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THE ECONOMIC FEASIBILITY OF UTILIZING WASTE HEAT FROM ELECTRICAL POWER PLANTS IN INTEGRATED AGRICULTURAL AND AQUACULTURAL SYSTEMS UNDER MICHIGAN CONDITIONS.

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THE ECONOMIC FEASIBILITY OF UTILIZING WASTE HEAT FROM ELECTRICAL POWER PLANTS IN INTEGRATED AGRICULTURAL AND AQUACULTURAL SYSTEMS UNDER MICHIGAN CONDITIONS

By

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ABSTRACT

THE ECONOMIC FEASIBILITY OF UTILIZING WASTE HEAT FROM ELECTRICAL POWER PLANTS IN INTEGRATED AGRICULTURAL AND AQUACULTURAL SYSTEMS UNDER MICHIGAN CONDITIONS

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Ronald L. Meekhof

Low grade energy in the thermal discharge of steam-electric power plants is dissipated into the environment via cooling towers, reservoirs, or spray canals. Waste heat is generally not considered to be a resource that can be applied to industrial processes or urban use. It has been found, however, that in controlled circumstances, the growth rates of selected agricultural crops and fish species have increased significantly with the use of waste heat in cultural practices.

Whether recycling of the waste heat in an integrated system of agricultural and aquacultural uses is economically feasible was evaluated. Least cost systems of sizes and types of uses were determined for several economic conditions. For each of the least cost system designs, a water transport system was designed. Whether a waste heat utilization system is a least cost alternative to conventional dissipation methods was then assessed. Several management and acquisition options were discussed. The impact of those

options on the distribution of costs, and consequently on the feasibility of a waste heat utilization system, was determined.

A pseudo-dynamic linear programming model was specified to solve for the optimal system design. Synthesized agricultural and aquacultural subsystems which are representative in terms of initial capital requirements, annual costs, productivity responses, and heat dissipation capability were the activities. Model specification stipulated that the amount of waste heat from a 1,000 megawatt electrical plant be dissipated.

Two cases of a purchase and leaseback option were analyzed should the utility decide not to manage the utilization system but maintain capital ownership. If ownership of fixed capital is not desired, a contractual arrangement was also evaluated. Partial budgeting analysis was used to assess the impact of each option on total monetary outlays of the utility.

The research results indicate that the least cost combination of subsystems is comprised of 375 acres of fish ponds, 100 acres of soil warming (tomatoes), and a 208 acre reservoir. However, when costs for the water transport system are included, the total monetary outlays for this system are greater than those for a system comprised of 160 acres of fish ponds, 100 acres of soil warming (tomatoes), and a 352 acre reservoir. Both systems are, however, least cost alternatives to conventional methods of waste heat dissipation. When prices for aquacultural and agricultural commodities were reduced 17 and 45 percent respectively, the waste heat utilization system was not a least cost alternative.

Analyses of alternative management and acquisition options indicate that when a purchase and leaseback option is employed and no claim on system revenues is made by the utility, the waste heat utilization system is not a least cost alternative. However, if the utility obtains rents that allow the utilization system management to cover the annual operating costs and managerial expense, the utilization system is a least cost alternative.

When the contractual arrangement is employed, all capital and annual costs are borne by the utilization system management. Net monetary returns to subsystem operation are, however, negative and a monetary incentive must be paid to attract capital and management resources. However, the utility could afford to pay costs for the transport system.

The primary implication of this research is that integrated agricultural and aquacultural systems which utilize waste heat should be further studied. The study shows positive gains from waste heat utilization. A small scale demonstration facility would better define operational characteristics of full scale systems and would allow refinement of the model. The viability of an integrated system also needs to be examined under a wider range of exogenous conditions and system parameters.

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CHAPTER I

INTRODUCTION

Waste heat generation from steam-electric generating facilities is a significant ecological and resource use problem. For every kilowatt hour of electricity produced, the equivalent of between one and one-half and two kilowatt hours of electrical energy will appear as waste heat in the cooling water of power plants. It has been estimated that the rate of waste heat discharge from these sources will increase from 2.15×10^{15} kilocalories per year in 1970 to 8.42×10^{15} kilocalories per year in the year 2000 (Boersma, et al. 1972). The rather conservative estimate of waste heat production in the year 2000 is nearly eight times greater than total generating capacity for the United States in 1970.

With minor exceptions, the thermal discharge effluent is directly dissipated into the environment by cooling towers, reservoirs, or spray canals. The waste heat produced in the electrical power generation process is treated as an externality in production. The energy in the cooling water is generally not considered to be a resource that can be managed for effective use. It is treated as waste. The dispersed nature of energy in the discharged cooling water of power plants has conventionally precluded the recycling of the cooling water for productive use.

Problem Statement

The general problem to which this study is addressed is whether the waste heat from power plants can be treated as a resource to be managed in controlled circumstances for productive use. More specifically, the problem which this study addresses is whether integrated waste heat utilization systems comprised primarily of agricultural and aquacultural uses are economically feasible under Michigan conditions. The emphasis of this research is on the least cost design and organization of a system structure that will achieve desired goals subject to specified constraints. To that effect, the task to be accomplished is one of determining a mixture of agricultural and aquacultural uses which in total form a system that utilizes waste heat in productive ways.

Should such a system be shown to be feasible, we could expect a reduction in the use of conventional means of dissipating thermal discharge effluent, the disuse of waste heat, and possible reduction in the use of other energy sources.

Several researchers have studied the economic aspects of individual uses of waste heat. Economic feasibility of waste heat utilization was assessed on the basis of costs and returns of a particular individual use. This research, however, will evaluate the feasibility of an integrated[1] as opposed to a combined system of several uses. For this problem,

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[1]The definition of a single use system is self-evident. Boersma, et al. (1974) defines a combined system as "... one made up of various numbers of waste heat components. No attempt is made to optimize the number of components or size of

integration can be defined as the level of economic and physical coordination among the several uses. This would involve the mobility of allocating inputs between uses according to some established criterion, the joint use of a fixed capital facility, and the common use of managerial skill. The degree of integration postulated here does not entail full utilization of the possibilities for coordinating power plant operations with that of the integrated waste heat utilization system. The only coordination specified, in this case, is that the integrated waste heat utilization system receives cooling water and returns it to the power plant subject to minimum water quality requirements.

Whether an integrated system of agricultural and aquacultural uses is economically feasible depends on satisfying two criteria. The first criterion is whether several uses can be integrated in an optimal manner to form a least cost system that utilizes a specified amount of waste heat. In this regard, we are operating in an optimization mode to satisfy a set of constraints. Economic feasibility in this context is a matter of cost effectiveness in that we are

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each component used, nor to consider the arrangement of the components in the total system...no interaction or feedback among the components is considered; and there is no overall philosophy to operate the system in order to maximize a particular parameter." The systems are in contrast to an integrated system which Boersma has also defined as a system in which "...the type and number of each component is carefully chosen and added to the system in an attempt to maximize an operational parameter such as profit. Interactions and feedback among all components are considered, and the overall system is designed and operated to maximize the above mentioned parameter..."

determining whether the optimal size and mix of agricultural and aquacultural uses is a least cost alternative to conventional methods (cooling towers, reservoirs) that are used to dissipate thermal effluent.

In order to determine whether this nonconventional approach is economically feasible, it is also necessary to examine whether basic operational criteria can be met. The issue here is not one of constrained optimization. The institutional apparatus which facilitates the transfer of waste heat from the utility to the use system and between the different types of uses will affect conditions necessary for an efficient allocation of waste heat, and, in some respects, the design of the system.

As stated earlier, the emphasis is on design or organization of a system structure that will achieve desired goals. The physical interdependencies between the power plant and the waste heat utilization system, formed by the common use of the water resource, necessitate an examination of how organizational arrangements between these two parties will affect that performance. The types of issues of importance here are ownership of capital and land resources and management of the individual uses and of the total system.

Utilization and Dissipation Approaches

Two methodological approaches have been developed for assessing the feasibility of using thermal discharge effluent from steam-electric power plants. While each is related to the effective use of waste heat, they differ greatly in terms of scope and objectives. Since the approaches differ in the nature of the objective function to be minimized or maximized, and assumptions concerning the plant discharge options and characteristics, siting the results will differ in the use of selected subsystems and optimal sizes of those subsystems. As an example of how results are influenced by these two approaches, Shapiro (1975) has evaluated the design of a soil warming subsystem for the level of use associated with the utilization and dissipation approaches.

Gilham (1974) states that "the principal objective under the dissipation philosophy is to dissipate heat, while the objective under the utilization philosophy is to derive some benefit from the heat which is currently being wasted ...the two approaches are not mutually exclusive, or indeed, completely separable..." With the dissipation approach, the explicit goal is to design a system which will serve as an alternative to conventional methods of dissipating waste heat. The design of this type of system, where presumably conventional methods of heat dissipation are not incorporated, is organized on the basis of maximizing dissipation at minimum cost. A system organized with this approach is constrained by these stipulations:

1. The system is comprised of uses which will ensure the dissipation of most, or preferably all, of the waste heat from a power plant for all seasons of the year and expected load patterns.

2. For closed systems, the return water must meet minimum temperature and quality requirements so as not to adversely affect plant operating efficiency.
3. The design of the system must ensure noninterrupted power plant operation.

Gillham states that there are two major advantages of such a system. First, plants with conventional dissipation systems (presumably closed systems) will have higher discharge temperatures than plants with once-through cooling systems.[1] Consequently, a greater level of energy is available for use. Secondly, the system dissipating the heat generates revenues and "less tangible social benefits" which can be used to offset capital costs and other monetary outlays by the utility. A comparison of the net monetary outlays of systems that use waste heat to those which do not can be made.

The major disadvantages of systems designated under this philosophy are that large seasonal excess capacity of subsystems and associated capital land resources can occur where there is seasonal fluctuation in meteorological conditions. Also, the operational capacity and efficiency of the power plant is directly associated with the dissipation and operating characteristics of the dissipation system.

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[1]This advantage accrues primarily to the waste heat utilization system as high input temperatures to the system will correspond to higher return temperatures, which in effect reduces plant efficiency.

The second approach designated by Gillham is the utilization approach. The primary objective incorporated in a utilization system design is "to maximize the economic and social benefits" of waste heat utilization rather than the minimization of costs (p. 3). This approach is primarily applicable to situations where there are no legal or regulatory pressures to refrain from one-through cooling.

The primary constraints are as follows:

1. In that this approach is feasible where legal, regulatory and physical constraints permit one-through cooling, the implementation of a waste heat system is justified by economic costs, returns and social benefits of each individual use.
2. The system should not interfere with power plant operation or be catastrophically affected by a plant shutdown.
3. As a closed system is not required, discharge temperatures are lower, and therefore, the year around operation of some uses is not certain.

It is argued that the advantages of systems designed on this principle are:

1. The use of capital, land, and other resources are justified by economic costs and returns and not on a production basis.
2. There is no requirement that a specified amount of waste heat be utilized by the different uses.

3. As the system is open, there is no restriction on the temperature of the water leaving the system which would allow greater flexibility in the system.

The disadvantage of such a concept for this research is that the Federal Water Quality Administration (now the Environmental Protection Agency, EPA) forbade dumping of virtually any heat into Lake Michigan in 1970. Several states have set similar standards. The more recent (1974) effluent limitation guidelines of the EPA require "essentially no discharge" of thermal pollutants for many plants now in operation or being built, and for "all new sources" that will begin operation after 1983 (Belter, 1974). Hence, closed-cycle cooling options are required for all sites.

Each of these approaches is useful where the scope of the research and problem definition conforms with the stipulated conditions and resources available. However, the dissipation approach does not guarantee an overall least cost combination of variable and capital resources. The utilization approach does not stipulate the dissipation of a specified amount of waste heat.

The Integration Approach

The primary disagreement with the dissipation approach is its failure to guarantee an optimal allocation of resources. It is not specified that in dissipating waste heat under this approach an attempt is made to allocate capital and land resources to uses which at the margin return the greatest revenue per dollar invested in these resources, or whether some other criterion is chosen. The utilization approach allocates waste heat on the basis of economic costs and returns per use and as such does not employ the advantages obtainable where optimization is carried out over the total system. Neither of these approaches is suited to deal with the design of a feasible system of waste heat uses given the technical, operational and economic factors that constrain the waste heat utilization problem as it has been previously stated.

The problem requires that optimization be over the number or types of subsystems and the size of subsystems used. The approach used must also account for the interaction and feedback among subsystems. Furthermore, the type and size of subsystem is carefully chosen in an attempt to maximize or minimize some operational parameter such as system profit or total monetary outlays respectively.

An integrated system can be achieved by economically and physically coordinating different subsystems. The higher the degree of integration within the system, the greater the ability to match waste heat energy availability with the level of energy optimal for subsystem operation, to spread fixed costs attributable to common fixed resources, ensure an optimal allocation of variable resources due to free mobility of those resources and arrive at a least cost combination of land, capital and other scarce resources.

With an integrated system, it is possible to allocate the waste heat water on the basis of achieving the highest possible return from those resources. While the operation of the different subsystems in a combined system are interdependent and coordinated to some extent, the effects of more completely integrating subsystems on a design basis has not been dealt with in previous studies of this topic.

Consideration of an integration approach permits greater flexibility in subsystem selection than would exist with the utilization approach. Optimization of resource use is carried out over total system operation and not for individual subsystems. The reason for this is that agricultural and aquacultural uses differ with respect to heat transfer, productivity response, cost of operation, and time period which waste heat can be used. Some generate significant revenues above costs but utilize waste heat at a slow rate. For others the reverse is true. The economic feasibility of individual subsystems is of less concern than the economic feasibility of the total system.

Another aspect of this approach is that it does not foreclose the option of partial or reduced use of cooling towers or reservoirs as the dissipation approach stipulates. This aspect is not so much derived from the meaning of integration as it is based on conformance with physical facts of power generation.

The constraints on a system organized under such an approach are as follows:

1. The total system (inclusive of conventional methods) will utilize all of the waste heat generated by a specified power plant regardless of season or load pattern.
2. The return water under a closed system must meet temperature and quality requirements so as not to reduce plant operating efficiency.
3. System design should ensure reliability in operation of the power plant.
4. While the above constraints will affect feasibility, the actual implementation is based on a least cost comparison with conventional methods of waste heat utilization.

The factors discussed above represent the basis for interest in an integrated approach and integrated system. Gillham underlines this reason for analyzing integrated systems when he states:

> By designing a system with several uses, the temperature requirements of individual components may be different and the output water from one component may serve as the input to another. As a result, more efficient use is made of the available heat, the system cooling function may be greater, and the economics of the overall system may be considerably more attractive than the economics of the individual components.

Boersma points to a different class of reasons when he states:

> Society faces many problems related to its growth in numbers as well as standard of living. Not the least of these problems is the degradation of the environment

> caused by industries, individuals, and communities. The ultimate solution must be found in the development of integrated systems in which resources are not used in a destructive manner, but are recycled. Power generating stations offer a unique opportunity to develop such systems. The waste heat represents a valuable resource to be managed for beneficial use. At the same time, water is becoming more and more a limited resource and should be subjected to multiple use. The production of food and fiber is rapidly becoming an industrialized process with high production rates on small areas (Boersma, et al., 1972).

Review of the Relevant Literature

Agricultural and aquacultural organisms have been shown to respond in a favorable manner when controlled use is made of waste heat energy to alter the environment in which these organisms grow. The productivity response of field and specialty crops to a warmed soil environment has been studied extensively by Allred et al. (1975), Boersma et al. (1972, 1974), Decker (1975), and Skaggs and Sanders (1975). The use of thermal effluent for increasing the growth rates of aquaculture organisms has been studied by Walker (1975), T.V.A. (1974), and by others (Guerra, et al. 1975) in New Jersey, New York, Texas, and California. The use of waste heat as a substitute heat source for greenhouse operation has been studied by Price and Peart (1973), Bond et al. (1974), Ashley et al. (1975), T.V.A. (1975) and Boersma et al. (1974). Boersma et al. (1972), Berry et al. (1974), and DeWalle et al. (1974) have studied the use of cooling water for irrigation. Some of these uses are a commercial reality, while others are in an experimental state of development.

These studies dealt primarily with investigating technical parameters of utilizing waste heat for productive means. Productivity responses to waste heat were studied and in many cases growth models were developed on the basis of the experimental data obtained.

Economic analysis on the feasibility of utilizing waste was conducted on an individual use basis or on a combined system basis. DeWalle et al. (1974) evaluated the capital, operating and maintenance costs of a soil warming system and also costs and benefits of a single use irrigation system. A comparison was made on the total net costs of the Agro-Power-Waste Water Complex relative to conventional methods of dissipating waste heat. The comparison is conducted on the basis of capitalized annual costs per kilowatt of plant capacity. As the system studied is a single use system, it was not necessary to optimally allocate the distribution of water. Rather, design parameters of field area, number of sections, ratio of field length to width and piping characteristics were optimized.

Boersma et al. (1974) conducted a systems analysis of the economic utilization of using waste heat and bleed-off steam in a combined system. This non-integrated system was comprised of urban uses, greenhouses, algal basins, and soil warming. Again the economic analysis was conducted on an individual subsystem basis. Costs and revenues were discounted. For urban uses, a comparison study was conducted which evaluated the cost of a steam heat system with alternative heat sources. For other subsystems, the type of economic analysis varied from rough cost of production studies to present value analysis. Design optimization analysis was conducted over individual subsystems and for different sets of contingencies.

The study conducted by Johns et al. (1971) deals specifically with using off-peak electrical energy and cooling water for agricultural purposes. While less specific in technical analysis than the two previously mentioned major reports, it does present well specified partial budgets and gross margins for several subsystems using waste heat. This study did not consider subsystem design optimization but economic advantages of using waste heat were evaluated.

The Tennessee Valley Authority (TVA) has also extensively studied possible beneficial uses of waste heat. A multi-objective applied research program has been conducted to examine the feasibility of raceway production of catfish (Goss et al. 1975). The research at the Gallatin Steam Plant concentrated primarily on technical aspects of fish production utilizing waste heat. The technical feasibility of this use was well documented. Questions remain concerning economic feasibility of raceway production methods.

The utilization of waste heat as a substitute heat source in greenhouses is also being examined by TVA. The emphasis of this research is on technical capability of controlling greenhouse environment, the effect of waste heat utilization on horticultural crop production and an evaluation of economic aspects of greenhouse use of waste heat.

The study of economic factors centered on cost of production for several crops, implications of alternative production management systems and consumer acceptance of new products.

A soil warming research facility has been installed at Muscle Shoals, Alabama to evaluate the potential of waste heat utilization in the production of field and vegetable crops. Economic results of various pipe spacing and water temperatures are not yet available.

The TVA has also been engaged in research studying the possibility of using waste heat for warmed animal shelters and practical applications of biological nutrients from animal wastes. Economic results from these studies are also not yet available.

In summary, the major economic studies on the feasibility of utilizing waste heat deal with individual uses or combined systems. The general philosophy of these studies is similar to the utilization approach discussed previously. If design optimization is studied, it is conducted at the subsystem level.

Purpose of the Research

The purpose of this study is to investigate the feasibility of utilizing waste heat in an integrated system of interdependent agricultural and aquacultural uses. As a feasibility study, it will provide insights and guidelines as to whether such an undertaking is economically reasonable. It is not the purpose of this research to reach a definitive statement concerning the likelihood or necessity of constructing such a system. Rather, the goal is to assess whether the topic requires further investigation.

To accomplish this task it is necessary to develop an analytical system which represents the major components of such a system. The construction of an analytical system facilitates the observation of how changes in important parameters affect economic feasibility of a system of waste heat uses, and the range of conditions where such a system is economically feasible. An analytical system is limited in that not all parameters can be made endogenous to the system. Hence, not all factors that affect feasibility can be represented.

Research Objectives

The purpose of this study is to assess the economic feasibility of utilizing waste heat energy from steam-electrical generating facilities. This requires an examination of what has been termed the design problem and also the institutional context in which the goals of the utility and owner(s) of the waste heat utilization facility can be most suitably met. In accomplishing these tasks it is necessary to accomplish the following objectives:

1. Identify relevant crops and species of fish for which their biological receptivity to intensive cultivation and the waste heat input is proven, and for which their growth response under controlled conditions has been estimated.

2. Determine the initial capital requirements, annual costs, and revenues for various types of subsystems and selected sizes.
3. Construct a model that determines an optimal system design subject to specified constraints.
4. Investigate the sensitivity of the optimal system design to changes in the value of critical parameters.
5. Identify a feasible set of institutional alternatives for the organization of capital, land, and managerial resources.
6. Identify information that describes important operational and economic characteristics of waste heat utilization systems.
7. Propose a system configuration for each least cost system and the pumping and piping characteristics of a corresponding water transport system.
8. Determine, within a limited range, the optimal flow rates of waste heat water to agricultural and aquacultural subsystems.

Dissertation Plan

Chapter 2 contains relevant concepts and information regarding parameters of the waste heat utilization problem and environmental considerations. The methodology employed in this study is discussed in Chapter 3. The sources and types of data, analytical and theoretical models, and the optimization procedure are presented and discussed. Chapter 4 shows the least cost system design for three alternative economic conditions. The general piping and distribution systems and comparisons of systems which use waste heat with conventional dissipation alternatives are discussed in Chapter 5. Management and acquisition options are discussed in Chapter 6. These options are narrowed to a list of feasible alternatives and their impact on the monetary outlays by the utility are shown. The summary and concluding statements are shown in Chapter 7.

CHAPTER II

PARAMETERS OF THE WASTE HEAT UTILIZATION PROBLEM AND ENVIRONMENTAL CONSIDERATIONS

Parameters of the Waste Heat Problem

The utilization of waste heat energy poses technical and economic problems for the utility generating the waste heat and the facility that receives the thermal effluent. The utility faces problems that stem from the complexity of the fuel conversion cycle, legal requirements of what can or must be done with thermal effluent before its discharge into the environment is deemed safe, federal and state regulatory requirements that constrain activities within that of power generation and supply, and the operation of conventional means of dissipating waste heat. The waste heat utilization facility faces problems that arise from the entropy characteristics of thermal effluent, uncertainty in input supply, the allocation of a multiple use input, external economies, and interdependencies in investment decisions.

The problem has been stated such that the utility and utilization facility are the primary agents that affect a solution to the problem. Hence the discussion of parameters of the problem centers on factors that affect their operation and performance in utilizing waste heat.

There is another class of factors that do not so much affect the nature of the solution to the problem as it has been defined, as they demand a solution. Fossil fuel availability and thermal effects of power generation are concerns that presently do not directly affect feasibility of utilizing waste heat. They are, however, third party concerns which give added importance to the actions of the primary agents and whether waste heat utilization in the manner discussed here is indeed feasible.

The purpose of presenting empirical information on these technical and economic problems and how they relate to the problem to which this research is addressed is to lay a basis for the formulation of research hypotheses, and insight into the nature of the problem. Outlining problem areas with related information also provides insights into the nature and necessity of assumptions that have to be made. Lastly, this exercise should show operational constraints that influence the behavior of the different parties.

Technical Factors Affecting the Waste Heat Utilization Facility

The factors mentioned below indicate some of the major technical problems affecting economic feasibility of the integrated waste heat utilization system. These factors have been researched by Michigan State University research groups or are peculiar in that information can be obtained on how they affect operational characteristics. Assumptions are made on other technical factors for which research evidence is not available.

Limited use

In the process of converting fuels to work, the fuel input moves from a highly concentrated, low entropy level to a more dispersed, disorganized state of lower value. The free, low entropy energy loses the ability to produce mechanical work in this process. "Waste" heat refers to energy which is so degraded in temperature that its uses are limited. That energy of this nature has zero or small negative value has typically meant that it is economically practical to discharge it directly into the environment.

Large amounts of such energy appear in the form of cooling water used for condensing steam discharged from the turbine in steam-electric power plants. Depending on the ambient temperature, the quantity of that water circulated, the type and age of the power plant, climate, type of heatsink and other factors; the typical outlet temperature for such cooling water is in the range of 7°C to 40°C (50°F to 105°F). Most industrial processes and urban uses require a much higher temperature range. Typical temperature requirements for processes where hot water can be used is from 71° to 204°C (160° to 400°F).

As we have seen in sections regarding literature review and subsystem description, the introduction of waste heat into certain biological and life cycle processes provide the most promising outlook for limited uses of waste heat. Even so, while there may be appreciable growth response to waste heat, several technical and economic questions remain.

Low value to cost ratio

The high entropy level of thermal discharge effluent means that the usable work per unit of volume is low. The relation of the supply cost of the input to its bulk is important. For bulky (low value-high entropy) resource inputs, unit transportation costs (which are part of supply costs) rise rapidly with the distance that the resource must be transported. If the transportation costs are absorbed by the waste heat user, the combined effect of these factors can significantly affect the optimal size of the enterprise that uses the waste heat input.

Cost of retrieval

Another element of supply cost is what will be termed cost of retrieval. The waste heat water enters the particular use in crude form. It is not so much the warmed water that is the resource input to be put into productive use, as it is the low grade energy in the water. In most instances the cost of extracting the usable energy is great. The fixed capital requirements for heat exchangers and control mechanisms for most uses are significant. Furthermore, the use for which the different facilities can be employed is limited.

The impact of high cost of retrieval on the use facility is that its ability to react to relative price changes is reduced and that new processes or technological innovations are adopted at a slower rate. Given that the firm is in a rather inflexible position and that capital requirements demand a large commitment of funds, its equity ownership may be initially low and thus lead to possible liquidity problems.

Need for highly controlled environment

The demand for waste heat by individual subsystems will vary on a daily basis. This is due to variability in meteoroligical conditions, the effect this variability has on the performance of the heat transfer mechanisms, and the desirability of maintaining the environment of the aquacultural and agricultural organisms at or near an optimal growth temperature. Failure to equate supply of waste heat with the physical demands of the organism can result in lost productivity by means of a death or retarded growth. Temperature is but one variable affecting productivity, but is an important one as the growth process of the organism is primarily temperature variant. The variety and number of other controllable inputs that affect growth will differ among uses.

The reason for introducing this information is that the introduction of the waste heat resource into agricultural and aquacultural processes increases the cost of error of not maintaining the system at optimal conditions. The necessarily large fixed cost complement increases the sensitivity of the firm to adverse price movements and also productivity losses. Losses of this nature will reduce returns to fixed factors which for some uses, can be significant.

Chemical fouling

Periodic cleaning of the condenser tubes results in the accumulation of chemical impurities (chlorine and heavy metals) and solids in the cooling water. These substances can adversely affect the productivity response of some organisms where the cooling water is a medium for growth. Similarly, the utility will require minimum water quality standards for water returned from the waste heat utilization system.

Economic Factors Affecting the Waste Heat Utilization Facility

As has been indicated, there are several technical factors that will affect operational characteristics of the waste heat utilization system as well as capital requirements. There are also economic factors that affect design and management behavior. The factors discussed are of a lesser magnitude of importance than the primary constraints affecting feasibility: a) a specified amount of waste heat must be utilized by the system, b) the system in total must generate sufficient revenues to cover costs, c) the total system, inclusive of the general piping and distribution system, must be a least cost alternative compared to conventional methods of dissipating waste heat.

Capital and land availability

Large amounts of initial capital for construction, replacement capital, and operating capital for subsequent years of operation are required. The interest rate at which these expenditures are financed affect desirability of investment. Control and ownership of capital facilities affect the nature of decisions. Characteristics of the soil affect thermal conductivity of the soil warming mechanism. Sandy types of soil are preferred as the growth response to the waste heat input is optimized. The proximity of land with this characteristic affect capital requirements and operating expense of the water transport system.

Optimization over system operation

Given the costs and returns, capital investment requirements, heat dissipating capability, and physical constraints for each individual subsystem, an optimal combination of size and type of subsystem can be found. The choice of subsystems and corresponding sizes is determined from the viewpoint of the total system. This optimization perspective is necessary as some uses contribute little to or subtract from total system profit, but yet may be efficient heat transfer mechanisms. Other systems may generate large revenues but dissipate heat inefficiently. Therefore, on a subsystem basis, it may be "optimal" to have all greenhouses, or all fish culture, but designing a system on this basis would possibly cause the use of excessively large amounts of land and/or capital, or large seasonal excess capacity in capital, labor, and managerial skill.

<u>Sensitivity of size to supply of waste heat</u>

The supply of waste heat is assessed to be equivalent to that supplied by a nominal one thousand megawatt, base loaded electrical generating facility. Electrical demand, however, fluctuates on a seasonal basis. Also, a specific plant may not remain on line as a base loaded facility, but rather be used for peak demand periods as its age increases. The issue of operational interest then is the extent by which optimal system design is affected by different levels of waste heat availability.

