A Decision Model To Evaluate The Cost-effectiveness of Alternative Virginia Oyster Grounds Management Strategies

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Agricultural Economics

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September, 1985

Blacksburg, Virginia

A DECISION MODEL TO EVALUATE THE COST-EFFECTIVENESS OF ALTERNATIVE
VIRGINIA OYSTER GROUNDS MANAGEMENT STARTEGIES

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(Abstract)

Public and private concern over the decline of Virginia's oyster industry prompted the General Assembly (GA) in 1977 and 1983 to commission its Joint Legislative Audit and Review Commmission (JLARC) to examine the State's oyster grounds management policies. In response to JLARC's findings the GA directed Virginia Marine Resources Commission (VMRC) to construct and implememt an oyster fisheries management plan. The GA set as the plan's objective to acheive the greatest production level possible subject to limits of physical resource availability and technical feasibility. That the plan should be attentive to cost-effectiveness was also expressed by the GA.

In developing its management plan VMRC must consider a variety of environmental, economic and political factors affecting the production and harvest of market oysters. A linear programming model developed for VMRC's use in evalu-

ating alternative oyster grounds management strategies is described. The objective of the programming model is to minimize the public plus private cost of producing a prespecified level of market oyster harvest over a ten year planning horizon. The model includes as its activities the different aquacultural techniques used by private planters and VMRC in its repletion program. The many environmental, economic and political factors are incorporated into the model's constraints ane technical coefficients.

Several management alternatives are evaluated with the model. The results of these analyses indicate that without a fundamental in the oyster repletion program, even if new oyster grounds management policies are considered, there would be little change in public grounds market oyster harvest over current levels. Under revised repletion program practices, however, marked increases in public grounds harvest could be effected for relatively small increases in repletion program budget allocations over current levels.

ACKNOWLEDGEMENTS

The author expresses his gratitude to his committee members Randall A. Kramer and Sandra S. Batie and especially to his chairman Leonard Shabman for their contribution to this research effort.

The author also wishes to thank and of the Virginia Marine Resources Commission for their willingness to participate in this research.

Support for this project was provided by the Virginia Sea Grant program and is deeply appreciated.

A debt of gratitude is expressed to the many friends who have made this undertaking a gratifying experience. Special thanks go to the guys at F-68, TEAM TOPICS, and especially for her constant encouragement and "pun"-ishing sense of humor.

The author expresses his thanks to his family whose support was unfailing and deeply appreciated. Last, and most importantly, a heartfelt thank you goes to the author's wife who's devotion and love has been a constant source of inspiration throughout.

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1.1 INTRODUCTION

The oyster fishery of Virginia has long been a part of the coastal economy. Because of this importance, the harvest of oysters has been a subject of law and public policy since colonial times. However, the most significant policy development in the oyster industry took place at the turn of the century. This development was the definition of two types of oyster grounds: public (Baylor) grounds and private (leased) grounds. In 1892 the Virginia General Assembly mandated a survey to determine the location and extent of the natural oyster beds, rocks, and shoals of the Commonwealth.[1] The natural oyster beds, those areas where oysters are found in abundance without human intervention, are generally areas where the bottoms are firm with a layer of oyster shells or other hard material (cultch) on which the free swimming oyster larvae can attach (set or strike) and grow to a harvestable size. In 1894 James Baylor delineated

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[1] A discussion of the natural history of the oyster can be found in Chapter II. It is suggested that readers unfamiliar with the biology of this estuarine organism read Chapter II before continuing.

210,477 acres of natural oyster grounds. Since the time of the Baylor survey, there have been a number of additions to the public grounds. At present, 243,000 acres are contained within the public grounds. Management of the public grounds by the Commonwealth includes (i) restrictions on permissable harvest gear to primarily hand tongs, ii) season and area harvest restrictions, and iii) a shell and seed planting program termed the repletion program. In general, State Baylor ground management is directed toward insuring the maintenance of cultch and successful reproduction on the Baylor grounds.

At the same time the Baylor survey was conducted, provision was made for the leasing to private individuals of grounds not defined by the Baylor survey as being naturally productive for cultivation of market oysters. In 1900, the first year for which reasonably accurate data are available, there were 47,803 acres under lease for private oyster production. (Haven et. al. 1978, p. 67). In 1982 leased acreage was 107,307 acres. However, because the State does not require proof of use, it is not possible to determine leased acreage under active cultivation. Also, the state does not prescribe any management standards for leased grounds.

The Baylor survey delineated the naturally productive bottoms by the presence of live oysters and/or the presence of oyster shells. As a result, those bottoms not included in the Baylor survey tend to be void of a firm substrate upon which oyster production depends. Cultivation of oysters on leased bottoms, therefore, first requires the planting of shell to establish a firm bottom. Shelling rates vary, but range between 5,000 to 15,000 bushels of shell per acre depending on the quality of bottom to be shelled (Haven et al 1981).

Once a firm substrate is established active cultivation can begin. Following shelling, planting seed oysters is required.[2] Seed oysters are left to grow on the bottom for 18 to 24 months depending on growth and predation rates. After the growing period the oysters are harvested. The oyster dredge is the preferred harvest gear by many private planters, because it is a more labor-efficient harvesting technique. The new shelling is required because as the dredge is pulled across the growing beds large quantities of shell are removed or dispresed creating furrows that must be filled in prior to replanting with seed.

Virginia oyster production from both public and private grounds in 1980 was almost 8.5 million pounds with a dock-side value approaching $9 million. Of these

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[2] If setting rates are sufficient the bottoms may be self-sustaining without requiring the expense of planting seed oysters.

totals,approximately one-half was from private grounds production. This level of harvest is down significantly from the 1950's. In 1958 almost 30 million pounds of oysters were harvested in Virginia with most taken from private grounds. In recent years market oyster harvest from public grounds has gradually increased from 1.3 million bushels harvested in 1972 to 5.8 million pounds in 1980 (VMRC Annual Report 1980).[3] In contrast to this trend there has been a rapid decline in private harvest beginning after 1960 for three interrelated reasons: (1) the appearance of Minchinia nelsoni (MSX), a disease which increases oyster mortality prior to harvest, reduced the productivity of many private grounds; (2) a sharp decline occured in seed oyster harvest from the James River seed beds (with few exceptions the public grounds, most importantly the James river seed beds, are the only source of seed for private planters) planters)[4] reducing quantities of seed available to private grounds planters; and, (3) a "price-cost squeeze" reduced

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[3] A conversion rate of 6.59 pounds per bushel (NMFS Fisheries Statistics 1977) was used to convert bushels to pounds where necessary.

[4] It is unusual, but some private grounds do experience setting rates high enough to support seed production. This privately produced seed may be sold to other planters or it may be used in the individual's own market oyster production enterprise. More often than not, however, setting rates are not sufficient on leased grounds to permit this form of production.

profitability of private planting. Indeed since 1958 nominal oyster prices rose from $2.48 to $5.43 per Virginia bushel, an increase of 119 percent. In the same time period input prices, as measured by the consumer price index, rose 209 percent. These productivity and price trends have limited the income producing potential of the fishery.

1.2 CURRENT POLICY TOWARD OYSTER GROUNDS MANAGEMENT

The decline of the Virginia oyster harvest has been the topic of considerable recent concern to public officials. In 1977 the Joint Legislative and Audit Review Commission (JLARC) of the Virginia General Assembly issued the report, Marine Resource Management in Virginia (JLARC 1977). The report documented the decline of the Virginia oyster harvest and cited the need to consider policy alternatives to enhance the production from the oyster fishery. Implementation of new policies would require an expanded role for management of both the oyster grounds and the harvesters.

However, such management must be undertaken with an understanding of the interaction of economic, biological and public policy forces affecting the fishery. To fill the knowledge gaps, scientists at the Virginia Institute of Marine Science (VIMS) issued a comprehensive study of the oyster industry in Virginia in 1978 (Haven,et al., 1978). Although the authors concluded that significant production increases were technically achievable, the study called for additional economic analyses of the oyster industry to see if such production would be profitable.

In 1981 the Virginia General Assembly adopted House Joint Resolution 59 which called upon JLARC to assess the economic potential and management of the seafood industry. In responding to this resolution JLARC staff devoted a substantial portion of the study to the oyster fishery. The staff report relied heavily upon an econometric model to define and evaluate oyster management policy options.

The model was used by JLARC to establish a 1990 baseline condition based upon continuation of current prices, policy and biological conditions to that year. Then the general effects on harvest levels and harvest revenue were simulated for five seperate public policy options.

1. Raising retail prices by marketing and promotion to enhance dockside prices to watermen.
2. Increasing the budget for shell and seed planting repletion programs on public grounds.
3. Reducing oyster and seed prices for private planters in public grounds programs.

4. Increasing state investments in managing selected public bottoms and leasing dredge rights for harvest.
5. Renting portions of the public grounds for private planting.

The general conclusion of JLARC was that without the implementation of one or more of the five policy options, the industry would continue its decline during the next decade. Specific conclusions of interest were: (i) that all the options would require seed oyster production substantially above current levels and (ii) that continuation of traditional approaches to public grounds repletion could have only limited effect on increasing production even if repletion budgets were doubled. When these two conclusions are considered simultaneously, it becomes apparent that unless current approaches to repletion of public grounds to enhance seed and market oyster production are changed, the oyster industry will continue to decline regardless of public policy changes considered in the 1983 JLARC study. In response to these findings, a series of executive and legislative actions have now resulted in the Virginia Resources Commission beginning development of an oyster management plan. A key component of the State's oyster fishery management plan will be the oyster repletion program. Indeed, an expanded role for the repletion program was called for in each of the 1977 and 1983 JLARC studies.

Today the Oyster Repletion Program (ORP) is not unlike an aquacultural enterprise on a grand scale. As stated in the 1980 VMRC annual report:

> The objective of the Repletion Program is to influence the availability of oysters through the application of aquacultural techniques p. 47.

The techniques referred to are: (i) transplanting immature seed oysters from seed producing areas to areas that are better suited for growing out to a harvestable size; (ii) the planting of oyster shells to catch spat (oyster larvae) in seed producing areas; and (iii) the planting of oyster shells as cultch (a hard surface upon which the spat attach) in the hope of obtaining a good set (the total spat collected in a given area in a season) and allow maturation to a harvestable size. Other activities include attempts to produce hatchery raised seed and development of an MSX resistant seed source. The thrust of the program is to assure that an adequate supply of seed is available for public and private interests, and to assure that an adequate population of harvestable market oysters is available for watermen working the public beds.

Managing repletion and setting harvest regulations is complicated by the need to consider an array of economic and biological factors which affect the oyster industry. Biological factors such as, type of cultch planted, timing of planting, density of shell and transplanted seed, and the array of environmental parameters unique to each river system must all be considered. The economic factors affecting the oyster industry are varied in nature ranging from individuals' harvest and production decisions, to the distributional effects on local watermen due to placement of shell or seed in one area versus another and who shall bear the cost of the repletion program. Microeconomic considerations include, the behavioral relationships that determine how watermen and private planters respond to price and cost conditions and how these decisions are affected by risk and uncertainty. Other economic factors such as the mechanims through which input and output prices are determined and how prices are affected by State regulatory or repletion actions must also be considered.

The ability of the ORP managers to run the program in a cost-effective manner, here defined as the least-cost mix of policy and repletion alternatives to achieve a prespecified level of market oyster harvest is predicated on the manager's knowledge of the aforementioned biological and economic factors and how they are related. Unfortunately, the information base upon which many repletion decisions are made is often deficient in one way or another. For example, the JLARC study of 1977 was unable to evaluate repletion program effectiveness because of the lack of site specific harvest data. In personal interviews, repletion program managers complained about a lack of scientific research and information they considered relevant for building a sound information base upon which their repletion decisions are made.

The 1977 JLARC study recommended that VMRC should solicit the assistance of the Virginia Institute of Marine Sciences to initiate a means of evaluating repletion program effectiveness. In JLARC'S 1983 study the repletion program was again the focus of attention. The need for an improved information base and an improved method of managing information was again emphasized. What becomes clear from these two reports is that VMRC; i) lacks an adequate information base, ii) lacks a scientific means to determine what information is required and in what priority research should be conducted, and iii) lacks a scientific evaluation framework or criterion upon which repletion decisions are based.

That the repletion program should attempt to accompish its repletion goals in the least costly way was expressed in each JLARC report and continues to be a concern of the State's executive and legislature. VMRC's ability to respond to this pressure will depend on its ability to coordinate and analyze management information to evaluate the cost-effectiveness of alternative oyster grounds management strategies. Without a scientific evaluation approach to oyster grounds management, an improved method of managing oyster fishery information, and a means to determine research needs and priorities VMRC will likely be unable to attain its repletion goals at a minimum cost over time to private and public interests.

1.3 OBJECTIVES

1. Develop a decision model to evaluate the cost-effectiveness of modifications to current Baylor grounds management. Alternative Baylor grounds management programs include:
   a) changing the mix and location of shell versus seed planting;
   b) changing the mix between seed oyster area versus market oyster area repletion;
   c) permitting alternative harvest methods for seed oysters from public grounds;
2. Determine the potential for setting oyster taxes to recover the cost of public management expenditures.
3. Establish future research needs and priorities to improve the knowledge base for oyster grounds management.

1.4 PROCEDURES

Based on a review of oyster biology and oyster management literature, feasible seed and market oyster producing activities will be determined. Limits of physical production potential and resource requirements will also be identified. This information will be the basis upon which a linear programming model will be constructed.

A standard linear programming model will permit the seperate and the simultaneous consideration of several oyster management strategies. The primary model purpose will be to determine the least-cost mix of repletion and policy options required to attain a prespecified level of market oyster harvest.

The model will also be used to identify research needs and priorities. A sensitivity analysis will be conducted for this purpose. By examining the results of the sensitivity analysis, it will be possible to determine which coefficients are most sensitive to changes in their estimated values. Coefficients found to be sensitive to change will be ranked on the basis of their importance to model accuracy, thereby, establishing research priorities.

The model will initially be solved based on present repletion and regulatory practices. Several alternative policy strategies will be evaluated and compared to present policies and to each other. Policy recommendations will be made based on these comparisons.

Chapter II provides a brief review of the biology of the oyster and the repletion program designed to insure its existence. Chapter III is devoted to a discussion of the formulation of the empirical model. Chapter IV will present the data needs for the model. The model's results and analysis will be presented in Chapter V. In chapter VI the results of the sensitivity analysis will be discussed and research priorities will be set. Chapter VII will offer conclusions and recommendations.

Chapter II

THE OYSTER: BIOLOGY AND REPLETION

2.1 INTRODUCTION

The oyster is a marine mollusc whose growth and subsistence depends on an array of interrelated environmental and biological factors. The success of any attempt to influence the availability of oysters through man-induced activities will depend on careful consideration and incorporation of these environmental and biological concerns into a management plan. This chapter begins with a natural history of the oyster followed by a brief overview of several key environmental characteristics important for oyster reproduction, survival and growth. Included in this section is a discussion of the relationship between these environmental concerns and successful repletion program management strategies. A similar treatment of several important biological factors follows this section. The final section of the chapter is a short review of past and present repletion program strategies.

2.2 NATURAL HISTORY

The Virginia oyster, *Crassostrea virginica* is a sessile mollusc attatching itself to any firm clean substrate, known as cultch, usually other oyster shells. Oysters may be found in intertidal zones and waters up to and sometimes exceeding 25 feet in depth. The oyster survives best in estuarine conditions where salinities range from 5 parts per thousand (ppt) to 35 parts per thousand (ppt) (Haven et. al. 1981). A filter feeder, the oyster subsists on nutrients extracted from the water column by passing water over its gills. As particulate matter is trapped in the gills, it is transported to the stomach by the action of small cilia. Once in the stomach, the food particles are ingested. The by-products of respiration and undesirable particles are ejected as pseudofeces. The oysters ability to select its food and extrude unwanted materials allows it to survive in waters carrying high silt and turbidity loads characteristic of estuarine environments.

Although oysters are unisexual, an individual may alternatively be male then female or vice versa. It is not uncommom for an oyster to change gender and at some later date switch back to its original sex. Spawning is temperature dependent and may occur from late June to early October depending on geographic location. Spawning in Virginia takes place from July to September (Haven et. al. 1981). Upon release of eggs and sperm, fertilization is effected in the water column. The resulting free-swimming larvae feed on phytoplankton and grow through several larval stages while remaining in the water column for about two weeks (Kennedy and Breisch 1981). As the larvae mature, much of their time is spent at or near the bottom searching for a hard surface upon which it attaches or sets itself. An abundance of clean cultch material is crucial at this stage if the larvae are to survive. Once a suitable substrate is found each larva cements itself to the substrate. Upon setting the developing larvae are called spat. The attached spat in any one river system or a given bar are collectively referred to as a strike, set or spatfall. After setting, growth is rapid and the young oyster may reach a length of 1 to 1.5 inches by the end of the first summer (Haven et al 1981). Spat of this length are suitable for transplanting and are, therefore, called seed oysters. Continued survival of the seed oysters to adulthood depends on several environmental factors of which, salinity, temperature and dissolved oxygen are the most important. not discussed here. Also, pollution has been implicated an important cause of declines in setting rates and adult oyster populations, particularly in the James river. Oyster repletion program managers should, therefore, avoid placing shell or seed in waters suspected of having water quality problems.

2.3 ENVIRONMENTAL CONSIDERATIONS IN MANAGING A REPLETION PROGRAM

2.3.1 Salinity

As stated previously, oyster salinity tolerance ranges from 5 ppt to 35 ppt. Below this lower limit, oysters cease feeding and eventually die. Although oysters can survive in lower salinity waters, growth and reproduction is greatly inhibited below 7.5 ppt (Kennedy and Breisch 1981). Above this level spawning activity increases as salinities increase. Salinities above 35 ppt are tolerated by *Crassostrea virginica*, however, with the exception of the Seaside of Virginia's Eastern Shore, salinities in Virginia waters seldom rise above 35 ppt. Higher salinities are, therefore, not a limiting factor to oyster growth and reproduction per se. they are very important, however, where oyster survival is concerned. Predators such as starfish, oyster drills and blue crabs and diseases, MSX, *Dermocystidium marinum* (DERMO), and *Minchinia costalis* (SSO) are all active in waters above 15 ppt in salinity (Haven et al 1981). These predators and diseases are particularly damaging to spat and young oysters. With respect to salinity, the prudent repletion manager would seek out those bottoms with average annual salinities ranging from 7.5 ppt to 15 ppt. This takes on particular importance when planting shell to catch spat. The Baylor grounds in the Upper James, for example, are free of diseases and predators. Unfortunately, this same region occaisonally experiences periods of lowered salinities. For example, in 1972 heavy rains brought on by Hurricane Agnes caused heavy seed oyster mortalities in this river system due to fresh water innundation. In spite of periodic freshwater kills the Upper James remains an important source of seed oysters in Virginia.

2.3.2 Temperature

A second source of environmental concern is temperature. Feeding and spawning activities are both temperature dependent. Optimal temperatures for feeding and growth fall between 15 and 25 degrees celsius. Oysters lie dormant during the cold winter months and do not resume feeding until Bay temperatures rise above 10 degrees celsius (Merritt 1977). As Spring turns to Summer, Bay temperatures increase inducing spawning activity starting in July and continuing into September as long as water temperatures exceed 20 degrees celsius (Merritt 1977).

According to Haven et al (1981), spawning temperatures in a given river system are reached at about the same time each year. Timing of shelling, therefore, becomes an important aspect of successful repletion program management. The primary reason for shelling is to provide a clean hard substrate on which oyster larvae may set. If shelling is conducted too soon, the shells may become silted over or covered with barnacles and other fouling organisms. Shells planted too late will be equally unsuccessful at catching spat. Careful monitoring of annual temperatures and spawning periods in each river system enables the program manager to time shelling to catch the maximum set.

2.3.3 Dissolved Oxygen

The final environmental consideration is availability of dissolved oxygen. Oysters can survive for short lenghts of time in waters as low as 1 part per thousand (ppt) in oxygen content (Kennedy and Breisch 1981). Extended exposure to such low levels, however, leads to deterioration in meat quality and eventual death. Although adult oysters may survive in oxygen deficient waters for several weeks, spat and seed oyster mortalities are quick and devastating. Recent declines in setting rates in deeper waters of the Rappahannock and the Potomac rivers have likely been caused by oxygen deficiencies in those waters (Kennedy and Breisch 1981).

2.4 BIOLOGICAL CONSIDERATIONS

2.4.1 Diseases

In addition to environmental considerations, oyster grounds managers need to be aware of several biological factors which influence the survival and availability of oysters. Of chief concern is the presence of diseases and predators. Dermo, SSO, and MSX are the three most important oyster diseases in the Chesapeake Bay. Of these three, MSX accounts for the majority of the disease related mortalities in any given year. First discovered in the Bay in 1959, MSX is active in all waters where fall salinities exceed 15 ppt. In these areas mortalities are as high as 70% (Haven et al 1981). A successful repletion strategy must consider two things with respect to MSX. First, MSX is not active in waters below 15 ppt in salinity. Shell or seed plantings in these lower salinity waters would, therefore, experience little or no losses to this disease. Second, different levels of MSX infestation have been identified. The categories run from Type I to Type IV MSX regions (Type I being the highest and Type IV being the lowest level of infestation). Seed oysters from regions of low MSX incidence do not survive well when transplanted to regions of high MSX incidence. On the other hand, it has been shown that seed oysters from high MSX regions may develop an immunity to the disease and survive quite well when transplanted in similar waters (Haven et al 1981). From a repletion point of view, therefore, seed oysters from any one region should only be transplanted to regions of similar or lower levels of MSX incidence. The MSX relationship is illustrated in Table 2.1. Table 2.1 presents a matrix of the different categories of MSX incidence. An "X" is placed in any cell of the matrix for which the receiving river system is of equal or lesser degree of MSX infestation than the system of seed origin. For example, if the river system of origin for a bushel of seed is of type III, then that seed should only be planted in a river system of MSX type III or IV.

2.4.2 Oyster Predators

Predators are another source of oyster mortality. The oyster drill or screwborer is the most damaging predator. Like MSX, the oyster drills (*Urosalpinx cinera* and *Eupleura caudetta etteri*) cannot tolerate salinities below 15 ppt but are very active in waters above this level (Haven et al 1981). Spat and young oysters are the favored prey of the oyster drill, and other predators such as the oyster leach, mud crab and blue crab because of their thin shell. Older

TABLE 2.1

River System Compatability by MSX Type

MSX Type of Seed Origin	MSX Type of Receiving System: I	II	III	IV
I	X	X	X	X
II		X	X	X
III			X	X
IV				X

This table shows the MSX Type relationship between system of seed origin and receiving seed origin and receiving system. An "X" indicates compatible MSX types.

and adult oyster shells are too thick for the drills to easily penetrate. For this reason seed to be transplanted in regions of drill abundance should be larger than otherwise to reduce losses to drill predation.

2.5 SUMMARY OF ENVIRONMENTAL AND BIOLOGICAL CONSIDERATIONS

Up to now the discussion has focused on particular environmental and biological factors and their unique effect on oyster survival and growth. It is now possible to create a composite description of a "good" seed area and a "good" market oyster growing area.

A good seed area must have an abundance of larvae which survive to the setting stage. The presence of larvae depends on two things, i) presence of adequate numbers of brood stock, and ii) proper currents which cause the suspended larvae to remain in the vicinity in which they were spawned and not flush out of the river system. Larval survival to the setting stage depends primarily on the existence of clean cultch at the time setting occurs. Larval survival also depends on the absence of predators, satisfactory levels of dissolved oxygen and salinities. For these reasons, bottoms favorable to seed production have i) an abundance of clean cultch, ii) salinities ranging from 5-15 ppt with infrequent incidents of freshwater innundation,

iii) low levels of disease and drill populations, and iv) sufficient quantities of dissolved oxygen. If a river has all of these river and bottom characteristics, it will likely be a successful seed producing area. One might think that a good seed area would also be a productive market oyster area. Suprisingly this is not the case.

Market and seed oyster producing grounds share many common characteristics. The distinction between the two comes down to growth rates. Oysters in seed areas may take up to seven years to reach the 3" legal harvestable size and in many instances oysters grown in these areas never reach a harvestable size. Oysters in good growing regions reach the 3" size limit in 3 to 3.5 years and in exceptional growing conditions may reach this size in as little as two years from larva to adult oyster (Kennedy and Breisch 1981). The exact reasons for the disparity in growth rates between seed and market oyster areas are not known with certainty. It is believed, however, that salinity and population density play a role in determining growth rates (Haven et al 1981). Oyster larvae and seed survive well in lower salinity waters because of the lack of disease and predators. While adult oysters survive better under similar conditions, lowered salinities that inhibit predators and disease also inhibit growth. Grow-out areas, therefore, are generally in higher salinity waters than seed areas.

One of the requirements of a good seed area is a heavy spatfall. This results in a very high population density on a given oyster bar. It is believed that overcrowding and competition for food results in stunted growth (Haven et al 1981). Population densities in market oyster areas tend to be much lower, and oysters grown in these less crowded conditions reach a harvestable size in a normal amount of time.

2.6 THE REPLETION PROGRAM: PAST AND PRESENT

The history of the repletion program began 1894 with the completion of the Baylor survey. The Act authorizing the survey marked the begining of a series of legislative actions designed to counteract a declining Virginia oyster industry. By establishing the State's stewardship over the "best" naturally productive oyster grounds (bottoms on which oysters exist without intervention from man), the Act implied a responsibility on the part of the State to insure the continued availability of oysters on the Baylor grounds to the people of the State. Following the Baylor survey, several legislative actions were passed that were conservation measures designed to slow the depletion of the natural oyster bars. One example of these conservation measures was the harvest restriction permitting only hand-tongs on all public oyster bottoms (with the exception of limited dredging permitted during specific times and in specific areas). Unfortunately this "regulated inefficiency" was not enough to stop the decline in oyster harvest.

Repletion, replacing shell taken from natural rocks, was proposed in 1921 by the Virginia Commission of Fisheries (VCF) but it was not until 1928 that active repletion by the State was authorized with the passage of the Oyster Repletion Act (Haven et al 1981). During the years 1931-1961, the Virginia Marine Resources Commission's (formerly the VCF) shell plantings ranged from 11,678 to 950,106 bushels of shell. Shell plantings varied from year to year and it was not until 1950 that the Commission's 1931 goal to plant at least 500,000 bushels of shell every year was realized (Haven et al 1981). During the same 1931-1961 period, VMRC planted seed oysters in addition to its shell planting program. Seed planting fluctuated widely over this time, was stopped altogether in 1946, and was not resumed until 1961 (Haven et al 1981).

From 1931 to 1961, numerous studies were conducted and recommendations were made to the Commission on ways to improve the repletion program. According to Haven et al (1981), much of this advice went unheeded by the Commission as poor setting areas such as the York river received heavy shelling to the expense of lowered shelling on more productive bottoms. Also, shells were planted in April or May, too soon for effective spat collection.

Drastic revisions in the repletion program were made in 1962 after the disease MSX appeared in the Bay. Shelling on Baylor grounds increased dramatically to a high of over 4,000,000 bushels in 1964-65 and averaging nearly 3,000,000 bushels until 1967-68 (VMRC Annual Reports 1981 and 1982). Shelling leveled off at just over 1,000,000 bushels annually until 1972 when the program was again stepped up in response to Hurricane Agnes. Shell plantings rose to nearly 3,000,000 bushels per year until 1976 when shelling fell to a little more than 1,000,000 bushels. Seed plantings were also resumed in 1961. Once again, however, the amount of seed transplanted each year was inconsistent and, unlike the shelling program, seems not to have been in response to any particular event.

In addition to increasing the sheer magnitude of the program, the VMRC began adopting several changes in program management which had for several years been recommended by the Virginia Fisheries Laboratory (now Virginia Institute of Marine Sciences). These changes included planting shells and seed in river systems having the best chance for a strike or survival, changing the timing of shell planting making the program more compatible with the oyster's natural spawning season and developing the Great Wicomico and the Piankatank rivers as alternative seed areas in the event of the catastrophic loss of the James river seed beds.

For the past five years (1979-1983) repletion efforts have leveled off at about 1.5 million bushels of shells planted annually. Relatively little seed has been planted, especially since 1980. In making these repletion decisions VMRC focuses on two objectives:

1. assuring that an adequate supply of seed oysters from seed growing areas is available for those private concerns and individuals planting on leased grounds.
2. maintaining a population of mature oysters on public rocks adequate for harvest by licensed watermen (VMRC Annual Reports 1981-1982)

Seeking to accomplish objective 1, the VMRC shells those areas known to be good seed areas, ie. areas having the environmental and biological characteristics previously described as being favorable to seed production. Attainment of objective 2 is attempted by planting shells in hopes of receiving a strike and subsequent grow-out or through the planting of seed oysters from seed areas to bottoms better suited for grow-out to a harvestable size.

The effectiveness of the repletion program has been the subject of numerous studies (JLARC 1977, 1983, Harris 1978).

Most of these studies conclude that the repletion program has indeed influenced the availability of seed and market oysters. Due to a lack of quantitative data, however, the question remains as to how much seed and market oyster supplies have been increased due to the repletion program's activities. Unfortunately, unless current record keeping systems are changed to permit recording of production from repleted bars it will never be possible to determine just how effective the VMRC has been in achieving its repletion objectives.

Chapter III

THE EMPIRICAL MODEL

3.1 INTRODUCTION

The Virginia Marine Resources Commission (VMRC) is responsible for the management of all oyster bottoms within the State's domain. VMRC is charged with the administration of the Oyster Repletion Program (ORP) and the formulation and enforcement of policies and regulations governing the production and harvest of oysters on public and private oyster beds. In attempting to acheive repletion and total State market oyster production goals VMRC must allocate limited resources over time among alternative aquacultural practices and river systems. In addition, VMRC must evaluate and recommend regulations on harvest of seed and market oysters.

These resource allocation and policy decisions should provide for the attainment of oyster production goals at minimum cost to public and private interests over time. VMRC's repletion activities and policies affect both public and private costs of producing market oysters. VMRC, therefore, should concern itself not only with the costs of administering and conducting its activities, but also how its actions affect the cost to private individuals harvesting oysters on public grounds or producing market oysters on leased bottoms. The decision problem faced by VMRC is one of minimizing costs over time subject to, limits of resource availability, market oyster production potential, and the range of policy options available. Linear Programming (LP) is a mathematical optimization technique that can be used to determine an optimal solution to this decision problem.

A multi-period LP model permits the simultaneous consideration of many different repletion and policy alternatives while recognizing that VMRC's decisions take place over time. In addition to being an optimization technique, LP provides useful information pertaining to shadow prices for included constraints, and the sensitivity of the model's solution with respect to changes in objective function or constraint coefficients.

Within a linear programming framework, VMRC's management problem may be stated in the following way. The VMRC has limited funds for repletion purposes, ie. planting shell or seed. VMRC may also choose to substitute repletion activities with policy changes designed to increase market oyster harvest such as, permitting dredging of seed or leasing of unproductive Baylor grounds, By allocating its funds and implementing alternative policies, VMRC can provide many combinations of aquacultural practices and policies to achieve a given market oyster harvest goal. These combinations form the activities of an LP model. Knowing how much each activity contributes to the harvest goal, and recognizing its limited resources, the Commission must determine the unique mix of activities required to meet a harvest goal at minimum cost over its planning horizon.

3.2 LINEAR PROGRAMMING MODEL

The linear programming model described below is the model which has been formulated to analyze VMRC's decision problem. The model considers the production of market oysters from public and private grounds over a period of ten years. All model activities are assumed to be initiated at the beginning of the year in which they occur.

The ten year planning horizon may be thought of as consisting of two distinct parts. The model is formulated as if no repletion program existed prior to the first year of the model's planning period. The first part of the planning horizon, therefore, is an interim period over which no market oyster harvest goal is set. This interim period is necessary because oysters take, on average, 2-5 years to reach the three inch minimum legal harvestable size (Haven et al 1981). A lag, therefore, exists between the time production activities are initiated and market oysters become available for harvest. The length of the lag depends on whether seed (2-3 year lag) or shell (3-5 year lag) is planted and the growth potential of the receiving system. The second part of the planning horizon is the period of years over which a specified market oyster harvest goal may be set.

