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THE PERMIT SYSTEM OF WATER ALLOCATION

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PART I
CHAPTER ONE: INTRODUCTION

Statement of the Problem

Many of man's activities depend upon the availability of water as one of the earth's resources. In Iowa, virtually every sector of the economy uses water (4, Table 2-A). In the future, industrial, agricultural, and population requirements for water in Iowa are expected to increase (4, Table 4-A) as population and output increase (64, 78). At some point in time, because of the uneven distribution of water supply both seasonally and geographically, requirements for water in Iowa may reach such a level that water becomes a constraining resource, one whose scarcity causes potential production to be foregone. This constraining influence on production could be felt either locally or generally, by individual water users or by groups of users. In such a situation, the manner in which water rights are allocated could have a direct effect on state and local economic fortunes.

In the United States, water has traditionally been allocated by non-market mechanisms. These systems have developed primarily in the customs, legislation, and court decisions of each state. In the State of Iowa, water resources are allocated by a system of water use permits (53). Since the inception of the water permit system in 1957, after a decade of below average rainfall (122), water supplies in Iowa have been relatively abundant.

During this period, all except two permit applications have been granted, and the two which were denied each requested a permit for the drainage of excess surface water.¹ It is therefore impossible to determine, on the basis of its historical performance, how the water permit system would allocate Iowa's water resources if scarcity of those resources began to impose a constraint on the state's economic

¹Louis R. Gieseke, Assistant Water Commissioner, Des Moines, Iowa. Data on the history of Iowa's water permit system. Private communication. February 9, 1969.

activity. This study addresses itself to the task of predicting, on some basis other than historical performance, the permit system's reaction to a water scarcity and also to the task of developing a method for economic evaluation of this reaction.

The three objectives of this study are as follows: 1) to analyze Iowa's water permit system, constructing an estimate of the system's allocation in times of water scarcity; 2) to construct a model which will yield in specific situations both an optimum water use pattern and values for water in its various uses; 3) to apply the model developed in objective 2 above and the estimate constructed in objective 1 to a specific situation.

Methods and procedures

This study is divided into four parts. Part I is both descriptive and theoretic in nature. First, water is examined both as a physical and as an economic entity, in an attempt to link the relevant concepts of hydrology and geology to the theoretic framework of economics. Theoretic necessary and sufficient conditions for optimum resource allocation are then derived. The origins and general characteristics of the allocative mechanisms currently in use in the United States are examined and to each system are applied the stated necessary and sufficient conditions in an effort to evaluate each system's recognition of these conditions of optimality. Emphasis is placed on Iowa's permit system in the discussion. As a result of this analysis of the permit system, a specific hypothesis is developed in Chapter Four.

In Part II, a general model of resource allocation is constructed utilizing linear programming to analyze the interaction between hydrologic and economic systems and to generate approximate values for water optimally allocated among competing uses. The results of the model's application can be used in testing hypotheses concerning water allocation under Iowa's permit system.

Part II also involves application of the general model to two water use situations, one real, the other hypothetical. Chapter Six contains a description of the results of these applications. In Chapter Seven, results are summarized, and conclusions drawn with respect to the applications of the general model. Recommendations for further research involving the general model are also suggested in Chapter Seven.

Part III extends the analysis significantly by adding, explicitly, water quality considerations under the general assumptions that water qualities resulting from use are important public policy variables and that water users, directly or indirectly, should bear the costs related to reduction in water quality attributable to their use. The Tandem Program System (TPS) developed to incorporate water quality considerations into the general model is described in Part III and possibilities for refinement and expansion of the TPS approach are identified and discussed.

Part IV summarizes the project efforts, makes recommendations for further research and suggests possible courses of action for administrative agencies involved in water allocation.

CHAPTER TWO: FRAMEWORK FOR ANALYSIS

Iowa's pattern of water use is made up of three dimensions. The first dimension comprises the quantitative and qualitative requirements¹ for water in all its uses, whether as an input to a production process or as a commodity for direct use as well as the quantitative and qualitative aspects of return flows following water use. The second dimension is Iowa's supply of water, existing both on the surface and underground, in varying quantities and qualities. The third dimension is Iowa's water permit system, under which rights of use are allocated to particular water users. At any point in time, the pattern of water use in the state, or any local area of the state, is the result of the permit allocation mechanism's interaction with water requirements and water supplies. Conceptual examination of each dimension is a useful prerequisite to discussion of any particular pattern of water use which would result from a scarce water supply.

Water as an Economic Entity

Occurrence

The earth's water supply is circulated by means of the hydrologic cycle, in which water is transferred from land to the sea and back to land (63, p. 8). Precipitation of evaporated seawater in this process accounts for almost the entire supply of fresh water, which occurs either as surface runoff collected in streams and rivers or as underground water collected in aquifers.² Units of the quantity of water in the hydrologic cycle are not homogeneous, but are differentiated by the time and location of their occurrence, and by their individual quality characteristics (44, p. 16; 76, p. 1259; 100, p. 7). The physical

¹The term "requirements" is used instead of "demands." By definition, demand for a resource is a function of resource price. Under Iowa's water permit system, water has no market price; use of the concept of demand would be imprecise. The distinction between requirements and demands is discussed in a later section of this chapter.

²Aquifers are quantities of water occurring in porous strata of rock and soil beneath the earth's surface (63, p. 8).

processes of the hydrologic cycle store, transport, and change the quality of the earth's water, creating and maintaining specific supplies of water throughout the earth.

Supply

The earth's physical supply of water is all water contained in the hydrologic cycle, whether in seas, lakes, or rivers; in the atmosphere or underground. However, portions of the entire physical supply of water are not available for use. At any point in time, use of some portion of the physical supply of water may be prohibited due to restrictions imposed by such social institutions as a legal system (2, p. 18). One such institutional restriction of water use in Iowa is that which prohibits withdrawals when streamflow reaches a certain legally protected minimum (53, sec.455A.1). The amount of water available up to this type of limit is known as the institutional supply (2, p. 18). Further, at any point in time technological limits may make some quantities of water unavailable. The impossibility of reclaiming predictable amounts of atmospheric water when and where they are required (15, pp. 4-7) is an example of a limit placed on water supply by present technology.

Some authors make use of the concept of economic supply (2, p. 18; 18, p. 198; 58, p. 1112; 99, p. 1245). Economic supply is that amount of water which is economically feasible to bring into production. Economic feasibility is determined by the relationship between the cost of acquisition of an additional unit of water and the returns which that unit yields to its users; if returns are greater than costs, use of the additional unit is feasible. The unit cost of acquisition of additional water is influenced by technology, so that if changes in technology decrease the cost, use of previously untapped water may become feasible. Assuming acquisition costs to be constant, an increase in returns to the use of an additional unit of water could increase economic supply. Returns increase if demand for water increases, raising the price which users are willing to pay for an additional unit. These effects

of technology and economic conditions on economic supply mean that water supply is not only a function of man's knowledge, but also of man's economic fortunes. Defining economic supply in terms of economic feasibility neatly illustrates the point that technological and economic change may make vast unused water supplies eligible for consideration in meeting existing and potential needs. The extent of these potential water supplies would be dependent upon the existence of any institutional or technological limit on physical supply.

Water supplies may be characterized as either stock or flow supplies. Kelso (58) defines stock supplies as those whose physical quantity does not increase appreciably over time; therefore, each rate of use of a stock resource diminishes some future rate of use. In defining a flow supply, Kelso points out that different units of the supply become available at different times, and that present flow does not diminish future flow. Therefore, it would be possible to maintain use of a flow resource indefinitely if flow continues. The hydrologic cycle, precipitation, surface runoff, and streamflow are examples of flow supplies of water, while an aquifer which recharges at a very slow rate could be considered a stock supply, fixed in magnitude.

Water use classification

The uses to which water resources can be put are myriad, perhaps as numerous as man's activities. A number of different schemes exist whereby these uses can be classified. One such device classifies water use by the final product, process, or activity of which water is a part, under the two general headings of production and consumption uses. Water uses in industry, mining, and agriculture are production uses (99, p. 1245), while such uses as human consumption and recreation are consumption uses (99, p. 1245; 18, p. 198). This method of classification is useful for the economist, for the same categories can be applied to water as an input or commodity in constructing demand relationships.

Some water uses, both production and consumption, may be designated as consumptive. In the traditional riparian definition,³ a water use is consumptive if the quantity of water in the watercourse is diminished by such use (1, p. 104; 48, p. 7; 102, p. 272). However, defining consumption in terms of quantity alone ignores other important ways in which a use may be consumptive. As an example, consider an industrial water user who returns to the watercourse all the water he withdraws, but returns it laden with the by-products of his production process. If a downstream user must treat intake water to remove these industrial pollutants, the second user is restoring quality utility which the upstream user consumed. It is therefore important to consider depletions in the utility which units of water in a watercourse possess, as well as depletions in quantity in the watercourse, when considering consumptive use.

Source depletion is also an important characteristic of those water uses which withdraw water from a stock supply. Since present rates of use of stock water supplies directly affect future rates of use, allocation decisions must be made inter-temporally, as well as among uses and users.

Finally, economic theory provides one further classification of water use by enabling the relationships between water uses to be characterized as complementary, competitive, or neutral (99, p. 1246; 85, p. 162). According to Timmons(99), water uses are complementary if allocation to one use increases net benefits accruing to water in another use, while a competitive relationship exists if one water use restricts net benefits available from another. If net benefits available from different uses are not affected by allocation to one use or another, the relationship is one of neutrality. Any consumptive use of water is competitively related to most other uses of that water, since

³The riparian doctrine is that legal system under which water rights are allocated in most of the thirty-one eastern states. Further discussion of the riparian doctrine is contained in a later section of this chapter.

allocation to a consumptive use generally does not permit further use of the water without at least restoring the utility which was consumed. A use which is consumptive with respect to quality impairment may not interfere with another use which requires low water quality, but this relation is at best neutral. Water used in hydroelectric power generation complements the use of that water for recreation, since power generation ideally requires a constant head of water, which would provide a constant reservoir depth for swimming, boating, or fishing. Use for power generation would be neutral with respect to downstream uses, since only the energy head of the elevated water is used in generating power, not necessarily impairing quality or quantity. Complementary uses are not the major concern in allocation, nor are neutral uses, for a unit of water allocated to one use does not decrease or preclude the benefits available from that unit of water in another use if the two uses are neutral or complementary with respect to each other. However, problems arise when allocation decisions must be made among competing uses for a water supply, since only one of the competing uses can realize the benefits accruing from use of the water.

In summary, the methods of classifying water use described above characterize each water use according to the product or activity of which it is part, and designate each use as consumptive, nonconsumptive, or source-depleting. Further, sets of uses are characterized as complementary, neutral, or competitive. Such a scheme coincides with concepts advanced by Snyder(93), who holds that uses should be categorized based on the concept of utility addition. Each use would be considered a conversion of water in an economic process such that not only quantity, but also time, place, and quality utility may be modified. Uses would then be identified according to their effect on Pareto⁴ optimality, which embodies the idea of interaction among water users.

⁴For a comprehensive discussion of the conditions of Pareto optimality, see (87, pp. 148-188).

Demands and Requirements

In discussions of non-market allocation of water rights, it is important to distinguish between demands and requirements for water. The distinction between these two terms as used in this study can be illustrated by a discussion of the concept of water resource demand.⁵ Demand for a resource is of two types, direct and indirect. For uses in which water is a factor input to be transformed into some product, demand is indirect. For such uses as drinking or bathing, water, or the utility which it possesses, is directly consumed; for these uses, demand is direct. Demand of both types is expressed for units of water of a particular quality at a particular time and location.

Direct and indirect demand are both based upon physical relationships. Direct demand by a water user is based upon the relationship between that individual's consumption of alternative amounts of water and the utility which he derives in consumption. This relationship between utility and consumption is expressed by the concept of the utility function. Indirect demand by a firm for water as a factor input is based upon the firm's production function, a technological relationship describing the transformation of a set of factor inputs into some product.

Demand for water, however, is dependent upon more than the physical relationships described above. The price of the water resource is an important component of demand, for in their purchases of water, direct demanders are constrained by a finite income, while indirect demanders are constrained by a finite revenue from the sale of the product of which water is a part. Thus, if water has a market price, the amount users are able to buy depends upon the level of market price and the amount of money available for the purchase of water.

Another important component of demand is the set of prices of other goods, particularly those which are either complements or substitutes for water as a commodity or factor. The amount of water

⁵General discussion of the concepts of demand can be found in (36, pp. 26-42).

which a user is willing to buy varies directly with the prices of substitute goods and inversely with the prices of complementary goods (36, pp. 54-60).

In summary, demand for water is initially derived from physical relationships. Direct demand is derived from the consumer's utility function, indirect demand from the firm's production function. In addition, demand for water is dependent upon the price of water, the prices of other goods which may complement or be substituted for water, and consumer's income or firm's revenue.

In this study, the term "requirements" is used to refer to demand in situations where there is no market price for water. The term is used in this way for two reasons. First, where water has no price, if income or revenue and the prices of other goods are held constant the requirement for water derives solely from the consumer's utility function or the firm's production function. This relationship is physical, not economic; to label it demand would be imprecise and misleading. Second, in situations where water supply is insufficient to satisfy all requirements and where water has no market price, the requirements of alternative uses do not reflect the opportunity cost of water. Water has an opportunity cost if allocation of water to one use requires that production be foregone in other uses (36, p. 164), as is true in situations of insufficient supply.

In situations where market allocation of water rights is prohibited or restricted by a legal system, the concept of demand is of limited usefulness for the reasons cited in the above discussion. In addition, the applicability of a microeconomic industry or market analysis to water allocation is limited by at least the following factors:

- a) many decentralized users, such as farms, industry, and non-profit water organizations, are self-supplied (18, p. 200; 20, p. 3). In 1950, 99 per cent of agricultural irrigation and 97 per cent of industrial use were self-supplied (18, p. 200). Allocation decisions in these cases are internal, and not expressed in the market place.

b) As a commodity or factor, water is not homogeneous; for each demand, differentiated by quality, time, and location requirements, a "market" could exist. Thus, there would be no reason to expect a single price for water.

c) Forms of ownership of rights to use of water are diverse.⁶ Among the various legal and administrative systems of water allocation in the United States, and within each system, a variety of restrictions have been placed on the free use and transfer of water. Without freedom to transfer commensurable rights to use a product, traditional market analysis is crippled.

d) Forms of payment are also diverse, and possibly are not based on a concept of market price (10, p. 37; 18, p. 198; 74, p. 2); ad valorem taxes have been the most popular mode of payment (10, p. 38).

For these reasons, it appears that the problems which need to be considered are more those of organization and management of self-supplying firms than of a traditionally defined industry (18, p. 201). However, even in their limited capacity, market concepts will prove useful in analysis of water allocation problems, since competition for water could develop among self-supplying firms.

Theoretic Conditions for Optimum Resource Use

It is not unreasonable to assume that the appropriative doctrine, the riparian doctrine, and Iowa's permit system (all to be discussed in the next chapter) were designed to be optimizing institutional mechanisms (106, p. 6). In this section, theoretic necessary conditions for optimum water resource use are derived and, under the assumption above, are applied to each of the three allocation mechanisms to show how allocation under each system can differ from the optimum. Necessary conditions for optimum resource use can easily be shown using a

⁶A summary description of these forms of ownership is contained in a later section discussing water law.

classical optimization method, the technique of Lagrange multipliers. The general maximization case of this technique, utilizing inequality constraints, treats problems of the form⁷

$$\begin{aligned} 1) \quad & \max Z = f(x), \text{ satisfying} \\ & g_i(x) \leq b_i \quad i = 1, \dots, u, \\ 2) \quad & g_i(x) \geq b_i \quad i = u+1, \dots, v, \\ & g_i(x) = b_i \quad i = v+1, \dots, m, \end{aligned}$$

where X is an n -component vector. Adding slack and surplus variables, the original constraints are equivalent to

$$\begin{aligned} & g_i(x) + x_{si} = b_i \quad i = 1, \dots, u, \\ 3) \quad & g_i(x) - x_{si} = b_i \quad i = u+1, \dots, v, \\ & g_i(x) = b_i \quad i = v+1, \dots, m. \end{aligned}$$

The corresponding Lagrangian function is

$$\begin{aligned} 4) \quad F(x, x_s, \lambda) = & f(x) + \sum_{i=1}^u \lambda_i [b_i - x_{si} - g_i(x)] + \\ & \sum_{i=u+1}^v \lambda_i [b_i + x_{si} - g_i(x)] + \sum_{i=v+1}^m \lambda_i [b_i - g_i(x)]. \end{aligned}$$

In order for $f(x)$ to take on a maximum at x_0 , the following necessary conditions must hold:

$$\begin{aligned} 5) \quad \frac{\partial F}{\partial x_j} = \frac{\partial f(x_0)}{\partial x_j} - \sum_{i=1}^m \lambda_i \frac{\partial g_i(x_0)}{\partial x_j} &= 0 \quad j = 1, \dots, n; \\ \frac{\partial F}{\partial x_{si}} = -\lambda_i &= 0 \quad i = 1, \dots, u; \\ \frac{\partial F}{\partial x_{si}} = \lambda_i &= 0 \quad i = u+1, \dots, v; \\ \frac{\partial F}{\partial \lambda_i} = b_i - x_{si} - g_i(x) &= 0 \quad i = 1, \dots, u; \\ \frac{\partial F}{\partial \lambda_i} = b_i + x_{si} - g_i(x) &= 0 \quad i = u+1, \dots, v; \\ \frac{\partial F}{\partial \lambda_i} = b_i - g_i(x) &= 0 \quad i = v+1, \dots, m. \end{aligned}$$

⁷Equations (1) through (5) are taken from the excellent discussion of constrained optimization in (41, pp. 69-71).

Sufficient conditions for $f(x)$ to be a maximum at x_0 are satisfied if the second total differential of $f(x_0)$ is negative (46, p. 272, note 1), a condition which is fulfilled if $f(x)$ is concave. For this analysis, it will be assumed either that second-order conditions are fulfilled, or that $f(x)$ is concave, at least in the range relevant to analysis.

Having derived the desired necessary conditions in the general case alone, an objective function and constraint equations can be specified, relevant to water resource use, and particular necessary conditions derived for optimum resource use. The following assumptions are made in order to simplify and restrict the analysis to the considerations of this study:

- a) there are n perfectly competitive firms using water in amounts x_j , $j = 1, \dots, n$, from a homogeneous supply fixed at \bar{x} ;⁸
- b) each firm's production function, in truncated form,⁹ can be written as $Q_j = f_j(x_j)$, where Q_j is the output of the j th firm's product;
- c) resource use decisions are made under an aggregate objective function, expressed in terms of total output of the n firms using water.

If the objective is to maximize total value of production, expressed as

$$6) \max Z = \sum_{j=1}^n P_j Q_j = \sum_{j=1}^n P_j f_j(x_j),^{10}$$

⁸Such a group of firms corresponds to a "watershed firm," a concept elaborated and utilized by Timmons. See (97).

⁹In the truncated form of the production function, all other inputs are assumed to be held constant. The necessary conditions for optimum resource use with respect to any single input are identical whether other inputs are constant or variable.

¹⁰The objective function can take this form only if output price is constant regardless of the level of output. This condition is fulfilled in the assumption of perfect competition.

where P_j is the price of the j th product, subject to the constraint

$$7) \sum_{j=1}^n x_j \leq \bar{x},$$

the necessary conditions for maximum Z at x_j^* ($j = 1, \dots, n$), after adding a slack variable to the constraint, are

$$8) \frac{\partial F(x^*, x_s^*, \lambda^*)}{\partial x_j} = P_j \frac{\partial f_j(x_j^*)}{\partial x_j} - \lambda^* = 0 \quad j = 1, \dots, n;$$

$$9) \frac{\partial F(x^*, x_s^*, \lambda^*)}{\partial x_s} = -\lambda^* = 0;$$

$$10) \frac{\partial F(x^*, x_s^*, \lambda^*)}{\partial \lambda} = \sum_{j=1}^n x_j + x_s - \bar{x} = 0.$$

Three important relationships are contained in these necessary conditions. First, from equation 8, it can be seen that

$$11) P_j \frac{\partial f_j(x_j^*)}{\partial x_j} = P_i \frac{\partial f_i(x_i^*)}{\partial x_i} \quad i, j = 1, \dots, n.$$

$\frac{\partial f_j(x_j^*)}{\partial x_j}$ is the marginal physical product of x in the production of Q_j ,

and $P_j \frac{\partial f_j(x_j^*)}{\partial x_j}$ represents the value of marginal product (vmp) of x in

the production of Q_j . Equation 11 defines the critical condition that, for optimum resource use, the vmp of the resource must be equal in all its uses.

Second, it can be shown that the following relationship holds:

$$12) \lambda^* = \frac{\partial Z^*}{\partial \bar{x}} \quad (37, \text{ p. } 73).$$

From this relationship, λ^* can be defined as the shadow price of water and is equal to the value of an additional unit of water. It is apparent from equation 8 that the unit value of water must be equal in all its uses. The third relationship follows from equation 9, and is

$$13) x_s^* \lambda^* = 0 \quad (41, \text{ p. } 72),$$

which means simply that if $x_s^* > 0$, $\lambda^* = 0$; if $x_s^* = 0$, $\lambda^* \neq 0$. x_s is a slack variable, and is positive only if the supply of water, \bar{x} , is not fully utilized. Therefore, from equation 13, if water is abundant and

some of the supply remains unused, then the shadow price, or unit value, of water is zero.¹¹

Possible Divergences from the Theoretic Optimum

Assuming that the second-order conditions noted above are fulfilled, allocation of water such that vmp is equal in all uses implies that the value of the objective function for the watershed firm is a maximum. Whether this maximum is also optimum with respect to larger planning units, such as the basin, state, or nation, depends on the equality of cost and benefit to the watershed firm (marginal private cost and benefit) with marginal cost and benefit to the larger planning area (marginal social cost and benefit). External economies or diseconomies (5, pp. 368-371; 36, pp. 391-394) may be present which cause marginal private cost and benefit and marginal social cost and benefit to diverge.

External economies and diseconomies are of two types: production and consumption (5, p. 369). Water pollution is a pertinent example of an external production diseconomy, in that pollution of water at one point on a stream incurs cost to any downstream user who must resort to substitute supplies or treat the water prior to his own use. Interaction between the production function of the downstream user and the upstream polluter implies that the downstream user must expend more inputs to produce the same output possible with unpolluted water. In this case, the marginal private cost of the polluting firm is less than its marginal social cost, if the pollution it causes is considered to be a negative portion of its output (87, p. 187).

An external production economy, conversely, occurs when marginal social benefit exceeds marginal private benefit (5, p. 369). This type of externality would occur if an upstream water user applying

¹¹Under the same assumptions employed above, plus the assumption that each water user is a profit maximizer, it can be shown that each producer will employ an input until its vmp is equal to the input price (36, p. 309). Therefore, at the optimum, decentralized resource allocation and allocation under an aggregate objective function are theoretically the same, and λ can be considered the market clearing price.

water to a cooling process discharged heated water into a stream from which a downstream user requiring heated water could withdraw. The increase in temperature from the upstream user's operation allows the downstream firm to expend fewer inputs in producing its output, making marginal social benefit greater than marginal private benefit.

External economies and diseconomies which arise from one individual's consumption are defined in much the same way as production externalities. The major difference is that any divergence between marginal social values and marginal private values arises as the result of consumption rather than production.

An important point with respect to external effects is made by Pigou (83, p. 183). He states that the existence of an externality is contingent not only upon the existence of interdependence between two or more producers, but also upon the lack of compensation for benefits or injuries resulting from this interdependence. This point qualifies the statement that external effects tend to cause misallocation of resources (5, p. 371). However, if costs and benefits can be measured, compensation is a remedy which can be applied to enhance optimum resource allocation.

Having established in this chapter a background of concept and theory, Chapter Three will discuss the allocative mechanisms under which water resources are controlled in the United States. Following this discussion, the allocative systems will be examined from the theoretic point of view established in this chapter.

CHAPTER THREE: LEGAL SYSTEMS OF WATER RESOURCE ALLOCATION

In the United States, most of the productive resources and factor inputs of the economy are allocated by market processes. Water, however, is one resource which has traditionally not been distributed by a market mechanism. Instead, a number of complex legal allocation systems have developed in the United States, evolving from customs, legislation, and court cases in each state (51, p. 868).

