see the section on Fish Habitat Generation, pp. 25-26.

TABLE 7. THEORETICAL VALUE ADDED PER TIRE TAKEN TO REEF

Fiscal Year	M^2 of Bottom Generated	Punched Tires[1]	Split Tires[2]	Costs per Punched Tire	Costs per Split Tire
1973/74	923	6,052	19,229	8.70	2.74
1974/75	2,963	19,430	61,729	5.50	1.73
1975/76	5,928	38,872	123,500	4.18	1.32

The alternative cost of the disposal--burying tires in the Toytown dump--is about two cents per tire.[3] It is thus obvious that whether punched or split tires are used, tire "burial" in the artificial reef brings costs of an entirely different order of magnitude. If reefs are to be preferred, they will have to demonstrate benefits as fishing and diving sites rather than as alternatives to dumps.

LONG RUN COSTS AND PRODUCTIVITY OF THE CLEARWATER ARTIFICIAL REEF

Projected Costs of Reef Building

In its initial stages, the Reef Project enjoyed the benefits of surplus equipment transferred from other county units, such as the crane and a fork lift, and the utilization of other equipment that had already been depreciated down to scrap value by other departments, such as a truck. In the projections it was assumed that a full market price of new equipment would be paid for replacements. Two sets of fixed cost projections were prepared based on: (1) sustaining the present plant and equipment, (2) adding sufficient equipment to enable the most expensive piece of equipment - the barge - to be efficiently utilized. According to the first alternative, equipment depreciation and overhead labor costs of $40,756 a year, in 1974 prices, should be expected until 1982/83, when replacement of the fork lifts would raise the total to $42,417.

[1] .1525 M^2 per punched tire.

[2] 0.048 M^2 per split tire.

[3] ...

But it should be noted that at present the different "plants" of the Project do not operate at full capacity. The barge captain estimates that with proper dock facilities the barge should be able to make three trips per week to the reefs. Allowing for 10 weeks of repairs and bad weather, this would still result in 126 trips a year in lieu of the current total of 70, or an increase of 80%.

The biggest bottleneck, however, lies in the tire splitting operations. This is mainly a production problem, not an equipment problem or plant problem. If the two tire splitters were operated eight hours a day at the rate of 100 tires per hour (80% of the capacity estimated by the manufacturer) 48 weeks a year (and the tire punch would not be used at all), a total output of 384,000 tires would result, instead of the current output of 74,000. Since the barge can carry an average load of 35 to 40 tons, at 18 lb. per tire, a load represents about 4,000 tires. The potential annual output of 384,000 tires would thus require about 96 trips to the reefs. On two thirds of the total trips in 1974/75, the barge load consisted exclusively of culvert. Assuming that the volume of culvert operations remains unchanged, the barge could actually take 79 trips with tires. Thus 82% of the potential output of 384,000 tires could be handled. Thus full utilization of the present barge capacity would require both a new dock and the utilization of more efficient labor in the tire splitting operations or an increase in the number of tire splitting machines. In the alternative calculations a new dock in the Clearwater site and one new tire cutter were assumed. The new dock in Clearwater that would be needed is estimated to require capital expenditures of $66,660 ($50,000 in 1974 prices). The tire cutter would cost $4,000.

The composition and life of the new dock setup was assumed to be the same as that of the old, including imputations, the fixed costs would rise to $43,890 in 1976/77, continue at that level for five years and rise to $45,550 in 1982/83.

In all these calculations it should be noted that doubling of the present tire splitting capacity and efficient utilization of this capacity would be required to effectively dispose of all tires generated in the county. Thus the supply of tires is unlikely to become an effective constraint to the operations.

Implied in the above two sets of fixed cost estimates are annual capital expenditures given in Table 8. Because of the long lives of the structures, benefits from the investments will be derived over many years to come.

TABLE 8. HISTORICAL AND PROJECTED CAPITAL EXPENDITURES IN 1974 PRICES

	Current Level of Operations Maintained	Expanded Operations
1973/74	149,662	
1974/75	12,306	
1975/76	121,011	
1976/77	3,824	60,979
1977/78	2,669	2,669
1978/79	90	90
1979/80	1,633	1,663
1980/81	3,795	3,795
1981/82	543	543
1982/83	3,422	3,422

Estimates of future variable costs are prepared on the basis of the second, higher, fixed cost alternative. With the efficiency of the men operating the equipment assumed to remain unchanged, about a 50 per cent increase in Emergency Jobs personnel would be required to operate the new tire cutter with its attendant chore of transporting additional tires. Electricity, gasoline and oil costs would also rise by 50 per cent. On this basis, and utilizing 1974 prices, an annual variable cost figure of $155,080 was projected for 1977/78-1982/83.