In the model all public and private oyster bottoms in Virginia have been disaggregated into the 13 river systems listed in Table 3.1. The indicated number for each river system corresponds to the system location depicted in Figure 3.1.[5] The Potomac river is managed jointly by Maryland and Virginia and is not considered in the model. Seperate river systems were identified using two criteria; i) geographic location and ii) similarities in environmental characteristics important for oyster growth.

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[5] Originally only ten river systems were identified for modelling. Upon the recommendation of VIMS oyster biologists, the James and York rivers were split into two regions each, the Rappahannock was split into upper, mid- and lower sections and the Corrotoman river was incorporated into the Lower Rappahannock forming the 13 river systems listed in Table 3.1.

TABLE 3.1

Description of Model River Systems

1	Upper James	above James River Bridge
2	Lower James	below James River Bridge
3	Upper York	
4	Lower York	
5	Mobjack Bay	including North, East, Ware and Severn Rivers
6	Piankatank	
7	Upper Rappahannock	
8	Mid-Rappahannock	
9	Lower Rappahannock	including the Corrotoman to Windmill Point
10	Great Wicomico	
11	Upper Management Area	Windmill Point to Smith Point
12	Pocomoke and Tangier	including Baylor bottoms on the Bayside of Eastern Shore
13	Eastern Shore Seaside	

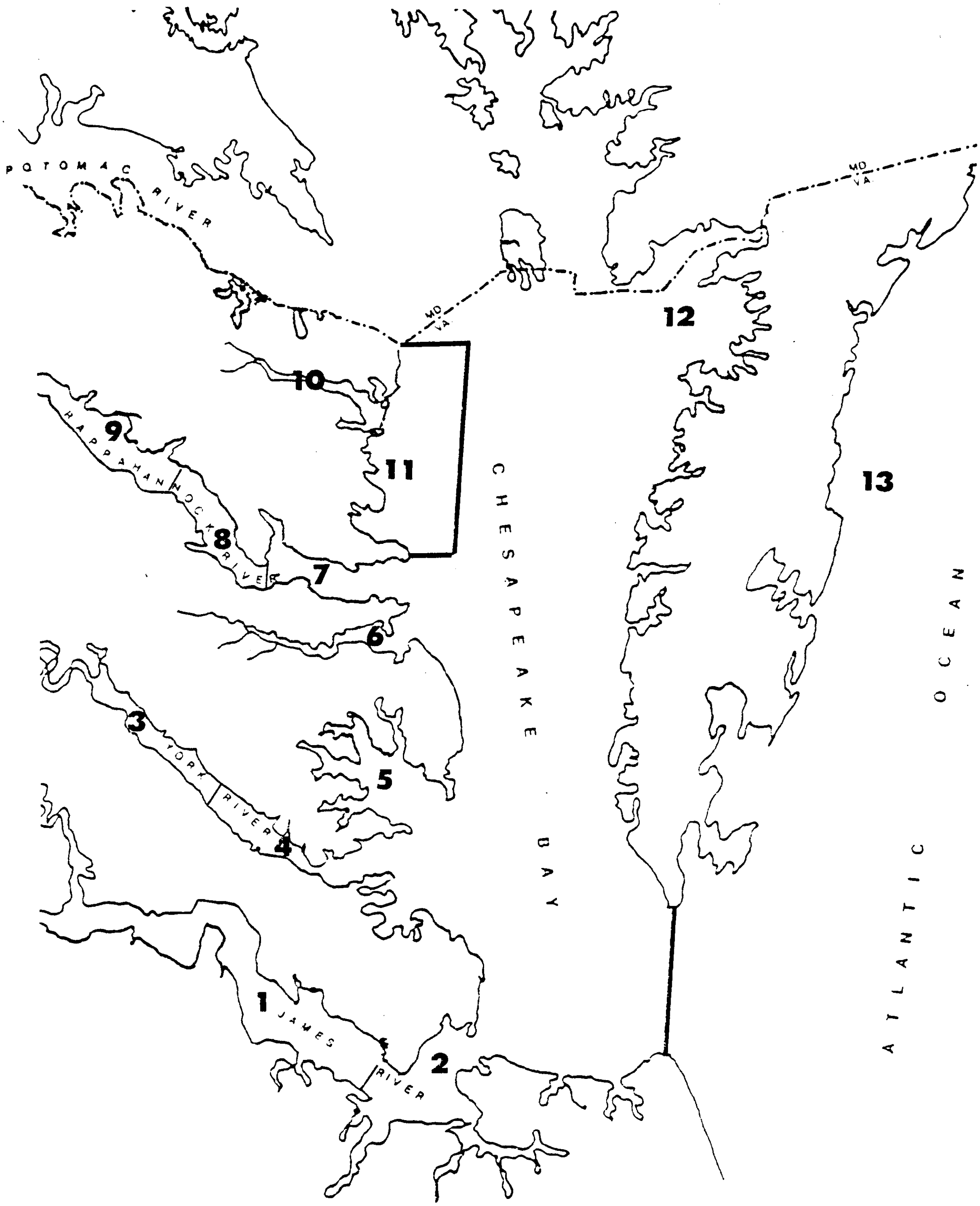

Figure 3.1: Model River Systems

3.3 OBJECTIVE FUNCTION

The objective of the linear programming model is to minimize the present value of public plus private cost cost of producing a prespecified level of market oyster harvest over the ten year planning horizon. The public costs included in the model are expenditures for contracted services incurred by VMRC as it carries out its repletion program. Private costs considered in the model are all costs incurred by private planters in the production and harvesting of market oysters and the cost of harvesting market oysters to watermen working the public grounds. It is normally assumed that the public sector has a longer-term investment horizon relative to the private sector. Given this assumption, an interest rate of 4.51 percent was used to discount public costs to the end of the first period. This public rate reflects the 1983 quarterly average interest rate offered on long-term state and local government securities (Federal Reserve Bulletin 1984) adjusted by a 5 percent inflation rate.

Private costs were discounted by an interest rate of 6.0 percent. The priate rate is equivalent to the 1983 prime rate on short term business loans adjusted by a 5 percent inflation rate. The short term private interest rate was used because it is assumed that such loans would be used to cover operating expenses incurred between harvest periods.

3.4 ACTIVITIES

There are two general types of activities considered in the model. Activities that result in market oyster production, hereafter referred to as primary activities, are represented in Figure 3.2 by the rectangular boxes. The primary activities of Figure 3.2 are the final products of production process depicted by a flow chart for each activity. Activities which do not directly result in the production of market oysters are represented by the circles in Figure 3.2.

3.4.1 Primary Activities

The four primary activities are based on current harvest regulations and aquacultural practices used in the Chesaspeaske Bay by public and private culturists. Each of these activities is uniquely defined by aquacultural technique, harvest technology, bottom ownership and production period.

The first primary activity is a shell-to-harvest activity where fresh or dredged oyster shells are planted on Baylor bottoms by VMRC to receive a set. The resulting young oysters are left to grow to a harvestable size. This aqua-

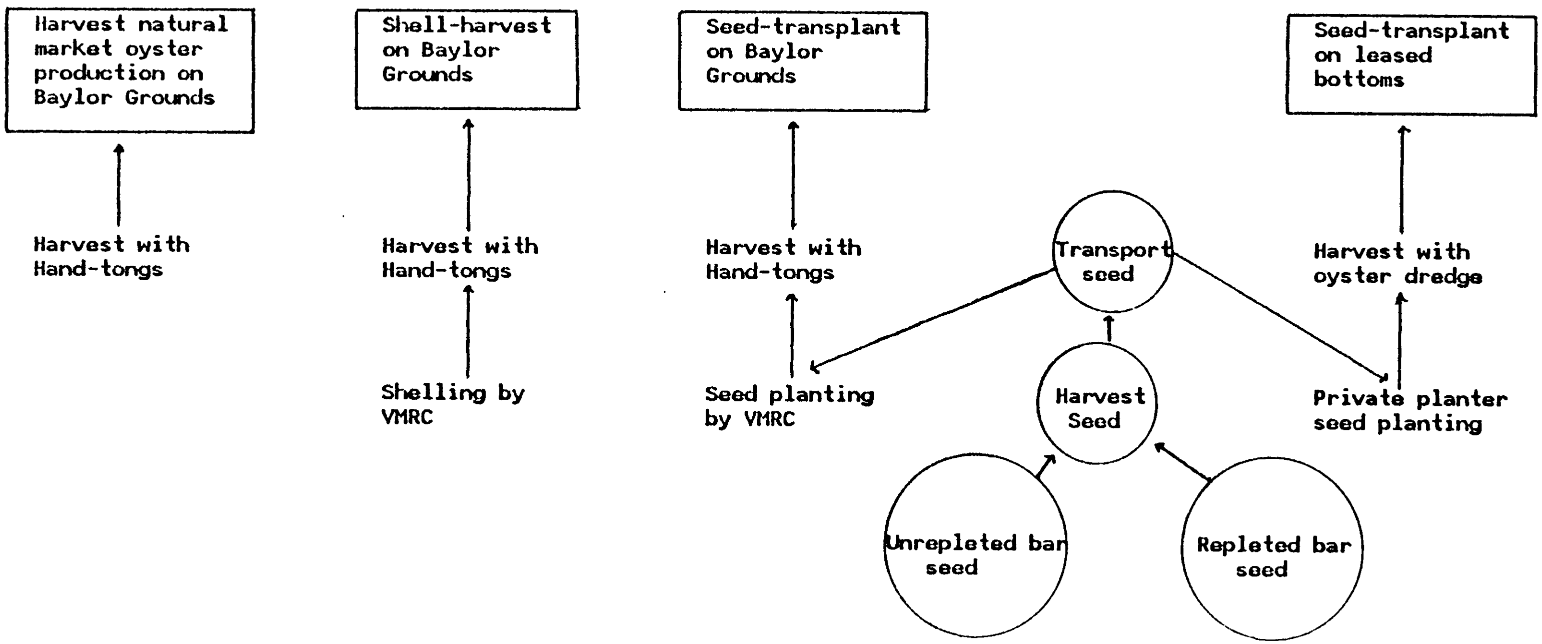

Figure 3.2: Diagram of Model Activities

cultural technique has for many years been the most important part of VMRC's repletion strategy. For this reason and because setting rates on private grounds are usually insufficient to make shell-to-harvest economically feasible, the model includes only the Baylor bottoms as candidates for oyster production using this technique. Setting rates vary from river system to river system. A shell-harvest activity is included in the model for only those river systems (listed in Table 3.2), determined by a literature survey and consultation with oyster management professionals, with sufficient setting rates to make shell-to-harvest a feasible oyster production activity.

The shell-to-harvest activity is carried out on Baylor grounds. Harvesting, therefore, will done by hand-tongers. A four year production period is used in which shelling takes place at the beginning of the first year of the production period and all oysters are harvested at the end of the fourth production year.

The second and third primary activty is a seed transplant-to-harvest activity. This activity involves harvesting seed from seed areas and transplanting the seed to grow-out areas on Baylor grounds or to growing areas on leased bottoms. Where setting rates are considered sufficient to support self-sustaining oyster populations on public grounds,

TABLE 3.2

Feasible Shell-Harvest River Systems

Great Wicomico
Mid-Rappahannock
Lower Rappahannock
Mobjack Bay
Seaside Eastern Shore
Piankatank
Upper Management Area
Pocomoke and Tangier

and where losses to diseases and predators to non-indigeneous seed, seed transplant-to-harvest activities were eliminated from model consideration. Public grow-out areas and leased growing areas are listed in Table 3.3.

The cultural technique is the same whether seed is planted on public or private grounds. The distinction between primary activity number two (seed transplanted onto Baylor grounds by VMRC) and primary activity number three (seed transplanted by private individuals on leased bottoms) is one of harvest technology. All harvesting on Baylor grounds is assumed to be done with hand-tongs, while all harvesting on leased bottoms is assumed to be done with an oyster dredge. The production period for both public and private seed-transplant activities is three years, where seed oysters are planted at the beginning of the first year of the production period and are harvested at the end of the third year of the production period. The only exception to this is seed transplanted on the Eastern Shore Seaside. Seed transplanted to these leased bottoms grow very rapidly and losses to disease and predation are heavy if the oysters are left on the bottom for more than eighteen months. A two year production period is assumed for leased bottoms in this region.

TABLE 3.3

Public and Private Growing Areas

Baylor Grounds	Private Grounds
Great Wicomico	Upper Management Area
Upper Rappahannock	Great Wicomico
Mid-Rappahannock	Upper Rappahannock
Upper York	Mid-Rappahannock
Lower York	Lower Rappahannock
Upper Management Area	Mobjack Bay
Piankatank	Upper York
	Lower York
	Piankatank
	Upper James
	Lower James
	Pocomoke and Tangier
	Seaside Eastern Shore

Not all market oyster harvest results from man-induced production. A fourth primary activity is included in the model which permits the harvest of market oysters from naturally occuring stocks. Natural production is simply defined as any production of market oysters that is not directly the intentional result of Man's repletion or cultural activities. The Baylor grounds were established on the basis of natural productivity. It is assumed, therefore, that all market oyster harvest of natural production takes place on the public oyster beds. No attempt is made to determine the natural productivity of each river system. For the model's purpose, therefore, a given level of annual Bay-wide natural market oyster production is assumed. This yearly production is harvested by the end of each year of the planning horizon. Table 3.4 provides a summary of all the primary activities by cultural technique, harvest gear, bottom ownership and production period.

3.4.2 Secondary Activities

Secondary activities do not directly result in market oyster production. The secondary activities are, instead, support activities providing the means through which i) seed is brought into the market oyster production process and ii) funds are made available to carry out VMRC's repletion pro-

Table 3.4

Summary of Primary Activities

	Cultural Technique	Harvest Gear	Bottom Ownership	Production Period*
Shell-Harvest	Plant shell on Baylor Bottoms to receive a set and grow-out to a harvestable size.	Hand-tongs	Public	4 Years
Public Seed-Transplant-Harvest	Transplant seed on Baylor bottoms and allow grow-out to a harvestable size	Hand-tongs	Public	3 Years
Private Seed-Transplant-Harvest	Transplant seed on leased grounds and allow grow-out to a harvestable size	Oyster Dredge	Private	3 Years**
Natural Production	————	Hand-tongs	Public	--------

* The production period includes harvesting the oysters.

** Except for Eastern Shore Seaside where growth is rapid and losses to predation are heavy if seed is left on the bottom for more than 18 months.

gram. Included in the model are four seed related secondary activities and two repletion fund related activities.

The model permits the harvest of seed from the Baylor grounds on unrepleted and repleted bars. Although some seed is produced by private planters, the majority of seed comes from public seed beds. For this reason private seed production is not considered in the model. Seed from unrepleted bars represents a stock which may be exploited. A given level of annual natural recruitment is assumed for modelling purposes. If in any year this annual stock is exhausted and more seed oysters are demanded, then the model permits seed to be produced by including a set of seed production activities. Unlike seed from unrepleted bars which can enter the market oyster production process as soon as it is required, seed from repleted bars must first be produced by shelling Baylor bottoms to catch a strike. River systems identified as seed areas are listed in Table 3.5. Once set, the immature oysters grow rapidly enough to be harvested by fall of the year they were spawned. All activities are assumed to take place at the beginning of any given period. A one year production cycle for seed production is assumed even though it may well be the case that the seed oysters will be harvestable before the year is up. Also included in the model is a seed harvest activity from unrepleted bars for each of the seed transplant-to-harvest activities. Figure 3.3 provides a pictoral summary of Tables 3.2, 3.3, and 3.5. Cultural techniques determined to be feasible are indicated for each river system.

The harvest of repleted-bar seed and the transport of seed from its origin to the planting site remain to be discussed. Both of these activities will only enter the model solution if seed production enters first. Seed that is produced must be harvested. Current regulations permit the harvest of seed only with hand-tongs. A separate seed harvest activity is included for each seed production activity to maintain continuity in the seed to market oyster production process. Separate activities are not required, but their absence could mask differing harvest technologies or regulations associated with the harvest of seed in one area versus another.

A set of seed transport activities is incorporated into the model for two reasons: i) to define the unique cost of transporting seed from one region to another, and ii) to prohibit the transport of seed from a given seed area to an MSX incompatible receiving system (as shown in Table 2.1). A seed transport activity is included to move seed from each seed producing area (from Table 3.5) to each grow-out area (Table 3.3) conditional on MSX compatability. Table 3.6 is

TABLE 3.5

Public Grounds Seed Areas

Upper James

Lower James

Mobjack Bay

Lower Rappahannock

Piankatank

Great Wicomico

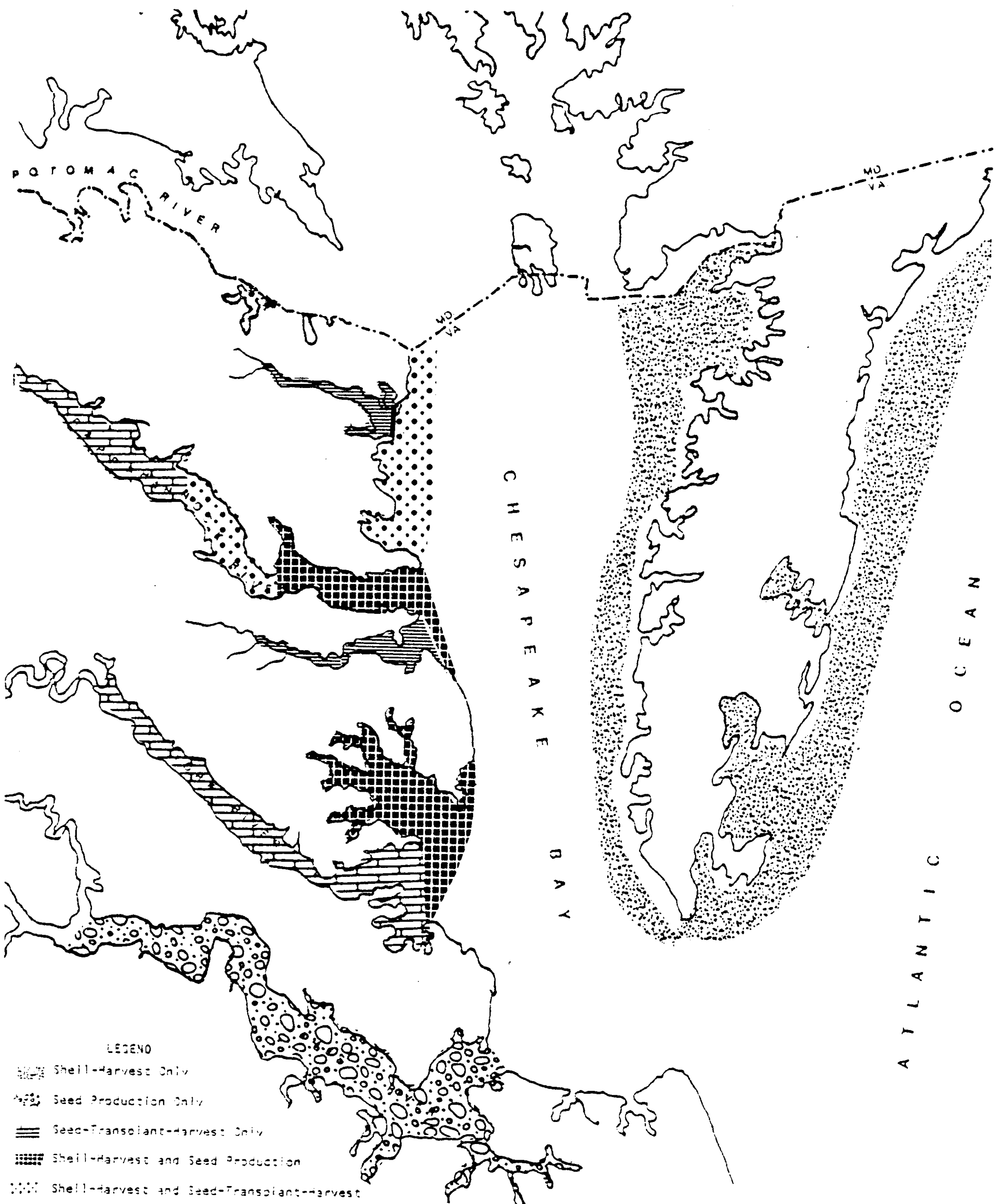

Figure 3.3: Cultural Technique Feasibility

a matrix of seed and grow-out area compatabilities by river system of origin and receiving system. MSX compatability is assumed to be the same on public and private grounds. Over 70% of the seed transplanted to leased bottoms in 1981 came from the James river seed beds (VMRC Annual Reports 1982). For this reason, only James river seed is allowed to go to all leased bottoms.

3.4.3 Tax Collection and Repletion Fund Transfer

The final secondary activities are: i) oyster repletion tax collection, and ii) repletion fund transfer from one year to another. One source of repletion funds is the Public Rocks Oyster Repletion Tax. The repletion tax is levied on all seed and market oysters harvested on the Baylor grounds. Any harvest of oysters on public grounds, therefore, generates revenue which goes into the State's repletion program budget. The model is designed so that whenever a market oyster harvest or production activity (all production is assumed harvested) or a seed harvest activity is initiated a tax collection activity is initiated in the year the oysters are harvested.

It is possible that ORP budgetary requirements will differ from year to year depending on the mix of repletion activities undertaken by VMRC. One would expect, therefore,

Table 3.6

MSX Compatability by Seed Origin and Receiving System

	Upper York	Lower York	Mobjack Bay	Pianka-tank	Upper Rapp.	Lower Rapp.	Mid-Rapp.	Great Wicom.	Upper Mgt. Area	Pocomoke &Tangier	Upper James	Lower James
Upper James	C				C	C	C	C	C		C	
Lower James	C	C			C	C	C	C	C		C	C
Lower Rapp.	C				C	C	C	C	C		C	C
Piankatank	C			C	C	C	C	C	C		C	C
Great Wicom.	C				C	C	C	C	C		C	C
Mobjack Bay	C	C	C	C	C	C	C	C	C	C	C	C

Source: Haven et. al. (1981)
A "C" indicates MSX compatability.

years of funding shortages and years of funding surpluses. The model permits the transfer of funds from years of budgetary surplus to years of budgetary shortage.

3.5 CONSTRAINTS

In the linear programming model, maximum constraints are placed on the availability of private and public oyster bottoms, the ORP budget, and the natural production of seed and market oysters on the Baylor grounds.

In addition to these resource availability constraints, there is a set of transfer rows which force an activity or sequence of activities into the solution whenever a primary activity requires an auxilliary secondary activity. If, for example, a seed-transplant activity enters the basis and natural seed availability is exhausted, these transfer rows force the following sequence of secondary activities into the basis; seed production, seed harvest and seed transport. Another set of transfer rows initiates a tax collection activity any time seed or market oysters are harvested on public grounds. Also included in the model is a set of transfers which effect the transfer of ORP funds from one year to another.

The final set of constraints is the setting of the harvest goal. The harvest goal is constrained with equality for each of the ten years of the planning horizon.

3.6 THE COMPUTER MODEL

The linear programming model just described is now presented in tableau form in Figure 3.4. The columns of the tableau represent the alternative activities which may be chosen to achieve the prespecified level of market oyster harvest.

The objective function for the model is described in the "COST" row. Included in this row are the public plus private costs of initiating a public grounds repletion and harvest activity or a private bottoms market oyster production and harvest activity. The coefficients in the objective function row represent the total cost of undertaking a single unit of a given activity discounted to the first year of the ten year planning period.

The bottom acreage, shell, seed, and budget requirements for each activity are included in the rows section. Also included in this section are tax revenues generated by each activity, the quantity of seed resulting from a given seed production activity, and the bushels of harvested market oysters generated by each primary activity.

Maximum levels of private and public acreage are listed under the column labled "RHS." Limitations on repletion funds, and natural seed and market oyster harvest are also

	$SHFF_{rt}$	$SHFD_{rt}$	$SHSF_{rt}$	$SHSD_{rt}$	TSF_{rt}	$TSSF_{rt}$	$TSSD_{rt}$	TSL_{rt}	$PSFF_{rt}$	$PSFD_{rt}$
RBF_t	1	1			1				1	1
RBS_t			1	1		1	1			
RL_t								1		
FRS_t	F		F			F			F	
DRS_t		D		D			D			D
$NSPC_t$										
$NMOP_t$										
BT_t	B	B	B	B	B	B	B		B	B
$GOAL_t$	G	G	G	G	G	G	G	G		
TR_t	-T	-T	-T	-T	-T	-T	-T			
TST_{rt}					SR	SR	SR			
$TSTL_{rt}$								SRL		
TSH_{rt}										
THT_{rt}									-SP	-SP
COST	$\frac{C_{SHFF_{rt}}}{(1+i)^n}$	$\frac{C_{SHFD_{rt}}}{(1+i)^n}$	$\frac{C_{SHSF_{rt}}}{(1+i)^n}$	$\frac{C_{SHSD_{rt}}}{(1+i)^n}$	$\frac{C_{TSF_{rt}}}{(1+i)^n}$	$\frac{C_{TSSF_{rt}}}{(1+i)^n}$	$\frac{C_{TSSD_{rt}}}{(1+i)^n}$	$\frac{C_{TSL_{rt}}}{(1+i)^n}$	$\frac{C_{PSFF_{rt}}}{(1+i)^n}$	$\frac{C_{PSFD_{rt}}}{(1+i)^n}$

Figure 3.4: Model Tableau

	$PSSF_{rt}$	$PSSD_{rt}$	$HARS_{rt}$	$STOR_{rt}$	$STORL_t$	$HNSP_t$	$HNMOP_t$	$TAXC_t$	$TFUND_t$	RHS
RBF_t										$\leq RBF^*$
RBS_t	1	1								$\leq RBS^*$
RL_t										$\leq RL^*$
FRS_t	F									≥ 0
DRS_t		D								≥ 0
$NSPC_t$						1				
$NMOP_t$							1			
BT_t	B	B						-1	1	$\leq RB^*$
$GOAL_t$							G			$= G^*$
TR_t			-T			-T	-T	1		$= 0$
TST_{rt}				-1		-1				$= 0$
$TSTL_{rt}$					-1	-1				$= 0$
TSH_{rt}			-1	1	1					$= 0$
THT_{rt}	-SP	-SP	1							
COST	$\frac{C_{PSSF_{rt}}}{(1+i)^n}$	$\frac{C_{PSSD_{rt}}}{(1+i)^n}$			$\frac{C_{STORL_t}}{(1+i)^n}$	$\frac{C_{HNSP_t}}{(1+i)^n}$	$\frac{C_{HMNOP_t}}{(1+i)^n}$			

Figure 3.4 Model Tableau (contd.)

listed in this column. It should be noted, however, that each dollar of tax revenue, as indicated by the coefficient in the "BT" row and "TC" column, increases the repletion budget for that year by the same amount. In addition, the budget for any given year can also be increased by transferring unused funds from one year to be used in another. This particular activity is represented in Figure 3.5.

In this submatrix the budget for the year receiving the fund transfer is increased while the budget year from which the funds are taken is decreased by the amount of the transfer. This is indicated by a negative one in each "BT" row of any year (j) receiving a transfer and a positive one in the "BT" row of the year (i) making the transfer. It is only possible to transfer funds forward in the planning period. A fund transfer activity, therefore, is included for all years i and j such that j > i. Also included in the RHS section is the prespecified level of market oysters, as indicated by the row labled "GOAL."

The technical coefficients for the model define the relationship between a given activity and a given constraint. The coefficients denoted by the letter "F" in Figure 3.4, for example, define the quantity of fresh shell required in order to undertake a particular shell-to-harvest activity. The estimation of these technical relationships will be discussed in detail in Chapter IV.

	TFUND12	TFUND13	TFUND14	TFUND15.....	TFUNDij		RHS
BT1	1	1	1	1		<	RB*
BT2	-1					<	RB*
BT3		-1				<	RB*
BT4			-1			<	RB*
BT5				-1		<	RB*
BTi					1	<	RB*
BTj					-1	<	RB*

* Note that the submatrix presented here includes only the first four years of the planning period. The submatrix continues in a similar manner for the remaining years of the planning period.

Figure 3.5: Fund Transfer Submatrix

The input data analyzed by the linear programming model is represented by generalized notation in the matrix tableau. Table 3.7 explains the notation used.

TABLE 3.7

Tableau Key

Subscripts and Superscripts

t = time period; t = 1-10

r = river system; r = the river systems listed in Table 1

i = the discount rate. An interest rate of 4.51 percent was utilized to discount the future cost of public expenditures for oyster bed repletion. Private grounds production expenditures are discounted by an interest rate of 6 percent.

n = the number of years over which discounting occurs.

Coefficients

C = the cost in current dollars of undertaking any secondary or primary activity.

F = the number of bushels of house shell required by an activity.

D = the number of bushels of reef shell required by an activity.

B = the amount of public expenditures required to initiate one unit of any public repletion program activity.

G = the contribution toward satisfying the harvest goal made by a unit of any given primary activity.

T = the tax revenue generated by a unit of seed or market oyster production on Baylor grounds.

SR = the number of bushels of seed required by a public seed-transplant activity.

SRL = the number of bushels of seed planted on private grounds.

SP = the bushels of seed produced on public grounds from a unit of a seed production activity.

RBF* = the maximum acreage of firm public bottoms in a given river.

RBS* = the maximum acreage of soft public bottoms in a given river.

RL* = the maximum leased acreage in a given river.

RB* = the maximum amount of repletion funds available in any given year.

G* = the market oyster harvest goal.

Columns

SHFF = a shell-harvest activity using fresh shell on firm Baylor grounds. Rivers included in this activity and the next three activities are listed in Table 2.

SHFD = a shell-harvest activity using dredge shell on firm Baylor bottoms.

SHSF = a shell-harvest activity using fresh shell on soft Baylor bottoms.

SHSD = a shell-harvest activity using dredge shell on soft Baylor bottoms.

TSF = transplanting seed to grow-out areas on firm Baylor grounds. River systems included in this and the next two activities are listed in Table 3.

TSSF = transplanting seed to grow-out areas on soft Baylor bottoms where shelling with fresh shell used.

TSSD = transplanting seed to grow-out areas on soft Baylor bottoms where shelling with dredge shell is used.

TSL = transplanting seed on private grounds, river systems included in this activity are listed in Table 3.

PSFF = shelling firm Baylor grounds with fresh shell to produce seed, river systems included in this and the next three activities are listed in Table 5.

PSFD = shelling firm Baylor grounds with dredge shell to produce seed.

PSSF = shelling soft Baylor grounds with fresh shell to produce seed.

PSSD = shelling soft Baylor grounds with dredge shell to produce seed.

HARS = harvest seed produced by the previous activities.

STOR = transport the harvested seed (from the HARS activity) to a receiving system on Baylor bottoms.

STORL = transport the harvested seed (from the HARS activity) to leased bottoms.

HNSP = harvest natural seed production.

HNMOP = harvest naturally occuring market oysters.

TAXC = tax collection.

TFUND = transfer funds from one year to another.

Rows

RBF = firm Baylor grounds.

RBS = soft Baylor grounds.

RL = leased bottoms.

FRS = fresh shell.

DRS = dredge shell.

NSPC = natural seed production.

NMOP = natural market oyster production.

BT = VMRC's repletion budget.

GOAL = the prespecified level of market oyster harvest.

TR = tax revenue.

TST = transfer transported seed to a public seed-transplant activity

TSTL = transfer transported seed to a private seed-transplant activity.

TSH = transfer seed harvested seed to a seed transport activity.

THT = transfer seed produced seed from repleted bars to a seed harvest activity.

Chapter IV

ESTIMATION OF TECHNICAL COEFFICIENTS

4.1 INTRODUCTION

The decision model developed in Chapter III permits an evaluation of the alternative oyster grounds management options available to VMRC. Underlying each management option is the assumption that the effects of implementing a given policy or repletion option are known. It is assumed, for example, that VMRC knows exactly how many bushels of market oysters will be produced when it plants seed in any given river system. Chapter I, however, introduced the problem of imperfect fisheries management information. An inadequate data base, the absence of an efficient means of collecting and processing fisheries management information and the lack of economic and biological modeling contribute toward management uncertainty. The purpose of this chapter is to provide a detailed treatment of how the technical coefficients required for the model developed in Chapter III were estimated. Data requirements for objective function constraints and activities are discussed seperately. Included in each section is a list of data sources used and a treatment of the informational or data problems associated with each coefficient type. The actual data used for each coefficient can be found in Appendix A.