Possibly the most important contributing factor in the growth of non-market allocation systems is the fact that water is a migratory resource; the flow of water does not respond to the delineation of property boundaries and political units. According to Harl (42, pp. 19-20), property rights in such a fugitive resource are generally less certain and unequivocal than rights in other property. Two factors which create uncertainty in a water right are a) the possibility that the water to which the right pertains will not be available, due to variability in physical supply; and b) the possibility that the water may be consumed by an upstream user. Because of the inherent uncertainty in a water right, the quantity of water which the right holder will have available for use is indeterminate. This quantity could vary from zero to the full amount defined by the right, depending upon hydrologic conditions and the exercise of any prior rights.

In turn, uncertainty of quantity leads to a similar uncertainty about price, since the unit price of a commodity generally varies with the quantity demanded or supplied. Establishment of a market in water rights could be inhibited by the lack of a clear price for water.

An additional obstacle to the establishment of a market for water is found in the fact that the use of a unit of water may cause changes in the hydrologic system where the water was used and in the system from which it was drawn if the two systems are not the same. Examples of such concomitant changes are a change in water quality downstream from the point of use or a change in the conditions in an aquifer due to heavy withdrawal at one point. Such external effects as these may have

substantial impact on parties who would not ordinarily be represented in any market transaction from which the external effect results. The obvious avenue for redress for such damages resulting from a transfer of water rights would be the courts. In this way, the establishment of legal precedents and principles of water allocation would be expected to accompany competition for water rights, if external effects resulting from transfers of rights are significant.

As a result of the unique character of water, several general legal systems of water allocation have developed in the United States, each adapted to the peculiarities of the region where it is practiced. In general, surface water allocation in the thirty-one eastern states is regulated under the riparian doctrine (106, p. 5), while the seventeen western states have developed a doctrine of appropriative rights (106, p. 5). In several states, administrative allocation systems, such as Iowa's water permit system, have been proposed or enacted (106, p. 5).

In order to provide a framework for evaluating the degree to which the appropriative doctrine, the riparian doctrine, and Iowa's water permit system recognize the necessary conditions for optimum resource use, each legal system will be examined in the role of an optimizing mechanism. Adoption of this point of view provides specific direction to the examination of each legal system, for a viable optimizing mechanism necessarily possesses the following characteristics:

- a) a clear, identifiable objective;
- b) provision of a mechanism which can measure and compare selected parameters for decision making; and
- c) identification of a set of measurable parameters upon which alternative courses of action can be compared.

The following discussion identifies and examines these characteristics in each of the three legal allocation systems listed above.

The Doctrine of Prior Appropriation

The so-called appropriative doctrine is based on Mexican and Spanish rights, developed in Utah by Mormon settlers and in California by miners after the discovery of gold in that state in 1848 (1, p. 104; 51, p. 867). The doctrine is followed chiefly in the seventeen states west of the Missouri River and in Alaska (1, p. 104; 42, p. 24). These states are characterized by broad similarities in their water allocation systems (51, p. 873): the water resources of the state are under public control by statute (106, pp. 19-20), with management placed in the hands of state officials, and statutory or administrative declaration is made concerning waste and beneficial use of water (51, p. 873).

An appropriative right is based on the "law of the first taker" (62, p. 28), the principle which governed mining rights during the pioneer days. Indeed, the first beneficial uses of water noted in this doctrine were in placer mining and gold refining (102, p. 279). The right has also been called "first in time, first in right" (1, p. 104). Whoever first took possession of water and put it to a beneficial use retains the right to use that water. It is upon this claim in history that an appropriative right is based. The right is defined in priority, quantity, period of use, and point of diversion (1, p. 105; 17, p. 256; 42, p. 27; 48, p. 22; 62, p. 28).

There are two elements of an appropriation (1, pp. 104-105). First, there must be an actual diversion of water, with the intent to apply it to some beneficial use. Second, the water must be applied to that use or some other beneficial use. The concept of beneficial use, as expressed in these elements, is central to the appropriative doctrine (102, p. 277), as evidenced by the maxim that "beneficial use is the basis, the measure and the limit of the right to use water...." (102, p. 277).

A few states list specific uses as beneficial, including domestic, municipal, stock watering, irrigation, manufacturing, and mining (1, p. 106; 42, p. 24; 102, p. 227). States have not, however, provided general definitions of beneficial use (1, p. 106; 102, p. 277), and some opinions hold that the question must be decided separately in each case

(1, p. 106; 102, p. 277). In all states, a use must not only be beneficial to the user, but must also be reasonable with respect to other uses and future demands for water (102, p. 284). The reasonable use criterion is apparently intended to insure that a privately beneficial use is not also socially detrimental. Reasonable use is defined in terms of relative economy and waste in intended uses (102, p. 284).

Centralized state control over appropriation has developed in almost all the western states (1, p. 105), and orders of preference among uses have evolved (43, p. 26; 102, p. 285). There is little general agreement among states on order of preference, except that man's survival needs, including water for drinking, bathing, and sanitation, come first, and navigation and water-based transportation are last (102, p. 286). Other uses, such as irrigation, mining, and manufacturing, vie for the middle ground of priority (102, p. 286). Some states require state officials to grant priorities among appropriations according to statutory preference ranks, while other states allow state officials to exercise discretion in granting priorities (102, p. 285). In both cases, preferences are based on relative benefit (102, p. 285). Under these preference rankings, water may be reallocated in one direction only along the preference scale, from less preferred uses to more preferred uses (102, p. 285). Rights may also be lost by abandonment, forfeiture, or action against an adverse use (1, p. 108).

In general, apart from a transfer of ownership of the land on which the right is based, transfer of an appropriative water right to another type of use or point of diversion is difficult. In some states,¹ a water right may not be transferred from either the original use or the original point of use (106, p. 69). In other states, the party desiring the transfer must prove that no damage will occur to other users of the water supply affected by the transfer (44, p. 22). To prevent loss of return

¹Notable examples are Arizona and Wyoming (44, p.22).

flow by transfer or rights, the general rule has been established that only the amount of consumptive use may be transferred (44, p. 22).

The Riparian Doctrine

In the thirty-one states east of the Missouri, and to a degree in some western states, a system of riparian water rights has developed, from roots in English common law (1, pp. 99-100; 51, p. 867). Central to the riparian doctrine is the concept of riparian land as that land which borders the course of a stream or underground watercourse (1, p. 100; 42, p. 23; 48, p. 6; 62, p. 26). The right of a riparian owner, which exists as a consequence of ownership of riparian land, gives him the use of water flowing in a watercourse which abuts his land, providing the water is returned, unimpaired in quantity and quality, except for impairment inseparable from reasonable use (1, p. 100; 42, pp. 22-23; 48, p. 6). The right is a modification of two legal concepts (42, p. 21; 102, p. 273). The first, the natural flow theory, grants a riparian owner the right to a "...natural condition of flow." (42, p. 21). The second concept, that of reasonable use, was imposed upon the earlier theory in order to allow uses which are consumptive (42, p. 21).

A riparian right is based on the nature of the source and the nature of the use (48, p. 4). Sources are defined as 1) diffused surface water, 2) surface watercourses, 3) underground watercourses, and 4) underground percolating water (48, p.4). Riparian owners may use these types of waters, except as limited by the rights of other riparians and restrictions based on certain categories of use (48, p. 4).

Uses are divided into two major categories, natural and artificial (102, pp. 273-274). Upstream riparian users may, if necessary, consume all the water in a surface watercourse for natural uses (42, p. 22; 48, p. 4; 102, p. 274), which include domestic use and watering an ordinary number of livestock (42, p. 22; 48, p. 4; 102, p. 274). Artificial uses, such as irrigation, industrial use, and municipal water systems (48, p. 8; 102, p. 274), are subordinate to natural uses (48, p. 8). Rights of all riparian owners with respect to artificial uses are coequal (1, p. 101; 19,

p. 877; 48, p. 7; 102, p. 274), and allocation decisions are based on relative reasonableness (48, p. 7). Determinations must be made in each case of how reasonable an intended artificial use will be (1, p. 101; 42, p. 22; 48, p. 9; 102, p. 283). No rules of reasonable use have been laid down by courts because what is reasonable in light of the equal rights of other riparians changes as physical, demographic and economic conditions change (1, p. 101; 102, p. 283).

In general, riparian rights are restricted to lands contiguous to the watercourse (1, p. 101; 42, p. 23; 48, p. 9) and contained in the watershed (1, p. 101; 48, p. 9). There are, however, exceptions to both these principles. In some cases, rights to use water have been transferred from riparian to non-riparian lands. In a number of these cases, the riparian land and the non-riparian land were held by different owners. The remainder of the transfers were from riparian land to non-riparian land held by the same owner (66, pp. 55-56; 106, p. 65). In Ohio, a city which is riparian is entitled to take water for use by its residents, even though they may be located outside the watershed (106, p. 16).

As a general rule, riparian rights are not lost by nonuse (1, p. 103), since these rights are not based upon use, but upon ownership of a particular type of land. Only adverse use or eminent domain proceedings can destroy a riparian right (1, p. 103).

Doctrines Governing Underground Water Supplies

The two underground water sources differentiated in law are underground watercourses and percolating groundwater (48, p. 4; 49, pp. 232-233; 52, p. 293). This distinction has been criticized by hydrologists as inapplicable, but continues to be observed in law (49, p. 233; 52, p. 294). Underground watercourses are governed by the legal system operating for surface watercourses in the area (49, p. 233; 52, p. 244). Percolating groundwater, which is water underground and not moving in a reasonably defined course (48, p. 9; 49, p. 233; 52, p. 274), is controlled by one of the following three doctrines. One, the

English rule, or the common-law doctrine, grants absolute ownership of the underground water to the overlying landowner (49, p. 233; 52, p. 294). The freedom of use associated with this doctrine led some jurisdictions to apply another doctrine, the American rule of reasonable use (48, p. 9; 52, p. 294), which recognizes the right of the overlying landowner but restricts his use of percolating groundwater with respect to waste or transportation to a distant use (48, p. 9; 49, p. 234; 52, p. 295). The third doctrine controlling percolating groundwater is that of "correlative rights" (49, p. 234; 52, p. 295), found chiefly in California. Under this doctrine, the rights of overlying owners are coequal for reasonable use; any surplus beyond reasonable use by these landowners may be appropriated for use on non-overlying lands, and in shortage situations the available supply is apportioned among overlying landowners in proportion to their reasonable needs (49, p. 234; 52, p. 295).

It appears that the riparian and prior appropriation doctrines, although legally dissimilar, have similar objectives. Each system seeks to provide a mechanism for orderly allocation of water rights, according to the parameters of reasonable and beneficial use. The decision-making mechanism in both doctrines is one of adjudication guided by legal principles and precedents. However, in both the appropriative and riparian doctrines, these principles may act to restrain transfer of water to more beneficial uses. The economic significance of these restraints will be examined in a later section of this chapter.

Administrative Allocation: Iowa's Water Permit System

Several of the states under the riparian doctrine have proposed or enacted programs which modify the riparian doctrine (18, p. 252; 33, p. 237). In some instances, as riparian concepts are modified they are replaced with appropriative concepts (33, p. 252). In other instances, the trend has been toward grants or permits, administered by a central

state authority (33, p. 252; 42, p. 27). Of these modifications, the one most important to this study is that which has been made in Iowa. The Iowa water permit system is similar to earlier proposals in other states (48, pp. 24-25), notably Wisconsin, Minnesota, and North Carolina. This study focuses on the Iowa system. Where significant differences exist between the Iowa system and proposals in other states, these differences are noted.

Iowa's permit system enacted in 1957, is defined by statute (53). Administrative decisions have been made in implementing the permit system which have become, operationally, a part of the mechanism,³ but the statute which created the permit system nonetheless constitutes its basic framework. For this reason, the analysis in this section will be based mainly on an examination of the provisions in the statute.

Objective of the water permit system

It is difficult to specify an objective for the permit system as an allocative mechanism. The following appears in the statute which creates the Iowa water permit system:

"It is hereby declared that the general welfare of the people of the state of Iowa requires that the water resources of the state be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use, or unreasonable methods of use, of water be prevented..."
(53, sect. 455A.2)

The statement specifies that each use be reasonable, beneficial, and not wasteful, but what constitutes the optimum degree of each is open to some difference of interpretation. The requirement that Iowa's water resources "... be put to beneficial use to the fullest extent of which they are capable..." (53, sect. 455A.2) could be interpreted in at least two distinct ways. First, the statement could mean that a maximum amount of water should be allocated to those uses which can be classified as beneficial. Alternatively, the statement could mean that the state's

³An excellent review of permit system operations between 1957 and 1967 can be found in Hines (48).

water resources should be allocated among all uses such that total benefit is a maximum. The two interpretations imply different conditions from the point of view of economic theory. Two similar interpretations could follow from the statement that declares control of the state's water resources to be in the state, in order "...to effectuate full utilization..." (53, sect. 455A.2), which could imply either use of a maximum amount of water, or allocation of the state's water resources such that maximum benefit per unit is achieved. Furthermore, there is no indication in the objective statement of whether the general welfare of the people of Iowa is to be maintained, increased, or maximized with respect to water use.

A set of definitions is contained in the statute (53, sect. 455A.1). Most of the terms with which the statute is constructed are defined, with the immediate exception of the terms "general welfare" and "reasonable use." Reference to the following two definitions assists in making the policy statement more specific:

"'Beneficial use' means the application of water to a useful purpose that inures to the benefit of the water user and subject to his dominion and control but does not include the waste or pollution of water;" (53, sect. 455A.1)

"'Waste' means (a) permitting ground water or surface water to flow, taking it or using it in any manner so that it is not put to its full beneficial use, (b) transporting ground water from its place of use in such a manner that there is an excessive loss in transit, (c) permitting or causing the pollution of a water bearing strata through any act which will cause salt water, highly mineralized water, or otherwise contaminated water to enter it;" (53, sect. 455A.1)

Imposing these definitions on the statute's stated goal (53, sect. 455A.2) facilitates a slightly more precise paraphrase of the statute's objective: the general welfare of the people of Iowa requires that the state's water resources be put to fully beneficial uses to the fullest extent of which they are capable; these uses should be reasonable and cause no pollution or excessive loss in transit of the state's water resources. This restatement of the statute's objective still does not indicate whether maximization is desirable, or which variable or combination of the three variables (general welfare, benefit, and

quantity allocated) is to be considered the goal of the system. As a method of selecting among alternative water allocations, Iowa's water permit system has no adequately specific objective statement.

The water permit system's administrative mechanism

To implement its stated policy, the statute creates and vests authority in the Iowa Natural Resources Council (53, sect. 455A.2-.3). Composed of nine members, the Council is charged to "...establish a ...comprehensive state-wide program for the conservation, development and use of the water resources of the state" (53, sect. 455A.17). The statute declares the water occurring naturally within the state to be public wealth of the people of Iowa (53, sect. 455A.2), and gives the Iowa Natural Resources Council jurisdiction over public and private waters in the state. The Council is directed to study and survey the state's water resources and their relation to problems in agriculture, industry, conservation, health, and stream pollution. Recommendations are to be made for further development, utilization, protection, and preservation of these water resources.

The statute provides for the selection of a water commissioner and one or more deputy commissioners, who serve at the Council's pleasure. The commissioner tries fact questions in processing permit applications, and conducts hearings on each application (53, sect. 455A.9).

Although jurisdiction of the Council is broad, not all uses are to be regulated. The following definitions partially limit the scope of regulation:

"'Depleting use' means the storage, diversion, conveyance, or use of any supply of water which might impair rights of lower or surrounding users, or might impair the natural resources of the state or might injure the public welfare if not controlled;" (53, sect. 455A.1)

"'Regulated use' means any depleting use except a use specifically designated as a nonregulated use;"⁴

⁴(53, sect. 455A.1). Only irrigation uses are regulated under the permit systems of Wisconsin and North Carolina (33, pp. 239, 244).

"'Nonregulated use' means the use of water for ordinary household purposes, use of water for poultry, livestock and domestic animals, any beneficial use of surface flow from rivers bordering the state of Iowa, or use of ground water on islands or former islands situated in such rivers, existing beneficial uses of water within the territorial boundaries of municipal corporations on May 16, 1957, except that industrial users of water, having their own water supply, within the territorial boundaries of municipal corporations, shall be regulated when such water use exceeds three per cent more than the highest per day beneficial use prior to May 16, 1957, and any other beneficial use of water by any person of less than five thousand gallons per day;" (53, sect. 455A.1)

A permit is required for all regulated uses as defined above. In addition, diversions of water from the surface to underground which existed prior to May 16, 1957 are exempt if they cause no pollution, but such diversions begun after that date must have a permit.⁵

Thus, a wide range of regulation is established, and the permit instrument is created to control allocation to uses throughout the range. The permit is the council's written authorization for use, limited "...as to quantity, time, place, and rate of diversion, storage or withdrawal..." (53, sect. 455A.1). The procedure for securing a permit is initiated by written application to the Council. The application, accompanied by a fifteen dollar fee, describes the intended beneficial use (53, sect. 455A.19).

Upon receipt of an application, the Council investigates the effect of the intended use upon other interests in the area (53, sect. 455A.18). and the water commissioner sets the date and location of a hearing (53, sect. 455A.19). A notice of the hearing, describing the intended use, must be published in the county of the proposed use prior to the hearing date. Copies of the notice are sent to officials in other interested state agencies, including the Conservation Commission, the Public Health Service, the Iowa Geological Survey, and the Iowa Development Commission (53, sect. 455A.19).

⁵(53, sect. 455A.25). In Minnesota, no use originating within a municipality requires a permit (33, p. 241).

At the hearing, interested parties may appear and present evidence (53, sect. 455A.19). On the basis of due investigation and testimony, the commissioner determines whether the intended use will be detrimental to either the public interest or the interest of any property owners with prior or superior rights. If not, a permit is granted (53, sect. 455A.20). Aggrieved parties may appeal the commissioner's decision to the Council within thirty days, and be granted a hearing before the director (53, sect. 455A.19).

Definition of a set of decision making parameters

The objective statement discussed earlier indicates that a use should be beneficial, reasonable, and not wasteful (53, sect. 455A.2). A beneficial use could be defined as one in which marginal benefit to the user is positive, but the statute specifies no measurable variable to represent this benefit. Waste is said to occur if any use is less than fully beneficial, if there is excessive loss in transporting groundwater, or if pollution of any groundwater is allowed through the introduction of any contaminated water into the supply (53, sect. 455A.1). Beyond the reference in this definition, what constitutes pollution is not specified, but water quality standards have been formulated under separate authority (55).

It is possible to classify uses as beneficial or not, based on the qualifications of waste and pollution. Deciding among alternative beneficial uses, however, requires that the alternatives be ranked. The statute provides that applications are to receive consideration based on date of application, and that certain uses existing prior to May 16, 1957 will be granted priority according to date of use (53, sect. 455A.21). In addition, the statute states that if no detriment to public or private interest can be found in an intended use, the commissioner "...shall grant a permit..." (53, sect. 455A.20) for that use. If not all uses can be satisfied, these standards and priorities may not aid in achieving the statute's objective, for they do not provide assistance in measuring relative benefit.

The importance of beneficial use is reinforced by statements granting the Council authority to issue permits to these uses (53, sect. 455A.22) and declaring that in the disposition of applications, the standard is to be beneficial use (53, sect. 455A.21). Relative benefit would then seem to be the critical factor in ranking alternative allocations, but since benefit is not defined so as to allow measurement, comparison among uses on this basis is not possible unless administrative judgments are made. (The costs of waste and pollution are measurable in theory, but since any use for which these costs are positive is not permitted, measurement is irrelevant.)

On the basis of the preceding discussion, it is apparent that the statute is unclear or incomplete on two vital points. First, its objective is not stated in unique, measurable terms. Second, the criterion of benefit from use, on which comparison and allocation among competing uses would be made, is not defined in measurable terms. Therefore, comparisons among uses are not possible. In a situation of inadequate supply, the permit system's ability to achieve optimum allocation of water resources could be increased if its objective were stated so that the performance of the system could be measured, and if a more viable criterion were given by which alternative allocations could be ranked.

Thus far, the analysis has concentrated on an assessment of the permit system's ability to achieve optimum allocation of the state's water resources given static conditions of requirement and supply. Another important facet of the system's optimizing ability is its responsiveness to changing physical, economic, and demographic conditions. To assist in examining this aspect of the permit system, a set of terms suggested by Ciriacy-Wantrup (18) will be used. These terms, "rigidity", "protection", and "security", denote nonresponse, while the term "flexibility" denotes responsiveness (18, p. 252). With respect to the permit system, rigidity refers to the lack of permit mobility among alternative uses. Protection refers to the assurance given a permit holder by the permit system that his water right is

protected against unlawful acts by others; this is a legal topic, beyond the scope of this analysis. Security can be thought of as protection against tenure uncertainty, which is the possibility that a right may be lost to superior rightholders, or physical uncertainty, which is the possibility of loss of right due to flow variability.

One component of the rigidity which the Iowa permit system possesses could decrease absolutely over time. This rigidity is found in certain rights which were to be preserved after the enactment of the statute (53, sect. 455A.23). As these prior uses are discontinued, more flexible allocations may take their place. However, the requirement that a low flow be protected in all watercourses (53, sect. 455A.22) represents a component of rigidity which could increase in relative importance in a time of general shortage. The uses for which the minimum flow is protected are the nonregulated uses, which are assured a top priority as long as there is flow in the stream. If flow decreases, regulated uses may be required to cease, while nonregulated uses are assured an increasing share of available flow.

Security is provided in the statute against both tenure uncertainty and physical uncertainty. Some protection against the physical uncertainty of variable flow is accorded to nonregulated uses by established low flow standards. Protection of this flow requires that consumptive uses cease when they endanger the protected flow, while nonconsumptive withdrawals may continue as long as flow is adequate. Thus, regulated consumptive uses are least secure, regulated nonconsumptive uses more secure, and nonregulated uses most secure from physical uncertainty.

Protection against tenure uncertainty is practically complete for nonregulated uses, as long as the minimum flow requirement stands. For permitted uses, this protection is less certain, as there are several ways a permit may be revoked or suspended. Violation of the terms of the permit or nonuse of the allocated water allow the water commissioner to revoke the permit (53, sect. 455A.20). In cases of emergency, the

commissioner may suspend the permit for no more than thirty days.⁶ Otherwise, permission of the user is required before a permit may be revoked (53, sect. 455A.20), and the permit is secure for its duration, at most ten years (53, sect. 455A.20).

Flexibility, reflecting responsiveness in the permit system to changing conditions, is limited. Partially because of the security aspects discussed above, allocation may be inflexible for the duration of the permits granted. Greater inflexibility arises from the stipulation that permits can be transferred only if ownership of the property on which the water is used is transferred (53, sect. 455A.30). If changes in demand or supply make current allocations suboptimal, to move toward optimization requires not only the ability to change existing allocations, but the ability to identify those uses which would increase total benefit. The Iowa water permit system possesses neither of these abilities.

Economic Interpretations of Legal and Permit System Allocation

Graphical representation of a hypothetical production function

Figure 1a shows the shape of a hypothetical production function for the j th product, embodying the assumption that marginal physical product (mpp), as shown in Figure 1b, first increases and then diminishes as water use increases, if all other inputs are held constant. Such a production function can be divided into three stages as follows (36, pp. 122-123):

Stage I: $\{x \mid 0 \leq x \leq a\}$; point \underline{a} is the point of maximum average physical product;

Stage II: $\{x \mid a < x \leq b\}$; at point \underline{b} , total product is a maximum and $mpp = 0$;

Stage III: $\{x \mid x > b\}$. Beyond \underline{b} , total product declines as additional water is used; $mpp < 0$.

⁶(53, sect. 455A.20). In Minnesota, a permit may be cancelled for any reason for protection of the public interest (33, p. 241).