To obtain the present value of all these costs up to 1980/81 in 1974, a seven percent interest rate was used. The costs of the county project came to $1,007,682. To this figure were added the estimated cost of $40,000 incurred by the City of Clearwater in dropping 72,000[1] tires in 1972-74, and $49,200 grant from the State of Florida Division of Recreation to yield a total present value of $1,096,882.

Productivity of the Reef

To establish the supply of fish available for recreational activity, several technological relationships were studied. First, estimates were prepared on the amount of fish habitat area generated by reef construction. Subsequently, the value of this habitat to fishes was established by fish counts. No literature on productivity of similar reefs was available to determine intermediate and sustained yields from the habitat. Questionnaires and interviews with anglers on the site and charter and party boat captains and diving clubs were utilized to determine how many anglers and divers of different types the estimated yield can theoretically support.

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[1]See p. 16.

Fish Habitat Generation

Two alternative hypotheses regarding the contribution of tires and culvert to habitat formation were considered. First, how many fish are attracted to the area and find feeding material depends on how large an area of the sea bottom is covered. The coverage by tires is about two feet high and that by culvert six to eight feet, but according to this hypothesis, the difference in the height and the nature of the coverage is inconsequential. The second hypothesis maintains that the new surface area generated by culvert and tires is the most relevant input variable in the production function for fish,[1] because it determines the amount of food for fish, and the available shelter. Thus two different sets of habitat calculations would be required.

The amount of ocean bottom covered was relatively easy to establish. The dimensions of the culvert dropped were accurately recorded. The area covered was established as the length times the diameter of the culvert, on the assumption that the culvert lie on its side partially covered on both sides with maximum width set by the diameter of the pipe. One half of a barge load is carefully placed in a pile some 6 to 10 feet high and approximately 40 feet in diameter. Then the remaining culvert is placed off the opposite side of the barge, giving 30 to 40 feet of separation between clumps. On subsequent trips, this 30 to 40 feet separation is maintained. This continuation more closely imitates a natural reef. All punched tire units were dropped to lie horizontal; 30" diameter of the tires became the width and the 8" thickness of each of the four tires the length of the unit. Thus it was estimated that a unit of four punched tires covered an area of .61 m^2. A split tire bundle usually consisted of 30 tires packed on a forklift with 42.5" forks, covering a total area of 1.45 m^2.

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[1] John G. Carlisle, Jr., Charles H. Turner and Earl E. Ebert, "Artificial Habitat in the Marine Environment," California Department of Fish and Game, Fish Bulletin 124, p. 38.

The amount of surface area generated was more complicated to estimate. Culverts were treated as cylinders with inner and outer surfaces. The inner and outer diameters of the culvert cylinders and the length of the pipes were measured and the surfaces calculated accordingly. Tests were run on how deeply the culvert sank into the gulf bottom, and adjustments were made to the submerged surface area available to the fishes.

Tire surfaces were calculated separately for the punched tires and the split tires. For punched tires the surface could be calculated essentially the same way as for culvert, since both the inner and outer surfaces were available for fish habitation. The split tires, however, were bunched so tightly outer surface upon inner surface that we estimated that only the outer surface and 40% of the inner surfaces of the entire stack of tires remained available. Therefore, measurements were made of the inner and outer diameters, and the number and width of tires in the stack and the adjusted surfaces were calculated. Because of a total lack of comparable fish counts, development of this hypothesis had to be postponed.[1]

Overall, it was estimated that the following amount of ocean bottom has been built into a reef each year.

TABLE 9. SQUARE METERS OF REEF BOTTOM GENERATED

Fiscal Year	Culvert		Punched Tire Units		Split Tire Units		Total	
	All	Clearwater	All	Clearwater	All	Clearwater	All	Clearwater
1973/74	55	55	11,848	11,848[2]	--	--	11,903	11,903
1974/75	1,652	1,221	221	74	1,525	1,409	2,963	2,704
1975/76	2,082	51	396	238	3,450	260	5,928	549

[1]The calculations already performed will be presented in the final report by Don Schug.

[2]includes an estimated 18000 bundles deposited by the City of Clearwater program before June 17, 1974.