4.2 OBJECTIVE FUNCTION COEFFICIENTS

The objective function coefficients indicate the total public plus private cost of undertaking a given primary or secondary activity. These cost coefficients may be broken down into three general categories; public grounds repletion costs, private grounds production costs and private harvest costs.

4.2.1 Public Grounds Repletion Costs

All activities that take place on public oyster rocks have associated with them a repletion cost and a private harvester cost. Together these costs make up the total cost of undertaking any public grounds activity. The private harvester costs, however, will be discussed later as estimation of these coefficients merits seperate consideration.

VMRC contracts the services of private watermen to carry out its repletion program. Estimation of these cost coefficients under current repletion program policies is an easy task as the per-bushel costs for contractual services are readily available from VMRC Annual Reports. To put these costs on a per-acre basis it is necessary to multiply the per-bushel cost of seed or shell planted by the quantity planted per acre. The public grounds shell planting costs are computed as follows:

$$\text{Repletion Cost/Acre}_i =$$

$$(\text{\$/bushel shell}_j) \times (\text{bushels planted}_{i,k})$$

where i = river system

j = shell type (fresh or dredge shell)

k = bottom type.[6]

Public shelling costs, therefore, depend on the river system shelled, the shell type and the quality of the growing bottom. Public grounds seed transplanting costs may be calculated in similar fashion by the following formula:

$$\text{Seed Planting Cost/acre}_i =$$

$$(\text{\$/bushel for seed}_h) \times (\text{bushels planted}).$$ [7]

---

[6] Two classes of bottom are considered in the model, firm and soft bottom. Bottoms in which grab samples contain at least 50% shell or shell fragments in volume are defined as being firm (Haven et. al. 1981). These bottoms require planting of 7,000 bushels of shell per acre to make them suitable for oyster culture. All other bottoms are classed as soft and require 10,000 bushels of shell per acre to make oyster culture possible.

[7] VMRC personnel reccommend planting between 550 and 750 bushels of seed per acre depending on the size and the spat count (number of spat per bushel) of the seed. An average of 650 bushels per acre was chosen for the model to allow for this variation in seed quality.

where i = receiving river system

h = system of seed origin

Using these formulae, the repletion cost of any specific public grounds repletion-harvest acvtivity can be determined. The objective function coefficient for any of these activities is simply the sum of the repletion cost and the cost of harvesting the resulting oysters. The per bushel repletion costs along with their respective objective function coefficients may be found in Appendix A tables A.1 and A.4 respectively.

The costs reported in these tables are from 1983 VMRC repletion cost data sheets (unpublished VMRC records). These recorded costs include the cost per bushel of acquiring, transporting and planting shell or seed by shell type, seed, and river system. Unfortunately these costs are not broken down into their individual components.

The inability to consider purchasing, transportation and planting costs separately masks the fact that each repletion activity is itself a process composed of several subactivities. Redefined in this way it can be seen that there exists alternative shell or seed sources and their associated transportation costs, transportation technologies, and shell or seed planting technologies. If it were possible to examine each of these costs separately it would enable the introduction of a greater level of detail into the model. The model would be able to determine not only the shell type to plant, where to plant it, and how much to plant, it would also determine the least costly way of purchasing, transporting and planting the shell.

4.2.2 Private Grounds Production Costs

Before describing how the private planter production costs were estimated it is first necessary to discuss the assumptions that were required to motivate private grounds market oyster production. It is assumed that private planters seek to maximize profit. In so doing, leaseholders minimize their costs by selecting the most cost-effective combination of activities required to produce market oysters. Recall that the model developed in Chapter III does not necessarily require that private grounds market oyster production be profitable. Economic theory of the firm, however, predicts that the individual will only produce a positive amount of output if at least all operating costs are recovered in the short run and at least all fixed plus operating costs are recovered in the long run. Given that the model considers a ten year planning period for public and private decisions, it is assumed that no private grounds production will occur unless long run economic returns to private grounds market oyster production is greater than or equal to zero. In order to garuntee that private grounds market oyster production is positive the assumption is made that the price of market oysters is always at least as great as the unit cost of producing market oysters. Similarly, for private watermen working the public grounds, it is assumed that the price of market oysters is always sufficient to cover all harvest costs incurred by the harvester. The costs associated with private grounds market oyster production are now discussed. As previously stated, harvester costs will be presented in a later section.

The costs associated with private grounds oyster production considered in the objective function, consist of the cost of acquiring, transporting, and planting seed along with the cost of harvesting the market oysters. The model considers production of market oysters in a two step process by including two separate activities. One for purchasing and transporting seed oysters, and another for planting seed and harvesting market oysters.

Each seed purchase and transport activity defines a unique combination of the river system from which seed is transported and the receiving river system. The objective function coefficient for each activity is determined by the price of the seed plus the cost of transporting the seed.

These coefficients are estimated by determining the price of seed in each seed producing river system and the transportation cost of bringing the seed to the planting site. VMRC seed and market oyster production and price data were used to determine the price of seed in seed producing river systems. Little information, however, is available to estimate the cost of transporting seed. According to records of a Rappahannock river planter obtained by Haven et. al (1981), transportation costs ranged between 25 and 50 cents per bushel. Unfortunately no insight is offered as to the distances corresponding to these costs.

In order to establish a relationship between transportation costs and distance, the 25 to 50 cent cost interval is assumed to provide upper and lower bounds to per bushel transportation costs. The purpose here is to provide a means of assigning transport costs based on relative distance between seed origins and receiving systems. In this respect the 25 to 50 cent interval is being used as an indexing mechanism. Using five cent increments, relative transportation costs were assigned to each seed purchase and transport activity. These assignments are made on the basis of the geographical location of a receiving system relative to how far away it is from a specific seed origin when compared to the closeness of other potential receiving river systems competeing for seed from the same source. For example, the cost assigned to transporting seed from the James to the Rappahannock is $.40. The cost of transporting seed assigned to the York from the James is $.25. Here shipping seed from the James to the York is less costly than shipping seed from the James simply because the York is closer to the seed source. The opposite is true when shipping seed from the Great Wicomico to the Rappahannock and the York, ($.30 and $.45 respectively).

These transport costs are not inflated because they are based only on relative distance between any two river systems and not on actual shipping cost data. If these shipping costs were inflated, only the magnitude of the cost would change. The relative difference in transport cost between any two river systems as compared to any other two river systems, however, would remain unaltered. The objective function coefficient for each seed purchase-to-transport activity is left on a per-bushel basis and may be calculated with the following formula:

Purchase-to-Transport Cost/bu_i =

Seed Price_j + transport cost from system_j to system_i.

where: i = receiving system

j = seed origin

The data used to estimate these coefficients is listed in Appendix A Table A.10.

The second step in the production process is the seed planting and market oyster harvesting activity. Once again a discussion of harvesting costs will be put aside momentarily. Seed planting costs simply involve the costs of putting the seed on leased growing bottoms. For simplicity it is assumed that a uniform planting technology is employed by all private planters. Seed planting costs can then be assumed to be the same across all private planters and river systems. Seed planting costs are reported by Haven et. al. (1981) as being \$.30/bu (1975 dollars). When inflated to 1983 dollars (using the CPI), and multiplied by a fixed per acre planting rate, the cost of planting seed on any one acre of leased bottom is \$412.5.[8]

The objective function coefficient for a one acre unit of any private seed-transplant-harvest activity is the sum of the seed planting cost and the cost of harvesting the resulting market oysters. The following formula can be used

[8] According to Haven et. al. (1981), planting rates on private grounds range between 500 and 1,000 bushels per acre. Planting rates chosen by private planters depend on seed size and the firmness of the growing bottoms. Bottom type for all leased bottoms is assumed to be the same across all planters and river systems. An average planting rate of 750 bushels per acre was chosen for the model to account for varying seed size and to reflect a bottom quality which is assumed to be representative of most leased acreage.

to determine the objective function coefficient for each private seed-transplant-harvest activity:

Seed-Transplant-Harvest Cost/acre_i =

Seed Planting Cost/acre + (Harvest cost/bu.) x

(bushels harvested_i).[9]

where: i = river system

Estimation of private production costs is made difficult by the lack of published information on what these costs are. The records of the Rappahannock grower mentioned previously constitute the only source of published quantitative data which was made available. While these records are better than none at all, they do not represent a sample of the cost conditions faced by other planters in the Rappahannock or any other river system. The lack of published information on private leaseholder's oyster production techniques also presents a problem in that there is no way to ensure that all relevant cost information has been included in the production cost estimates incorporated in the model. For example, during the normal production process some

[9] Note that the seed planting cost per acre has already been assumed constant. It will be shown later that per bushel harvest cost is also assumed constant. The value of this coefficient varies, therefore, only with the number of bushels of market oysters harvested from a given acre of leased bottom in a given river system.

amount of shell is lost due to siltation or removal during harvesting. Substrate maintenance costs are, therefore, likely to be incurred. It was not possible to determine under the current information base what these costs might be. A better information base would permit more accurate and reliable estimation of private market oyster production costs.

4.2.3 Oyster Harvesting Costs

The harvest of market oysters takes place on both public and private grounds. It is assumed that only hand tongs are used on public grounds and all private planters use an oyster dredge. It is necessary, therefore, to estimate a cost coefficient for each gear type. Both hand tong and dredge harvest costs were estimated by creating a budget which was estimated on an annual cost per harvest season basis. Items included in each budget are vessel and gear maintenance, fuel, wages, food, and amortized vessel and gear principle plus interest costs.

Table 4.1 presents the budget format that was used to estimate the harvest cost by gear type for a representative harvester. The actual budget estimated for each gear type can be found in Appendix A, Tables A.2 and A.7 for hand-tong and dredge respectively. Per bushel harvest cost for each gear type was estimated by dividing total annual harvest cost by average annual landings for a representative harvester. This coefficient is assumed to be constant for all harvesters. It is now possible to substitute this per bushel harvest cost coefficient into the following formula to obtain the objective function coefficient for each activity previously discussed in this chapter.

$$\text{Objective Function Value}_{i,k} = \text{\$/activity unit}_{i} + (\text{harvest cost/bu}_{j}) \times (\text{bushels harvested}_{i,k})$$

where: i = activity type

j = gear type

k = river system

The principle source of data for compiling the harvest budgets is the Chesapeake Bay Harbors Study (1961). This study, conducted by the Corps of Engineers is 1961 surveyed watermen to determine various harvest related expenditures. While the study does not construct budgets for different gear types, it does provide insight into the cost items associated with harvesting oysters for several gear types and vessel sizes. Also included in the survey is information relating to hours and days worked per year and average daily catches. The more recent work by Haven et. al.

TABLE 4.1

Annual Harvest Cost Budget

Variable Costs			
	Vessel Maintenance	_____	
	Gear Maintenance	_____	
	Fuel	_____	
	Wages	_____	
	Food	_____	
		Total Variable Costs	_____
Fixed Costs			
	Vessel Principal	_____	
	Gear Principal	_____	
	Interest Payment	_____	
		Total Fixed Cost	_____
		Total Cost	_____

(1981), The Oyster Industry of Virginia: Its Status, Problems and Promise, was also used to confirm and supplement the findings reported in the the Corps study.

Even with these sources, one basic difficulty arises. While technical information on vessel, gear, fuel and labor costs is not difficult to obtain, information on average daily catch by gear type remains elusive. The problem arises because daily catches vary depending on where oysters are being harvested, how many men are in the boat and even with the harvester himself. The most complete information which is contained in the Corps study reports a range of 20-300 bushels per day for a medium dredge and 5-100 bushels per day for hand-tongers. These ranges apply to the entire survey area which includes only the Southern half of the Virginia portion of the Chesapeake Bay. More reliable harvest cost coefficients would necessitate a new survey or improved methods of catch reporting to obtain a better understanding of what average daily catches might be by region and gear type.

4.3 ESTIMATION OF CONSTRAINT COEFFICIENTS

This section discusses only estimation of the coefficients which determine the bounds or Right-Hand Side (RHS) for each constraint. All other coefficients found in the constraint rows will be discussed in the Activities Coefficients section of this chapter.

Referring to the model tableau (Figure 3.4) it can be seen that the first three constraints are oyster grounds acreage constraints. The RHS for the constraints RBF_t and RBS_t define the total quantity of firm and soft bottomed Baylor grounds respectively in any given river system. The RHS coefficient for RL_t defines the total available acreage of leased bottoms in any given river system. In the most recent survey of the Baylor grounds VIMS scientists classified each discrete oyster growing area by size and bottom type. This information is recorded and reported in The Present and Potential Productivity of the Baylor Grounds in Virginia (haven et. al. 1981). Total availability of public grounds by bottom type and river system was determined by summing the acreage of each discrete area classified as being at least ten acres in size. The ten ace cut-off was used because it is the minimum discrete acreage that VMRC repletion officers considered feasible to replete. Acreage of privately held oyster grounds by size of holding is is published in The Oyster Industry of Virginia: It's Status, Problems Promise (Haven et. al. 1981). The total lease acreage was estimated by determining the amount of privately held bottoms in each river system held in units of twenty acres of more in size. Any acreage held in units less than twenty acres is either riparian or considered too small to be commercially productive and was, therefore, not included in the leased bottoms totals.

Following the acreage constraints are two constraints, one for each of the two different shell types used by VMRC in its repletion program. An inspection of the RHS coefficients shown in Figure 3.4 for each of these constraints (FRS_t and DRS_t) reveals that they have no upper limit. The main reason for this is a lack of information in regard to the limits of availibility of either reef or fresh shell. There is no way to tell whether VMRC uses reef shell instead of fresh shell or vice versa because one is in short supply relative to another. Alternatively there may other reasons for choosing one shell type over the other. In some studies, for example, reef shell has been found to be slightly more eficient in catching spat than fresh shell (Campbell and Forste 1978). The lack of an upper bound avoids this measurement problem as the quantity of either type of shell used becomes an output of the model solution.

The constraints $NSPC_t$ and $NMDP_t$ determine the limits of natural (unaided by man) seed and market oysters produced annually on Baylor grounds. Annual natural seed production was estimated by averaging seed harvest reported in VMRC Annual Reports and VMRC Oyster Repletion and Production Data (in pub.) for the years 1976-1983. It was then assumed that some of that production had been man-induced. The quantity of man-induced seed oyster production can be calculated by multiplying the number of acres shelled in the James River seed area in the previous year by the corresponding seed oyster productivity coefficient.[10] This estimate of man-induced seed oyster production was then subtracted from total seed production to obtain an estimate of naturally produced seed. This quantity is estimated with the following formula:

$$\text{Natural Seed}_t = \text{Total Seed Harvested}_t - (\text{Acres Seed Beds Shelled}_{i,t-1}) \times (\text{Productivity}_i).$$

where: i = river system

t = time

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[10] The term "productivity coefficient" refers to the total production of seed or market oysters per unit of a seed or market oyster production activity. The estimation of these coefficients are discussed in the next section.

Natural market oyster production was calculated in a similar manner. Total public ground market oyster production was averaged over the same eight year period. The 1983 repletion program was chosen as a representative repletion year. The man-induced market oyster production was then estimated by summing the product of repleted acres in each river system and the appropriate market oyster productivity coefficient. Total man-induced market oyster production was then subtracted from total public grounds production to obtain an estimate of "natural" market oyster production. In formula form this coefficient may be expressed as;

Natural Market Oyster Production =

$\text{Total Public Grounds Production}_{t}$ -

$\text{Sum (Repleted Acres}_{i,t-z}) \times$

$(\text{Productivity Coefficient}_{i,j})$

where: i = river system

j = type of repletion activity

t = time

z = maturation period ie. for;

j = shell-harvest, z = 3

j = seed-transplant-harvest, z = 2.

The RHS coefficient for the BT row represents the total funds available to VMRC to carry out its repletion activities. This coefficient was estimated by averaging VMRC expenditures for repletion purposes over the years 1979-1982. VMRC Annual Reports were used to obtain the necessary data.

The coefficient for the prespecified harvest goal was determined by averaging oyster production from both public and private grounds to determine a total market oyster production goal. This coefficient provides a harvest goal under current repletion policies and budgetary levels. The initial production goal will be varied and the cost and policy implications of an increased harvets goal will be examined. Harvest on public grounds was averaged over the 1976-1983 period. VMRC production and repletion data were used for this average. Private grounds market oyster production data from VMRC Annual Reports were only available for the years 1976-1980. The sum of average public and private market oyster production was then calculated to estimate current average annual market oyster production.

The remaining rows in Figure 3.4 are transfer rows whose RHS coefficients are by definition equal to zero. These rows will not be further discussed.

4.4 ESTIMATION OF MATRIX ELEMENTS

The following discussion will deal specifically with the matrix elements of the model tableau. Once again Figure 3.4 will be used as a reference. The matrix elements in the RBF, RBS, and RL rows indicate the amount of Baylor or lease acreage required to undertake any given activity. A coefficient of 1 will be found in the intersection of any one of these rows and market or seed oyster production columns. The interpretation being for every unit of a seed or market oyster production activity one acre of bottom must be used.

All matrix elements denoted by the letter F represent the quantity of fresh shell required by employing a unit of any particular oyster production activity. Similarly the letter D represents the quantity of dredge shell required per unit of given oyster production activity. An inspection of these coefficients shows that all of them are associated with public grounds repletion activities. Estimation of these coefficients is based, therefore, on shelling rates recommended by VMRC personnel.[11]

The next set of matrix elements coefficients is denoted by the letter B in Figure 3.4. These coefficients define the expenditures required by VMRC to undertake an acre of any public grounds seed or market oyster repletion activity.

[11] Shelling rates for firm and soft bottoms were obtained through personal interview with VMRC repletion officers.

VMRC contracts private individuals to carry out its repletion activities. The value of these services represents the cost or budget requirement for a particular repletion activity. These costs are reported in the VMRC Annual Reports on a total cost per river system basis. Also reported is the total amount of shell or seed placed in each river system.

The coefficient B was estimated by calculating the per bushel cost of planting fresh or dredge shell or seed by river systems. The per bushel cost of planting shell or seed was multiplied by their respective shell or seed per acre planting rates. The resulting product yields the estimated budget requirement of undertaking an acre of a given repletion activity. In formula form, this relationship may be expressed as follows:

$$B/acre_{r,i} = (\$/bu_{r,i}) \times (planting\ rate_{j}).$$

where: i = river system

r = type of repletion activity

j = material planted ie. shell or seed.

The elements denoted by T determine the amount of dollars generated by initiation of any public grounds market oyster or seed oyster harvest activity. The coefficient T is a function of the quantity of seed or market oysters harvested on public grounds and the per bushel price of the seed or market oyster. The tax revenues come directly from the public rocks oyster repletion tax which is levied on all oysters harvested on public grounds with the amount of the tax depending on the per bushel sale price of the harvested oysters. Tax rates from seed and market oysters were obtained from Laws of Virginia (1980). The coefficient T was then estimated by multiplying the appropriate tax rate ($.50 for all market oysters and $.10 for all seed oysters) by the number of bushels of seed or market oysters produced when a given seed or market oyster production activity was initiated.

The matrix coefficients denoted by SR and SRL indicate bushel per acre seed planting rates by public-market oyster repletion and private market oyster production activities respectively. Seed planting rates for public grounds market oyster repletion activities were determined through personal interview with VMRC repletion officers. Seed planting rates for private grounds market oyster production activity were determined by a literature search to be 750 bushels of seed per acre, Haven et. al. (1981) and Bailey and Biggs (1968).

Initiation of any public or private market oyster production activity results in a specific level of market oyster harvest which contributes toward the statisfaction of the prespecified market oyster harvest goal. These coefficients are indicated by the letter G in Figure 3.4. An examination of these coefficients shows that they all correspond to either a shell-harvest activity on public grounds or a seed-transplant-harvest activity on public or private grounds.

Seed-transplant-harvest coefficients were determined by establishing a relationship between bushels of market oysters produced per bushel of seed planted. This relationship is easily expressed as a ratio which can be estimated. According to Haven et. al. (1981) long run trends indicate that the bay-wide average for this ratio is 1:1 or one bushel of market oysters harvested for every bushel of seed planted. This ratio does, as one might expexct, vary depending on the receiving system. A lack of data made quantitative estimation of the seed-market oyster relationship impossible to determine on a river system by river system basis. This problem was overcome by asking VMRC repletion officers to rank each river system relative to the 1:1 ratio. Based on their personal experience in the field each river system was ranked according to its relative productivity. In several instances it was possible to obtain quantitative estimates of the seed-market oyster relationship for specific river systems. Using these quantitative estimates and the qualitative rankings, it was possible to estimate a seed-market oyster ratio for each river system on both public and private grounds. The actual seed-transplant-harvest production coefficients were estimated by multiplying the seed-market oyster ratios for each river system by seed planting rates for public and private grounds.

Although the 1:1 ratio claimed by Haven is confirmed by other researchers (Bailey & Biggs 1968) and is quite often cited as being the industry standard, there exist no attempts in the literature surveyed to estimate this ratio by different river systems. The problem comes down to a lack of data. This data problem relates particularly to the unavailability of bar-specific harvest data. It is known, for example, where VMRC places its shell but without bar-specific harvest data it is not possible to determine the quantity of market oysters which were produced as a result of that repletion effort.

The second market oyster producing activity is the shell-harvest activity. Ideally a similar ratio comparing bushels of market oysters harvested to every bushel of shell planted should be used. Unfortunately, as before, the data necessary to calculate this ratio is lacking and VMRC personnel were unable to rank or estimate the shell-seed-market oyster relationship for any of the river systems considered in the model. What is required is an estimator for this relationship that can serve as a suitable proxy for the shell-seed-market oyster relationship.

The purpose of shelling oyster bottoms is to ensure that oyster larvae have a suitable substrate upon which to attach. Shelling oyster bottoms, if done at the appropriate time, enhances the possibility that a successful strike of seedling oysters will result. If the assumption is made that an oyster bar repleted by shelling is at least as productive as an unrepleted "natural" bar and if it is possible to determine the per acre adult oyster population density on the unrepleted bar then, it may be assumed that the adult oyster population on the unrepleted bar provides a lower bound to mature oyster densities on the repleted bar. Fortunately, mature oyster per acre population densities are reported by Haven et. al. (1981). In the manner described above these population density estimates were used as proxies for the shell-seed-market oyster relationship.

The final coefficient to be discussed here is denoted by SP in Figure 3.4. These coefficients represent the quantity of seed produced by shelling and acre of seed bed. Once again Haven et. al. (1981) was relied upon for estimates for these coefficients. The lack of quantitative date is as much a problem here as it was for the previous two coefficients. Like the seed-transplant-harvest productivity coefficients, the shell-seed productivity coefficients involve estimating a ratio. Here the ratio is bushels of seed oysters produced per 100 bushels of shell planted. Shell-seed ratios are reported in Haven et. al. (1981) only for the Piankatank and the Great Wicomico. Both of these river systems were not productive of seed prior to intensive shelling efforts on the part of VMRC. This unusual situation allowed Haven et. al. to estimate the shell:seed ratios for these two systems by making the assumption that all seed produced in these river systems was attributable to VMRC's shelling activities.

Similar situations, however, do not exist for the James, Corrotoman or Mobjack Bay areas. Shell:seed ratios for these systems were determined by ranking all the river systems in terms of their historical production and importance as a seed area. This ranking (from most to least important) is as follows: James, Great Wicomico, Piankatank, Corrotoman and Mobjack Bay. As stated earlier, quantitative estimates of the shell:seed ratio exist for both the Great Wicomico and the Piankatank rivers (1:5 and 1:7 respectively). The James has been and remains the most important seed area in the Virginia portion of the Bay. For this reason, the shell:seed ratio for the James was set higher than either the Great Wicomico or the Piankatank at

1:4. Neither the Corrotoman nor the Mobjack Bay are currently productive of seed but could possibly be brought into seed production if VMRC chose to shell these areas heavily (Haven et. al. 1981). The seed production potential of these systems is unknown and the shell:seed ratios for these areas were, therefore, set arbitrarily low at 10:1. The actual shell-seed production coefficients for each river system was estimated by multiplying the shell:seed ratios by the number of bushels of shell planted on firm Baylor grounds.[12]

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[12] The shelling rate for firm bottoms was chosen because it reflects the minimum amount of shell required to provide sufficient quantities of exposed shell to ensur satisfactory spat settlement. The shelling rate for soft bottoms includes additional shelling to firm up the bottom. this shell becomes buried and is not available as a setting material. As a result, shell:seed coefficients would be biased upwards because of the additional non-productive shell.

Chapter V

MODEL RESULTS

5.1 INTRODUCTION

The first research objective stated in Chapter I was the development of a decision model to determine the cost-effectiveness of alternative Virginia oyster grounds management strategies. Just such a model was formulated and presented in Chapter III. The technical information required for this model was then described in Chapter IV and incorporated into the model. To accomplish the second part of this research objective, to evaluate alternative oyster grounds management policies, the model is first used to evaluate the production and repletion consequences of current conditions and policies affecting the production of market oysters in Virginia. Once this base solution is determined, a series of policy alternatives available to VMRC to increase market oyster production are introduced. The cost and repletion consequences of these policy alternatives are determined after appropriate adjustments to the model's technical information have been made.

The first set of analyses determines the maximum amount of annual sustained market oyster harvest acheivable for various repletion budget levels. The second set of scenarios determines the repletion budget requirements of a harvest goal oriented policy for various desired levels of market oyster harvest. In separate analyses the third set of scenarios evaluates the production and repletion budget consequences of permitting the dredging of reef shell in Virginia waters. Similarly, the production and repletion budget needs are determined for a policy permitting the dredging of seed in a fourth set of analyses. The final set of scenarios evaluates the consequences of simultaneously allowing the dreding of both shell and seed. Separate analyses for the market oyster production and budgetary requirements for prespecified budget levels and market oyster harvest goals respectively will also be conducted for this policy change.

The second research objective was to determine the possibility for increasing market oyster taxes to recover all repletion program expenditures. The last part of this Chapter discusses what implications the analyses conducted here have toward this end.

5.2 LEAST-COST SOLUTION UNDER CURRENT OYSTER GROUNDS MANAGEMENT POLICIES

The least-cost solution for producing market oysters under current regulations and repletion practices serves as a benchmark against which alternative regulatory or repletion strategies may be compared. Under the current situation the prespecified level of market oyster harvest was set at 1,275,000 bushels.[13] Of this total, private production was constrained to be not more than 625,000 bushels annually and total yearly production on Baylor grounds was constrained to be not less than 650,000 bushels. The public rocks repletion budget was set at $900,000. Annual availability of naturally occurring seed and market oysters were constrained to be not more than 382,863 and 610,622 bushels respectively. To reflect current repletion practices the 1983 repletion program was selected as a representative repletion season. The mix of repletion activities undertaken in that program were replicated for each of the ten years considered in the model. These minimum repletion requirements were set at the levels indicated in Table 5.1 and will hereafter be termed "non-discretionary" activities. The acreage figures

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[13] It is assumed in the model that prior to the first year of the planning horizon the only form of oyster production is harvesting natural production from the public rocks. Year one, therefore, is the first repletion year and the first year in which private production on leased bottoms may begin.

presented in Table 5.1 were calculated by dividing the total amount of shell or seed planted in each river system in 1983 by their planting rates indicated in Chapter IV.

The non-dicretionary activities are included in the model for two reasons. First, it is recognized that the mix of repletion activities determined by the model may not in any way resemble current repletion practices or patterns. The non-discretionary activities are included so that no one who had been benefiting from current repletion strategies is made worse off under any new repletion policies. The second reason for maintaining historical repletion patterns is to reflect the political context in which VMRC's decisions are made. Prior to every repletion season the decision where to place repletion effort is made with the assistance of an oyster industry advisory committee. This advisory committee consists of citizens representing different tidewater areas and different sectors of the oyster industry. It should come as no surprise that a great deal of lobbying goes on to ensure that VMRC places at least some shell or seed in each representatives oyster district.

Due to the lag in time between the initiation of an oyster production activity and the actual harvest of market oysters, the prespecified market oyster harvest goal was set at 610,622 bushels (a level equivalent to harvesting natural

TABLE 5.1

Minimum Annual Repletion Requirements

River System	Acreage
Shell-Harvest Activities	
Upper James D*	12.47
Great Wicomico D	10.22
Mid-Rappahannock D	25.44
Mid-Rappahannock F	13.59
Mobjack Bay D	27.92
Eastern Shore D	13.19
Piankatank D	8.9
Upper Managemant Area D	15.44
Pocomoke and Tangier D	44.29
Seed-Transplant-Harvest	
Upper Rappahannock	6.23
Seed Production	
Upper James D	25.12

*Indicates shell type used, D = dredge shell
F = fresh shell.

production) for the first three years of the planning period. The harvest goal to be attained by the end of the fourth year and sustained over the remainder of the ten year planning horizon is as stated previously.

Based on these constraints, and the technical information contained in the model the minimum cost of meeting and sustaining the 1,275,000 bushel harvest goal over the ten year period was $29,186,075 in 1983 dollars. Table 5.2 presents the seed and market oyster production activities (hereafter referred to as discretionary activities) that are required to acheive the production goal. The activities listed in this table are activities that were selected by the model in addition to the required repletion activities listed in Table 5.1. Columns 1-10 in Table 5.2 indicate the level and year at which each discretionary activity is initiated. A review of Table 5.2 shows that public grounds discretionary activities enter the model solution at only 3.73 acres of the seed-transplant-harvest repletion activity in the Upper Rappahannock. The implication of this result is that at the specified harvest goal, current repletion program practices are sufficient to maintain total State market oyster harvest at, or near, current levels. On leased bottoms, the most cost-effective activity is the production of market oysters in the Great Wicomico. The level of this activity is constrained by the private grounds market oyster production constraint. Availability of leased bottoms in the Great Wicomico is limited, and in years in which bottoms availability becomes binding private grounds production shifts to the Upper Rappahannock, Upper York or the Piankatank rivers.

Also included in Table 5.2 is a detailed picture of the movement of seed between river systems. From Table 5.1 it was shown that 25.12 acres of seed beds in the Upper James are shelled each year as a non-discretionary repletion activity. Recall that in the development of the model the assumption was made that any seed or market oysters produced by VMRC or private planters would be harvested. In the case of non-discretionary seed production, however, this assumption is removed. The purpose of non-discretionary seed production is to enhance naturally available seed stocks and is, therefore, conducted regardless of need. The model treats seed resulting from non-discretionary seed production activities as simply an increase in the constraint on naturally available seed. Table 5.2, therefore, does include movement from both natural and VMRC induced seed production. However, because the non-discretionary seed produced in the Upper James is treated as natural production, it is not possible to determine exactly where it is transported.

Table 5.2

Timing and Level of Discretionary Activities, Base Solution

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73
Great Wicomico	L		416.67	416.67	166.67	416.67	416.67	166.67	416.67	416.67	166.67
Upper Rappahannock	L							333.33			
Upper York	L				333.33						
Piankatank	L										333.33
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4049.5	6476.8	6476.8	6476.8	6476.8	6476.8	6476.8	6476.8	6476.8	6476.8
Great Wicomico	L		312500.0	312500.0	125000.0	312500.0	312500.0	125000.0	312500.0	312500.0	125000.0
Upper Rappahannock	L							250000.0			
Upper York	L				250000.0						
Piankatank	L										250000.0

* P = Public Grounds, L = Leased Grounds

A schedule of State oyster tax collections and repletion expenditures is presented in Table 5.3. Column 1 indicates the year in which transactions occur. Column 2 indicates the expenditure level required in each year for the repletion program. The taxes collected that are legislatively approved to be applied to the repletion program are shown in column 3. Column 4 is the difference between columns 2 and 3 and represents the amount of repletion funding not paid for out of tax collections alone. This amount must come out of State general funds or from royalties paid to the state for the use of publicly owned marine resources. The final column indicates the tax rate that would be required in each year in order for the repletion program to be self-supporting[14]

[14] The tax rate shown in Table 5.3 indicates a tax rate on market oysters only. The tax rate for seed oysters is assumed to remain constant. The tax rates listed, therefore, would be lower if taxes on seed oysters were increased.