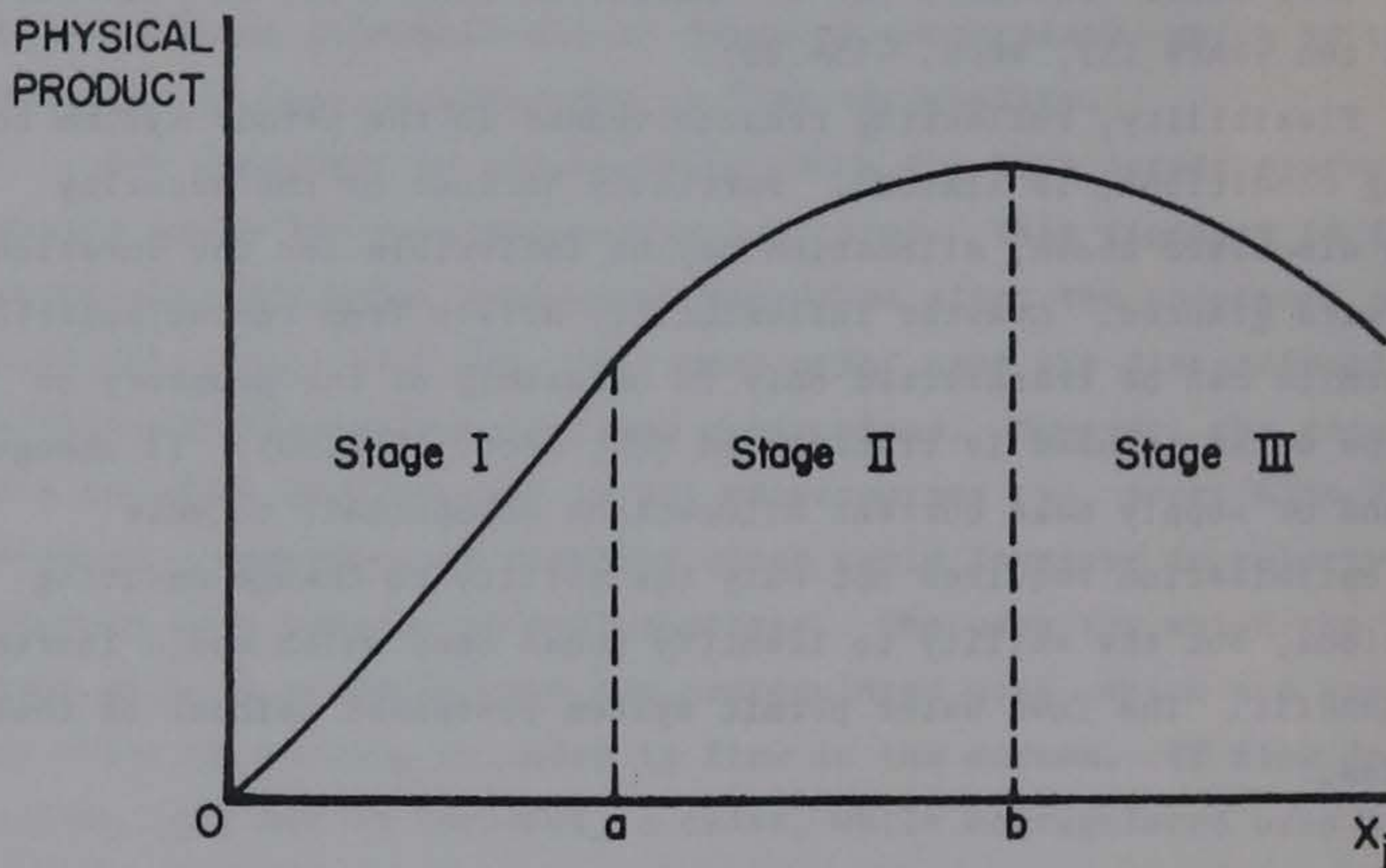


Figure 1a. A Hypothetical Production Function - Total Physical Product

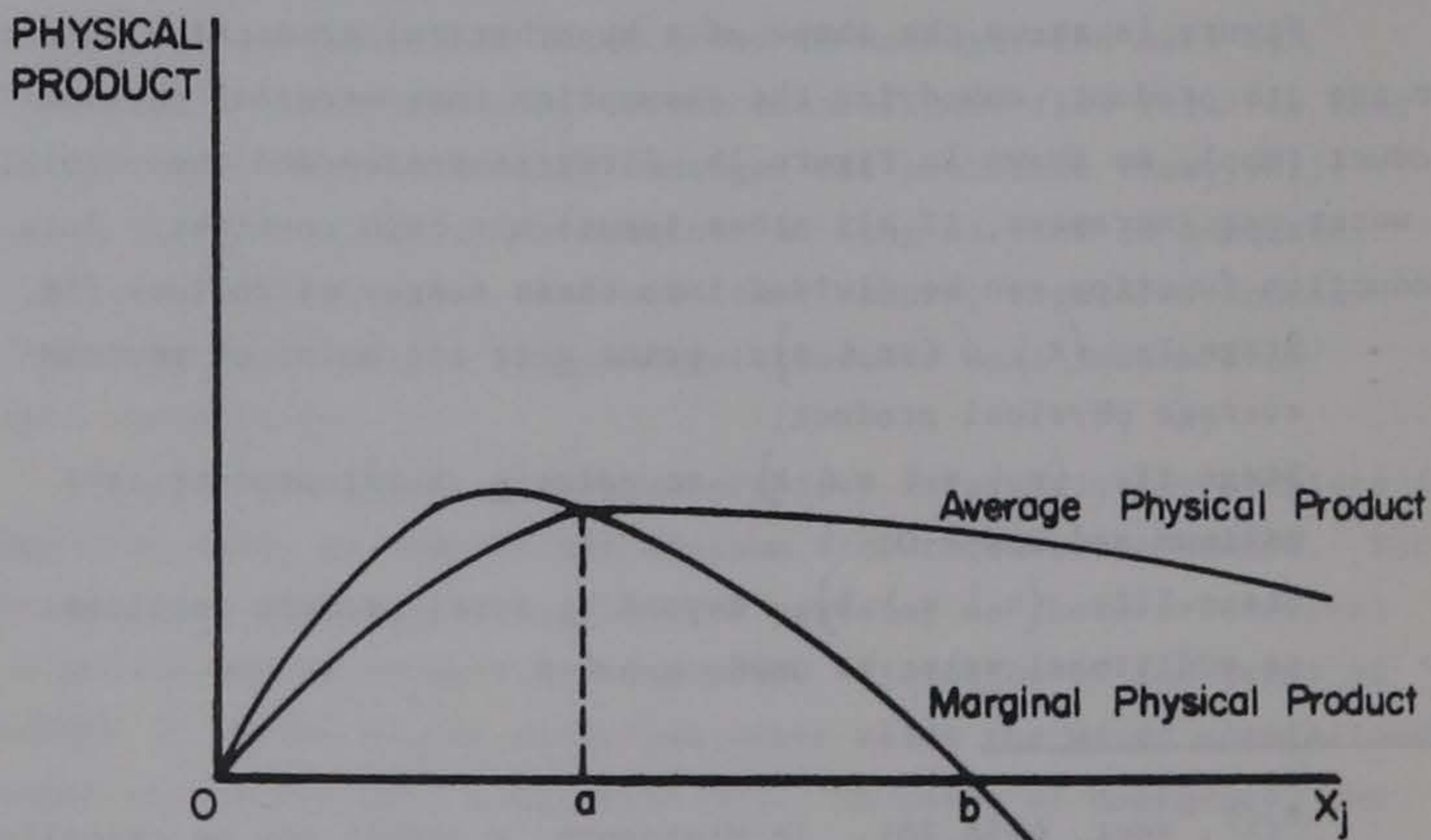


Figure 1b. A Hypothetical Production Function - Average and Marginal Physical Product

It can be shown that no rational producer would continue operating in stage I, where average physical product is increasing.⁷ Instead, he would increase water use beyond point a. A rational producer, in most cases, would also restrict water use to $x \leq b$, for beyond b, water is not only wasted, but total physical product is decreased with every additional unit of water.

Thus, analysis can be restricted to stage II, in which a rational producer would operate, and stage III, where production implies that water is being wasted. From the general necessary conditions for optimum resource use developed in Chapter II, two conclusions are obvious. First, if total water use is less than the available amount, $vmp = \lambda = 0$,⁸ and optimum allocation occurs at b. Second, if total potential water use is greater than or equal to the available amount, $vmp = \lambda > 0$, and optimum allocation occurs between a and b, with the particular allocation depending upon the value of vmp .

Recognition of necessary conditions in centralized allocation systems

In measuring relative worth of water in alternative uses, the appropriative doctrine, the riparian doctrine, and the Iowa permit system all depend upon criteria developed in statutory or case law. For all systems, the criteria are similar. The appropriative doctrine ranks uses according to their relative benefit, contingent upon the

⁷This can be seen intuitively by considering that as use of x is increased from $x = 0$ to $x = a$, the producer experiences increasing returns to x ; in this range, increasing x increases the return to all units of x . It would be logical to continue to increase x until the point $x = a$ is reached. Furthermore, in the interval $0 \leq x < a$, the marginal physical product of any fixed input is negative (36, p. 123).

⁸ $vmp = \text{output price} \times mpp$; under the assumption of perfect competition made in Chapter II, output price is constant regardless of the level of output. Therefore, the vmp curve and the mpp curve are similarly shaped, and are equal to zero at point b.

existence of a preference ranking within the jurisdiction. The riparian doctrine states the priority of natural uses over artificial uses, and maintains that the riparian owner has the right to reasonable use of the flow across his riparian land. In times of scarcity, allocation is made based on relative reasonableness, defined in terms of benefit to the user. The permit system in Iowa requires that a use be beneficial to the user, and as in the riparian and appropriative doctrines, disallows waste.

A use is beneficial to the user if the vmp of water in that use is positive. This fact implies that such a user will be operating in stage II of his production function, as discussed in the previous section, since no rational producer would continue operating in stage I. Water use will also not occur in stage III, since in stage III the use is both nonbeneficial and wasteful.⁹ The only two points, therefore, which the appropriative doctrine, the riparian doctrine, and Iowa's permit system define are those two points where vmp is zero: at zero input use, and at maximum total physical product. No point between these two extremes is defined.

For abundant water supplies, this lack of definition is unimportant, since vmp of abundant water is zero. However, if the supply is scarce, then vmp becomes positive. Optimum allocation of a scarce supply occurs at some point where vmp is positive; none of the three legal allocation systems identifies such a point without judicial or administrative procedure.

Moreover, if vmp is positive, indicating that water supplies have value, allocation of those supplies to applicants under a permit system at a nominal fixed cost per permit suggests a windfall gain to the fortunate permittee. The value of the scarce resource thus incures to the benefit of the permittee and not to society in general.

Iowa's permit system, by inhibiting free transfer of water rights (53, sect. 455A.30) precludes the operation of a market for water rights. Such a market would, in theory, tend to allocate water rights in an optimal manner. A system of ad valorem taxation could have a similar allocative effect. Since no market exists and water use is not taxed, and the permit system does not define the necessary conditions for optimum resource use, the following chapters describe the construction of models to generate estimates of optimum resource use.

⁹This is untrue if the production function is horizontal in the interval $x = a$. In this case, water use beyond $x = a$ does not produce negative benefits, but is nevertheless wasteful.

CHAPTER FOUR: HYPOTHESIS

Hypotheses, as guides to inquiry, are propositions concerning cause-effect relationships (37, pp. 41-53). Depending upon the objectives of an analysis, its hypotheses may be described as problem delimiting, diagnostic, or remedial (98, p. 24). Problem delimiting hypotheses illustrate the nature of a problem in terms of divergences between existing situations and desired goals. Diagnostic hypotheses attempt to explain why a problem exists, and remedial hypotheses describe methods by which the desired goal can be reached.

The hypothesis constructed to guide this analysis is problem delimiting, and it is based upon the following two assumptions:

- 1) Iowa's water permit system was designed to be an optimizing institution, one which allocates water rights such that progress is maximized toward some goal or set of goals.
- 2) The set of goals toward which the permit system is designed to move includes goals of equity, security, and economic growth.

The equity concept in the permit system's assumed goal set refers to a distribution of wealth throughout society consistent with generally accepted standards of distributive justice (87, pp. 59-69). In the context of water rights allocation, the goal of security refers to the assurance of a right holder that his water right will not be lost for at least some specified time period.¹ There are static and dynamic aspects of the goal of economic growth. Investment is the dynamic aspect,

¹According to Ciriacy-Wantrup (18), a water right holder faces physical uncertainty, for flow may not always be sufficient to meet his needs; legal uncertainty, in that his water right may be infringed upon due to the illegal acts of others; and tenure uncertainty, whereby his water right may be lost due to the actions of others with prior or superior rights. Dams, impoundments, and other physical structures provide a degree of security against the physical uncertainty of variable supply, and legal systems provide security or recourse against loss under legal uncertainty. Security of tenure, however, is one of the protections which systems of water rights allocation seek to provide.

inasmuch as net investment in capital goods increases the productive capacity of the economy. The static aspect is efficiency, which refers to that allocation of resources and output which maximizes social benefit (87, pp. 59-69).

Given assumptions (1) and (2), it is possible to construct the following general hypothesis: Iowa's water permit system, in situations of insufficient water supply, will optimally allocate Iowa's water resources, where optimum allocation maximized movement toward the set of goals assumed in (2). A study of this general hypothesis would require both static and dynamic analyses of the effect of water allocation on equity, security, efficiency, and investment in Iowa. Consideration of all these questions is beyond the scope of this analysis; therefore, a more restricted, operational hypothesis is used as a guide.

Only efficiency, the static dimension of economic growth, is examined in this analysis. Further, analysis will be confined to considerations of short-run efficiency.² In addition to defining a problem of manageable proportions, the analysis focusses on this single goal for two reasons. First, the theory of short-run efficiency is relatively complete, and several analytical techniques exist upon which a model can be built. Second, it will be shown in Chapter Five that the model used in this analysis can be adapted to account for considerations of equity, security, and investment. With these restrictions, the "working hypothesis" (37, pp. 46-47) is as follows: Iowa's water permit system will achieve efficient short-run allocation of Iowa's water resources in situations of scarce water supply.

It was noted in Chapter One that since the inception of the permit system in 1957, only two permit applications have been refused, and that each of these requested a permit to dispose of excess surface water. Therefore, the hypothesis above will not be empirically tested in this

²That period over which all inputs are variable is the long run (36, pp. 107-108). One of the inputs held constant in the short run is capital, which is consistent with the decision not to examine the investment goal.

study, since the problem apparently has not arisen. It is illustrated by a linear programming optimum water allocation with the allocation system in the same situation.

³According to the permit system, permits are often granted according to the applicant. In addition to that applied for, an applicant's request for his use (48, p. 38). Allocation decisions are made on the basis of the applicant's request.

study, since the problem of allocating an insufficient water supply apparently has not arisen.³ However, this hypothesis will be illustrated by a linear programming model. This model will show optimum water allocation in a given situation, which can be compared with the allocation which might result from operation of the permit system in the same situation.

³According to Hines (48, pp. 38-39, note 179), permits are often granted according to terms more restrictive than those requested by the applicant. In some cases, the amount of water granted is less than that applied for, but these reductions are often the result of an applicant's request for more than a reasonable amount of water for his use (48, p. 38). Shortages of water which necessitate critical allocation decisions apparently have yet to occur.

PART II

CHAPTER FIVE: GENERAL LINEAR PROGRAMMING
MODEL FOR RESOURCE USE

A linear programming model was chosen in this analysis primarily because of the excellent correspondence between the requirements of the problem and the features of this type of model. Because of the wide acceptance and frequent use of linear programming as an empirical tool in economic analysis, no theoretical discussion of the technique will be given.¹ Instead, the points of correspondence between the problem and the tool will be summarized.

As an analytical technique, linear programming can be applied to many types of situations. A common type of problem is that of finding the optimum levels of a number of alternative activities, when these activities are constrained by fixed quantities of available inputs. This is analogous to the problem under consideration in this thesis: identification of the set of activities which makes optimum use of a fixed water supply.

Another advantage of using a linear program can be found in the primal-dual relationship.² The relevant implication of this relationship can be summarized in the following way. For every linear programming problem there exists simultaneously another programming problem, called the "dual" of the original problem (which is known as the primal). The primal-dual relation is symmetric, and if the primal is a maximization problem, the dual is a minimization problem. Further, if the primal objective is to maximize the value of output subject to input constraints, then the objective of the dual is to minimize the "shadow prices" (5, p. 110), or internally imputed values of the inputs. Thus, the solution to the dual generates for each input in the primal a value which corresponds to the Lagrange multiplier discussed in Chapter Two.

¹Full discussions of linear programming can be found in (5, pp. 70-128), (40), and (93, pp. 88-171).

²For discussions of duality, see supra, note 1.

The dual optimum solution tells by how much the value of the objective function would be increased if an additional unit of each of the primal inputs were available.

A further advantage in the use of a linear programming model is its flexibility. Such a model can be used to describe allocation problems involving only a few alternative uses for a scarce water supply as well as allocation problems in which there are many diverse alternative uses. A linear program can also be used for single-period analysis or, with minor modifications, for multi-period analysis in a recursive framework. For multi-period analysis, a recursive linear program can also be linked with a simulation model which provides exogenous data to the linear program for each succeeding time period. For any period, this information is based on the reaction of simulated physical or economic systems to the results of the linear program's optimum solution in the preceding period.³

Model Structure

The model described in this chapter is simplistic in its nature, endeavoring to provide the desired information with a minimum amount of required data input. Only the short run, as defined in Chapter Four, is considered. However, within this limited scope, the model exhibits dynamic properties in considering seasonal variation in water requirements and supplies. The time period of the model is defined as one year, but in applying the model to any given area, the year can be partitioned into single months or groups of months. The time periods would be constructed to illustrate seasonal fluctuations in water requirements and supplies and transfer of water supply from month to month through storage facilities. In the application in this study, four groups of months are defined, as shown in Chapter Four.

³For an example of such an application, see (43).

The aforementioned single-year approach notwithstanding, multi-year applications can be made with relative ease. This could be done either by solving the model once for each year in the interval considered, or by solving the model for the first and last years of the interval. In either case, changing conditions would be denoted by corresponding changes in the model's coefficients and parameters between solutions.

The form of the model is as follows:

$$\text{maximize } Z = c'X^P$$

subject to

$$A \begin{bmatrix} X^P \\ X^S \\ X^R \end{bmatrix} \leq b$$

$$X^P \leq \bar{X}^P$$

$$X^S \leq \bar{X}^S$$

$$X^R \geq \bar{X}^R$$

$$[X^P, X^S, X^R] \geq 0.$$

The variables have the following dimensions:

- 1) c is a p -vector;
- 2) X^P is a p -vector; X^S is an s -vector; X^R is an r -vector;
 $p + s + r = n$;
- 3) A is an $m \times n$ matrix;
- 4) b is an m -vector.

The primal form of the model is composed of four components: a set of activity variables, $[X^P, X^S, X^R]$; a matrix A of technical coefficients; a set of constraint parameters, $[b, \bar{X}^P, \bar{X}^S, \bar{X}^R]$; and an objective function, $c'X^P$. The dual form, which generates the shadow price of each primal input, is determined once the primal is defined. The structure of each of the model's components is dictated in part by the type of information the model is intended to provide. The model is constructed to find the optimum level of water using activities in an area. No attempt is made to specify the optimum combination of

activities within each agricultural or industrial water user's operation. It is assumed that this optimization has already occurred within each firm.⁴ Each of the four primal components will be described in the following section.

Activities

For any time period, the model's set of activity variables represents each actual or potential use to which water withdrawn from specific sources considered in the model can be put. These activity variables fall into three subsets which can be defined as follows:

- a) X^P , the set of uses demanding water as an input to a production process. The assumption that each firm has found the optimum combination of technological alternatives for the production of each of its products implies that there is only one process per product. There will be, therefore, one X_j for each product produced in the area under consideration. The production function of each of these activities is defined by assumption to be $X_j = f_j(\text{water, land, labor, capital}_j)$, $X_j \in X^P$. Each of these inputs is subject to a constraint on the amount available per time period.

In this study, most activities in X^P are represented by aggregate sectors defined in Table 22, Appendix A. These sectors are composed of a number of manufacturing or non-manufacturing activities producing the same type of output. The output of any of these sectors is a fictional product type, so that the shadow price of water in that activity does not refer to any particular product, but to an aggregate of the products in the sector. Such general shadow prices are useful in determining the value of water in these sectors, but for some activities, more specific information may be desirable.

⁴This two-stage decision-making process is developed in (77).

Where information is desired with respect to a specific product, an activity is defined which represents the production of that product.

Meat packing, cattle feed lots, corn production, and soybean production are represented specifically in application of the model. The level of each of these activities is measured in physical output units. All other activities in X^P are represented by aggregate sectors. Output in each of these activities is measured in money valued units, which are defined below in the section discussing the model's objective function.

b) X^S , the set of uses which represent treatment of water to change its time, quality, or location characteristics. Included in this subset are municipal water treatment and water pollution control plants, as well as storage and transport facilities. Each of these activities is assumed to have a production function of the same type shown in (a) above for X^P , the producing activities. The unit in which activities in X^S are expressed is one thousand gallons of water.

c) X^T , in part, a set of public water uses in which water can be conceived as a commodity, yielding utility directly by its use. Residential use and recreation are included in this subset, as well as an activity for each surface stream source in the model, representing use of water to satisfy the "protected low flow" requirement of the permit system (53, sect. 455A.1). Also included in X^T is an activity to represent the amount of water which must remain in a source to service the rights of downstream permit holders who are not explicitly represented in the model. Activities in X^T are measured in units of one thousand gallons of water.

Technical coefficients

The model's matrix of technical coefficients consists of ratios defining the amount of each resource required for the production of a unit of each activity. For each $X_j = f_j(\text{water, land, labor, capital})$. $\forall X_j \in X^P, X^S$, there is a technical coefficient for each input in the production function. For domestic use there are two coefficients, one representing transfer of water either from a source or a treatment activity to a public use, the other representing transfer of waste water from domestic use to a treatment facility. For recreation and flow protection, a single coefficient for each represents net use per period from sources in the model.

All water use coefficients show net consumption per unit of activity, except where withdrawals are from one source and discharge is into another source, or where water inputs and waste water outputs are treated by separate facilities. In each case, both coefficients must be explicitly accounted for to show movement of water from one supply to another. Consumption of location, quality, or time utility in water supplies can be illustrated in this way, differentiating water supplies according to these three parameters.

Constraint parameters

The set of constraint parameters contains components representing the maximum amount of each resource available to the model per time period. Water, land, and labor are represented by elements of the b vector.⁵ Each of these resource classes is heterogeneous and can be divided into more homogeneous subclasses. The number of

⁵Within the system $Ax \leq b$, the following specific constraint inequalities can be identified:

$$\text{let } \sum_{j=1}^n a_{1j} X_j \leq b_1$$

$$\sum_{j=1}^n a_{2j} X_j \leq b_2$$

. .
. .
. .

(footnote continued on following page).

subclasses used is determined by the amount of detailed information desired from the model. A shadow price is generated for each resource subclass delineated, but more detailed input data are required as the number of subclasses increases.

Consistent with this relation between input data and output information, the water and land resources in the model are differentiated, while the labor resource is considered homogeneous. This is done for the water resource because information is desired concerning the differential value in use of various water supplies. Land is subclassified because there is evidence⁶ that some agricultural activities have a

(footnote continued from previous page)

$\sum_{j=1}^n a_{uj} X_j \leq b_u$ express the area water use constraints;

$\sum_{j=1}^n a_{u+1j} X_j \leq b_{u+1}$

$\sum_{j=1}^n a_{u+2j} X_j \leq b_{u+2}$

· · ·
· · ·
· · ·

$\sum_{j=1}^n a_{m-1j} X_j \leq b_{m-1}$ express the area land use constraints; and

$\sum_{j=1}^n a_{mj} X_j \leq b_m$ express the area labor force constraint.

⁶In Arizona, where water is generally scarce, Young and Martin (122) showed personal income generated per acre foot of water used to be approximately 1000 times higher in manufacturing than in the highest-valued crop use.

significantly lower return to a scarce water resource than some industrial activities. By considering return to water used in alternative activities on different types of land, planning decisions could be made which would enhance the movement of water used on low productivity agricultural land into higher productivity agricultural or industrial uses.

Labor supply could also be considered in this manner. However, labor is a relatively mobile resource both geographically and occupationally. Further, knowledge of the magnitude of the return to water used by labor subclasses is of doubtful value. For these reasons, labor is treated as a homogenous resource class.