Fish Counts

Fish counts have been taken at the artificial reef locations on several occasions between Fall 1975 and Fall 1976, although not yet in sufficient numbers to allow adjustment for seasonal fluctuations. Separate coverages are available for split tire bundles, punched tire units, and culvert. Three types of censuses were conducted: total counts of fishes on isolated habitat "patches," transect counts, and poison sample counts. Numbers only were obtained from the first two censuses; weight and length measurement were collected from the poison samples.[1] In transect counts one diver counted all fishes observed within an approximate one meter wide band while a second diver followed behind holding a current meter mounted on a board. The number of current meter revolutions was recorded for each transect swam and later converted to distance travelled based upon calibrated runs along a 22 meter transect. Visual estimates were also prepared about the percentage of bottom covered by artificial reef materials in the transect. The transect fish counts given below refer to densities per meter of covered area (center holes of tires are assumed to be covered areas), i.e., if a 17 meter transect is 75% covered, it is equivalent to 13 meters of 100% covered transect. The behavioral assumption underlying this conversion is that the fish population is generated and maintained entirely by the covered substrate rather than by the adjacent natural habitat.

Taking together the habitat patch, transect and poison counts, yielded the following average numbers of species and the number of individual fishes per square meter of 100% covered bottom area in the three types of artificial environments.[2]

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[1]Gregory Smith, "Comparative Efficacy of Artificial and Natural Gulf of Mexico Reefs as Fish Attractants," Unpublished paper, St. Petersburg, Fl., 1976.

[2]At one station both a habitat patch count and a poison count was conducted. The latter repres nted 84% of the former, a rather satisfactory accuracy.

TABLE 10. RESIDENT FISH COUNTS/m^2

	Number of Species	Number of Individuals
Punched Tire Units	.42	2.63
Split Tire Bundles	2.57	18.71
Culvert	3.00	9.00
Combinations	1.38	7.38

Because of the limited number of the fish counts, only resident fish populations have been estimated. Estimates of migrant fish-Spanish mackerel, kingfish, and snook-could not be obtained.

The above productivity figures per unit were used to calculate the entire resident fish population on the Clearwater reef. The results are given in Table 11. After the first year, the age of the reef is of little consequence in these calculations, because it was found that it takes only about a year,[1] depending on the season, for the game fish population of artificial reef to reach its climax population without migration from adjacent reef areas. Subsequent variations occur in response to normal seasonal and weather patterns.

A knowledge of fish counts taken from time to time without knowledge of either the rates at which fish population under similar circumstances normally grows or about fish catches over a period of time from a known population, does not enable determination of the removals that would still permit maximum sustained yield. The one pertinent species on which a growth study has been carried out is the red grouper[2], but this species does not spend its entire life cycle at such reefs. Thus no sustained yield figures can be presented.

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[1] Heyward H. Mathews, History of Publicly Funded Artificial Reefs of Pinellas County. Manuscript, p. 6.

[2] Martin A Moe, Jr., *Biology of the Red Grouper Epinephelus morio (Valenciennes) from the Eastern Gulf of Mexico*, Florida Department of Natural Resources, Professional Paper Series Number 10, Dec. 1969, Marine Research Laboratory, St. Petersburg, Fl.

TABLE 11. PRODUCTIVITY OF CLEARWATER REEF

	Culvert			Punched Tire Units			Split Tire Bundles			Fish[1]	Person-day Of Fishing
	Fish Per Sq. Meter of Transect	Square Meters of Culvert In Place	Total Fish[1]	Fish Per Sq. Meter of Transect	Square Meters of Units In Place	Total Fish[1]	Fish Per Sq. Meter of Transect	Square Meters of Bundles In Place	Total Fish[1]	Grand Total	
1973/74	9.00	55	495	2.63	11,848	31,160	18.71	---	---	31,655	5,275
1974/75	9.00	1,276	11,484	2.63	11,922	31,354	18.71	1,410	26,381	69,219	11,536
1975/76	9.00	1,327	11,943	2.63	12,160	31,980	18.71	1,670	31,246	75,169	12,528

[1] Reported for year of initial size; user days in Table 13 calculated on the basis of fish of catchable size a year later.

Projections of resident fish population were made on the basis of the new reef bottom generated with the projected expenditures. Since the only new equipment introduced was a tire splitter, it was assumed that the output of split tires increases accordingly, i.e., by about 50 per cent. It was assumed further, for purposes of simplification, that all new materials will be deposited on the Clearwater Reef. Thus all benefits of the program can be evaluated in terms of that reef alone. The following figures were obtained.

TABLE 12. PROJECTED PRODUCTIVITY OF CLEARWATER REEF

	M^2 of Artificial Reef Bottom In Place	Total Fish
1976/77	20,810	176,306
1977/78	26,175	276,685
1978/79	31,540	377,064
1979/80	36,905	477,443
1980/81	42,270	577,822

POTENTIAL BENEFITS TO ANGLERS AND DIVERS

There is no unique relationship between the productivity of a reef and the benefits derived from fishing or diving on a reef, because different people derive different satisfaction from the same activity. Surveys of anglers' attitudes toward the benefits of the reefs led us to form four categories of beneficiaries: (1) "Sunday" anglers, (2) sports anglers, (3) divers, and (4) shark anglers.[1]

Sunday Anglers

Sunday anglers are usually retirees or families fishing on weekends. A relatively large number of women and children is involved. Small boats of 16 to 18 feet or half-day party boats are most commonly used by this group.