TABLE 5.3

Base Solution Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) Tax Rate* ($)
1	622496.28	305716.0	316780.0	1.02
2	629778.04	337209.0	292569.0	0.98
3	629778.04	337209.0	292560.0	0.98
4	629778.04	363148.0	266630.0	0.91
5	629778.04	356898.0	272880.0	0.92
6	629778.04	356898.0	272880.0	0.92
7	629778.04	363148.0	266630.0	0.91
8	629778.04	356898.0	272880.0	0.92
9	629778.04	356898.0	272880.0	0.92
10	629778.04	363148.0	266630.0	0.91
			average rate	0.94

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

5.3 LEAST-COST SOLUTIONS WITH MODIFIED REPLETION BUDGET LEVELS

The repletion program expenditure levels indicated in Table 5.3 are consistent with historical repletion program spending patterns. In recognition of the oyster industry's decline and the important role played by the repletion program in countering the decline, the state of Virginia increased its financial commitment to the repletion program for the 1985 repletion season. For 1985 VMRC has been authorized to spend $900,000 on repletion of the public oyster rocks. Support for this funding level will come from State general funds and from taxes and royalties collected by VMRC. The State has agreed to contribute a maximum of $350,000 toward the $900,000 spending authorization. The difference must, therefore, be made up by oyster tax collections or royalty fees.

In order to determine what market oyster production levels might be acheived under increased funding levels, subject to maintaining the non-discretionary repletion activities indicated in Table 5.1, the original restrictions on the repletion budget were increased and the harvest goal was increased incrementally until the new repletion funding level became binding. For fiscal year 1985 VMRC's repletion budget will be $900,000. It is possible that in subsequent years this funding level may be increased. Three funding levels are evaluated: $900,000, $1,012,500 and $1,125,000. Discussion of the first funding level will be discussed here while a treatment of the latter two levels can be found in Appendix B.

For each funding level, two solutions were determined. The first solution varies only the harvest goal at a given budget level. The second solution allows production on private grounds to increase by an amount equivalent to 50% of the change in the total market oyster harvest increase acheived in the first solution. In the first solution of this scenario any increase in market oyster production must come entirely from the public grounds, meaning that the use of any additional ORP funds would go entirely toward public grounds repletion. Increasing private grounds market oyster harvest in the second solution is equivalent to allowing VMRC to allocate some portion of additional ORP funding to seed production activies that benefit private planters in addition to public grounds repletion. All other constraints for both solutions are left unchanged.

5.3.1 Solution 1: Budget = $900,000, Private Harvest ≤ 625,000

Annual sustained market oyster harvest on public and private grounds with an average annual repletion budget of $900,000 is 1,468,825 bushels. Total market oyster production over the ten year period is 12,113,641 bushels at a present value cost of $34,024,932. Note that the increased harvest of 193,825 bushels comes entirely from the public grounds. Annual budgetary outlays required to meet this goal are listed in Table 5.4.

An inspection of column 2 of this table shows that years 2-9 require funding in excess of $900,000. Year 1, however, requires lower funding making an excess of funds available for future repletion years. Column 3 indicates the taxes collected in each year. Column 4 represents that portion of repletion expenses not paid for with oyster taxes. Column 5 indicates the remaining amount of repletion expenditures that must be paid for with royalty or permit collections after oyster tax collections and State support have been subtracted from total expenses. The final column indicates the tax rate on market oysters that would be required to just pay for all repletion program expenditures.

Table 5.5 lists the discretionary activities required to acheive the harvest goal. In this solution the only discretionary market oyster repletion activity is oyster production in the Upper Rappahannock from transplanted seed. In years 2-9 the level of this activity is 152.83 acres but in year 10 the level increases to 190.28 acres. This public grounds repletion activity increases in the final year of

TABLE 5.4

Solution 1 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) (4) - 350000 ($)	(6) Tax Rate* ($)
1	622496.0	305716.0	316780.0	---	1.02
2	920516.0	347993.0	572523.0	222523.0	1.44
3	962095.0	347993.0	614102.0	264102.0	1.51
4	920516.0	467565.0	452951.0	102951.0	1.04
5	920516.0	464595.0	455921.0	105921.0	1.04
6	962095.0	464595.0	497500.0	147500.0	1.09
7	920516.0	467565.0	452951.0	102951.0	1.04
8	920516.0	464595.0	455921.0	105921.0	1.04
9	950734.0	464595.0	486139.0	136139.0	1.08
10	900000.0	466753.0	433247.0	83247.0	1.02
				average rate	1.13

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

the planning period because the next best alternative (private grounds production in this case) requires seed production at a level that is greater than what can be produced given the limited funds available in year 9 and 10.

This solution requires production of seed in years 3, 6 and 9. Seed production is required in these years because reduced availability of private grounds in the Great Wicomico necessitates the use of lower productivity bottoms in the York and Rappahannock rivers. Using lower productivity bottoms requires higher acreage requirements and, therefore, more seed. This is the case for years 4, 7 and 10 in which seed from natural production is exhausted requiring additional production of seed in the previous years. Table 5.5 indicates that the increased seed production is transferred to leased bottoms in the Upper York river.

5.3.2 Solution 2: Budget = $900000, Private Harvest ≤ 721,912 bu

Solution 2 differs from solution 1 in that the maximum allowable production on leased grounds is increased to 721,912 bushels. The annual sustained level of market oyster harvest is 1,521,813 bushels with 799,901 and 721,912 bushels coming from public and private grounds respectively. Total market oyster harvest over the ten year period is 12,484,557 bushels at a present value cost of $35,540,082.

Table 5.5

Timing and Level of Discretionary Activities, Solution 1

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		152.83	152.83	152.83	152.83	152.83	152.83	152.83	152.83	190.28
Great Wicomico	L		372.93	372.93	254.14	372.93	372.93	254.14	372.93	372.93	254.14
Upper Rappahannock	L		58.31	58.31		58.31	58.31	177.11	58.31	58.31	
Upper York	L				216.71		39.60				173.43
Seed Production											
Acres: Upper James	P			16.97			16.97			12.33	
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4049.5	103389.8	103389.0	103389.0	103389.0	103389.0	103389.0	103389.0	103389.0	127733.0
Great Wicomico	L		279699.0	279699.0	190601.0	279699.0	279699.0	190601.0	279699.0	279699.0	190601.0
Upper Rappahannock	L		43734.0	43734.0		43734.0	43734.0	132832.0	43734.0	43734.0	
Upper York	L				132832.0						108488.0
From Upper James to:											
Bu.: Upper York	L				29699.0			29699.0			21585.0

* P = Public Grounds, L = Leased Grounds

The schedule of annual funding requirements, tax collections and required revenues required over and above State funding and tax collections is presented in Table 5.6. Discretionary public and private seed and market oyster production activities are listed in Table 5.7. Once again only the Upper Rappahannock is selected as a site for market oyster production on public grounds. Production in this river system is constant at 119 acres for years 2-9 but in year 10 the level for this activity increases to 190.28 acres. As in solution 1, the budget constraint for years 9 and 10 becomes binding causing market oyster production to shift away from private grounds to the public grounds. Seed production is also required but because more market oyster production is taking place on private grounds more seed is necessary to acheive the harvest goal. Seed production, therefore, is required in addition to non-discretionary production in each year.

5.3.3 Summary of Solutions 1-2

Table 5.8 presents a summary of private and public harvest levels and the total present value cost of producing market oysters over the ten year period for each solution. This table shows that increases in total market oyster production are made possible with a repletion budget increase.

TABLE 5.6

Solution 2 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) (4) - 350000 ($)	(6) Tax Rate* ($)
1	644281.0	305716.0	338565.0	---	1.05
2	876414.0	349549.0	526865.0	176865.0	1.36
3	1031753.0	349549.0	682204.0	332204.0	1.62
4	876414.0	455284.0	421130.0	71130.0	1.03
5	876414.0	444189.0	432225.0	82225.0	1.04
6	1031753.0	444189.0	587564.0	237564.0	1.23
7	876414.0	455284.0	421130.0	71130.0	1.03
8	876414.0	444189.0	432225.0	82225.0	1.04
9	1010143.0	444189.0	565954.0	215954.0	1.21
10	900000.0	453741.0	446259.0	96259.0	1.06
				average rate	1.17

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table 5.7

Timing and Level of Discretionary Activities, Solution 2

Activity and River			Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest												
Acres:	Upper Rappahannock	P*		119.04	119.04	119.04	119.04	119.04	119.04	119.04	119.04	190.28
	Great Wicomico	L		481.30	481.30	37.50	481.30	481.30	37.50	481.30	481.30	37.50
	Upper Rappahannock	L							423.10			
	Upper York	L				591.80			168.70			509.40
Seed Production												
Acres:	Upper James	P	8.90	8.90	72.30	8.90	8.90	72.30	8.90	8.90	63.50	
Seed Transport												
From Natural Production to:												
Bu.:	Upper Rappahannock	P	4049.5	65867.0	65867.0	65867.0	65867.0	65867.0	65867.0	65867.0	65867.0	127733.0
	Great Wicomico	L		360956.0	360956.0	28088.0	360956.0	360956.0	28088.0	360956.0	360956.0	28088.0
	Upper Rappahannock	L							317308.0			
	Upper York	L				317308.0						271002.0
From Upper James to:												
Bu.:	Upper York	L				126516.0			126516.0			111081.0
	Upper Rappahannock	P		15560.0	15560.0		15560.0	15560.0		15560.0	15560.0	

* P = Public Grounds, L = Leased Grounds

When the budget was increased 42.9% from the Base Solution to Solution 1, total market oyster production increased 15.2%. When the constraint on private grounds production was relaxed in Solution 2 total market oyster production increased 19.4% for the same budgetary increase. These results demonstrate that a tradeoff exists between private and public grounds market oyster production.

Note that the seed requirements in Solution 2 are greater than they are in Solution 1. This happens most importantly because the private grounds are more demanding of seed and in Solution 2 private grounds production is greater than it was in Solution 1. The repletion program, therefore, can have the effect of limiting private grounds production if it decides to plant less shell on public grounds seed beds. The tradeoff comes in at this point. By altering its repletion decision to increase shelling of seed beds in Solution 2, private grounds market oyster production is "allowed" to increase by 15.5%. Given that VMRC has fewer dollars in this scenario to alocate to public grounds market oyster producing activities, public grounds market oyster production does go down. The decrease in public grounds market oyster production, however, is only 5.2%. It can be seen, therefore, that it is possible to increase total market oyster production by increasing shelling for

Table 5.8

Cost and Production Level Summary for Solutions 1-2

	Annual Repletion Budget	Annual Total Harvest	Annual Public Harvest	Annual Private Harvest	Total Present Value	Tax Rate
Base Solution	629778.0	1275000.0	650000.0	625000.0	29186075.0	0.94
Solution One	900000.0	1468825.0	843825.0	625000.0	34024932.0	1.13
Solution Two	900000.0	1521813.0	799901.0	721912.0	35349082.0	1.17

seed production and making more seed available to private planters without seriously affecting VMRC's ability to make market oysters available to private watermen working the Baylor bottoms.

The mix of discretionary public and private activities did not change as production levels increased although the levels at which the activities entered the solution varied. Due to ever-increasing harvest levels each solution required progressively higher levels of seed production. The total repletion cost recovery tax rate also increases as harvest and budget levels increase. The tax rate is higher in Solution 2 than in Solution 1 because in Solution 2 the taxable quantity of market oysters goes down.

5.4 LEAST-COST SOLUTIONS WITH MODIFIED PRESPECIFIED HARVEST GOALS

The harvest goal in the base solution was 1,275,000 bushels of market oysters. In order to determine what the repletion budget requirements would be to achieve higher levels of market oyster harvest, the repletion budget in each year was unconstrained and alternative harvest goals were set. The harvest goal of the base solution was increased 50% and 100% to 1,912,500 and 2,550,000 bushels respectively. Private grounds market oyster production was also allowed to increase by the same proportions in each solution. Other than these modifications no changes from the baseline condition were made.

5.4.1 Solution 3: Harvest Goal = 1,912,500 bushels

Total market oyster harvest over the ten year period was 15,219,366 bushels at a present value cost of $47,267,108. Yearly harvest of market oysters on public and private grounds is presented in Table 5.9. The total repletion expenditures required to achieve the 1,912,500 bushel annual goal were $15,335,551. Average annual expenditures were $1,533,555. The schedule of actual outlays and tax collections is listed in Table 5.10. Column 4 of this table indicates the amount of repletion expenses not paid for out of oyster tax collections. These figures show that on average only 35% of annual repletion expenses could be recovered with oyster taxes at their current levels. Column 5 of this table presents the oyster tax rate that would be requiured to recover all repletion spending in a given year. An average annual rate of $1.69 per bushel on market oysters would be sufficient to recover all repletion costs over the ten year period.

The mix of public and private seed and market oyster production activities required to meet the harvest goal is presented in Table 5.11. Market oyster production in the

TABLE 5.9

Solution 3 Public and Private Market Oyster Harvest

Year	Public Harvest (bushels)	Private Harvest (bushels)
1	610622.0	--
2	610622.0	--
3	610622.0	--
4	975000.0	937500.0
5	1423249.0	489250.0
6	975000.0	937500.0
7	975000.0	937500.0
8	1423249.0	489250.0
9	975000.0	937500.0
10	975000.0	937500.0

TABLE 5.10

Solution 3 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) Tax Rate* ($)
1	932436.0	305716.0	626720.0	1.53
2	1412543.0	369084.0	1043459.0	2.21
3	2286576.0	369084.0	1917492.0	3.64
4	1427218.0	565702.0	861516.0	1.38
5	1412543.0	775422.0	637121.0	0.95
6	2286576.0	551298.0	1735278.0	2.28
7	1428760.0	565702.0	863056.0	1.38
8	1510965.0	775863.0	735102.0	1.02
9	1614202.0	558328.0	1055874.0	1.58
10	1023732.0	565702.0	458030.0	0.97
			average rate	1.69

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Upper Rappahannock remains the most important public grounds repletion activity. In years 3 and 5 repletion in this river system practically doubles because the cost of producing and transporting seed to alternative river systems including private grounds is prohibitive. The pattern of seed production reveals that at this harvest goal seed requirements in years 2, 5 and 7 are such that it is more cost-effective to produce seed in the Great Wicomico to be planted on private grounds in the same river system than to produce and transport seed from the James river.

5.4.2 Solution 4: Harvest Goal = 2,550,000

Total market oyster harvest over the ten year period was 19,681,866 bushels at a present value cost of $67,317,638. Annual public and private sustained market oyster harvest was 1,300,000 and 1,250,000 bushels respectively. Average annual budgetary outlays required to meet and sustain the market oyster harvest goal were $2,458,752 for a total of $24,587,521. Actual annual cash outlays and tax collections are presented in Table 5.12. Recovery of repletion expenses at current oyster tax levels is 26% of total repletion expenditures. The full repletion cost recovery tax rate is $2.38 per bushel of market oysters.

Table 5.11

Timing and Level of Discretionary Activities, Solution 3

Activity and River		1	2	3	4	5	6	7	8	9	10
		Year and Activity Level									
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		253.73	598.54	253.73	253.73	598.54	253.73	253.73	253.73	253.73
Great Wicomico	L		625.00	326.17	48.83	625.00	326.17	48.83	625.00	343.73	48.83
Upper Rappahannock	L				294.96			294.96			
Upper York	L				473.26			473.26	23.50	374.94	473.26
Piankatank	L										294.96
Seed Production											
Acres: Upper James	P	96.56	120.52	202.83	96.56	120.52	202.83	106.63	160.69	202.83	
Great Wicomico	P	29.95			29.95			20.50			
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4049.5		182198.0	168977.0		182198.0	168977.0		168977.0	168977.0
Great Wicomico	L		426823.0	244625.0	36625.0	426823.0	244625.0	36625.0	426823.0	257846.0	36625.0
Upper Rappahannock	L				221222.0			221222.0			
Piankatank	L										221222.0
From Upper James to:											
Bu.: Upper York	L				354946.0			354946.0	17628.0	281205.0	354946.0
Upper Rappahannock	P		168977.0	210904.0		168977.0	210904.0		168977.0		
From Great Wicomico to:											
Bu.: Great Wicomico	L		41927.0			41927.0			28706.0		

* P = Public Grounds, L = Leased Grounds

TABLE 5.12

Solution 4 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) Tax Rate* ($)
1	1433373.0	305716.0	1127658.0	2.35
2	2583152.0	400958.0	2182194.0	4.07
3	2757342.0	417877.0	2339465.0	4.33
4	2679030.0	775033.0	1903997.0	1.96
5	2583152.0	745672.0	1837453.0	1.91
6	2757342.0	762591.0	1994751.0	2.03
7	2679030.0	775033.0	1903997.0	1.96
8	2583152.0	745672.0	1837453.0	1.91
9	2757342.0	762591.0	1994751.0	2.03
10	1774606.0	764333.0	1010273.0	1.27
			average rate	2.38

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

The timing and level of discretionary public and private seed and market oyster production activities required to attain the harvest goal is presented in Table 5.13. Here for the first time the oyster harvest goal is high enough to require public grounds repletion in river systems other than the Upper Rappahannock. In years 4, 7 and 10 repletion is required in the Mid-Rappahannock and/or the Great Wicomico. These river systems are chosen because they are the most productive of the public grounds and the cost of transporting seed to alternative river systems is not cost-effective. As in previous solutions seed production in the Great Wicomico is required in years 1, 4 and 7 to satisfy private grounds seed requirements in years 2, 5 and 8.

5.4.3 Summary of Solutions 3 and 4

The results from these two solutions show that increasing total market oyster harvest 41.49% from 10,756,866 bushels in the Base solution to 15,335,551 bushels in Solution 4 results in a 143.79% increase in repletion funding requirements and a 61.95% increase in total present value cost. In Solution 4 an even greater increase of 82.97% in the harvest goal over the Base solution results in a 290.87% increase in repletion budget needs and a 130.65% increase in total discounted costs. These figures indicate that doubling the

Table 5.13

Timing and Level of Discretionary Activities, Solution 4

Activity and River		Year and Activity Level: 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		503.73	503.73	98.54	503.73	503.73	98.54	503.73	503.73	98.54
Mid-Rappahannock	P				540.26			540.26			376.00
Piankatank	P										165.00
Great Wicomico	L		833.33	156.59	10.07	833.33	156.59	10.07	833.33	156.59	10.07
Upper York	L			902.32	1097.68		902.32	1097.68		902.32	1097.68
Seed Production											
Acres: Upper James	P	189.42	399.34	470.43	189.42	399.34	470.43	189.42	399.34	470.43	
Great Wicomico	P	141.56			141.56			141.56			
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4049.5		309377.0	68101.0		309377.0	68101.0		309377.0	68101.0
Mid-Rappahannock	P				351167.0			351167.0			244164.0
Great Wicomico	P										107003.0
Great Wicomico	L		426823.0	117445.0	7554.0	426823.0	117445.0	7544.0	426823.0	117445.0	7544.0
From Upper James to:											
Bu.: Upper York	L			676739.0	823260.0		676739.0	823260.0		676739.0	823260.0
Upper Rappahannock	P		331476.0	22099.0		331476.0	22099.0		331476.0	22099.0	
From Great Wicomico to:											
Bu.: Great Wicomico	L		198177.0			198177.0			198177.0		

* P = Public Grounds, L = Leased Grounds

percentage increase in the harvest goal from the base solution to Solutions 3 and 4 results in approximately doubling the repletion funding requirements and more than doubles the percentage increase in total present value cost of producing the market oyster harvest goal.

5.5 LEAST COST SOLUTIONS WITHOUT NON-DISCRETIONARY REPLETION REQUIREMENTS

Each of the previous solutions were determined with a specific level of non-discretionary repletion required for each scenario. It was mentioned earlier and is restated here that these non-discretionary repletion requirements represent political constraints requiring that VMRC place some repletion effort in river systems that have historically received seed or shell. The purpose of this scenario is to determine the production and repletion cost consequences of maintaining the non-discretionary requirements.

Two analyses will be conducted. First, the analysis conducted for Solution 1 will be duplicated with the sole modification that the non-discretionary activities will not be required. This analysis will determine the acheivable level of market oyster production when the repletion budget is set at $900,000 per year and the mix and level of repletion activities are determined entirely by the model. The second analysis duplicates the analysis conducted in Solution 3. This solution will determine the repletion expenditures required to produce the 1,912,500 bushel harvest goal when the non-discretionary repletion requirements are dropped.

5.5.1 Solution 5: Budget = $900,000

When the non-discretionary repletion constraints are dropped and the repletion budget is set at $900,000 each year, the annual sustained level of market oyster harvest is 1,713,344 bushels. Of this total, 1,088,344 bushels came from public grounds and 625,000 bushels were harvested on private grounds. This production level represents a 16.65% increase over harvest levels determined in Solution 1 and an increase of 34.38% increase over the Base solution. The total present value cost over the ten year period of this market oyster production level is $37,312,748 and is 9.67% greater than in Solution 1. Note, however, that the increase in the acheivable production is nearly twice as great as the increase in total cost. The schedule of repletion outlays and tax collections is presented in Table 5.14.

An inspection of this table shows that the production level acheived in this solution is made possible by borrowing heavily from the first years repletion budget. An examination of Table 5.15 reveals why this is the case. The

TABLE 5.14

Solution 5 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) (4) - 350000 ($)	(6) Tax Rate* ($)
1	235899.0	305311.0	-69412.0	---	0.39
2	952479.0	360447.0	592032.0	242032.0	1.47
3	1039979.0	360477.0	679782.0	329782.0	1.61
4	952479.0	605556.0	346923.0	---	0.82
5	952479.0	599308.0	353171.0	3171.0	0.82
6	1039979.0	599308.0	440671.0	90671.0	0.90
7	952479.0	605556.0	346923.0	---	0.82
8	952479.0	599308.0	353171.0	3171.0	0.82
9	1021748.0	599308.0	422440.0	72440.0	0.89
10	900000.0	604226.0	295774.0	---	0.77
				average rate	0.93

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

only repletion activity conducted in year one of the planning period is the shelling of James River seed beds for the production of seed. Another observation from Table 5.14 is that the average full repletion cost recovery tax rate of $0.93 is less than that for the Base solution. Recall that the repletion budget in the Base solution was approximately $630,000 per year and the tax rate required to recover that expense was $0.94. This lower tax rate can be attributed to the substantially greater taxable base of market oyster harvest determined in this solution even though the budget to be recovered is nearly 30% greater.

The activities presented in Table 5.15 differ little from those determined in previous solutions. Recall, however, that the non-discretionary repletion activities are no longer required meaning that, with the exception of natural production, the only river system in which public grounds production occurs is the Upper Rappahannock. With the non-discretionary activities no longer required the repletion program determined in this solution focuses primarily on the transplanting of seed. The only shelling activity is the shelling of James river seed beds to support the transplanting program and to make seed available to private planters. The mix of private grounds market oyster production activities required to acheive the harvest goal is concentrated in

Table 5.15

Timing and Level of Discretionary Activities, Solution 5

Activity and River		1	2	3	4	5	6	7	8	9	10
		Year and Activity Level									
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		367.48	367.48	367.48	367.48	367.48	367.48	367.48	367.48	389.74
Upper Rappahannock	P**										37.84
Great Wicomico	L		416.67	416.67	166.67	416.67	416.67	166.67	416.67	416.67	166.67
Upper Rappahannock	L				25.34			25.34			
Upper York	L				308.00			308.00			263.88
Seed Production											
Acres: Upper James	P	96.28	96.28	132.00	96.28	96.28	132.00	96.28	96.28	124.56	
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P		70363.0	70363.0	238861.0	70363.0	70363.0	238861.0	70363.0	70363.0	257863.0
Great Wicomico	L		312500.0	312500.0	125000.0	312500.0	312500.0	125000.0	312500.0	312500.0	125000.0
Upper Rappahannock	L				19002.0			19002.0			
From Upper James to:											
Bu.: Upper Rappahannock	P		168498.0	168498.0		168498.0	168498.0		168498.0	168498.0	20065.0
Upper York	L				230998.0			230998.0			197910.0

* P = Public Grounds, L = Leased Grounds
** Indicates soft bottom type.

the Great Wicomico. Leased bottoms production also takes place in the Upper Rappahannock and the Upper York in years in which availability of leased bottoms in the Great Wicomico is exhausted.

5.5.2 Solution 6: Harvest Goal = 1,912,500 Bushels

When the non-discretionary activities are eliminated and the harvest goal is set at 1,912,500 bushels per year total market oyster harvest over the ten year period is 15,219,366 bushels at a present value cost $43,269,129. Yearly harvest of market oysters on public and private grounds is presented in Table 5.16. Total repletion expenditures required to acheive and sustain the 1,912,500 bushel harvest goal over the ten year planning period is $10,240,531 when non-discretionary requirements are dropped. The actual schedule of repletion expenditures and tax collections is presented in Table 5.17. The figures in this table indicate that at current tax levels 61.0% of total repletion expenditures could be recovered through tax collections.

Repletion expenditures in years 1 and 10 are lower than in all other years. In year 1 the only repletion activity required is the shelling of James river seed beds. No market oyster production activities are initiated in this

TABLE 5.16

Solution 6 Public and Private Market Oyster Harvest

Year	Public Harvest (bushels)	Private Harvest (bushels)
1	610622.0	--
2	610622.0	--
3	610622.0	--
4	975000.0	937500.0
5	1343976.0	568524.0
6	975000.0	937500.0
7	975000.0	937500.0
8	1343976.0	568524.0
9	975000.0	937500.0
10	975000.0	937500.0

TABLE 5.17

Solution 6 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) Tax Rate* ($)
1	405367.0	305311.0	100056.0	0.66
2	960881.0	370405.0	590476.0	1.47
3	1656485.0	373191.0	1283294.0	2.60
4	951934.0	565533.0	386401.0	0.90
5	960881.0	737082.0	223799.0	0.67
6	1656485.0	555380.0	1101105.0	1.63
7	951934.0	565533.0	386401.0	0.90
8	1046976.0	737082.0	309894.0	0.73
9	1103021.0	561530.0	541491.0	1.06
10	546567.0	565533.0	-18966.0	0.48
			average rate	1.11

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

year becasuse the 1,912,500 bushel harvest goal need not be met until the fourth year of the planning period. Since seed-transplant-harvest activities have a three year production cycle no production activities are initiated until the year 2. Conversely, in year 10 repletion expenditures are low because no seed production activities are required. Seed production is no longer necessary after year 9 because the planning period stops after ten years. Any shelling for seed in year 10 would result in seed produced beyond the planning time considered by the model and is, therefore, not needed. The timing and level of seed and market oyster production activities required to produce the harvest goal is presented in Table 5.18.

As in Solution 5 the focus of all public grounds market oyster production is the Upper Rappahannock. Similarly, the Great Wicomico remains the most important source of private grounds production with the Upper Rappahannock, Upper York and the Pinakatank making up the difference in years when leased bottoms in the Great Wicomico are exhausted. Like Solution 3, the majority of seed is produced in the Upper James but in years 1, 4 and 7 bottoms in the Great Wicomico are also shelled to produce seed to be used by private planters in the same river system.

Table 5.18

Timing and Level of Discretionary Activities, Solution 6

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		280.29	564.12	280.92	280.92	564.12	280.92	280.92	280.92	389.74
Great Wicomico	L		625.00	267.57	107.43	625.00	267.57	107.43	625.00	267.57	107.43
Upper Rappahannock	L				160.13			160.13			
Upper York	L			148.60	530.00		148.60	530.00		476.58	530.00
Piankatank	L										160.13
Seed Production											
Acres: Upper James	P	104.11	169.11	227.12	104.11	169.11	227.12	104.11	204.25	227.12	
Great Wicomico	P	61.35			61.35			61.35			
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P			182189.0	182189.0		182189.0	182189.0		182189.0	182189.0
Great Wicomico	L		382863.0	200674.0	80576.0	382863.0	200674.0	80576.0	382863.0	200674.0	80576.0
Upper Rappahannock	L				120098.0			120098.0			
Piankatank	L										120098.0
From Upper James to:											
Bu.: Upper Rappahannock	P		182189.0	184488.0		182189.0	184488.0		182189.0		
Upper York	L			111451.0	397467.0		111451.0	397467.0		357435.0	397467.0
From Great Wicomico to:											
Great Wicomico	L		85887.0			85887.0			85887.0		

* P = Public Grounds, L = Leased Grounds

5.5.3 Summary of Solutions 5 and 6

When the non-discretionary repletion constraints were removed in Solution 5 total market oyster production over the ten year period was 13,825,274 bushels for an annual repletion budget of $900,000. The total present value cost of acheiving this production level was determined to be $37,312,748. In Solution 6 total market oyster harvest increased 10.08% over Solution 5 to 15,219,366 bushels. Total repletion expenditures and the total present value cost required to produce the 1,912,500 annual harvest goal in Solution 6 increased 13.78% to $10,240,531 and 15.96% to $43,269,129 respectively over Solution 5.

5.6 LEAST-COST SOLUTIONS WITH MODIFIED POLICY: PERMITTING DREDGING OF SHELL IN VIRGINIA

From 1963-1968 VMRC planted 13,007,495 bushels of reef shells that were mined in Virginia. In 1968 the mining agreement between the State and Radcliff Materials (the mining company) was terminated and no new agreement was reached with another mining company. Today VMRC continues to plant large quantities of reef shell but, since reef shell is unavailable in Virginia it must be imported from Maryland. The cost of purchasing and transporting shell from Maryland to the various river systems shelled by VMRC ranges from $0.408/bu. planted in Pocomoke and Tangier Sounds to $0.532/bu. planted in the Upper James seed beds.

In order to determine the cost and harvest consequences of permitting the dredging of shell in Virginia waters it was necessary to reestimate the coefficients for the budgetary constraint and the cost coefficient in the objective function for each shell-harvest activity that used reef shell. It was not possible to determine where in Virginia deposits of reef shell might be found. It was assumed, therefore, that reef shell deposits were evenly distributed and of uniform volume throughout the Bay. Under this assumption the cost of mining and transporting shell from any mining site to any receiving river system is the same for all river systems. Only one per bushel cost coefficient, therefore, need be estimated.

The average per bushel cost to Maryland planters for reef shell was chosen as a proxy for the cost of mining and transporting reef shell in Virginia. This cost was estimated to be $0.38/bu.. After appropriately adjusting all affected coefficients three solutions were determined. The first solution reevaluates Solution 1 with the adjusted coefficients, a $900,000 annual repletion budget and private planters held to 625,000 bushels of annual market oyster production. The second and third solutions reevaluate the cost and budgetary requirements of producing 1,912,500 and 2,550,000 bushels of market oysters annually.

5.6.1 Solution 7: Budget = $900,000

Annual sustained harvest of market oysters is 889,438 and 625,000 bushels on public and private grounds respectively. Total market oyster production over the ten year period is 12,432,932 bushels at a present value cost of $34,669,513. The schedule of repletion fund and tax collections is presented in Table 5.19.

The timing and level of discretionary activities required to achieve the harvest goal is presented in Table 5.20. This table shows that there is very little difference between the mix of discretionary activities required to achieve the harvest goal in this solution and other previous solutions. The levels of the activities, however, are higher than they were in Solution 1. This occurs because the cost of shelling Baylor bottoms with reef shell is lower than it was in Solution 1. With fewer repletion dollars being used to satisfy non-discretionary repletion requirements, discretionary activities can be increased thereby increasing the level of market oyster harvest that can be achieved for the same amount of dollar expenditures.