<u>Flow rates</u>

The initial step in determining optimal system design is to specify flow rates that maintain the temperature in the subsystem at or near the optimal range for growth purposes. These temperatures are determined by the allocation-simulation program, which is discussed in a later chapter. The flow rates given by the allocation program determine heat dissipation rates for subsystems and thus affect optimal system design.

The pumping costs, and capital requirements associated with these flow rates are incorporated in the linear programming model. These costs are not incorporated in the allocation model. In order to evaluate whether the flow rates given by the allocation program are economically optimal, the costs associated with flow rates 10 percent above and 10 percent below the flow rate given by the allocation model are also incorporated in the linear programming model. This is done for each activity in the linear programming model. Dissipation rates, pumping costs, and productivity responses are changed in proportion to these flow rates. Economically optimal flow rates are then determined by solving the linear programming problem.

Management and ownership options

The form of economic organization affects the level of economic and physical integration, the nature and distribution of externalities generated, and the distribution of costs and revenues. The type of management organization governing the use of capital and variable resources, as well as the allocation of waste heat forms the basis on which intrasystem tradeoffs and complementarities are affected. Long term stability of system operation is also affected.

Spatial relationships and the distribution system

The spatial relationships of the subsystems to the power plant and to each other brings in another set of issues that affect economic feasibility. Connecting subsystems to the power plant is a general piping and distribution system. In finding the optimal size and mix of subsystems, the general piping and distribution has been treated as analytically separate. The costs associated with the distribution system are not directly attributable to the operation of any one subsystem. An optimal configuration for the distribution system and location of subsystems is then chosen after the best mix of subsystems has been determined.

The set of spatial relationships, or configuration is subject to environmental and physical constraints. Several criteria can be used to determine optimal spatial characteristics. The choice of this criteria can cause significant differences in spatial relationships.

Type of commodity

The decisions concerning the choice of agricultural and aquacultural products to be raised/reared are influenced by the capability of the existing food marketing system in the region to process, distribute, and sell those products in local and regional markets. Consideration must be given to existing demand, perishability, seasonality, and the impact of additional volume on price. Whether existing facilities exist for off-season production is also an important consideration.

Factors other than marketing constraints must also be dealt with. The biological receptivity of the organism to a changed environment is critical. Within the constraints mentioned above it is desirable to produce a mixture of crops that react favorably in terms of growth to the waste heat input.

Timeliness of operation

The time period in which subsystems demand waste heat is critical as the total flow rate generated by the plant is fixed. Higher flow rates to each subsystem are required as air and cooling water temperature falls. If one of the objectives is to minimize reservoir or cooling tower size, the period in which subsystems operate and the mix operating at any one time will affect achievement of this goal. The solution of this problem is complicated by the desirability of finding a mix of subsystems that is optimal for year around operation. Designing a system that is optimal for operation during the summer will result in large excess capacity during colder periods.

Technical Factors Affecting the Utility

Cost of retrofitting

The lead time for a power plant ranges from seven to ten years. Plants already in operation or in the process of being constructed would require redesigning in order to complement a waste heat utilization complex. Costs of retrofitting for either facility would be significant (Womeldorff, 1975). Hence, there is increased importance placed on planning and coordinating both plant design and design of a waste heat utilization facility in initial stages of planning (Rochow and Hall, 1975).

Reliability of supply

Reliability in supply of the returned condensate is crucial for uninterrupted power plant operation. Due to the nature of heat transfer mechanisms, a waste heat utilization complex will not be able to accept the complete heat load during warm, humid periods. This requires that a back-up system or supplementary cooling system be used. Failure to dissipate sufficient heat by the utilization system can result in decreased plant operating efficiency.

Not only must the returned cooling water meet temperature requirements but the quality of the returned cooling water must enable its continued use in the power generating cycle. If supply requirements are not met, plant outage costs can be significant and totally outweigh profits from the utilization system (Ray, 1975), or increased fuel efficiency attributable to the waste heat utilization system.

Plant outages

If the utilization system is fully integrated with plant operation, a plant shutdown is of significant concern. The effect of such an outage will depend on length of the outage, type of uses affected, and the season of the year. If the use complex is associated with a multiple plant siting, then this concern is not as crucial. Where single plant sites are used, back-up heating systems may be required when feasible. Planned maintenance outages can be scheduled to comply with periods of low demand, but forced outages can cause thermal shock to the biological organism (Ray, 1975).

Economic Factors Affecting the Utility

Salable commodity

With significantly higher fuel prices and rapidly diminishing oil reserves, the discussion of the value of waste heat has increased. The reject heat may be a salable commodity. If so, net monetary outlays by the utility will be reduced. However, the value of the waste heat can vary greatly Factors affecting the value of the waste heat are the usable level of energy available, water loss by the user, condensate return from steam, demand and load factor, capital requirements for conversion, possible deoptimization of plant efficiency, firmness of heat sink, and duration of the contract (Womeldorff, 1975). System design and product price will also influence the value of the waste heat resource.

Site selection

Consideration of implementing a waste heat utilization facility would necessitate incorporating additional factors into the site selection process. The proximity of agricultural land has been mentioned. Other factors may include nearness to urban markets and the consumptive use of the waste heat utilization facility. If the system is a closed system and makeup water requirements are minimal, the possibility exists for inland siting. The land use effects of a utilization system are not as severe as with reservoirs; nor are the environmental effects as adverse as cooling towers because point source concentration of waste heat disposal is not as high as that for cooling towers.

Regulatory approval

The primary responsibility of investor owned utilities is the production and sale of electricity. The management and ownership of agri-business ventures of any nature is not perceived as compatible with their primary concern or within the scope of existing capabilities (Rochow and Hall, 1975). There are also serious questions or objections, as perceived by the utility, that can be asked by State and Federal Regulatory Commissions regarding this type of activity and the utilization of required funds and resources. Communications with two major utility companies of this type reveal that their responsibility in an activity of this nature should be one of supplying the waste heat to an independent organization. Their involvement would cease at that point.

Uncertainty

The seeking of regulatory approval, commitment or hiring of required management skills, and establishing a new department, division, or subsidiary to manage the utilization system require a fixed commitment of resources. The implementation of waste heat utilization in plant engineering and planning is approached with caution. This hesitancy is related to the commitment of the above resources and also scarce capital resources to projects that involve a high degree of technical and economic uncertainty (Lam, 1975).

Cost of backup facility

It has been previously mentioned that reliability in the supply of cooling water is the first priority for power plant operation and that the waste heat utilization system will not always demand or dissipate heat at a rate in harmony with which it is produced. These factors necessitate a backup system preferably along conventional lines. The cost for such a system will vary and depend on whether an open or closed system is implemented and site characteristics.

If the system (waste heat utilization system plus backup) is designed for once through use of the cooling water (open system) and regulatory permission is obtained, the capital costs can be relatively low (Ray, 1975). If on the other hand, the cooling water is recirculated (closed system) and the utility desires to optimize fuel conversion efficiency and reduce risk, the costs for possible underdesign of the backup system can be significant. (Higher temperatures of plant input water means less steam can be extracted to drive the turbines). The backup system should be designed to dissipate a high proportion of the thermal discharge.

Lead time and life cycle

The life of a power plant is between twenty-five and forty years with an average of about thirty years without major refitting. Its life as a base loaded facility is less than its operational life. The planning and operating decisions of the utility are made on this basis. As mentioned, the lead time for implementing a particular design is from 7 to 10 years (Womeldorff, 1975). If the implementation of a waste heat utilization system is a joint venture, a difference in planning horizons and the expected life of major capital components can lead to operational and/or financial differences between parties with investment interests.

Environmental Costs of Thermal Discharge

The purpose of this section is to present a general evaluation of the impact of thermal discharge into the environment. By giving such information the additional heat load discharged into the environment from power plants can be put in perspective. Emphasis is also placed on the ecological costs, advantages and disadvantages of conventional methods of waste heat dissipation and a waste heat utilization system.[1]

Heated water discharges

The increase in steam-electric power generation has led to increasing concern for the impact of waste heat on the environment and water resources. The Committee on Water Resources Research in the Executive Office of Science and Technology has concluded that the problem of "satisfactory control of heated water discharges"[2] has emerged as one of the ten most critical areas in the water resources field (Belter, 1974). The effect on aquatic life and reproduction of thermal effluent discharged into natural bodies of water

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[1]The once-through cooling alternative is not fully evaluated. Because of possible adverse effects on aquatic life, this alternative is being increasingly foreclosed.

[2]While it is not explicit, this statement refers to discharges into rivers, lakes and streams. It does not refer to discharge of waste heat into the atmosphere via towers or reservoirs.

is a major concern. Warren, in 1969, found that electric power generation accounted for three-fourths of total cooling water use and one-third of total water use. It has also been estimated that at 1980 "approximately one-fifth of the total runoff in the United States will pass through power plant condensers at one time or another" (Boersma et al. 1972).

The control of heated water discharge from power plants is not only a water use problem. Rather, the rate at which heat is produced and the method of dissipation give added importance. In 1970, electric power generation accounted for 22 percent (14×10^{15} Btu's) of total energy consumption. As approximately two-thirds of the energy input is rejected as waste heat in this process,[1] the amount of energy input rejected into the atmosphere is 13 percent (8×10^{5} Btu's) of total United States energy consumption. Christianson and Cannon project that by the year 2000, electrical power generation will account for 50 percent of total United States energy requirements. Based on this projection, waste heat rejection from this source alone would nearly equal total

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[1]An efficiency of 33 percent to 40 percent is not low. Given the second low of thermodynamics which states: "It is impossible by means of inanimate material agency to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects," 100 percent efficiency can be achieved if the surrounding temperature is 459.4°F below zero. The maximum theoretical ideal thermal efficiency limit of 60 percent is considered to be the upper limit for thermal steam cycle (Rankine cycle) (Kolflat, 1971). Therefore, thermal efficiency of 40 percent is in actual terms, 67 percent thermal efficient.

United States energy consumption in 1970 (Christianson and Cannon, 1975).

Table 2-1 shows the estimated growth of U. S. electrical generating capacity to the year 2020, and for projected operating efficiencies, the rate of waste heat production. It should be noted that for the later years in this period, the estimated rates of waste heat production are based on the implementation of MHD converters, fusion, and other high temperature conversion processes in power generation. As Table 2-1 illustrates, increasing the efficiency of energy-to-work conversion process reduces the amount of waste heat while also extending energy resources.

TABLE 2-1

ESTIMATED GENERATING CAPACITY, OPERATING EFFICIENCY AND WASTE HEAT PRODUCTION, 1970-2020 (BOERSMA, ET AL. 1972)

Year	Projected Generating Capacity	Projected Operating Efficiency[1]	Rate of Waste Heat Production
	10^{18} cal/yr	%	10^{18} cal/yr
1970	1.11	34	2.15
1980	2.27	37	3.86
1990	4.24	41	6.11
2000	7.20	46	8.42
2010	10.99	53	9.78
2020	16.28	61	10.42

[1]Projected operating efficiencies are in all probability over estimated as the technology required to meet these efficiencies (Breeder reactors, metal MHD and plasma MHD cycles, and fusion) are in varying stages of research and basic development.

Presently, the thermal discharge from steam-electric plants is dissipated by mechanical and natural draft cooling towers, man-made reservoirs; or spray canals. One-through cooling (open cycle), which was at one time the predominant method being used is being increasingly foreclosed. Boersma, et al. (1972) states that the "recent history of power plant development indicates that utilities will be forced to use cooling towers even at locations where one-through cooling is technically feasible." The Federal Water Quality Administration (now the Environmental Protection Agency) in the spring of 1970 forbade the dumping of virtually any heat into Lake Michigan. Since then several states have set similar standards. The more recent (1974) effluent limitation guidelines of the Federal Environmental Protection Agency require "essentially no discharge" of thermal pollutants for many plants now in operation or being built and for "all new sources" that will begin operation after 1983 (Belter, 1974). Without the granting of variances, the guidelines would eventually require construction of cooling towers or other closed cycle cooling options at all sites.

The rates of waste heat production shown in Table 2-1 are exceedingly large numbers but can be put in perspective. Approximately 150 cal/cm^2 day is received by the earth through solar radiation. In 1972, 0.063 additional cal/cm^2 day was generated by electrical generation. This rate of waste heat rejected into the atmosphere is about 0.04 percent of the total radiation received. Waste heat rejection in the year 2000 will represent 0.163 percent of the total heat load received by the earth.

Conventional systems[1]

For purposes of comparison, it would be advantageous to present general information on land use and possible environmental effects of alternative cooling methods.

Cooling ponds

Cooling ponds require approximately three-fourths of an acre per megawatt of electrical generation. A medium size plant of 1000 MW can then require a significant area to be withdrawn from agricultural production or some other use. Depending on soil type and pond construction, consumptive water losses can be significant. Plant capacity is not as adversely affected as by other alternatives where pumping requirements are significantly greater. Fans are also not required. The outlet temperature approaches wet-bulb temperature under favorable conditions.

Evaporative-mechanical draft towers

Evaporative-mechanical draft cooling towers require from two to three acres for a 1000 MW plant. Maximum contact of air with water surface is achieved.

Disadvantages of this method are that significant power is required to operate fans and pumps for water distribution.

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[1]Discussion of these systems is taken primarily from Kline, 1971.

Cold water temperature is limited by wet bulb temperature. Evaporative losses and drift losses can amount to two percent and one percent of water circulation flow respectively (Kolflat, 1971). Electrical power for pumps can require .5 and .8 percent of plant capacity, whereas fans may require one percent of plant output. Due to evaporation, salts, chromium and zinc will accumulate in the blowdown. Water treatment is required as these elements can be toxic. The location of these apparatus is limited due to fogging, noise, and aesthetics. Kolflat (1971) estimates that this type of dissipation will constitute 50 to 70 percent of all types by 1980.

Evaporative-natural draft towers

Approximately five acres are required for this type of tower for the same 1000 MW plant. A significant advantage is that fans are eliminated which reduce plant capacity. Fogging is not seen as a major problem. Furthermore, the efficiency of natural draft towers improves as relative humidity increases for a given wet bulb temperature.

The disadvantages of such a system are that water loss can be significant. Also, siting is important for full efficiency. Under certain conditions cooler air plumes from towers can result in plume lowering. Hence, plume dispersion and direction are important factors given possible effects of the vapor plume on the local environment.

Dry mechanical and natural draft towers

Where availability of water limits evaporative types of towers, dry mechanical and natural draft cooling towers are most often used. While these types of systems minimize water loss through evaporation and drift, there are several major disadvantages.

The amount of cooling is limited by ambient dry bulb air temperature. As this temperature is higher than wet bulb temperatures the temperature of the heat sink is higher. This leads to reduced efficiency of the steam cycle which affects fuel waste and greater waste heat generation. As the heat transfer mechanism is indirect, both apparatus are extremely costly. The life of such systems is less than evaporative methods as the finned tubes are subject to corrosion and deposits which also reduce heat transfer. Kline (1971) states that because of the water temperature limitation and resulting high back pressure, dry towers cannot be used with the types of turbines presently in service or manufactured.

Conventional cooling system cost

Kolflat in 1971 summarized several studies on the initial capital costs for various types of conventional systems (Table 2-2). While these figures range significantly for each type and are somewhat dated, they do give an indication of relative capital requirements.

While a comparative analysis of operating expenses for the various types of systems has not been compiled, the increased energy requirements for pumps and fans has been

TABLE 2-2

COMPARISON OF COOLING SYSTEMS COST ON A DOLLAR PER KILOWATT BASIS[1]

Cooling System	$/KW
Once-through	2 - 10
Cooling Lakes	2 - 13
Evaporative Mechanical Draft Tower	4 - 14
Evaporative Natural Draft Tower	6 - 20
Dry Mechanical Draft Tower	15 - 37
Dry Natural Draft Tower	25 - 65

[1]Costs include towers, lakes, pumps, structures, piping, and miscellaneous costs. Costs of the power plant condenser is excluded as are maintenance, operating and capability (capacity) costs.

estimated (Kline, 1971). If wet cooling towers were used for all steam-electric plants in Michigan, an additional 500 MW would be needed or the equivalent of 1.5 million tons of coal ($137.5 million at 1977 prices). If dry mechanical towers were used, an additional 1500 MW capacity would be required or the equivalent of 4 million tons of coal at a cost of $340.0 million.

Environmental Considerations of an Integrated Waste Heat Utilization System

It should be understood that a system which utilizes waste heat does not reduce the amount of thermal effluent eventually discharged into the environment. However, the

the method of heat transfer, as we have seen, can affect environmental conditions.[1] The heat transfer mechanisms which agricultural and aquacultural uses employ disperse waste heat effluent over a larger geographical area. Hence the first advantage of this type of system is that the power plants' point source concentration level of thermal discharge is reduced. Fogging and blowdown problems are not present as they would be for evaporative-mechanical and natural draft cooling towers.

The second advantage is that the types of heat transfer mechanisms postulated for use in a waste heat utilization system do not rely on water dispersion (spraying or splashing) to cause heat transfer. This reduces evaporative and drift losses that exist with wet towers. Consumptive losses are not entirely eliminated.[2] Whether a net benefit exists depends on siting characteristics and other factors.[3]

A third advantage which Faucher (1972) mentions is that this type of system can provide improved efficiency in

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[1]As an example, cooling ponds do not affect a vapor plume that can alter or have an adverse impact on the microclimatological conditions and wildlife. Most towers, however, do not require the large amount of land.

[2]Evaporative loss will occur when water surface is in contact with air. Furthermore, consumptive loss can occur where ponds are used due to drainage losses.

[3]No study has been found which compares consumptive losses for alternative systems for a specific site.

the use of energy resources.[1] While "first law efficiency"[2] is an important technical standard upon which an evaluation of system performance can be made, it is not the only performance parameter. A low first law efficiency rating means that energy is being lost or wasted in conversion to work. This parameter is useful in comparing systems with like or equal grade inputs and outputs.

A perhaps more useful measure of performance is "second law efficiency." This performance parameter is defined as the ratio of heat or work usefully transferred to maximum possible heat or work transferable[3] (Physics Today, 1975). This parameter measures the effectiveness of a use or system and as such indicates true thermodynamic performance of a system. Reistad (1975) states that this parameter measures how well a device or system performs with respect to the optimum possible performance. A low effectiveness rating means

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[1]The definition of energy efficiency can be stated as the ratio of energy output in desired product to energy input required (Reistad, 1975). When Faucher states that an improved efficiency in energy resource use can be realized with a waste heat utilization system, it is my belief he bases this statement on reduced losses in power generation due to used plant capacity for pumps, fans, and other mechanisms which reduce energy output or size of the numerator in above definition. Whether this is in fact true will depend on the pumping requirements and other losses in plant capacity found in a waste heat utilization system. Hopefully, results of this analysis provide the basis for a comparison of whether a waste heat utilization system is more energy efficient as defined above.

[2]First law efficiency is defined in the immediately preceding footnote.

[3]Second law efficiency is defined as the ratio of increase in availability of desired output to decrease in availability required (Reistad, 1975).

that energy is being wasted while it is being used. Commoner (1976) states that a low thermal effective system is one where work is poorly directed and that there is a faulty relationship between energy source and energy requiring task.[1] Hence, this is a task related performance parameter not a devide related performance parameter.

The reason for introducing these parameters is for discussing the potential a waste heat utilization system has for improved effectiveness in the use of energy resources. If energy efficiency of the system is the discriminating criterion, the decision as to whether resources were conserved would depend on whether, in gross terms, more work was obtained per unit of energy consumed by the plant and utilization system. No indication would be given as to whether energy sources had been more effectively used or whether the type of energy available had been best suited to the task for which it was used.

A waste heat utilization system, by supplying low grade energy to uses or tasks that effectively transfer that energy to desired output, has the potential for energy conservation. Research conducted on waste heat utilization[2]

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[1]Commoner explains this concept via two examples. Given this definition of effectiveness, a diesel engine is an effective way to convert fuel energy into electricity but effectiveness is wasted if electricity is in turn used to produce hot water. Similarly, the effectiveness of corn as a solar energy trap is reduced if inorganic nitrogen is used.

[2]Reference to this research is made in the sections, Review of Literature, and will not be further mentioned here.

indicates that the productivity response to this input is significant for many biological (agricultural and aquacultural) processes. The implication then is that additional productivity (desired output) or work can be obtained from the low grade energy input for specific tasks and that the low grade energy can serve as a substitute for inorganic fertilizers which represent high energy sources and other cultural practices which require petroleum based products.[1]

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[1]The extent of that saving will not be examined here.

CHAPTER III

METHODOLOGY

Sources and Types of Data

Several researchers have conducted studies on the costs and technical coefficients relating to the subsystems in this study. These studies, while indicating the physical operating and capital requirements, were specific to conventional fish cultivation techniques, greenhouse operation methods, or crop cultivation requirements. Where individual and/or combined systems were studied, the plant size, design, and operating characteristics, and environmental conditions differed significantly from those employed or found in an integrated waste heat utilization system and subsystems studied herein.

The design of the general piping and distribution systen is specific to a given mixture of types and sizes of subsystems with corresponding flow rates. Hence, much of this data is generated internally.

In order to allocate waste heat efficiently, heat transfer models, growth models, a weather model, and a water transport model were developed.[1] General models to deal with

[1]These models were developed by other members of the research group at Michigan State University. Description and citation of those models are mentioned in a later section of this chapter.

these problems were modified for Michigan conditions or were completely developed within the Michigan State University research group studying waste heat utilization.

Subsystem Cost Data

The economic feasibility of beneficial uses of waste heat has been evaluated on an experimental basis where pilot studies have been conducted. Other uses are a commercial reality. Data on costs and technical coefficients have been obtained from these studies and also from studies on conventional methods (where waste heat is not used) of fish culture, greenhouse operation, or cultural practices for field crops.

Modifications are necessary, however, as these data are specific to subsystems where the utilization approach was applied, the scale of operation was not appropriate for use in this study, or the subsystems did not meet the physical characteristics or suitable design properties to serve as a heat dissipation device for a power plant. That these subsystems are used in conjunction with power plants will necessitate design changes to insure reliability. As some uses will employ intensive methods of cultivation, complex control and monitoring devices, or non-conventional technologies; a reassessment of managerial and labor skill requirements must also be made.

After the necessary modifications are made, each subsystem is synthetically constructed according to the purposes for which it is used. As it is an integral part of a complex heat transfer mechanism, capital and operating costs for water transport within the subsystem are estimated.

Data on the various costs associated with non-conventional requirements of the subsystems were obtained from construction costs manuals, and mechanical engineers. Construction supply firms and utility companies were also a useful source. Construction and costs of major components were validated by reliable experts.

General Piping and Distribution System Cost Data

Costs for the water transport system are obtained in a similar fashion as those for subsystems. Technical coefficients relating to the water transport system were evaluated by an engineering graduate student specializing in hydrology. After flow rates, friction losses, pressure requirements, and piping distances were determined, appropriate sized pumps, motors, pipes and auxiliary requirements could be specified to meet these and utility requirements.

Flow rates and pressure requirements determine pump sizes. Major operating expenses accrue to pumping. Electrical expense was estimated by calculating power replacement costs and capacity replacement costs per kilowatt hour of electrical consumption.

Sub-models

Data on the productivity response of fish and heat dissipation rates for fish ponds and cooling reservoir are taken from models developed by Walker and Bakker-Arkema (1975).[1] Subsoil heat dissipation rates and field crop productivity responses to waste heat were obtained from models developed by Schisler and Bakker-Arkema (1975). Optimal flow rates and corresponding dissipation rates were determined by a multivariate, nonlinear optimization routine modified and adapted by VanKuiken and Tummala (1975). Pump size specifications, pipe diameters and piping distances were determined by Schultink (1975).

Productivity response of the organisms is important in determining gross revenues for the subsystems. The flow rates determine pumping and design characteristics internal to the subsystems. The dissipation rates of the subsystems and cooling reservoir are technical coefficients used in design optimization. The physical characteristics of the water transport system significantly affect capital requirements.

Analytical Constructs

The research presented here interfaces with component models and techniques developed by others on the Michigan State University research group studying waste heat utilization. These models and simulation techniques are difficult

[1] L. P. Walker, I. Schisler, J. VanKuiken, and W. Schultink were also members of this group.

to describe as the construction is unique and interaction multifaceted. To assist in the understanding of these models, a general description is given of the allocation simulation model and followed by a general description of the component models. Appropriate appendices are indicated which give a better description of these models.

The Allocation Simulation Model[1]

In order to find an optimal allocation of waste heat from the power plant to subsystems, given subsystem sizes, a simulation model comprised of mathematical models which describe important parameters of those subsystems was constructed. Models of the subsystems are comprised of growth rate equations, and heat and mass transfer equations. As an important factor affecting heat dissipation at any one time is meteorological conditions, a weather model is incorporated as a component.

Figure 3-1 illustrates major components for a system comprised of two subsystems plus a reservoir, the inputs affecting modelled subsystem behavior, and outputs of those subsystems. This figure illustrates in gross form that weather parameters, input heat rates and initial subsystem sizes in combination with fish and crop growth characteristics and heat dissipation rates for each subsystem determine output temperatures to the power plant and final amounts of agricultural and aquacultural products.

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[1]For a complete description see Appendix 2-A.

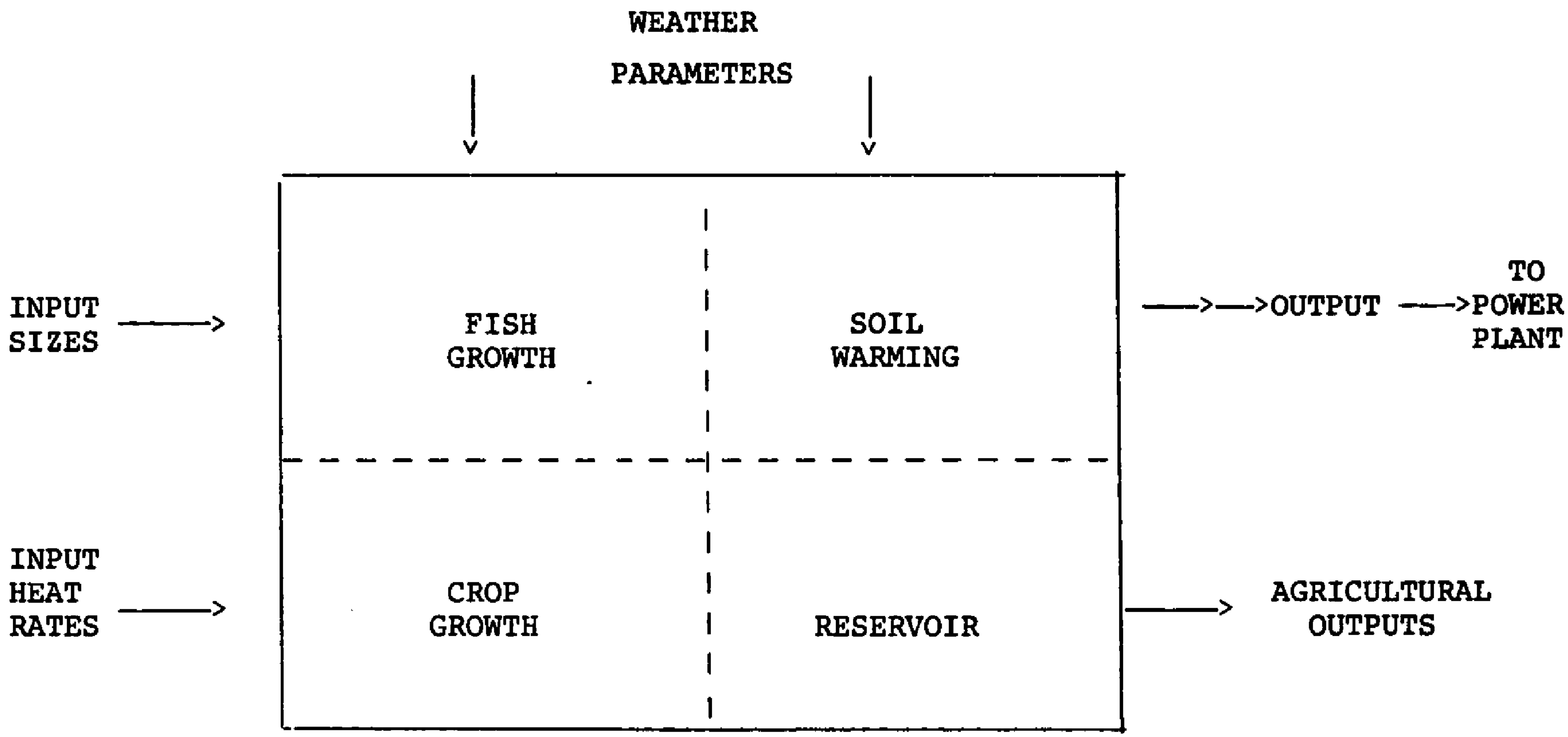

Figure 3-1

Major components and component interfaces of the Allocation-Simulation Model.
(VanKuiken and Tummala, 1975)

The flow of operations in program ALLOC begins with initialization of subsystem sizes, optimization parameters, initial estimated flow rates, and length of simulation run. The WEATHER model is then called to give appropriate average monthly values for wind speed, drybulb temperature, dewpoint, and solar radiation. With this and initial heat input, the subsystem temperatures are found.[1] As the primary variable affecting incremental growth rates for the agricultural and aquacultural crops is temperature, the incremental growth and hence subsystem revenue for those surface and soil temperatures is found with established models.