Sunday anglers consider a day well spent at sea even if catches are relatively

[1] It was also revealed that the charter boats almost invariably have a limit to the amount of fish the customers are allowed to take home. The rest is sold at local fish markets. The benefits of these sales are excluded from our benefit calculations. And so are all secondary benefits, such as increased tourist trade.

modest. Questionnaires administered to anglers in small private boats at the reef site and interviews with captains of half-day party boats indicated that half a dozen fish per person per trip made the anglers so satisfied that they said they would come back later. According to the charter boat captains, considerable variation existed between local customers and out-of-county customers, on one hand, and men vs. women and children, on the other. Out-of-county customers were satisfied with relatively fewer fish, whereas local anglers who were familiar with typical catches in the area were more demanding. Women and children were generally satisfied with smaller catches than men. The size of the fish did not seem to make much difference in this group.[1] It was assumed that the maximum rate Sunday anglers were willing to pay is equal to the average charter boat rate per person of $40, since charter boats are clearly a more expensive substitute and are normally not used for bottom fishing at the reefs. Since no current data were available on the costs of anglers going out in their own boats, the market price paid per person in half-day party boats was taken as the marginal benefit of these trips. Inquiries at several operators established the prevailing half-day rate at $8.00 per person, including bait and tackle. The full-day rate is $15.00.

The maximum number of user days demanded at zero cost was determined by the minimal satisfaction derived from going out to the reef. This limit is reached when weather is acceptable, (80 per cent of the time on the average[2]), but the site is so crowded that there is no room for boats to maneuver (about 80 boats[3]). With four persons per boat, these assumptions yield a total annual demand of 92,160 user days. On these assumptions, the following demand schedule was obtained.

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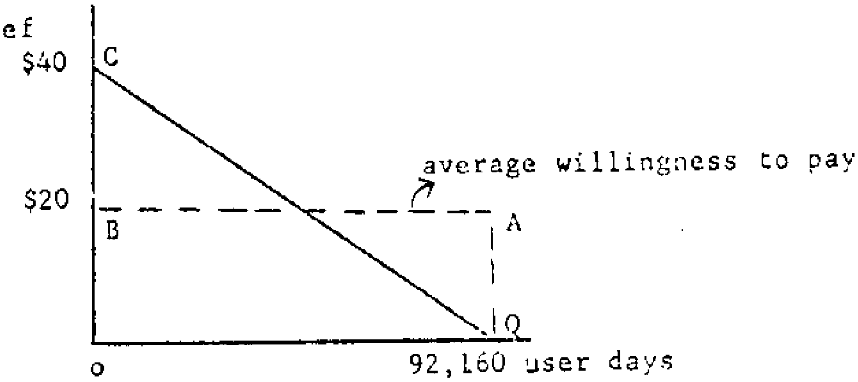
[1] Local residents are estimated to constitute about 80 per cent of anglers at the Clearwater Reef, according to on-site surveys conducted by our group in Summer - Fall, 1976.

[2] Expert estimate in December - February and early March weather is good only half the time, whereas in mid-summer it is almost always good.

[3] The buoys indicate the maximum dimensions of the reef; anglers have no way of knowing how much of the bottom area is actually covered by reef material. Therefore, the invariant area marked by the buoys is used throughout.

Figure 6. Potential Reef Fishing Demand by Sunday Anglers



The area under the demand curve OQAB equals $1,843,200. These would be the annual benefits if there were enough fish to satisfy all Sunday anglers that the site can accommodate at the rate of about six fish per person and no transportation and equipment costs. The annual benefits per year started much lower in 1973/74 when the numbers of resident fish were small but increased as construction progressed. Assuming that it takes one year for the reef to internally produce fish of catchable size and further assuming that any fish caught is equally satisfactory--an extremely optimistic assumption--, we obtained the following annual figures on the maximum number of user days and benefits in the Sunday angler category supported by the Clearwater Reef, through its expected construction period.[1]

TABLE 13. MAXIMUM AVAILABLE USER DAYS AND BENEFITS FOR SUNDAY ANGLERS, CONSTANT PRICES

	User Days	Undiscounted Benefits	Discounted Benefits
1973/74	4,150	162,265	162,265
1974/75	5,275	204,960	191,551
1975/76	11,662	436,975	381,671
1976/77	12,655	471,462	384,854
1977/78	29,384	988,037	753,766
1978/79	46,114	1,382,959	986,032
1979/80	62,844	1,636,882	1,104,051
1980/81	79,573	1,809,092	1,126,613
Total			5,090,803

Costs for individual years as well as for the entire assumed construction period were calculated in two parts: reef construction costs and boat rental and equipment costs to the anglers. These figures as well as the resultant benefit cost ratios are given in Table 14.