TABLE 5.19

Solution 7 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) (4) - 350000 ($)	(6) Tax Rate* ($)
1	546330.0	305716.0	240614.0	---	0.89
2	918311.0	349181.0	569130.0	219130.0	1.43
3	994730.0	349576.0	645154.0	295154.0	1.56
4	912770.0	494468.0	418302.0	68302.0	0.97
5	918311.0	488614.0	429697.0	79697.0	0.98
6	994730.0	489010.0	505720.0	155720.0	1.07
7	912770.0	494468.0	418302.0	68302.0	0.97
8	918311.0	488614.0	429697.0	79697.0	0.98
9	983736.0	489010.0	494726.0	144726.0	1.06
10	900000.0	493683.0	406317.0	56317.0	0.96
				average rate	1.09

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table 5.20

Timing and Level of Discretionary Activities, Solution 7

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		187.92	187.92	187.92	187.92	187.92	187.92	187.92	187.92	224.15
Great Wicomico	L		416.67	400.84	182.50	416.67	400.84	182.50	416.67	400.84	182.50
Upper York	L			21.11	93.89		21.11	93.89		21.11	83.42
Upper Rappahannock	L				218.34			218.34			
Piankatank	L										186.39
Seed Production											
Acres: Upper James	P	6.78	9.05	40.24	6.78	9.05	40.24	6.78	9.05	35.75	
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4050.0	114323.0	126196.0	126196.0	114323.0	126196.0	126196.0	114323.0	126196.0	149753.0
Great Wicomico	L		312500.0	300627.0	136873.0	312500.0	300627.0	136873.0	312500.0	300627.0	136873.0
Upper Rappahannock	L				163754.0			163754.0			
Piankatank	L										140197.0
From Upper James to:											
Bu.: Upper York	L			15831.0	70415.0		15831.0	70415.0		15831.0	62563.0
Upper Rappahannock	P		11873.0			11873.0			11873.0		

* P = Public Grounds, L = Leased Grounds

5.6.2 Solution 8: Harvest Goal = 1,912,500.0 Bushels

The total present value cost over the ten year period of meeting a 1,912,500 bushel annual harvest goal was $46,536,040. Total harvest over the ten year period is 15,219,366 bushels. The pattern of annual public and private market oyster harvest in this solution is identical to that determined in Solution 3 and listed in Table 5.9. The total repletion funding required to produce the annual harvest goal was $14,434,406 and averaged $1,443,441. Actual yearly outlays and tax collections are presented in Table 5.21.

The schedule of public and private discretionary activities is identical to the activities determined in Solution 3 and can be found in Table 5.11. This result arises because the only activities using reef shell are shell-harvest activities. Even though, in this solution, these activities are lower cost than in previous solutions they remain low productivity activities. The schedule of discretionary activities, therefore, is unaffected by a cost change in shell-harvest activities of the magnitude considered in this solution.

TABLE 5.21

Solution 8 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) Tax Rate* ($)
1	839650.0	305716.0	533934.0	1.37
2	1319756.0	369084.0	950672.0	2.06
3	2193789.0	369084.0	1824705.0	3.49
4	1334430.0	565702.0	768728.0	1.29
5	1319756.0	775422.0	544334.0	0.88
6	2193789.0	551298.0	1642491.0	2.18
7	1335973.0	565702.0	770271.0	1.29
8	1418178.0	775422.0	642756.0	0.95
9	1521414.0	558328.0	963086.0	1.49
10	957671.0	565702.0	391969.0	0.90
			average rate	1.59

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

5.6.3 Summary of Solutions 7 and 8

When reef shell can be obtained from sources in Virginia total market oyster harvest determined in Solution 7 is 14,307,932 bushels for an annual repletion budget of $900,000 over the ten year period. Total present value cost of this harvest level is $34,669,513. The 15,219,366 bushel total harvest of market oysters determined in Solution 8 represents an increase in harvest of 6.37%. This increase in harvest is made possible with a 60.38% increase in the level of repletion program expenditures to a total of $14,434,406 and an increase in total production and harvesting cost to $46,536,040.

5.7 LEAST COST SOLUTIONS WITH MODIFIED POLICY: PERMITTING THE DREDGING OF SEED

In 1983 VMRC paid $3.00 per bushel to purchase, transport and plant seed in the Upper Rappahannock. The price of seed in the same year was $2.38/bu. representing 76% of the cost of transplanting seed to the public. The cost of seed is also a large portion of market oyster production costs on private grounds. A policy that would reduce the cost of this essential seed oyster input is to permit the more efficient harvest technology of dredging for seed. To determine the cost consequences of such a policy it is necessary to make appropriate adjustments to the budget constraint and objective function coefficients of affected public and private market oyster production activities.

The Potomac River Fisheries Commission (PRFC) contracts watermen to harvest, transport and plant seed oysters as part of its repletion program. The contracted seed is harvested with an oyster dredge and the total cost of harvesting, transporting and planting seed in 1983 was 50¢ per bushel. The distances over which seed is transported in Virginia are greater than that experienced by PRFC. The 50¢ per bushel cost, therefore, is used as a proxy for the price of seed under a seed dredging policy and the appropriate seed transportation costs remain unchanged from previous solutions. As before, three solutions are determined for this policy change. The first solution reevaluates solution 1 with the adjusted coefficients. The second and third solutions evaluate the annual level of repletion expenditures required to achieve a harvest goal of 1,912,500 and 2,550,000 bushels respectively.

5.7.1 Solution 9: Budget = $900,000

The annual sustained level of market oyster harvest under a seed dredging policy and a repletion budget of $900,000 is 1,656,542 bushels of market oysters. Of this total, yearly harvest on public and private grounds is

1,031,542 and 625,000 bushels respectively. Total public plus private harvest over the ten year period is 13,427,660 bushels at a present value cost of $32,937,258. The schedule of repletion funding and tax collections required to achieve the harvest goal is presented in Table 5.22. Column 5 of this table shows that in six of the ten years tax collections and State funding allocations are more than sufficient to cover all repletion costs without any royalty or permit revenues.

The level and timing of discretionary activities required to meet the harvest goal is presented in Table 5.23. Once again the mix of discretionary activities differs little from previous solutions. The Upper Rappahannock is the most important public rocks oyster production area and the Great Wicomico is the most important area for private oyster production. The pattern of timing and level of the various activities holds until the final year of the planning period. In year ten the repletion budget becomes binding forcing more production to take place on public rocks than would otherwise occur. This result arises because even though oyster production on leased bottoms is more cost-effective than on public grounds, the leased bottoms require more seed. The levels of private grounds market oyster production activities ultimately depend on the

TABLE 5.22

Solution 9 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) (4) - 350000 ($)	(6) Tax Rate* ($)
1	729968.0	305716.0	424252.0	74252.0	1.19
2	906743.0	356286.0	550457.0	200457.0	1.40
3	976853.0	356286.0	619946.0	269946.0	1.52
4	898049.0	572400.0	325649.0	---	0.82
5	906743.0	566771.0	339972.0	---	0.83
6	976853.0	567392.0	409461.0	59461.0	0.90
7	898049.0	572400.0	325649.0	---	0.82
8	906743.0	566771.0	339972.0	---	0.83
9	900000.0	567392.0	332608.0	---	0.82
10	900000.0	566910.0	333090.0	---	0.82
				average rate	1.00

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

availability of VMRC induced seed production which is in turn determined by budgetary constraints.

The pattern of activities is also broken in year ten because the availability of firm Baylor bottoms in the Upper Rappahannock is exhausted. The 39.04 acres of seed-transplant-harvest in the Upper Rappahannock in year ten represents oyster production on soft Baylor bottoms. Ordinarily the exhaustion of firm bottoms in a particular river system would favor the use of firm bottoms in an alternative river system. In this case, however, even though it is more costly to incur the additional expense of having to shell the bottom prior to planting seed the Upper Rappahannock is the most productive river system of the public waters and, therefore, requires lower levels of seed production.

5.7.2 Solution 10: Harvest Goal = 1,912,500 Bushels

Total market oyster production over the ten year period is 9,600,441 bushels at a present value cost of $38,593,202. The schedule of annual harvest on public and private grounds is listed in Table 5.24. Total public grounds repletion expenditures required to achieve and maintain the harvest goal were $10,579,568 and averaged $1,057,957 each year. Actual yearly repletion outlays are presented in Table 5.25. The figures in this table show that because of the lower

Table 5.23

Timing and Level of Discretionary Activities, Solution 9

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		297.22	297.22	297.22	297.22	297.22	297.22	297.22	297.22	511.55
Upper Rappahannock	P**										39.04
Upper Rappahannock	L				114.59			114.59			
Great Wicomico	L		416.67	391.82	191.51	416.67	391.82	191.51	416.67	391.82	191.51
Upper York	L			33.12	185.62		33.12	185.62		33.12	7.4
Seed Production											
Acres: Upper James	P	47.39	50.93	79.55	47.39	50.93	79.55	47.39	50.93	48.18	
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4050.0	197248.0	197248.0	197248.0	197248.0	197248.0	197248.0	197248.0	197248.0	361934.0
Great Wicomico	L		229575.0	229575.0	143632.0	229575.0	229575.0	143632.0	229575.0	229575.0	64889.0
Upper Rappahannock	L				85943.0			85943.0			
From Upper James to:											
Bu.: Upper York	L			24843.0	139214.0		24843.0	139214.0		24843.0	5576.0
Great Wicomico	L		82925.0	64293.0		82925.0	64293.0		82925.0	64923.0	78743.0

* P = Public Grounds, L = Leased Grounds

cost of harvesting seed, average annual oyster tax collections recover 51% of yearly repletion expenditures as compared to 35% in Solution 3. Similarly the full repletion cost recovery tax rate in this solution is $1.22 as compared to $1.69 in Solution 3.

The mix and level of discretionary activities required to meet the harvest goal are presented in Table 5.26. An examination of this table reveals that, like previous solutions, a three year cycle emerges in years 2 to 4 that repeats itself in years 5 to 7. The cycle, however, is broken in year eight. In years 2 and 5 the most cost-effective use of naturally available seed is to plant it on public rocks in the Upper Rappahannock. In year eight, however, it becomes more cost-effective to use the seed for planting on leased bottoms in the Great Wicomico, reduce the acreage planted with seed on public grounds in the Rappahannock and make up this lost production by producing seed in the Upper James to be planted to private grounds in the Upper York.

The switch from public grounds production in the Upper Rappahannock to private grounds production in the Upper York because of the differential in discount rates used for public and private activities. In year two the per bushel cost of producing market oysters is $2.25 and $2.21 on public and private grounds in the Upper Rappahannock and

TABLE 5.24

Solution 10 Public and Private Market Oyster Harvest

Year	Public Harvest (bushels)	Private Harvest (bushels)
1	610622.0	--
2	610622.0	--
3	610622.0	--
4	1423249.0	489250.0
5	975000.0	937500.0
6	975000.0	937500.0
7	1423249.0	489250.0
8	975000.0	937500.0
9	975000.0	937500.0
10	1022077.0	890422.0

TABLE 5.25

Solution 10 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) Tax Rate* ($)
1	985156.0	305716.0	678440.0	1.61
2	1346033.0	369428.0	976605.0	2.10
3	1151045.0	376114.0	774931.0	1.77
4	1127643.0	782453.0	345910.0	0.74
5	1346033.0	551642.0	794391.0	1.31
6	1151045.0	558328.0	592717.0	1.10
7	1151045.0	782453.0	368592.0	0.76
8	1171523.0	558328.0	613195.0	1.13
9	1151045.0	558328.0	592717.0	1.11
10	663811.0	581867.0	81944.0	0.58
			average rate	1.22

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table 5.26

Timing and Level of Discretionary Activities, Solution 10

Activity and River			Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest												
Acres:	Upper Rappahannock	P*		598.54	253.73	253.73	598.54	253.73	253.73	289.95	253.73	253.73
	Great Wicomico	L		312.41	343.79	343.79	312.41	343.79	343.79	312.41	343.79	343.79
	Upper York	L		18.34	374.94	374.94	18.34	374.94	374.94	18.34	374.94	374.94
Seed Production												
Acres:	Upper James	P	7.86	160.69	160.69	7.86	160.69	160.69	160.69	160.69	160.69	
	Great Wicomico	P	143.28			143.28						
Seed Transport												
From Natural Production to:												
Bu.:	Upper Rappahannock	P	4050.0	393101.0	168977.0	168977.0	393101.0	168977.0	168977.0	192545.0	168977.0	168977.0
	Great Wicomico	L		33722.0	257846.0	257846.0	33722.0	257846.0	257846.0	234308.0	257846.0	257846.0
From Upper James to:												
Bu.:	Upper York	L		13757.0	281205.0	281205.0	13757.0	281205.0	281205.0	281205.0	281205.0	281205.0
From Great Wicomico to:												
Bu.:	Great Wicomico	L		200586.0			200586.0					

* P = Public Grounds, L = Leased Grounds

Upper York respectively. By year eight the discounted cost of producing market oysters in the same river systems is $1.73 and $1.56 respectively. The cycle, therefore, is not broken because of any change in the underlying relationships contained in the model. Rather, the production cycle is broken because on a present value basis, private grounds production in the York river becomes less costly relative to alternative oyster production activities.

5.7.3 Summary of Solutions 9 and 10

When the lower cost harvest technology of dredging for seed is allowed the total market oyster harvest over the ten year period is 13,427,660 bushels in Solution 9. This market oyster goal was achieved with a total repletion budget of $9,000,000 and at a present value cost of $32,937,258. In Solution 10 total market oyster harvest increased 13.34% over Solution 9 and required $10,579,568 in repletion funding, an increase of 17.55%. The total present value cost of harvesting market oysters in Solution 10 was 17.17% greater than in Solution 9 at $38,593,202.

5.8 LEAST COST SOLUTIONS WITH MODIFIED POLICY: PERMITTING THE DREDGING OF SEED AND SHELL

This set of solutions examines the cost consequences of permitting the dredging of seed and shell in Virginia waters. In a similar manner to previous analyses, three solutions were determined. The first solution reevaluates solution one with the combined technical information changes incorporated into solutions seven and ten. The second solution uses the same technical information to determine the cost consequences and repletion expenditures required to produce an annual harvest goal of 1,912,500 bushels. Similarly the third solution evaluates the cost and repletion expenditure requirements associated with an annual harvest goal of 2,550,000 bushels of market oyster production. A discussion of the first two solutions is found in this section while the results from the third solution are presented in Appendix B.

5.8.1 Solution 11: Budget = 900,000

Total market oyster production over the ten year period is 13,997,425 bushels at a present value cost of $34,072,453. Annual sustained production on public and private grounds is 1,112,937 and 625,000 bushels of market oysters respectively. Annual repletion expenditures required to meet and sustain the harvest goal are presented in Table 5.27. Column five of this table shows that in all but the first three years of the planning period oyster tax collections plus State contributions to the repletion program are sufficient to cover all repletion costs incurred by VMRC.

Table 5.28 presents the schedule of timing and level of all private and public discretionary activities. As in solution ten discretionary oyster production on public grounds takes place exclusively in the Upper Rappahannock and private grounds production takes place only in the Great Wicomico and the Upper York. A cyclical pattern in the level of each activity develops and continues until year ten. In this year the budget constraint becomes binding making the cycle maintaining seed production impossible to achieve.

5.8.2 Solution 12: Harvest Goal = 1,912,500 Bushels

Total market oyster production over the ten year period is 15,219,366 at a present value cost of $37,862,133. Annual market oyster production on public and private grounds varies over the ten year period but duplicates the pattern of production determined in solution 10 and indicated in Table 5.24. The total repletion cost of meeting the harvest goal is $10,342,231 and averages $1,034,223.

TABLE 5.27

Solution 11 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) (4) - 350000 ($)	(6) Tax Rate* ($)
1	694154.0	305716.0	388438.0	38438.0	1.14
2	927453.0	360356.0	567097.0	217097.0	1.43
3	955335.0	362485.0	592850.0	242850.0	1.47
4	897644.0	615659.0	281985.0	---	0.75
5	927453.0	611538.0	315915.0	---	0.78
6	955335.0	613667.0	341668.0	---	0.81
7	897644.0	615659.0	281985.0	---	0.75
8	927454.0	611538.0	315915.0	---	0.78
9	917527.0	613667.0	303860.0	---	0.77
10	900000.0	612958.0	287042.0	---	0.76
				average rate	0.94

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table 5.28

Timing and Level of Discretionary Activities, Solution 11

		Year and Activity Level									
		1	2	3	4	5	6	7	8	9	10
Activity and River											
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		359.84	359.84	359.84	359.84	359.84	359.84	359.84	359.84	386.33
Upper Rappahannock	P**										98.15
Great Wicomico	L		416.67	331.50	251.84	416.67	331.50	251.84	416.67	331.50	251.84
Upper York	L			113.56	219.77		113.56	219.77		113.56	75.74
Seed Production											
Acres: Upper James	P	70.64	82.81	94.19	70.64	82.81	94.19	70.64	82.81	78.76	
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4050.0	237945.0	237945.0	237945.0	237945.0	237945.0	237945.0	237945.0	237945.0	318962.0
Great Wicomico	L		188878.0	188878.0	188878.0	188878.0	188878.0	188878.0	188878.0	188878.0	107861.0
From Upper James to:											
Bu.: Upper York	L			85170.0	164830.0		85170.0	164830.0		85170.0	56808.0
Great Wicomico	L		123622.0	59745.0		123622.0	59745.0		123622.0	64923.0	81016.0

* P = Public Grounds, L = Leased Grounds

The schedule of actual outlays and tax collections is presented in Table 5.29.

The level and timing of all public and private production activities replicates the set of activities determined in Solution 10. The only difference between the technical information incorporated into this solution and Solution 10 is that VMRC now has the option to purchase less costly shell mined in Virginia for use in its repletion program. The availability of this cheaper source of shell does not, however, affect the choice of discretionary activities. The cost savings associated with Virginia reef shell are not great enough to make any reef shell using activity more cost-effective than any of the discretionary activities determined in Solution 10. The activities in this solution, therefore, are the same as those determined previously.

5.8.3 Summary of Solutions 11 and 12

When the policy to permit the dredging of shell and seed was introduced in Solution 11 total market oyster production over the planning horizon was 13,997,425 bushels for an annual repletion budget of $900,000. Total present value cost of producing this harvest goal was determined to be $34,072,453. The total market oyster harvest determined in solution 12 was 15,219,366 bushels representing an increase

TABLE 5.29

Solution 12 Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required ($)	(3) Taxes Collected ($)	(4) (2) - (3) ($)	(5) Tax Rate* ($)
1	891369.0	305716.0	585653.0	1.46
2	1253246.0	369428.0	883818.0	1.95
3	1058257.0	376114.0	682143.0	1.62
4	1034855.0	782453.0	252402.0	0.68
5	1253246.0	551642.0	701604.0	1.22
6	1058257.0	558328.0	499929.0	1.01
7	1058257.0	782453.0	275804.0	0.69
8	1078736.0	558328.0	520408.0	1.03
9	1058257.0	558328.0	499929.0	1.01
10	597751.0	581867.0	15884.0	0.52
			average rate	1.12

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

of 8.73% over Solution 11. The required repletion budget to produce the market oyster harvest goal increased 14.91% as compared to Solution 11 and was found to be $10,342,231. Total present value cost of producing and harvesting the harvest goal was $37,862,133, an increase of 11.11%.

5.9 SUMMARY OF SOLUTIONS 1-12

The scenarios evaluated in solutions 1-12 will be summarized in the following way. Solutions 1, 2, 5, 7, 9 and 11 all introduce different policy changes but keep repletion funding at the same level. Each of these solutions will be compared in Table 5.30 on the basis of acheivable sustained market oyster harvest, total present value cost of acheiving the harvest goal and the full repletion cost recovery tax rate for each solution. For the same policy changes solutions 3, 6, 8, 10 and 12 determine the least costly way of acheiving the prespecified harvest goal of 1,912,500 bushels of annual sustained market oyster harvest. Solution 4 evaluates the same scenario for a harvest goal of 2,550,000 bushels. These solutions will be compared on the basis of repletion cost, total present value cost and repletion cost recovery tax rate and are presented in Table 5.31.

The figures in Table 5.30 show that there are significant cost and market oyster production consequences of

Table 5.30

Cost and Production Level Summary for Solutions 1,2,5,7,9,11

	Total Harvest (bushels)	Total Present Value Cost ($)	Average Present Value Cost ($/bushel)	Total Public Harvest (bushels)	Total Private Harvest (bushels)	Total Repletion Budget ($)	Tax Rate ($)
Solution One	12113641.0	34024932.0	2.8088	7738641.0	4375000.0	9000000.0	0.94
Solution Two	12484557.0	35540082.0	2.8467	7431173.0	5053384.0	9000000.0	1.17
Solution Five	13825274.0	37312748.0	2.7000	9450274.0	4375000.0	9000000.0	0.93
Solution Seven	12432932.0	34669513.0	2.7885	8057932.0	4375000.0	9000000.0	1.09
Solution Nine	13427660.0	32937258.0	2.4529	9052660.0	4375000.0	9000000.0	1.00
Solution Eleven	13997425.0	34072453.0	2.4342	9622425.0	4375000.0	9000000.0	0.94

Table 5.31

Cost and Production Level Summary for Solutions 3,4,6,8,10,12

	Total Harvest (bushels)	Total Present Value Cost ($)	Average Present Value Cost ($/bushel)	Total Public Harvest (bushels)	Total Private Harvest (bushels)	Total Repletion Budget ($)	Tax Rate ($)
Solution Three	15219366.0	47267108.0	3.1057	9553364.0	5666002.0	15335551.0	1.69
Solution Four	19681866.0	67317638.0	3.4203	10931866.0	8750000.0	24587521.0	2.83
Solution Six	15219366.0	43269129.0	2.8400	9394818.0	5824548.0	10240531.0	1.11
Solution Eight	15219366.0	46536040.0	3.0577	9553364.0	5666002.0	14434406.0	1.59
Solution Ten	15219366.0	38593202.0	2.5360	9600441.0	5618922.0	10579568.0	1.22
Solution Twelve	15219366.0	37862133.0	2.4878	9600441.0	5618922.0	10342231.0	1.12

implementing different oyster grounds management policies. Solution 1 represents the baseline case with no policy changes from the present except that the repletion budget is increased to $900,000 annually. Allowing private grounds production to increase in Solution 2 by 15.5% results in an overall 3.06% increase in total market oyster harvest over the planning horizon and a 4.45% increase in total present value cost. In Solutions 1 and 2 the repletion budget was the same, but in Solution 2 public grounds market oyster harvest is less than it was in Solution 1. The total repletion cost recovery tax rate increases, therefore, by 24.47%. In the remaining solutions included in Table 5.30 private planters are held to 625,000 bushels annually and the repletion budget is held at $900,000 per year. When the baseline condition is changed by dropping the non-discretionary repletion constraints the acheivable level of market oyster production increases 14.13% in Solution 5 for the same budget level evaluated in Solution 1. The 13,825,274 bushel harvest level acheived in Solution 5 comes at a 9.66% increase in total present value cost but the average present value cost declines by $0.1088. The full repletion cost recovery tax rate also decreases from $0.94 per bushel in Solution 1 to $0.93 in Solution 5.

When the scenario analyzed by Solution 1 is changed to permit the mining of reef shell in Virginia Solution 9 indicates that this policy change would result in a market oyster harvest increase of 2.64% and a total present value cost increase of 1.89%. The total repletion cost recvovery tax rate would increase 15.96% under this policy change.

The cost and production consequences of permitting the dredging of seed determined by Solution 9 indicate that implementation of this policy would result in an acheivable level of market oyster harvest 10.85% greater than in Solution 1. This higher harvest level is acheivable for a 3.2% reduction in total present value cost. The full repletion cost recovery tax rate under this policy change is 6.38% higher than under Solution 1. Solution 11 indicates that a policy permitting the dredging of both shell and seed would permit a harvest level 15.55% greater than if these changes were not made. The total present value cost of this harvest goal increases only .14% over Solution 1 and no increase in the repletion cost recovery tax rate would be required.

An examination of Table 5.31 shows that similar cost savings to those just described can be achieved for the solutions shown in this table. Solution 3 will be used as the base for comparison because, like Solution 1, it reflects current oyster grounds management policies. When current oyster repletion program practices are modified by dropping the non-discretionary repletion requirements, the repletion cost of producing the 1,912,500 annual harvest goal declines 30.42%. The total present value cost of acheiving this harvest goal and the full repletion cost recovery tax rate also declines by 9.24% and 52.25% respectively. The repletion cost of acheiving the 15,219,366 bushel harvest goal is decreased 5.88% when the policy change evaluated in Solution 8 of permitting the mining of reef shell in Virginia is introduced. Total present value cost of producing the harvest goal is decreased 1.55% and the repletion cost recovery tax rate goes down by 5.92%. A marked decrease in all costs occurs when the dredging of seed is permitted. Solution 10 indicates that repletion costs decrease by 31.01% and total present value cost of producing and harvesting the market oyster harvest goal declines by 18.35%. The full repletion cost recovery tax rate also goes down by 27.81%. When both reef shell and seed are harvested with a dredge total repletion budget requirements decrease 32.56% as indicated by the figures presented for Solution 12. Additionally, total present value cost and the repletion cost recovery tax rate decline by 19.9% and 33.73% respectively as compared to Solution 1.

The average present value cost figures presented in column three of Table 5.31 have an important interpretation. Without any other changes in management policies except the increased harvest goal, the average cost of producing market oysters in Solution 3 is $3.1057 per bushel. As each new policy is introduced a marginal change in oyster grounds management policy is effected. The difference between the average cost of production under the scenario with the added policy and the former policy without the new policy can be interpreted as the unit opportunity cost of not undertaking the new policy. In Solution 6, for example, the non-discretionary repletion constraints were dropped. The unit cost of maintaining the non-discretionary activities is $0.2657 per bushel amounting to a $4,043,786 prsent value loss to the oyster industry. The unit opportunity cost of foregoing the option to dredge reef shell and to dredge seed is $0.048 and $0.5697 per bushel respectively. When both the dredging of seed and shell is not implemented the opportunity cost is $0.6179 per bushel resulting in a loss to the oyster industry of $9,404,046 in present value.

The results from Solution 4 are also presented in Table 5.30. It can be seen here that the additional 29.32% total market oyster harvest comes at an 84.0% increase in repletion funding requirements and an increase in total present value cost of 42.42% as compared to Solution 3. Although evaluation of any one or all of the policy options considered in Solutions 6, 8, and 10 would reduce the repletion needs and total cost of producing this level of market oyster harvest it is quite clear that increases in market oyster harvest of the magnitude evaluated in Solution 4 must come at substantial increases in repletion funding and total cost.

5.10 THE POSSIBILITY FOR A FULL REPLETION COST TAX RATE

The second objective was to determine the potential for setting oyster taxes at levels that would recover all costs incurred by the repletion program. The model developed in this study is not suited for an evaluation of what level the market oyster tax could or should be levied in a normative sense. Rather, the model's output permits the calculation of the tax rate that would be required to recover all repletion expenses in a given year. The tax rates reported for Solutions 1-12 and the Base solution are summarized in Table 5.32.

The figures in Table 5.32 show that for Solutions 1 and 2 the tax rate increases occur because the taxable quantity of public grounds market oyster harvest is lower in Solution 2 than it is for Solution 1. When Solution 1 is compared to

TABLE 5.32

Tax Rate Summary for Solutions 1-12

Solution	Tax Rate ($)	Solution	Tax Rate ($)
Base	0.94	3	1.69
1	1.13	4	2.38
2	1.17	6	1.11
5	0.93	8	1.59
7	1.09	10	1.22
9	1.00	12	1.12
11	0.94		

Solutions 7, 9, and 11 it can be seen that the full repletion cost recovery oyster tax decreases as each new policy is introduced. These tax rate decreases are made possible because as each policy change is introduced the unit cost of repleting the Baylor grounds goes down making greater production levels attainable for the same repletion budget. The cost savings attributable to changes in oyster grounds management policies is reflected in the tax rates reported for Solutions 3, 8, 10, and 12.

A comparison of Solution 3 and Solutions 8, 10, and 12 reveals that marked tax rate decreases are made possible with the repletion cost saving policies evaluated in these three scenarios. Under current management policies the tax rate required to recover all repletion expenditures is $1.69 per bushel. This tax rate can be brought down to $1.12. Of the $0.57 difference $0.47 can be attributable to permitting the dredging of seed and $0.10 can be attributed to dredging reef shell in Virginia.

The tax rates presented in Table 5.32 were calculated under the assumption that taxes on seed oysters would remain at their current levels. Relaxing this assumption, a new tax rate on market oysters was determined for a series of alternative seed oyster tax levels. The results of these calculations are presented in Table 5.33.[15]

The general results discussed earlier remain unchanged for the figures shown in Table 5.33. These figures do indicate, however, that the combination of increasing seed oyster taxes and changing present State public and private oyster grounds policies can result in lowering the tax rate required to make the repletion program self-sufficient.

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[15] The figures reported in this table were calculated in a slightly different way than the taxes shown in Table 5.32. Instead of calculating a full repletion cost recovery tax rate for each year of the planning period the tax rates recorded in Table 5.33 were calculated by multiplying the proposed tax rate on seed oysters indicated by the column headings by the average quantity of seed oysters used in each year. This revenue was then subtracted from the ten year average repletion requirements and dividing average public grounds market oyster harvest by the remainder yeilds the tax rates indicated in Table 5.33.

TABLE 5.33

Tax Rates For Solutions 1-12 Under Alternative Seed Oyster Tax Rates

Solution	Alternative Seed Oyster Tax Rate .10 ($)	.20 ($)	.30 ($)	.40 ($)	.50 ($)
Base	0.94	0.89	0.84	0.79	0.75
1	1.13	1.06	1.01	0.96	0.91
2	1.17	1.10	1.04	0.98	0.92
3	1.69	1.64	1.57	1.50	1.42
4	2.38	2.07	1.97	1.88	1.79
5	0.93	0.84	0.79	0.73	0.68
6	1.11	0.94	0.87	0.80	0.73
7	1.09	1.01	0.96	0.91	0.86
8	1.59	1.54	1.46	1.39	1.32
9	1.00	0.89	0.84	0.79	0.73
10	1.22	0.97	0.91	0.84	0.78
11	0.94	0.72	0.67	0.62	0.58
12	1.12	0.95	0.88	0.82	0.75

5.11 CHAPTER SUMMARY

The results of the analysis of the cost and production consequences of alternative oyster grounds management policies indicate that changes in policy can affect the level of acheivable market oyster harvest, the total cost of producing and harvesting market oysters and the level of repletion expenditures required to attain the harvest goal. Increasing the repletion budget from the base solution to Solution 1 resulted in an annual market oyster harvest increase of 15.2%. When a goal oriented market oyster harvest increase policy was evaluated in Solution 3, it was determined that the additional repletion funding requirements increased 70.39% for a 1,912,500 bushel annual sustained market oyster harvest goal. When reef shell was mined in Virgina the acheivable increase in market oyster harvest increased 19.36% and the total repletion cost of the 1,912,500 declined 5.88%.

Of the individual policy options examined, permitting the dredging of seed oysters had the greatest effect on production and cost consequences. This policy option was introduced and evaluated in Solution 9 and 10. The annual acheivable market oyster harvest goal increased 29.92% over the current situation. Implementation of this policy kept the increased repletion funding needs of producing the

1,912,500 bushel harvest goal down to just 17.55% greater than current funding allocations. Additional production increases and repletion cost reductions were made possible when both dredging for seed and shell were permitted. Under this policy change, it was possible to increase market harvest 36.31% over the Base solution. Additionally, the repletion cost of producing a 1,912,500 bushel goal was held to a 14.49% increase over present funding levels when a seed and shell dredging policy was considered.

Chapter VI

SENSITIVITY ANALYSIS AND SETTING RESEARCH PRIORITIES

6.1 INTRODUCTION

In Chapter I the issue of an inadequate management information base was mentioned. Recognizing that certain kinds of information are more critical than others the last reasearch objective was to determine what further research was necessary and to rank these needs so that research priorities could be set. The research needs are varied but this study concentrates on ranking research needs that are relevant specifically for improving the accuracy of the model's results. To this end an analysis of the model's sensitivity to changes in its technical coefficients was conducted. Critical coefficients are then identified based on the magnitude of change in the coefficient of interest required to bring about a significant change in the model's solution.

6.2 SOLUTION SENSITIVITY TO CHANGES IN TECHNICAL COEFFICIENTS

To determine the sensitivity of the model's solutions to changes in the technical coefficients contained within it, two methods are employed. First, a standard sensitivity analysis is conducted to determine the stability of the model's solution with respect to changes in the right-hand-side (RHS) coefficients on the model constraints and changes in objective function coefficients for the model's activities. A second test of the model's sensitivity is conducted by incrementally changing the value of selected key coefficients and determining the cost and repletion consequences of the new coefficient values.

6.3 SENSITIVITY ANALYSIS ONE:

The first test of the model's sensitivity is conducted on the base solution where the harvest goal was set at 1,275,000. Public and private harvest levels were determined to be 675,000 and 625,000 bushels respectively, and the repletion budget was set at not more than $900,000.