The remaining heat is then allocated to the reservoir and POND is called to determine necessary reservoir size to meet system constraints. Simulation then returns to WEATHER and continues until the objective function shown in the preceding section is minimized.

The outputs given the allocation simulation model are surface temperatures of the fish ponds and reservoirs, the soil temperature at the root zone, and temperature of the cooling water to the plant. Heat dissipation rates of the subsystems and reservoir are determined as are corresponding flow rates. Area of the reservoir is found. Other important outputs are monthly incremental profits and fish growth, expected yields at harvest, final fish size and population.

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[1]The relevant temperatures are pond surface temperature, subsoil temperature at the lateral, and greenhouse temperature.

Components of the Allocation Model

POND model[1]

The POND model is used to determine the equilibrium temperature, or temperature at which the heat input and amount of heat dissipated are balanced, for both the fish ponds and reservoir. Once the equilibrium and thermal exchange coefficient are determined, water temperature at the surface can be found. Strong dependence on local meteorological conditions for several of the coefficients in the model requires interaction with the WEATHER model.

The output of this model is fish pond and reservoir surface temperature. Interaction with WEATHER determines heat dissipation rates which are readily converted into flow rates. The interface with the linear programming model is that flow rates and thus temperatures of fish ponds affect revenue by affecting incremental productivity and quantity of fish harvested. The optimal flow rates affect physical requirements for ponds and the reservoir and hence capital and annual costs.

Soil warming model[2]

The premise on which this model is based is that the flow rates and physical aspects of the underground grid of pipes are designed to give optimal temperatures to maximize

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[1] For a more detailed description, see Appendix 2-B.

[2] For a more detailed discussion, see Appendix 2-C.

the objective function found in the upcoming sections. Stated simply, the computational scheme begins with finding a root zone temperature that will maximize the objective function. A heat dissipation rate is found which is then assigned to a surface balance equation. A surface temperature is found which is then evaluated on the basis of being feasible given the necessary pipe temperature needed to attain that temperature. If the solution is feasible, the corresponding flow rate is used to calculate capital and annual costs. Incremental rates of production and final production are temperature dependent, hence, revenues will be determined.

Fish growth[1]

Population density and temperature are the primary factors affecting the growth rate of fish (Andrew and Stickney, 1972; Brett, et al. 1969; Swift, 1964). While it is known that the growth rate for fish follows an exponentially decreasing function that can be characterized by a set of differential equations (Laird, et al. 1965), data were not available to estimate coefficients in these equations for the species chosen. As necessary data for estimating the growth response was not available for a broad temperature range, a constant growth rate was assumed. As temperature will change, a linear approximation of the growth rate at different temperatures was used (Walker and Bakker-Arkema, 1975). While this is a gross approximation, significant

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[1]For a further discussion of the fish growth model, see Appendix 2-D.

results were obtained in employing this method.

Monthly incremental yields are obtained given the average monthly temperatures from the POND model. As final population and average fish weight can be found on an annual basis, annual revenues can also be determined.

Crop growth model[1]

In many of the models based on experimental data, incremental crop growth was observed under conditions where the root zone temperature was maintained at close to a fixed temperature (Mack and Ivarson, 1972; Rykbost, et al. 1974). For integrated systems where two or more subsystems may operate coincidentally and compete for waste heat, the occurance of this is unlikely. Because of this, Schisler and Bakker-Arkema (1975) suggest that a switched growth model developed by Paltrige and Denholm (1974) be used. The parameters and the switch time in the set of differential equations are hypothesized to depend on a set of climatic factors discussed by Gross and Ruse (1972). The shape of the growth function, assuming constant parameters, gives a reasonable approximation for the crops considered.

The results from this model are in a similar form as those from the fish growth model and are used in the analysis of optimal design for similar purposes.

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[1]For a further discussion of the crop growth model see Appendix 2-E.

Iterative Procedure

The above models and a statement of constraints comprise subroutine OPTBOX. Its primary function is to determine an optimal combination of flow rates and corresponding heat dissipation rates for subsystems operating during any monthly period, given a set of subsystem sizes. The heat dissipation rates then become a new set of constraints to determine a new set of subsystem sizes. Figure 3-2 shows the iterative procedure between the linear programming model (which will be discussed) which optimizes design and the OPTBOX program which determines waste heat allocation. It should be noted that both programs optimize the same objective function for reasons of converging combinations of monthly flow rates, constant subsystem sizes, and monthly reservoir sizes.

Optimization Procedure

As was stated in the "Problem Statement," the problem addressed by this research is whether a waste heat utilization system comprised of agricultural and aquacultural uses is economically feasible. One of the major questions is whether the optimal design is a least cost system compared to conventional cooling methods. The procedure chosen to deal with this question is least cost or cost effectiveness analysis.

This type of analysis, as opposed to benefit-cost analysis, can be used to determine a least cost combination or resources that will achieve a specified goal. It is also

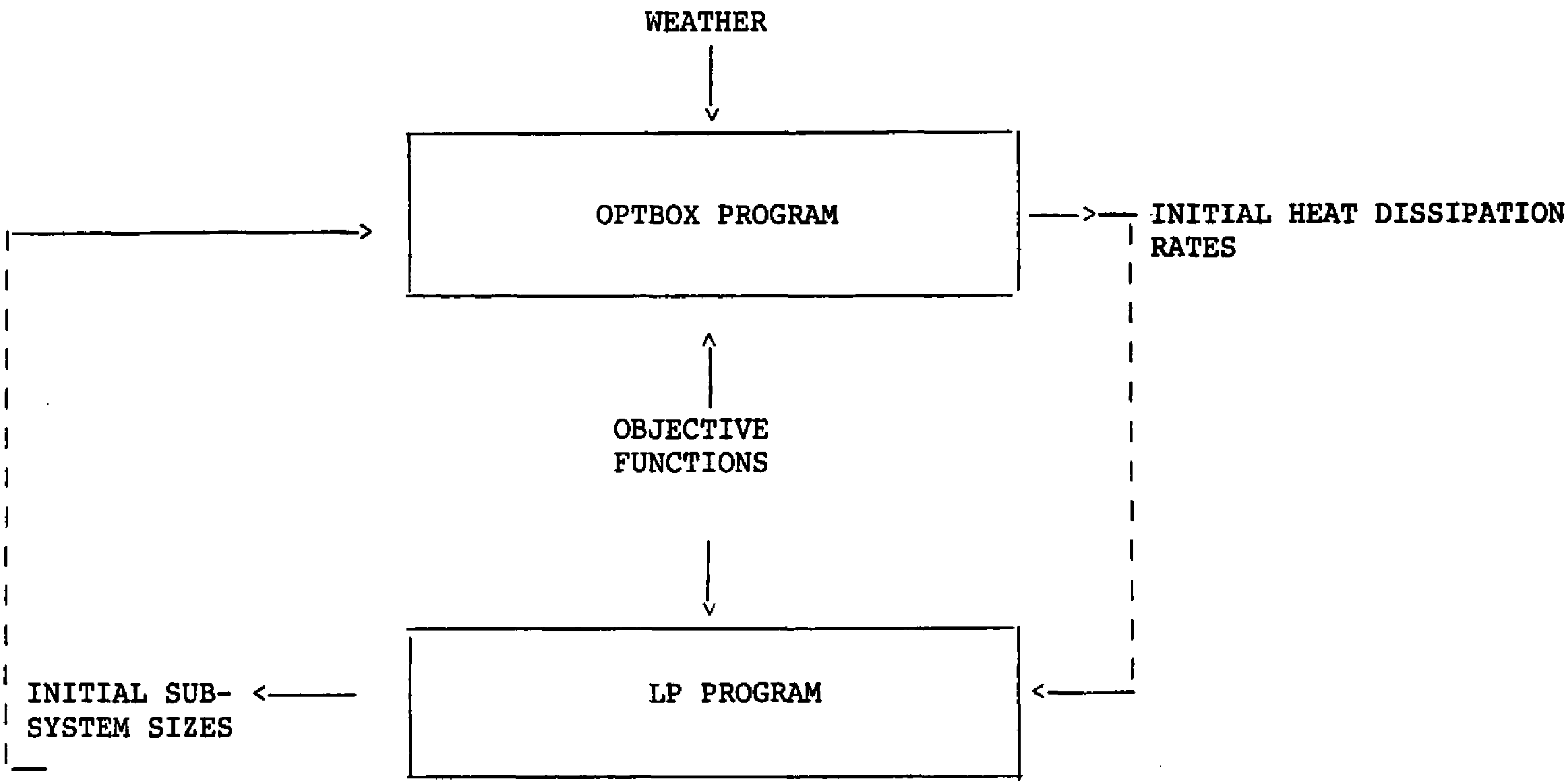

Figure 3-2

Schematic of the Iterative Procedure between the OPTBOX Program and Linear Programming Model to find an Optimal Solution (VanKuiken and Tummala, 1975) effective in comparative analysis of different investment alternatives. With the use of present value discounting techniques, this method is especially useful in analyzing the cost of long-range planning alternatives. With this procedure then as the general format there are other characteristics specific to optimization that must be dealt with by the procedure.

Optimization Characteristics

1. The utilization of an agricultural and aquacultural system is one investment alternative out of several that is faced by a utility or firm. Each investment alternative will affect the cash flow or total monetary outlay by the firm over the planning horizon. In order to make decisions concerning future expenditures or revenues, these sums must be converted into current dollars. Hence the time value of money is a decision variable.

2. The cost per unit of output changes with the scale of the plant. Diseconomies of size is related to several operational characteristics of the subsystems and limited variable resources. The objective function then is nonlinear.

3. The allocation routine specifies optimal flows for productivity and thus revenue purposes. Whether these flows are optimal, given pumping costs and corresponding capital requirements, is an important economic question.

4. Power plant operation is contingent on the system utilizing a specified amount of waste heat. For each month,

however, there will be a residual amount of waste heat that will not be utilized by agricultural or aquacultural uses and must be diverted to a cooling reservoir. One of the design objectives is to minimize reservoir size and examine which monthly periods are surplus periods for the beneficial uses.

5. There are a finite number of processes or activities by which the objective of utilizing a specified amount of waste heat can be obtained. Among these alternatives we want to find those activities which are least costly in utilizing resources to meet that objective.

Properties of the Algorithm

Problems, which require as a solution a course of action to be taken, for which some parameter is to be maximized or minimized, for which a limited amount of resources are available, and that can be resolved in a finite number of ways; can be suitably treated with linear programming methods. Given the optimization characteristics listed above, the following properties are incorporated into the algorithm.

1. To deal with the long term planning problem, pseudo-dynamic properties are incorporated which will allow the summation of net revenues and capital costs over the planning horizon. The pseudo-dynamic aspect of incorporating the time value of money to find the net present value of future net returns reduces to multiplication within the algorithm when the net revenues to be discounted are constant over the planning horizon. The multiplicative constant is the

discounting factor which is determined by the discount rate and length of the planning horizon. As objective function values are sensitive to the discounting factor, it is desirable that the discounting be handled internally.

This can be accomplished by grouping discounted and non-discounted annualized cost coefficients as separate rows in the activity matrix. A diagonal submatrix is then used to weight and transfer the sum of discounted and non-discounted values for activities in solution to a cost coefficient column that is nonzero only in the entries above this submatrix (Schisler, Meekhof, et al. 1976). The discounting factor is the weight in the submatrix and can be conveniently changed when the effect of a different discount rate and time horizon on the objective function value needs analysis.

2. The characteristic of a non-linear objective function can be dealt with by separable programming techniques (Charnes and Lemke, 1954). The non-linear relationship is linearized by dividing the curve into linear segments. This technique solves non-linear problems where (a) the objective function separates into a sum consisting of functions of single variables, (b) each function in the sum is concave, This can be shown as:

$$1)\ \text{Max } Z = \sum_j C_j X_j + \sum_j f_j\ (X_j)$$

subject to:

$$2)\ \sum_j a_{ij} X_j = b$$

3) $X_j \geq 0$

where:

Z = net monetary returns

C_j = net returns per unit area of subsystem j

X_j = size of subsystem j

$\sum_j C_j X_j$ = total net returns for subsystem j, where cost size relationships are linear

$\sum_j f_j X_j$ = total net returns for subsystem j, where cost size relationships are non-linear

a_{ij} = heat dissipation rates per subsystem j for month i

b = total amount of waste heat to be dissipated by agricultural and aquacultural uses, and reservoir

The non-linear formulation is converted to an appropriate linear programming problem (Schisler, Meekhof et al. 1976):

4) $\text{Max } Z = \sum_j C_j X_j + \sum_j S_j \; Y_j$

with the additional convexity condition

5) $$\sum_{j = V_{(k)}}^{V_{(m)}} Y_j = 1$$

where:

$V_{(k)}$ = a vector of column indicators which indicate the start of convexity controlled activities

$V_{(m)}$ = a vector of column indicators which indicate the end of convexity controlled activities

S_j = areas of convexity controlled j activities

While the activities denoted by size for each subsystem are mutually exclusive to the extent permitted by the constraints, this condition also implies

$$6)\ \ 0 = R_{i1} \leq Y_j \leq R_{iN}$$

where R_{i1} and R_{iN} denote the smallest and largest areas of a subsystem respectively in the linear approximation scheme.

The objective function and properties of the algorithm show that separable characteristics are employed to deal with the non-linear cost-size relationship for the utilization subsystems. This non-linear relationship indicates a non-linear objective function. It will also be shown that in the fish pond subsystem as additional amounts of waste heat are supplied the productivity response of fish will decline. This situation implies diminishing marginal returns to the waste heat input and that the algorithm is non-linear in constraints.

3. The flow rates to each subsystem impose costs and create revenues. Whether the flow rates given by the allocation subroutine are indeed optimal or whether "non-optimal" flow rates are desirable can be analyzed with minor changes to the above formulation. The consequent changes will also permit analysis of non-optimal flows or shortages and surpluses in available supply on monetary outlays for individual subsystems and the system in total. With this added condition, the linear programming problem then becomes

$$7)\ \ \text{Max } Z = C_j X_j + \sum_j \sum_w S_{jw} Y_{jw}$$

with the convexity condition that

$$8)\quad \sum_{j=V(k)}^{V(m)} \; \sum_{W=V(1)}^{V(n)} Y_{jw} = 1.$$

where:

$V_{(1)}$ = a vector of column indicators which indicate the start of convexity controlled activities with less than optimal, optimal, and greater than optimal flow rates.

$V_{(n)}$ - a vector of column indicators which indicate the end of convexity controlled activities with less than optimal, optimal, and greater than optimal flow rates.

The Objective Function

The above mathematical formulation is the basis for the objective function. The objective function chosen for analyzing the integrated system is consistent with the planning and investment decision making criteria of the utilities with whom this research was conducted. This function will determine optimal subsystem sizes and flow rates subject to dissipating a specified amount of waste heat.

$$9)\quad \text{Max } Z = \sum_{j=i}^{S} \sum_{w=i}^{3} A_{jw} \left[\sum_{1}^{n} \frac{(R-C)_{jw}}{(1+r)^{n}} - K_{jw}\right]$$

where:

Z = Net monetary returns current dollars

S = Subsystems

A_{jw} = Area of subsystem j with flow rate w, acres

K_{jw} = Initial capital outlay of subsystem j with flow rate w, $/acre

n = Life of project or planning horizon, years

R = Annual gross revenue for subsystem j with flow rate w, \$/acre

C = Annual operating cost of subsystem j with flow rate w, \$/acre

r = Discount rate or opportunity cost

While this objective function is useful for determining the optimal combination of subsystem sizes and flow rates, it does not give the total monetary outlay as the costs for the general piping and distribution system are excluded. In order to make comparisons with conventional methods, the capital and operating costs of the distribution system must be accounted for. The preceding objective function was modified outside the optimization model to reflect

$$10) \quad \text{Max } Z = \sum_{j=1}^{S} \sum_{w=1}^{3} A_{jw} \left[\sum_{1}^{n} \frac{(R-C)_{jw}}{(1+r)^n} - K_{jw} - \sum_{1}^{n} \frac{P_t}{(1+r)^n} - K_{gp} \right]$$

the additional costs associated with the general piping and distribution systems. They are defined as follows:

P_t = Make-up power and other annual costs of the general piping and distribution system in year t

K_{gp} = Capital outlays for the general piping and distribution system.

Theoretical Model

The allocative efficiency in waste heat distribution is an important theoretical concern and a major factor affecting feasibility. The problem to be dealt with is the allocation of a variable input which initially has zero or small negative value. The input to be allocated between competing uses is the high entropy, waste heat effluent.

While the allocation of zero-prices inputs with seemingly unlimited supply can be perceived to be a trivial problem, there are cost constraints which necessitate efficient allocation.

Economic theory is explicit with regard to conditions which satisfy the optimal allocation of inputs. Inputs are allocated between uses in an optimal manner when the ratio of marginal value products to marginal factor costs is the same for all uses of the input. (A shadow price of a linear programming model is a specialized marginal value product. This definition is useful for further discussion). Theorems of this nature are often used for insight into and interpretation of applied problems. The characteristics of the optimization models developed for analyzing the waste heat problem and the manner in which this problem is defined permits a modified application of marginal analysis or the model provided by economic theory. It should be interpreted as a construct by which optimal allocation of the waste heat resource can be discussed. The strict conditions defining the optimal allocation of a resource were not employed. The following discussion should be interpreted as a theoretical discussion concerning the allocation of a zero or possibly negatively priced input.

Assumptions

Several assumptions must be made before directly proceeding with this discussion. The time period for which the decision affecting an efficient allocation is one month. This is necessary to assure constancy in several parameters and particularly for the plant, general piping and distribution system, and number and level of subsystems. Secondly, within this time period heat dissipation rates per subsystem are constant as meteorological conditions are assumed constant.

Growth rates for the organisms being grown for this time period are also constant. This is necessary as the analytical models are discretized for this same time period. Prices for all agricultural products and input costs are constant. Lastly, for matters of convenience the waste heat is sold at a zero price to the waste heat utilization system.

The Model

With these facilitating conditions, a model can be specified. The marginal factor cost (MFC) of the waste heat input per subsystem is determined by the cost of supplying the input. The supply cost is constant within a set of spatial relationships, and for the number and type of subsystems operating for any one month.

The value of the intermediate product, waste heat, is determined by its value to the subsystem. The value of the waste heat over a monthly period is imputed. The increase in the revenues of the subsystem due to an increase in supply or capacity to utilize waste heat is the measure of the value of an additional unit of waste heat. Let the increased revenues for a use due to the supply of waste heat indicate the shadow price (SP) of waste heat for that use.

The problem of finding the optimal allocation of waste heat per subsystem becomes one of finding an allocation between uses where MFC of the j^{th} subsystem equals the shadow price in subsystem j, for all subsystems. Hence, the revenue function to be maximized can be stated as:

$$11)\quad \text{Max } \P = \sum_j SP_j\, X_j$$

Subject to:

$$12)\quad C = \sum_j MFC_j X_j$$

Finding the optimal allocation for waste heat in the i^{th} month, given costs and revenues, is an exercise for which the Lagrange technique for constrained optima can be used. This is shown as:

$$13)\quad \P = \sum_j SP_j X_j - \lambda\,(\Sigma MFC_j X_j - C)$$

By taking the first partial derivatives and setting them equal to zero:

$$14)\quad \begin{array}{l} \dfrac{\partial \P}{\partial X_1} = SP_1 - MFC_i = 0 \\ \vdots \qquad \vdots \qquad \vdots \qquad \vdots \\ \dfrac{\partial \P}{\partial X_j} = SP_j - MFC_j = 0 \end{array}$$

it can be shown by first order conditions that allocating waste heat on the basis of

$$15)\quad \frac{SP_1}{MFC_1} = \frac{SP_2}{MFC_2} = \cdots = \frac{SP_j}{MFC_j}$$

will give an optimal allocation.

Factors Limiting Allocative Efficiency

The preceding model postulates a constant marginal factor cost for a specified month, design, and spatial relationship. For the same conditions a declining relationship is postulated for the dollars per unit and quantity of waste heat allocated. These relationships are shown in the following graphical illustration.

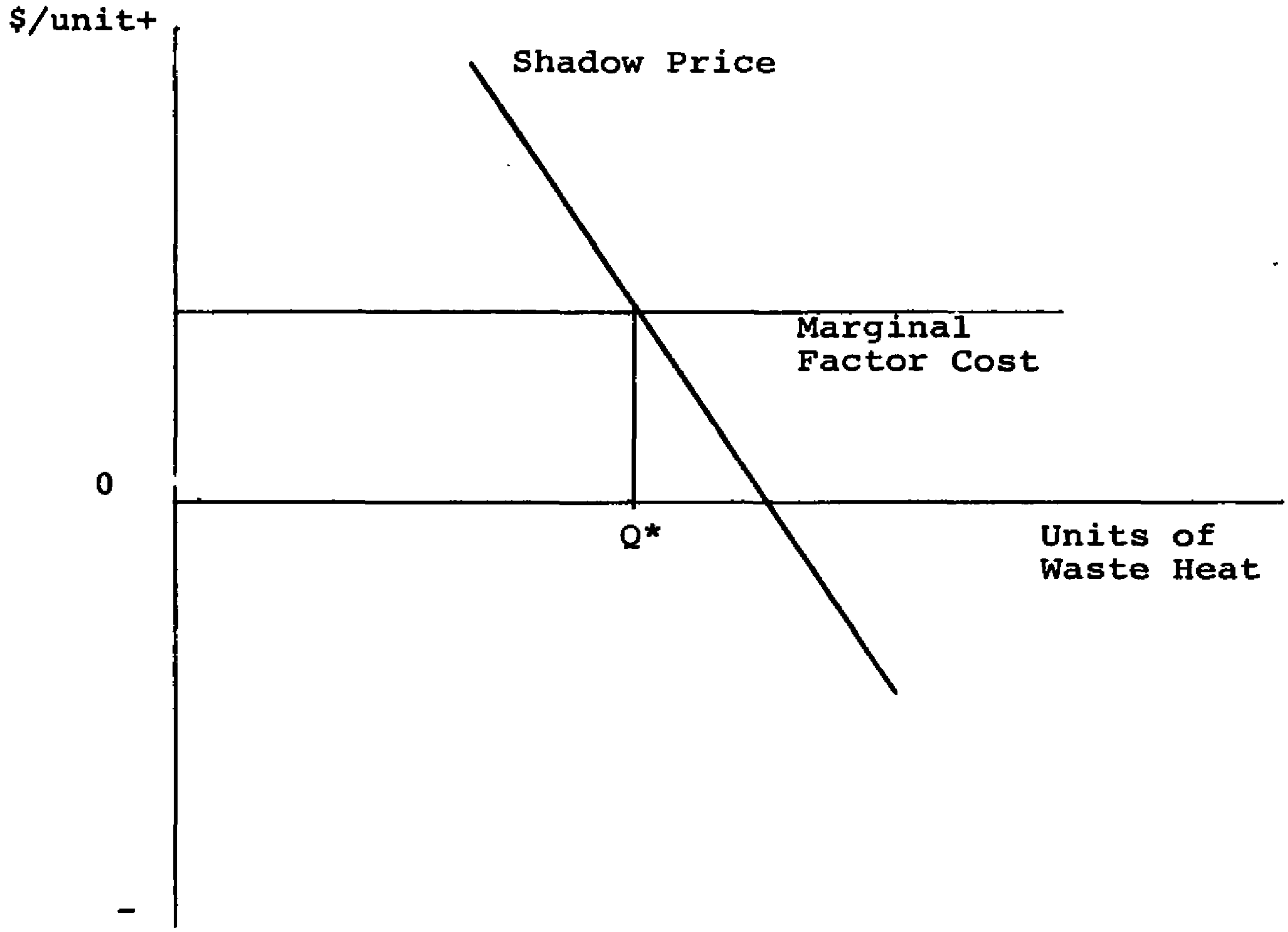

Figure 3-3

Allocative Efficiency in Waste Heat Use:
Marginal Factor Cost Equals Shadow Price

That the marginal factor cost of waste heat is determined by the constant cost of supply and is assumed to be priced at zero by the seller leads to an improper conclusion of an unlimited supply of the variable resource.

In actuality, the total amount is physically limited such that:

$$16)\quad \sum_{i=1}^{S} q_i^* \leq Q^*$$

where S is the number of subsystems operating, q_i^* is the quantity allocated to the ith subsystem and Q* is a fixed amount of discharged thermal effluent. For months where the total amount Q* is an insufficient supply, the allocative efficiency criterion as shown in equation 15 will not be met for one and possibly all subsystems.[1]

A second factor limiting allocative efficiency is that in some monthly periods Q* does not fulfill subsystem demand. Where supply is limited one subsystem is not allowed to transfer its usage to another. The waste heat resource is not perfectly mobile.

Figure 3-3 is drawn to allow for instances where the shadow price for waste heat is negative. The theoretical model developed above will still apply with negative shadow prices for waste heat. In order to obtain conditions of

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[1]As system profits are to be maximized and there are physical constraints on the reduction of waste below levels desirable for the organism, the standard principle of reducing input usage to less productive subsystems first is not employed.

allocative efficiency with negative shadow prices, a negative marginal factor cost is incurred. The negative marginal factor cost that equals the negative shadow prices is the payment to the utilization system for dissipating waste heat.

The Model Revisited

Figure 3-4 gives a simplified graphical interpretation of the allocation problem. This analysis is more suggestive than indicative as these demand and supply relationships are not empirically estimated. While the explanation of the supply curve (MFC) facing the firm is reasonably straight forward and plausible, what is represented as a demand curve (SP) is not as intuitively clear.

The shadow price or imputed value of waste heat cannot, in fact, be represented as a schedule of quantities and prices. In reality the shadow price of the input is represented by a point given those factors fixed in the monthly period (e. g., climatological conditions, design, spatial relationships, growth rates, dissipation rates, etc.). If this is so then the graphical illustration of allocative efficiency is shown as:

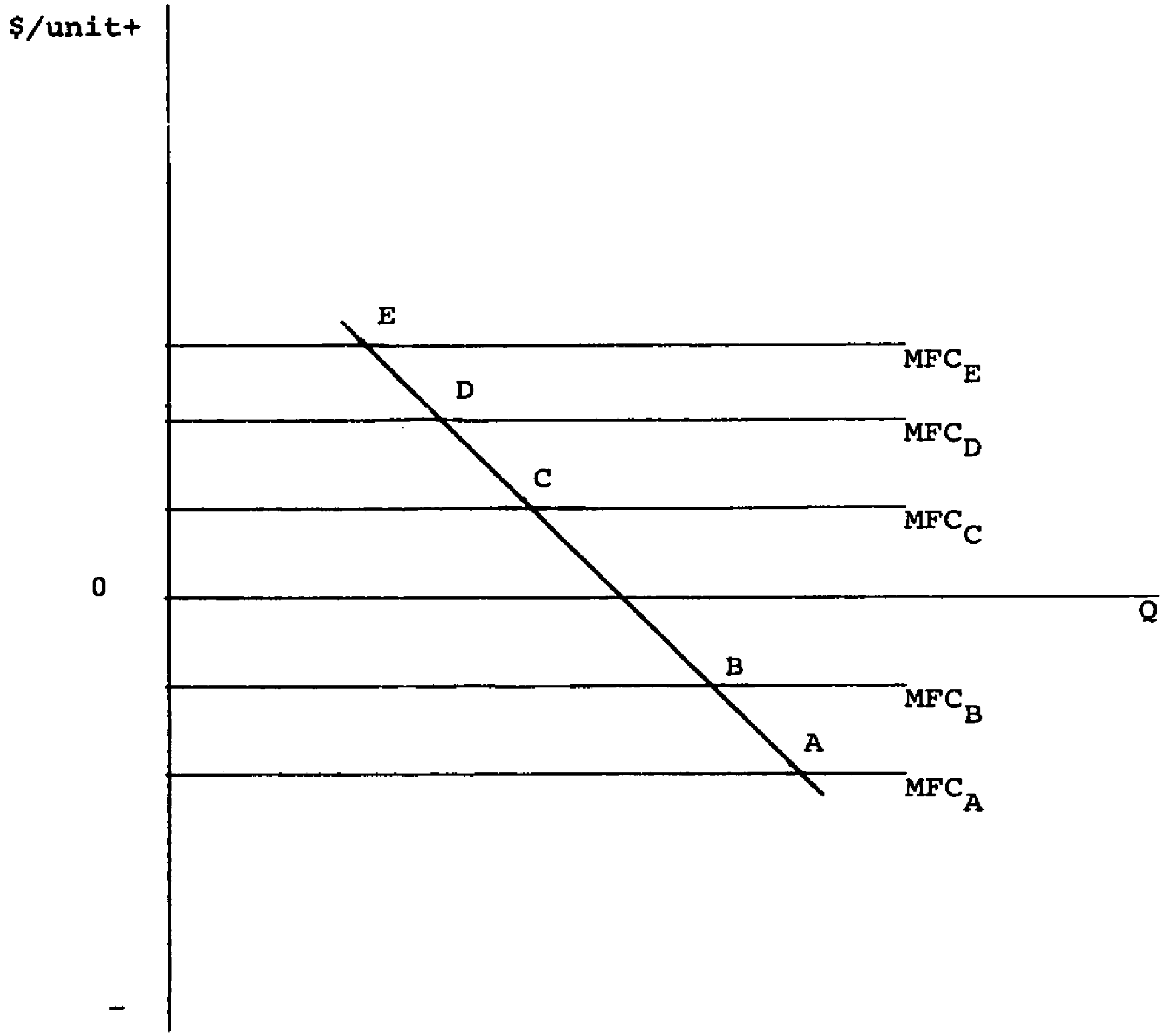

Figure 3-4

Schematic of Program OPTBOX Method for Finding the Efficient Allocation of Waste Heat Given the Dynamics of Changing Flow Rates where point A indicates the imputed negative value of waste heat to the firm at the negative MFC_1. Should the general piping and distribution system change so as to decrease supply price to the subsystem, the imputed value of waste heat will correspondingly increase. Points A, B, C, D, and E represent shadow prices for waste heat with different plants. A curve connecting these points is not analogous to the marginal curve of a single variable input for the firm.