[1]No allowance is made for substitution between fishing/diving at the artificial reef and similar activities elsewhere, because even the largest total represents only

TABLE 14. BENEFITS AND COSTS OF CLEARWATER REEF TO SUNDAY ANGLERS

AT FULL UTILIZATION OF AVAILABLE FISH

	User Days	Discounted Benefits	Discounted		Total Discounted Costs	Marginal Benefit-Ratio
			Construction Costs 1)	Boat Rental and Equipment Costs		
73/74 (73/74)	4,150	83,000	52,678	62,250	114,928	0.72
74/75 (74/75)	5,275	98,600	90,880	73,949	164,829	0.60
75/76 (75/76)	11,536	201,680	13,158	151,260	164,418	1.23
76/77 (76/77)	12,528	204,540	161,890	153,400	315,290	0.65
77/78 (77/78)	31,785	485,670	151,383	363,950	515,333	0.94
78/79 (78/79)	51,052	729,314	141,656	546,986	688,642	1.06
79/80 (79/80)	70,312	937,493	132,213	703,120	835,333	1.12
80/81 (80/81)	89,572	1,116,160	18,570	837,150	855,720	1.30
81/82 (81/82)	92,160	1,072,880	---	804,660	804,660	1.33
Total for Construction Period		4,929,337	762,428	3,696,725	4,459,153	1.11

1) Excludes about $140,000 depreciated value of the plant at the end of the construction period for most of which alternative uses can be found.

Even during the construction period a favorable benefit-cost ratio results. When construction ceases in 1981, the benefits remain but only the user costs of boat and equipment rental are incurred and the marginal, discounted benefit cost ratio rises to 1.33. Given the extremely long life of the reef, the average of the marginal ratios will asymptotically approach the same value.

Sports Anglers

Sports anglers either go out in their own bigger boats (21-25 feet) or charter a boat that accommodates up to six anglers. Sports anglers usually time their trips with reported good seasons, such as the Spanish mackerel and kingfish runs. Charter boats take anglers to the reefs only during trolling seasons, not for bottom fishing. The satisfaction of a sport fishing party depends on the kind and size of fish. Typically 30-40 Spanish mackerel per charter boat invites return trips, whereas only 15-20 kingfish are required for the same result. 100-200 lbs. of grouper also makes a good fishing day. But one of the captains stated that variability of satisfaction is great: a true sports fisherman is happy even if he doesn't catch any; after all, the fish don't bite all the time. There may be so many forage fish at the artificial reef that the fish just don't care for your bait. (Our divers have confirmed this on several occasions.)

Even though trolling boats do not limit themselves to the covered area or even to the marked reef area, as a rule, the charter boat captains show a preference for the general reef area rather than ordinary sand bottom. In principle, migratory pelagic fish like kingfish and Spanish mackerel can be found anywhere there are menhaden, sardines, and other similar forage fish. Even though the large pelagic fish are not primarily dependent upon reefs, the juveniles do consistently congregate over reef areas rather than over sand bottoms.[1] Thus at this stage, it was simply assumed that during the trolling seasons the demand by sports anglers saturates the reef area at the market price of chartering a boat with fishing gear.

Some 25 charter boats operate from the Clearwater Marina and another dozen or so from other marinas within easy reach of the reefs already established. Our survey of a sample of captains at the Clearwater Marina on a cold and windy November morning when small craft warnings deterred activity at sea revealed that the average daily charter rate is $175 including bait and tackle, and the average load is 4.5 persons. Thus the market price was set at $39 per person. Since for all intents and purposes there are no superior alternatives to a fully equipped charter boat, the maximum rate that would drive use to zero was established as the highest charter boat rate, estimated at $220 a day or $49 per person. On the assumption that a 21 foot boat is used for 10 days of sports fishing a year (no other use)with standard trolling equipment and 4.5 persons aboard, an alternative cost figure of $37.44 per person per trip, in 1977 prices, was obtained.