Available capital inputs to activities in the model are considered to be fixed in any time period. Each activity which requires capital operates under a constraint on the available amount of fixed plant and equipment. This constraint can be expressed either as a physical quantity representing the production capacity of each of the activities, or as the dollar value of available fixed plant and equipment. For activities in the producing sector, X^P , the constraint is denoted by \bar{X}^P ; for water supply activities, X^S , the constraint is denoted by \bar{X}^S . By the hypothesis in Chapter IV, investment is disregarded in this analysis, but \bar{X}^P and \bar{X}^S could be changed between periods in a dynamic analysis to allow for consideration of investment.

Objective function

The model's objective function follows from the hypothesis in Chapter Four, in which the analysis is restricted to considerations of short-run efficiency in water allocation. By definition (87, p. 148), efficient allocation is that which maximizes social benefit gained in the use of water; therefore, the model's objective is to maximize social benefit.

Social benefit is difficult to measure, for it includes not only the dollar-valued output of goods and services, but also many items which have no readily discernible market value. For instance, social benefit from water use includes the benefit derived from such water uses as

recreation and conservation. Further, water is necessary to sustain life, and its value in fulfilling this function is difficult to quantify. Because of these difficulties, it is necessary to find a proxy for social benefit.

In this study, the proxy used is based upon the value of output of the producing activities in the model; these activities are represented by the elements of X^P . Value of output is represented by $\sum_{j=1}^p P_j X_j$, where P_j is the unit price of the output of X_j . However, value of output may include payments to factors not located in the area affected by the hydrologic system under consideration. Therefore, for each activity X_j , these payments are excluded from the objective function by the method described below.

For each activity, total value of product is assumed to be exhausted by payments to the various inputs and factors of production, as expressed by the following relationship:

$$\text{Product value/unit of } X_j = \text{Wages and Salaries/unit of } X_j + \text{Materials Cost/unit of } X_j + \text{Other Income/unit of } X_j.$$

The several terms of this relationship are defined as follows:

- a) Wages and Salaries/unit of X_j is the portion of product value paid to those whose labor is expended in production of the j th product.
- b) Materials Cost/unit of X_j is the portion of product value paid to purchase the materials which are part of the j th product, including materials imported from outside the area.
- c) Other income/unit of X_j is the remainder of product value, including profits, return on capital invested, and rents according to land and water in the production of X_j .

The element in the objective function corresponding to X_j is

$$c_j = \text{Product Value/unit of } X_j - \text{Materials Cost/unit of } X_j = \text{Wages and Salaries/unit of } X_j + \text{Other Income/unit of } X_j.$$

Thus, each activity is weighted according to the portion of its product value earned by those factors of production local to the hydrologic system

under study. These factors are labor, land, water, fixed capital, and managerial ability.

By excluding the cost of materials from the objective function coefficient, two problems are avoided. First, any payments for materials produced outside the model area are excluded; these payments do not represent benefit to individuals in the model area. Second, excluding materials cost insures that only the value of final production is measured.⁷

There are at least three theoretical difficulties in using a portion of product value to approximate social benefit. First, if there are any external effects present in the model area, marginal private cost and benefit may not be equal to marginal social cost and benefit, respectively. In this case, the market value of output does not represent its value to society; if marginal social benefit exceeds marginal private benefit, output value understates social benefit. If marginal private benefit exceeds marginal social benefit, which is the case where air and water pollution result from production, the value of output overstates social benefit.

Another difficulty is that an increase in output, while increasing some individual's benefit, may decrease the benefit derived by others. If this occurs, it is not possible to specify whether social benefit has increased, because no method for making interpersonal utility comparisons exists at this time (87, p. 64). A third difficulty in the use of a portion of total output value to approximate social benefit is that this measurement conceals any changes in either the quality of the several outputs produced, or in the relative proportions in which these outputs are produced (output mix). Changes in both output quality and output mix can influence social benefit.

⁷Bread is a final product, the value of which includes the value of the flour used in its production. Flour is an intermediate product, and to add the value of bread production and the value of flour production would be to count the value of flour twice. See (84, pp. 183-186).

Notwithstanding the existence of these difficulties, the objective function of the model is defined as

$$Z = c'X^P$$

where $c_j = \text{Product Value/unit of } X_j - \text{Materials Cost/unit of } X_j = \text{Wages and Salaries/unit of } X_j + \text{Other Income/unit of } X_j, j=1, \dots, p$. Those activities which are treated specifically are measured in physical production units; the corresponding element in c is the price per unit for that product. Those activities represented by aggregate sectors are measured in dollar-valued output units. These units are defined to be the amount of production required to generate a one dollar increase in product value from that sector. c_j , as defined above, is the product value per unit of output. Therefore, the unit of measurement of each activity in X^P represented by an aggregate sector is $c_j X_j$, and the coefficient in the objective function is actually unity. The objective function of the model is identical to that defined above, $Z = c'X^P$.

The coefficients in the objective function associated with elements in X^S , the water-supply activities, and X^R , the residual social water uses, are defined to be zero in all activities except one because most water in Iowa presently has no market price. Therefore, the value of a unit of treated water, which derives from the use of that unit in production of consumption uses, cannot be directly measured, nor can the value of a unit of water used in human consumption, recreation, or low-flow protection. The activities in X^R are instead constrained to appear in the solution, while the activities in X^S will appear at some positive level due to linkages with activities in both X^P and X^R .

In one application of the model, one activity in X^S is assigned a negative coefficient in the objective function. This activity represents treatment of a polluted water supply. It differs from the activity representing treatment of a less polluted supply only in the objective function coefficient assigned to each. The negative c_j is the amount per unit by which treatment costs are increased by the presence of pollutants in the water supply.

Interpretation of the Solution

Solution of the model yields an activity set $[X^{P*}, X^{S*}, X^{R*}]$ which maximizes the value of the objective function. Optimal water use in activities in X^P must be calculated indirectly from the optimal solution since these activities are expressed in terms of output units. For X_j^* , $\forall X_j \in X^P$, water use is calculated by multiplying X_j^* , the optimum level of that activity, by its technical coefficient of water use (water used per unit of output). From any water supply represented by b_α , the water used in activities in X^P would be equal to $\sum_{j=1}^P a_{\alpha j} X_j^*$. Total water use in activities in X^P from all sources would be obtained by $\sum_{i=1}^u \sum_{j=1}^p a_{ij} X_j^*$ for all water sources, b_1, b_2, \dots, b_u .

Activities in X^S and X^R are expressed in units of one thousand gallons of water. Total water use in these activities would be $\sum_{i=1}^u \sum_{j=p+1}^n a_{ij} X_j^*$, while total water use in all activities would be given by $\sum_{i=1}^u \sum_{j=1}^n a_{ij} X_j^*$.

Also generated are shadow prices for each constraint. For the b vector, the shadow prices represent the value of an additional unit of land, labor, or water resource. For \bar{X}^P , \bar{X}^S , and \bar{X}^R , the shadow prices have an analogous interpretation. However, the shadow prices associated with each parameter in \bar{X}^R represent the amount by which the objective function would be increased if minimum requirements for public use were lowered by one unit. This value, while not a price, is an opportunity cost measure which could be an aid in planning, especially with respect to water reserved for residential, recreational, or flow protection uses.

Changes in Parameters

To express actual or proposed changes in water supply or requirements in an area, the parameters of the model can be changed. Population growth, for example, can be expressed by increasing the amount of water reserved for residual and municipal use. Increased

recreation use can be represented analogously. Increases in industrial or agricultural requirements can be shown by raising the limit of the constraining resource (land, labor, capital, or water) and allowing that activity to expand.

Secular changes in water quality levels can also be represented by shifting quantities of water from high quality supplies in the model to lower quality supplies. If an increased cost is shown to be associated with use of lower quality supplies, the value of treatment will be reflected. By identifying the source of quality degradation and identifying the consequence area where treatment finally takes place, the model may also provide planning information for quality improvement programs.

Adapting the Model to Multi-Dimensional Goals

Considering only the one-dimensional goal of short-run efficiency implies that this goal is independent of the goals of equity, security, and investment. If the four goals are independent, maximization with respect to any single goal is not inconsistent with maximization in terms of any or all of the other three. Operationally, this assumption may be unwarranted. Security and investment are related in that, for planning purposes, the length of time over which a water-related investment must pay for itself (the planning horizon) depends upon how long the investor's water right is assured. For a given rate of return, the maximum feasible investment decreases as the planning horizon becomes shorter, while for investments of a given size, higher rates of return must be forthcoming as the planning horizon is shortened. Equity and efficiency are also not mutually exclusive. Efficient resource allocation given current income distribution may be inefficient if income is redistributed to be more equitable.

In a model designed to show short-run efficiency, these interactions can be shown as additional constraints. As an example, if an increase in investment is desired, those activities in which investment is desired can be granted permits for the maximum allowable period, shown in the model by reducing the amount of available water in

succeeding time periods by this secured amount. The model also shows which activity will have the greatest direct increase in output and employment from the use of additional water.

Investigation of the effect of permit security could take the form of a constraint representing, in successive iterations of the model, the amount of water secured from reallocation by permits in force. Under each different assumed permit duration, the model could be reiterated yearly for a specified time period, and the present value of each year's production computed. These present values could then be summed over the time period for which the model was run, and compared with the present values associated with each assumed permit duration.

CHAPTER SIX: APPLICATION OF THE GENERAL MODEL

The model described in Chapter Five is applied to two situations in this chapter. One application is to a hypothetical water use situation. Apparently, no water shortage exists presently in Iowa which is serious enough to affect a diverse group of economic activities.¹ Therefore, the hypothetical situation is constructed to illustrate the use of the model more completely than could application to an existing situation of limited scope in Iowa.

The second application of the model is to the use, by existing activities, of water from a shallow sand and gravel aquifer, located near an Iowa town of approximately 5000 population. This application encompasses fewer activities and a more abundant water supply than the hypothetical situation, but it illustrates what could be considered a typical application of the model in a real situation. These applications, designated I and II respectively, are described in the following sections.

Application I: A Hypothetical Water Use Situation

The water use situation under study in application I is illustrated in Figure 2. In this situation, water may be used in crop and livestock agriculture, industry, and domestic uses. The water supply on which these uses depend is a stream with a 20 square mile drainage area. The flow in this situation is assumed to be dependent upon rainfall in the basin. The mathematical relation expressing this dependence is shown in a later section discussing the model's resource parameters.

The annual time frame of the general model described in Chapter Five is partitioned into four time periods in application I. These time periods are constructed to reflect the seasonal variation in water supply and in the water requirements of the agricultural activities. The time periods are as follows:

¹Interviews with officials of the Iowa Water Commissioner's staff and the U. S. Geological Service, as well as with members of the Iowa State University faculty in several departments failed to reveal any situation of scarcity.

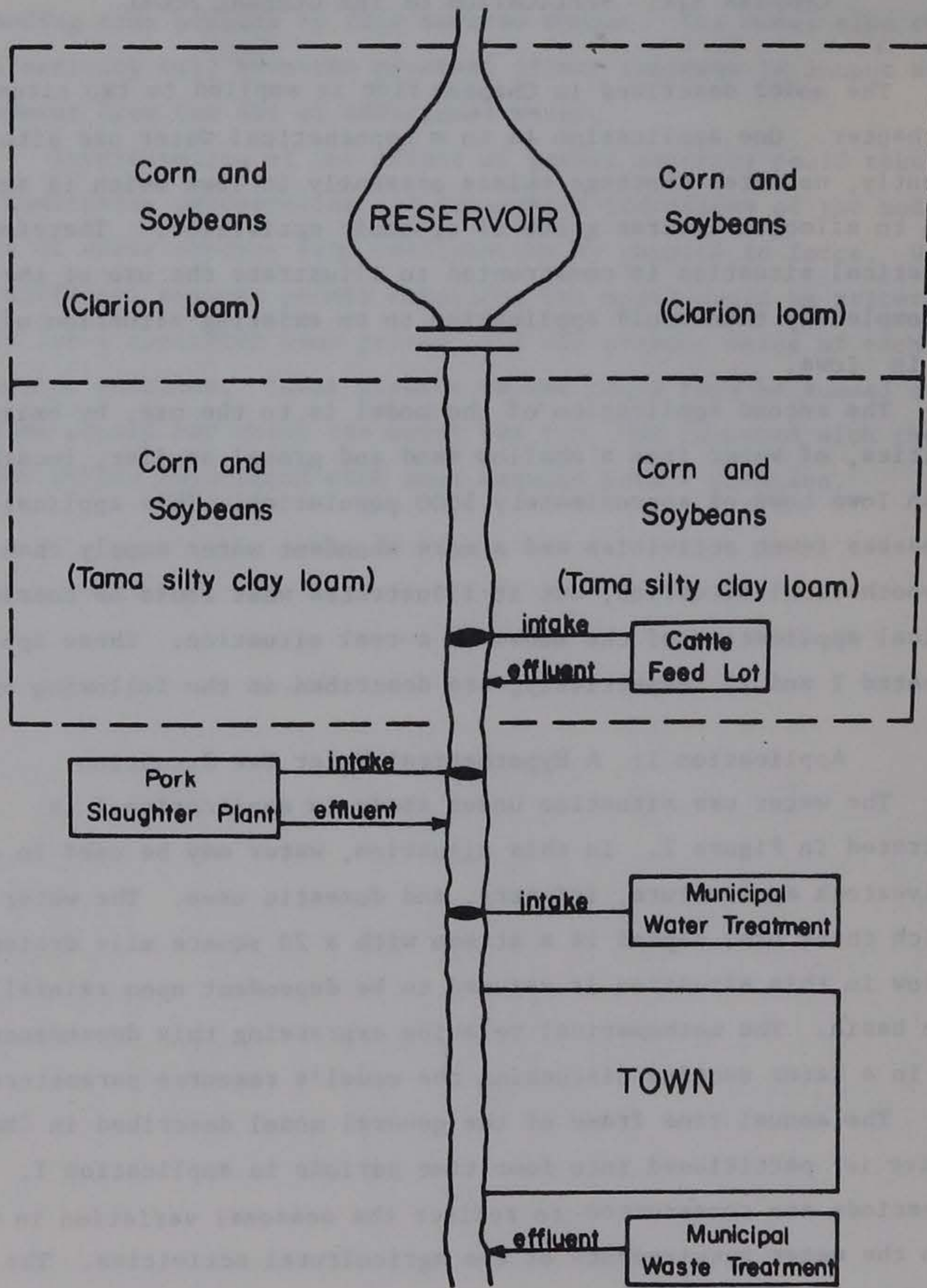


Figure 2. Spatial Arrangement of Activities in Application I

- period 1 - November through April;
- period 2 - May and June;
- period 3 - July and August;
- period 4 - September and October.

Figure 3 shows these time periods superimposed upon the distribution of annual rainfall by months. It can be seen that period I contains the winter months of low rainfall while period 2 contains the spring months, which have the highest average rainfall of the year. Period 3 contains those months during which rainfall reaches its lowest level for the summer season, while period 4 contains a peak which occurs as rainfall increases from the low level of period 3 and begins to decrease to the winter season low rainfalls.

Crop water requirements during the growing season also fluctuate. The time periods defined above serve to isolate the period of maximum crop water requirements for crops considered in application I. According to Shaw, et. al (90), estimated average water requirements for corn during the periods defined above are as follows:

- period 1 - 4.9 inches;
- period 2 - 7.1 inches;
- period 3 - 10.7 inches;
- period 4 - 5.1 inches.

The time periods of the model, as they are defined, allow for the juxtaposition of rainfall and crop water requirements in such a way as to isolate those periods during which supplemental irrigation may be required.

Activities

Figure 2 shows the arrangement of activities in the situation represented in model application I. One central feature of this arrangement is the relationship of the pork slaughtering activity to the town. If, as is assumed in the model, significant pollution results from slaughter operations, the town downstream, which has no alternative supply, must bear the cost of removing this pollution from the water withdrawn for municipal use. This assumed relationship creates a

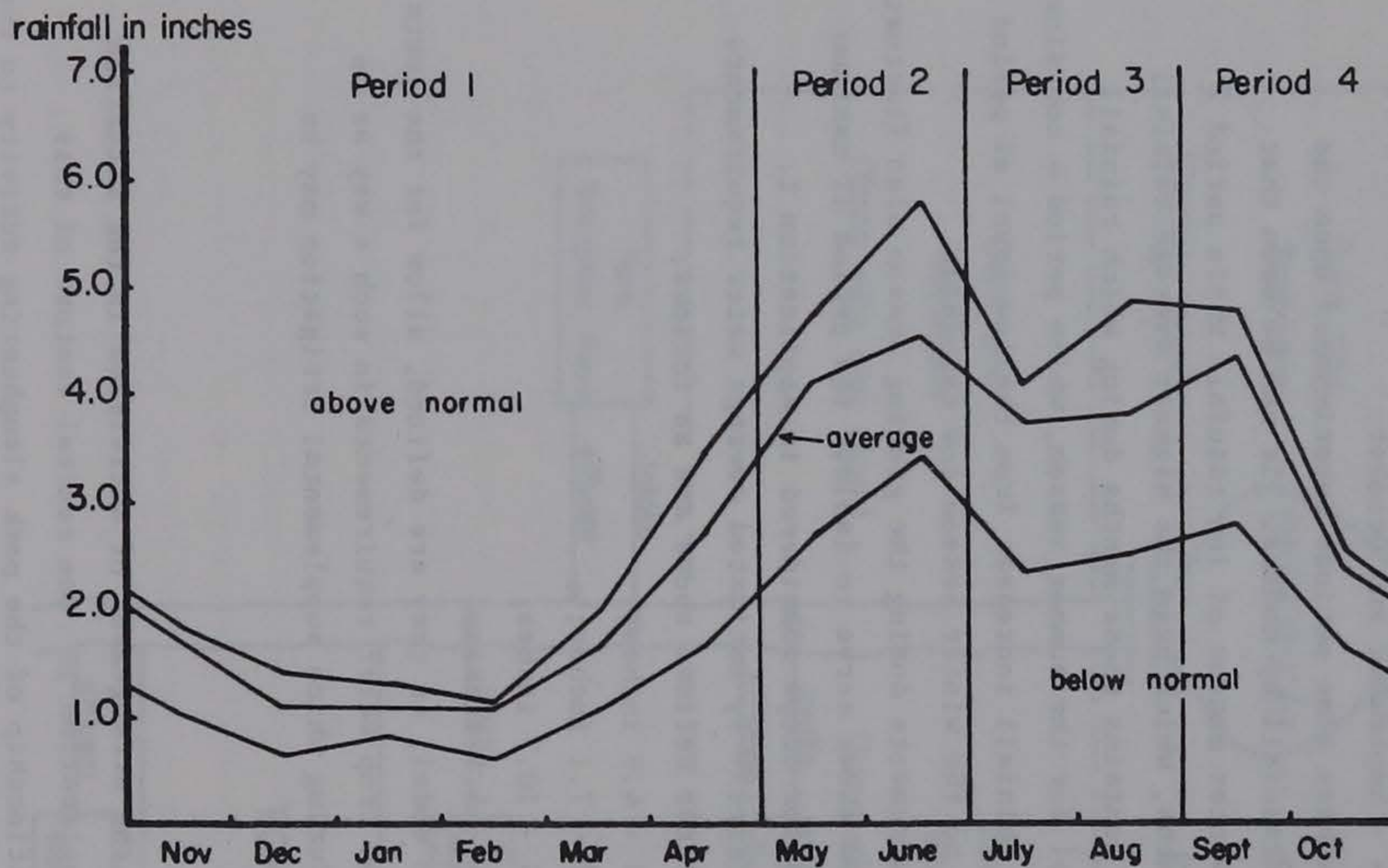


Figure 3. Distribution of Rainfall Through Assumed Time Periods, Application I

^a(80, p. 7)

framework in which to study the feasibility of using the stream between the pork plant and the town as an effluent carrier.

The reservoir is included to illustrate the value of transfer of water between time periods. Inclusion of this facility also allows consideration of the competition between recreation, for which a stable reservoir level is desirable, and water storage, for which a fluctuating water level may at times be necessary.

Two soil types are shown in the hypothetical situation so that comparisons can be made between the value of water used in crop production on each soil type. Further, the cattle feed lot operation is located on irrigable land, so that the value of water in different agricultural uses on the same soil type can be calculated.

In this section, each activity in application I is defined. Each activity's coefficient of resource use and its coefficient in the objective function are shown in tabular form. The derivation of each of these coefficients is explained in the text. The four variables listed below for each activity designate that activity in each of the four time periods of the model.

The producing sector (XP)

Agricultural activities There are five activities in the agricultural portion of the producing sector. They are a cattle feed lot, corn production on the two soil types, and soybean production on the two soil types. Aside from differences in yield due to soil type as shown in Table 19, Appendix A, the crop activities are defined similarly, so that comparisons can be made of the value of water in each crop on the same soil type.

Crop activities on Tama silty clay loam are designated Corn Production I and Soybean Production I. Crop activities on Clarion loam are designated Corn Production II and Soybean Production II. Each agricultural activity withdraws water from the stream shown in Figure 2. The activities are defined as follows:

$X_1, X_{25}, X_{49}, X_{73}$ - Cattle Feed Lot, which utilizes land, labor, water withdrawn from the stream in Figure 2, and capital as illustrated

Tables 1a and 1b. The activity involves feeding heifer calves, which are purchased at 400 pounds, fed a high roughage feed for 288 days, and sold at 925 pounds. Feed lots can be considered completely consumptive water uses, since liquid waste from the cattle is the only discharge of intake water. Most of this waste would either evaporate or infiltrate into the soil, never reaching the stream.² For this reason, no discharge is shown for this activity.

Cattle feed lot operations which have no waste treatment facilities may also be significant contributors to agricultural pollution (67, p. 1582). If feed lot solid wastes are not constantly treated, but are allowed to accumulate, these wastes may contribute only intermittently to high pollution loads in surface streams. Rainfall of sufficient intensity must occur to cause solid wastes to dissolve and run into the stream (67, p. 1951). Such a phenomenon is stochastic, and is not considered in this report.

Production coefficients for labor, land, and water use in the cattle feed lot activity are based upon data given in James (57). Capital required per calf fed is based upon data in a study of feed lot operations in Northeast Iowa by Gross (39).

The relationship used to estimate revenue per unit of output is the same for each of the activities in the producing sector. This relationship, given previously in Chapter Five, is

$$c_j = \text{Product Value/unit of } X_j - \text{Materials Cost/unit of } X_j - \text{wages and Salaries/unit of } X_j + \text{Other Income/unit of } X_j.^3$$

²J. R. Miner, Agricultural Engineering Department, Iowa State University, Ames, Iowa. Data on the nature of cattle feed lot runoff. Private communication. July 1, 1969.

³Included in Other Income are returns to all non-labor factors of production, such as land, capital and entrepreneurial ability. The value of c_j differs from total product value only by the cost of primary inputs; with this single restriction, c_j may be treated as revenue.

For each activity, estimated materials cost per unit of output is deducted from estimated product value per unit of output. For X_1 , Cattle Feed Lot, product value was estimated according to 1967 average prices for good and choice heifer calves to be \$23.98 per hundredweight (32, Table 155, p. 107), or \$221.82 for a 925 pound animal. The same calf, purchased at 1967 average prices, cost \$28.00 per hundredweight (32, Table 160 - 160L, p. 113), or \$112.00 for a 400 pound calf. Feeding costs are estimated by James (57, Table 2.12, p. 55) to be \$73.57 for a 525 pound gain. Net revenue is as follows:

Product Value		\$221.82
less Materials cost:		
calf	\$112.00	
feed	73.57	
		<u>185.57</u>
net revenue (C_1)		\$ 36.25

$X_2, X_{261}, X_{50}, X_{74}$ - Corn Production I, the production of corn on Tama silty clay loam under high fertilization.

$X_3, X_{27}, X_{51}, X_{75}$ - Corn Production II, the production of corn on Clarion loam under high fertilization.

$X_4, X_{28}, X_{52}, X_{76}$ - Soybean Production I, growing soybeans on Tama silty clay loam under high fertilization.

$X_5, X_{29}, X_{53}, X_{77}$, - Soybean Production II, soybeans grown on Clarion loam under high fertilization.