In order to determine what coefficients were sensitive to changes in their estimated values and which were not, an arbitrary decision rule was adopted. Any coefficient that would force a change in the final solution if its value increased or decreased by less than 25% is defined as being sensitive. Based on this rule sensitive coefficients were determined and are discussed below. Right-hand-side coefficients are presented first, and objective function coefficients are presented next by activity type.

6.3.1 Right Hand Side Coefficients:

A sensitivity analysis on the RHS coefficients has the interpretation of being the range over which the value of the RHS coefficient may be changed without changing the shadow price of the resource. The sensitivity analysis reveals little sensitivity to changes in the RHS coefficients. The RHS coefficients in the solution tested for sensitivity are found to be stable because with few exceptions, they are nonbinding constraints. The exceptions are availability of leased acreage in the Great Wicomico and availability of naturally occurring market oysters on the Public grounds.

It was seen that, in every solution, the leased bottoms in the Great Wicomico were the most important oyster production beds from private production. The sensitivity analysis shows that a one acre decrease in the value of this constraint would lead to a cost increase of $587.25. Conversely, a one acre increase in the value of this constraint would decrease cost by the same amount. Additionally, the shadow price of this resource constraint would no longer be the same as it was formerly.

In every year of the planning horizon, all available natural production is harvested. Choosing a representative year, the range over which the value of this RHS coefficient would leave its shadow price unchanged in year 4 is from 430,474 to 615,476 bushels. Over this range every one acre increase in the value of the natural seed availability constraint would result in a $1.70 reduction in total cost. Similarly, every one acre decrease in the value of this constraint would lead to a $1.70 increase in total cost. The indicated reduction or increase in cost associated with changes in the value of this RHS coefficient is also equivalent, in this case, to the shadow price of the resource. If the limits of the range shown above were exceeded, the shadow price of this constraint would increase when the lower limit is exceeded and decrease if the upper limit were exceeded.

In all other cases the RHS coefficients for the resource availability constraints were found to be stable because the level of resource use was so small in relation to total quantities available. With respect to availability of private and public oyster bottoms, there is little reason to expect that these coefficients were overestimated given that of the 243,000 acres of oyster bottoms constituting the Baylor Survey Grounds only 23% or 55,598.79 are included in the model. Additionally, 76% or 82,616.6 of the 107,307 acres of private bottoms are included in the model.

Little information is yielded by the sensitivity analysis about the model's sensitivity to changes in the value of the RHS coefficient for the naturally ocurring seed oyster and fresh shell availability constraints. This happens because the former is nonbinding while the latter is unbounded. Both resources are critical to the model solutions and were selected for further analysis in the second test of the model's sensitivity. They will, therefore, be discussed later.

6.3.2 Sensitivity of Objective Function Coefficients:

The sensitivity analysis reveals that, without exception, all public grounds shell-harvest activity objective function coefficients are stable parameters. For example, the objective function coefficient for the most cost-effective public grounds shell-harvest activity is $3093.95. According to the sensitivity analysis, this coefficient would have to be reduced to $1049.40 before this activity would enter the final solution. Considering that the repletion cost alone of this activity is $2450 it is evident that unless repletion costs were substantially reduced, even the most cost-effective shell-harvest activity would not enter the model's solution. In general the results of the sensitivity analysis show that in all cases the highest cost at which any shell-harvest activity would enter the final solution was greatly exceeded by the repletion cost of the activity. The model's solution is stable, therefore, over a wide range of possible values for these coefficients.

The objective function coefficients for public seed-transport-harvest activities exhibit varying degrees of sensitivity. Based on the 25% decision rule only two of the six public seed-transport-harvest activities were found to be sensitive to changes in their coefficient values. The sensitive coefficients correspond to public seed-transport-harvest activities in the Great Wicomico and the Mid-Rappahannock rivers. These activities share identical objective function coefficients and are sensitive to change in the same order of magnitude. If, for example, in year 2 the objective function coefficient for these activities declined by more than $375.48 then the final solution would change. The minimum cost decrease before a change in the final solution would be implied is of a similar magnitude for years 3-10 of the planning period.

The private grounds seed-transport-harvest activities also show varying degrees of sensitivity. Of the twelve private grounds production activities, five were found to be sensitive to changes in the value of their objective function coefficients. The affected river systems and the ranges of coefficients over which the activities in the final solution would remain unchanged are listed in Table 6.1. For each river system listed in Table 6.1, there are three rows. The first row indicates the actual objective function coefficient contained in the model. The second row shows the maximum cost increase that would leave the final solution unchanged while the third row indicates the maximum cost decrease that could occur without altering the final solution. The figures indicate, for example, that in year 2 if the coefficient of private market oyster production in the Great Wicomico increased by $32.94 or decreased by $134.64 a change in the final solution would be implied. An entry of "I" in any cell of this table means that the corresponding objective function coefficient could increase infinitely without changing the final solution. In general, the activities corresponding to these coefficients are currently not in the final basis of the solution analyzed.

An examination of the sensitivity analysis results on seed production coefficients reveals nothing useful about the model's sensitivity to changes in these coefficients. No additional seed production is required in the solution analyzed. This is reflected in the sensitivity analysis by

Table 6.1

Sensitivity of Private Grounds Seed-Transplant-Harvest Activities

	Year								
	2	3	4	5	6	7	8	9	10
River system									
Great Wicomico*	2503.11	2361.42	2227.76	2101.66	1982.70	1870.47	1764.50	1664.71	1570.48
Lower Limit	32.94	4.31	0.26	37.79	4.31	0.26	4.31	1.92	0.26
Upper Limit	134.64	0.26	4.31	0.26	34.41	4.31	0.26	28.08	4.31
Upper Rappahannock*	1971.79	1860.17	1754.88	1655.55	1561.84	1473.43	1367.88	1311.35	1237.12
Lower Limit	I	I	10.00	I	I	3.23	0.19	10.00	1.50
Upper Limit	59.02	27.42	5.75	28.34	3.23	0.19	3.23	1.44	21.00
Mid Rappahannock*	1981.79	1870.17	1764.88	1665.55	1561.84	1473.43	1367.88	1311.35	1237.12
Lower Limit	I	I	I	I	I	I	I	I	I
Upper Limit	69.02	37.42	10.00	38.34	13.23	10.00	10.00	10.00	10.00
Upper York*	1982.47	1870.25	1764.38	1664.51	1570.30	1481.42	1397.56	1318.45	1612.50
Lower Limit	I	0.20	24.75	0.21	25.81	22.01	20.32	21.46	27.70
Upper Limit	24.70	3.23	15.25	29.80	41.69	7.99	29.68	8.54	27.70
Piankatank*	1976.79	1865.17	1759.88	1660.55	1566.84	1478.43	1372.88	1375.35	1216.12
Lower Limit	100.98	125.08	137.50	109.16	119.27	115.0	115.0	48.50	0.20
Upper LImit	86.52	62.42	10.75	56.04	38.23	5.00	5.00	57.94	0.20

* The figures in these rows indicate the actual coefficient values for the activities in the model.

very wide ranges over which the coefficients could increase or decrease without affecting the final solution.

It would be useful to select a solution that did require seed production and conduct a sensitivity analysis to determine the sensitivity of these seed production cost coefficients. But because the coefficients for the seed production activities are simply the repletion costs associated with each activity (which are known with reasonable certainty), little could be gained from doing this. The more important coefficient associated with each seed production activity is the seed productivity coefficient, i.e., the amount of seed resulting from the imitation of a seed production activity. Unfortunately, this coefficient is a matrix element and the sensitivity analysis cannot tell us anything about the affects of changes in its value. The seed productivity coefficients, therefore, were selected for additional analysis in the second test of the model's sensitivity and will be discussed later.

The final set of model activities discussed here is the set of seed transport activities. The cost of transporting seed from seed beds to planting sites on public grounds is included in the public seed-transplant-harvest cost coefficient and does not appear in the model as its own coefficient. The sensitivity analysis, therefore, can only reveal information about the sensitivity of the private grounds transportation costs coefficients. It is not unreasonable to expect, however, that both public and private transport costs would be similar and would behave similarly with respect to changes in their coefficient values. The following discussion will likely be applicable to sensitivity of public seed-transport coefficients as well as private seed-transport coefficient sensitivity.

Table 6.2 provides a listing of seed transport coefficients found to be sensitive to changes in their values. For each pair of seed origin and receiving river system two columns are presented. The first column is the actual cost coefficient included in the model. The second column is the maximum amount the transport cost coefficient may be decreased without forcing a change in the basis of the final solution. If, for example, the cost of transporting seed from the upper James decreased by more than $0.033 the final solution would change. Blank cells in this table indicate a nonsensitive relationship between the corresponding pair of indicated river systems. The figures presented in Table 6.2 correspond to the sensitivity analysis results for each coefficient in year two of the planning horizon. The results vary each year but are on the same order of relative sensitivity and are, therefore, not presented here.

Table 6.2

Sensitive Seed-Transport Activities

System of Seed Origin	Receiving River Systems: Upper Rappahan.	Mid Rappahan.	Great Wicomico	Upper York	Pianka-tank
Upper James					
Actual Value	2.25	2.39	2.34	2.43	2.39
Upper Limit of Sensitivity	0.033	0.159	0.115	0.070	0.172
Lower James					
Actual Value	2.25	2.39	2.39	2.34	2.43
Lower Limit of Sensitivity	0.033	0.159	0.172	0.115	0.070
Lower Rappahan.					
Actual Value	2.39	2.25	2.25		
Lower Limit of Sensitivity	0.233	0.079	0.092		
Mobjack Bay					
Actual Value	2.30	2.43	2.43	2.39	2.47
Lower Limit of Sensitivity	0.083	0.199	0.212	0.165	0.11
Piankatank					
Actual Value					2.30
Lower Limit of Sensitivity					0.135

6.3.3 Summary of Sensivity Analysis One

The results of the sensitivity analysis on RHS and objective function coefficients indicate that the solution analyzed here is quite stable with respect to changes in the value of a majority of these coefficients. The sensitivity analysis on RHS coefficients shows particular stability with respect to these coefficients. This is of course somewhat misleading because as previously stated only two resource constraints were binding (leased bottoms in the Great Wicomico and natural market oyster availability) and none of the remaining constraints were very close to their upper limits. Three RHS coefficients were selected for further analysis because of this problem. The coefficients selected are availability of fresh shell, naturally occurring seed and naturally occurring market oysters.

The sensitivity analysis does yield somewhat more useful results for the objective function coefficients. These results show that the objective function coefficients for all the shell-harvest activities are stable over a wide range of values. Coefficients that were found to be sensitive (according to the decision rule) to changes in their estimated values are summarized in Table 6.3. In general the activities found in this table are defined as being sensitive in all years, but the degree of sensitivity does vary across the time horizon considered in the model. This table shows that there is a correspondence between the sensitivity of private grounds market oyster production activities and the transport acitvities that bring seed to those river systems.

TABLE 6.3

Sensitive RHS and Objective Function Coefficients

RHS Coefficients:

Natural Market Oyster Availability
Leased Bottoms in the Great Wicomico

Objective Function Coefficients:

Private Grounds Seed-Transport-Harvest Coefficients

Great Wicomico
Upper York
Upper Rappahannock
Mid-Rappahannock
Piankatank

Private Seed-Transport Coefficients

Upper James, Lower James, Mobjack Bay to:
- Upper York
- Upper Rappahannock
- Mid-Rappahannock
- Piankatank
- Great Wicomico

Lower Rappahannock to;
- Upper York
- Upper Rappahannock
- Mid-Rappahannock

Piankatank to:
- Great Wicomico

6.4 SENSITIVITY ANALYSIS TWO: ANALYSIS OF MODEL SENSITIVITY FOR SELECTED COEFFICIENTS

It was shown in the previous sections that, for this solution, a standard sensitivity analysis was not very useful in determining the importance of certain coefficients to the model's solution. Four coefficients are selected for further analysis in this section. The coefficients chosen for additional study are: 1) availability of natural seed, 2) availability of natural market oysters, 3) availability of fresh shell, and 4) the productivity of Baylor grounds seed beds. These four coefficients were chosen for two reasons. First, with the exception of availability of naturally occurring market oysters, the standard sensitivity analysis yielded little useful information with respect to changes in their estimated values. Second, all these coefficients describe a resource availability constraint or a technical relationship that is critical to the final solutions of all the analyses described in Chapter V.

The base solution does not provide a useful means to evaluate the individual analyses conducted here. Instead, the scenario evaluated in Solution 1 was chosen for the analysis of sensitivity for individual coefficients. Recall that the analysis in Solution 1 simply incrementally increased the prespecified harvest goal until the budget constraint became binding. The same technique is employed here except that the coefficients tested are incrementally decreased while the harvest goal is increased until the solution becomes bounded. The sensitivity of the coefficient incremented will be determined by the difference in the level of market oyster production achievable under alternative parametric schemes.

6.4.1 <u>Test of Fresh Shell Availibility Coefficient</u>:

A limit of fresh shell availability was arbitrarily set at 250,000 bushels. This level was chosen because it did not change the results obtained in Solution 1 and it provides a reasonable starting point from which to increment downward. The 250,000 bushel limit was incrementally decreased by 50,000 bushels and 100,000 bushels in two separate analyses. In both analyses the parametric routine produced results that showed decreasing quantities of market oysters produced as the incremental decrease in the fresh shell availability was increased. Unfortunately, the optional solutions were suboptimal with respect to the achievable market oyster harvest goal because in both situations the budget constraint was not binding which meant that reef shell could be substituted for fresh shell and more oyster production could have been achieved. This result arises because of the nature of the parametric programming technique.

The parametric routine decreases or increases the value of a coefficient until the desired limits are reached or the solution becomes binding with respect to the coefficient on the constraint of interest or any constraint not changed becomes binding, whichever comes first. In the solution determined for this analysis the fresh shell constraint became binding first so the parametric routine stopped prematurely with respect to the market oyster harvest goal.

An alternative to the parametization technique is to simply set the value of the fresh shell coefficients at specific levels and reevaluate the scenario analyzed in Solution 1. Applying this, fresh shell availability was set at 175,080 bushels. This level was chosen because it is the minimum level of this coefficient that would satisfy the fresh shell requirements for the nondiscretionary activities. When fresh shell availability was set at this level annual sustained market oyster harvest was 1,466,417 bushels. Total market oyster harvest over the ten year period was 12,696,785 bushels at a present value cost of $34,028,247. The impact of restricting the use of fresh shell to nondiscretionary acitvities only is relatively small in terms of total cost and market oyster production. When fresh shell was nonbinding annual market oyster harvest was 1,468,825 and total present value cost was $34,024,932.

Restricting fresh shell use results in a reduction in annual harvest of only 2,408 bushels of market oysters and present value cost was increased by just $3,315. Although the cost and production of market oysters is not affected very much by limiting fresh shell use, the mix of discretionary activities does change in one important way.

Recall that in Solution one the production of discretionary seed took place in the Upper James. When fresh shell cannot be used the cost of transporting reef shell from Maryland makes seed production in the Upper James no longer cost-effective. In its stead the seed beds of the Great Wicomico become the most cost-effective seed production area. In addition to being the least costly river system in which to produce seed the decision where to transplant the seed will be made with respect to proximity to the Great Wicomico and not the Upper James.

For example, when fresh shell is available in abundance seed would be produced in the James. The decision where to plant that seed between several river systems of equal productivity would be based on closeness to the James. In this case the transport cost of seed would favor seed production leased bottoms in the Upper York, Piankatank, and Uper Rappahannock rivers in that order. It is obvious that when reef shell must be used and seed production is taking place in the Great Wicomico the order of river system favorability would be easily reversed. It is clear from this discussion that while cost and market oyster production are not very sensitive to changes in availability of fresh shell (as long as resources are allocated cost-effectively) the choice of seed and market oyster production activities does depend very much on the availability of fresh shell.

6.4.2 Limiting Availability of Naturally Occurring Market Oysters

In every year of Solution 1, all available naturally occurring market oysters were harvested. The level of market oyster production achieved in solution would have been lower if naturally occurring market oyster availability had been set at a lower level. To determine the production impacts of lower levels of naturally occurring market oysters solution was reevaluated by incrementally decreasing the level of this constraint. A series of seperate analyses were conducted and their results are presented in Table 6.4.

The first column of Table 6.4 simply provides a row identification number. The second column indicates the increment by which the RHS coefficient of the naturally occurring market oyster availability constraint was parametized. Column three of this table presents the level of natural market oyster production that actually forced a

Table 6.4

Results of Natural Market Oyster Sensitivity Test

Row	Incremetal Change (bushels)	Market Oyster Coefficient Value (bushels)	Change in Value (bushels)	Acheivable Harvest Goal (bushels)	Change in Harvest (bushels)
1	+50000.0	804447.0	___	1662651.0	___
2	+25000.0	675230.0	-129217.0	1533434.0	-129217.0
3	---	610622.0	-64608.0	1468825.0	-64608.0
4	-25000.0	571857.0	-38765.0	1430060.0	-38765.0
5	-50000.0	543886.0	-27971.0	1408472.0	-21588.0
6	-75000.0	527554.0	-16332.0	1385757.0	-22715.0
7	-100000.0	513709.0	-13845.0	1371913.0	-13845.0
8	-150000.0	494326.0	-19383.0	1352530.0	-19383.0
9	-200000.0	481405.0	-12921.0	1339608.0	-12921.0
10	-250000.0	472175.0	-9230.0	1330379.0	-9230.0
11	-300000.0	465253.0	-6922.0	1323456.0	-6922.0

binding solution to each parametric routine. The fourth column represents the reduction in the level of market oyster availability over the previous solution. Column five indicates the annual sustained level of market oyster production achievable if the natural availability constraint were set at the level shown in column two of the corresponding row. The last column indicates the reduction in market oyster production over the previous solution.

The figures indicate three regions of interest. The first region lies in the interval from row one to row four. Rows 4 through 7 lie in region two while the rows 7 through 11 are included in region three. An inspection of the figures in columns four and six of regions one and three reveal that the reduction in the value of the RHS coefficient for natural market oysters is exactly, or nearly so, equal to the reduction in annual sustained market oyster harvest for the corresponding parametization. Increasing the level of this constraint, for example, above 571,857 bushels would lead to an increase in annual sustained market oyster harvest precisely equal to the increase in naturally occurring market oysters and vice versa for a decrease in the value of this coefficient below 513,709 bushels. This result occurs because above and below these limits the repletion budget is already being used in the most efficient manner possible and no further production can be achieved at the $900,000 budgetory level used to determine these solutions. The implication is that the most cost-effective combination of repletion policies and discretionary activities is exactly the same for any RHS value of the natural market oyster availability constraint falling within regions one and three. The figures in region two, however, suggest a different interpretation.

Region two is a relatively narrow interval between the upper limit of region three and the lower limit of region one. Over this interval it is possible to reallocate public and private resources in such a way that the final solution will vary depending on the number actually assigned to the naturally available market oyster coefficient. A closer look at the numbers in rows four through seven of Table 6.4 show that there is a point above which resources can be reallocated such that the reduction in the acheivable level of market oyster harvest is less than the reduction in natural market oyster availability, and below which the reduction in sustainable market oyster production is greater than the reduction in the level of naturally occuring market oysters. This point lies somewhere between 543,886 and 527,554 bushels of natural market oysters.

From the preceding discussion it can be determined that total acheivable market oyster production is sensitive with respect to changes in the level of naturally available market oysters. This coefficient is also sensitive with respect to total cost. More specifically, the impact on total present value cost can easily be determined for coefficient values in regions one and three. In these two regions the change in total cost will simply be the total discounted increase or decrease, for region one and three respectively, in the cost of harvesting the naturally produced market oysters over the ten year planningh period. In region two, however, the amount of the change in total discounted cost will vary depending on the outcome of how the level of this coefficient is set although total cost will always be lower for decreasing values of this coefficient. The mix of repletion policies and discretionary activities is insensitive with respect to regions one and three. Over coefficient values in region two, however, a new mix and level of discretionary activities will be implied for different levels of natural market oyster availability.

6.4.3 Limiting the Availability of Naturally Occuring Seed

Like the coefficient just discussed, the availability of natural seed limits the acheivable level of market oyster production subject to the constraints put on the model. The analysis conducted to test the sensitivity of this coefficient is exactly the same as that done on naturally occuring market oysters. The results of this analysis are presented in Table 6.5.

The columns in Table 6.5 should be interpreted in exactly the same way Table 6.4 was interpreted with the exception that column three now indicates naturally available seed instead of market oysters. A comparison of columns four and six on a row by row basis exhibits the common characteristic that the reduction in market oyster harvest is always less than the reduction of naturally available seed. Note that the difference between columns four and six decreases through all rows of the table. If natural seed availability were decreased to levels even lower than those indicated in Table 6.5, a point would likely be reached where further reduction in the natural seed coefficient would have no further reducing effect on acheivable market oyster production. Similarly, the level of this coefficient would also become irrelevant at coefficient values not much greater than the estimated value for this coefficient

Table 6.5

Results of Seed Sensitivity Test

Row	Incremetal Change (bushels)	Seed Coefficient Value (bushels)	Change in Value (bushels)	Acheivable Harvest Goal (bushels)	Change in Harvest (bushels)
1	——	382863.0	——	1468825.0	——
2	-50000.0	310536.0	-72327.0	1419653.0	-49172.0
3	-100000.0	267480.0	-43056.0	1390382.0	-29271.0
4	-150000.0	238917.0	-28563.0	1370963.0	-19419.0
5	-200000.0	218917.0	-20333.0	1357139.0	-13824.0
6	-250000.0	203371.0	-15213.0	1346797.0	-10343.0
7	-300000.0	191561.0	-11810.0	1338767.0	-8030.0

because the ability to make use of greater quantities will be limited by the availability of repletion funds and the constraint on private grounds market oyster production.

The actual estimated value of naturally available seed is 382,863 bushels. As stated previously, if the value of this coefficient were underestimated there would be very little change in the solution determined in Solution 1. If, however, this coefficient were overestimated what would the market oyster production consequences be? A further analysis of Table 6.5 answers this question. A 30.14% decrease from 382,863 to 267,480 bushels of natural seed oyster availability leads to a 5.3% reduction in market oyster harvest from 1,468,825 to 1,390,382 bushels. A 50% reduction in the value of the natural seed coefficient results in only an 8.8% reduction in acheivable market oyster harvest. These figures indicate that even a large error in the estimation of the value of this coefficient would have a relatively small market oyster production effect.

The cost consequences of an error in estimation of this coefficient are also small. For the 30.14% decrease in natural seed availability case the corresponding decrease in total present value cost was only 3.3% as compared to the cost determined in Solution 1. This small effect is a direct result of the small oyster production effect. The consequences for the level and mix of discretionary activities is also influenced by the level of natural seed availability but, like the cost and production effects, the mix and level of discretionary activities is changed only in a llimited sense.

The mix and level of discretionary activities for incremental changes indicated in rows two and three of Table 6.5. In both cases no changes in the mix of discretionary activities were implied. The only difference between these solutions and Solution 1 was that the use of public grounds in the Upper Rappahannock was reduced and increased levels of seed production in the Upper James were required to offset the decreased availability of natural seed. With respect to repletion strategies as well as cost and production effects, therefore, the solution tested here is relatively insensitive to changes in the level of naturally occurring seed oysters.

6.4.4 Test of Sensitivity of Seed Productivity Coefficients

The previous three sections examined the sensitivity of RHS coefficients. The seed productivity coefficients determine the number of bushels of seed oysters produced per bushel of shell planted on a seed bed in a particular river system. These productivity coefficients are matrix elements that cannot be analyzed with a standard sensitivity analysis. The cost and production effects of changes in these parameters were evaluated by manually reducing the value of these coefficients. The analysis conducted for Solution 1 was once again selected to test the sensitivity of these coefficients. Two solutions were determined, one each for a 25% and a 50% reduction in the estimated value of every seed productivity coefficient. The results of these analyses are discussed below.

When the seed productivity coefficients were decreased 25% annual sustained market oyster harvest declined only 0.7% to 1,458,086 bushels as compared to 1,468,825 bushels determined in Solution 1. Similarly, when the seed productivity coefficients were reduced by 50% sustained market oyster harvest declined only 1.8% over Solution 1. The corresponding cost effects for the 25% and 50% reductions were $33,9062,601 a decrease of 0.4% and $33,658,623 a decrease of 1.1% over Solution 1 respectively. Quite clearly, cost and production effects are virtually insensitive to the seed productivity coefficient changes examined in this analysis. Likewise for changes in the mix and level of discretionary activities as a result of seed productivity coefficient changes.

6.4.5 Test of Sensitivity to Simultaneous Change in Multiple Coefficients

The results of the tests on individual coefficients showed that isolated changes in the values of any one of the coefficients examined do not significantly alter the acheivable level of market oyster harvest, the cost of producing the harvest goal or the mix and level of discretionary activities required to meet the harvest goal. The purpose of this section is to determine the cost and production consequences of simultaneously reducing the level of natural seed and market oyster availability and changes in seed productivity coefficients. Two solutions were determined for each reduction in seed productivity. The production and cost consequences resulting from these coefficient changes are presented in Table 6.6.

The first column of this table presents the level of the relevant coefficient determined in Solution 1. Columns two and three present the levels for the indicated coefficient for the indicated parametization for a seed productivity coefficient reduction of 25%. Columns four and five indicate the level of the coefficient determined for the indicated parametization for a 50% decrease in seeed productivity. In column one all the figures indicated are at levels originally set or determined by the model . In this sense these values represent a "best case" situation. Con-

Table 6.6

Annual Production and Cost Results of Simultaneous Change in Several Cofficents.

		Reduce Seed Productivity 25%		Reduce Seed Productivity 50%	
	Solution One	Increment Parametized -50000	-100000	Increment Parametized -500000	-100000
Natural Market Oyster Availability	610622.0	562583.0	545494.0	568876.0	554986.0
Natural Seed Oyster Availability	382863.0	334824.0	317735.0	341117.0	327227.0
Annual Acheivable Harvest Goal	1468825.0	1371079.0	1340129.0	1358492.0	1330636.0
Total Present Value Cost	32497162.0	32497162.0	32001642.0	32325668.0	31884159.0

versely, the figures in column five are the result of the greatestr reductions in all coefficient values and represents a "worst case" situation.

A comparison between the best and worst case situations shows that, by reducing all the coefficients by the indicated amounts, a 9.4% decrease in the acheivable level of market harvest results. Total cost of this reduced harvest level is 6.3% less than in the best case. This harvest reduction is a result of the reduction in natural seed and natural market oyster availability which was 14.5% and 9.11% respectively. The important result here is that acheivable market oyster harvest declined by an amount roughly equivalent to the reduction in natural seed and market oyster levels. Recall that when these coefficients were reduced individually the difference between the acheivable level of market oyster harvest and the maximum level to which the coefficient could be reduced and still attain the harvest goal was much greater. It was found, for example, that the level of natural seed availability could be decreased by 50% and market oyster harvest declined only 8.8%.

It is evident from this analysis that production and cost effects are more sensitive to simultaneous changes in several coefficients than they are to individual changes in single coefficients. The mix and level of discretionary activities implied by the above solutions behave much as they did for solutions determined for changes in individual coefficients. In all four solutions determined for this analysis the mix of discretionary activities did not change from the activities determined in Solution 1. Once again, however, the levels of each activity declined as the coefficients of interest were decreased.

6.4.6 Summary of Sensitivity Analysis Two

Sensitivity tests on fresh shell, natural seed availability, natural market oyster availability, and seed productivity coefficients show that when these coefficients are changed individually, cost effects, market oyster production effects, and the implied level and mix of discretionary activities are relatively insensitive. On the basis of these individual analyses, however, it is possible to rank the four coefficients according to degree of sensitivity.

The criterion by which the coefficients are ranked is by examination of the difference in the reduction in market oyster harvest and the reduction in the coefficient of interest. The larger the difference between the two the less sensitive the coefficient. Using this criterion, availability of fresh shell is the least sensititve. Even when this coefficient was held to its lowest possible value and still permit a feasible solution the reduction in acheivable market oyster production was only .16% as compared to Solution 1. The second least sensitive coefficient is the seed productivity coefficients. Reducing these coefficients by 50% resulted in just a 1.8% decline in market oyster harvest. The coefficient found to be second most sensitive is the natural seed avaialbility coefficient. A 50% reduction in this coefficient resulted in an 8.8% reduction in annual market oyster harvest. Availability of naturally occuring market oysters resulted in the narrowest gap between reduction in the level of its coefficient and acheivable market oyster harvest. A 23.8% decrease in this coefficient resulted in 9.8% decline in acheivable market oyster harvest. This reduction in acheivable market oyster harvest was the largest for the smallest change in the value of the coefficient being examined.

Although, the solutions analyzed here were found to be relatively insensitive to changes in individual coefficients when these coefficients were decreased simultaneously the solutions became relatively more sensitive to coefficient changes. The solutions were particularly more sensitive with respect to production and cost effects. In every instance when natural seed and market oyster availability and seed productivity coefficients were reduced the mix of discretionary activities required to meet the harvest goal remained unchanged. In this regard, therefore, the discretionary activities are insensitive to changes in these coefficients.

6.5 SUMMARY OF SENSITIVITY ANALYSES ONE AND TWO

The results from sensitivity analysis One show that there are a fairly small number of sensitive RHS and objective function coefficients compared to the total number of these coefficients. The RHS coefficients were found to be particularly stable with only leased grounds in the Great Wicomico and natural market oyster availability being sensitive. The objective function coefficients for all shell-harvest coefficients were found to be insensitive to change. Of the seed-transplant-harvest activities only the objective function coefficients for leased bottoms in the Upper York, Upper Rappahannock, Mid Rappahannock, Great Wicomico and the Piankatank rivers were determined to be sensitive. The seed transport activities to these river systems also displayed varying degrees of sensitivity. Coefficients selected for additional analysis were availability of fresh shell, natural seed, natural market oysters and seed productivity coefficients.

The results of this second analysis show that these coefficients are not very sensitive when changes in their values are introduced on an individual basis. When these coefficients are changed simultaneously, the solution results become relatively more sensitive than if the changes were made in isolation. These coefficients were also ranked in ascending order of sensitivity in this second analysis. The ranking established from lowest to highest sensitivity is as follows; 1) fresh shell availability, 2) seed productivity coefficients, 3) natural seed availability, and 4) natural market oyster availability.

6.6 CHAPTER SUMMARY

The results of both sensitivity tests show that the model's solutions are relatively stable with respect to isolated changes in single coefficients. When the values of several coefficients were decreased simultaneously, however, the model did show increased sensitivity in cost and production effects. Both tests of the model's sensitivity did reveal that the mix, but not necessarily the level of discretionary activities remained unaltered for the solution selected for testing. The only coefficient that caused important changes in the mix of discretionary activities was the availability of fresh shell. When this coefficient was decreased, seed production shifted to the Great Wicomico instead of the James and market oyster seed-transplant-harvest activities in close proximity to the Great Wicomico became relatively more cost-effective.

Although, both sensitivity tests show that the solution tested here is relatively stable, it does not necessarily follow that the model's technical coefficients need not be further investigated. It must be considered that a standard sensitivity analysis reveals how the model's solution is affected when only one coefficient changes. It was shown that when several coefficients change simultaneously the solution becomes more sensitive. Additionally, the results of the sensitivity analysis depend to a great degree on the quality of the initial coefficient estimates. It was found, for example, that no shell-harvest activity would enter the solution unless its objective function coefficient were drastically reduced, ceteris paribus. It is entirely possible that the productivity coefficients for the seed-transplant-harvest activities were overestimated, and/or the shell-harvest productivity coefficients were underestimated. In either case, it could be found that the shell-harvest activities might be far more critical than the sensitivity analyses conducted here show.

Chapter VII

RECOMMENDATIONS AND CONCLUSIONS

7.1 INTRODUCTION

The purpose of this study was to construct a linear programming model that could be used to evaluate the cost-effectiveness of alternative oyster grounds management strategies. In Chapter II the important environmental and biological factors affecting the seed and market oyster productivity of a given river system that VMRC must consider in deciding where to place its repletion effort were introduced. Chapter III developed the model and Chapter IV discussed how the technical information contained in the model was estimated. Chapter V demonstrated the uses of the model in an evaluation of the cost-effectiveness of several potential oyster grounds policy changes. A sensitivity analysis was also conducted to determine the stability of the model's solutions to changes in its technical coefficients. The results of the sensitivity test were presented in Chapter VI. In this chapter several policy and repletion program revisions will be recommended. Also included in this chapter is a discussion of, and priorities for, further research.