Design

The Model

The decision making process of determining optimal design is a problem of making decisions in the present that will affect the attainment of other goals or the ability to undertake alternative investments over a multi-period time horizon. With the growth models, dissipation models and cost coefficients known, the decision maker is assumed to have perfect knowledge. Risk and uncertainty can be incorporated into each investment alternative by weighing each alternative by an appropriate discounting factor.

The ideal model would be built on the maximization of a payoff function where the current and future actions are incorporated. As not all future actions are known, the monetary outlay, or conversely cash flows, will not be known. A fully dynamic model where all input usage and generated revenues are dated cannot be employed.

A pseudo-dynamic model is then employed. The decision criteria becomes one where the profitability of alternative investments are reduced to present dollar terms instead of basing present decisions on all possible investment paths over the specified future time period. Alternatives available at the current time period constrain the range of choice.

A capital budgeting approach is used to formulate a basis on which decisions concerning the optimal design[1] can be made. In using the net present value method, all future net revenues are converted to present value terms using a discounting factor. The decision criteria on which optimal design is found is to maximize the net present value of monetary flows (Z) where:

$$Z = \sum_{j=1}^{S} \sum_{w=1}^{3} A_{jw} \left[\sum_{1}^{n} \frac{(R-C)_{jw}}{(1+r)^{n}} - K_{jw}\right]^{2}$$

Hence, for j agricultural and aquacultural activities w flow rates for each activity, and monthly sizes for the reservoir, the linear programming algorithm, will find the optimal solution.

Discount Rate

The discount rate is a measure of what is lost by receiving money later rather than now. Interest rates have

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[1]Given the preceding discussion, the choice of "optimal" design refers to alternatives available at the present.

[2]This statement is unchanged from equation 9, page 63. A description of terms is listed there and will not be repeated here.

a broader meaning as it covers all costs which accrue automatically with the passage of time.[1] The two concepts are related by the formula $D= 1/(1+i)$ if the capital market is at least approximately perfect.[2]

Different firms will discount investment and construction projects at different rates. In an effort to compare investment in a waste heat utilization system by a utility with other possible investments, some comparability is desired in the discount rate. One utility participating in this research uses a weighted average of the cost of seven different sources of funds. As the amount of funds derived from each source will vary on an annual basis, the discount rate may differ over the life of the investment.

It should also be noted that the discount rate will differ depending on the nature of the investment. For this reason and lack of certainty on the exact procedures used by utilities, sensitivity analysis is conducted on the effect of several discount rates on present value.[3]

Summary

This chapter presented the methodology that is employed in assessing whether utilizing waste heat in an integrated agricultural-aquacultural system is economically feasible.

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[1] William J. Baumol, Economic Theory and Operations Analysis, Englewood Cliffs, Prentice Hall, Inc., 1972.

[2] Ibid., p. 451.

[3] While the exact procedure has not been given, a general indication of the appropriate rate has been indicated.

The data employed are derived from several sources. The subsystem costs developed from synthetic data. The mathematical models in the allocation-simulation model were used to find productivity responses and heat dissipation characteristics of the subsystems. Those models are also discussed. The linear programming model is developed and its interaction with the allocation program is shown. A theoretical model is also developed to illustrate the basis for the optimal allocation of the waste heat input.

CHAPTER IV

OPTIMAL DESIGN CHARACTERISTICS FOR THE WASTE HEAT UTILIZATION SYSTEM

This chapter presents the results of the linear programming model under three alternative situations. The primary characteristic of the first alternative situation (Model I) is that subsystem sizes are not explicitly constrained.[1] Model II determines the optimal design when the fish pond enterprise is constrained at the eight-20 acre pond level. Model III shows the optimal combination of subsystems and subsystem sizes when prices are reduced below levels assumed in the previous models. While these three models do not incorporate all alternative constraints and probable economic conditions, they do show the sensitivity of important subsystem parameters to the alternative sets of constraints. They also provide a basis for which comparisons of the waste heat utilization system to conventional heat dissipation systems can be made.

The figures reported represent the net monetary returns for the optimal combination of subsystem size and types given 1974 input and product prices. Net monetary returns for subsystem operation do not include initial capital cost or discounted annual expenditures for the general

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[1] Constraints for each subsystem, except the reservoir, are implicitly provided by the separability constraints.

piping and distribution system.

Price Assumptions

Product price for corn was assumed to be $2.75 per bushel. The per bushel price for tomatoes and soybeans is $5.50. The price received for sweet corn is $.75 per dozen, and field beans are priced at $15.00 per hundredweight. The price per pound for undressed channel catfish is $.30 per pound.[1] The wholesale prices for a standard ornamental flower rotation are as follows: $2.60 for 6-inch Chrysanthemums, $3.25 for 6-inch Poinsettias, $2.60 for 6-inch Lilies, and $.65 for 4-inch Geraniums.

Availability of Resources Assumptions

Land and initial capital are stipulated to be readily available at market prices[2] and are not a limiting factor in optimal system design.[3] Skilled and unskilled labor is also assumed to be available at market prices as are managers with skills required for intensive aquaculture and an ornamental greenhouse operation.

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[1]The price is representative of what would be received for fish reared for commercial and fresh market use.

[2]Initial capital requirements are discussed in sections dealing with each particular model.

[3]The exception to this is the availability of 2-inch PVC piping. Price per unit for this material is not constant throughout. This is reflected in the statements for initial capital requirements as shown in Appendix 4-E.

Base Yields and Stocking Rates Assumptions

The allocation program determines the productivity response for optimal flow rates of waste heat water and for initial yields for the soil warming enterprises. A base stocking rate of 24,000 fingerlings per acre was assumed for the fish pond enterprise. This rate is low for commercial rearing facilities. The per acre rates for corn and tomatoes are 125 bushels and 500 bushels respectively. The base yield for sweet corn is 750 dozen, while the assumed rate for field beans is 17.5 hundredweight per acre. Soybean yield is assumed to be 42 bushels per acre. While the growth rates of ornamental flowers are not affected by the waste heat input,[1] it was assumed that Chrysanthemums, Poinsettias, and Lilies use one square foot of available space while Geraniums use one-quarter square foot of available bench space.

Optimal Design with no Constraints on Subsystem Size (Model I)[2]

System Design

Model I represents a set of circumstances where there are no constraints on the allocation of fixed resources.

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[1]The waste heat serves as a substitute heat source in the greenhouse with no affect on yields.

[2]While there were no explicit constraints on subsystem sizes, the solution is implicitly constrained by the largest of the separable parts. Fish ponds are implicitly constrained at 24-20 acre ponds. Soil warming for field crops is

The results under these conditions show that 375.44 total acres of fish ponds and 100 acres of soil warming acreage where tomatoes are grown comprise the optimal combination of waste heat utilization enterprises. The utilization of reservoir acreage, which will vary with the availability of waste heat not dissipated by the activities listed above, is shown in Table 4-1. These waste heat utilization activities and reservoir utilization rates are similar for all discount rates and time horizons studied.

The total fish pond acreage is comprised of .2639 of the first separable part (4-20 acre ponds) and for a flow rate 10 percent greater than that indicated to be optimal by the allocation program. The remainder of the total fish pond acreage is accounted for by .7361 of the fourth separable part of the fish pond subsystem (24-20 acre ponds). Again, a flow rate 10 percent greater than that indicated by the allocation program was found to be economically optimal. The initial capital requirements and annual costs for 4-20 acre ponds are shown in Appendix Tables 4-A and 4-B respectively. The same information for 24-20 acre ponds is shown in Appendix Tables 4-C and 4-D. Those for the soil warming (tomato) subsystem are shown in Appendix Tables 4-E and 4-F. The initial capital requirement and annual costs for the reservoir are jointly shown in Appendix Table 4-G.

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constrained as 400 acres. Soil warming for specialty crops is constrained at 100 acres. Greenhouse size is constrained at 216,000 square feet.

TABLE 4-1

RESERVOIR UTILIZATION RATES BY MONTH FOR MODEL I

Month	Acreage Required to Dissipate Waste Heat Not Utilized by Subsystems
January	101.56
February	101.41
March	.0
April	.0
May	207.41
June	207.04
July	206.89
August	206.89
September	207.91
October	.0
November	.0
December	101.31

Financial Analysis

Table 4-2 shows the inital capital costs, discounted net revenues, discounted annual costs for the reservoir, discounted capital replacement costs for capital replaced at the tenth and twentieth years and net monetary returns. Discount rates of 8, 10, 12, and 15 percent were used in combination with 25, 28, and 30-year time horizons. These results show that the greater the opportunity cost of capital and funds used in the investment decision, the less desirable is the investment of resources in a waste heat utilization system. As expected, however, the results also show that the greater the time period over which these expenditures are made, the greater will be the net monetary returns.[1] This table also shows that net monetary returns are sensitive to what the investor determines as his appropriate discount rate for such an investment.

Cost Minimizing Flow Rates

The linear programming results also show that for the separable parts of the fish pond subsystem that came into solution, flow rates 10 percent higher than those in the allocation program were found to be the cost minimizing rates

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[1]Net monetary returns are the difference between discounted net revenues and initial capital outlays, discounted reservoir operating costs, and discounted capital replacement costs.

TABLE 4-2

INITIAL CAPITAL REQUIREMENTS, DISCOUNTED NET REVENUES, RESERVOIR OPERATING COSTS, REPLACEMENT CAPITAL COSTS, AND NET MONETARY RETURNS FOR THE OPTIMAL DESIGN OBTAINED FROM MODEL I (IN THOUSANDS OF DOLLARS)

Discounted rate and Time Horizon	Initial Capital Outlays (a)	Discounted Net Revenues (b)	Discounted Reservoir Operating Costs (c)	Discounted Capital Replacement Costs at the 10th Year (d)	Discounted Capital Replacement Costs at the 20th Year (e)	Net Monetary Returns[1] (f)
8 percent-25 years	7269.7416	19718.5439	3336.2230	1346.4955	1970.1810	5795.9028
10 percent-25 years	7269.7416	16731.2654	2830.7989	1233.0141	1708.3993	3689.3115
12 percent-25 years	7269.7416	14456.9765	2446.0071	1133.8137	1498.8787	2108.5355
15 percent-25 years	7269.7416	11915.0741	2015.9371	1035.9032	1256.0442	337.4480
8 percent-28 years	7269.7416	20369.8197	3446.4239	1346.4955	1970.1810	6337.0377
10 percent-28 years	7269.7416	15693.7791	2655.2644	1233.0141	1108.3993	2827.3597
12 percent-28 years	7269.7416	14717.3898	2490.0669	1133.8137	1498.8787	2324.8889
15 percent-28 years	7269.7416	12042.8994	2037.6973	1035.9032	1256.0442	433.5131
8 percent-30 years	7269.7416	20567.8552	3479.9198	1346.4955	1970.1810	6501.5173
10 percent-30 years	7269.7416	17376.2012	2939.9170	1233.0141	1708.3993	4225.1292
12 percent-30 years	7269.7416	14847.7969	2512.1308	1133.8137	1498.8787	2433.2321
15 percent-30 years	7269.7416	12102.7580	2047.6918	1035.9032	1256.0442	493.3773

[1] Net monetary returns (f) are the difference of column b and columns a, c, d, and e.

in the design formulation.[1] It was found from the allocation program that by increasing flow rates by 10 percent, the average weight per fish for the two harvesting periods increased from .682 pounds and .6418 pounds to 1.1768 pounds and .4785 pounds.[2] The final fish population remained the same for the first harvesting period while increasing eight-tenths of one percent for the second population. Total pounds per pond at the end of a year was 26.55 percent higher where flow rates were increased by 10 percent. Where flow rates were decreased by 10 percent from the optimal (as determined by the allocation program) it was indicated by the allocation program that total pounds of fish per pond increased by only one-half of one percent.[3]

The linear programming results also show that the flow rates to the soilwarming subsystem which minimized total monetary outlays were 10 percent below that determined to be

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[1]While this discrepancy is difficult to account for, discussions with the systems analyst and person with the most intimate knowledge of the allocation program indicate that it is probably due to the linear programmings ability to better incorporate changes in flow rates with changes in pumping costs and feed costs. The changes in flow rates were assumed to have no impact on initial capital requirements (e.g., pumps, motors, pipes) of the subsystem.

[2]A marketable size fish is larger than this and is approximately the size fish harvested in the first crop in August. This small size is the size of fish at year's end.

[3]That total poundage for the year increased at all with reduced flows goes against model construction should be attributed to an inability to control all interactions and is treated as insignificant.

optimal by the allocation program. This can be explained again by looking at the productivity response and associated costs due to changed flow rates. When flow rates are increased by 10 percent, yield per acre for tomatoes increased by only 7.6 percent from the base yield. This would indicate that the corresponding increased root zone temperature was too high. For a 10 percent reduction in flow rates, yields increased by 52.27 percent. This productivity increase is the same as that obtained with the flow rate determined by the allocation program as optimal. It is obtained, however, at correspondingly reduced pumping costs.

Shadow Prices

Positive shadow prices can be used to indicate the amount by which income can be increased if one more unit of a limiting resource is available. They can also be used to indicate increased income if a unit of a constrained activity is brought into solution. The value of this information is also illustrated in that they indicate pressure to expand the use of particular resources or eliminate bottlenecks that reduce the level of constrained activities. Negative shadow prices will indicate the amount by which income can be increased if one less unit of the constraint is specified. They are also interpreted as the increase in costs due to the use of the last unit of that resource.

The limiting resource in the linear programming formulation is waste heat. Shadow prices can be used to estimate the value of the last unit of thermal discharge used in the waste heat utilization system.[1] Positive values will show what entrepreneurs will pay for an additional unit of the waste heat input. Negative values indicate what they will pay for receiving one less unit of waste heat. Negative shadow prices would also indicate when it would be profitable to add or increase a waste heat utilization subsystem. Table 4-3 shows the shadow prices for the waste heat resource for the specified interest rate and time horizons. The figures in Table 4-4 indicate that more units of waste heat could be effectively utilized during March, April, October and November.[2] It is also consistently shown that an excess supply of waste heat exists in September. Generally speaking, the shadow prices for waste heat would indicate that the soil warming enterprise, which presently operates from May through August, could be expanded to operate later in the fall. This would be subject to maintaining soil surface temperature at a level conducive to plant growth.

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[1]Shadow prices should not be confused with marginal value products (MVPs) derived from continuous functions. MVP by definition is the addition to total value product attributable to the addition of one unit of the variable to the production process, given a fixed schedule of fixed resources. MVPs will differ from shadow prices due to the assumed perfect complementary relationship among all inputs in the model. Hence other resources will not remain constant.

[2]The absolute values of shadow prices should not be given as much attention as should their relation to each other. Shadow prices will often exhibit instability due to factors mentioned earlier.

TABLE 4-3

SHADOW PRICES FOR WASTE HEAT BY MONTH FOR SPECIFIED DISCOUNT RATES AND PLANNING HORIZONS, MODEL I
(in dollars per thousand Btu's)

Month	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
January	-	-	-	-	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-	-	-	-
March	2.2019	-	1.5111	1.1788	2.2991	-	-	-	-	-	1.5694	1.2068
April	-	-	-	-	-	1.6532	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	-	-	-	-	-	-	-	-	-
September	-1.7992	-1.6305	-1.5021	-1.3585	-1.8472	-1.5719	-1.5168	-1.3658	-1.8412	-1.6669	-1.5241	-1.3691
October	-	-	-	-	-	-	1.5499	1.1979	-	1.9041	-	-
November	-	1.8079	-	-	-	-	-	-	2.3286	-	-	-
December	-	-	-	-	-	-	-	-	-	-	-	-

The shadow prices for waste heat are in agreement with conclusions drawn from Table 4-1. March, April, October, and November are months where reservoir utilization rates are zero. Waste heat utilization subsystems are fully utilizing the thermal discharge. The maximum reservoir utilization rate occurs during September. An excess supply condition exists and an expansion of subsystems will reduce reservoir size.

Shadow prices are also available for reservoir utilization activity. Table 4-4 presents those values. Non-zero shadow prices exist only for the month of September. These positive values indicate the amount by which costs can be reduced or income increased if one more acre of reservoir is available.

Constraints on separable parts of a subsystem limit activity sizes by restricting the sum of the fractions of the separable parts that come into solution to be less than or equal to one. Hence subsystems that come into solution are implicitly restricted to the maximum acreage of the separable parts. Table 4-5 indicates the amount by which income will be increased if another acre of fish ponds or soil warming (tomatoes) were available.

The figures indicate that constraints of 480 acres on the fish pond enterprise and 100 acres on tomatoes grown for fresh market on the soil warming acreage are relatively severe. While total fish pond acreage in the basis solution is not 480 acres, the shortage of waste heat in March, April,

TABLE 4-4

SHADOW PRICES FOR RESERVOIR UTILIZATION FOR SPECIFIED DISCOUNT RATES AND PLANNING HORIZONS, MODEL I
(IN THOUSANDS OF DOLLARS PER ACRE)

Month	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
September	25.9266	23.4956	21.6448	19.5762	26.4566	27.6513	21.8567	19.6809	26.6177	24.0204	21.9628	19.7290

TABLE 4-5

SHADOW PRICES FOR ONE ADDITIONAL ACRE OF FISH POND AND SOIL WARMING (TOMATOES)
FOR SPECIFIED DISCOUNT RATES AND PLANNING HORIZONS, MODEL I
(IN THOUSANDS OF DOLLARS PER ACRE)

	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
Fish Ponds	1124.7	933.6	789.3	627.7	1170.2	861.2	807.5	636.7	1184.0	978.7	816.6	640.8
Soil Warming (Tomatoes)	2013.2	1584.7	1259.6	896.0	2110.6	1429.6	1298.5	915.1	2140.2	1681.1	1318.0	924.1

October, and November does act to constrain this activity. The separability constraint on the soil warming enterprise does, however, restrict that activity. The value of the shadow prices and inclusion of all 100 potential acres of soil warming (tomatoes) in the optimal design verify the severity of that constraint.

Non-Basis Activities

The cost of forcing in activities which are non-optimal indicate the income penalties of bringing in one unit of non-basis activities into the solution. These values are always positive. If non-optimal activities were forced in, with the given income constraint, they would replace an activity already in solution which contributes more to system profits. In this respect they act as shadow prices for non-basis activities. Their value in the analysis of this problem is that they indicate the relative profitability of non-basis activities. The cost of forcing in non-optimal activities shows relative competitive positions of those activities. As such they indicate the order in which those activities would come into the optimal design were there more of the limiting resource available. The cost of the preferences of system management is also indicated should they desire a non-optimal subsystem to be a part of the total waste heat utilization system. Table 4-6 indicates the competitive position for the first 20 of the non-basis activities.[1]

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[1]As it would be redundant and time-consuming to report the cost of forcing in non-optimal activities for all discount

The greenhouse subsystem did not enter as a basis activity in the optimal design. As has been indicated, its competitive position with non-basis activities was not high either. Despite its capacity for generating significant revenues and system profit, the heat transfer mechanism is not efficient. The ability of the finned tube heat exchangers to dissipate heat during the middle six months of the year is rated as poor. Capital costs for initial and replacement capital are high on a dollars per Btu dissipated basis. The types of crops grown provide better returns than most specialty crops; however, greater revenues could be generated should foliage plants (house plants) be raised.

The greenhouse activity was specified to use waste heat on a year-around basis. That it uses waste heat on a year-around basis placed it in direct competition with fish ponds which are efficient dissipation mechanisms and have relatively high net returns. What could have been done, given the results obtained, would be to set up an activity whereby the greenhouse would be allocated waste heat when there existed conditions of excess supply of waste heat in the other subsystems. Greenhouses may be used as a supplementary system that would utilize waste heat when shadow prices for other systems are negative. It may be a feasible subsystem in non-integrated systems. But as its cost per

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rates and time horizons, only those for 12% at 28 years is reported. Relative positions would not change greatly from one discount rate-planning horizon to another.

TABLE 4-6

COMPETITIVE POSITIONS OF NON-BASIS ACTIVITIES
(IN THOUSANDS OF DOLLARS PER ACRE)

Order	Activity	Cost
1.	S.W.,[1] Tomatoes, 100 A,[2] Optimal[3]	16.7355
2.	S.W., Sweet Corn, 25 A, 10%↓ and Optimal	120.0223
3.	S.W., Sweet Corn, 25 A, 10%↑	157.7330
4.	S.W., Sweet Corn, 50 A, 10%↓ and Optimal	271.4899
5.	S.W., Tomatoes, 75 A, 10%↓	282.4247
6.	S.W., Tomatoes, 75 A, Optimal	294.9523
7.	F.P., 16-20 A Ponds, 10%↑	386.5396
8.	S.W., Sweet Corn, 75 A, 10%↓ and Optimal	440.9042
9.	F.P., 8-20 A Ponds, 10%↑	481.6776
10.	S.W., Sweet Corn, 75 A, 10%↑	554.0203
11.	S.W., Tomatoes, 50 A, 10%↓	574.4493
12.	S.W., Tomatoes, 50 A, Optimal	582.8010
13.	G.H., 54000 ft^2, 10%↓	592.4543
14.	G.H., 54000 ft^2, Optimal	621.5047
15.	G.H., 54000 ft^2, 10%↑	678.1750
16.	S.W., Sweet Corn, 100 A, 10%↓ and Optimal	691.8187
17.	S.W., Corn, 100 A, 10%↓ and Optimal	780.8696
18.	S.W., Soybeans, 100 A, 10%↓ and Optimal	856.1792
19.	S.W., Field Beans, 100 A, 10%↓ and Optimal	856.2032
20.	S.W., Corn, 100 A, 10%↑	865.5769

[1] S. W. indicates soil warming, F.P. indicates fish ponds, G. H. indicates greenhouse.

[2] A number followed by "A" indicates size in acres (e.g., 100 acres).

[3] "Optimal" indicates flow rate determined to be optimal by the allocation program, 10%↑ indicates flow rates 10% above that optimal, 10%↓ indicates flow rates 10% below that optimal.

unit of waste heat dissipated per time remains low relative to other subsystems, it is not feasible in an integrated system. Appendix Tables 4-H and 4-I show the estimated initial investment requirements and annual costs for a 216,000 square foot greenhouse.

Optimal Design with Constrained Fish Pond Acreage (Model II)

Model I indicated that a 375 acre fish pond subsystem is one of the major components in the optimal system design. The amount of channel catfish produced from this subsystem would strain existing marketing and distribution channels. Unless input supply contracts could be obtained, there is also some possibility of not obtaining fingerlings of specified size and quality. Given these marketing constraints, Model II was developed.

System Design

In Model II, the acreage available for fish ponds is restricted to 8-20 acre ponds. In that a fixed amount of waste heat must be dissipated, this will lead to changes in the optimal design given by Model I. The results, with this added constraint, show that the fish pond enterprise is 160 acres and the soil warming plot on which tomatoes are grown is 100 acres in size. The utilization of reservoir acreage by month is shown in Table 4-7. The utilization rate is determined by the availability of waste heat not dissipated by the waste heat utilization system and is unchanged by discount rate and planning horizon.

TABLE 4-7

RESERVOIR UTILIZATION RATES BY MONTH FOR MODEL II

Month	Acreage Required to Dissipate Waste Heat Not Utilized by Subsystems
January	348.47
February	347.96
March	351.64
April	350.36
May	351.64
June	350.87
July	350.63
August	350.63
September	351.14
October	331.74
November	351.00
December	347.63

The 160 acres of fish ponds is comprised of .5775 of the second separable part (8-20 acre ponds), and .1450 of the fourth separable part (24-20 acre ponds). All flow rates were indicated to be 10 percent above the optimal determined by the allocation program. The soil warming (tomatoes) subsystem is 100 acres in size with a flow rate 10 percent below optimal. The initial capital requirements for 8-20 acre ponds are shown in Appendix Table 4-J. Corresponding annual costs are presented in Appendix Table 4-K. Similar cost information for the first and fourth separable parts of the fish pond subsystem, the soil warming area, and reservoir are cited in the discussion of optimal design for Model I in the previous section.

Financial Analysis

The capital requirements, discounted net revenues and replacement capital, and subsequent net monetary returns are shown in Table 4-8. Comparison of these figures with those in Table 4-2 for Model I indicates that the cost of the explicit constraint that the fish ponds in total can be no greater than 160 acres is substantial. For all specified discount rates and planning horizons, net monetary returns are negative. For a planning horizon of 28 years where costs and returns are discounted at a rate of 12 percent, the loss in net monetary returns is $6,233,426.50 from that indicated for Model I. The difference in discounted net revenues amounts to a combined loss of $7,070,068.00 to ownership of

TABLE 4-8

INITIAL CAPITAL REQUIREMENTS, DISCOUNTED NET REVENUES, RESERVOIR OPERATING COSTS AND REPLACEMENT CAPITAL COSTS, AND NET MONETARY RETURNS FOR THE OPTIMAL DESIGN OBTAINED FROM MODEL II
(IN THOUSANDS OF DOLLARS)

Discount Rate and Time Horizon	Initial Capital Outlays (a)	Discounted Net Revenues (b)	Discounted Reservoir Operating Costs (c)	Discounted Capital Replacement Costs at the 10th Year (d)	Discounted Capital Replacement Costs at the 20th Year (e)	Net[1] Monetary Returns (f)
8 percent-25 years	6146.51	10245.9779	5642.6465	612.6324	896.3987	3052.2098
10 percent-25 years	6146.51	8693.7543	4187.8087	561.0003	777.2925	3578.8573
12 percent-25 years	6146.51	7512.0081	4136.9996	515.8658	681.9642	3969.3315
15 percent-25 years	6146.51	6187.5201	3429.1516	471.3182	571.4786	4430.9383
8 percent-28 years	6146.51	10584.4193	5829.0324	612.6324	896.3987	2900.1542
10 percent-28 years	6146.51	8154.6647	4490.9223	561.0003	777.2925	3821.0605
12 percent-28 years	6146.51	7647.3218	4211.5193	515.8658	681.9642	3908.5376
15 percent-28 years	6146.51	6257.6264	3446.4139	471.3182	571.4786	4318.0945
8 percent-30 years	6146.51	10687.2896	5885.6849	612.6324	896.3987	2853.9365
10 percent-30 years	6146.51	9028.8702	4972.3632	561.0003	777.2925	3428.2958
12 percent-30 years	6146.51	7751.0828	4248.8365	515.8658	681.9642	3878.0938
15 percent-30 years	6146.51	6288.7296	3463.3179	471.3182	571.4786	4363.8952

[1]For definition of net monetary return see Table 4-2.

the system. Due to increased reservoir size, discounted operating costs are $1,721,452.40 higher over 28 years for a percentage increase of 69.13 percent. Initial capital requirements for this design are reduced from $7,269,741.60 to $6,146,510.00. Table 4-9 summarizes this information by showing absolute and percentage differentials for the specified items for a 28-year planning horizon and discount rate of 12 percent.