Production coefficients for all four crop activities are shown in Table 1a and Table 1b. The data from which labor, land and capital use coefficients were compiled are contained in James (57). Coefficients of water use per unit of corn output are based on data given in Shaw, et. al. (90). These water requirements express the amount that must be withdrawn from the stream to supplement insufficient rainfall. Negative irrigation requirements, which imply an abundance of rainfall, are considered to be zero in the model. Irrigation requirements for corn and soybeans and the method of derivation of these requirements for three levels of rainfall are shown in Table 21, Appendix A.

Water requirements for soybeans are assumed to be approximately the same as requirements for corn.⁴ The data given by Shaw, *et. al.* (90) shows consumptive crop use; return flow is assumed to be zero in each crop activity.

Product value is assumed to be the same for a crop regardless of the soil type on which the crop was grown. James (57, Table 6.8 p. 169) gives the average 1967 price per bushel for corn and soybeans, as well as estimates of the variable costs per acre (materials cost) for each crop (57, Table 8.1, p. 214). Variable costs per acre were converted to variable cost per bushel by the following manipulation:

$$\text{variable cost/acre} \div \text{bushels/acre} = \text{variable cost/bushel.}$$

The net revenue per bushel for each crop is as follows:

Corn (per bushel) -	
Product Value	\$1.13
less Materials Cost:	<u>-0.55</u>
net revenue (C ₂ , C ₃)	\$0.58

Soybeans (per bushel) -	
Product Value	\$2.60
less Materials Cost:	<u>-1.07</u>
net revenue (C ₄ , C ₅)	\$1.53

Non-agricultural activities There are eleven non-agricultural production activities in each time period in application I of the general model. Of the eleven activities, two are represented as producing a specific product, while nine activities are represented as aggregate sectors. As discussed in Chapter Five, one distinction between these two methods of representation is that resource requirements in specific product activities are expressed as resources used per physical unit of output, while resource requirements in sector activities are expressed as resources used per \$1000 of product value. By assumption, none of the eleven activities has any seasonal variation in resource requirements. However, each of these activities must appear in every time period in the model. Table 2 shows, for any one of the model's

⁴R. L. Shaw, Agronomy Department, Iowa State University, Ames, Iowa. Data on crop water requirements. Private communication. June 27, 1969.

time periods, the resource requirements of each non-agricultural producing activity. These activities are defined as follows:

$X_6, X_{30}, X_{54}, X_{78}$ - Pork Slaughter I, which is a pork slaughtering plant operating at a rate of 230 carcasses per hour. Plant wastes from this activity are discharged into the stream after treatment for removal of biochemical oxygen demand (BOD).⁵ It is assumed that the waste treatment facility of the pork plant provides adequate treatment of plant wastes at the rate of operation specified for Pork Slaughter I. By assumption, treated effluent from Pork Slaughter I does not decrease the stream's quality to such a level that existing treatment facilities of downstream users are inadequate. In terms of stream quality, the relationship between Pork Slaughter I and downstream activities is neutral. A competitive relationship exists only with respect to quantity consumption; therefore, only the amount of water consumed per unit of output in Pork Slaughter I is shown in Table 2.

$X_7, X_{31}, X_{55}, X_{79}$ - Pork Slaughter II, which differs from Pork Slaughter I in two respects. First, the slaughtering plant is operating at a rate of 310 carcasses per hour, so that its rates of resource use differ from those of Pork Slaughter I. Second, it is assumed that, in increasing plant output, this activity exceeds the design capacity of its waste treatment facility,⁶ thereby reducing the facility's efficiency and increasing the level of BOD in plant discharge. The resulting pollution load is hypothesized to be sufficient to force the town downstream from

⁵The bacterial decomposition of organic waste in effluent water consumes dissolved oxygen. Biochemical oxygen demand (BOD) expresses the amount of dissolved oxygen which will be consumed in the decomposition of a given quantity of organic waste (63, p. 548).

⁶The treatment facility's design capacity may be exceeded because the slaughter rate has increased, because the amount of waste discharged per carcass has increased, or because poor maintenance of the treatment facility has reduced its capacity.

Table 1a. Seasonal resource requirements per unit of output in agricultural activities, application I

Resource	Period 1				
	X ₁ Cattle feed lot (per head)	X ₂ Corn I (per 100 bu.)	X ₃ Corn II (per 100 bu.)	X ₄ Soybeans I (per 100 bu.)	X ₅ Soybeans II (per 100 bu.)
Land I (acres)	0.004 ^a	0.0 ^b	-	0.0 ^b	-
Land II (acres)	-	-	0.0 ^b	-	0.0 ^b
Labor (workers)	0.60 ^c	0.18 ^c	0.18 ^c	0.25 ^c	0.29 ^c
Water (gallons)					
below normal rainfall	1,810.0 ^d	0.0 ^e	0.0 ^e	0.0 ^e	0.0 ^e
normal rainfall		0.0	0.0	0.0	0.0
above normal rainfall		0.0	0.0	0.0	0.0

^a(57, Table 5.3, p. 146)

^b(57, Table 1.10, p. 15)

^c(57, Table 3.1, p. 93)

^d(57, Table 5.4, p. 147)

^e(90, Table 11, p. 237)

Table 1a. (Continued)

Resource	Period 2				
	X ₂₅ Cattle feed lot (per head)	X ₂₆ Corn I (per 100 bu.)	X ₂₇ Corn II (per 100 bu.)	X ₂₈ Soybeans I (per 100 bu.)	X ₂₉ Soybeans II (per 100 bu.)
Land I (acres)	0.004 ^a	1.02 ^b	-	2.9 ^b	-
Land II (acres)	-	-	1.1 ^b	-	3.4 ^b
Labor (workers)	0.28 ^c	0.20 ^c	0.23 ^c	0.66 ^c	0.78 ^c
Water (gallons)					
below normal rainfall	0.0 ^d	29.0 ^e	31.6 ^e	83.7 ^e	98.1 ^e
normal rainfall		0.0	0.0	0.0	0.0
above normal rainfall		0.0	0.0	0.0	0.0

Table 1a. (Continued)

Resource	Period 3				
	X ₄₉ Cattle feed lot (per head)	X ₅₀ Corn I (per 100 bu.)	X ₅₁ Corn II (per 100 bu.)	X ₅₂ Soybeans I (per 100 bu.)	X ₅₃ Soybeans II (per 100 bu.)
Land I (acres)	0.004 ^a	1.02 ^b	-	2.9 ^b	-
Land II (acres)	-	-	1.1 ^b	-	3.4 ^b
Labor (workers)	0.25 ^c	0.06 ^c	0.06 ^c	0.25 ^c	0.29 ^c
Water (gallons)					
below normal rainfall	0.0 ^d	161.5 ^e	175.9 ^e	465.5 ^e	545.8 ^e
normal rainfall		90.1	98.1	259.6	304.4
above normal rainfall		50.9	55.4	146.7	172.0

Table 1a. (Continued)

Resource	Period 4				
	X ₇₃ Cattle feed lot (per head)	X ₇₄ Corn I (per 100 bu.)	X ₇₅ Corn II (per 100 bu.)	X ₇₆ Soybeans I (per 100 bu.)	X ₇₇ Soybeans II (per 100 bu.)
Land I (acres)	0.004 ^a	1.02 ^b	-	2.9 ^b	-
Land II (acres)	-	-	1.1 ^b	-	3.4 ^b
Labor (workers)	0.12 ^c	0.11 ^c	0.12 ^c	0.50 ^c	0.58 ^c
Water (gallons)					
below normal rainfall	300.0 ^d	17.6 ^e	19.1 ^e	50.6 ^e	59.3 ^e
normal rainfall		0.0	0.0	0.0	0.0
above normal rainfall		0.0	0.0	0.0	0.0

Table 1b. Capital requirements and net revenue per unit of output for any period in agricultural activities, application I

Resource	X ₁ ,X ₂₅ ,X ₄₉ ,X ₇₃ Cattle feed lot (per head)	X ₂ ,X ₂₆ ,X ₅₀ ,X ₇₄ Corn I (per 100 bu.)	X ₃ ,X ₂₇ ,X ₅₁ ,X ₇₅ Corn II (per 100 bu.)	X ₄ ,X ₂₈ ,X ₅₂ , X ₇₆ Soybeans I (per 100 bu.)	X ₅ ,X ₂₉ ,X ₅₃ ,X ₇₇ Soybeans II (per 100 bu.)
Capital (dollars)	33.20 ^f	45.41 ^g	48.55 ^g	113.77 ^h	132.57 ^h
Net revenue (dollars)	36.25 ⁱ	58.00 ⁱ	58.00 ⁱ	153.00 ⁱ	153.00 ⁱ

^f(39, Table 9, p. 47)

^g(57, Table 8.1, pp. 213-214)

^h(57, Table 8.2, pp. 215-516)

ⁱSee text for sources and derivation.

the slaughter plant to incur higher treatment costs. For the purposes of this model, it is necessary only to specify by what amount downstream treatment costs are increased, and not to specify the nature of the pollution load which causes the increase. The specific cost increase will be discussed in a later section describing the town's water treatment facilities.

As shown in Figure 2, water is withdrawn from and returned to the stream by both pork slaughter activities. Pork Slaughter II, if it enters the solution of the model, however, adds significant pollution to the stream, consuming entirely the supply of relatively unpolluted water designated in the model as stream I. At the same time, Pork Slaughter II creates a new water supply with lower quality characteristics, designated stream II. Defining two separate supplies in this way emphasizes the artificial scarcity of stream I water created by the inefficient waste treatment of Pork Slaughter II. The model generates the shadow price of any scarce resource, so that the cost of using the stream as an effluent carrier between the pork plant and the municipal water treatment facility can be determined.

Labor use and capacity coefficients for Pork Slaughter I and Pork Slaughter II are calculated from data given in Daellenbach (24). Water use coefficients are based on a survey and analysis of five meat packing operations by Thornton and Frederick (96) and also on data gained in personal interview with production personnel at selected meat packing plants in Iowa.

New revenue is the same in both Pork Slaughter I and Pork Slaughter II. Daellenbach (24, Appendix 2, p. 131) shows identical Material Costs for 230 carcasses per hour and 310 carcasses per hour. Using the 1967 average wholesale value, carcass and by-products (32, Table 203A, p. 140), as Product Value, and including in Materials Costs the average 1967 price for 200-220 pound barrows and gilts (32, Table 203A, p. 140), net revenue is as follows:

Pork Slaughter (per carcass)	
Product Value	\$59.62
less Materials Costs	
(assuming 210 pound carcass)	<u>46.49</u>
net revenue (C ₆ ,C ₇)	\$13.13

The remaining activities in the producing sector of the model are represented by aggregate industrial and trade sectors. Table 22, Appendix A lists thirteen such aggregate sectors which encompass economic activity in agriculture, manufacturing, trade, and service industries. Each of these sectors represents a number of individual industries, each producing a similar product. The industries included in each sector are denoted by the Standard Industrial Classification industry code numbers corresponding to that sector. The sectors defined in Table 22 may be used as activities in the model wherever information concerning water use in the production of specific products is not desired.

The coefficients of resource use for each of the thirteen sectors are given in Table 2. These coefficients are based on data given in Barnard (3,4) and MacMillan (75).⁷ The general method of calculation for these coefficients is described below.

Data given in the sources cited above express, for each sector, capital, water, and labor requirements per unit of gross output. Capital required per dollar of gross output (3, Table 8, p. 53) and water intake and discharge per dollar of gross output (4, Table 4, p. 14) are given directly. The labor requirements data (75, Table 29, p. 127) are given in terms of dollars of gross output per worker; the reciprocal of this ratio is the workers required per dollar of gross output.

This revised labor coefficient, the capital coefficient, and the water coefficients must be adjusted to find the amount of each resource

⁷Barnard defines fourteen sectors in his work (3,4). MacMillan (75) defines only thirteen; the transportation and the communication and utilities sector are combined into one, entitled Regulated Industries. In aggregating the resource use coefficients given by Barnard for the two separate sectors, each coefficient was weighted by the proportion of that sector's output to total output in both sectors.

required per unit of value added in that sector in the area under study. In Chapter V, the coefficient in the objective function for any activity X_j was defined to be

$$c_j = \text{Product Value/unit of } X_j - \text{Materials Cost/unit of } X_j.$$

Therefore, that portion of gross output value in a sector which is used to purchase materials for the production of that sector's output must be calculated and deducted from gross output value.

For any one of the thirteen sectors listed in Table 22, Appendix A, the sum of that sector's purchases, per dollar of gross output, of intermediate goods from the other twelve sectors and from states outside Iowa (Table 23, Appendix A) represents that sector's materials cost per dollar of output. Gross output minus materials cost is value added, the portion of output value which is earned by labor, management, and capital factors of production. Thus, for the j th sector, the resource coefficients are computed as follows:

$$\text{Labor/dollar value added in } X_j = \frac{1}{\frac{\text{Output}_j}{\text{Worker}_j}} \cdot \frac{1}{k_j}$$

where output per worker is given by MacMillan (66, Table 29, p. 127), and k_j = value added per dollar of gross output.

$$\text{Capital/dollar value added in } X_j = \frac{\text{Capital}_j}{\text{Output}_j} \cdot \frac{1}{k_j};$$

the capital output ratio is given in Barnard (3, Table 8, p. 53).

$$\text{Water intake/dollar value added in } X_j = \frac{\text{Water intake}_j}{\text{Output}_j} \cdot \frac{1}{k_j};$$

$$\text{Water discharge/dollar value added in } X_j = \frac{\text{Water discharge}_j}{\text{Output}_j} \cdot \frac{1}{k_j};$$

Water intake and water discharge per dollar of gross output are given in Barnard (4, Table 4, p 14). Since each unit of output in a sector activity generates \$1000 value added, the coefficient in the objective function is \$1000 for any sector activity.

In application I, activities X_8 through X_{17} in period 1, and the corresponding activities in periods 2, 3, and 4 are represented by sectors, as follows:

- $X_8, X_{32}, X_{56}, X_{80}$ - Sector 4: Other Food and Kindred Products.
- $X_9, X_{33}, X_{57}, X_{81}$ - Sector 5: Other Non-Durables,
- $X_{10}, X_{34}, X_{58}, X_{82}$ - Sector 6: Farm Machinery,
- $X_{11}, X_{35}, X_{59}, X_{83}$ - Sector 7: Other Machinery,
- $X_{12}, X_{36}, X_{60}, X_{84}$ - Sector 8: Other Durables,
- $X_{13}, X_{37}, X_{61}, X_{85}$ - Sector 9: Regulated Industries,
- $X_{14}, X_{38}, X_{62}, X_{86}$ - Sector 10: Wholesale and Retail Trade,
- $X_{15}, X_{39}, X_{63}, X_{87}$ - Sector 11: Finance, Insurance, and Real Estate,
- $X_{16}, X_{40}, X_{64}, X_{88}$ - Sector 12: Other Services,
- $X_{17}, X_{41}, X_{65}, X_{89}$ - Sector 13: Construction and Mining.

Each of these activities is assumed to be located in the town shown in Figure 2. Each activity uses municipally treated water and discharges waste water to be treated by the municipal waste water treatment facility. Resource requirements per unit of each of these activities are shown in Table 2.

The water supply sector (X^S).

There are four activities in the water supply sector. Two of these activities, Water Treatment and Water Treatment II, represent treatment of stream water to meet commercial and residential requirements in the assumed municipality. Waste water treatment represents treatment of municipal waste water, while the fourth activity is Reservoir Storage, carried out in the reservoir shown in Figure 2. Resource requirements for each of these activities are shown in Table 3. The activities are defined as follows:

$X_{12}, X_{42}, X_{66}, X_{90}$ - Water Treatment I, the activity which treats water withdrawn from stream I, water containing effluent from Pork Slaughter I. It is assumed that Pork Slaughter I discharges waste in quantities too small to affect the level of treatment costs at the municipal water treatment plant. The output of Water Treatment I is distributed among the various

Table 2. Resource requirements and net revenue per unit of output for any time period in non-agricultural production activities, application I^a

	Activity					
	X ₆₁ , X ₃₀ , X ₅₄ , X ₇₈ , Pork Slaughter I (1000 hogs)	X ₇ , X ₃₁ , X ₅₅ , X ₇₉ , Pork Slaughter II (1000 hogs)	X ₈ , X ₃₂ , X ₅₆ , X ₈₀ , Other Food and Kindred, (exc. meat products) (\$1000 VA)	X ₉ , X ₃₃ , X ₅₇ , X ₈₁ , Other Non- Durables (\$1000 VA)	X ₁₀ , X ₃₄ , X ₅₈ , X ₈₂ , Farm Machinery (\$1000 VA)	X ₁₁ , X ₃₅ , X ₅₉ , X ₈₃ , Other Machinery (\$1000 VA)
Labor (workers)	.1380	.1241	.1319	.1346	.1448	.1598
Land ^b	-	-	-	-	-	-
Water (gallons)						
stream I	8700	239,000				
stream II		-232,000				
treated water			119136.0	96970.3	59281.7	12135.2
waste water			-5170.0	-90109.3	-59281.7	-11216.4
Capital (dollars)			1572.2	1364.4	946.2	870.6
Net revenue (dollars)	13,130	13,130	1000	1000	1000	1000

^afor sources and derivation of data, see text.

^bthe quantity of land used is invariate with the volume of production. Therefore no coefficient need be included in the model.

Table 2. (Continued)

	Activity					
	X ₁₂ , X ₃₆ , X ₆₀ , X ₈₄ Other Durables	X ₁₃ , X ₃₇ , X ₆₁ , X ₈₅ Regulated Industries	X ₁₄ , X ₃₈ , X ₆₂ , X ₈₆ Wholesale and Retail Trade	X ₁₅ , X ₃₉ , X ₆₃ , X ₈₇ Finances, Insurances and real estate	X ₁₆ , X ₄₀ , X ₆₄ , X ₈₈ Other Services	X ₁₇ , X ₄₁ , X ₆₅ , X ₈₉ Construction and Mining
	(\$1000 VA)	(\$1000 VA)	(\$1000 VA)	(\$1000 VA)	(\$1000 VA)	(\$1000 VA)
Labor (workers)	.1343	.0819	.2100	.0510	.2021	.1412
Land	-	-	-	-	-	-
Water (gallons)						
stream I						
stream II						
treated water	80,268.2	522,978.4	8,276.8	2,608.2	31,667.3	1,261,768.9
waste water	-70,668.7	-108,312.7	-7,357.2	-2,412.6	-10,050.5	-883,582.8
Capital (dollars)	1,024.3	3,266.9	857.0	1,706.9	1,273.5	506.0
Net revenue (dollars)	1,000	1,000	1,000	1,000	1,000	1,000

commercial and residential water using activities in the town.

X₁₉, X₄₃, X₆₇, X₉₁ - Water Treatment II, which treats water withdrawn from stream II, containing effluent water from Pork Slaughter II. The main difference between Water Treatment II and Water Treatment I is the level of treatment cost per unit of water. Water Treatment II shows a higher cost, reflecting the increased pollution load caused by the Pork Slaughter II activity.

The amount by which treatment costs are increased by the effluent of Pork Slaughter II is based upon \$175 per million gallons average cost for treatment including filtration, given in Seidel and Cleasby (88, p. 1522). It is assumed that Water Treatment II is ten per cent more costly than Water Treatment I, and that Water Treatment I costs equal the average cost shown above. Water Treatment II, therefore, is \$17.50 per million gallons more expensive than Water Treatment I.

In most water treatment facilities, some proportion of total output is "unaccounted-for" water, not distributed to customers (88, p. 1509). According to the Seidel and Cleasby survey, the most frequently reported proportion was in the range of ten per cent to fifteen per cent. For this study, the mid-point of this range, a twelve and one-half per cent loss before distribution, will be assumed. Therefore, for each 1,000 gallons treated, 1138.6 gallons must be withdrawn from the stream in both Water Treatment I and Water Treatment II.

X₂₀, X₄₄, X₆₈, X₉₂ - Waste Water Treatment. This activity represents the treatment of sewage from residential and commercial activities in the town. The sewage effluent from the town is considered to be of the same quality regardless of the water's quality prior to initial treatment. Therefore, one activity is constructed to represent waste treatment under any configuration of activities and stream quality levels.

The capacity of each of the three water supply activities listed above represents the average capacity of that type of facility for all towns in Iowa of 2500 to 10,000 population in 1960. These capacities, expressed in gallons, were estimated based on data in the 1962 Inventory

of Municipal Waste Facilities (111) and the 1962 Inventory of Municipal Water Facilities (112). A ratio estimate, treatment capacity per capita, was calculated and used to estimate treatment facility capacity in the hypothetical town of 10,000. The coefficient representing capacity used per gallon of water or waste water treated is unity, since capacity in each activity is expressed in gallons.

Labor and land are not included as variable resource requirements. Interview data for selected Iowa water treatment and sewage plants showed that over a broad range of output, a fixed amount of labor is required due to process automation. In the short run, therefore, labor requirements for each treatment operation are assumed to be invariate with output. Land requirements are considered also to be invariate for the water treatment and waste treatment activities.

X_{21} - Reservoir, a storage facility, which is also used for recreation. Reservoir capacity is discussed in a later section on the model's parameters. Stored water can be released during low-flow periods for flow augmentation, either to meet withdrawal requirements or to be used for pollution abatement. Recreation use and flow augmentation of reservoir water are competing uses to some degree, since a relatively stable water level is desirable for recreation, while flow augmentation implies a fluctuating water level.

Because storage is a transfer activity, it must appear in every time period. Therefore, X_{45} , X_{69} , and X_{93} are reservoir storage activities in periods 2, 3, and 4, respectively.

The residential sector (X^R)

The residential sector contains four activities representing some of the uses of water which do not normally produce market valued output. The four activities are defined as follows:

X_{22} , X_{46} , X_{70} , X_{94} - Residential Use, based on an average use of 79,000 gallons per residence per year (66, p. 1512). This activity does not represent water used by commercial activities in the assumed municipality.

Table 3. Resource requirements and net revenue per 1000 gallons of water or waste water treated

Resource	X ₁₈ , X ₄₂ , X ₆₆ , X ₉₀ Water Treatment I	X ₁₉ , X ₄₃ , X ₆₇ , X ₉₁ Water Treatment II	X ₂₀ , X ₄₄ , X ₆₈ , X ₉₂ Waste Water Treatment
Land (acres) ^a	0	0	0
Labor (workers) ^a	0	0	0
Water intake (gallons)	1,138.6 ^b (Stream I)	1,138.6 ^b (Stream II)	1,000.0
Capacity (gallons)	1,000.0	1,000.0	1,000
Net revenue (dollar)	0	-.175 ^c	0

^aThe quantities of land and labor used are invariate with the volume of water heated. Therefore, no coefficient is required.

^bBased on 12.5 per cent loss between intake and distribution (88, p. 1509).

^cSee accompanying discussion for source and derivation.

X_{23} , X_{47} , X_{71} , X_{95} - Recreation Use of Reservoir, which represents reservation of some proportion, in this model an assumed 90 per cent, of reservoir storage for recreational uses such as swimming, boating, or fishing.

X_{24} , X_{48} , X_{72} , X_{96} - Low Flow Protection, which is a feature of Iowa's permit system (53, sect. 455A.1). Reservation of a minimum amount of flow for nonregulated uses grants these uses maximum protection of right as long as there is water in the stream. Knowledge of the opportunity cost of reserving a quantity of water for low flow protection requires that it be explicitly recognized as an activity.

Constraint parameters

In the general model shown in Chapter Five, the set of constraint parameters was defined to contain four vectors, b , \bar{X}^P , \bar{X}^S , and \bar{X}^I . The elements of the b vector represents available amounts of labor, water, and reservoir storage capacity in each time period, as well as the amount of land available annually to agricultural activities in the model. In Table 4, where the parameter values used in application I are shown, the elements of the b vector corresponding to labor, water, and reservoir storage parameters are designated b_{it} , $t = 1, \dots, 4$, denoting that the parameter value varies among the four time periods.

Elements in \bar{X}^P and \bar{X}^S , denoted by \bar{X}_i , $i = 6, \dots, 22$, are shown only as annual amounts. These parameters specify the amount of available annual capacity in producing and water-supply activities. Elements of \bar{X}^I , which represent the minimum amounts of water reserved for residential, low flow, and recreation uses, are denoted by \bar{X}_i , $i = 23, 24, 25$.

The individual constraint parameters for application I were calculated as follows:

Water - all water in the model is initially in stream I (ϕ_{1t} , $t = 1, \dots, 4$). The available runoff was based on below normal, average, and above normal rainfalls (89, p. 6), assuming that the relationship between

Table 4. Resource parameters, application I.