7.2 A REVISED BAYLOR GROUNDS REPLETION PROGRAM

Over the 1979 to 1983 repletion seasons VMRC spent, on average, 88.61% of all program funding on shell-harvest activities and 11.39% of all available funding went to transplanting seed. The results of this study show that seed-transplant-harvest activities are consistently more productive and more cost-effective than shelling Baylor grounds to receive a set. The findings from the sensitivity analysis support this statement and demonstrate that the per acre cost of any shell-harvest activity would have to be far below its current repletion and harvest cost before it would become cost-effective relative to even the least productive seed-transplant-harvest activity. This study, therefore, suggests a fundamental change in the emphasis of the repletion program.

The model results indicate that the VMRC should abandon its emphasis on shelling Baylor grounds market oyster producing bottoms and concentrate on increased planting of seed from seed beds to market oyster growing areas. The absence of any discretionary shell-harvest activity in any of the solutions determined for this study indicates that continued shelling would not be the most productive use of VMRC's limited resources. An indication of the cost to the Commonwealth of continuing the current emphasis on Baylor grounds shelling is provided by a comparison between Solutions 1 and 5.

In Solution 1 the repletion budget was set at $900,000 per year and non-discretionary repletion constraints reflecting the current mix of repletion activities were placed on the model. Solution 5 duplicated this scenario with the one modification that the non-discretionary repletion requirements were eliminated. Total market oyster production in Solutions 1 and 5 was 12,113,641 and 13,825,274 respectively. The total present value cost of producing these harvest levels was, for Solutions 1 and 5 respectively, $34,024,932 and $37,312,748. The annual repletion expenditures required to satisfy the non-discretionary repletion constraints in Solution 1 was $622,496. The production level increase acheived in Solution 5 was made possible by reallocating the yearly $622,496 that would have gone toward the shelling of Baylor grounds in Solution 1 to other uses. The difference in present value net revenue to the oyster industry, assuming a constant price of $10.50 per bushel, between Solutions 1 and 5 is $9,337,454. The opportunity cost in terms of lost net revenue to the Commonwealth of continued reliance on the shelling of Baylor grounds market oyster producing grounds is, therefore, $9,337,454.

Changing the focus of the repletion program would greatly increase seed requirements. To provide for this increased requirement VMRC could increase the level of shelling in the James river seed beds. If, however, reef shell is used and continues to be purchased in Maryland, serious consideration should be given to developing seed beds in the Piankatank or Great Wicomico rivers to reduce the cost of transporting shell to the James. In Chapter VI, for example, it was shown that when fresh shell was not available and reef shell is purchased in Maryland it is more cost-effective to produce seed in the Great Wicomico than the James.

That any attempts to increase market oyster production would require seed production in excess of current harvest levels was emphasized by JLARC (1983). The results of this study bear this conclusion out. Table 7.1 shows that every solution determined for this study requires a greater level of seed oyster production than the Base solution. Increase-ing market oyster production 41.48% to 15,219,366 bushels over the Base solution requires seed production to increase by more than twice the levels determined in the Base solution. When market oyster harvest is increased 84.97% to 19,681,866 bushels seed oyster requiremsnts nearly triple. In general the percentage change in market oyster harvest is exceeded by the percentage change in seed production required to attain the corresponding market oyster production increase. That increased market oyster production becomes increasingly dependent on increased seed oyster production is borne out by the figures in column six of Table 7.1. These figures are equivalent to the ratio between bushels of seed used and market oysters produced for each harvest level. It is evident from these figures that increasing market oyster harvest will become increasingly dependent on Virginia's seed beds and VMRC's expertise in managing this vital resource.

TABLE 7.1

Level of Seed Used by Market Oyster Harvest Levels

Market Oyster Harvest	% Change	Seed Oyster Requirements	% Change	Dependecy Ratio
10756866.0		3062341.0		0.2847
	12.61		28.22	
12113641.0		3926439.0		0.3241
	2.64		5.23	
12432932.0		4131962.0		0.3323
	0.42		3.38	
12484557.0		4271810.0		0.3422
	7.55		10.59	
13427660.0		4724387.0		0.3518
	2.96		8.73	
13825274.0		5136726.0		0.3715
	1.25		-0.25	
13997425.0		5123730.0		0.3660
	8.73		21.84	
15219366.0		6242578.0		0.4102
	29.32		56.46	
19681866.0		10000710.0		0.5081

7.3 MEETING ALTERNATIVE HARVEST GOALS UNDER CURRENT MANAGEMENT POLICIES

The results of this study indicate that if the only change in current oyster bottoms management policies is to adopt the recommendation presented previously any efforts to increase market oyster harvest must be accompanied by repletion expenditures substantially greater than current funding levels. The results determined in Solution 1 show that increasing repletion expenditures 42.91% resulted in a 15.20% increase in market oyster harvest. Similarly, when the Base Solution harvest goal was increased by 50% and 100%, the required increase in average annual repletion expenditures was 143.50% and 290.42% respectively.

Due to the fixed proportions production function implied by the linear programming framework, these figures demonstrate that under current oyster grounds management policies, a one percent increase in the prespecified market oyster harvest goal must be accompanied by approximately a three percent increase in repletion expenditues. Extrapolating in this manner, it can be seen that, as the harvest goal is increased, the ability to achieve the harvest goal will be increasingly demanding of State funding resources.

7.4 REVISED OYSTER GROUNDS MANAGEMENT POLICIES

The previous discussions dealt only with the actual placement of shell and seed on Baylor grounds. This section provides recommendations for changes in the regulations or contractual arrangements governing the harvest of seed oysters and the mining of reef shell in Virginia.

7.4.1 Dredging Reef Shell in Virginia

Section 28.1-94.1 of the *Laws of Virginia Relating to The Marine Resources of the Commonwealth* (1980) grants VMRC the authority to contract the services of an individual or firm to dredge reef shell deposits. These shells may be sold or used for planting in the State's repletion program. VMRC currently uses large quantities of reef shell in its repletion program, but these shells are purchased and transported from Maryland. The cost of purchasing and transporting the shell, particularly to the lower reaches of the Bay, is probably greater than if the shells were mined in Virginia. Additionally, the ability of VMRC to purchase reef shell from Maryland sources may decrease as Maryland reef shell deposits become exhausted.

Setting an annual harvest goal of 1,912,500 bushels in Solution 8 and permitting the dredging of reef shell resulted in a $901,145 savings in repletion program costs over the ten year period. When, in Solution 7 the repletion budget was $900,000 per year and the dredging of reef shell was allowed, the present value net revenue was $61,211,208 assuming a constant price of $10.50 per bushel. In Solution 1 the drdging of reef shell was not permitted and present value net revenue was $59,501,001. With a repletion budget of $900,000 per year the present value opportunity cost to the Commonwealth of not contracting for the mining of reef shell in Virginia is $1,710,207.

VMRC should investigate the possibility of providing for its future reef shell requirements by contracting for shell mined in Virginia. Initiation of such a policy would either 1) reduce annual funding requirements or 2) increase the amount of Baylor bottoms VMRC is able to replete for the same funding level. Whichever of these two effects would occur would depend on VMRC's harvest goal.

7.4.2 Permitting the Dredging of Seed

Except for a few designated areas Article 9, Section 28.1-128 of the Laws of Virginia Relating to The Marine Resources of the Commonwealth (1980) prohibits the dredging of seed on public grounds oyster beds. The results from this study, however, show that permitting the dredging of seed would have a great impact on market oyster cost and production. A 50% increase in annual sustained market oyster production would be made possible with just a 17.55% increase in annual repletion funding over fiscal year 1984-85 budget allocations of $900,000. The cost of the increased market oyster harvest is estimated to be 30.32% less when dredging is permitted than under current harvest regulations. Even if budget allotments were not increased, a 29.92% increase in market oyster harvest would be possible if this policy alternative were implemented and, the revised repletion strategy suggested previously were chosen. The total present value cost of this additional production would only be 12.85% greater than the costs determined in the Base Solution. Once again Solution 1 may be used for comparison. In Solution 1 the present value net revenue to the oyster industry was $59,501,001. Solution 9 evaluated the same scenario as Solution 1 with the exception that a seed dredging policy was considered. In this solution the present value net revenue was $67,836,225. The $8,335,224 difference represents foregone income to the industry and the Commonwealth when the dredging of seed is not permitted and the annual repletion budget is $900,000.

Of the policy changes analyzed in this study, permitting the dredging of seed is the only one that would significantly affect the cost of private grounds market oyster production. One of the most often cited reasons for declining private grounds market oyster production is the high cost of procurring seed. Permitting the dredging of seed would greatly reduce the cost of this input and would likely stimulate increased private grounds production. A change in the seed harvest regulations would, therefore, reduce the repletion funding requirements of producing a prespecified harvest goal or increase the acheivable level of market oyster production for a given budget level and would make private grounds production a more profitable venture thereby stimulating an increase in production on leased bottoms.

7.4.3 Increasing Private Grounds Production

Most of the analayses conducted here concentrate on evaluating oyster bottoms management policies designed to increase market oyster harvest while keeping private grounds production at or near its current level. The analyses were conducted in this manner to address the concerns expressed by VMRC repletion program managers that increased public investment in the oyster industry be directed toward increasing market oyster production on public grounds. Solution 2 demonstrated that it was possible for VMRC to increase total State harvest by increaseing seed oyster supplies available to private planters without compromising its commitment to increasing public grounds market oyster harvest. It was found in Solution 2 that every 1% increase in total private grounds production required only a 0.267% scrifice in public grounds market oyster production. In Chapter I it was stated that the objectives of the ORP were to increase supplies of market oysters available to private planters working the public grounds and to increase supplies of seed oysters available to private individuals producing oysters on leased bottoms. The findings from Solution 2 suggest that, although, both objectives compete for VMRC's limited resources, it is possible to acheive the first objective without unduly hindering VMRC's ability to acheive the second.

7.5 A REVISED VIRGINIA OYSTER GROUNDS MANAGEMENT STRATEGY

From the preceding section, it can be seen that, individually, each of the recommended repletion and oyster grounds management policies tend to reduce the total cost of producing oysters, reduce the repletion program funding requirements for a given harvest level, and increase achievable market oyster harvest levels. The magnitude of these effects vary for each policy change. The effects of simultaneously implementing all the policy and repletion changes are even greater in magnitude. The following recommendations are made for a comprehensive State oyster grounds management strategy for increasing annual sustained market oyster production. The State should;

1. Change the focus of the repletion program from shelling Baylor grounds to transplanting seed on public oyster growing beds.
2. Permit the dredging of seed.
3. Increase the repletion program budget.
4. Use reef shell mined in Virginia when its use is necessary.
5. Increase shelling of seed beds to increase seed available to private planters.

Table 7.2 provides a summary of the management policies evaluated in this study. Changing the focus of the repletion program is critical. Table 7.2 shows that, compared to the Base solution, of the policy options evaluated changing the repletion program focus results in the largest increase in total market oyster production for an annual $900,000 repletion budget and requires the lowest increase in repletion program costs when an annual 1,912,500 bushel harvest goal is set. Additional production increases and cost savings would be acheivable if the dredging of seed were allowed and VMRC contracted for reef shell mining in Virginia. It is recognized that any attempts to increase market oyster production would put put additional stress on existing seed stocks. VMRC should, therefore, increase its shelling of public seed beds and intensify its efforts to develop other seed sources in addition to the James river. The figures in Table 7.2 show that under any one of the policy options evaluated, the most that State oyster harvest can be expected to increase at a repletion program funding level of $900,000 per year is 14.13%. If greater levels of market oyster production are deemed desireable by the Commonwealth then more than one of the policy alternatives considered in this study must be implemented simultaneously or the State will have to increase its financial commitment to public grounds oyster repletion.

The recommendations for a revised oyster grounds management plan made here are not new. As early as 1948 oyster biologists at the Virginia Marine Laboratory, known today as VIMS, recommended that VMRC plant shell only in seed areas to be transplanted to growing areas. Haven et. al. (1981) chronicles the recommendations made to VMRC by various State agencies from 1900 to 1969. A continuing theme expressed in this series of recommendations is the importance of shelling seed areas in the James, the development of alternative seed sources other than the James and the transplanting of seed to growing areas. That VMRC should also contract for the mining of reef shell in Virginia was also expressed by Haven et. al. (1981). In the 1983 JLARC study the shelling of seed areas and developing new seed sources was once again called for to supplement natural seed stocks and to increase seed supplies available to private planters. The 1983 JLARC study also called for consideration of a seed dredging policy to decrease the price of seed, thereby, stimulating private planting. Both JLARC studies of 1977 and 1983 stressed the need for increased State involvement in the replenishment of the public grounds implying a need for increased State support for the repletion program.

Table 7.2

Summary of Oyster Grounds Policy Evaluation

Management Policy	Total State Harvest (bushels)	Total Repletion Budget ($)	Total Present Value Cost ($)	Average Present Value Cost ($ per Bushel)
Base Solution	10756866.0	6290498.0	29186075	2.71
Current Regulations with:				
a) Increase Repletion Budget to $900,000 per year	12113641.0	9000000.0	34024932.0	2.81
b) Increase Annual Harvest Goal to 1,912,500 bushels	15219366.0	15335551.0	47267108.0	3.11
Change ORP Focus with:				
a) Increase Repletion Budget to $900,000 per year	13825274.0	9000000.0	37312748.0	2.69
b) Increase Annual Harvest Goal to 1,912,500 bushels	15219366.0	10240531.0	43269129.0	2.84
Permit Seed Dredging with:				
a) Increase Repletion Budget to $900,000 per year	13427660.0	9000000.0	32937258.0	2.45
b) Increase Annual Harvest Goal to 1,912,500 bushels	15219366.0	10579568.0	38593202.0	2.54
Permit Shell Dredging with:				
a) Increase Repletion Budget to $900,000 per year	12432932.0	9000000.0	34669513.0	2.79
b) Increase Annual Harvest Goal to 1,912,500 bushels	15219366.0	14434406.0	46536040.0	3.06

7.6 THE POTENTIAL FOR A FULL REPLETION COST RECOVERY OYSTER TAX

In Chapter V it was stated that the model developed in this study was inappropriate to determine what tax should be levied to recover all repletion costs. Table 5.32 presented the tax rates that would be sufficient to recover all repletion costs holding seed oyster taxes at their current levels. An examination of this table reveals that in nine of the thirteen scenarios analyzed the repletion programs implied by these solutions could be self-sufficient for less than a $0.75 increase in current market oyster taxes. A striking example is offered by a comparison between the Base Solution and Solution 11.

In the Base solution an oyster tax of $0.94 would be required to recover a $629,050 annual repletion budget. In Solution 11 the same tax rate is sufficient to recover annual costs of $900,000 when the policy changes indicated in the previous section are implemented. It is obvious that if these policy changes were made and if the repletion budget were not increased, market oyster production on public grounds would still be greater than in the Base solution and the cost recovery tax rate would be lower than $0.94. The point illustrated here is that a full cost recovery repletion program can be achieved at lower tax increases if appropriate cost reducing policy alternatives are exercised.

The results presented in Table 5.33 go further and indicate that if changes in present oyster grounds management policies are made and seed oyster taxes are increased even lower market oyster tax rates can be achieved. Recommendations for oyster grounds management policies have already been made and, if implemented, would result in greater market oyster production. Also, due to larger supplies of cheaper seed generated through increased shelling of seed beds and permitting seed harvest with a dredge, private grounds production is likely to increase in greater quantities than indicated in the scenarios analyzed here.

It seems clear that if the proposed policy changes are made, private planters stand to benefit substantially. A small bottoms rental fee is collected from leaseholders by the State but is not legislatively approved to be applied to the repletion program. Currently the only means of extracting any payment from private planters for repletion services is through the tax on seed oysters. Adopting the concept of a user fee, private planters should pay the unit cost of producing seed on public grounds. If, for example, the unit repletion cost of seed is $0.20 per bushel then the tax on seed oysters should be this amount. If seed oyster taxes are set at levels below the unit repletion cost of producing seed and market oyster taxes are set so as to recover all repletion expenses then, watermen working the public grounds would effectively be subsidizing private grounds production. An examination of the need to increase seed oyster taxes is, therefore, recommended. In addition or alternatively an investigation of alternative means of extracting payment from private leaseholders for repletion services is also recommended.

7.7 SETTING RESEARCH PRIORITIES

At the end of Chapter V, research priorities were determined for the technical coefficients evaluated in the sensitivity analysis. These coefficients were chosen because they were believed to be the most critical to the stability of the model's solutions and were amenable to the tests of sensitivity conducted for this study. There are other coefficients and assumptions that are also important but were not tested or the sensitivity tests did not lend themselves to adequate evaluation with the methods employed here. In this section research priorities will be discussed first for technical coefficients and then for the assumptions made in the model.

It is stressed that while most of the technical coefficients were found to be insensitive and the majority of the assumptions made in the model are not discussed here, this does not mean that they need not be subjected to review. In fact the opposite is recommended for anyone having any intention of using this model for policy or resource allocation decisions. For the most part, coefficients and assumptions not mentioned specifically in the sensitivity analysis or this chapter need only be subjected to verification and modification if necessary. An example of these coefficients is the availability of firm and soft bottoms in each river system. These coefficients could be easily checked against records available at VIMS or VMRC. The assumption that growth rates in each river system are the same is an example of one of the model's assumptions that should be reviewed by oyster biologists and management specialists before the model is used in oyster grounds management decision making.

7.7.1 Research Priorities for Techncal Coefficients

The highest priority for research on the technical coefficients should go to investigating the seed and market oyster productivity coefficients. Of most importance is the relationship between bushels of seed planted and bushels of market oysters produced for public and private grounds. This coefficient is particularly important because, as the results presented in Chapter V, indicate all discretionary repletion activities take this form. A better knowledge base for these relationships on a river system level would ensure that the placement of seed in a given river system would result in the greatest production per dollar spent.

The seed productivity coefficients receive second priority because as the sensitivity analysis shows, this coefficient does not affect the selection of repletion activities required to achieve a given harvest goal for most policy changes. It is given a high priority, however, because, when fresh shell is limited in supply, the results of the sensitivity test suggest that the focus of seed production should shift from the James to the Great Wicomico or Piankatank rivers. Special emphasis should, therefore, be given to investigating the feasibility of developing additional seed beds in these two river systems. Additionally, it was shown that a policy permitting the dredging of seed would greatly reduce costs and increase potential market oyster prodcution for a given repletion budget. Careful consideration should given to the effects of dredging in the James because of the kepone problem. Once again the importance of developing the Great Wicomico and the Pinkatank as alternative seed sources so that VMRC and the private sector can take advantage of a cheaper source of seed.

Next priority for technical coefficient research is the estimation of the cost and daily harvest of market oysters by different gear types for the various river systems in the Bay. This research would provide more accurate evaluation of the cost and production effects of alternative harvest gear restrictions.

Last priority in this section is the evaluation of natural seed and market oyster production. The results of the sensitivity analysis show that these coefficients are sensitive with respect to cost and production effects. The magnitude of the changes in the solutions was not great, however, when compared to the magnitude of change investigated for these coefficients. This result probably arises because the solution tested was for relatively small increases in the repletion budget and market oyster harvest. It is likely that these natural production coefficients would be more important at higher levels of market oyster production. These coefficents are given a lower research priority, however, because of the difficulty of estimating natural seed and market oyster production with any degree of accuracy. It is better, therefore, to concentrate on research areas that may be of less importance but have a higher likelihood of acheiving some real knowledge gains.

7.7.2 Research Priorities for Model Assumptions

The most critical assumption made in the model is that all market and seed oyster production is harvested and that private grounds production would be at least at the levels determined in the model. There is no way to know whether or not the harvest levels and activities implied by the model's solutions will bear any resemblance to what actually occurs. Additional research is needed to determine the desirability of increased levels of oyster production. The results of the econometric modeling conducted for the 1983 JLARC study indicate that oyster prices are relatively inflexible over the range of output levels considered in this study. It is not clear, however, that even if oyster prices do not fall private grounds production will become profitable enough to encourage additional private grounds production. Further, it is not certain that even if market oyster supplies are increased sufficient labor will exist to harvest the increased production.

Considered second most critical is the assumption that a zero cost of transporting the harvested market oysters to the processing site. In general the solutions determined in this study indicate that most production takes place in areas that are currently in proximity to shucking houses located in the area. It is possible that these results may change, and the production of market oysters could be concentrated in areas removed from nearby processing houses. Consideration, therefore, should be given to adding an additional cost to the market oyster production activities to reflect the extra cost of transporting oysters to a shucking house or buy boat. If, however, these costs are great enough, it may be more cost-efective to relocate shucking houses to the harvest site. Consideration should be given to the development of a spatial equilibrium model to determine the optimal location for shucking houses and transportation methods and routes.

Last priority in this section is given to the general result that private grounds market oyster production is more cost-effective than public grounds production. It is quite clear, however, that the Baylor grounds were delineated on the basis of naturally occuring shell or market oysters. These bottoms are, therefore, supposedly the "best" growing areas in the State. The results of the scenarios evaluated here, however, indicate that private grounds production is more cost-effective than public grounds production. The reason this occurs is because the establishment costs of private growing beds are assumed to be zero and private planters are assumed to use more cost-effective harvest technologies. The oyster grounds preparation costs are assumed zero because no information was available in regard to their magnitude. Indeed, information on most aspects of the oyster production activities of private leaseholders is lacking. Further research is recommended to better understand the cost and production conditions faced by private planters and how VMRC's repletion and policy decisions affect these conditions. The results of this research will likely reveal that the Baylor grounds are in fact the "best" growing bottoms but because of harvest cost disadvantages the public grounds are not the most cost-effective growing areas.

That the results of this analysis show the public grounds to be less cost-effective than private grounds is a product of the assumptions made in formulating the model, the assumptions made to estimate the technical coefficients and the policy alternatives evaluated. There is no reason to believe that under different policy arrangements not evaluated here, that public grounds production could be equally as cost-effective as private grounds production. One such policy might be the leasing of dredging rights on public grounds.

7.8 CONCLUSIONS

The purpose of this study was to construct a model that could be used to evaluate the cost and production effects of alternative oyster bottoms management stategies. The use of the model was demonstrated for several types of management options. While little weight should be paid to the actual numeric results of these analyses, the consistency of the results and the sensitivity analysis does provide convincing support for the policy recommendations listed earlier in this chapter. Among these, changing the mix of repletion activities from shell-harvest to seed-transplant-harvest is the most important. Indeed, without this fundamental change in the repletion program, the policy recommendations made in this chapter would be virtually ineffective in increasing market oyster oyster harvest particularly on the public oyster grounds without massive increases in repletion program funding.

Even if all the policy recommendations made in this study are implemented, it is not likely that Virginia market oyster landings will increase dramatically without some form of increased repletion program funding. This increased funding must come from either additional State contributions or from higher taxes on seed and market oysters taken from the public grounds or more likely some combination of the two. This study shows that the policies recommended here reduce the cost of the repletion program and, therefore, reduce the tax necessary to recover these costs. If additional market oyster harvest is desired beyond what the current repletion program budget allows, the State must assess the possibility of increasing oyster taxes and to what level the taxes can be increased in order to recover some portion of the increased repletion program funding needs.

Previously it was stated that the absolute numeric results of the analyses conducted for this study should not be interpreted with caution. The reason for this is that the estimation of the model's technical coefficients represents only a first approximation at understanding the complex interrelated economic, environmental and biological factors that determine the economic feasibility and productivity of any one aquacultural technique in any one river system. The same can be said for the assumptions that went into the formulation of the tecnical structure of the model. The purpose of the sensitivity analysis was to determine which of these coefficients were of greatest importance and suggest research priorities for them. It is hoped that future research will be incorporated into the model's technical information and the numeric results of the model will be able to be interpreted with a reasonable amount of reliability. In short, before the quantitative results of the model's solutions can be treated with confidence, a close scrutiny of every coefficient and every assumption is paramount to the proper and responsible use of this model.

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Appendix A

MODEL TECHNICAL COEFFICIENTS

Model Technical Coefficients

A.1 INTRODUCTION

The estimation of the model's technical coefficients was discussed in Chapter IV. This appendix provides the actual coefficients that were determined and incorporated into the model developed in Chapter III. The technical coefficients presented in the appendix will be discussed and presented in the same order as they were discussed in Chapter IV. The analyses conducted in Chapter V required changes in some of the technical coefficients. The adjusted coefficients are discussed in the last section of this appendix.

A.2 PUBLIC GROUNDS MARKET OYSTER PRODUCTION COST COEFFICIENTS

The total cost of public grounds market oyster production includes the repletion cost plus the harvest cost. Table A.1 presents the per bushel cost by repletion activity and shell type of repleting public oyster grounds in the first three columns. The figures in columns 5, 6 and 7 indicate the total cost of repleting one acre of Baylor bottoms by river system, bottom type and shell type. These figures are the actual technical coefficients used for the budget constraint now indicating the amount of the repletion budget used when the corresponding seed or market oyster production activity is initiated. The private cost component of one acre of any public grounds market oyster production activity requires the estimation of the per bushel harvest cost and the productivity of each repletion activity.

It is assumed that the harvest gear used on all public grounds is the hand-tong. Table A.2 presents the annual harvest budget that was estimated for a representative harvestor. The figures in this table are in 1961 dollars. Inflating the $1136.139 annual cost to 1983 dollars results in an annual harvest cost of $3037.65. Assuming that the average tonger fishes 75 days each year and catches 20 bushels per day, the cost per bushel of harvesting market oysters is estimated to be $2.025. The productivity of each public grounds repletion activity is presented in Table A.3 by activity type and river system. The figures in Table A.3 represent the number of bushels of market oysters produced on one acre of Baylor bottoms by river system and correspond to the technical coefficients denoted by the letter "G" in the constraint row labeled GOAL in Figure 3.4.

The figures in Tables A.1, A.2 and A.3 contain the necessary information to calculate each public grounds market oyster production activity objective function coefficient. Each public grounds market oyster production activ-

Table A.1
Public Grounds Repletion Cost Coefficients

	Shell-Harvest Repletion Cost per Bushel		Seed-Transplant-Harvest Cost Per Bushel ($)	Shell-Harvest Repletion Cost per Acre				Seed-Transplant-Harvest Repletion Cost Per Acre		
				Firm Bottoms*		Soft Bottoms**		Firm Bottoms ($)	Soft Bottoms*	
	Fresh Shell ($)	Reef Shell ($)		Fresh Shell ($)	Reef Shell ($)	Fresh Shell ($)	Reef Shell ($)		Fresh Shell ($)	Reef Shell ($)
Upper James	0.35	0.532		2450.0	3724.0	3500.0	5320.0			
Lower James	0.35	0.532		2450.0	3724.0	3500.0	5320.0			
Great Wicomico	0.35	0.408	3.00	2450.0	2856.0	3500.0	4080.0	1950.0	3700.0	3990.
Upper Rappahannock			3.00					1950.0	3700.0	4100.
Mid-Rappahannock	0.35	0.43	3.00	2450.0	3010.0	3500.0	4300.0	1950.0	3700.0	4100.
Lower Rappahannock	0.35	0.43		2450.0	3010.0	3500.0	4300.0			
Mobjack Bay	0.35	0.483		2450.0	3381.0	3500.0	4830.0			
Upper York			3.00					1950.0	3700.0	4487.
Lower York			3.00					1950.0	3700.0	4440.
Eastern Shore	0.35	0.50		2450.0	3500.0	3500.0	5000.0			
Piankatank	0.35	0.43	3.00	2450.0	3010.0	3500.0	4300.0	1950.0	3700.0	4100.
Upper Mgt. Area	0.35	0.408	3.00	2450.0	2856.0	3500.0	4080.0	1950.0	3700.0	3990.
Pocomoke and Tangier	0.35	0.408		2450.0	2856.0	3500.0	4080.0			

* @ 7,000 bushels of shell per acre.
** @ 10,000 bushels of shell per acre.
*** @ 5,000 bushels of shell per acre and 650 bushels of seed per acre.

TABLE A.2

Annual Hand Tong Harvest Budget

Variable Costs		
Vessel Maintenance	85.0	
Gear Maintenance	35.0	
Fuel $1.10/day for 75 days	82.50	
Wages	900.0	
	Total Variable Costs	1102.5
Fixed Costs		
Vessel Principal*	10.35	
Interest Payment	23.29	
	Total Fixed Cost	33.64
	Total Cost	1136.139

* $1700.0 first cost amortized over 15 years at 5%.

Source: Chesapeake Bay Fishing Harbors Economic Study 1961.

TABLE A.3

Public Grounds Productivity Coefficients

	Shell-Harvest Activities	Seed-Transplant Activities
Upper James	63.75	
Lower James	50.0	
Pocomoke & Tangier	161.0	
Eastern Shore	20.0	
Upper York		650.0
Lower York		650.0
Upper Rappahannock		1300.0
Middle Rappahannock	254.0	975.0
Lower Rappahannock	200.0	
Mobjack Bay	70.0	
Piankatank	318.0	975.0
Great Wicomico	206.0	975.0
Upper Management Area	50.0	650.0

Source: Haven et. al (1981)
Present Potential Prod: and persons interview w/VMRC repletion officers

ity is listed in Table A.4 by bottom type, production activity, shell type and river system. Each coefficient in this table is on a one acre basis calculated by multiplying the $2.025 per bushel harvest cost coefficient by the appropriate productivity coefficient listed in Table A.3 and adding the corresponding repletion cost coefficient. For example, to calculate the objective function coefficient for an acre of the shell-harvest activity using reef shell on firm bottom in the Mobjack Bay the following steps are required. First, from Table A.3 a shell-harvest activity in the Mobjack Bay results in the production of 70 bushels of market oysters. The total private cost of this activity is 70 bushels per acre multiplied by the $2.025 per bushel harvest cost or $141.75. The total repletion cost of $3381.0 for this activity can be found in column 5 row 7 of Table A.1. The sum of the private plus public cost for the Mobjack Bay shell-harvest activity is $3522.75 and is recorded in column 2 row 10 of Table A.4. To determine the value for each public grounds objective function coefficient for any given year it is necessary to multiply the coefficient of interest by the appropriate discount factor listed in Table A.5.

Table A.4

Public Grounds Repletion Activity Objective Function Coefficients

	Shell-Harvest Repletion Cost per Acre				Seed-Transplant-Harvest Repletion Cost Per Acre		
	Firm Bottoms		Soft Bottoms		Firm Bottoms ($)	Soft Bottoms	
	Fresh Shell ($)	Reef Shell ($)	Fresh Shell ($)	Reef Shell ($)		Fresh Shell ($)	Reef Shell ($)
Upper James	2579.09	2853.09	3629.09	5449.09			
Lower James	2551.25	3825.25	3601.25	5421.25			
Great Wicomico	2867.15	3382.50	3917.15	4497.15	3924.38	5674.38	5964.38
Upper Rappahannock					4582.50	6332.50	6732.50
Mid-Rappahannock	2964.35	3524.35	4014.35	4814.35	3924.38	5674.38	6075.38
Lower Rappahannock	2855.00	3415.00	3905.00	4705.00			
Mobjack Bay	2590.75	3522.75	3641.75	4971.75			
Upper York					3266.25	5015.25	5803.75
Lower York					3266.25	5015.25	5756.25
Eastern Shore	3641.75	3641.75	5141.75	5141.75			
Piankatank	3093.95	3653.95	4143.95	4943.95			
Upper Mgt. Area	2551.25	2957.25	3601.25	4181.25	3266.25	5016.25	5306.25
Pocomoke and Tangier	2776.03	3182.03	3826.03	4406.00			

TABLE A.5

Public Grounds Activity Discount Factors

Year	Discount factor
1	1
2	.9155547
3	.876048
4	.838237
5	.8020661
6	.7674538
7	.7343384
8	.7026469
9	.6723232
10	.6433102

Source: Federal Reserve Bulletin January 1984

A.3 PRIVATE GROUNDS PRODUCTION COST COEFFICIENTS SEED PLANTING AND MARKET OYSTER HARVEST

The objective function coefficient for private grounds market oyster production cost consists of two elements, the cost of planting seed and the cost of harvesting market oysters. It is assumed that the per bushel cost of planting seed is the same for all private planters and is estimated to be $0.55 per bushel in 1983 dollars (Haven et al. 1981). Private planters are assumed to plant 750 bushels of seed on one acre of leased bottoms. The cost of planting seed on one acre of leased bottom is, therefore, $412.50 for all private planters. The harvest cost for one acre of leased ground depends on the productivity of that acre.