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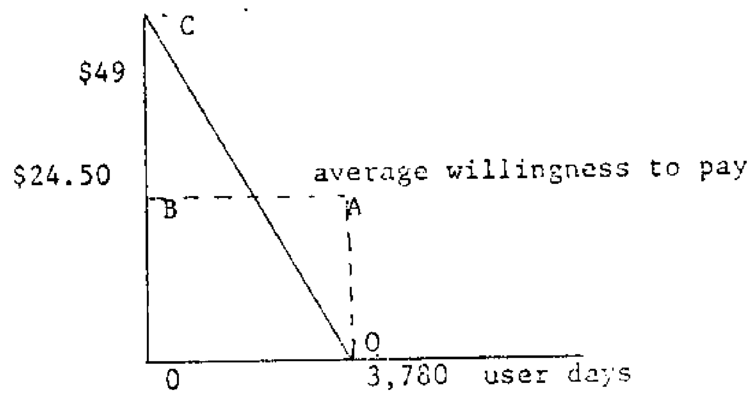
[1]Our divers have repeatedly observed this phenomenon within a few days after reef material has been deposited.

The trolling season usually lasts about 2½ weeks in spring and in fall.[1] Another two weeks was included in summer for snook fishing. With an adjustment for good weather 80% of the time in spring and fall, 100% of the time in summer, a total of 42 user days per boat was obtained. The reef becomes crowded with only 20 larger moving boats on it. With 4.5 persons per boat, a total number of user days generated at $39 per day comes to 3,780. The potential market demand is described in Figure 7.

Figure 7. Potential Reef Trolling Demand by Sports Anglers



The area under the demand curve equals $900,375.

Sports Divers

There are a number of diving clubs and charter boats in the area which take groups of divers out in the Gulf. Information gathered from these clubs and from individual operators indicated that $29 per person was usually charged for a full-day excursion, including scuba gear. This figure thus represents the travel costs (marginal user costs). The most expensive guide charged $40. A good diving day does not have to result in any fish catch at all. This is especially true of beginner divers who represent the typical diver group at the reef. Not all these divers carry spear guns with them and even those who do are often satisfied with watching the fish rather than catching them.

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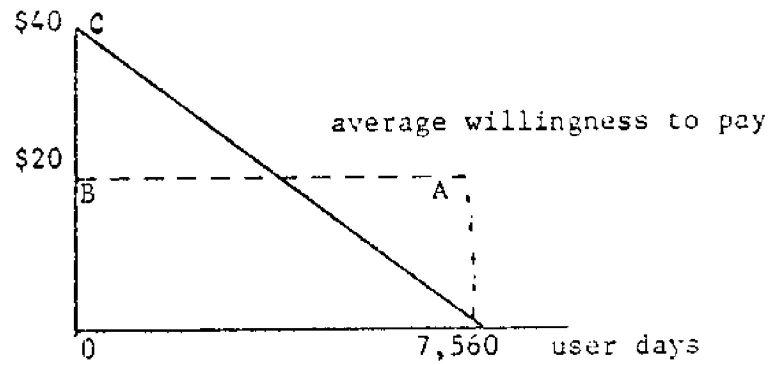
[1] But in Fall 1976, for example, there were no kingfish runs on the reefs perhaps because of the sudden onset of cold weather that cooled the shallow waters rapidly and made the kings migrate south in deeper waters.

Only about six diving boats can be accommodated on the reef at any one time, because of the requirement that all boats stay at a safe distance from underwater divers. With six persons per boat in good weather and acceptable temperatures (25% diving in four winter months, 50% diving in fall and spring and 90% of the remaining time), a total of 7,560 user days is generated by capacity use. Thus the area under the demand curve comes to $302,400. Figure 8 depicts the potential market demand and marginal user costs.

Figure 8. Potential Diving Demand



Since watching marine life rather than catching fish represents diving benefits, the supply of diving recreation is related directly to the amount of reef bottom covered. The intended size of the reef is 63,000 m^2. Clusters of material are placed on it, with open spaces in between. For simplicity's sake it is assumed that the intended open space equals intended coverage. On that basis, the reef would yield the potential annual diver benefits shown in Table 15.

If the reef was used to its maximum exclusively by divers, irrespective of average boat and equipment charges, the annual marginal benefit cost ratios of the order of 0.37 would result. With 7,560 user days, the marginal ratio would change to 0.7 a year after construction ceases. With the practically indestructible nature of the reef, benefits offset by boat and equipment rental would continue to accrue until the entire benefit cost ratio would asymptotically approach 0.69. Clearly, unsatisfactorily small benefits would result if the reef was devoted exclusively to divers rather than to Sunday anglers.