Resource	Available amount				
	Annual	Period 1	Period 2	Period 3	Period 4
b_1 stream I (gallons)					
above normal rainfall		1,453,525,336	1,161,429,336	462,485,334	406,848,000
normal rainfall		952,789,336	760,840,534	303,918,934	367,059,200
below normal rainfall		315,046,400	254,540,800	100,530,934	88,324,266
b_2 stream II (gallons)					
above normal rainfall		1,453,525,336	1,161,429,336	462,485,334	406,848,000
normal rainfall		952,789,336	760,840,534	303,918,934	267,059,200
below normal rainfall		315,046,400	254,540,800	100,530,934	88,324,266
b_3 labor (workers)	1,427				
b_4 reservoir (gallons)		252,896,964	252,896,964	252,896,964	252,896,964
b_5 land I (acres)	500				
b_6 land II (acres)	500				
\bar{x}_1 feed lot capital (\$)	32,200				
\bar{x}_2 corn capital (\$)	44,330				
\bar{x}_3 soybean capital (\$)	39,620				
\bar{x}_4 pork slaughter I capacity (carcasses)	478,400				

Table 4. (Continued)

Resource	Available amount				
	Annual	Period I	Period 2	Period 3	Period 4
\bar{X}_5 pork slaughter II capacity (carcasses)	166,900				
\bar{X}_6 non-durable goods capital (\$)	1,005,422				
\bar{X}_7 durable goods capital (\$)	866,810				
\bar{X}_8 regulated industries capital (\$)	3,743,972				
\bar{X}_9 wholesale and retail trade capital (\$)	3,904,438				
\bar{X}_{10} finance, insurance and real estate capital (\$)	4,705,960				
\bar{X}_{11} other services capital (\$)	4,991,927				
\bar{X}_{12} construction and mining capital (\$)	928,240				
\bar{X}_{13} water treatment capacity (gallons)	448,950.000				

Table 4. (Continued)

Resource	Available amount				
	Annual	Period 1	Period 2	Period 3	Period 4
\bar{X}_{14} waste water treatment capacity (gallons)	381,279,000				
\bar{X}_{15} residential use (gallons)	266,862,000				
\bar{X}_{16} protected low flow (gallons)		6,300,754	12,563,779	3,150,377	2,527,847
\bar{X}_{17} recreation in reservoir (gallons)		12,650,000	12,650,000	12,650,000	12,650,000
\bar{X}_{18} treated water (gallons)		0			
\bar{X}_{19} waste water (gallons)		0			

annual rainfall and annual runoff can be expressed as

$$\log (\text{annual runoff}) = -3.1 + 2.6 \left[\log (\text{annual rainfall}) \right]^8$$

It is further assumed that runoff is distributed unevenly throughout the year, with 41.7 per cent appearing in period 2; 33.3 per cent in period 2; 13.3 per cent in period 3; and 11.7 per cent in period 4, based on information given by Bennion (6, p. 11). If a 20 square mile drainage area is assumed, the amount of available water with below normal, normal, and above normal rainfall is that shown in Table 2, Appendix A.

According to Shaw (89, p. 6), each of the three ranges of rainfall discussed above is equally probably. Of the three events, below normal rainfall is the event which would create situations most conducive to water scarcity. It is conditions arising in water scarcity which this model is designed to treat. Therefore, streamflow levels and crop water requirements in this application are those which result when rainfall on the drainage area of the stream is below normal.

Stream II (b_{2t} , $t = 1, \dots, 4$) is a transfer row showing movement of water from a higher to a lower quality supply as wastes from the Pork Slaughter II activity are discharged into Stream I. The value of b_{2t} in any period depends upon the amount of water initially available in that period in Stream I and upon the amount consumed by those activities which withdraw water from Stream I. These activities are as follows:

Cattle Feed Lot -	$X_1, X_{25}, X_{49}, X_{73}$
Corn I	$X_2, X_{26}, X_{50}, X_{74}$
Corn II	$X_3, X_{27}, X_{51}, X_{75}$
Soybeans I	$X_4, X_{28}, X_{52}, X_{76}$
Soybeans II	$X_5, X_{29}, X_{53}, X_{77}$
Pork Slaughter I	$X_6, X_{30}, X_{54}, X_{78}$

⁸Merwin Dougal, Civil Engineering Department, Iowa State University, Ames, Iowa. Data on rainfall - runoff relationship. Private communication. July 3, 1969.

Pork Slaughter II	$X_7, X_{31}, X_{55}, X_{79}$
Water Treatment I	$X_{18}, X_{42}, X_{66}, X_{90}$
Reservoir	$X_{21}, X_{45}, X_{69}, X_{93}$
Low Flow Protection	$X_{29}, X_{48}, X_{72}, X_{96}$

Thus, for time period 1, b_{23} is given by the expression

$$b_{21} = b_{11} - \left[a_{11} X_1 + a_{12} X_2 + a_{13} X_3 + a_{14} X_4 + a_{15} X_5 + a_{16} X_6 + (a_{17} - a_{27}) X_7 + a_{1,21} X_{21} + a_{1,24} X_{24} \right].$$

Applying this relation to the b_{21} row yields

$$a_{11} X_1 + a_{12} X_2 + a_{13} X_3 + a_{14} X_4 + a_{15} X_5 + a_{16} X_6 + (a_{17} - 2a_{27}) X_7 + a_{1,18} X_{18} + a_{1,21} X_{21} + a_{1,24} X_{24} = b_{11},$$

which becomes the row of the A matrix representing use of the Stream II resource. For each of the other time periods in the model, the form of the corresponding Stream II row is the same as that shown above.

Land (b_5, b_6) - for each soil type in the model, Tama silty clay loam and Clarion loam, 500 acres are hypothesized to be available and irrigable annually.⁹ Land which is not irrigable due to unfavorable slope or erosion characteristics is not considered in the model.

Labor (b_3) - the annual labor resource, expressed in man-years, is 1,427 persons, calculated using the Iowa average employment in 1960 in urban places of 2,500 to 10,000 population, which is computed from data in the U. S. Census of population, 1960 (109, Table 70, p. 17-199). Labor is assumed to have no seasonal fluctuations, and is therefore expressed as an annual total.

Reservoir Capacity ($b_{4t}, t = 1, \dots, 4$) - according to Schwab (86, p. 28), a survey of ten reservoirs in Iowa showed that those which contained sufficient storage to last through the 1934 drought had an average watershed area (acres): reservoir capacity (acre-feet) ratio of

⁹500 acres for crop production is not intended to reflect any actual configuration of land use. The quantity available here is hypothetical and may be varied at will by future users of this model.

3.3. This ratio is used to determine the storage requirements for a watershed area of 20 square miles, or 12,800 acres.

Each activity in X^P , the producing sector, and X^S , the water supply sector, is constrained by its available short-run production capacity. This annual capacity limit can be expressed either as a physical or monetary amount. The capacity constraint parameters, denoted as \bar{X}_i , used in application I were computed as follows:

Feedlot Capacity (\bar{X}_1) - this activity is assumed to have available enough capital to produce 1000 fed steers, each animal requiring \$33.20 in capital, including land, buildings, and equipment (39, Table 35, p. 75).

Corn Production Capacity (\bar{X}_2) - it is assumed that this activity has sufficient capital to utilize all available land of both soil types in the model. On Tama loam, \$44.52 per acre is required (57, Table 8.1, p. 213-214); on Clarion loam, \$44.14 per acre is required (57, Table 8.1, pp. 213-214).

Soybean Production Capacity (\bar{X}_3) - soybean activities are also assumed to have sufficient capital to utilize all available land in the model. For soybean production, \$39.23 per acre is required on Tama loam, and \$38.99 per acre is required on Clarion loam (57, Table 8.2, pp. 215-216).

Pork Slaughter I and Pork Slaughter II (\bar{X}_4, \bar{X}_5) - each packing activity is limited to an annual capacity equal to production at the activity's assumed rate for 260 work days (52 weeks, 5 days per week). Pork Slaughter I operates at 230 carcasses per hour, or 1840 carcasses per work day. Its annual limit is therefore 476,400 carcasses. Pork Slaughter II operates at 310 carcasses per hour, or 2480 carcasses per work day. Its limit is therefore 644,800 carcasses per year.

Other Producing Activities (\bar{X}_6 through \bar{X}_{11}) - Capacities in activities X_8 through X_{17} are based on a capital-labor ratio computed as shown in Table 23, Appendix A, from Barnard (3). The capital stock in each major industry group is shown in Table 25, Appendix A. In computing available capital stock, some groups of activities are aggregated

because 1960 employment data in sectors corresponding to those defined in this model do not exist for urban places of 2,500 to 10,000 population (109, Table 70, p. 16-199). The capital stock in a sector activity or a major industry group of sector activities is calculated by the equation

$$\text{Capital Stock}_i = \left(\sum_{j=1}^n e_j \frac{\text{Capital}_j}{\text{Worker}_j} \right) \text{Workers}_i (1960).$$

The terms denoted by subscript j refer to sectors as defined in this study; the terms denoted by subscript i refer to major industry groups for which employment data are published specific to urban places of 2,500 to 10,000 population. The sum enclosed in parentheses represents a weighted average of capital per worker ratios in those sectors which must be aggregated to correspond with published employment data. The weights, e_j , are of the form $e_j = \frac{\text{Employment}_j}{\sum_{j=1}^n \text{Employment}_j}$, where n is the number of sectors included

in the major industry groups. $\text{Worker}_i (1960)$, the employment in the model in the i th major industry group, was calculated by allocating total labor force to the several industry groups in proportion to that industry group's share of 1960 total employment in urban places, 2,500 to 10,000 population.

Water Treatment Capacity (\bar{X}_{12}) - the sum of the outputs of both treatment activities is constrained to be no greater than the capacity of the plant. The assumed capacity is based on the average production in treatment plants serving populations of 5,000-10,000, as estimated by Seidel and Cleasby (58, Table 2, p. 1509). The average, 123 gallons per capita per day, is equivalent to 1.23 million gallons per day for a city of 10,000, or 448.95 million gallons per year.

Waste Water Treatment Capacity (\bar{X}_{14}) - a ratio of gallons of treatment capacity per capita was calculated for 48 places in Iowa of 2,500 to 10,000 population, based on data given in the 1962 Inventory of Waste Facilities (112). Estimated waste treatment capacity is 104.46 gallons per capita per day. Applying this average to a town of 10,000 population yields an estimate of 381,279,000 gallons annual capacity.

Residential Use (\bar{X}_{15}) - This constraint represents the amount of water which is reserved in the model for human consumption. In order to avoid reserving water for use by commercial or industrial users in the hypothetical town, average residential use, rather than per capita total water use, is the basis of estimated requirements. The average given by Seidel and Cleasby (88, Table 5, p. 1512), for treatment facilities with a daily output of 1.0 to 2.0 million gallons, is 79,000 gallons per year per residence.

The number of residences in the hypothetical town was estimated by using the 1960 average population per household, 2.96, in urban places 2,500 to 10,000 population (109, Table 71, p. 200). It is assumed that there is only one household per residence, so that there are an estimated 3.378 residences in the town, requiring 266,862,000 gallons per year.

Protected Low Flow (\bar{X}_{16}) - according to Hines (48, p. 44), the protected low flow in Iowa streams is generally set at that level of flow expected to be exceeded 84 per cent of the time between April and September. In applying the above standard to individual streams, protected flow may be increased or decreased according to public interest (48, p. 44). However, since the 84 per cent standard is the basis of the protected flow standard, the amount reserved for protected flow in this model is similarly calculated, in the following manner.

Log (annual rainfall) follows a normal distribution.¹⁰ The parameters of this distribution, the mean and variance, are estimated from annual rainfall data for a period of 96 years (119). The sample mean is $\bar{X} = 1.493$, and the sample variance is $s^2 = 0.0043$. Given the relationship

$\log (\text{annual runoff}) = 3.1 + 2.6 \log (\text{annual rainfall})$, the distribution of $\log (\text{annual runoff})$ can be specified as normal, with an estimated mean of

$$\bar{y} = - 3.1 + 2.6 (\bar{X}) = 0.7418$$

¹⁰Craig Beer, Agricultural Engineering Department, Iowa State University, Ames, Iowa. Data on the statistical distribution of rainfall. Private communication. July 10, 1969.

and an estimated variance of $s^2_y = 2.6^2 (s^2_x) = 2.9068$.

Based on the estimates above, the annual runoff which can be expected to be exceeded 84 per cent of the time (y^*) is given by

$$y^* = \bar{y} - t_{.84 (n-1)} s_y \quad (80, p. 92),$$

where $-t_{.84 (n-1)}$ is the point on the t-distribution such that $P [t \geq -t_{.84(n-1)}] = .84$ (80, p. 528); $n = 96$ is the sample size. The tabulated

t-value closest to $-t_{.84 (95)}$ is $-t_{.85 (90)}$ (80, Appendix 5, p. 528).

Using this approximate t-value, y^* is given by

$y^* = 0.7418 - 1.043 (1.7049) = -1.0364$, or .1085 inches of annual runoff.

Over the 20 square mile drainage basin assumed this runoff is equal to an annual flow of 37,729.066 gallons, of which 16.7 per cent (6, p.11), or 6,300,754 gallons, occurs in period I, during the month of April. During period 2, 33.3 per cent (6, p.11), or 12,563,779 gallons, occurs. During period 3, 13.3 per cent (6, p.11), or 3,150,377 gallons, occurs, and during the month of September in period 4, 6.7 per cent (6, p.11) appears, or 2,527.847 gallons.

Recreation in Reservoir (\bar{X}_{17}) - the amount of water reserved in the reservoir for recreation use is assumed to be 90 per cent of reservoir capacity.

Four additional constraints are imposed on the model. The amounts of treated water and waste water in the model are constrained to be zero, indicating no storage of treated water or sewage. In addition, Pork Slaughter II is constrained to be at a level greater than or equal to 478,400 carcasses annually, since Pork Slaughter I and Pork Slaughter II are assumed to be mutually exclusive up to the maximum available from Pork Slaughter I. The fourth constraint insures that the sum of output in Pork Slaughter I and Pork Slaughter II must be no greater than 648,400 carcasses, the maximum amount of production possible.

Application II: an Existing Water Use Situation

Application II represents the analysis of water use from a shallow sand and gravel aquifer by industrial, commercial, and residential uses in a town whose 1960 population was 4,350. The water supply and the activities which withdraw from it are not atypical of Iowa. Application II illustrates the problems encountered in applying the model developed in this study to real situations. In estimating technical coefficients and parameters for use in the model, accuracy increases as the sample size on which the estimate is based increases. Inasmuch as the resources available in governmental agencies for the collection of large amounts of primary data may be limited, an effort was made in this analysis to utilize secondary sources instead of primary sampling in estimating as many coefficients and parameters as possible.

The activities are located along a river with estimated average flow of 210 cubic feet per second. No activity considered in the model withdraws water from this stream; the only use of the stream at this point is for effluent carriage. There are no significant uses of the stream for at least 10 miles downstream¹¹ so that this river is not considered as a water supply in the model.

In this application, there are no activities whose water requirements fluctuate seasonally. Also, the water supply under study would not be expected to show significant seasonal variation in quantity.¹² Therefore, only a single, annual time period is considered.

Activities

A number of activities in application II are identical to activities in application I. Where this is the case, reference is made to that activity's definition in the discussion of application I above; where the activity is unique to application II, it is defined in paragraphs below.

¹¹Richard G. Bullard, State Water Commissioner, Des Moines, Iowa. Data on water use in Iowa. Private communication. June 30, 1969.

¹²Dr. Lyle V. Sendlein, Department of Earth Sciences, Iowa State University, Ames, Iowa. Data from a study in progress of surficial aquifer in a southwestern Iowa river bottom. Private communication. July 7, 1969.

Resource and objective function coefficients for these activities appear in Table 5.

The producing sector (X^P) There are no crop agricultural activities in application II. A soil survey of the area under consideration (110) shows very little land of a slope and soil type which would permit irrigation from the aquifer water supply under study. Therefore, only nonagricultural producing activities are considered. These activities are defined as follows:

X_1 - Pork Slaughter, which has coefficients of resource use identical with Pork Slaughter II in application I. In pumping its water from an aquifer and discharging it into a stream, this activity moves the water which it does not consume into a different water supply. For this reason, only the gross water intake coefficient is shown.

Activities X_2 through X_{10} are represented by sectors, which are defined as shown in Table 4, Appendix A.

- X_2 - sector 4: Other Food and Kindred Products,
- X_3 - sector 5: Other Non-durables,
- X_4 - sector 6: Farm Machinery,
- X_5 - sector 7: Other Machinery,
- X_6 - sector 8: Other Durables,
- X_7 - sector 9: Regulated Industries,
- X_8 - sector 10: Wholesale and Retail Trade,
- X_9 - sector 11: Finance, Insurance, and Real Estate,
- X_{10} - sector 12: Other Services,
- X_{11} - sector 13: Construction and Mining.

With the exception of X_1 , all these activities are located in the town, and are dependent upon municipal facilities for water supply and waste water treatment.

The water-supply sector (X^S) There are only two activities in the water supply sector, a water treatment activity and a waste water treatment activity. Data on which the resource coefficients of these two activities were calculated were gathered in personal interview with the

Table 5. Resource requirements and net revenue per unit of output for activities, application II

	Activities				
	X ₁ Pork Slaughter (1,000 hogs)	X ₂ Other Food and Kindred (\$1,000 VA)	X ₃ Other Non- durables (\$1,000 VA)	X ₄ Farm Machinery (\$1,000 VA)	X ₅ Other Machinery (\$1,000 VA)
Labor (workers)	.1241	.1319	.1346	.1448	.1598
Water (gallons)					
from aquifer	239,000				
treated water		119,136.0	96,970.3	59,281.7	12,135.2
waste water		-5,170.0	-90,109.0	-59,281.7	-11,216.4
Capital (dollars)		1,572.2	1,364.4	946.2	870.6
Net revenue (dollars)	13,130	1,000	1,000	1,000	1,000

Table 5. (Continued)

	X ₆ Other Durables (\$1,000 VA)	X ₇ Regulated Industries (\$1,000 VA)	X ₈ Wholesale and Retail Trade (\$1,000 VA)	Activities X ₉ Finances, Insurances, & Real Estate (\$1,000 VA)	X ₁₀ Other Services (\$1,000 VA)	X ₁₁ Construction and Mining (\$1,000 VA)
Labor (workers)	.1343	.0819	.2100	.0510	.2021	.1412
Water (gallons)						
from aquifer						
treated water	80,268.2	522,978.4	8,276.8	2,608.2	31,667.3	1,261,768.9
waste water	-70,668.7	-108,312.7	-7,357.2	-2,412.6	-10,050.5	-883,582.8
Capital (dollars)	1,024.3	3,266.9	857.0	1,706.9	1,273.5	506.0
Net revenue (dollars)	1,000	1,000	1,000	1,000	1,000	1,000

plant supervisory personnel.

X_{12} - Water Treatment, withdraws water from the same aquifer system on which the Pork Slaughter activity depends. This water is then distributed to activities within the town.

X_{13} - Waste Water Treatment, which treats waste effluent from municipal users, discharging treated water into the stream on which the town is located. Since the stream is not considered as a source in this study, the discharge from the waste treatment activity is not shown.

The residential sector (X^r) The residential sector contains only a residential use activity. There is no protected low flow activity in this model. The Iowa Water Commissioner had not found any low flow protection necessary, since there are no withdrawals being made from the stream in the reach under study.¹³ The residential use activity is defined as follows:

X_{14} - Residential Use, which requires an estimated 79,000 gallons per residence per year (88; Table 5, p. 1512).

Constraint Parameters

The general set of constraint parameters consists of four vectors, b , \bar{X}^p , \bar{X}^s , and \bar{X}^r . In application II, the b vector contains two elements, which express the annual amount of water available from the aquifer and the annual labor supply. \bar{X}^p and \bar{X}^s express the annual capacity of each of the producing activities and water supply activities, respectively. \bar{X}^r expresses the amount of water reserved in the aquifer for residential use. The individual constraint parameters, listed in Table 6, are defined as follows:

¹³Richard G. Bullard, State Water Commissioner, Des Moines, Iowa. Data on water use in Iowa. Private communication. July 3, 1969.

Water (b_1) - the maximum safe yield¹⁴ in the municipal well field was estimated at the time the wells were installed to be two million gallons per day, or an annual amount of 730 million gallons per year. This estimated capacity, however, does not include the water available from the aquifer at points other than the municipal well field.

An estimate of the total flow in the aquifer was made¹⁵ based on the following relation:

$$Q = K \cdot I \cdot A \quad (63, \text{ p. } 81),$$

where Q is total flow in the aquifer in gallons per day; K is a constant describing the permeability of the aquifer, or its ability to transmit water, in gallons per square foot per day; I is the gradient in the aquifer, in feet per horizontal foot. A represents the cross-sectional area of the water-bearing material, in square feet. Permeability (K) was assumed to be 4000 gallons per day per square foot, based on tests made in similar aquifer systems. Gradient (I) is estimated to be 13.5 feet per 1000 feet. The aquifer under study lies in a river valley, and the largest component of flow in the aquifer is from the valley wall to the stream bed. This gradient constant represents the gradient of flow in that direction, perpendicular to the direction of stream flow. A , the cross-sectional area of the water-bearing material, is estimated to be 158,000 square feet, since the bed of sand and gravel is approximately one mile wide and thirty feet deep. The quantity of water flowing in the system described above, according to the formula $Q = K \cdot I \cdot A$, is approximately 8.5 million gallons per day.

¹⁴Maximum safe yield is that rate at which water can be withdrawn from an aquifer without exceeding the rate at which the aquifer is recharged. To exceed the recharge rate in withdrawal is to incur an overdraft, which may damage the medium of the aquifer, permanently impairing the storage or transmission characteristic of the aquifer (63, pp. 101-102).

¹⁵Dr. Lyle V. A. Sendlein, Department of Earth Sciences, Iowa State University, Ames, Iowa. Data from a study in progress of surficial aquifers in a southwestern Iowa river basin. Private communication. June 30, 1969.

Table 6. Resource parameters, application II^a

	Resource	Parameter Value
b_1	aquifer (gallons)	2,372,500,000
b_2	labor (workers)	2,014
\bar{X}_1	pork slaughter capacity (carcasses)	644,800
\bar{X}_2	manufacturing capital (dollars)	2,669,952
\bar{X}_3	regulated industries capital (dollars)	3,896,166
\bar{X}_4	wholesale and retail trade capital (dollars)	2,348,734
\bar{X}_5	finance, real estate and insurance capital (dollars)	3,991,953
\bar{X}_6	other services capital (dollars)	2,182,688
\bar{X}_7	construction and mining capital (dollars)	616,640
\bar{X}_8	water treatment capacity (gallons)	365,000,000
\bar{X}_9	waste water treatment capacity (gallons)	182,500,000
\bar{X}_{10}	residential use (gallons)	133,431,000

^aRefer to text for sources and derivation.

A second estimate of capacity was made, based on base flow¹⁶ in the stream flowing through the valley in which the aquifer is located. After an extended period of little or no rainfall, the flow in the river, which comes largely from ground water sources, represents a portion of the water flowing in the aquifer. Analysis of stream flow records in the basin and particular hydrologic conditions near the point of study in the stream yielded a preliminary estimate of base flow of 10 cubic feet per second, or approximately 6.5 million gallons per day. Thus, all withdrawals from the aquifer may total as much as 6.5 million gallons per day without causing flow in the stream to disappear.

Inasmuch as the disappearance of stream flow may have serious effects on downstream uses, the limiting capacity of the aquifer will be assumed to be 6.5 million gallons per day, or 2372.5 million gallons per year.

Labor (b₂) - Defining the labor force available to the activities in this model is a difficult task, since there are few indicators of how many people located outside the municipal boundary travel to town to work. In this study, it is assumed that the available labor force is 2014 workers. Labor force was estimated by calculating the proportion of 1960 county employment which was located in the town, for seven major industry groups as shown in Table 26, Appendix B. These proportions were then applied to estimates of 1967 county employment, by the same seven industry groups. These employment estimates were made by Dr. Marvin Julius, of the Department of Economics, Iowa State University. The resulting employment estimates are shown in Table 26, Appendix B. The total of employment in these industry groups is the assumed labor force.