The productivity coefficients for an acre of leased bottom by river system are listed in column 1 of Table A.6. In Figure 3.4 these coefficients correspond to the letter "G" in the row labeled "GOAL" and the columns indicated as being private grounds production activities. It is assumed that private planters use an oyster dredge to harvest their market oysters. An estimated annual budget for representative harvestor using an oyster dredge is presented in Table A.7. Like the hand-tong budget the cost figures are in 1961 dollars. Inflating the total annual harvest cost to 1983 dollars and dividing by total annual harvest yields a $1.602 per bushel harvest cost of using an oyster dredge. Multiplying this harvest cost by the productivity coefficients indicated in Table A6 and adding the $412.50 seed planting costs to this product yields the objective function coefficients for the private grounds market oyster production activities listed in column 2 of Table A.6. The discount factors applied to each year of the planning horizon for the private grounds activities are listed in Table A.8.

TABLE A.6

Private Grounds Productivity Coefficients And Obejective Function Coefficients

	Private Grounds Total Cost Coefficients ($ per acre)	Private Grounds Productivity Coefficients (bushels per acre)
Upper James	1612.50	750.0
Lower James	1612.50	750.0
Pocomoke & Tangier	1612.50	750.0
Eastern Shore	4800.00	750.0
Upper York	2215.50	1125.0
Lower York	1612.50	750.0
Upper Rappahannock	2215.50	1125.0
Middle Rappahannock	2215.50	1125.0
Lower Rappahannock	1612.50	750.0
Mobjack Bay	1612.50	750.0
Piankatank	2215.50	1125.0
Great Wicomico	2812.50	1500.0
Upper Management Area	1612.50	750.0

*Source: Personal Interview w/VMRC repletion officers, Haven et al. 1981

TABLE A.7

Annual Dredge Harvest Budget

Variable Costs			
Vessel Maintenance	1800.0		
Gear Maintenance	350.0		
Fuel $7.00/day for 75 days	525.0		
Wages	3562.5		
Food	675.0		
		Total Variable Costs	6912.5
Fixed Costs			
Vessel Principal*	58.9		
Gear Principal**	133.3		
Interest Payment	85.45		
		Total Fixed Cost	277.68
		Total Cost	7190.18

* $4300.0 first cost amortized over 15 years at 5%.
** $2000.0 fisrt cost amortized over 15 years at 5%.

Source: Chesapeake Bay Fishing Harbors Economic Study 1961.

TABLE A.8

Private Grounds Activity Discount Factors

Year	Discount factor
1	1
2	.8899964
3	.8396165
4	.7290918
5	.7472557
6	.7049601
7	.6650572
8	.6274116
9	.5918981
10	.5583941

Source: Federal Reserve Bulletin January 1984

A.4 SEED PURCHASE AND TRANSPORT COST COEFFICIENTS

The cost of harvesting, purchasing and planting seed oysters for the public grounds repletion activities are included in the per bushel repletion cost figures listed in Table A.1 for the seed-transplant-harvest activities. For the private grounds activities, however, the cost of purchasing and transporting seed is not included in the objective function coefficient for the private grounds production activities. Rather these costs are the objective function coefficients for the private grounds seed transport activities.

The price of seed was assumed to be constant and was set at $2.38 (VMRC Production and Repletion Data 1962-1983). Estimation of the transport cost was discussed in Chapter IV. In this chapter a weighting system was established. The actual cost of transporting seed assigned to each river system is presented in Table A.9. To each coefficient listed in Table A.9 the $2.38 per bushel purchase price is added, yielding the objective function coefficients listed in Table A.10 for each private seed transport activity. The discount factors listed in Table A.8 were used to discount these objective function coefficients to the first period of the two year planning horizon.

Table A.9

Seed Transport Cost to Private Grounds

Receiving River System	Seed Source					
	Upper James	Lower James	Piank-atank	Lower Rapp-ahannock	Mobjack Bay	Great Wicomico
Upper James	0.00	0.00			0.35	
Lower James	0.00	0.00			0.35	
Great Wicomico	0.45	0.45	0.30	0.30	0.50	0.00
Upper Rappahannock	0.40	0.40	0.25	0.25	0.45	0.30
Mid-Rappahannock	0.40	0.40	0.25	0.25	0.45	0.30
Lower Rappahannock	0.40	0.40	0.25	0.25	0.45	0.30
Mobjack Bay	0.30	0.30			0.25	
Upper York	0.25	0.25	0.35	0.40	0.30	0.45
Lower York	0.25	0.25		0.40	0.30	
Eastern Shore	0.50	0.50			0.50	
Piankatank	0.35	0.35	0.00		0.40	
Upper Mgt. Area	0.45	0.45	0.30	0.30	0.50	0.0
Pocomoke and Tangier	0.50	0.50			0.50	

Table A.10

Private Grounds Seed Transport and Purchase Cost Coefficients

Seed Source

Receiving River System	Upper James	Lower James	Piank-atank	Lower Rapp-ahannock	Mobjack Bay	Great Wicomico
Upper James	2.38	2.38			2.73	
Lower James	2.38	2.38			2.73	
Great Wicomico	2.83	2.83	2.68	2.68	2.88	2.38
Upper Rappahannock	2.78	2.78	2.63	2.63	2.83	2.68
Mid-Rappahannock	2.78	2.78	2.63	2.63	2.83	2.68
Lower Rappahannock	2.78	2.78	2.63	2.63	2.83	2.68
Mobjack Bay	2.68	2.68			2.63	
Upper York	2.63	2.63	2.73	2.78	2.68	2.83
Lower York	2.63	2.63		2.78	2.68	
Piankatank	2.73	2.73	2.38		2.78	
Upper Mgt. Area	2.83	2.83	2.68	2.68	2.88	2.38
Pocomoke and Tangier	2.88	2.88			2.88	

A.5 SEED PRODUCTION COST COEFFICIENTS

All seed is assumed to be produced on public grounds seed beds. The cost of producing seed consisted only of the repletion cost of shelling Baylor bottoms seed beds. It is assumed that the shelling rates used for seed production activities are the same as they were for shell harvest market oyster production activities. The cost, therefore, of producing seed is the same as that listed in Table A.1 for the shell-harvest activities for river systems designated as seed areas. The objective function coefficients for one acre of the seed production activities are listed in Table A.11 by bottom type, shell type and river system. The productivity of one acre of each seed area is presented in column 5 of Table A.11. These coefficients correspond to the letters SP in the row labeled THT and the columns indicated as being seed production activities in Figure 3.4.

Table A.11

Public Grounds Repletion Cost Coefficients

	Seed Beds Repletion Cost per Acre				
	Firm Bottoms*		Soft Bottoms**		
	Fresh Shell ($)	Reef Shell ($)	Fresh Shell ($)	Reef Shell ($)	Seed Area Productivity (Bushels/Acre)
Upper James	2450.0	3724.0	3500.0	5320.0	1750.0
Lower James	2450.0	3724.0	3500.0	5320.0	700.0
Great Wicomico	2450.0	2856.0	3500.0	4080.0	1400.0
Lower Rappahannock	2450.0	3010.0	3500.0	4300.0	700.0
Mobjack Bay	2450.0	3381.0	3500.0	4830.0	700.0
Piankatank	2450.0	3010.0	3500.0	4300.0	1000.0

* @ 7,000 bushels of shell per acre.
** @ 10,000 bushels of shell per acre.

A.6 ESTIMATION OF CONSTRAINT COEFFICIENTS

The only constraint coefficients not previously presented are the limits of public and private market oyster production grounds. The limits to availability of firm and soft Baylor grounds and to leased bottoms are presented in Table A.12.

TABLE A.12

Acreage of Public And Private Growing Bottoms

	Public Grounds		
	Firm	Soft	Leased Bottom
Upper James	4175.30	9801.89	10081.63
Lower James	4175.30	9801.89	5040.82
Pocomoke & Tangier	1557.60	4400.30	8918.80
Eastern Shore	504.90	6720.90	15736.10
Upper York	381.90	484.30	5855.45
Lower York	98.80	932.10	5855.45
U. Rappahannock	1124.70	2696.10	4472.90
M. Rappahannock	946.70	1840.70	4472.90
L. Rappahannock	717.40	2389.60	4472.90
Mobjack Bay	152.20	455.10	12555.60
Piankatank	331.00	1118.10	1867.40
G. Wicomico	205.50	287.40	1000.00
Upper Management Area	100.0*	200.0*	2287.2**

*Source: Haven et al. 1981 Oyster Ind. et.
**Source: Haven et al. 1981 Present and Pot. Prod.

A.7 ADJUSTED COEFFICENTS

In Solutions 7 and 8 the policy to permit the dredging of reef shell was analysed. To evaluate this policy it was necessary to estimate what the cost of dredging reef shell in Virginia might be. It was assumed that the dredging costs would be similar to what they are for Maryland dredgers. The cost of reef shell to private planters in Maryland was $0.38 per bushel (Langenfelder & Sons Inc. prices 1983). Using this figure the coefficients for the public grounds shelling activities requireing reef shell listed in Table A.4 were recalculated and are presented in Table A.13. The numbers listed in Table A.13 are, therefore, the objective function coefficients for the public grounds shell-harvest and seed production activities when the policy to permit the dredging of reef shell was evaluated.

Solutions 9 and 10 considered a policy permitting the dredging of seed. Evaluating this policy required two adjustments. First, the cost of harvesting seed under such a policy was estimated to be $0.50 per bushel. Substituting this figure for the $3.00 per bushel repletion cost indicated in Table A.1 the objective function coefficients for the public grounds seed-transplant-harvest activities were recalculated and are presented in Table A.14. The second adjustment required to evaluate a seed dredging policy is to

Table A.13

Adjusted Public Grounds Repletion Objective Function Coefficients

	Shell-Harvest Repletion Cost per Acre		Seed-Transplant-Harvest Repletion Cost Per Acre	Seed Production Cost Per Acre	
	Firm Bottoms Reef Shell ($)	Soft Bottoms Reef Shell ($)	Soft Bottoms Reef Shell ($)	Firm Bottoms Reef Shell	Soft Bottoms Reef Shell
Upper James	2789.09	3929.09		2660.00	3800.0
Lower James	2761.25	3901.25		2660.0	3800.0
Great Wicomico	3077.15	4217.15	5824.38	2660.0	3800.0
Upper Rappahannock			6482.50		
Mid-Rappahannock	3174.35	4314.35	5824.38		
Lower Rappahannock	3065.00	4205.00		2660.0	3800.0
Mobjack Bay	2801.75	3941.75		2660.0	3800.0
Upper York			5166.25		
Lower York			5166.25		
Eastern Shore	2801.75	3941.75			
Piankatank	3303.95	4443.95		2660.0	3800.0
Upper Mgt. Area	2761.25	3901.25	5166.25		
Pocomoke and Tangier	2986.03	4126.03			

adjust the private grounds seed transport objective function coefficients. These adjusted coefficients are listed in Table A.15 and were calculated by adding the $0.50 per bushle harvest cost of seed to the transport costs indicated in Table A.9.

The final solutions evaluated for this study included a policy the allowed both the dredging of shell and the dredging of seed. The coefficients in the baseline model for the shell-harvest activities using reef shell were replaced with the coefficients listed in Table A.13. The public grounds seed-transplant-harvest and the private grounds seed transport objective function coefficients were replaced with the coefficients listed in Tables A.14 and A.15 respectively with one exception. The objective function coefficients for the seed-transplant-harvest activity on soft bottom using reef shell had to be reestimated accounting for the lowered cost of seed and reef shell. These coefficients are presented in Table A.16.

TABLE A.14

Adjusted Public Seed-Transplant-Harvest Objective Function Coefficients

River System	Objective Function Coefficient by: Shell Type / Bottom Type	Fresh	Reef
	Firm	Soft	Soft
Great Wicomico	2299.38	4049.38	4339.38
Upper Rappahannock	2957.50	4707.50	5107.50
Mid-Rappahannock	2299.38	4049.38	4449.38
Upper York	1641.25	3391.25	4178.75
Lower York	1641.25	3391.25	4131.25
Upper Mgt. area	1641.25	3391.25	3681.25

Table A.15

Adjusted Seed Transport Private Grounds Objective Function Coefficients

Receiving River System	Seed Source					
	Upper James	Lower James	Piank-atank	Lower Rapp-ahannock	Mobjack Bay	Great Wicomico
Upper James	0.50	0.75			0.85	
Lower James	0.00	0.00			0.85	
Great Wicomico	0.95	0.95	0.80	0.80	1.00	0.00
Upper Rappahannock	0.90	0.90	0.75	0.75	0.95	0.80
Mid-Rappahannock	0.90	0.90	0.75	0.75	0.95	0.80
Lower Rappahannock	0.50	0.90	0.75	0.75	0.95	0.80
Mobjack Bay	0.80	0.80			0.75	
Upper York	0.75	0.75	0.85	0.90	0.80	0.95
Lower York	0.75	0.75		0.90	0.80	
Eastern Shore	1.00	1.00			1.00	
Piankatank	0.85	0.85	0.50		0.90	
Upper Mgt. Area	0.95	0.95	0.80	0.80	1.00	0.50
Pocomoke and Tangier	1.00	1.00			1.00	

TABLE A.16

Adjusted Public Grounds Seed-Transplant-Harvest Objective Function Coefficients

River System	Total Cost With Soft Bottom and Reef Shell ($ per acre)
Great Wicomico	4199.38
Upper Rappahannock	4557.50
Mid-Rappahannock	4199.38
Upper York	3541.25
Lower York	3541.25
Upper Mgt. Area	3541.25

Appendix B

ADDITIONAL SOLUTIONS

Additional Solutions

B.1 INTRODUCTION

In Chapter V several options to increase market oyster harvest were evaluated. The first policy to be evaluated was to increase repletion program funding. An annual budget level was set at $900,000 in Solution 1. This budget level was chosen because it was the actual funding allocated for repletion for final year 1985. In conversations with VMRC repletion program managers the likelihood of further increasing repletion program funding in the future was discussed. Two alternative funding levels are evaluated in this appendix. The annual repletion budget was set at $1,012,500 and then at $425,000. The achievable sustainable level of market oyster production was then determined. The results of these two analyses are then presented.

Policies of changing the focus of the repletion program, dredging shell, dredging seed and combining the dredging of shell and seed were also evaluated in Chapter V. For each scenario a 1,912,500 bushel annual harvest goal was set and the repletion and production costs of sustaining such a goal over a ten year period were determined. Each of these policy options will be re-evaluated in this appendix with an annual harvest goal of 2,550,000 bushels.

B.2 SOLUTION A: INCREASING ORP FUNDING TO $1,012,500 ANNUALLY

In this solution authorized spending by VMRC is assumed to be increased 25%. The State is also assumed to increase its financial commitment to the repletion program by the same percentage to $437,500. The total harvest of market oysters over the ten year period with an average annual repletion budget of $1,0125,000 is 12,502,666 bushels. The present value cost of this harvest level is $35,617,595. Sustained production on public grounds is 899,401 bushels while private production in each year is 625,000 bushels. Table B.1 presents the schedule of repletion expenditures, tax collections and revenue deficiencis that VMRC must raise through royalty or permit collections.

Discretionary seed and market oyster production activities for public and leased bottoms are presented in Table B.2. The Upper Rappahannock remains the most important public grounds growing area. Seed production is required in each year to supplement naturally available seed stocks. Again, as in previous solutions and for the same reason, the activity level for public grounds oyster production increases while private production decreases in year 10 as the repletion budget becomes binding.

TABLE B.1

Solution A Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required	(3) Taxes Collected	(4) (2) - (3)	(5) (4) - 437500	(6) Tax Rate*
1	646093.0	305716.0	340377.0	---	1.06
2	1027475.0	349678.0	677797.0	240297.0	1.61
3	1114975.0	349678.0	765297.0	327797.0	1.75
4	1027475.0	500318.0	527157.0	89657.0	1.09
5	1027475.0	494068.0	533407.0	95907.0	1.09
6	1114975.0	494068.0	620907.0	183407.0	1.19
7	1027475.0	500318.0	527157.0	89657.0	1.09
8	1027475.0	494068.0	533407.0	95907.0	1.09
9	1099082.0	494068.0	605014.0	167514.0	1.17
10	1012500.0	499183.0	513317.0	75817.0	1.09
				average rate	1.22

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table B.2

Timing and Level of Discretionary Activities, Solution A

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		195.60	195.60	195.60	195.60	195.60	195.60	195.60	195.60	248.00
Great Wicomico	L		416.67	416.67	166.67	416.67	416.67	166.67	416.67	416.67	166.67
Upper Rappahannock	L							228.00			
Upper York	L				333.33			106.00			273.00
Seed Production											
Acres: Upper James	P	9.6	9.6	45.3	9.6	9.6	45.3	9.6	9.6	38.8	
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4049.5	114323.0	114323.0	131177.0	114323.0	114323.0	131177.0	114323.0	114323.0	165233.0
Great Wicomico	L		312500.0	312500.0	125000.0	312500.0	312500.0	125000.0	312500.0	312500.0	125000.0
Upper Rappahannock	L							170645.0			
Upper York	L				170645.0						136590.0
From Upper James to:											
Bu.: Upper York	L				79354.0			79354.0			68002.0
Upper Rappahannock	P		16800.0	16800.0		16800.0	16800.0		16800.0	16800.0	

* P = Public Grounds, L = Leased Grounds

B.3 SOLUTION B: INCREASING ORP FUNDING TO $1,125,000

When annual repletion program funding is increased 25% over the $9,000,000 funding level to $1,125,000 the annual sustainable levle of market oysters harvested is 1,579,976 bushels. Of this total 625,000 and 954,976 bushels come from private and public grounds respectively. Total market oyster harvest over the ten year planning horizon is 12,891,698 bushels at a present value cost of $37,341,717. The actual level and timing of repletion expenditures and tax collections is presented in Table B.3.

The actual mix of repletion and production activities required to achieve the harvest goal presented in table B.4 differs very little from Solution A when the repletion budget was set at $1,012,500. The Upper Rappahannock and the Great Wicomico respectively remain the dominant public and private market oyster producing areas.

TABLE B.3

Solution B Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required	(3) Taxes Collected	(4) (2) - (3)	(5) (4) - 437500	(6) Tax Rate*
1	684995.0	305716.0	379279.0	29274.0	1.12
2	1170574.0	352457.0	818117.0	468117.0	1.84
3	1216408.0	353946.0	862462.0	512462.0	1.91
4	1149741.0	529422.0	620319.0	270314.0	1.15
5	1170574.0	524660.0	645914.0	295914.0	1.18
6	1216408.0	526148.0	690260.0	340260.0	1.22
7	1149741.0	529422.0	620319.0	270319.0	1.15
8	1170574.0	524660.0	645914.0	295914.0	1.18
9	1195983.0	526148.0	669835.0	319835.0	1.20
10	1125000.0	527963.0	597037.0	247037.0	1.13
				average rate	1.31

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table B.4

Timing and Level of Discretionary Activities, Solution B

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		238.33	238.33	238.33	238.33	238.33	238.33	238.33	238.33	305.66
Great Wicomico	L		416.67	357.14	226.19	416.67	357.14	226.19	416.67	357.14	226.19
Upper Rappahannock	L				130.95			130.95			
Upper York	L			79.36	123.02		79.36	123.02		79.36	103.56
Piankatank	L										72.60
Seed Production											
Acres: Upper James	P	25.51	34.01	52.72	25.51	34.01	52.72	25.51	34.01	44.38	
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4050.0	114323.0	158965.0	158965.0	114323.0	158965.0	158965.0	114323.0	158965.0	202733.0
Great Wicomico	L		312500.0	267858.0	169642.0	312500.0	267858.0	169642.0	312500.0	267858.0	169642.0
Upper Rappahannock	L				98216.0			98216.0			
Piankatank	L										54448.0
From Upper James to:											
Bu.: Upper Rappahannock	P		44642.0			44642.0			44642.0		
Upper York	L			59522.0	92261.0		59522.0	92261.0		59522.0	77672.0

* P = Public Grounds, L = Leased Grounds

B.4 SUMMARY OF SOLUTIONS A AND B

Table B.5 presents a comparison between the Baseline condition and Solution 1 presented in Chapter V and Solutions A and B presented here. In Solution 1 total repletion expenditures increased 42.9% over the base solution resulting in a 12.61% increase in total market oyster harvest. Market oyster production increased 16.23% over the Base solution in Solution A for a repletion budget increase of 60.77%. In Solution B the repletion budget increase of 28.63% resulted in market oyster harvest increase of 19.85% as compared to the Base solution.

Expressing these results in terms of a ration between the percentage increase in market oyster harvest and the percentage increase in repletion program expenditures reveals that this ratio declines as repletion expenditures increase. The impliction of this observation is that as repletion funding levels increase the rate of increase in market oyster production is less than the rate of increase in repletion funding. In evaluating alternative oyster grounds management policies, therefore, VMRC should consider that if no policy changes are made other than increasing the repletion budget attempts to increase market oyster harvest will be increasingly costly to the commonwealth.

Table B.5

Summary of Base Solution and Solutions 1, A and B

	Total Harvest (bushels)	Total Present Value Cost ($)	Average Present Value Cost ($/bushel)	Total Public Harvest (bushels)	Total Private Harvest (bushels)	Total Repletion Budget ($)	Tax Rate ($)
Base Solution	10756866.0	29186075.0	2.7133	6381866.0	4375000.0	6297780.0	0.94
Solution One	12113641.0	34024932.0	2.8088	7738641.0	4375000.0	9000000.0	0.94
Solution A	12502666.0	35617595.0	2.8488	8127666.0	4375000.0	9000000.0	1.22
Solution B	12891698.0	37341717.0	2.8966	8516698.0	4375000.0	9000000.0	1.31

B.5 REPLETION AND COST CONSEQUENCES OF INCREASING ANNUAL MARKET OYSTER HARVEST TO 2,550,000 BUSHELS

Each of the policy changes evaluated in Chapter V are evaluated here with a 2,550,000 bushel annual harvest goal.

B.5.1 Solution C: Changing the Focus of the Repletion Program

When non-discretionary repletion requirements are eliminated and the annual harvest goas is set at 2,550,000 bushesl the total repletion-funding-required to attain this harvest goal over the ten year planning horizon is $19,923,105. The total present value cost of producing and harvesting the harvest goal is 63,440,160. The schedule of repletion program outlays and tax collections is presented in Table B.6. At curent repletion taxes the average yearly difference between collections and expenditures is -$1,344,165. An average tax of $1.90 per bushel on market oysters would be required to recover repletion expenditures under the harvest goal. The level and timing of repletion and production activities required to produce the harvest goal is presented in Table B.7.

TABLE B.6

Solution C Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required	(3) Taxes Collected	(4) (2) - (3)	(5) Tax Rate*
1	906304.0	305311.0	660993.0	1.58
2	2088957.0	402280.0	1686677.0	3.26
3	2288695.0	418947.0	1869748.0	3.55
4	2243383.0	777903.0	1465480.0	1.62
5	2088957.0	746969.0	1341988.0	1.53
6	2288695.0	763636.0	1525059.0	1.67
7	2433831.0	777903.0	1465480.0	1.62
8	2088957.0	746969.0	1341988.0	1.53
9	2288696.0	763636.0	1525057.0	1.67
10	1337079.0	777903.0	559176.0	.93
			average rate	1.90

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table B.7

Timing and Level of Discretionary Activities, Solution C

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		530.29	530.29	64.12	530.29	530.29	64.12	530.29	530.29	64.12
Mid-Rappahannock	P				589.02			589.02			621.56
Great Wicomico	P				32.55			32.55			
Great Wicomico	L		833.33	166.67		833.33	166.67		833.33	166.67	
Upper York	L			888.89	1111.11		888.89	1111.11		888.89	1111.11
Seed Production											
Acres: Upper James	P	196.97	430.57	512.09	196.97	430.57	512.09	196.97	430.57	512.09	
Great Wicomico	P	172.96			172.96			172.96			
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P			257863.0			257863.0	41677.0		257863.0	41677.0
Great Wicomico	P				21154.0			21154.0			
Mid-Rappahannock	P				361709.0			320032.0			341186.0
Great Wicomico	L		382863.0	125000.0		382863.0	125000.0		382863.0	125000.0	
From Upper James to:											
Bu.: Upper Rappahannock	P		344689.0	86826.0	41667.0	344689.0	86826.0		344689.0	86826.0	
Mid-Rappahannock	P				21153.0			62830.0			62830.0
Upper York	L			666667.0	833333.0		666667.0	833333.0		666667.0	833333.0
From Great Wicomico to:											
Great Wicomico	L		242137.0			242137.0			242137.0		

* P = Public Grounds, L = Leased Grounds

B.5.2 Solution D: Permitting the Dredging of Reef Shell

The repletion funding required of a 2,550,000 annual harvest goal under a policy permitting the dredging of reef shell is $23,686,381. The total present value cost of achieving the harvest goal over the ten year period is $66,556,569. The schedule of repletion outlays and tax collections is presented in Table B.8. As in the Solution C, repletion program expenditures in such years are far greater than revenues received from oyster tax collections under current oyster tax levels. The schedule of repletion and production activities required to achieve the harvest goal is presented in Table B.9.

B.5.3 Solution E: Pemitting the Dredging of Seed

For a 2,550,000 bushel annual harvest goal the repletion funding required under a policy permitting the dredging of seed is $17,753,096. The present value cost of meeting and sustaining the harvest goal is $53,446,467 over the ten year period. Actual annual repletion expenditures and tax collections are presented in Table B.10. The schedule of repletion and production activities required to achieve the harvest goal duplicates that of Solution D and is presented in Table B.9.

TABLE B.8

Solution D Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required	(3) Taxes Collected	(4) (2) - (3)	(5) Tax Rate*
1	1340585.0	305716.0	1034869.0	2.19
2	2490365.0	400959.0	2089406.0	3.92
3	2664556.0	417877.0	2246679.0	4.18
4	2586243.0	775033.0	1811210.0	1.89
5	2490365.0	745672.0	1744693.0	1.84
6	2664556.0	762591.0	1901965.0	1.96
7	2586243.0	775033.0	1811210.0	1.89
8	2490365.0	745672.0	1744693.0	1.84
9	2664556.0	762591.0	1901965.0	1.96
10	1708547.0	775033.0	933514.0	1.22
			average rate	2.29

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

Table B.9

Timing and Level of Discretionary Activities, Solution D

Activity and River		Year and Activity Level 1	2	3	4	5	6	7	8	9	10
Seed-Transplant-Harvest											
Acres: Upper Rappahannock	P*		503.73	503.73	98.54	503.73	503.73	98.54	503.73	503.73	98.54
Mid-Rappahannock	P				540.26			540.26			540.26
Great Wicomico	L		833.33	156.59	10.07	833.33	156.59	10.07	833.33	156.59	10.07
Upper York	L			902.32	1097.68		902.32	1097.68		902.32	1097.68
Seed Production											
Acres: Upper James	P	189.42	399.34	470.43	189.42	399.34	470.43	189.42	399.34	470.43	
Great Wicomico	P	141.56			141.56			141.56			
Seed Transport											
From Natural Production to:											
Bu.: Upper Rappahannock	P	4050.0		309377.0	68101.0		309377.0	68101.0		309377.0	68101.0
Mid-Rappahannock	P				351167.0			351167.0			351167.0
Great Wicomico	L		426823.0	117446.0	7554.0	426823.0	117446.0	7554.0	426823.0	117446.0	7554.0
From Upper James to:											
Bu.: Upper Rappahannock	P		331477.0	22099.0		331477.0	22099.0		331477.0	22099.0	
Upper York	L			676739.0	823261.0		676739.0	823261.0		676739.0	823261.0
From Great Wicomico to:											
Great Wicomico	L		198177.0			198177.0			198177.0		

* P = Public Grounds, L = Leased Grounds

TABLE B.10

Solution E Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required	(3) Taxes Collected	(4) (2) - (3)	(5) Tax Rate*
1	1451073.0	305716.0	1145357.0	2.38
2	1892529.0	400959.0	1491570.0	2.94
3	2051298.0	417877.0	1633421.0	3.18
4	1797290.0	775033.0	1022257.0	1.29
5	1893816.0	745673.0	1148143.0	1.38
6	2051298.0	762591.0	1288707.0	1.49
7	1797290.0	775033.0	1022257.0	1.29
8	1904130.0	745673.0	1158457.0	1.39
9	2037614.0	763328.0	1274286.0	1.48
10	876758.0	774297.0	102461.0	.58
			average rate	1.74

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

B.5.4 Solution F: Permitting the Dredging of Shell and Seed

When both, the dredging of shell and the dredging of seed is considered the repletion cost of achieving the 2,550,000 bushel harvest goal is $16,851,951. The present value cost of attaining the harvest goal over the ten year planning horizon is $52,715,938. Table B.11 presents the schedule of repletion program expenditures and tax collections. The schedule of repletion and production activities required to achieve the harvest goal is the same as that as for Solutions D and E and can be found in Table B.9.

B.5.5 Summary of Solutions

Table B.12 presents a summary of Solution 4 from Chapter V and Solution C, D, E and F that were presented here. Solution 4 is included because it represents current oyster grounds repletion and regulatory management policies and will be used as a basis for comparison. A reduction in total repletion funding requirements for the 2,550,000 bushel harvest goal of 23.41% is realized when non-discretionary repletion constraints are dropped. Additionally, the average market oyster tax rate required to recover all repletion costs goes down 48.95% and the total present value cost of producing and harvesting the harvest goal falls 6.11%. Introducing the policy permitting the dredging of

TABLE B.11

Solution F Schedule of Repletion Funds and Tax Collections

(1) Year	(2) Funds Required	(3) Taxes Collected	(4) (2) - (3)	(5) Tax Rate*
1	1358286.0	305716.0	1052570.0	2.22
2	1799742.0	400959.0	1398783.0	2.79
3	1958510.0	417877.0	1540633.0	3.02
4	1704503.0	775033.0	929470.0	1.21
5	1801030.0	745673.0	1055357.0	1.31
6	1958510.0	762591.0	1195919.0	1.42
7	1704503.0	775033.0	929470.0	1.21
8	1811342.0	745673.0	1065669.0	1.32
9	1944827.0	763328.0	1181499.0	1.41
10	810698.0	774297.0	36401.0	.53
			average rate	1.64

*Calculated by subtracting revenues generated by the harvest of seed from column 2 and dividing the remainder by total public grounds market oyster harvest in the corresponding year.

reef shell does not result in substantial reduction in repletion on total costs as repletion costs decline only 3.8% and the total present value cost of attaining the harvest goal declines just 1.1%. A more dramatic cost reducing effect is produced by the policy permitting the dredging of seed. Under this policy the repletion cost and the total present value cost of meeting the harvest goal decrease 38.5% and 25.95% respectively. The full repletion cost recover tax rate also declines sharply from 2.83 in the Base solution to 1.24 in Solution E. Combining the policy permitting the dredging of reef shell and seed in Solution F results in cost reductions slightly greater than that determined in Solution E. Repletion funding requirements, total present value cost and the full repletion cost recovery tax rate declines 45.90%, 27.70% and 72.56% in Solution F over the Base solution.

Table B.12

Summary of Solutions 4, C, D, E, F

	Total Harvest (bushels)	Total Present Value Cost ($)	Average Present Value Cost ($/bushel)	Total Public Harvest (bushels)	Total Private Harvest (bushels)	Total Repletion Budget ($)	Tax Rate ($)
Solution Four	19681866.0	67317638.0	3.4203	10931866.0	8750000.0	24587521.0	2.83
Solution C	15219366.0	63440160.0	3.2233	10931866.0	8750000.0	19923105.0	1.90
Solution D	15219366.0	66586569.0	3.3831	10931866.0	8750000.0	23686381.0	2.29
Solution E	15219366.0	53446467.0	2.7155	10931866.0	8750000.0	17753096.0	1.74
Solution F	15219366.0	52715938.0	2.6784	10931866.0	8750000.0	16851951.0	1.64

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