Shadow Prices

A change in the design of the waste heat utilization system will alter the value of the waste heat resource. As less utilization capacity is available because of the acreage constraint on the aquacultural enterprise, a larger proportion of the thermal effluent is dissipated by the reservoir. A comparison of Tables 4-1 and 4-7 indicates that the size of the reservoir under Model I is 208 acres, whereas under Model II maximum reservoir utilization is 352 acres. At no time under Model II is the rate of reservoir utilization zero acres per month. As a result of these conditions, at no time do waste heat utilization systems compete for the waste heat input, nor is there a shortage of waste heat available for use in the system. This contrasts with results of Model I where during the months of March, April, October and November reservoir acreage requirements were at the zero level. Hence, instead of temporary conditions of excess demand for waste heat, conditions of excess supply exist given the constraints and design of the system with

TABLE 4-9

COMPARISON OF ABSOLUTE DIFFERENTIALS AND PERCENTAGE CHANGES IN CAPITAL OUTLAYS, DISCOUNTED NET REVENUES, RESERVOIR OPERATING COSTS AND CAPITAL REPLACEMENT COSTS, AND NET MONETARY RETURNS AT A DISCOUNT RATE OF 12 PERCENT FOR 28 YEARS FOR MODELS I AND II (IN THOUSANDS OF DOLLARS)

	Initial Capital Requirement	Discounted Net Revenues	Discounted Reservoir Operating Costs	Discounted Capital Replacement Costs at the 10th Year	Discounted Capital Replacement Costs at the 20th Year	Net Monetary Returns
Model I	7269.7416	14717.3898	2490.0669	1133.8137	1498.8787	2324.8889
Model II	6146.51	7647.3218	4211.5193	515.8658	681.9642	3908.5376
Absolute Difference	1123.2316	7070.0680	1721.4524	617.9479	816.9145	6233.4265
Percentage Change	15.45	48.04	69.13	54.44	54.47	268.2

Model II. An examination of the shadow prices for the waste heat input indicates the amount by which system income will be increased if one less unit of waste heat is available. The incidence of negative shadow prices also indicates when there is pressure to contract utilization capacity. The absolute value of the negative shadow price indicates what system ownership would pay for one less available unit of waste heat. Table 4-10 shows the shadow prices for waste heat by month and for specified discount rates and planning horizons. The only months with non-zero shadow prices are March and May.

The results show that for the months of March and May waste heat is in excess supply for the mix of subsystems. Another conclusion is that there may be some pressure to reduce system size during those months with the incentive to reduce size being greater in May.

The maximum reservoir utilization rates occur for the months of March and May. The minimum utilization rate occurs during October and is only 20 acres less than the maximum 352 acres. Positive shadow prices exist for reservoir utilization during the months where there is no excess capacity. Table 4-11 indicates the increase in system income if another acre of reservoir were available.

Along with the implicit constraints resulting from restricting the separable parts, Model II restricts acreage for aquacultural production. The cost of these constraints is stated in terms of income that would be obtained if one

TABLE 4-10

SHADOW PRICES FOR WASTE HEAT BY MONTH FOR SPECIFIED DISCOUNT RATES AND PLANNING HORIZONS, MODEL II
(IN DOLLARS PER THOUSAND BTU'S)

Month	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
March	-.7549	-.6405	-.5535	-.4587	-.7798	-.6008	-.5634	-.4610	-.7874	-.6652	-.5684	-.4633
May	-1.2315	-1.1495	-1.0871	-1.0180	-1.2494	-1.1211	-1.0943	-1.0209	-1.2584	-1.1672	-1.0979	-1.0225

TABLE 4-11

SHADOW PRICES FOR RESERVOIR UTILIZATION FOR SPECIFIED DISCOUNT RATES AND PLANNING HORIZONS, MODEL II
(IN THOUSANDS OF DOLLARS PER ACRE)

Month	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
March	8.30	7.04	6.08	5.04	8.57	6.61	6.20	5.07	8.66	7.32	6.25	5.10
April	17.62	16.45	15.56	14.00	17.88	16.04	15.66	14.61	17.95	16.70	15.71	14.63

more acre were available for each of the different subsystems in the basis solution. The per acre cost of the explicit constraint limiting fish ponds to 160 acres is also shown in Table 4-12.

For a discount rate of 12 percent for 28 years, it is shown that an additional acre of each subsystem will result in $84,510.00 increased income to fish ponds and that additional income in the amount of $943,720.00 will accrue to the soil warming enterprise. The cost of the explicit constraint on aquacultural production is $35,110.00.

Optimal Design with Lower Commodity Prices (Model III)

The assumed price for tomatoes in the previous two models reflect what could be obtained were they sold for consumption in the fresh market. There are market conditions which may prevent the price of $5.50 per bushel from being obtained. First, the quantity available from 100 acres (76,000 bushels) would in all likelihood have a dampening effect on price. Secondly, in many states and local areas existing supply and demand conditions would not warrant this price. Lastly, for the production practices specified in the models presented here, this is no allowance for double cropping of 50 acres or for marketing a portion of the crop other than during the traditional August-September period.

The price assumed for undressed channel catfish at $.30 per pound would be in a reasonable range for most uses. Greenfield (1970) indicates that the prices paid by

TABLE 4-12

SHADOW PRICES FOR ONE ADDITIONAL ACRE OF SPECIFIED SUBSYSTEMS AND COST OF EXPLICIT CONSTRAINT
(IN THOUSANDS OF DOLLARS PER ACRE)

	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
Fish Ponds	113.82	96.58	83.45	69.17	117.84	90.59	84.95	69.51	118.73	100.30	85.71	69.86
Soil Warming (Tomatoes)	2047.72	1616.91	1290.04	936.69	2145.60	1461.00	1329.18	943.72	2175.35	1713.84	1348.78	952.72
Explicit Constraint on Fish Pond Acreage	49.35	40.76	34.28	27.23	51.43	37.45	35.11	27.43	52.06	42.82	35.53	27.63

processors in 1969 for cultured catfish averaged \$.41. Given a 25 cent per pound charge for dressing (gills and viscera removed) and packing, the resulting price would correspond to that presently being received for processed channel catfish by commercial catfish farming enterprises. Should, however, the catfish be used for feed and as a source of protein for livestock, we would expect a lower price to be received.

Questions concerning changing market conditions, their effect on price, and consequently the profitability of the waste heat utilization are important. To deal with these questions we will assume that lower prices will be received for these two commodities. In this model (Model III) a price of \$3.00 per bushel is assumed for tomatoes while a price of \$.25 per pound is assumed for channel catfish. These lower prices are used to reflect the probable influences of increased supply on local and regional markets. A lower price for catfish makes its increased use as a source of protein in feeds more appealing.

System Design

Model III represents a set of circumstances where lower prices are assumed as stated above and where there are no constraints on the allocation of fixed resources (system design). The size and types of subsystems determined as optimal under these conditions are identical to those in Model I. The results show that 375.44 acres of fish ponds and 100 acres of soil warming (tomatoes) comprise the optimal waste heat utilization system. The total fish pond acreage is comprised of .2639 of 4-20 acre ponds and .7361 of 24-20 acre ponds. Both separable parts have flow rates 10 percent above the optimal level determined by the allocation program. The linear programming model also indicates that 100 acres of soil warming (tomatoes) have a flow rate 10 percent below that optimal rate indicated by the allocation program.

The monthly utilization rates for reservoir activity are consequently identical to those indicated in Model I. The maximum acreage used occurs during September and is 207.91 acres for that month. The reservoir acreage required to dissipate the waste heat not utilized by the above subsystems can be reviewed in Table 4-1.

Financial Analysis

The similar design characteristics under different assumed prices indicate that the design is stable for different market conditions. Table 4-13, however, indicates that there will be significant differences in net monetary returns for specified interest rates and time horizons. As initial capital requirements, discounted replacement costs for the tenth and twentieth years, and discounted reservoir operating costs are identical to those in Model I, they will not be presented here.[1] Discounted net revenues and net monetary returns for Model III will be presented. For comparison the net monetary returns of Model I will also be shown.

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[1]For review purposes, these figures are available in Table 4-2.

TABLE 4-13

DISCOUNTED NET REVENUES AND NET MONETARY COSTS FOR MODEL III AND THEIR COMPARISONS WITH THOSE FOR MODEL I (IN THOUSANDS OF DOLLARS)

	Model III		Model I	
	Discounted Net Revenues	Net Monetary Returns	Net Monetary Returns	Difference in Net Monetary Returns
8 percent-25 years	7779.7416	-6143.5912	5795.9028	11939.4940
10 percent-25 years	6600.5558	-6441.3982	3689.3115	10130.7097
12 percent-25 years	5703.3391	-6645.1019	2108.5355	8753.6374
15 percent-25 years	4421.3758	-6850.4739	337.4480	7187.9519
8 percent-28 years	8036.0047	-5996.8374	6337.0377	12333.8751
10 percent-28 years	6191.2630	-6675.1564	2827.3597	9502.5161
12 percent-28 years	5806.0732	-6586.4277	2524.8889	8911.3166
15 percent-28 years	4468.8085	-6824.8014	433.5131	7258.3145
8 percent-30 years	8114.1068	-5952.2311	6501.5173	6452.7484
10 percent-30 years	6854.9857	-6296.0863	4225.1292	10521.2155
12 percent-30 years	5851.5194	-6557.0454	2433.2321	8990.2775
15 percent-30 years	4515.0015	-6798.9969	493.3773	7292.3742

While the optimal design is not changed with a different regime of prices, the net monetary returns show significant modification. For a discount rate of 12 percent over a 28-year time period, the discounted net monetary returns are -$6,586,427.70 given the prices assumed for Model III. The corresponding amount for Model I is $2,324,888.90. The difference for these two models amounts to $8,911,316.60 over 28 years.

Shadow Prices

A relevant question to be asked for this particular model is whether the lower prices for the agricultural and aquacultural products, and consequently reduced discounted net monetary returns, will significantly affect shadow prices for the waste heat resource for monthly time periods. Table 4-14 indicates the amount by which system income will increase if another unit of waste heat is available (positive shadow prices) and also the amount by which system costs will increase if another unit of waste heat is used.

A comparison of Table 4-14 with Table 4-3[1] indicates the negative shadow prices (which occur almost exclusively during September) are either identical or nearly so for the specified discount rates and time periods. This would indicate that the effect of excess supply of waste heat for this

[1] Table 4-3 presents the corresponding shadow prices for Model I.

TABLE 4-14

SHADOW PRICES FOR WASTE HEAT BY MONTH FOR SPECIFIED DISCOUNT RATES AND PLANNING HORIZONS, MODEL III
(IN DOLLARS PER THOUSAND)

Month	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
January	-	-	-	-	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-	-	-	-
March	.6746	-	.3914	-	.7213	.4377	-	-.3902	-	-	.4194	.5149
April	-	-	-	-	-	-	-	-	-	-	-	-
May	-	-	-	-.7181	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	-	-	-	-	-	-	-	-	-
September	-1.7992	-1.6305	-1.5021	-.6454	-1.8360	-1.5719	-1.5168	-.9783	-1.8472	-1.6669	-1.5241	-1.3691
October	-	-	-	.2585	-	-	.4100	.2665	-	.5582	-	-
November	-	.5120	-	-	-	-	-	-	.7355	-	-	-
December	-	-	-	-	-	-	-	-	-	-	-	-

time period has close to an identical impact on the cost of operation of the system for both models. The average shadow price during September for Model I is -1.5833. For Model III, the corresponding amount is -1.4906. The implicit value of the marginal unit of the variable resource where shadow prices are positive differs significantly between Models I and III. The average shadow price for March is 1.6611 for Model I and .3956 for Model III. The corresponding shadow prices for October and November are 1.7539 for Model I and .4568 for Model III. The conclusion to be drawn from these results should be no surprise. The demand price for a variable resource will be greater the higher the selling price of the commodity it is used to produce (1).

The shadow prices for additional acreage of the two subsystems in Models I and II indicate that the soil warming (tomatoes) subsystem is a greater bottleneck to increased system income than is the aquacultural subsystem. Given the prices assumed in Model III, system income can be increased more by expanding the aquacultural subsystem than by the soil warming (tomatoes) subsystem.[1] Table 4-15 indicates the amounts by which system income will be increased should additional acreage of each subsystem be forced into solution.

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[1]This is true except where a discount rate of 8 percent is applied.

TABLE 4-15

SHADOW PRICES FOR ONE ADDITIONAL ACRE OF FISH PONDS AND SOIL WARMING (TOMATOES) FOR SPECIFIED DISCOUNT RATES AND PLANNING HORIZONS, MODEL III
(IN THOUSANDS OF DOLLARS PER ACRE)

	8% 25 Yrs.	10% 25 Yrs.	12% 25 Yrs.	15% 25 Yrs.	8% 28 Yrs.	10% 28 Yrs.	12% 28 Yrs.	15% 28 Yrs.	8% 30 Yrs.	10% 30 Yrs.	12% 30 Yrs.	15% 30 Yrs.
Fish Ponds	602.5	490.6	406.45	313.09	630.8	445.6	417.7	318.2	639.3	518.5	423.4	325.3
Soil Warming (Tomatoes)	675.9	450.0	279.1	129.5	729.2	365.3	300.4	130.1	745.3	502.7	311.1	130.8

CHAPTER V

COMPARATIVE ANALYSIS OF WASTE HEAT UTILIZATION SYSTEMS WITH CONVENTIONAL DISSIPATION METHODS

The previous chapter dealt with important operational and financial characteristics of waste heat utilization systems. Certain exogenous variables were changed so that the effect of different economic situations could be measured as to their effect on these characteristics. The utilization systems were analyzed as sets of economic activities organized to accomplish a specific goal. Least cost criteria determined the optimal design of those systems given the specified constraints.

Ignored in this previous analysis are the overhead activities, the costs of which cannot be directly attributed to the operation of a single subsystem. The determination of the least cost combination of activities which satisfy specified constraints could not be conducted with the techniques available if overhead costs were specified as a function of subsystem size. However, whether a waste heat utilization system is a least cost alternative to conventional methods of waste heat dissipation necessitates the inclusion of overhead costs.

Chapter 5 assesses whether a waste heat utilization system specified in the previous chapter and its consequent overhead costs is a least cost alternative to conventional methods that power plants presently use to dissipate waste heat. Capital and annual costs were obtained for natural and mechanical draft cooling towers, cooling pond (reservoir), and spray canal type heat dissipation alternatives. These costs are found in Appendix Table 5-A.[1]

General Piping and Distribution System

Overhead capital and operating costs are incurred by the operation of a general piping and distribution system.[2] Several alternative types of distribution systems were studied. These included open flow channel, surface pipe, buried pipe, and combinations of the above. From these, a buried pipe system was chosen.

As the waste heat utilization system is not site specific, assumptions were made regarding topology and spatial relationships between the subsystems and between subsystems and the power plant. For simplicity, it was assumed that

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[1]The comparability of the cost studies compiled by this researcher and those obtained from one of the participating utilities cannot be insured. As the investment criteria and objective functions utilized by utilities differ from those used herein, the presentation of secondary data will not be in a form immediately usable. Hence the secondary data found in Appendix Table 5-A underwent slight modification for use in this analysis. The modifications made did not in any instance make those alternative methods more costly.

[2]For a detailed study of this system, see V. M. Schultink, "Feasibility Study of the Utilization of Waste Heat in Agriculture," Unpublished Masters Thesis, Michigan State University, Department of Agricultural Engineering, October, 1975.

the plant and subsystems are located on a plane field. Assumptions regarding spatial relationshipswere not so easily made.

The obvious cost minimizing general piping and distribution system is that for which all subsystems are located at a point immediately adjacent to the power plant. The next best alternative would be to locate them in a vertical relationship immediately adjacent to the plant. While both alternatives would minimize transport and capital costs, they would in all likelihood not meet legal sanctions. A more reasonable approach was taken in locating subsystems. Schematics for the proposed layout of subsystems for Models I and III, and Model II are shown in Appendix Figures 5-A and 5-B It is not known whether these layouts minimized capital costs or operating costs for the general piping and distribution system. Legal questions were also not considered.

The purpose of the general piping and distribution system is to convey the heated water from the power plant to the subsystems and then return the cooled water from the subsystems to the power plant. It does not include the pumping of the water through the condenser or subsystems. It does regulate flows to subsystems and insure return of cooling water to the power plant.

Comparisons Among Waste Heat Utilization Systems

The comparison of the three waste heat utilization systems with conventional alternative methods is conducted in two steps. The first step is comprised of assessing net monetary returns for each utilization system, and initial capital requirements and discounted annual costs for the general piping and distribution system for each of the three models studied in the previous chapter. It indicates the least cost system among systems that use waste heat when general piping and distribution costs are included. The second step compares each of the three designs (general piping and distribution costs included) with conventional heat dissipation methods. It is then determined which alternative is the least cost alternative for dissipating the specified amount of waste heat.

Table 5-1 shows the initial net monetary returns for Model I as they have been derived in Table 4-2, initial capital requirements, the discounted annual operating costs of the general piping and distribution system and total system costs. Table 5-2 shows a corresponding analysis for Model II. The derivation of net monetary returns is shown in Table 4-8. The corresponding figures for Model III are shown in Table 5-3. Net monetary returns for this model have been derived in Table 4-13. The initial capital requirements and discounted annual costs for the general piping and distribution system for Models I and III are shown

TABLE 5-1

NET MONETARY RETURNS AND INITIAL CAPITAL REQUIREMENTS AND DISCOUNTED ANNUAL COSTS FOR GENERAL PIPING AND DISTRIBUTION SYSTEM: MODEL I (IN THOUSANDS OF DOLLARS)

Discount Rate and Time Horizon	Net Monetary Returns (a)	Initial Capital Requirements GP & DS[1] (b)	Discounted Annual Operating Costs GP & DS[1] (c)	Total[2] Monetary Outlays (d)
8 percent for 25 years	5795.9028	9727.235	51713.481	55644.813
10 percent for 25 years	3689.3115	9727.235	43973.027	50010.950
12 percent for 25 years	2108.5355	9727.235	37995.466	45614.165
15 percent for 25 years	337.4480	9727.235	31314.976	40704.763
8 percent for 28 years	6337.0377	9727.235	53536.446	56932.174
10 percent for 28 years	2827.3597	9727.235	43390.510	50290.385
12 percent for 28 years	2324.8889	9727.235	38679.986	46082.332
15 percent for 28 years	433.5131	9727.235	31651.181	40994.902
8 percent for 30 years	6501.5173	9727.235	54537.792	57763.509
10 percent for 30 years	4225.1292	9727.235	45668.098	51170.203
12 percent for 30 years	2433.2321	9727.235	39022.973	46316.975
15 percent for 30 years	493.3773	9727.235	31808.528	41042.385

[1]General Piping and Distribution System.

[2]Total monetary outlays (d) are equal to (a), (b), (c)

TABLE 5-2

NET MONETARY RETURNS AND INITIAL CAPITAL REQUIREMENTS AND DISCOUNTED ANNUAL COSTS FOR GENERAL PIPING AND DISTRIBUTION SYSTEM: MODEL II (IN THOUSANDS OF DOLLARS)

Discount Rate and Time Horizon	Net Monetary Returns (a)	Initial Capital Requirements GP & DS[1] (b)	Discounted Annual Operating Costs GP & DS[1] (c)	Total[2] Monetary Outlays (d)
8 percent for 25 years	-3052.2098	5180.726	39391.367	47624.302
10 percent for 25 years	-3578.8573	5180.726	35495.282	42254.856
12 percent for 25 years	-3969.3315	5180.726	28942.035	38092.092
15 percent for 25 years	-4430.9383	5180.726	23853.349	33465.013
8 percent for 28 years	-2900.1542	5180.726	40719.962	48800.842
10 percent for 28 years	-3821.0605	5180.726	34575.013	43576.893
12 percent for 28 years	-3908.5376	5180.726	29463.450	38552.713
15 percent for 28 years	-4378.0945	5180.726	24109.444	33668.264
8 percent for 30 years	-2853.9345	5180.726	41542.711	49577.371
10 percent for 30 years	-3428.2958	5180.726	34786.458	43395.479
12 percent for 30 years	-3878.0938	5180.726	29724.711	38783.530
15 percent for 30 years	-4363.8952	5180.726	24243.396	33788.017

[1]General Piping and Distribution System.

[2]Total monetary outlays (d) are equal to (a), (b), (c).

TABLE 5-3

NET MONETARY RETURNS AND INITIAL CAPITAL REQUIREMENTS AND DISCOUNTED ANNUAL COSTS FOR GENERAL PIPING AND DISTRIBUTION SYSTEM: MODEL III (IN THOUSANDS OF DOLLARS)

Discount Rate and Time Horizon	Net Monetary Returns (a)	Initial Capital Requirements GP & DS[1] (b)	Discounted Annual Operating Costs GP & DS[1] (c)	Total[2] Monetary Outlays (d)
8 percent for 25 years	-6143.5912	9727.235	51713.481	67584.307
10 percent for 25 years	-6441.3982	9727.235	43973.027	60141.660
12 percent for 25 years	-6645.1019	9727.235	37995.466	54367.802
15 percent for 25 years	-6850.4739	9727.235	31374.976	47952.684
8 percent for 28 years	-5996.8374	9727.235	53536.446	69260.518
10 percent for 28 years	-6675.1564	9727.235	43390.511	59797.902
12 percent for 28 years	-6786.4277	9727.235	38679.986	55193.646
15 percent for 28 years	-6824.8014	9727.235	31651.181	48203.217
8 percent for 30 years	-5952.2311	9727.235	54537.792	70217.258
10 percent for 30 years	-6296.0863	9727.235	45668.098	61691.419
12 percent for 30 years	-6557.0454	9727.235	39022.973	55307.253
15 percent for 30 years	-6798.9969	9727.235	31803.528	48329.759

[1]General Piping and Distribution System.

[2]Total monetary outlays (d) are equal to (a), (b), (c).

in Appendix Tables 5-B and 5-C respectively. Initial capital requirements for the distribution system of Model II are shown in Appendix Table 5-D, while annual costs are shown in Appendix Table 5-E.

When capital and operating costs for the general piping and distribution system are included, it is shown that Model II is the least cost waste heat utilization system. Model II, where fish pond acreage is constrained, was not, however, a least cost combination of sizes and types of subsystems. Tables 5-1 through 5-3 show that the initial capital requirements for the distribution system are $5,180,726.00 for Model II as opposed to $9,727,235.00 for Models I and II. This significant difference can be accounted for by the differences in design. The fish pond acreage for Model II is 160 total acres versus 375 total acres for Models I and III. Reservoir size for Model I is 352 acres, whereas the maximum size for Models I and III is 208 acres. The capital required for pipes and pumps for 375 acres as compared to 160 acres of fish ponds is significantly greater than reduction in these costs in going from 352 acres of reservoir to 208 acres.

Discounted annual costs for the general piping and distribution system for Model II are $29,463,450.00 for 28 years at 12 percent. Those for Models I and III are $38,679,986.00. The difference in these costs is attributable to the increased flow rates and distances that the waste heat water must be pumped for the aquacultural subsystem.

The higher initial capital requirements and discounted annual operating costs for the general piping and distribution system for Model I are not offset by the higher discounted net returns for this model. Hence, as Tables 5-1 and 5-3 show, the least cost system of waste heat uses is not the least cost alternative between waste heat utilization systems when costs for the general piping and distribution system are included. The total costs for the system design under Model I are $46,082,332.00 whereas the total cost for the system configuration in Model II is $38,552.713.00 for a 28-year planning horizon at a discount rate of 12 percent.

Comparison Among Conventional Mechanisms and Waste Heat Utilization Systems

Table 5-4 indicates the total monetary outlays for the three integrated waste heat utilization systems, natural and mechanical draft cooling towers, cooling pond, and spray canal type heat dissipation systems. These figures show that Model III will, over the planning horizons and for discount rates specified, generate approximately the same total monetary outlays as cooling ponds and natural draft cooling towers. It is also shown that utilization of an agricultural-aquacultural system such as that specified in Model I will for all discount rates and time horizons cost slightly less than mechanical draft cooling towers and spray canals. Model II, where the fish pond subsystem is constrained to 160 acres in size, is indicated as the least cost method for dissipating

TABLE 5-4

COMPARISON OF TOTAL MONETARY OUTLAY FOR INTEGRATED WASTE HEAT UTILIZATION SYSTEMS AND ALTERNATIVE METHODS
(IN THOUSANDS OF DOLLARS)

	Waste Heat Utilization System Model I	Waste Heat Utilization System Model II	Waste Heat Utilization System Model III	Natural Draft	Mechanical Draft	Cooling Ponds	Spray Canals
8 percent for 25 years	55644.813	47624.302	67584.307	68973.806	61268.320	67547.297	62382.997
10 percent for 25 years	50010.950	42254.856	60141.660	63045.924	55690.012	62398.423	57027.011
12 percent for 25 years	45614.164	38092.092	54367.802	58423.229	51382.167	58422.209	52890.855
15 percent for 25 years	40804.763	33465.013	47952.684	53351.991	46567.743	53978.413	48268.309
8 percent for 28 years	56932.740	48800.842	69260.518	70369.890	62582.075	68759.915	63644.392
10 percent for 28 years	50290.385	43576.893	59792.902	64131.478	56711.550	63341.320	58077.836
12 percent for 28 years	46082.332	38552.713	55193.646	58992.347	51875.480	58877.545	53364.507
15 percent for 28 years	40994.902	33668.264	48203.217	53609.467	48810.480	54202.053	48500.945
8 percent for 30 years	57763.509	49577.371	70217.258	71136.753	63303.715	69426.001	64337.271
10 percent for 30 years	51170.203	43395.479	61691.419	64344.062	56911.598	63475.968	58199.991
12 percent for 30 years	46316.975	38783.510	55307.253	59255.017	52122.660	59105.696	53601.835
15 percent for 30 years	41042.385	33708.017	48329.759	53729.969	46923.431	54306.715	48609.821

waste heat for the size plant previously specified.

Table 5-5 indicates the relative order in terms of total monetary outlays for each of the alternatives considered. It also indicates the percentage in terms of total monetary outlays that less costly alternatives are of the most costly.

It should be noted that the ranking of the different alternatives in some instances will change with the discount rate and planning horizon. Two instances are shown in Table 5-5. For a discount rate of 8 percent for 25 years, the system design for Model III becomes relatively more costly than the cooling pond. For 30 years at 15 percent, cooling ponds become the most expensive alternative. The change in order of costliness is due to the varying proportions between discounted annual costs or returns and initial capital requirements for each alternative.

In all cases, however, Table 5-4 indicates that Model II is the least cost alternative given the conditions specified. Table 5-5 shows that the cost savings over a 28-year time period at a discount rate of 12 percent is approximately 20 million dollars if the waste heat utilization system specified in Model II is used rather than a natural draft cooling tower.

TABLE 5-5

RANKING, IN TERMS OF TOTAL MONETARY OUTLAYS, OF DISSIPATION ALTERNATIVES
(IN THOUSANDS OF DOLLARS)

Dissipation Alternative	Total Monetary Outlay (12%, 28 Yrs.)	Percentage of Most Costly (12%, 28 Yrs.)	Percentage of Most Costly (8%, 25 Yrs.)	Percentage of Most Costly (15%, 30 Yrs.)
1. Natural Draft Cooling Tower	58992.347	100.00	100.00	98.94
2. Cooling Ponds	58877.545	99.80	97.93	100.00
3. Model III	55193.646	93.60	97.985	88.99
4. Spray Canals	53364.507	90.50	90.40	89.51
5. Mechanical Draft Cooling Tower	51875.480	87.90	88.85	86.40
6. Model I	46082.332	78.10	80.67	75.57
7. Model II	38552.713	65.50	69.05	62.22

CHAPTER VI

MANAGEMENT AND ACQUISITION OPTIONS

In this chapter, a variety of management and capital acquisition options are discussed. Based on the institutional and operational constraints mentioned in the first chapter, the possible options are narrowed to ones which appear to be feasible. Where there is a divergence from the management and ownership options underlying the analysis of the preceding two chapters, a partial budgeting approach is used to indicate how the distribution of investment costs, operating costs, and costs of providing operating capital change. Correspondingly, if the distribution of monetary benefits is altered, those changes are also distinguished. The net result is reformulated budgets which indicate net changes in costs and/or benefits.

As this chapter is written to assess the impact of management and acquisition options, the emphasis is on the final empirical results of changes in those options. More can be said about the relative bargaining positions and alternative pricing arrangements that could possibly be employed by the utility and firm(s) that manage or own the waste heat utilization subsystems. Bargaining and pricing of waste heat are, however, treated as intermediate steps in arriving at a feasible set of management, ownership and pricing agreements. Areas where the price of waste heat can be bargained are indicated. That alternative bargaining positions and prices for waste heat, other than the zero price assumed here, are not evaluated as to their impact on the total monetary outlays of the utility or net monetary returns of the utilization system is a limitation of the study.