Pork Slaughter Capacity (\bar{X}_1) - this parameter is the number of carcasses which could be processed annually at a rate of 310 carcasses per hour, which is 644,800 carcasses.

¹⁶Base flow is that flow in a stream which originates not as surface runoff, but as inflow from an aquifer (63, p. 39).

Capacity in other producing activities (\bar{X}_2 through \bar{X}_{10}) - the amount of available capital stock for each of these activities is calculated by the same method used to calculate this parameter for these same activities in application I above. The relationship used is

$$\text{Capital Stock}_i = \left(\sum_{j=1}^n e_j \frac{\text{capital}_j}{\text{worker}_j} \right) \text{workers}_i (1967), \text{ where}$$

the term enclosed in parentheses represents a weighted average of capital per worker ratios in those sectors defined in this study (Table 23, Appendix A) which must be aggregated in order to compare with employment data for the major industry groups shown in Table 1, Appendix B. The term, $\text{workers}_i (1967)$, is the estimated employment in the i th major industry group, as shown in Table 26, Appendix B. The calculated capital stocks are shown in Table 27, Appendix B.

Water Treatment Capacity (\bar{X}_{11}) - the capacity of the municipal treatment plant is one million gallons per day, or 365 million gallons per year.

Waste Water Treatment (\bar{X}_{12}) - the capacity of the waste treatment facility is 500,000 gallons per day, or 182.5 million gallons per year.

Residential Use (\bar{X}_{13}) - the amount of water reserved for residential use is based on an estimated population of 5000 and an average annual requirement of 79,000 gallons per residence (88, Table 5, p. 1512). Assuming 2.96 persons per household (109, Table 71, p. 200) and one household per residence, there are approximately 1689 residences requiring 79,000 gallons each per year, or 133,431,000 gallons per year.

Based on the data described in this chapter, the two model applications were solved. The results of these solutions, as well as a summary of the study, are contained in the following chapter.

CHAPTER SEVEN: RESULTS OF GENERAL MODEL SOLUTIONS

Solution of the model, in either application I or application II, yields a vector of optimum activity levels which is unique to the particular set of constraints and parameters in the problem. In general, a change in either the constraints or parameters of the problem will cause the solution vector to be changed. Therefore, by solving each application repeatedly under various sets of constraints or parameters, certain comparisons can be made which will be valuable in reaching a conclusion with respect to the hypothesis developed in Chapter Four.

The initial solution of each application was reached using the data and relationships described in Chapter Six. This solution is the basis for subsequent comparisons within the framework of each application. The initial solution determines optimum activity levels, optimum water use and allocations, and the optimum value of marginal product of water. The value of the objective function in this solution represents the value added in production when a scarce water resource is optimally allocated.

The second solution of each application approximates the actual pattern of water use by forcing the level of each producing activity to be equal to the estimated actual output of that activity in the year which the particular data used represents. This solution determines a new value of the objective function for each application which is less than or equal to the value determined in the initial solution. These two values define a range over which the permit system could, if properly operated, improve the value added in production which utilizes the particular water sources under study. This range of values of the objective function indicates the potential gain to the hydrologic area from optimum allocation under the permit system. Each of the solutions listed above is described in this chapter.

Results of Application I

Tables 7a, 7b, and 7c show the results of the initial solution of application I. This solution is based on the data described in Chapter Six. Table 7a shows water to be a constraining resource in this situation, but not throughout the year. The supply of water in Stream I is exhausted only in Periods 3 and 4, which are low rainfall periods.¹ This shortage serves to provide in this initial optimum solution, a baseline against which the comparisons previously discussed can be made.

Before any comparisons are undertaken, several points of interest should be noted in the initial solution. First, the scarce water resource is Stream I, which carries the relatively unpolluted effluent of the Pork Slaughter I activity. The relative abundance of Stream II, which carries the more polluted effluent of Pork Slaughter II, indicates that the scarcity arises from the degradation of water in Stream I. The shadow price of this water, \$0.15 per thousand gallons, represents the value of marginal product of Stream I water. This value can be interpreted in several ways within the restrictions of the model. The \$0.15 is the dollar benefit which would be realized from every additional thousand gallons of Pork Slaughter II effluent returned to the original quality of the stream, whether by the pork processor or by the town. \$0.15 is also the opportunity cost associated with the loss of one thousand gallons of less polluted water. This cost, as well as the municipal treatment cost and the cost of adequate treatment at the source of pollution, are data which can be used in analysis of this production diseconomy. Such an analysis is beyond the scope of this study and is not attempted here.²

¹See Figure 3, Chapter Six for a depiction of rainfall by periods.

²For discussion of an analytical technique which would apply to this particular external effect, see Turvey (107)

Table 7a. Initial solution of application I, seasonal resource use

Objective function value: \$17,480,639.99

Resource	Resource used (gallons)	Unused Resource (gallons)	Shadow Price (dollars)
Period 1:			
Stream I	267,339,726	47,706,674	0
Stream II	229,913,857	85,132,543	0
Reservoir Capacity	12,650,000	0	0.00015
Period 2:			
Stream I	90,240,024	164,300,775	0
Stream II	77,764,735	177,676,065	0
Reservoir Capacity	12,650,000	0	0.00015
Period 3:			
Stream I	100,404,934	0	0.00015
Stream II	95,823,946	4,670,988	0
Reservoir Capacity	12,650,000	0	0.00015
Period 4:			
Stream I	88,324,266	0	0.00015
Stream II	76,656,645	11,667,620	0
Reservoir Capacity	12,650,000	0	0.00015

Table b. Initial solution of Application I, nonseasonal resource use

Resource	Resource used	Unused Resource	Shadow Price (dollars)
Labor (workers)	1,427	0	4,687.46
Land I (acres)	0	500	0
Land II (acres)	0	500	0
Cattle Feed Lot Capital (dollars)	0	33,200	0
Corn Capital (dollars)	0	44,330	0
Soybean Capital (dollars)	0	39,260	0
Pork Slaughter I Capacity (carcasses)	476,800	0	12.48
Pork Slaughter II Capacity (carcasses)	168,000	0	12.55
Non-durable Goods Capital (dollars)	1,005,422	0	0.16373
Durable Goods Capital (dollars)	866,810	0	0.26142
Regulated Industries Capital (dollars)	0	3,743,972	0
Wholesale and Retail Trade Capital (dollars)	669,641	3,234,797	0
Finance, Real Estate and Insurance Capital (dollars)	4,705,960	0	0.44
Other Services Capital (dollars)	4,491,927	0	0.01
Construction and Mining Capital (dollars)	0	928,240	0
Water Treatment Capacity (gallons)	448,950,000	0	0.001
Waste Water Treatment Capacity (gallons)	381,279,000	0	0.001
Additional Water Treatment Capacity required (gallons)	99,550,400		
Additional Waste Water Treatment Capacity required (gallons)	23,147,800		

Table 7c. Initial solution of application I, optimum activity levels

Seasonal Activities:	Activity Level	Reduced Revenue
Period 1:		
Cattle Feed Lot	0	5,823.07
Pork Slaughter I (carcasses)	237,752	0
Pork Slaughter II (carcasses)	80,659	0
Water Treatment I (gallons)	215,496,000	0
Water Treatment II (gallons)	2,128,075	0.175
Waste Water Treatment (gallons)	107,736,000	0
Storage (gallons)	0	0.00015
Recreation (gallons)	12,625,000	0.00015
Residential Use (gallons)	89,959,632	0.00015
Low Flow (gallons)	629,989,000	0
Period 2:		
Corn I (bushels)	0	879.49
Corn II (bushels)	0	1,020.16
Soybeans I (bushels)	0	2,940.72
Soybeans II (bushels)	0	3,502.22
Pork Slaughter I (carcasses)	76,584	0
Pork Slaughter II (carcasses)	26,886	0
Water Treatment I (gallons)	71,122,650	0
Water Treatment II (gallons)	709,350	0.175
Waste Water Treatment (gallons)	35,912,000	0
Storage (gallons)	100,000	0
Recreation (gallons)	12,625,000	0.00015
Residential Use (gallons)	30,313,089	0.00015
Low Flow (gallons)	1,259,979	0
Period 3:		
Corn I (bushels)	0	223.25
Corn II (bushels)	0	223.25
Soybeans I (bushels)	0	1,018.87
Soybeans II (bushels)	0	1,206.38
Pork Slaughter I (carcasses)	85,840	0
Pork Slaughter II (carcasses)	33,608	0
Water Treatment I (gallons)	80,196,530	0
Water Treatment II (gallons)	9,593,470	0
Waste Water Treatment (gallons)	86,657,000	0
Storage (gallons)	0	0.00015
Recreation (gallons)	12,525,000	0.00015
Residential Use (gallons)	89,790,000	0.00015
Low Flow (gallons)	504,044	0

Table 7c. (Continued)

Seasonal Activities:		
	Activity Level	Reduced Revenue
Period 4:		
Corn I (bushels)	0	364.00
Corn II (bushels)	0	504.66
Soybeans I (bushels)	0	2,191.38
Soybeans II (bushels)	0	2,566.48
Pork Slaughter I (carcasses)	76,584	0
Pork Slaughter II (carcasses)	26,886	0
Water Treatment I (gallons)	71,122,650	0
Water Treatment II (gallons)	709,350	0
Waste Water Treatment (gallons)	42,145,810	0
Recreation (gallons)	12,625,000	0.00015
Residential Use (gallons)	56,829,164	0.00015
Low Flow (gallons)	251,890	0

Table 7c. (Continued)

Non-Seasonal Activities:	Activity Level (dollars)	Reduced Revenue (dollars)
Other Food & Kindred	639,500	0
Other Non-durable Goods	0	41.41
Farm Machinery	0	44.66
Other Machinery	995,646	0
Other Durable Goods	0	48.24
Regulated Industries	0	15.19
Wholesale and Retail Trade	781,400	0
Finance, Insurance, and Real Estate	2,757,000	4.82
Other Services	3,919,848	0
Construction and Mining	0	1,807.22

The second point of interest is that the initial solution shows that two of the reserved water uses, residential use and recreation, show a "reduced revenue"³ value of \$0.15 per thousand gallons reserved. This is consistent with the fact that water reserved for these uses is withdrawn from Stream I, and is equivalent, therefore, to a reduction in Stream I flow. The low flow protection activity, however, does not "cost" anything in terms of the objective function value, since low flow can be reserved from Stream II, which is abundant. In situations of water scarcity, the reduction of reserved use levels would achieve the same increase in the objective function value as an increase in water supply, and should be considered explicitly as an alternative to the development of a new supply.

It is also of interest to note the presence to the Storage activity in period 2, representing the transfer of Stream I water from period 2 into period 3 for subsequent use. Optimal allocation of a scarce water resource may require, in just the fashion represented in the model, that water be stored in times of adequate flow to be used in later time periods. The need for such storage would arise from differences in the time pattern of water requirements and the pattern of seasonal water availability. It can also be seen that the discharge of this stored water in period 3 has decreased the amount of water available for recreation in period 3, during which the stored water is used. This drawdown of the reservoir level illustrates the conflict between recreation and intertemporal water transfer discussed in Chapter Six and points to the possibility of some point of intersection between the demand for water in its recreational role and the demand for water in its role as an input to production. If a positive value in the objective function could be established for recreation, comparable to the

³"Reduced revenue", shown in Table 7c, denotes the amount by which the value of the objective function would be decreased if a non-basis activity were included in the basis at unit level. Conversely, it shows the increase in the objective function due to reduction of any activity which is forced into the solution at a minimum level.

positive values of each producing activity, the model would indicate this optimum point of intersection, at which water would be of equal value in each role.

A modification was required in the model in both application I and application II. It was necessary to introduce real disposal activities⁴ into each matrix which correspond to the constraints on water treatment capacity and waste water treatment capacity. In both applications, these capacities are not sufficient to process the entire water supply, which must be done if water is to be exhausted. The effect of a disposal activity associated with either treatment capacity constraint is to indicate, by the optimum level of the disposal activity, how much additional capacity is required to treat all available water, either initially or as waste water. The additional capacity required for treatment in the initial solution of application I is shown in Table 7b.

The second solution of application I is made subject to a set of bounds, one for each producing activity in the model. These bounds approximate the outputs which might have resulted in each of the producing activities in 1960, the year the data represent, had this hypothetical situation existed. Each agricultural activity and both Pork Slaughter processes are bound at their maximum levels determined by the smallest value which land or capital would allow in each case. The remainder of the producing activities, the aggregate sectors, were bound at the level which would result if the remaining labor in the model were distributed as it was distributed among the same sectors in Iowa in 1960. (75, Table 33, p. 131 shows this distribution). Table 8 shows the distribution of labor and the pertinent output bound fixed for each producing activity. Seasonal activities are not restricted seasonally, but only in total so that the model is free to allocate production among time periods.

⁴A disposal activity is represented by a vector X_j in which all elements except one are zero. The single non-zero element, which has a value of minus one, is in the row representing the resource to which the disposal activity corresponds.

Table 8. Distribution of labor force among producing activities; output bounds used in application I

Activity	Labor used (workers)	Output with maximum labor use ^a	Maximum output is ^b
Cattle Feed Lot	5	1000 hd. ^c	1000 hd.
Corn I	0.6	24,310 bu. ^c	24,310 bu.
Corn II	0.5	22,730 bu. ^c	22,730 bu.
Soybeans I	0.7	8,550 bu. ^c	8,550 bu.
Soybeans II	0.5	7,530 bu. ^c	7,530 bu.
Pork Slaughter I	65.8	476,000 carcasses ^c	476,800 carcasses
Pork Slaughter II	20.8	168,000 carcasses ^c	168,000 carcasses
Other Food and Kindred products	57.2	\$ 433,666	\$ 350,126 ^c
Other Non-durable Goods	70.6	\$ 524,517	\$ 333,446 ^c
Farm Machinery	42.0	\$ 290,055	\$ 144,926 ^c
Other Machinery	65.6	\$ 410,513	\$ 242,639 ^c
Other Durable Goods	84.9	\$ 632,167	\$ 505,971 ^c
Regulated Industries	127.0	\$1,550,672	\$1,146,032 ^c
Wholesale and Retail Trade	391.5	\$1,864,286 ^c	\$4,555,937
Finance, Insurance, and Real Estate	73.2	\$1,435,294 ^c	\$2,757,021
Other Services	311.1	\$1,539,337 ^c	\$3,919,848
Construction and Mining	109.3	\$ 774,079 ^c	\$1,834,466

^aThis is the output which would be achieved if all allocated labor were used.

^bThis is the maximum output which either capacity or capital will allow.

^cThese values were chosen as output bounds.

In setting output bounds, it was necessary to compare the production which would result in any activity from total use of allocated labor with the maximum production possible given that activity's capital stock. In order to avoid infeasibility⁵, the lower of these two maxima was chosen as the output bound in the second solution, as indicated in Table 8.

The activity level and levels of resource use in the second solution are shown in Table 9a, 9b, and 9c. Comparison of the first two solutions shows immediately that the initial solution makes far more efficient use of the resources in the model. The value of the objective function of the initial solution is \$3,073,291.06 higher than the value of the objective function in the second solution. This difference in the value of output in the two situations under consideration shows, within the limitations of the model, how much greater benefits would be received in the model area if scarce resources were reallocated optimally among the alternative producers of the model.

Table 9a also shows that water from Stream I is the constraining resource in this solution and that this scarcity occurs only in periods 3 and 4. This table further shows the shadow price of water to be \$0.15 per thousand gallons, which is equal to the shadow price of water in the previous solution. Thus, in this situation and over the range of these two solutions, the shadow price of water does not vary, even though the allocation of the resource and the value of output resulting from its use may vary widely.

These two solutions have shown, with certain restrictions to be discussed in a later section, the magnitude of the increase in total value of production which might be realized if scarce resources were optimally allocated. The upper end of a range is therefore constructed over which the permit system might increase the value of production which utilizes this stream as a source of water input.

⁵An infeasible solution is one in which one or more of the constraints in the linear program cannot be met.

Table 9a. Second solution of application I; seasonal recourse use

Objective function value: \$14,407,348.93

Resource	Resource used (gallons)	Unused Resource (gallons)	Shadow Price (dollars)
Period 1:			
Stream I	269,149,726	45,896,674	0
Stream II	231,723,857	83,322,543	0
Reservoir Capacity	12,650,000	0	.00015
Period 2:			
Stream I	90,268,624	164,272,176	0
Stream II	77,793,334	176,747,465	0
Reservoir Capacity	12,650,000	0	.00015
Period 3:			
Stream I	100,494,934	0	.00015
Stream II	95,823,946	4,670,988	0
Reservoir Capacity	12,650,000	0	.00015
Period 4:			
Stream I	88,324,266	0	.00015
Stream II	76,656,646	11,667,620	0
Reservoir Capacity	12,650,000	0	.00015

Table 9b. Second solution of application I, nonseasonal resource use

Resource	Resource Used	Unused Resource	Shadow Price (dollars)
Labor (workers)	1,290	137	0
Land I (acres)	500	0	— ^a
Land II (acres)	500	0	— ^a
Cattle Feed Lot Capital (dollars)	33,200	0	— ^a
Corn Capital (dollars)	22,075	22,255	0
Soybean Capital (dollars)	19,471	20,149	0
Pork Slaughter I Capacity (carcasses)	476,800	0	— ^a
Pork Slaughter II Capacity (carcasses)	168,000	0	— ^a
Non-durable Goods Capital (dollars)	1,005,422	0	— ^a
Durable Goods Capital (dollars)	866,637	173	0
Regulated Industries Capital (dollars)	3,743,972	0	— ^a
Wholesale and Retail Trade Capital (dollars)	1,597,693	2,306,745	0
Finance, Insurance, and Real Estate Capital (dollars)	2,449,903	2,256,057	0
Other Services Capital (dollars)	1,960,346	3,031,581	0
Construction and Mining Capital (dollars)	391,684	536,556	0
Water Treatment Capacity (gallons)	448,950,000	0	.00083
Waste Water Treatment Capacity (gallons)	381,279,000	0	.001
Additional Water Treatment Capacity required (gallons)	116,042,666		
Additional Waste Water Treatment Capacity required (gallons)	161,298,000		

^aNo shadow price is given in the solution for these resources because they were not entirely consumed; in each case the unconsumed portion was less than 0.001 units. This difference disappears in rounding, but is sufficient to cause a zero shadow price.

Table 9c. Second solution of application I, optimum activity levels^a

Activities	Activity Level
Cattle Feed Lot (head)	1,000
Corn I (bushels)	24,310
Corn II (bushels)	22,730
Soybeans I (bushels)	8,550
Soybeans II (bushels)	7,350
Pork Slaughter I (carcasses)	476,800
Pork Slaughter II (carcasses)	168,000
Water Treatment I (gallons)	438,637,177
Water Treatment II (gallons)	10,302,822
Waste Water Treatment (gallons)	381,279,000
Storage (gallons)	100,000
Recreation (gallons)	50,500,000
Residential Use (gallons)	266,891,866
Low Flow (gallons)	2,645,902
Other Food & Kindred Products (dollars)	350,126
Other Non-durable Goods (dollars)	333,446
Farm Machinery (dollars)	144,926
Other Machinery (dollars)	242,639
Other Durable Goods (dollars)	505,971
Regulated Industries (dollars)	1,146,032
Wholesale and Retail Trade (dollars)	1,864,286
Finance, Insurance, and Real Estate (dollars)	1,435,294
Other Services (dollars)	1,539,337
Construction and Mining (dollars)	774,079

^aSeasonal activities are not shown because the large number of constraints to which the model was subject caused the water supply activities in any period to be inconsistent with the levels of water using activities in that period.

Results of Application II

The results of the initial solution of application II are shown in Tables 10a and 10b. The data which this solution represents are those discussed in Chapter Six. In this situation, the water supply is not exhausted; the constraining resource is the capacity of the waste water treatment activity. Since a portion of the water supply remains unused, its shadow price is zero. Optimum allocation in this case is that allocation which allows each water user to use water up to the point where the value of marginal product of water in that use becomes zero. In Chapter Three, it was shown that this is the amount of water which each user will require if the water is free, as it is in this case. Allocation in this situation is not critical, except for the possibility of waste, wherein a water user's production function becomes horizontal at its maximum waste used in this type of process will never have a negative vmp, which would discourage further use of the resource, and there is no loss to the producer if he continues to withdraw.

In order to find the point where water supplies, which flow at a relatively constant rate in application II, become scarce the requirements for water must be increased. This is done by increasing the value of all constraint parameters except those in the water supply sector (water supply itself, water treatment capacity, and waste water treatment capacity). In this case, the appropriate parameter values were doubled. In addition, as discussed in the section dealing with application I, two real disposal activities were included in the matrix. One is associated with water treatment capacity, the other with waste water treatment capacity. The effect of these two activities in the optimum solution is to indicate by how much the capacities of these treatment facilities must be increased to accommodate the higher water requirements. Such information would be of use in planning the need for capital expenditures in water supply facilities.

Table 10a. Initial optimum solution of application II (original constraints)

Objective function value: \$18,997,170.20

Activity	Optimum Level	Reduced Revenue (dollars)
Pork Slaughter (carcasses)	644,800	0
Other Food and Kindred Products (dollars)	0	666.54
Other Non-durable Goods (dollars)	0	1,236.84
Farm Machinery (dollars)	0	521.62
Other Machinery (dollars)	3,066,753	0
Other Durable Goods (dollars)	0	707.19
Regulated Industries (dollars)	15,926	0
Wholesale & Retail Trade (dollars)	2,845,722	0
Finance, Insurance, and Real Estate (dollars)	2,338,714	0
Other Services (dollars)	1,713,830	0
Construction and Mining (dollars)	0	7,157.70
Water Treatment (gallons)	263,484,232 gal.	0
Waste Water Treatment (gallons)	180,000,000 gal.	0
Residential Use (gallons)	133,431,000 gal.	0

Table 10b. Initial optimum solution of application II (original constraints)

Resource	Level of Resource Use	Unused Resource	Shadow Price
Labor (workers)	1,635	379	0
Aquifer (gallons)	417,591,432	1,954,908,568	0
Pork Slaughter Capacity (carcasses)	644,800	0	13.13
Manufacturing Capital (dollars)	2,669,952	0	1.03
Regulated Industries Capital (dollars)	52,030	3,844,086	0
Wholesale & Retail Trade capital (dollars)	2,438,733	0	1.09
Finance, Insurance and Real Estate Capital (dollars)	3,991,953	0	0.57
Other Services Capital (dollars)	2,182,688	0	0.71
Construction and Mining Capital (dollars)	0	616,640	0
Water Treatment Capacity (gallons)	263,484,232	101,515,768	0
Waste Water Treatment Capacity (gallons)	180,000,000	0	0.009

Table 11. Revised resource parameters, application II

Resource	Parameter Value
b_1 Aquifer (gallons)	2,372,500,000
b_2 Labor (workers)	4,028
\bar{X}_1 Pork Slaughter (carcasses) Capacity	1,289,600
\bar{X}_2 Manufacturing (dollars) Capital	5,339,904
\bar{X}_3 Regulated Industries (dollars) Capital	7,792,232
\bar{X}_4 Wholesal & Retail (dollars) Trade Capital	4,877,466
\bar{X}_5 Finance, Insurance, (dollars) and Real Estate Capital	7,983,906
\bar{X}_6 Other Services (dollars) Capital	4,365,376
\bar{X}_7 Construction and (dollars) Mining Capital	1,233,280
\bar{X}_8 Water Treatment (gallons) Capacity	365,000,000
\bar{X}_9 Waste Water (gallons) Treatment Capacity	180,000,000
\bar{X}_{10} Residential Use (gallons)	266,862,000

A time horizon can be roughly estimated over which the aquifer under study will be sufficient to meet the needs of activities represented in application II. According to projections by Maki (64, Table 4, p. 8), population in the middle Missouri River basin area of Iowa, where this aquifer is located, is expected to double by the year 2020. Given a constant rate of participation in the labor force, constant production coefficients, and constant ratios of capital stock among the activities in the model, it will be at least fifty years before the supply of water in this aquifer becomes critical.

The increased values of the constraints are shown in Table 11 and the solution of the model using these constraints is shown in table 12a and 12b. A water shortage now exists; consequently, the water resource has a positive shadow price. This solution establishes a base against which comparisons can be made, assessing the possible operation of the permit system in this situation.