TABLE 15. DIVING BENEFITS AND COSTS WITH FULL CAPACITY UTILIZATION

	Intended % of Reef Available	User Days	Undiscounted Benefits	Discounted Benefits	Discounted Construction Costs	Discounted Boat Rental and Equipment Costs	Total Discounted Costs	Marginal Benefit-Cost Ratio
73/74	34.8	2,631	52,620	52,620	52,678	76,299	128,977	0.41
74/75	37.8	2,858	57,160	53,421	90,880	77,460	168,340	0.32
75/76	46.3	3,500	70,000	61,190	13,158	88,880	102,038	0.60
76/77	48.1	3,636	72,720	59,360	161,890	102,350	264,240	0.22
77/78	71.1	5,375	107,500	82,061	151,383	118,989	270,372	0.30
78/79	94.2	7,122	142,440	101,021	141,656	146,481	288,137	0.35
79/80	100.0	7,560	151,220	100,764	33,633	146,089	198,292	0.51
80/81	100.0	7,560	151,220	94,147	-0-	136,513	136,513	0.69

Shark Anglers

The fourth group of beneficiaries, the shark anglers, does not compete at all with the other groups, because they go out at night. Their demand schedule has a maximum willingness to pay point at $49, the same as the sports anglers. The market price, however, is only $25 per person. (Apparently, the charter boats' practice resembles marginal cost pricing). If they go out as often as weather permits in charter boats, their demand is otherwise similar to that of sports anglers except that the boat density at night should be assumed lower, 10 at a maximum, for safety reasons. The potential market demand and user costs are depicted in Figure 5.

Calculation of benefit cost ratios faces the same obstacles as in the case of sports anglers. Sharks are not resident reef animals, and the extent to which they are attracted to the reef by forage fish is difficult to ascetain. Therefore, only the user days demanded at average demand price and at marginal cost price were calculated. (See Table 16 below).

Optimum Reef Size

Our model led us to conclude that optimum capacity is reached when average demand price equals marginal cost of capacity and operations. For Sunday anglers the entire reef should be built. If other users had to bear all the costs of reef construction, the benefits derived would not justify these costs.

A summary of the benefits yielded annually to the two principal users is presented in Figure 9. The best use of the reefs is for bottom fishing by Sunday anglers. This use yields a potential marginal benefit cost ratio of about 1.33 at optimum reef size. Potential benefits to divers converge toward 0.69 marginal ratio. The reef is already too large for exclusive use by divers and shark anglers.