The preceding discussion of the financial and operating characteristics of waste heat utilization systems employed assumptions regarding the management of the waste heat utilization system, general piping and distribution system, and the acquisition of land and capital resources. The financial results of Chapters 4 and 5 were predicated on management of the agricultural and aquacultural subsystems and general piping and distribution system by the utility company. All capital requirements and operating costs were borne by the utility. This set of assumptions facilitated the comparison of waste heat utilization systems with conventional alternatives for waste heat disposal. That a single firm supplies all necessary resources, inputs, and managerial skills implies that the results of the two preceding chapters apply to cases where the utility company is investor owned or where the utility is publicly owned and managed, such as the case with electrical generating plants of the Tennessee Valley Authority.

Other Management and Acquisition Options

Several options exist which lie between the extremes of full private or public ownership and management. Several institutional and technical questions were raised in Chapter 1 of this analysis which suggest that other management and ownership options should be assessed.[1] In this section, institutional alternatives are discussed and evaluated with regard to their appropriateness as a framework for organizing subsystem operation and as an interface with the utility company.

The management and acquisition options shown in Table 6-1 can be evaluated from several viewpoints. As this analysis deals primarily with the effect of feasible options on the cost of operation and economic feasibility; the viewpoint of the utility and organization taking control of the use rights of the land, or provision of capital or managerial resources, or some combination of these activities are given primary consideration.[2] Diverse criteria can be used to

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[1]The two management and acquisition options assumed in the previous analysis are conditional upon the utility providing the managerial expertise for intensive aquaculture and cultivation of specialty crops. Marketing and organizational expertise would also be required. Specialized capital for these subsystems is also stipulated. The utility companies with which this research was conducted have stated that entering agribusiness and aquacultural ventures is not consistent with the firm's goals or the state regulatory agency's restrictions. These conditions were, however, ignored to facilitate the comparison of waste heat utilization systems with alternative mechanisms.

[2]This is not to say that the viewpoint of present owners of the land in question, or local community are unimportant. However, given the questions being considered and the non-existence of necessary information, the breadth of the analysis of institutional alternatives is necessarily limited.

TABLE 6-1

MANAGEMENT AND ACQUISITION OPTIONS FOR WASTE HEAT UTILIZATION SYSTEMS

Management and Capital Acquisition Option
Fee Simple Acquisition[1]
Purchase and Manage
Purchase and Leaseback
Purchase and Resale on Condition
Less than Fee Simple Acquisition
Purchase Easements
Contractual Agreements - No Real Property Interest
Waste Heat Water Cooperative
Contractual Arrangement[2]
Public Authority[3]

[1]Costs incurred by a body seeking fee simple acquisition include payment of interest and principal on bonds raised to finance purchase of the land, administrative costs, possible cost of compensating the affected communities for property taxes foregone where land is purchased by a tax exempt body and leased back for agriculture-aquaculture.

[2]Should the utility company decide not to fully control the total integrated system and not raise the capital for one or all the separate subsystems, it can enter a contractual agreement with private entrepreneur(s) to supply waste heat water.

[3]Publicly owned and managed, per examples provided by Tennessee Valley Authority.

evaluate these options. Among those that are of potential importance are economic and social impacts on the local community.[1] The viewpoint from which these options are evaluated will, however, narrow these criteria. The criteria utilized are the financial characteristics that the option implies as well as stability of system operation and degree of control exercised by the utility and/or organization operating the subsystems.

Fee Simple Acquisition

Fee simple acquisition of land confers absolute ownership by the purchaser. The owner can sell all rights to the land on a voluntary basis, or if a public agency is involved, the power of eminent domain can be employed. The land can be leased, resold on condition, or managed by the purchaser.

Purchase and manage

This option represents the most highly integrated form of operation of the waste heat utilization system. Land is purchased by fee simple acquisition. Capital for the general piping and distribution system and individual subsystems is provided by the utility. Operating capital as well as managerial expertise would also be procured by the utility. Subsystem distribution system and management becomes an accessory

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[1]Of primary importance here would be the impact on local or regional employment for both construction and continuing operation, the impact of increased local and regional income on other industries and secondary services, shifts in the supply and demand of inputs and other resources, as well as indirect monetary and non-monetary costs and benefits.

to utility operation.

Purchase and leaseback

Again fee simple title to the land is obtained. Investment capital is provided by the utility. Instead of managing the individual subsystems, the utility can lease the land to farmers for use of the soil warming plots or to aquaculturists for operation of fish ponds. The integrated nature of the system would be maintained if the physical facilities were leased to a single management firm which would maintain the operation of all subsystems. A cash rent or crop sharing contract are the most common types of leasing arrangements. All or a major share of operating costs are borne by the lessee. Whether there is a fee for the waste heat resource and/or services of the general piping and distribution system is a further consideration.

Where net monetary returns are negative for the system operation, the instance of offering an incentive to private entrepreneurs to manage the individual subsystems must be studied. In all cases, a long term leasing agreement would be necessary for stability and continuous operation of the plant.

Purchase and resale on condition

Another management option available following fee simple acquisitions of land and provision of investment capital is to resell the land and facilities on condition that they can be used in conformance with continuous and stable power plant operation. This type of arrangement is frequently used in urban renewal projects. It insures that the subsequent use of the land conforms to land use objectives and development plans.

Less than Fee Simple Acquisition

Easement purchase

An easement is a right or advantage in the use of land that is purchased from the total bundle of rights that land ownership confers. Easement purchase refers to the transfer of partial property rights from private individuals to another individual or governmental unit.

It should be noted that easement purchase and resale on condition will in all probability apply only to the soil warming subsystem. Easements are most easily used when the original uses of the land are not disturbed.

Contractual Agreements

Waste heat cooperative

The goals of an integrated system can be accomplished by cooperative ownership of subsystem investment capital and the provision of managerial services. Under such an arrangement, a cooperative group of firms would agree to use the waste heat from the power plant and bear necessary expenses of subsystem operation. It is assumed that initial capital expenses and annual operating costs of the distribution system are incurred by the utility. This option along with the purchase and resale option would minimize the financial and managerial responsibility of the utility. However, control over the heat dissipation mechanism is also substantially reduced.

Contractual arrangement

Should the utility decide not to fully control the total system and not raise the capital for one or all of the separate subsystems, it can enter into contractual arrangements with private firms to supply waste heat water. Bargaining will occur between the utility and the individual users with regard to the distribution of costs and benefits associated with the supply and utilization of waste heat water. With this type of institutional arrangement, the utility would likely supply the capital for the general piping and distribution system, and conceivably be involved in cost sharing for other items associated with individual subsystems such as initial capital outlays. The contracts would necessarily be long term in nature with specific and binding stipulations on both parties. The contract would conceivably be open for periodic negotiation. The degree of control exercised by the utility in such an arrangement would depend upon the nature of specific conditions in the contract.

Public Authority

This option would be quite similar to the fee simple acquisition option of purchase and management. The system would be fully integrated in terms of ownership and operation.

The primary difference would be that public capital versus private capital would be involved. An example of such a system would be the Tennessee Valley Authority owned and operated power stations.

Feasible Options[1]

Not all of the capital acquisition and management options previously discussed are feasible. The discussion of feasible uses of waste heat was not meant to be constructed around redesigning institutions and their normal operating procedures so that such a system would be affected. Rather the analysis presented here presumes that the salient and relevant operating procedures of existing arrangements will remain relatively unchanged.

Discussions with planning and engineering personnel of two investor owned utilities in Michigan indicate that reliability in the operation of the heat transfer mechanism is essential in power plant operation as the cost of plant shutdown or operating at reduced capacity is significant. They also indicate that direct management of agribusiness or aquacultural enterprises is not a goal or objective of the utility regardless of financial incentives. These two prerequisites are sufficient to limit several acquisition and management options.

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[1]Feasibility often describes the technical or economic workability of something. The concern here is workability of an option within existing institutional constraints.

The purchase and management option can be excluded if the utility does not desire direct involvement in the management of agricultural and aquacultural enterprises. While purchase and resale is an option for which these enterprises are no longer an adjunct to utility operation, the reliability of system operation is diminished. That the utility can sue for damages or injunctive relief, if conditions specified in the sales contract are not suitably performed, is insufficient compensation for inefficient plant operations or possible shutdown.

Easement purchase can be eliminated as a feasible option in that total and exclusive use of the rights accruing to land ownership is necessary. As such, this option would cost equally as much as fee simple ownership. This option can also be excluded in that significant alteration of the land would be required for installation of soil warming pipes, fish ponds and the general piping and distribution system.

The waste water cooperative is attractive in that no real property interest is necessary by the utility. For this reason, however, the degree of control exercised over the system is significantly reduced. Such an option would have desirable characteristics if waste heat water were sold to or obtained without charge by the cooperative. Transporting the waste heat water beyond the immediate perimeter of the plant location would represent significantly increased capital and operating costs beyond those stipulated in Chapter 3. As the utility would have little control over the cooperative's actions it is doubtful they would supply this capital or bear a larger proportion of pumping costs. As these costs are significant, it is doubtful that sufficient investment capital could be obtained by the cooperative.

The Tennessee Valley Authority is an example of the public authority option. It has conducted experimental research and funded pilot projects studying waste heat utilization. While no discussions have been held with them concerning implementation of an integrated waste heat utilization system, there is no reason to suspect a commitment of managerial expertise for aquacultural and agricultural enterprises of the required scale, or the commitment of large amounts of capital expenditure financed through public funds.

Partial Budget Analysis for Purchase and Leaseback

Purchase and leaseback, and some form of contractual arrangement remain as possible institutional alternatives if the utility does not wish to become involved in the management of subsystems. These two alternatives are evaluated with the design and general piping and distribution system found in Model II. The optimal design and general piping and distribution system found in Model I was not chosen as the capital requirements for the distribution system are substantially greater than that for Model II, as shown in Table 6-2. While this would not be a critical factor if the system and general piping and distribution system were owned by a single firm, it is when the two systems are owned by

TABLE 6-2

INITIAL CAPITAL REQUIREMENTS, DISCOUNTED NET REVENUE AND REPLACEMENT CAPITAL COSTS FOR MODELS I, II, AND III AND CORRESPONDING GENERAL PIPING AND DISTRIBUTION SYSTEM FOR 12 PERCENT AND 28 YEARS.[1] (IN THOUSAND DOLLARS)

Model, Discount Rate and Time Horizon	$-K$	$+\sum_{1}^{n} \frac{(R-C)}{(1+r)^n}$	$-\sum_{1}^{n} \frac{K_R}{(1+r)^n}$	$-\sum_{1}^{n} \frac{R_C}{(1+r)^n}$	$-K_{gp}$	$\frac{\sum_{1}^{n} P_t}{(1+r)^n}$
Model I 12% for 28 Yrs.	-7269.7416	14717.3898	-2632.8924	-2490.0669	-9727.235	-38679.986
Model II 21% for 28 Yrs.	-6146.51	7647.3218	-1197.83	-4211.5193	-5180.726	-34575.013
Model III 12% for 28 Yrs.	-7269.7416	5806.0752	-2632.8924	-2490.0669	-9727.235	-38679.986

[1]Description of terms used in Table 6-2:

K is the initial capital requirement for the set of subsystems in the model.

$(R-C)$ is the annual net return or net cost of the set of subsystems in the model.

K_R is the replacement capital requirements for the set of subsystems in the model.

K_{gp} is the enitial capital requirements for the general piping and distribution system.

P_t is the annual operating cost for the general piping and distribution system.

r is the discount rate or opportunity cost.

n is the life of the project or planning horizon.

R_c is the annual cost for operation of the reservoir.

different firms. Given the choice of providing capital for a general piping and distribution system, the utility will opt for that described in Model II due to the relatively lower initial capital requirements and discounted annual operating costs.

A prospective lessee or owner would, however, have greater interest in the waste heat utilization system described by Model I as the discounted net monetary returns are greater for that configuration than for Model II.

That the utility, which is assumed to own the general piping and distribution system, can offer a monetary incentive to the lessee of utilization system and yet operate the overall dissipation system at a lower level of costs indicates that there is an opportunity to bargain. If discounted net returns to subsystem operation are negative, the monetary incentive necessary to attract a lessee or owner is that which will equate this discounted sum to zero. That amount will be the minimum amount, payable by the utility to a lessee or utilization system owner, to make the above two institutional options feasible.

A comparison of the initial capital requirements for the general piping and distribution system and utilization system, discounted net monetary returns, discounted system annual operating costs, discounted reservoir operating costs, and discounted operating costs for the general piping and distribution system for the three models are shown in Table 6-2. A discount rate of 12 percent and time horizon of

28 years was chosen for this comparison. The first four items are costs that accrue to waste heat utilization system operation. The last two are incurred by the distribution system.

Purchase and Leaseback

Under a purchase and leaseback option the utility bears the cost of ownership of the fixed resources associated with the waste heat utilization subsystems. A management firm or lessee will pay all annual operating costs that do not accrue to ownership of fixed resources and interest on operating capital.[1] Depending on the nature of the contract, specifics in the lease, the utility and lessee can share in the gross receipts of the waste heat utilization system.

Table 6-3 shows a partial budget analysis for the purchase and leaseback option from the viewpoint of the utility. It is initially assumed that the utility will have no claim to the revenues of the waste heat utilization system (Case I). From that initial position, the instance where the utility receives all revenues minus an amount that allows the lessee to cover all annual operating costs and interest on operating capital will be assessed (Case II). The result of this analysis will be to assess

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[1]Reference should be made to any one of the appendix tables dealing with annual costs to see what is included in annual operating costs.

TABLE 6-3

PARTIAL BUDGET ANALYSIS: PURCHASE AND LEASEBACK MANAGEMENT OPTION. CASE I.[1]

Item	Dollars
1. Additional Receipts	
None	
2. Reduced Costs	
a. Managerial Expense	$ 49,470
b. Interest on Operating Capital	79,720
TOTAL CREDITS	$ 129,190
3. Additional Costs	
None	
4. Reduced Receipts	
Net Revenues from Subsystems[2]	1,258.860
TOTAL DEBITS	$1,258,860

[1]In this case it is assumed that the utility supplies all fixed capital requirements of the subsystems and has no claim on the revenues.

[2]Net revenues is here defined as total revenues minus annual operating costs exclusive of managerial expense and interest on operating capital.

the impact of this management option and the variations it can have on the total monetary outlays of the utility and consequently whether the waste heat utilization system remains as a least cost alternative.

As can be observed from Table 6-3 the loss in annual income from this lease agreement (Case I) is $1,129,670. In order to assess the impact of this change in annual income on the ranking of the waste heat utilization system in terms of total monetary outlays, Table 6-4 was constructed. This comparison applies to conditions where all costs associated with the general piping and distribution system, and with capital and land ownership of the subsystems are borne by the utility. The utility also has no claim on revenues of the utilization system.

The results indicate that for a discount rate of 8 percent, the waste heat utilization system is as costly, in terms of total monetary outlays, as natural draft cooling towers and cooling ponds which are the most costly of the alternative methods. If the appropriate discount rate is 12 percent, then the waste heat utilization is as costly as mechanical draft cooling towers and spray canals. For a discount rate of 15 percent slightly less monetary outlays are made by the utility if the waste heat utilzation system is used than if mechanical draft cooling towers are used. Hence, total monetary outlays for the utilization system are sensitive to the discount rate and that for different discount rates it compares more or less favorably relative to

TABLE 6-4

TOTAL MONETARY OUTLAYS FOR ALTERNATIVE SYSTEMS WHERE THE PURCHASE AND LEASEBACK OPTION IS USED FOR THE UTILIZATION SYSTEM: CASE I (IN THOUSAND DOLLARS)

Discount Rate and Time Horizon	Model II with Purchase and Leaseback	Natural Draft	Mechanical Draft	Cooling Ponds	Spray Canals
8 percent for 25 Yrs.	67083.519	68973.806	61268.320	67547.297	62382.997
10 percent for 25 Yrs.	60737.939	63045.924	55690.012	62398.423	57027.011
12 percent for 25 Yrs.	52293.072	58423.229	51382.167	58422.209	52890.855
15 percent for 25 Yrs.	45090.321	53351.991	46567.743	53978.413	48268.309
8 percent for 28 Yrs.	69072.375	70369.890	62582.075	68759.915	63644.392
10 percent for 28 Yrs.	60289.352	64131.478	56711.550	63341.320	58077.836
12 percent for 28 Yrs.	53059.665	58992.347	51875.480	58877.545	53364.507
15 percent for 28 Yrs.	45465.911	53609.467	48810.480	54202.053	48500.945
8 percent for 30 Yrs.	70050.249	71136.753	63303.715	69426.001	64337.271
10 percent for 30 Yrs.	60542.504	64344.062	56911.598	63475.968	58199.991
12 percent for 30 Yrs.	53372.348	59255.017	52122.660	59105.696	53601.835
15 percent for 30 Yrs.	45623.454	59255.017	46923.431	54306.715	48609.821

alternative dissipation methods. Total monetary outlays with the purchase and leaseback options can be compared to those where full ownership and management is employed. Total monetary outlays for the later option are found in Table 5-2.

The set of leasing arrangements just assessed is one extreme case that can be employed under the purchase and leaseback option. The other extreme case that can be specified, and yet maintain incentive sufficient to attract a lessee (subsystem management firm), would be to allow the lessee sufficient revenues to cover annual operating costs and interest on operating capital (Case II). The remaining revenues are then applied by the utility to cover costs of capital ownership for the subsystems and general piping and distribution system.

The revenues from the operation of the fish ponds and soil warming subsystems that would be available once the aforementioned costs are paid is $784,648. This is the amount that can be used as payment to the utility on an annual basis. Table 6-5 shows the partial budget analysis for this leasing agreement. It shows that after the additional receipts from rents are received, and reduced costs due to leasing are accounted for, the net loss in income is $345,022. This amount must then be discounted for specified discount rates and time horizons to assess the impact on total monetary outlays.

Table 6-6 shows the comparison of alternative dissipation methods with the costs to the utility as they would

TABLE 6-5

PARTIAL BUDGET ANALYSIS: PURCHASE AND LEASEBACK OPTION - CASE II[1]

Item	Dollars
1. Additional Receipts	
a. Rents from lessee	$ 784,648
2. Reduced Costs	
a. Managerial expense	49,470
b. Interest on Operating Capital	79,720
TOTAL CREDITS	$ 913,838
3. Additional Costs	
None	
4. Reduced Receipts	
a. Net revenues from subsystem[2]	1,258,860
TOTAL DEBITS	$1,258,860
NET INCOME	-$ 345,022

[1]In this case it is assumed that the utility supplies all fixed capital requirements for the subsystems and claims the residual revenues after all subsystem annual operating costs and interest on operating capital are paid by the lessee.

[2]Net revenues are here defined as total revenues minus annual operating costs exclusive of managerial expense and interest on operating capital.

TABLE 6-6

TOTAL MONETARY OUTLAYS FOR ALTERNATIVE SYSTEMS WHERE THE PURCHASE AND LEASEBACK OPTION IS USED FOR THE UTILIZATION SYSTEM: CASE II (IN THOUSAND DOLLARS)

	Model II with Purchase and Leaseback	Natural Draft	Mechanical Draft	Cooling Ponds	Spray Canals
8 percent for 25 Yrs.	58707.559	68973.806	61268.320	67547.297	62382.997
10 percent for 25 Yrs.	53615.689	63045.924	55690.012	62398.423	57027.011
12 percent for 25 Yrs.	46139.000	58423.229	51382.167	58422.209	52890.855
15 percent for 25 Yrs.	40018.278	53351.991	46567.743	53978.413	48268.309
8 percent for 28 Yrs.	60401.152	70369.890	62582.075	68759.915	63644.392
10 percent for 28 Yrs.	52937.514	64131.478	56711.550	63341.320	58077.836
12 percent for 28 Yrs.	46794.722	58992.347	51875.480	58877.545	53364.507
15 percent for 28 Yrs.	40339.413	53609.467	48810.480	54202.053	48500.945
8 percent for 30 Yrs.	61216.839	71136.753	63303.715	69426.001	64337.271
10 percent for 30 Yrs.	53145.706	64344.062	56911.598	63475.968	58199.991
12 percent for 30 Yrs.	47051.852	59255.017	52122.660	59105.696	53601.835
15 percent for 30 Yrs.	40471.471	59255.017	46923.431	54306.715	48609.821

appear for the purchase and leaseback option with the aforementioned leasing agreement. We find that for low discount rates, the total monetary outlays by the utility for the system as specified by Model II and associated general piping and distribution system are roughly the same as those for mechanical draft, cooling towers and spray canals. For a discount rate of 15 percent, it is the least costly alternative.

The findings of the previous partial budget analyses suggest that whether the lessee gets all of the revenues from subsystem operation or whether he receives an amount sufficient to cover all annual operating costs, interest on operating capital. The impact on whether the waste heat utilization system is a least cost system is minimal. The difference of $784,648 in annual costs payable by the utility is not sufficient over the planning horizons and discount rates indicated to affect the choice of which alternative is the least cost alternative. The choice of the two extreme cases affect the distribution of revenue between the utility and the lessee.

Contractual Arrangement

The purchase and leaseback management and acquisition option entails a long term contractual agreement[1] between

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[1]It should be noted that long term contractual agreements are necessary for stability in the heat dissipation function of power generation. They can be so specified that periodic review be given to account for changing economic conditions and price relationships.

the utility and a management firm. Capital requirements for the subsystems are supplied by the utility. The costs of capital ownership are incurred by the utility with varied claims on the revenues of the subsystems.

The remaining feasible management and acquisition option is a contractual arrangement whereby the utility has no capital ownership in the subsystems but yet agrees to supply waste heat water to a management firm which has both capital and land ownership.

Table 4-8 indicates that net monetary returns for the optimal combination of subsystems in Model II are negative for all discount rates and time horizons. This would indicate that a monetary incentive payable by the utility, would be necessary to attract a management firm to supply the requisite capital. From the standpoint of the management firm, the minimum incentive would be an annual payment that would make net monetary returns equal to zero. This amount would then be added to the utility's annual expenditure stream and discounted to assess the impact on total monetary outlays. From that point a comparative analysis is made to assess whether the expenses incurred in the form of initial capital requirements and annual operating costs for the general piping and distribution system, and monetary incentives to the management firm, would indicate the waste heat utilization system to be a least cost alternative. Table 6-7 indicates the annual payments necessary to make net revenues equal zero over the planning horizon and the current dollar

TABLE 6-7

PAYMENTS BY UTILITY NECESSARY TO MAKE NET MONETARY RETURNS OF SUBSYSTEM OPERATION AND OWNERSHIP EQUAL TO ZERO: ANNUAL AND DISCOUNTED BASIS[1]

Item	Dollars Annual	Dollars Discounted
8 percent for 25 years	285,926	3,052,210
10 percent for 25 years	394,278	3,578,857
12 percent for 25 years	506,092	3,969,331
15 percent for 25 years	685,469	4,430,938
8 percent for 28 years	262,431	2,900,154
10 percent for 28 years	407,815	3,821,060
12 percent for 28 years	540,816	3,908,538
15 percent for 28 years	660,916	4,378,094
8 percent for 30 years	253,507	2,853,934
10 percent for 30 years	363,672	3,428,296
12 percent for 30 years	481,440	3,878,094
15 percent for 30 years	664,622	4,363,895

[1]As derived from Table 4-8.

value of those annual outlays.

As the net monetary returns are equal to the discounted annual incentive, the total monetary outlay by the utility for specified planning horizons and discount rates are shown in Table 5-2. A comparison of the cost to the utility for supplying waste heat to a management firm, inclusive of the monetary incentive is shown in Table 5-4. The cost of the utility for this option is shown in the column entitled "Waste Heat Utilization System Model II." These figures show it to be the least cost alternative for all discount rates and planning horizons.

Bargaining range when a contractual arrangement is employed

The preceding analysis of the contractual arrangement between the utility and system management firm indicates that the total monetary outlays by the utility are significantly less than when the least costly conventional heat dissipation method is employed. If a firm with sufficient managerial expertise and capital resources available to construct these waste heat utilization subsystems has knowledge of this differential, several questions can be raised. First, what annual amount would the utility be willing to pay for which it would be indifferent to constructing the least costly conventional heat dissipation alternative or the general piping and distribution that supplies waste heat to the management firm? Secondly, what would then be the net monetary returns to the waste heat utilization system? These same questions can be asked if the utility is willing to pay an amount less than the full differential.

Table 6-8 indicates the total monetary outlays by the utility for the general piping and distribution system when the optimal design given by Model II is employed. The monetary outlays for specified time horizons and discount rates, as well as the amount on an annual basis is indicated.

The least costly conventional alternative is mechanical draft cooling towers. The total monetary outlays for specified discount rates and time horizons for this alternative are indicated in Table 5-4. The difference between the monetary outlays for this alternative and the monetary outlays for the general piping and distribution system when the design indicated by Model II is employed is shown in Table 6-9. The difference is shown for the planning horizon on an annual basis. The amounts shown in Table 6-9 indicate the maximum annual discounted payments that the owners of the waste heat utilization system could bargain for if they have knowledge of the least costly conventional alternative for waste heat dissipation. These figures also represent the maximum amount the utility would be willing to pay before they are indifferent to constructing a mechanical draft cooling tower or constructing a distribution system to supply waste heat to a utilization system management firm.

Should the system management receive that maximum amount it can bargain for, it is applied to net monetary returns for utilization system operation. The net monetary

TABLE 6-8

TOTAL MONETARY OUTLAYS FOR THE GENERAL PIPING AND DISTRIBUTION SYSTEM WHEN MODEL II IS EMPLOYED: ANNUAL AND DISCOUNT DOLLAR BASIS (IN THOUSANDS OF DOLLARS)

Discount Rate and Time Horizon	Dollars Annual	Dollars Discounted
8 percent for 25 years	$4,175,449	$44,572,093
10 percent for 25 years	4,481,217	40,676,008
12 percent for 25 years	4,350,672	34,122,761
15 percent for 25 years	4,491,588	29,034,075
8 percent for 28 years	4,153,439	45,900,688
10 percent for 28 years	4,243,056	39,755,739
12 percent for 28 years	4,338,983	34,644,176
15 percent for 28 years	4,495,472	29,371,170
8 percent for 30 years	4,150,316	46,773,437
10 percent for 30 years	4,239,695	39,967,184
12 percent for 30 years	4,333,279	34,905,437
15 percent for 30 years	4,481,299	29,424,122

TABLE 6-9

THE DIFFERENCE, IN TERMS OF TOTAL MONETARY OUTLAYS, BETWEEN THE MECHANICAL DRAFT COOLING TOWER AND THE GENERAL PIPING AND DISTRIBUTION SYSTEM FOR MODEL II

Discount Rate and Time Horizon	Dollars	
	Annual	Discounted
8 percent for 25 years	$1,564,078	$16,696,227
10 percent for 25 years	1,654,071	15,014,004
12 percent for 25 years	2,200,584	17,259,406
15 percent for 25 years	2,712,468	17,533,668
8 percent for 28 years	1,509,479	16,681,407
10 percent for 28 years	1,809,662	16,955,811
12 percent for 28 years	2,158,122	17,231,304
15 percent for 28 years	2,537,732	19,439,310
8 percent for 30 years	1,472,781	16,580,276
10 percent for 30 years	1,797,453	16,944,414
12 percent for 30 years	2,137,404	17,217,223
15 percent for 30 years	2,665,148	17,499,308

returns for the waste heat utilization given this set of conditions, are shown in Table 6-10. These figures are obtained by adding the net monetary returns for Model II found in Table 4-8 and the maximum amount that can be bargained for, as indicated in Table 6-9.

With this set of conditions in effect, the net monetary returns to the waste heat utilization system for Model II are significantly positive. The total monetary outlays by the utility are equivalent to those indicated for the mechanical draft cooling towers.

If fifty percent of the difference between total monetary outlays for mechanical draft cooling towers and the general piping and distribution system for the design indicated by Model II are bargained for, the distribution of system costs will change. The total monetary outlays by the utility and net monetary returns to system management are indicated in Table 6-11 when this set of conditions is in effect. The total monetary outlays by the utility for this set of conditions can be compared to those indicated in Table 5-4 for ranking purposes.

The total monetary outlays indicated in Table 6-11 can be compared with those in Table 5-4 for ranking purposes. The net monetary returns for the utilization subsystems under these conditions can be compared with those for Model II when no bargaining has occurred. Those figures are shown in Table 4-8.