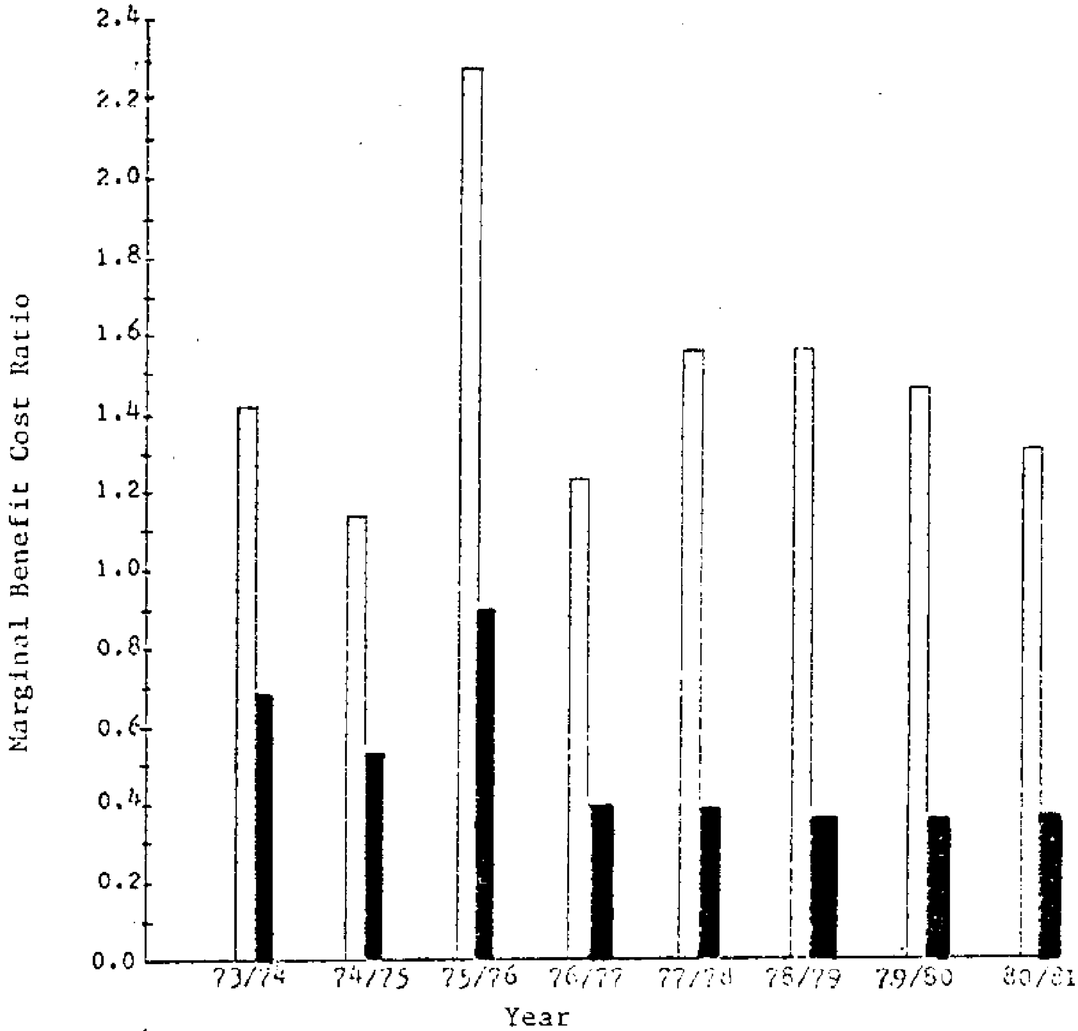


Fig. 9. A summary of marginal annual benefit cost ratios for Sunday anglers (light) and divers (dark).

If marginal cost pricing were assumed, demand would have become satisfied at the level of 57,603 user days for Sunday anglers by 1979/80 and before 1974 for all other users. Thus construction of the Clearwater Artificial Reef beyond its assumed size in 1975/76 would be justified only if Sunday anglers were its only daytime users; additional benefits from night-time use would accrue to shark anglers.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

The present report has assessed the costs and potential benefits of artificial reefs and compared those with other modes of disposing of the primary raw material, tires. Although tires can be buried quite cheaply in landfills, in the long run they can be more beneficially used in reef construction that yields recreational benefits for centuries to come. It is expected that the reef population will reach its sustained level in about two years but will endure an estimated 1,000 years if the reef is build with tires[1] and practically forever if built with culvert, provided that annual maintenance of the buoys of the order of $500 is undertaken.

An interdisciplinary study like this one which has to rely heavily on nature's biological technologies in the conversion of tires to catchable fish

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1 There are very few marine bacteria capable of decomposing synthetic rubber.

suffers from the uneven state of art between the disciplines of economics and biology. Even though an economist does not have the expertise to fill many of the gaps in the biological knowledge, the benefit cost framework developed above enables the indication of areas where data are lacking or deficiencies exist and thus further research is called for.

As has been pointed out repeatedly, all the benefits assessed have been potential, i.e., realizable benefits rather than actual benefits. The first order of business is to study the actual benefits today and to project benefits into the future. Substantial work on interviews of anglers, charter boat captains, diving clubs and boat owners in general is under way currently and more is needed in the next few years to chart the user pattern.[1] Recommendations as to how the potential benefits can be realized should then be possible.

A number of technological transformations of tires to fish rest on an exceedingly narrow data base. A systematic study of the layouts of various reef materials, the bottom area covered and the reef surface area generated should be undertaken. Fish counts, especially poison counts, need to be multiplied. It has been suggested[2] that the height of the reef is very important in determining the size of the fish that inhabit it. The present study had no suitable data available to test that hypothesis, but such data should be collected. The more general hypothesis that it is the amount of surface area rather than the reef bottom area that determines reef productivity could not be tested either because the few fish counts were not conducted with such differentiation in

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[1] Don Schug, Graduate Assistant in Marine Science, will present his findings in the final report.

[2] Richard Stone, "General Introduction to Artificial Reefs," Proceedings of Sport Fishing Seminar, November 18-19, 1971, Jekyll Island, Georgia, Seminar Series No. 1, p. 2.

mind. A study of the algae on the reefs and their relationship to productivity of catchable fish would greatly enhance our understanding of why productivities of different kinds of reefs differ.

No life cycle studies have been conducted on any of the fish that typically inhabit the reefs. Such a study of the white grunt, the most common species of sports fish on the reefs, would be most valuable. Even more demanding would be studies of the role of the reef in the life cycles of the migratory fish like kingfish and Spanish mackerel.

Reef building activity is going on all along the Suncoast. The costs of reef building are of an entirely different order of magnitude than the costs of burying tires in landfills. Reef construction expenditures are voluntary and postponable. Their merits should be evaluated in comparison with the merits of other discretionary private and local government expenditures before decisions are made. Cost effective techniques of reef construction are not well known by the many volunteer groups that now advocate and support reef construction. A series of conferences in the various counties should be offered by a group of experts to interested local officials and private groups in order to reduce the chance of costly mistakes and to speed up the construction of other potentially equally beneficial artificial reefs. Since substantial amounts of public funds also support reef construction, the public has a similar right to know and should be kept informed of the opportunities available to them as well as of the associated costs.

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