TABLE 6-10

NET MONETARY RETURNS FOR MODEL II WHEN THE UTILIZATION SYSTEM MANAGEMENT OBTAINS THE MAXIMUM AMOUNT IT CAN BARGAIN FOR (IN THOUSANDS OF DOLLARS)

Discount Rate and Time Horizon	Net Monetary Returns
8 percent for 25 years	$13,644,018
10 percent for 25 years	11,435,147
12 percent for 25 years	13,290,075
15 percent for 25 years	13,102,730
8 percent for 28 years	15,442,370
10 percent for 28 years	13,134,821
12 percent for 28 years	13,322,767
15 percent for 28 years	15,121,216
8 percent for 30 years	13,726,340
10 percent for 30 years	13,516,119
12 percent for 30 years	13,339,130
15 percent for 30 years	13,135,413

TABLE 6-11

NET MONETARY RETURNS TO SYSTEM MANAGEMENT AND TOTAL MONETARY OUTLAYS BY THE UTILITY WHEN FIFTY PERCENT OF THE MAXIMUM BARGAINING RANGE IS TRANSFERRED FROM THE UTILITY TO MANAGEMENT OF THE UTILIZATION SYSTEM (IN THOUSANDS OF DOLLARS)

Discount Rate and Time Horizon	Net Monetary Returns	Total Monetary Outlays
8 percent for 25 years	$2,243,695	$52,920,206
10 percent for 25 years	3,928,145	48,183,010
12 percent for 25 years	4,660,372	42,752,464
15 percent for 25 years	4,335,896	37,800,909
8 percent for 28 years	5,440,549	54,241,391
10 percent for 28 years	4,656,845	48,233,644
12 percent for 28 years	4,707,115	43,259,828
15 percent for 28 years	5,401,556	39,090,303
8 percent for 30 years	5,436,197	55,195,644
10 percent for 30 years	5,043,912	48,439,391
12 percent for 30 years	4,730,518	43,514,048
15 percent for 30 years	4,387,759	38,175,776

This section indicates the effect of various bargaining alternatives when the contractual arrangement is used. Two alternatives were evaluated. The effects of the utilization system owners obtaining the full amount and fifty percent of that bargaining range were assessed as to the impact on net monetary returns and total monetary outlays.

Summary

The analysis of management and acquisition option has, through the use of rudimentary economic concepts and methods, put in empirical terms the costs and benefits of purchase and leaseback, and a contractual arrangement. Instances where the utility supplied capital and land for the subsystems were compared to that where all capital requirements and annual costs would be assumed by a management firm. The cost to the utility over various planning horizons was put in current dollar terms to assess whether the costs associated with the waste heat utilization system indicated it to be a least cost alternative.

The analysis shows that with a purchase and leaseback management and acquisition framework, whether the waste heat utilization system is a least cost system will depend on the discount rate used by the utility in its investment decisions. With this option, it is at best as costly as two other alternatives. The utility bears the cost of capital ownership and receives the benefit of not providing managerial expertise. Whether it exerts a claim on subsystem revenues does not affect the cost status of the system.

The contractual arrangement specified shows minimum involvement by the utility. It does not provide initial capital requirements, annual costs, costs of capital ownership, or managerial expertise. However, initial capital requirements for the subsystems are such that a monetary incentive is required to attract firms with sufficient capital and managerial skills. The cost to the utility with this option show that its involvement in the waste heat utilization system is a least cost alternative to other methods of waste heat dissipation.[1]

One further management and acquisition option not addressed here is the case where the utility agrees to supply waste heat to greenhouse operators, aquaculturalists or other types of enterprises that use waste heat and can readily retrofit existing facilities to dissipate the specified amount of waste heat. The feasibility of such an option would depend on the incremental costs and benefits to these firms and the distances that the waste heat must be transported to and from those firms. It is extremely doubtful, however, that the types and sizes of firms could be found in proximity to power plants to permit this option.

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[1]It should be kept in mind the results indicated here are specific to the prices productivity rates, and system design that has been specified. Results in previous chapters show sensitivity in total monetary outlays and net revenues to changes in price relationships and design.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Problem Definition

The context of the problem to which this study was addressed is whether the thermal effluent from power plants can be treated as a valuable input for productive use. With minor exceptions, the thermal effluent, or waste heat, is directly discharged into the environment via cooling towers, cooling reservoirs or spray canals. The waste heat produced in the electrical power generation process is treated as an externality in production. The high entropy characteristic of this energy has generally precluded the recycling of the cooling water for industrial or home heating uses.

The specific research problem is whether an integrated waste heat utilization system comprised of agricultural and aquacultural subsystems is economically feasible under Michigan conditions. The focus of this research is on the mixture of types and sizes of subsystems which use waste heat. Economic feasibility is judged on the basis of whether the optimal mixture, or design of the system, is a least cost alternative to conventional methods of waste heat dissipation. In this regard, feasibility is reduced to a constrained optimization problem and a matter of cost effectiveness. It was also necessary to study management and acquisition options as to whether they meet operational standards, and if so, their effect on the cost of the waste heat utilization system. An examination of how organizational arrangements affect total monetary expenditures is necessitated by the physical interdependencies between the utility company and the waste heat utilization system.

Research Objectives

In order to determine whether an integrated system of agricultural and aquacultural uses is economically feasible, the following objectives were specified:

1. Identify relevant types of information that describe technical and economic characteristics or properties of the waste heat utilization system and power generation and heat dissipation process.

2. Identify crops and species of fish for which productivity response to waste heat has been estimated.

3. Determine the initial capital requirements, annual costs, and revenues for subsystems where those crops and fish are raised/reared.

4. Determine, within a limited range, the optimal flow rates of waste heat to those subsystems.

5. Construct an analytical model that will determine a least cost system subject to specified constraints.

6. Determine spatial characteristics of the least costs system and a corresponding water transport system.

7. Investigate the sensitivity of the least cost system design to changes in the values of critical economic

parameters.

8. Identify management and acquisition options that satisfy important operational criteria and assess the impact of those options on total monetary outlays for the waste heat utilization system.

Methodology

Information regarding the productivity response of selected crops and fish was obtained from mathematical and simulation models developed by the staff of the Michigan State University Waste Heat Utilization Project. Waste heat dissipation characteristics of the subsystems were also obtained from this source. Cost information for the subsystems was obtained from studies where conventional cultural practices were used and adjusted for Michigan conditions and cultural practices where waste heat is used. To establish the nature of the adjustments, mechanical engineers and experts in the field were consulted.

In order to determine the least cost system of uses, optimal flow rates, and the sensitivity of the system design to changes in economic parameters, a pseudo-dynamic linear programming model was developed. In order to deal with concave cost size relationships of the subsystem and diminishing returns, separable programming characteristics were employed. For the different flow rates specified for each subsystem, budgets were developed which reflect changes in pumping costs and productivity responses.

The linear programming model determined optimal or least cost design. The allocation model which simulated productivity responses and heat dissipation rates determined "optimal" flow rates for that design. These models can interact in an iterative fashion. Design characteristics are initial conditions for the allocation model. The heat dissipation rates associated with "optimal" flow rates become technical coefficients for the linear programming model.

In order to assess the impact of the feasible management and acquisition options, partial budgeting analysis was used. Where the distribution of costs or revenues changed in response to ownership patterns different than those assumed in the model, partial budgets were set up to determine net annual income changes to the utility. The annual income changes were then discounted to assess the impact on total monetary expenditures for specified discount rates and time horizons.

Empirical Results

Model I represented conditions where no constraints were placed on subsystem sizes and higher commodity prices were assumed. The results of the linear programming model indicate that the optimal design of the waste heat utilization system, under these conditions, is comprised of 375 acres of fish ponds, 100 acres of soil warming where tomatoes are grown, and that the maximum reservoir utilization rate is 208 acres. The flow rates for all separable parts of the fish pond subsystem are 10 percent above those indicated as optimal by the allocation program. For the soil warming subsystem, the linear programming model indicates that a 10 percent reduction in flow rates is desirable. Sensitivity analysis with discount rates and planning horizons indicate that optimal design is not changed with regard to those parameters.

For a discount rate of 12 percent for a 28 year time horizon, discounted net revenues are $14,717,390.00. After initial capital requirements, discounted reservoir operating costs, and discounted capital replacement costs are accounted for, net monetary returns to the waste heat utilization system are $2,324,889.00. For the spatial relationships indicated and the consequent general piping and distribution system, total monetary outlays by the utility company are $46,082,332. Model I is a least cost alternative to conventional dissipation systems included in the study.

Model II represented conditions where fish pond acreage was constrained, and a schedule of higher prices was used. The least cost combination of subsystem sizes and types is 160 acres of fish ponds, 100 acres of soil warming where again tomatoes are grown, and a maximum monthly reservoir utilization rate of 352 acres. Both fish pond and soil warming enterprise sizes were at the constrained limit. The linear programming model also shows that flow rates of 10 percent above those indicated as optimal by the allocation program are cost minimizing flow rates for the fish pond subsystems.

A reduction in flow rates of 10 percent was the cost minimizing flow rate for the soil warming activity. For the discount rates and planning horizons specified, system design did not change.

For the waste heat utilization system indicated by Model II, discounted net revenues are $7,647,332.00 when at 12 percent discount rate is used for a 28 year planning horizon. After appropriate costs are accounted for, net monetary returns to this system design are -$3,908,538.00. This represents a difference of $6,233,426.00 from that amount shown for Model I. The total monetary outlays for this system design, stipulated spatial relationships, and associated general piping and distribution is $38,552,713.00. This is $7,529,619.00 less than the total monetary outlays for the system described in Model I. The difference is primarily attributable to additional units of fish pond activity being relatively more costly than additional units of reservoir activity in terms of the capital requirements and annual operating costs for the general piping and distribution system. The system design, hypothesized spatial relationships, and general piping and distribution system for Model II is the least cost alternative for all utilization systems and conventional methods considered.

In Model III, subsystem sizes are not constrained at a level lower than that emptied by the largest separable part. Commodity prices were, however, reduced to a lower level. The least cost combination of flow rates and subsystem types and sizes are the same as those indicated in Model I. However, for a discount rate of 12 percent for 28 years, the discounted net revenues are $5,806,073.00 and the net monetary returns are -$6,586,482.00. Due to the lower assumed commodity prices, net monetary returns are $8,911,317.00 less than that indicated for Model I. Total monetary outlays for the same system design, spatial relationship and general piping and distribution system, as indicated for Model I, are $55,193,646.00. Model III is not a least cost system. It is less costly than natural draft cooling towers and cooling ponds, and mechanical draft cooling towers, and as costly as spray canals.

Several management and acquisition options were initially considered. Of those indicated, the purchase and leaseback option and some contractual agreement remained as feasible given the operational criteria employed. For the purchase and leaseback option where the utility supplies all fixed resources and has no claim to subsystem revenues, the loss in annual net income is $1,129,670. For a discount rate of 8 percent, total monetary outlays for the system design, spatial relationship and general piping distribution system for Model II are approximately as great as those for natural draft cooling towers and cooling ponds. They are, however, greater than the total monetary outlays for mechanical draft cooling towers and spray canals. For discount rates of 10, 12, and 15 percent, total monetary outlays are of the same magnitude as those for mechanical draft towers and spray canals.

This indicates that the utilization alternative is not more costly than other conventional alternatives, but it is not clearly a least cost alternative.

For the purchase and leaseback option when all fixed capital is supplied by the utility company and claims on system revenues are such that total annual operating costs are just covered by subsystem management, the loss in annual net income to the utility is $345,022. With these conditions the utilization system described in Model II is a less costly alternative for all discount rates and time horizons.

A contractual arrangement was considered where the utility has no capital ownership in the subsystems and no claim on subsystem revenues. As net monetary returns for Model II are negative, a monetary incentive, which would be at minimum, equivalent to those negative net monetary returns incurred by the subsystem management, would have to be paid by the utility to make this option feasible. When this monetary incentive is paid, the total monetary outlay by the utility is less than that for alternative conventional systems.

Implications

1. The analytical model developed is sufficiently specified to find the least cost combination of subsystems types, sizes and flow rates. The pseudo-dynamic property of the model facilitated analysis of the effects of important decision variables on system parameters. Long range

planning and decision making were assisted by this technique. The model also incorporated non-linear cost-size relationships for the subsystems which aided in finding the least cost system. The reservoir activity was constructed so that monthly acreage utilization rates could be determined.

2. The findings show that a waste heat utilization system is feasible in the sense of being a least cost alternative to conventional dissipation methods. Feasibility is, however, conditioned by several factors:

a) Spatial relationships on the hypothesized configuration of the waste heat utilization system determine pump and piping requirements, and annual water transport costs for the general piping and distribution system. Total monetary outlays for the overall system are largely comprised of costs associated with water transport. Changes in the hypothesized configuration will significantly affect the total monetary outlays and hence feasibility.

b) The least cost combination of subsystems is represented by Model I. When costs for the general piping and distribution system were accounted for, Model II was the least cost alternative. This dichotomy would suggest that least cost criteria should be more broadly applied to include operational characteristics of the general piping and distribution system. If subsystem ownership and management are distinct from the utility, suboptimization of utilization system design will affect feasibility.

c) In the analytical model, it was assumed that firm would have unlimited access to investment capital and operating capital. Additional amounts of these requirements would not be at the expense of higher interest rates. Should additional capital requirements be available only at higher interest rates, the impact could be significant given the large investment and operating capital requirements.

d) The purchase and leaseback option, where no claim is made by the utility on subsystem revenues, implies that the discount rate used in investment planning decisions will determine which alternative is a least cost alternative. For other instances where similar comparisons were made, the discount rate was not a critical factor affecting the ranking of alternative utilization and conventional systems.

3. The management and acquisition options that were determined to be feasible primarily affect the distribution of costs and revenues. Only for the case mentioned in 2.d is the redistribution of such significance to affect whether

the overall system described in Model II is a least cost alternative. Where revenues beyond that necessary to cover total annual costs are claimed by the utility, the overall system described by Model II is a least cost alternative. For the contractual agreement where the utility covers annual costs, all costs associated with capital ownership in the general piping and distribution system, and a monetary incentive, the involvement by the utility in a waste heat utilization system (Model II) is also a least cost alternative.

4. When lower commodity prices were assumed in the unconstrained case (Model III) the utilization system design remained the same as when higher prices were assumed. This would indicate stability in the type and size of subsystems over varied economic conditions.

It was also observed that total monetary outlays increased significantly with these lower prices. Even though system design did not change, due to lower commodity prices, Model III was not a least cost alternative.

Limitations of the Study

Recognition of the following limitations under which this study was conducted is necessary for proper interpretation of the empirical findings and implications.

1. Synthetic data was used to describe cost characteristics of subsystems as well as the general piping and distribution system. Costs for subsystems are based on the requirements for conventional enterprises of these types and

modified to account for waste heat use. The synthetically constructed subsystems may not represent the typical firm's cost structure or the appropriate production technology.

Cost estimates for the general piping and distribution were developed with the assistance of an engineer well qualified for problems concerning pump and piping requirements. Engineers qualified for design and construction problems were not available to provide technical assistance.

2. Secondary data was used for the development of growth and heat dissipation models in the allocation program. Experimental data based on Michigan conditions is not available. The availability of data on growth responses for various crops or fish species and heat dissipating capacity of the subsystems would assist in building better models and validation of simulation results.

3. A modelling technique was not available that could determine an optimal spatial relationship and corresponding general piping and distribution system. With the existing models, the pumping costs for a particular configuration could not be related to optimal utilization system design.

4. Land characteristics of soil type and topology were assumed in the calculation of crop growth responses, soil dissipation rates, and pumping costs. As these land characteristics change, system characteristics will also vary.

5. The optimal system design is based on specified, constant price relationships. Stability of system design was indicated for changes in the price of two commodities

and over a limited range.

Suggestions for Further Research

This research was a feasibility study, or a preliminary examination, of waste heat utilization under Michigan conditions. There are several areas which need further research.

1. The data problems previously discussed can be alleviated by a demonstration project incorporating the concepts and subsystems for which this research indicates favorable economic results. Such a demonstration project would facilitate the development of more reliable productivity response and heat dissipation models by accumulating primary data.

2. The models constructed on this basis can be utilized for simulating a wider variety of economic and climatological conditions. There is also a need to model the effects of temporary plant shut-downs or where the level of plant operation is reduced over prolonged periods.

3. There are several types of problems which require that the simulation and modelling programs not operate in an optimization mode. Such programs are expensive to construct and generally require more computer resources. Nonetheless, a nonoptimizing program is needed to deal with problems like plant shut-down or periodic condenser cleaning.

4. The development of a model to determine a least cost general piping and distribution system will aid in reducing total monetary expenditures. Furthermore, making adjustments in distribution system costs due to topographical

changes or other constraints would be greatly simplified.

5. Possible areas for increased integration between the power plant and the utilization system can be investigated. The costs and benefits of using high temperature bleed-off steam to power the pumps in the distribution system is one option.

APPENDICES

APPENDIX 1

COMMENTS

APPENDIX 1

COMMENTS

The purpose of these appendices is to briefly describe the procedures that were used in finding the heat dissipation values which form the technical coefficients of the linear programming model. The appendices also serve to credit the authors of the mathematical models which represent the physical characteristics of the subsystems. The development of these models and computer programs are a major achievement of the Michigan State University Waste Heat Utilization Project. The information obtained from these efforts formed the basis of the linear programming model. Without this information, the present study would not have been possible.

APPENDIX 2

APPENDIX 2-A

THE ALLOCATION PROGRAM[1]

Given initial subsystem sizes, the allocation program seeks to optimally allocate the heat output from the power plant to the subsystems. The allocation of heat rates among subsystems is determined by a non-linear optimization routine using appropriate weather models, heat dissipation models, and growth models. Each subsystem is represented by growth rate equations for crops or fish, heat and mass transfer equations for dissipation characteristics of each subsystem. These are discussed in subsequent appendix remarks on those models.

The method selected to find the optimum heat rates is a non-linear, multivariable, constrained search routine called OPTBOX as described in Kuester and Mize (1973). It finds the global optimum, with a high probability, of the non-linear function:

$$F(X_1, X_2 \ldots X_N)$$

subject to the non-linear constraints:

$$G_k \leq X_k \leq H_k \text{ where } K = 1, \ldots M$$

and X_1, $X_2 \ldots X_N$ represent independent variables. Implicit

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[1]Portions of these remarks are taken directly from VanKuiken and Tummala, 1975.

variables X_{N+1}, X_{N+2}, ... X_M are dependent functions of the independent variables. The limits H_k and G_k are either constants or functions of the independent variables. Function derivatives are not required.

An initial feasible solution is stipulated by the user and K - 1ZN additional points are randomly scattered throughout the feasible region according to

$$x_{i,j} = G_i + r_{o.k} (H_i - G_i) \qquad \begin{array}{l} i = 1,2, \ldots, N \\ j = 2,3, \ldots, K \end{array}$$

where $r_{k,j}$ are random numbers between p and 1. This scattering of the initial points tends to locate the global maximum rather than local optimum. The $k \geq N + 1$ points form the first "complex." The program evaluates the objective function at each point and replaces the point of smallest value with a new point located at a distance α times as far from the centroid of the remaining points as the distance of the rejected point along the line connecting the rejected point and the centroid. The coordinates of the centroid of the remaining points are given by:

$$\overline{X}_{i,c} = \frac{1}{k-1} \left[\sum_{j=1}^{k} x_{i,j} - x_{i,j} \text{ (old)} \right], \; i = 1,2, \ldots, N$$

The coordinates of the new point are specified by:

$$X_{i,n}\text{(new)} = \alpha \; (\overline{X}_{i,j}\text{(old)} \;\; + \overline{X}_{i,c}, \; i = 1,2, \ldots, N$$

and $\alpha = 1.3$ is recommended.

The remaining set of points together with the new one become a new complex and the process is repeated until convergence, as specified by the user, is acquired. Convergence occurs when the objective function values at each point of the complex are within β units for γ consecutive iterations.

Each point of the complex must satisfy constraint limits. If explicit constraints are violated, the point is moved a distance δ inside the violated limit. Kuester and Mize use δ = .0001. If implicit constraints are violated the point is moved one-half of the distance to the centroid of the remaining points:

$$x_{i,j}(\text{new}) = (x_{i,j}(\text{old}) + \overline{X}_{i,c}) /2 \qquad i = 1,2, \ldots, N$$

It a point repeats in giving the lowest function value, that point is moved one-half the distance to the centroid.

Program ALLOC is the simulation package that controls the order of operations, provides storage of information, and calculates additional simulation variables (other than independent variables) at optimums. A flow chart of program ALLOC is shown in Figures 1 and 2.

Inputs to ALLOC are subsystem sizes and optimation parameters. OPTBOX then selects various heat dissipation values for the fish pond and soil warming plots. POND and TSOIL determine pond surface temperature and root zone temperature with the use of weather inputs. FISH and CROP find associated productivity responses on a monthly basis.

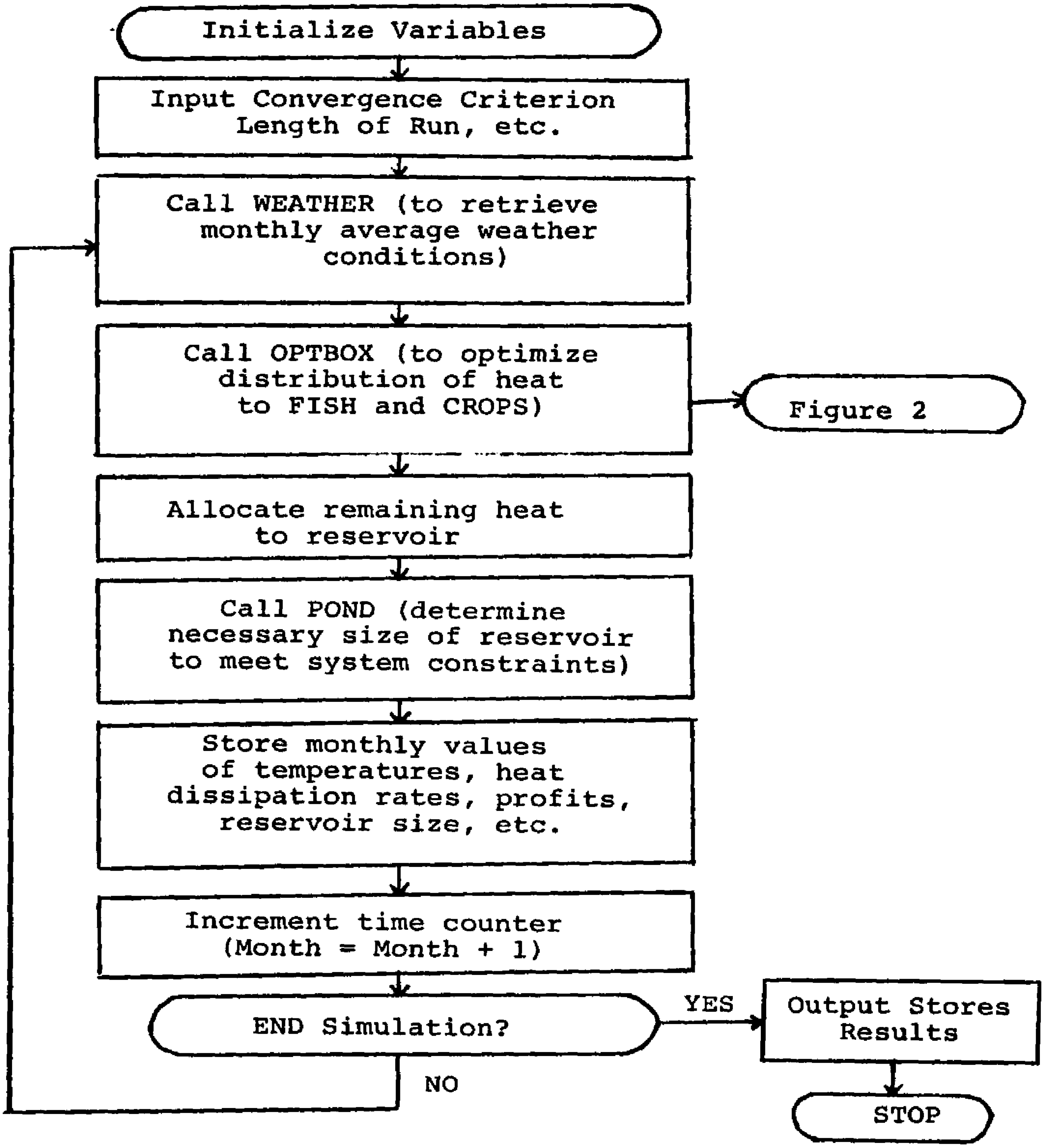

Figure 1

Simulation Flow Chart of ALLOC

```
Subroutine OPTBOX
        .
        .
        .
        .
Call FUNC (objective function to be maximized--Q1 and Q2 the
        . independent variables)
        .
        .
        .
Call CONST (constraints)
        .
        .
        .
        .
Return
```

```
Subroutine FUNC

Call POND (to find surface temp., given heat input and weather)

Call FISH (to find incremental growth and profit at given temp.)

Call SOIL (to find soil temp. given heat input and weather)

Call CROP (to find incremental growth and profit at given temp.)

F = profit fish + profit crops (objective function)

Return
```

Subroutine CONST

$0 \leq Q_1 \leq Q_p$

$0 \leq Q_2 \leq Q_p$

$0 \leq Q_1 + Q_2 \leq Q_p$

Return

Figure 2

Optimization Sequence

APPENDIX 2-B

THE POND MODEL[1]

The POND model is used in both the FUNC subroutine and in the reservoir component. The POND model is based on investigations by Edinger, et al. (1968) and Littleton (1970). The principle on which this model operates is that the temperature of a shallow natural pond (e.g. fish pond or reservoir) when subject to constant climatic conditions will approach a steady state or equilibrium temperature. The equilibrium temperature is defined as that temperature a body of water reaches when the heat input and heat dissipated are balanced.

The importance of this model is that if climatic conditions, physical characteristics of the pond, and rate of heat input are known; the pond temperature can be found. This will then determine growth rates of fish and consequently revenues for the fish ponds. As Figure 1 of Appendix 2-A shows, once the input heat rates to subsystems are known the amount of waste heat that must be dissipated by the reservoir can be determined and hence reservoir size. It should be noted that a well mixed pond (one with no vertical temperature gradient) was assumed in finding pond surface temperature and the size

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[1]For further reference as to the development and characteristics of the POND model, Walker and Bakker-Arkema (1975), can be reviewed.

of the reservoir.

APPENDIX 2-C

THE SOIL WARMING MODEL[1]

A differential equation model was used to calculate soil temperature for a given heat input into a system of sub-surface piping. The soil warming model is based on work by Kendrick and Havens (1973) where soil temperature is stated as a major indicator for crop growth.

The flow of operations for this model starts with the maximization of net revenues. From this operation heat dissipation rate can be found and assigned to the surface balance equation. The surface temperature is then found. The Hendrick-Havens equation used for calculating surface temperature can also be used to assess whether the pipe temperature is physically feasible. If so, the flow rate which corresponds to the surface temperature is used to calculate pumping costs and fixed capital requirements.

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[1]The mathematical model and the method by which it is solved is found in Schisler, and Bakker-Arkema (1975).

APPENDIX 2-D

THE FISH GROWTH MODEL[1]

The fish growth model is also a mathematical model used in predicting biological productivity. The variables affecting fish growth rates are temperature (as derived from the POND model) and population density (given in initial conditions). Investigations by Brown, 1957; Swift, 1964; Brett, et al., 1969; and Andrew and Stickney, 1972; support the model. While it is desirable to express growth rates as exponentially related to temperature and density, important parameters which represent the proportional growth rate for the specie of fish used in the model was not known. The lack of appropriate data and known relationships between temperature population density, and growth rates forced the use of a constant growth rate.

The constant growth rate was estimated using linear approximation methods using data available in Andrew and Stickney, 1972. While a nonlinear function would have been desirable, given the possible range of plant output temperatures, the linear approximation used made it possible to assess the impact of different temperature on fish growth. This mathematical model forms the core of the FISH component.

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[1]A complete description of this model and its limitations is found in Walker and Bakker-Arkema, 1975.

As can be observed in Figure 2 of Appendix 2-A, FISH is part of the FUNC subroutine. The flow chart indicates that given simulated weather conditions and flow rates which maximize the objective function, surface temperature is found for the fish ponds. This is then used in the FISH model to find incremental growth rates.

APPENDIX 2-E

THE CROP GROWTH MODEL[1]

The crop growth model or CROP is also a mathematical model formulated to describe a biological growth process. Many models for crop response had been predicated on a fixed root zone temperature. Given the impact of weather, variable flow rates, and physical constraints, a model was developed to accommodate non-constant soil temperatures. Furthermore, for economic evaluation, the model must relate the effect of improved emergence and vegetative growth on grain yield or fruit yield.

Given the nature of the problem and desired information a switched growth model in the form suggested by Partridge and Denholm (1974) was used. While the coefficients of the model depend on climatic factors and hence should change with time, constant coefficients were used as a reasonable approximation to model the growth of the crops used in the study.

The placement of the crop growth model in the compilation sequence and use in the economic analysis is similar to that for the fish growth model.

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[1]For a further discussion of this model and the procedures used in its development, see Schisler and Bakker-Arkema, 1975. A description of crop data is also discussed.

APPENDIX 3

APPENDIX TABLE 3-A

INITIAL CAPITAL REQUIREMENTS FOR A
4-20 ACRE FISH POND SUBSYSTEM

Item	Dollars
Land	57,000
Pond Construction	400,000
Feeding Equipment	1,000
Disease and Parasite Control Equipment	1,000
Harvesting Equipment	4,300
Storage Barn	6,000
Offices	2,500
Miscellaneous	7,500
Pumps (8)	174,000
Installation	174,000
Motors (8)	24,000
Fluid Drive Couplings (8)	45,000
Belts, Splines, Circuit Breakers, Starters	3,000
Filtration and Aeration	50,000
TOTAL	948,800

APPENDIX TABLE 3-B

ANNUAL COSTS FOR THE 4-20 ACRE FISH POND SUBSYSTEM[1]

Item	Dollars
Annual ownership costs[2]	
Interest on land investment	4,560
Depreciation[3]	
Pond construction	13,333
Feeding	100
Disease and parasite control	100
Harvesting equipment	540
Filtration and aeration	1,667
Storage	100
Pumps	5,800
Motors	1,600
Fluid drive coupling	1,600
Belts, splines, circuit breakers and starters	375
Miscellaneous	750
Interest on investment	
Pond construction	16,000
Feeding	40
Disease and parasite control	40
Harvesting equipment	172
Filtration and aeration	200
Storage barn	120
Office	100
Miscellaneous	300
Pumps	6,960
Motors	960
Fluid drive coupling	1,970
Belts, splines, circuit breakers and starters	120
SUBTOTAL	57,507
Annual operating costs	
Repairs and maintenance	
Feeding equipment	65
Disease and parasite control	32
Harvesting equipment	200
Pumps, motors, accessories	1,250
Miscellaneous equipment	400
Pumping costs	137,200
Chemicals	3,550
Fingerlings	307,200

APPENDIX TABLE 3-B (continued)

Item	Dollars
Feed	310,680
Manager	15,000
Labor	10,000
Taxes, insurance, bookkeeping and general office overhead	5,000
Filtration and aeration[4]	5,000
SUBTOTAL	795,577
Interest on operating capital	30,203
TOTAL ANNUAL OPERATING COSTS	825,780
TOTAL COSTS	883,287

[1]Thomas H. Forster, John E. Waldrop, Cost Size Relationships in the Production of Pond Raised Catfish for Food, Mississippi State University Agricultural and Forestry Experiment Station, State College, Mississippi, January, 1972. Costs are modified to reflect Michigan conditions, 1976 prices and other costs incurred due to the non-conventional nature of the pond construction and operation.

[2]Interest at a rate of 8 percent was charged on one-half of the original investment in depreciable items and at 9 percent on one-half of the estimated operating costs. Non-depreciable items, land, and land improvements were charged at a rate of 8 percent of full inventory value. These charges will remain the same throughout for other subsystems, general piping and distribution system and alternative systems.

[3]A straight-line depreciation method was used where the first, fifth, sixth, seventh, eighth and ninth items were depreciated over a thirty-year period. The second, third, and fourth items were depreciated over a ten-year time period. The tenth item was depreciated for a six-year time period, and the eleventh item for an average of twenty-one years. A straight-line depreciation system will be applied to other subsystems and the general piping and distribution system.

[4]As the exact needs of the filtration system have yet to be determined, the inclusion of the initial capital expense and annual operating cost for this component is more a matter of completeness than accuracy.

APPENDIX TABLE 3-C

INITIAL CAPITAL REQUIREMENTS FOR 24-20 ACRE PONDS

Item	Dollars
Land	342,000
Pond Construction	2,400,000
Feeding Equipment	6,000
Disease and Parasite Control Equipment	6,000
Harvesting Equipment	22,800
Storage Barn	18,000
Offices	15,000
Miscellaneous	45,000
Pumps (24)	1,044,000
Installation	1,044,000
Motors (24)	144,000
Fluid Drive Couplings (24)	288,000
Belts, Splines, Circuit Breakers, Starters	18,000
Filtration and Aeration	300,000
TOTAL	5,692,800

APPENDIX TABLE 3-D

ANNUAL COSTS FOR THE 24-20 ACRE FISH POND SUBSYSTEM[1]

Item	Dollars
Annual ownership costs[2]	
Interest on land investment	27,360
Depreciation[3]	
Pond construction	80,000
Feeding	600
Disease and parasite control	600
Harvesting equipment	3,225
Filtration and aeration	10,000
Storage	600
Pumps	34,800
Motors	9,600
Fluid drive coupling	9,000
Belts, splines, circuit breakers and starters	2,250
Miscellaneous	4,500
Interest on investment	
Pond construction	96,000
Feeding	240
Disease and parasite control	240
Harvesting equipment	1,032
Filtration and aeration	1,200
Storage barn	240
Office	600
Miscellaneous	1,800
Pumps	41,760
Motors	5,760
Fluid drive coupling	11,520
Belts, splines, circuit breakers and starters	720
SUBTOTAL	339,327
Annual operating costs	
Repairs and maintenance	
Feeding equipment	390
Disease and parasite control	275
Harvesting equipment	1,350
Pumps, motors, accessories	7,500
Miscellaneous equipment	2,400
Pumping costs	823,200

APPENDIX TABLE 3-D (continued

Item	Dollars
Chemicals	21,333
Fingerlings	1,946,983
Feed	1,864,080
Manager	60,000
Labor	118,125
Taxes, insurance, bookkeeping and general office overhead	30,000
Filtration and aeration[4]	50,000
SUBTOTAL	4,925,636
Interest on operating capital	208,542
TOTAL ANNUAL OPERATING COSTS	5,264,963
TOTAL COSTS	5,473,505

Refer to Appendix Table 3-B for Footnotes 1-4.

APPENDIX TABLE 3-E

INITIAL CAPITAL REQUIREMENTS FOR
100 ACRES OF SOIL WARMING AREA

Item	Dollars
Land	63,000
Lateral Piping	
2-inch PVC @ .24 ft.	523,224
Installation @ .015/ft.	32,701
Headers	
1.25 diameter @ 4.20/ft.	16,380
Installation	16,380
Pumps - 2 X 9,000	18,000
Installation - 2 X 9,000	18,000
Valves - 4 X 2,200	8,800
Installation - 4 X 1,375	5,500
Motors - 2 X 4,050	8,100
Belts and Splines - 2 X 600	1,200
Circuit Breakers and Starters - 2 X 200	400
TOTAL	774,685

APPENDIX TABLE 3-F

ANNUAL COSTS FOR 100 ACRES OF SOIL WARMING FOR TOMATOES

Item	Dollars
Annual ownership costs	5,040
Depreciation	
Lateral Piping	17,440
Headers	585
Pumps	643
Valves	314
Motors	289
Belts, etc.	57
Interest on investment	
Laterals	22,237
Headers	1,310
Pumps	1,440
Valves	572
Motors	324
Belts, etc.	64
SUBTOTAL	50,315
Annual operating costs	
Materials	70,800
Labor	54,400
Custom hire	9,837
Pumping costs	9,870
Manager	10,000
SUBTOTAL	164,907
Interest on operating capital	3,630
TOTAL ANNUAL OPERATING COSTS	158,667
TOTAL COSTS	208,982

APPENDIX TABLE 3-G

INITIAL CAPITAL REQUIREMENTS AND
ANNUAL COSTS FOR THE RESERVOIR

Item	Dollars
Initial capital requirements	
Land	225,000
Reservoir construction	3,450,000
TOTAL	3,675,000
Annual costs	
Annual ownership cost	1,800
Depreciation	115,000
Interest on investment	138,000
SUBTOTAL	254,800
Annual operating costs	
Manager and labor	20,000
Chemicals	91,388
Filtration	100,000
Repairs	50,000
Miscellaneous	37,700
SUBTOTAL	299,088
Interest on operating capital	8,612
TOTAL ANNUAL OPERATING COSTS	307,700
TOTAL COSTS	562,500

APPENDIX TABLE 3-H

INITIAL CAPITAL REQUIREMENTS FOR A 216,000 SQUARE FOOT GREENHOUSE

Item	Dollars
Land	4,800
Structure	139,700
Covering (T-20 tedlar acrylic)	124,800
Forced air finned tube heat exchangers (15)	60,000
Finned tubing	148,000
Boiler (hot water - fuel oil)	72,000
Controls	12,000
Single speed ventilator fans (14 X 48")	22,400
Dual speed ventilator fans (14 X 48")	28,000
Installation, wiring and lighting	301,600
Benches (80% space utilization)	180,000
Head house, storage, office, work area, loading facility and lavatories	120,000
Climate controls	4,800
Pumps and installation	24,000
Motors	60,000
Circuit breakers, belts, splines and starters	2,400
TOTAL	1,291,300

APPENDIX TABLE 3-I

ANNUAL COSTS FOR A 216,000 SQUARE FOOT GREENHOUSE

Item	Dollars
Annual ownership costs	
Interest on land investment	384
Interest on investment	
Structure and covering	9,312
Forced air finned tube heat exchanger	2,400
Finned tubing	5,920
Boiler	2,880
Controls	480
Fans	504
Installation	12,064
Benches	7,200
Head house, etc.	6,400
Climate controls	192
Pumps	960
Motor	240
Belts, etc.	128
Depreciation	
Structure and covering	7,760
Heating system and controls	11,064
Ventilator fans	5,040
Installation, wiring and lighting	30,160
Benches	6,000
Head house, etc.	5,332
Pump	800
Motors	200
Belts, etc.	108
SUBTOTAL	29,260
Annual operating costs	
Labor	120,000
Materials	454,284
Heating	100,000
Maintenance	230,000
Office supplies	2,400
Management	88,000
Office workers	12,000
Selling costs	20,000

APPENDIX TABLE 3-I (continued)

Item	Dollars
Pumping costs	87,400
Miscellaneous	20,000
SUBTOTAL	1,134,112
Interest on operating capital	22,572
TOTAL	1,185,944

APPENDIX TABLE 3-J

INITIAL CAPITAL REQUIREMENTS FOR 8-20 ACRE PONDS

Item	Dollars
Land (190 acres)	114,000
Pond construction (earth moving, drainage structures, rip-wrap armored)	800,000
Feeding equipment	2,000
Disease and parasite control	2,000
Harvesting equipment	8,600
Storage barn	6,000
Offices	5,000
Miscellaneous	15,000
Pumps (8)	348,000
Installation	348,000
Motors (8)	48,000
Fluid drive couplings (8)	96,000
Belts, splines, circuit breakers and starters	6,000
Filtration and aeration	100,000
TOTAL	1,897,600

APPENDIX TABLE 3-K

ANNUAL COSTS FOR THE 8-20 ACRE FISH POND SUBSYSTEM[1]

Item	Dollars
Annual ownership costs[2]	
Interest on land investment	9,120
Depreciation[3]	
Pond construction	26,667
Feeding	200
Disease and parasite control	200
Harvesting equipment	1,080
Filtration and aeration	3,333
Storage	200
Pumps	11,600
Motors	3,200
Fluid drive coupling	3,200
Belts, splines, circuit breakers and starters	750
Miscellaneous	1,500
Interest on investment	
Pond construction	32,000
Feeding	80
Disease and parasite control	80
Harvesting equipment	344
Filtration and aeration	400
Storage barn	240
Office	200
Miscellaneous	600
Pumps	13,920
Motors	1,920
Fluid drive coupling	3,840
Belts, splines, circuit breakers and starters	240
SUBTOTAL	114,914
Annual operating costs	
Repairs and maintenance	
Feeding equipment	130
Disease and parasite control	66
Harvesting equipment	432
Pumps, motors, accessories	2,500
Miscellaneous equipment	800

APPENDIX TABLE 3-K (continued)

Item	Dollars
Pumping costs	274,400
Chemicals	7,110
Fingerlings	643,911
Feed	621,360
Manager	25,000
Labor	37,500
Taxes, insurance, bookkeeping and general office overhead	10,000
Filtration and aeration[4]	10,000
SUBTOTAL	1,633,209
Interest on operating capital	69,285
TOTAL ANNUAL OPERATING COSTS	1,702,494
TOTAL COSTS	1,817,408

Refer to Appendix Table 3-B for Footnotes 1-4.

APPENDIX 4

APPENDIX TABLE 4-A

INITIAL CAPITAL REQUIREMENTS AND ANNUAL COSTS FOR WASTE HEAT DISSIPATION ALTERNATIVES[1]

Initial Capital Requirements	Once Through	Natural Draft	Mechanical Draft	Cooling Pond	Spray Canal
	(Dollars)				
Cooling System					
Net Unit Output - MW (1)	1,336	1,329.4	1,334.6	1,329.4	1,334.6
Annual Heat Rate Diff - Btu/kWh	Base	+71	+85	+71	+71
Cooling Water Flow - GPM	1,100,000	750,000	750,000	750,000	750,000
Cooling Water Power Reqmt - kW	15,385	15,700	15,700	6,279	6,279
Make-up Water Power Reqmt - kW	-	76 kW	76	76	76
Fan Power Reqmt - kW	-	-	4,642	-	-
Spray Power Reqmt - kW	-	-	-	-	11,190
1975 Capital Cost for 2 Units	Base	$29,370,000	$24,000,000	$33,148,000	$26,600,000
Annual Cost (2 Units)					
Fixed Charges on Investment	Base	$4,467,000	$3,650,000	$5,042,000	$4,046,000
Circ Water - Power Consumpt	$1,190,800	$1,217,500	$1,217,500	$487,000	$487,000
Make-up Water Power Consumpt	-	$7,000	$7,000	$7,000	$7,000
Fan Power Reqmt	-	-	$293,900	-	-
Spray Power Reqmt	-	-	-	-	$708,500
Annual Heat Rate Cost	Base	$757,800	$907,200	$757,800	$757,800
Water Treatment Costs/Yr	Base	$236,600	$236,600	$118,300 (2)	$118,300 (2)
Maintenance Cost/Yr	Base	$33,100	$53,100	$10,000	$40,000
Fixed Charges on Net Capability	Base	$175,700	$42,600	$175,700	$42,600
	$1,190,800	$6,894,700	$6,407,900	$6,597,800	$6,207,200
		$1,190,800	$1,190,800	$1,190,800	$1,190,800
		$5,703,900	$5,217,100	$5,407,000	$5,016,400

[1]These costs were used as a basis for computing the values used in Chapter IV. Minor modifications were made to make the data comparable for this study.

APPENDIX TABLE 4-B

INITIAL CAPITAL REQUIREMENTS FOR THE GENERAL PIPING AND DISTRIBUTION SYSTEM FOR MODELS I AND III

Item	Dollars
Pumps[1]	
1. At power plant to subsystems	1,925,000
2. At fish pond to reservoir	706,275
3. At soil warming plot to reservoir	30,000
4. At reservoir to plant[2]	1,612,500
TOTAL PUMP COSTS	4,273,775
Piping costs	
1. To soil warming plot from plant	
1,100' at 1.75' diameter	
Materials	7,865
Installation	7,685
1,175' at 1.25' diameter	
Materials	4,725
Installation	4,725
2. From soil warming to reservoir	
2 X 200' at 1.25' diameter	
Materials	1,680
Installation	1,680
3. From plant to reservoir	
2 X 200' at 11' diameter	
Materials	80,540
Installation	38,000
4. From reservoir to plant	
3 X 200' at 10' diameter	
Materials	101,340
Installation	48,000
5. Supply and return lines for fish ponds	
2 X 450' at 11' diameter	
Materials	183,150
Installation	85,500
4,200' at 11' diameter	
Materials	856,170
Installation	400,000
4 X 350' at 8.5' diameter	
Materials	199,570
Installation	85,400
4 X 650' at 8.0' diameter	
Materials	300,300
Installation	143,000
4 X 650' at 7.0' diameter	
Materials	234,570
Installation	114,400

APPENDIX TABLE 4-B (continued)

Item	Dollars
4 X 650' at 6.0' diameter	
Materials	171,600
Installation	102,960
5 X 650' at 5.0' diameter	
Materials	150,150
Installation	104,979
4 X 500' at 3.5' diameter	
Materials	48,400
Installation	40,000
650' at 7.5' diameter	
Materials	62,205
Installation	31,850
650' at 10' diameter	
Materials	120,185
Installation	58,500
650' at 11.0' diameter	
Materials	132,275
Installation	61,750
350' at 11.0' diameter	
Materials	71,347
Installation	33,250
650' at 8.5' diameter	
Materials	92,657
Installation	39,650
650' at 4.5' diameter	
Materials	24,310
Installation	19,500
100' at 2.5' diameter	
Materials	1,320
Installation	1,320
1,650' at 10.0' diameter	
Materials	278,685
Installation	136,950
2 X 1,650' at 9' diameter	
Materials	536,250
Installation	227,700
TOTAL PIPING COSTS	5,453,460
Total Initial Capital Investment	9,727,235

[1]Cost for pumps is inclusive of motor, belts, splines, circuit breakers, and starter.

[2]It is assumed that power plant will contain condenser pump.

APPENDIX TABLE 4-C

ANNUAL COSTS FOR THE GENERAL PIPING AND DISTRIBUTION SYSTEM FOR MODELS I AND III

Item	Dollars
Depreciation[1]	347,401
Interest on investment[2]	389,089
SUBTOTAL	736,490
Annual operating costs	
Repairs and maintenance[3]	486,362
Pumping costs	3,379,515
Manager	-30,000
Labor	30,000
Miscellaneous	30,000
Interest on operating capital[4]	152,078
TOTAL ANNUAL OPERATING COSTS	4,844,445

[1]Depreciation is calculated by the straight-line method. For simplicity, the expected life of capital items is assumed to be 28 years with zero salvage value for those assets at that time.

[2]Interest on investment is equal to 8 percent of one-half of initial capital costs.

[3]Repairs and maintenance are estimated to be 5 percent of initial capital investments.

[4]Interest on operating costs is equal to 9 percent on one-half of major annual operating costs (pumping costs).

APPENDIX TABLE 4-D

INITIAL CAPITAL REQUIREMENTS FOR THE GENERAL PIPING AND DISTRIBUTION SYSTEM FOR MODEL II

Item	Dollars
Pumps[1]	
1. At power plant to subsystems	1,612,500
2. At fish pond to reservoir	470,850
3. At soil warming plot to reservoir	58,650
4. At reservoir to plant[2]	1,612,600
TOTAL PUMP COSTS	3,754,500
Piping costs	
1. To soil warming plot from plant (1,675' of 1.75' diameter)	
Materials	11,900
Installation	11,900
2. From soil warming to reservoir (2,250' of 1.25' diameter)	
Materials	9,450
Installation	9,450
3. Supply and return lines for plant to plant	
2 X 200' at 11' diameter	
Materials	81,540
Installation	38,000
2 X 200' at 11' diameter	
Materials	81,540
Installation	38,000
1 X 200' at 10' diameter	
Materials	33,780
Installation	19,000
4. Pipes to fish ponds	
550' at 9.5' diameter	
Materials	91,163
Installation	41,800
3,300' at 6.5' diameter	
Materials	257,730
Installation	141,735
350' at 6.5' diameter	
Materials	27,335
Installation	15,033
1,300' at 5.5' diameter	
Materials	71,500
Installation	47,950
1,300' at 4.5' diameter	
Materials	48,625
Installation	39,000

APPENDIX TABLE 4-D (continued)

Item	Dollars
1,300' at 3.0' diameter	
Materials	24,310
Installation	24,310
5. Out of fish pond to reservoir	
650' at 4' diameter	
Materials	20,020
Installation	20,020
650' at 5' diameter	
Materials	30,030
Installation	25,995
650' at 7' diameter	
Materials	58,630
Installation	38,600
400' at 7.5' diameter	
Materials	38,280
Installation	29,600
TOTAL PIPING COST	1,426,226
Total Initial Capital Investment Costs	5,180,726

[1]Cost for pumps is inclusive of motor, belts and splines, circuit breaker, and starter, if appropriate, and installation.

[2]It is assumed the power plant will contain the condenser pumps.

APPENDIX TABLE 4-E

ANNUAL COSTS FOR THE GENERAL PIPING DISTRIBUTION SYSTEM FOR MODEL II

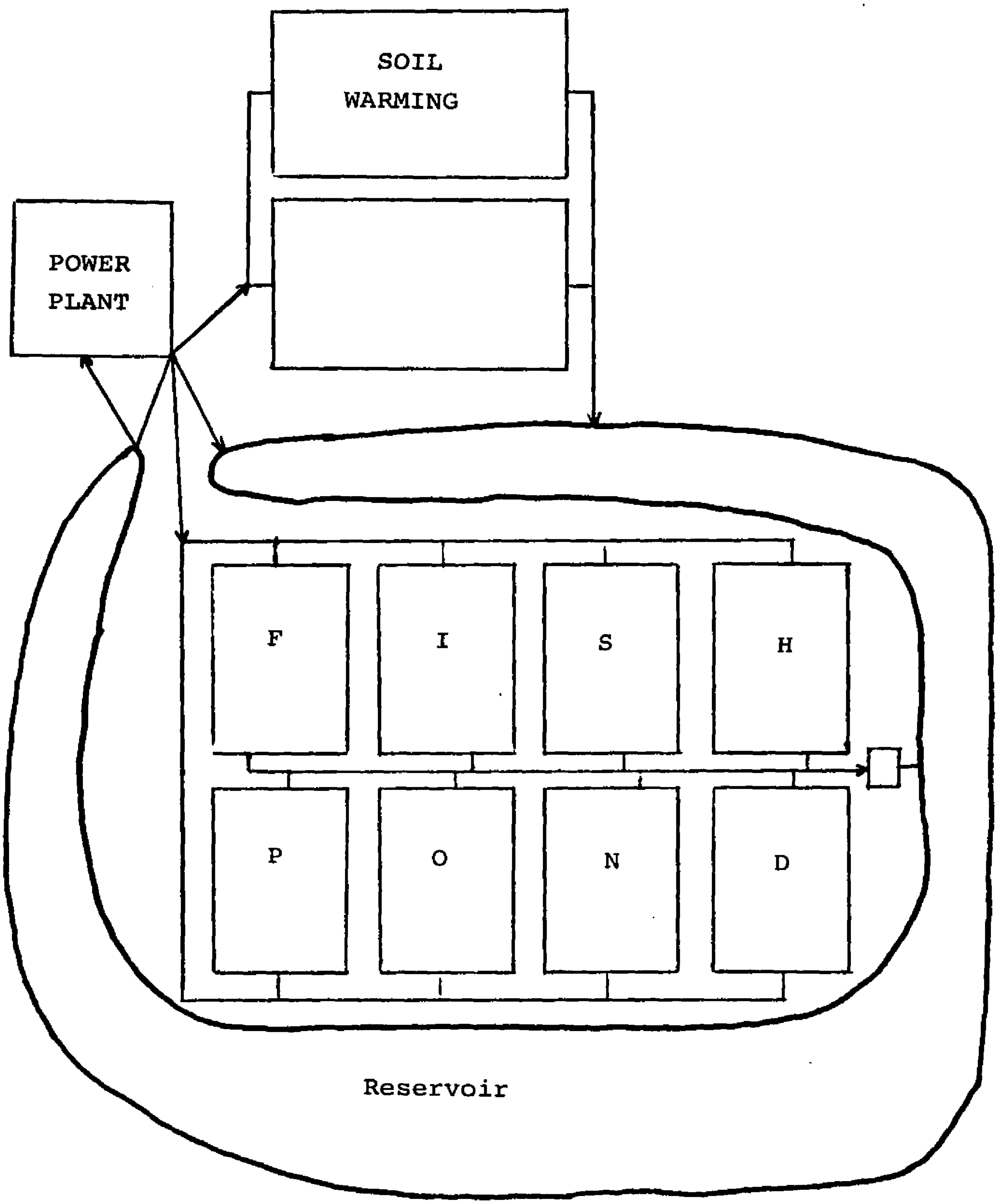
Item	Dollars
Depreciation[1]	185,026
Interest on investment[2]	207,329
SUBTOTAL	392,355
Annual operating costs	
Repairs and maintenance[3]	259,036
Pumping costs	2,793,049
Manager	30,000
Labor	30,000
Miscellaneous	30,000
Interest on operating capital[4]	125,087
TOTAL ANNUAL OPERATING COSTS	3,690,127

[1]Calculated by the straight-line method. For the sake of simplicity, life of capital items is assumed to be 28 years with zero salvage value.

[2]Interest on investment is a cash cost and equal to 8 percent of one-half of the initial capital costs.

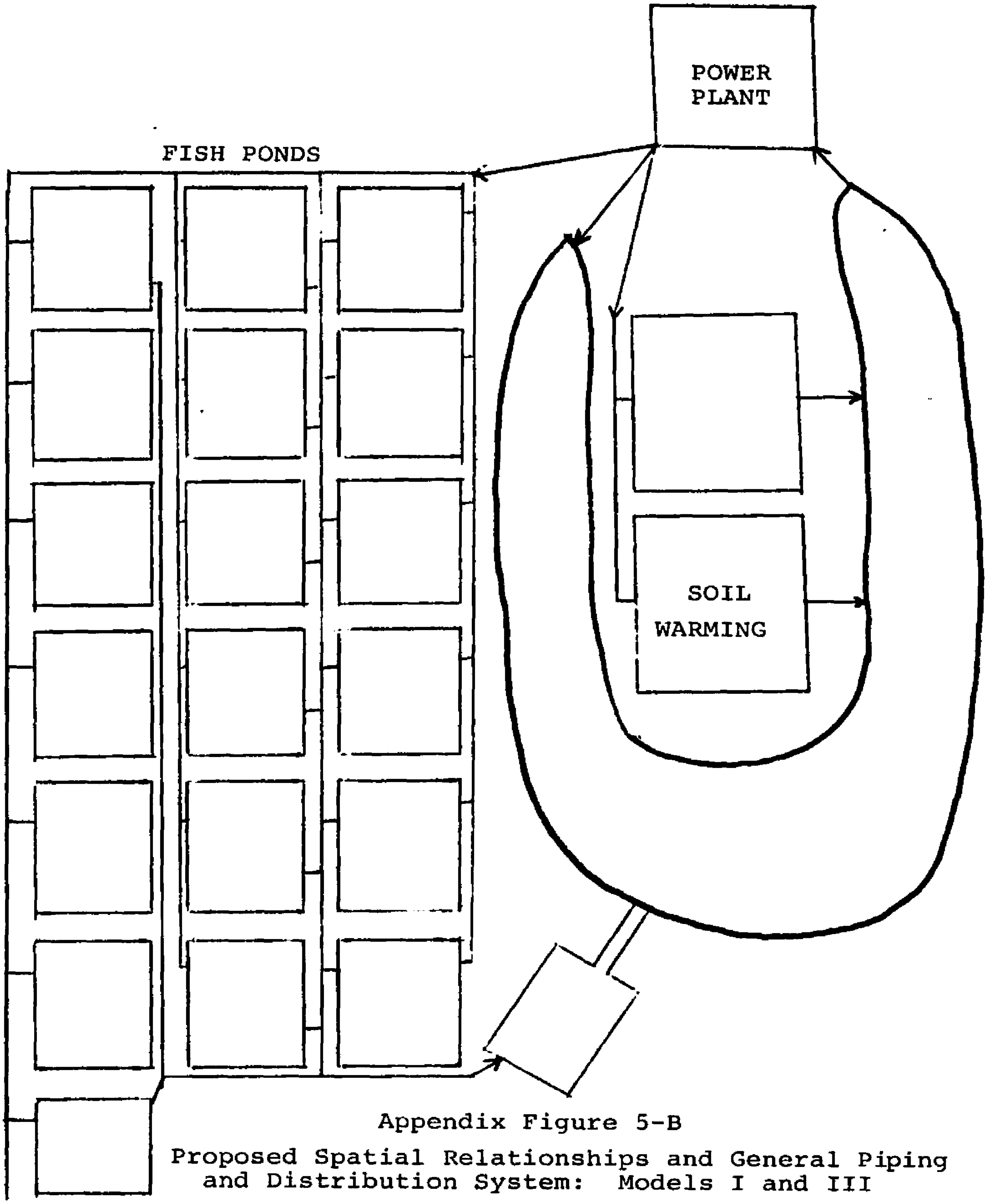
[3]Repairs and maintenance are estimated to be 5 percent of initial capital requirements.

[4]Interest on operating costs is equal to 9 percent on one-half of major annual operating costs (pumping costs).



Appendix Figure 5-A

Proposed Spatial Relationships and General Piping and Distribution System: Model II



Appendix Figure 5-B

Proposed Spatial Relationships and General Piping and Distribution System: Models I and III

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