Note that in neither optimum solution is labor a scarce resource. This indicates that, given the existing capital - labor ratios and capital stocks in each activity, there is excess labor relative to capital as an input. Regardless of the availability of other resources, such as land or water, labor will always be in excess in this model. The inconsistency between the estimates of capital stock and labor can likely be traced to inconsistencies among the several sources from which the estimates were drawn. In any actual application of the model, it would be necessary to resolve these differences in data wherever possible, so that the productive potential of any activity will not be underestimated.

It would seem intuitively correct that if all resources except water were doubled in value, the activity levels and the value of the objective function would also double. This is not the case, however, in application II. The value of the objective function more than doubled, from approximately \$19 million to approximately \$41 million. Also, the mix of activities changed significantly, with several activities

Table 12a. Initial optimum activity levels, application II, using revised constraint parameters

Objective function value: \$41,081,687.60

Activity	Optimum Level	Reduced Revenue (dollars)
Pork Slaughter (carcasses)	1,289,600	0
Other Food and Kindred Products (dollars)	0	882.59
Other Non-durable Goods (dollars)	0	628.75
Farm Machinery (dollars)	0	123.22
Other Machinery	6,133,506	0
Other Durable Goods (dollars)	0	228.64
Regulated Industries (dollars)	2,385,223	0
Wholesale and Retail Trade (dollars)	5,691,445	0
Finance, Insurance and Real Estate (dollars)	4,677,428	0
Other Services (dollars)	3,427,661	0
Construction and Mining (dollars)	1,833,977	0
Water Treatment (gallons)	365,000,000	-0.00079
Waste Water Treatment (gallons)	180,000,000	-0.00079
Residential Use (gallons)	266,862,000	0.00079
Additional Water Treatment Capacity Required (gallons)	1,699,285,600	
Additional Waste Water Treatment Capacity Required (gallons)	2,055,370,640	

Table 12b. Initial optimum levels of resource use, application II, using revised constraint parameters

Resource	Level of Resource Use	Used Resource	Shadow Price (dollars)
Labor (workers)	3,721	307	0
Aquifer (gallons)	2,372,500,000	0	0.00079
Pork Slaughter Capacity (Carcasses)	1,289,600	0	12.94
Manufacturing Capital (dollars)	5,339,904	0	1.13
Regulated Industries Capital (dollars)	7,792,232	0	0.18
Wholesale & Retail Trade (dollars)	4,877,466	0	1.16
Finance, Insurance, & Real Estate Capital (dollars)	7,983,906	0	0.58
Other Services Capital (dollars)	4,365,376	0	0.76
Construction and Mining Capital (dollars)	928,055	305,225	0
Water Treatment Capacity (gallons)	365,000,000	0	0.00079
Waste Water Treatment Capacity (gallons)	180,000,000	0	0.00079

increasing by large amounts given the increased resource parameters. These disproportionate increases are due in part to the existence of a completely new set of resource constraints and in part to the introduction of the disposal activities described above, which eliminated the constraining effect of waste water treatment capacity.

Having obtained the baseline optimal solution of application II, another solution was generated in which each production activity was forced to equal a particular value. This value approximates, within the limitations of the data, the actual relative rates of production in each activity in 1960, the year represented by the data in the model. These rates are projected into 2020 A.D., in accordance with the population projection discussed earlier. It is necessary to project the rates in order to insure that water used will have a positive shadow price. The fixed bounds on output were calculated by allowing each producing activity, with one exception, to use labor at the same rate as in 1960, as indicated in Table 22, Appendix B. The single exception is the pork slaughter activity, which was forced to operate at maximum capacity, since this is the rate of output indicated by personal interview with packing plant officials. In the case of the Manufacturing sector indicated in Table 16, Appendix A, it was necessary to apportion the labor force among the sectors, Other Food & Kindred Products, Other Non-durable Goods, Farm Machinery, and Other Durable Goods. Table 13 shows the labor force distribution and the values of the output bounds for application II. The 702 workers in the manufacturing sector were distributed among the activities on the basis of that activity's share of total employment in manufacturing in Iowa in 1960 (75, Table 33, p. 131).

In order to avoid infeasibility in the second solution, it was necessary to compare the bounds calculated above with the maximum production which the given capital stock would allow in any activity. In those activities where the use of all allocated labor was not possible because of the capital constraint, the lower output was used as an output

Table 13 Distribution of labor force among producing activities;
output bounds used in application II

Activity	Labor used (workers)	Output with Maximum labor use ^a	Maximum output ^b
Pork slaughter	160	1,289,600 ^c carcasses	644,800 carcasses
Other Food & Kindred Products	124	\$ 943,000	\$ 603,800 ^c
Other Non-durable Goods	154	\$1,150,000	\$ 866,400 ^c
Farm Machinery	92	\$ 638,200 ^c	\$ 744,600
Other Machinery	142	\$ 893,600 ^c	\$1,252,800
Regulated Industries	256	\$3,076,800	\$2,385,800 ^c
Wholesale and Retail Trade	1,238	\$5,876,000	\$5,798,000 ^c
Finance, Insurance and Real Estate	246	\$4,784,200	\$4,679,800 ^c
Other Services	1,066	\$5,264,600	\$3,430,000 ^c
Construction	376	\$2,634,600	\$2,437,200 ^c
Other Durable Goods	186	\$1,379,000 ^c	\$1,380,200

^aThis output would result if all the labor allocated to any activity were used.

^bThis is the maximum output which the given capital stock will allow.

^cThese output limits were used as output bounds in the second solution.

bound. This allows the linear program to proceed to a feasible optimal solution, in which all output bounds are satisfied.

Having specified the value of each producing activity, only the water supply vectors are allowed to change. However, the shadow price of water and the objective function value in this situation are the items of primary interest. The optimum solution given using these constraints is shown in Tables 14a and 14b.

A serious modification of the model was required in the second solution of application II. The total water use by all activities bound at the given levels is more than the total annual supply of water available from the aquifer source. Such a situation could easily arise in reality, since the aquifer parameter represents the maximum safe yield of the aquifer; an overdraft may be incurred, but damage to the aquifer would likely result. To account for this additional water requirement, a disposal activity was included which corresponds to the aquifer resource and which shows how much water would have to be withdrawn beyond the maximum safe yield. By first solving the model with the disposal activity unbounded, and then solving again with the activity bounded at the level given by the previous solution, a positive shadow price can be found which represents the vmp of a unit of water supplied either by incurring a further overdraft or by developing a new supply. A direct comparison can still be made between solutions, but it must be remembered that the solutions differ not only with respect to the value of the objective function and the vmp of water, but also with respect to the quantity of water used.

Comparison of the two solutions shows that although more water is used in the second solution than the first, the value of the objective function is smaller. This indicates clearly that the greatest return to the scarce water supply is not being realized in the projected allocation. It can be seen that optimal allocation will increase the total value added in the area by more than \$1 million, and that the rate of water use can also be made significantly lower, avoiding an overdraft of the aquifer.

Table 14a Optimum activity levels second solution of application II

Activity	Optimum Level	Reduced Revenue ^a
Pork Slaughter (carcasses)	1,289,600	-13,130.00
Other Food and Kindred Products (dollars)	603,800	- 1,000.00
Other Non-durable Goods (dollars)	866,400	- 1,000.00
Farm Machinery (dollars)	638,200	- 1,000.00
Other Machinery (dollars)	893,600	- 1,000.00
Other Durable Goods (dollars)	1,379,000	- 1,000.00
Regulated Industries (dollars)	2,385,800	- 1,000.00
Wholesale and Retail Trade (dollars)	5,798,000	- 1,000.00
Finance, Insurance and Real Estate (dollars)	4,679,800	- 1,000.00
Other Sources (dollars)	3,430,000	- 1,000.00
Construction and Mining (dollars)	2,437,200	- 1,000.00
Residential Uses (gallons)	266,862,000	0.00079

^a Negative Reduced Revenue values indicate that the objective function value would increase if any activity with a negative coefficient were increased.

Table 14b Optimum levels of resource use, second solution of application II

Objective function value: \$39,919,070.00

Resource	Resource Used	Unused Resource	Shadow Price (dollars)
Labor (workers)	3,442	586	0
Aquifer (gallons)	2,372,500,000	0	0.00079
Pork Slaughter Capacity (carcasses)	1,289,600	0	12.94
Manufacturing Capital (dollars)	4,922,735	417,169	0
Regulated Industries Capital (dollars)	7,792,232	0	0.18
Wholesale and Retail Trade Capital (dollars)	4,877,466		1.16
Finance, Insurance & Real Estate Capital (dollars)	7,982,906		0.58
Other Services Capital (dollars)	4,365,176		0.76
Construction and Mining Capital (dollars)	1,233,671	99,609	0
Water Treatment Capacity (gallons)	365,000,000		0.00079
Waste Water Treatment Capacity (gallons)	180,000,000		0.00079
Additional Water required (aquifer overdraft -gallons)	241,022,003		

The shadow price of water in this application remains constant between the two solutions, reinforcing the earlier conclusion that the shadow price of water is apparently stable over some range of possible allocations.

The point was made in Chapter Three that it is not possible to specify how the permit system will react to a water shortage. However, it can be concluded from the analysis presented in this chapter that the existence of an optimizing mechanism within the permit system would allow that system to achieve significant increases in the returns to water in a given area.

Limitations of the General Model

Each application of the general model developed in this study possesses certain characteristics and flows which limit the applicability of the conclusion drawn above. Explicit mention of these limitations of the analysis is necessary in order to place the study in its proper perspective. In application I, a hypothetical situation was created so that water allocation among diverse alternative uses could be examined. The hypothetical situation required that average data be used in calculating the production coefficients for each activity, and in drawing the parameters of the model. These average data, such as that determined by using sector aggregates as activities, may not be representative of the production function of any single component of the average, such as a single firm in one of the sectors of the model. Furthermore, the reliability of many of the estimates cannot be determined empirically, since these estimates are not based upon any statistical sampling technique.

The linear nature of the production functions used in this study for each producing activity is the source of two difficulties. The first difficulty became evident above in selecting those activities which would become part of the final solution in each application. This

solution is intended to approximate the permit system allocation, in that each water user in the solution is given water up to the point of maximum use. However, the point of maximum use was defined in Chapter Three as the point where total physical product becomes a maximum with respect to continued water inputs. Such a maximum point does not exist in a linear production function. Output continues to increase as water use increases until another resource becomes constraining; in both applications, the constraining resource is capital stock.

The second difficulty is related closely to the first, described above. The linear production functions used in this study allow for any producing activity, no substitution between inputs, which may not be representative of the true production function. Thus, any optimum position determined using a set of linear functions may be different from the true optimum position.

One way in which both the problems described above can be accommodated is to consider more than one alternative production process for each activity. As the number of alternative processes, which can be thought of as planar approximations of the production function service, considered increases, the accuracy with which the production function is represented also increases. Such an increase in accuracy would also lend reliability to the optimum solution of the model.

Another flaw in both applications is the representation of labor as a completely homogeneous, mobile resource. This over simplification relaxes in the model constraints of immobility or of shortage of critical skills which may be important in an actual situation. Any constraints present in an actual situation and absent in the model of that situation will cause the value of the objective function to be overstated. Thus, in the short run, the maximum value of product possible if all scarce resources are optimally allocated may be impossible to achieve.

Use of the same aggregate sectors was required in application II, for although this application described an existing situation, no secondary data were available which specifically described the producing activities

in the town under consideration. This application is therefore subject to the same limitations described above for application I. In addition, the problem of defining the size of the labor force on which a small, rural community can draw is a study in itself, inasmuch as it is difficult to define the geographical limits within which an available labor force may reside. For this reason, the labor resource represented in the model may constrain the producing activities at an artificially high or low level.

A further limitation of the general model relates to the inadequate analytic treatment of water quality problems. In Part III, is described the Tandem Program System (TPS) model developed specifically to deal with this limitation.

It is because of these limitations that these two applications serve best to demonstrate the methodology which the model represents. Values determined in application, such as the value of marginal product of water, may not be valid in other situations, and should be applied in other situations only with caution.

PART III

CHAPTER EIGHT: ADDITION OF WATER QUALITY CONSIDERATIONS
TO THE GENERAL MODEL--APPLICATION I

This chapter introduces a second major section of this project that was carried out after completion of the work discussed in Parts I and II and as a separate study. The foregoing discussion has demonstrated that the economic implications of quantitative water allocation methods can be satisfactorily analyzed using a linear programming format with dynamic modifications. However, the rising tide of environmental concern is rapidly altering the water allocation sphere to include not only questions of quantity but also questions of quality. Therefore, Part III of this study was commissioned for the purpose of developing an approach to incorporate the economic implications of some physical water quality criteria into the general model.

Further delimitation of water quality

The various aspects of water quality are so numerous that some immediate delimiting of the area is necessary to define adequately the means and ends used in this study. Water is often classed as either fresh surface water, ground water, or salt water. Quality considerations are vastly different among these three classifications, and the frequency of water quality crises is unevenly distributed among the groups. The applications presented with the general model involve both surface and ground water; however, this section of the project is concerned only with application I, the fresh surface water problem, because of the much more

ubiquitous occurrence of this type of water quality concern. The use of ground water as a waste sink and the resulting water quality problems can be found in only a few specific locations; whereas, the use of surface streams in this same manner is indeed common.

Surface water quality may be defined as a function of the demands made upon the water resource by its users. A firm producing drinking water from a surface source has an entirely different concept of water quality than a fisherman or any one of a number of other direct users, even though all users may have common facets to their water quality picture. The five predominant demands sensitive to quality considerations for a surface water resource are for: (a) human and industrial water supply, (b) recreation, (c) waste sink (disposal),^{1/} (d) aquatic ecosystem environment, and (e) aesthetic appeal. Bacteriological considerations are of major concern to the water supply users, may be of less concern to the recreation users, and are often of little concern to certain other demands. Toxicity criteria are highly important to water supply users and aquatic ecosystem users, but assume a minor role with the rest of the groups. Similarly, temperature, odors, tastes, radioactivity, pH and other parameters are of greater concern to some users than to others. Thus, before the work of incorporating surface water quality criteria can begin in earnest, additional delimiting is required.

^{1/}Waste sink (or waste disposal) is used in this context to denote the demand for the stream's waste assimilation capacity. Practically all fresh water surface resources can accept an amount of biologically degradable waste material and convert it to innocuous substances through natural processes. This is called the waste sink capacity; and, in some resources, this capacity is substantial.

The surface waterway defined in application I of the general model (Chapter Six) is used as a water supply and a waste sink by the feed lot, the pork slaughter plant, and also by the municipality. In addition the waterway is most likely a place of recreation for the local population. A parameter of significant importance to all of these uses is the level of the dissolved oxygen in the river water. Maintenance of a minimum level is necessary to prevent fish kills, odors, and bad tastes; and the surplus oxygen level above the minimum is important to the waste sink users. For these reasons, the water quality criteria to be incorporated into the general model will deal with dissolved oxygen levels in the stream.

The general model, application I also includes a minimum flow parameter, often called low flow, which will be retained in the expanded model in a different manner. In the first application, this parameter functions as a guarantee of source to downstream users, thus becoming basically a quantitative parameter. However, low flow parameters are often related to quality considerations because of the waste diluting activities of streams used as waste sinks. Other factors affecting low flow criteria can also arise from the recreation and aquatic ecosystem environment demand areas.

Thus, as a result of delimitation, the water quality criteria to be incorporated into the general model include only dissolved oxygen and low flow parameters. Elimination of so many significant variables often found in the complex real world water quality area was done in

the interests of simplification. While the stated purpose of Part III of the study is to incorporate relevant criteria into the model, the point of greatest interest is not what criteria are incorporated but how this incorporation is accomplished. The approach, then, is the crux of this work, and the complexity needed to analyze a real problem can follow in later applications.

Review of the general model

The discussion of the general model in Part II has been quite detailed, and readers are referred to Chapters Five, Six and Seven for a complete discussion of the general model. For readers interested primarily in water quality aspects, a brief summary of the general model, Application I, is presented in the next few paragraphs. This summary serves also to extract (or modify) from the detailed earlier presentation features of specific interest to this work.

The overall structure of the model follows the typical linear programming (LP) format where the objective function takes the form $C'X^P$. The vector X^P consists of a number of production activities using water as an input factor. These activities produce a good or service of greater or lesser value than the value of the raw material inputs. The vector C' contains a series of coefficients that describe the amount of "value added" by each unit increase in an activity's level. The maximization of the objective function, then, may call for the determination of that group of activity levels that produces a maximum aggregate amount of "value added."

However, in application I an activity appears from outside the production activity vector in the form of "water treatment 2;" and this event will happen several times again as the water quality considerations are added, so this section of the report modifies the objective function slightly. The new form is:

$$\max C'X,$$

where X is a vector array $[X^P : X^S : X^R]$ with X^P representing the production activities, X^S representing the water manipulating activities, and X^R representing the public water uses, all as defined earlier. Most of the activities in X^S and X^R do not enter the objective function; and this is accomplished by setting their respective C values equal to zero. This change causes the C vector to lengthen to dimension n , the total number of activities. This change permits the inclusion in the objective function of those activities requiring an input of resources from the aggregate community but producing a product with a cardinal value less than the cost of the input resources. Municipal waste water treatment is typical of such an activity.

The units of the elements of the vector X^P are defined in two different ways. In the cattle feed lot, corn, soybean, and pork slaughter activities, the units represent either one (or one thousand) production entities. In the aggregate activities, the units are the amount of production required to produce one thousand dollars of "value added." Therefore, the units of C in the first case are the dollars of value added per unit of production activity; and, in the second case, are

dollars of value added per units of 1,000 dollars value added.

The units of the activities in the X^S and X^R activities entering the objective function are in units of 1,000 gallons of water used or processed. The C vector coefficients for these activities are in terms of dollars of value added (in this case, the value added is negative because it is actually the treatment cost) for every 1,000 gallons of water processed or used.

No LP problem is complete without a set of restraining equations, and in the general model these constraints are of the form:

$$AX \leq b$$

$$x \geq 0,$$

where A is a matrix of coefficients of size $m \times n$ (m equals the number of constraints, and n equals the number of activities), b is a unit vector of constraint parameters of length m, and x is any single activity. This last constraint is the non-negativity condition that insures against unreal negative activity levels entering a solution.

The b vector includes the constraints for the four assumed resource inputs (water, labor, land, and capital) plus some physical capacity restraints on the public use activities, the pork slaughter plant, and the available stream flow. The components of these groups can be seen in Fig. 4.

The coefficients of the A matrix are the real source of the activity level units. In the case of the individual production activities in X^P , these coefficients represent the amount of resource consumed in

producing one (or one thousand) units of production. The coefficients for the aggregate production activities in X^P are in terms of the amount of resource consumed to produce a unit of 1,000 dollars value added. The coefficients for the activities in X^S and X^R represent the amount of resource consumed for every unit of 1,000 gallons of water consumed or processed.

One of the very important features of the general model in both applications is the incorporation of temporal variability. This is accomplished by breaking the total time span of analysis (in this application, one year) into four separate time periods of unequal length. Some of the constraints have differing maximum values between time periods which requires the use of four different entries. In Fig. 4 this type of entry is denoted by a, b, c, or d in the column headed "time period." The balance of the constraints are yearly maximums and are denoted by the letter y. The general model apportions this latter type of resource among the time periods in an optimal manner. The mechanics of this feature are further clarified in the discussion in Chapter Ten.

One particular facet of this dynamic arrangement should be noted. In application I, a reservoir exists in the upstream portion of the watershed, and the general model uses the resource constraints for stream flow and low flow to transfer water from one time period to the next, a very real and important function of a reservoir.

The treated water and waste water constraints are used to

transfer the individual demands of the various municipal activities for these two commodities to the appropriate activity columns. This is accomplished by using coefficients in the water or waste water treatment activity columns of a sign opposite to those in the other columns and then setting the whole constraint equal to zero.

The coefficients for the A matrix that are used but not derived in this section are taken from the earlier discussion in Chapter Five. Similarly, constraints have been used as developed in Chapter Five, also. Lastly, the objective function coefficients that are not derived in Part III have been discussed in Chapter Five. A number of features of the general model have not been discussed here, and a reader wishing greater understanding of the basic model at this point should read or reread the preceding chapters of this report.

Water quality limitations of the general model

In application I, as presented in Chapter Six, the possibility of stream pollution by the pork slaughter operation has been designed into the problem by providing two distinct pork slaughter activities, 1 and 2. The model assumes that the lower capacity of pork slaughter 1 will not exceed the assumed treatment facilities, but that the higher capacity, pork slaughter 2, will exceed the same treatment capacity, thereby polluting the stream. To account for the polluting of the stream, a second resource, stream 2, is created to replace stream 1 when the pollution occurs. This polluted stream then triggers an additional water treatment activity (water treatment 2) at the down-

stream municipality which enters the objective functions on the assumption that polluted water increases the cost of treating drinking water.

This approach has a number of limitations. First, the assumption that treatment is provided ignores the existence of three major levels of treatment^{2/} with a number of sub levels possible within each major level. To account for the multiplicity of treatments possible a pork slaughter activity for each level would have to be created, and at the same time separate streams would have to be created for each treatment level. The expansion of the general model in this manner in an effort to better mirror real life situations would rapidly become complex and too cumbersome to handle conveniently.

Another shortcoming is that the general model ignores the effect of the quantity of stream flow on the amount of waste treatment needed. This model has assumed that the pork slaughter plant is subject to effluent standards.^{3/} At present, there is a great deal of debate concerning the relative merit of these two approaches to standards, but it is generally admitted that, under proper management conditions, the use of stream standards is economically preferable because the waste

^{2/}The three major levels are primary, secondary, and tertiary treatment. The first level, primary, consists of one or more unit processes that remove a significant portion of the suspended particulate matter. The secondary treatment level uses biological treatment processes to remove dissolved or suspended biodegradable matter. And the tertiary level includes one or more of a large number of treatment processes such as disinfection by chlorination; odor, color or taste removal by carbon absorption; fine particulate removal by filtration; and nutrient removal by one of a number of processes.

^{3/}Effluent standards specify the maximum or minimum values for water quality parameters in the waste streams being discharged while stream standards specify these parameters for the receiving stream after receiving the discharge.

assimilation capacity of the stream can be utilized.

Another assumption that limits the application of the general model is the handling of increased water treatment costs by the downstream municipality. The treatment of a surface water supply usually involves such extensive investment and operating expense that most pollutants have little effect on treatment costs unless they are of an exotic nature. Very little data are available for use in estimating such costs on a generalized basis. McDonnell (71) has recently investigated the effects of raw water ammonia levels on the treatment costs of the city of Philadelphia. The report shows a 1.5% increase in operating costs for a significant ammonia level. Therefore, the economic effects of this phenomenon as applied in application I of the general model would not be of the same magnitude as the waste treatment effects added in Part III analysis.

The most significant economic effects of water quality degradation occur when waste discharges must be treated or activities must be curtailed because of excessive waste.

The final major limitation of the general model, application I, is the lack of spatial relationships between the activities. This is an essential factor in assessing the location and the magnitude of the effects resulting from water quality degradation. The fact that the pork slaughter plant was upstream and an assumption about the effect of the waste on the water treatment operation had to be made before setting up the model since the model itself cannot take such variables into account.

All of these limitations discouraged attempts to include additional water quality criteria considerations within the LP problem itself; however, there is another feature of LP which is probably even more obstructive, and that is the need to use only linear relationships or linear transformations of curvilinear relationships. A typical dissolved oxygen relationship is shown in Fig. 5, and, even though a linear transformation of this relationship may be possible, it is far too complex and cumbersome for use in this application. Similar problems exist in the treatment level relationships shown in Fig. 6. This curve shows that the treatment cost is zero as the waste strength or amount increases until there is a need for primary treatment where the cost rises vertically. As the waste continues to increase in volume or strength, the operating expense rises very slowly until a second point is reached where secondary treatment is required. This is repeated again through tertiary treatment. This type of relationship does not lend itself to linearization over the total span of waste strength or volume.

Evaluation of TPS approach

All of the considerations outlined in the preceding section led to a search for an approach that would combine more flexible analytical techniques with the existing LP procedures. The first avenue investigated placed the LP program in a subroutine role to a Fortran river model program; however, efforts were thwarted because the overall concept was incompatible with available computer techniques.

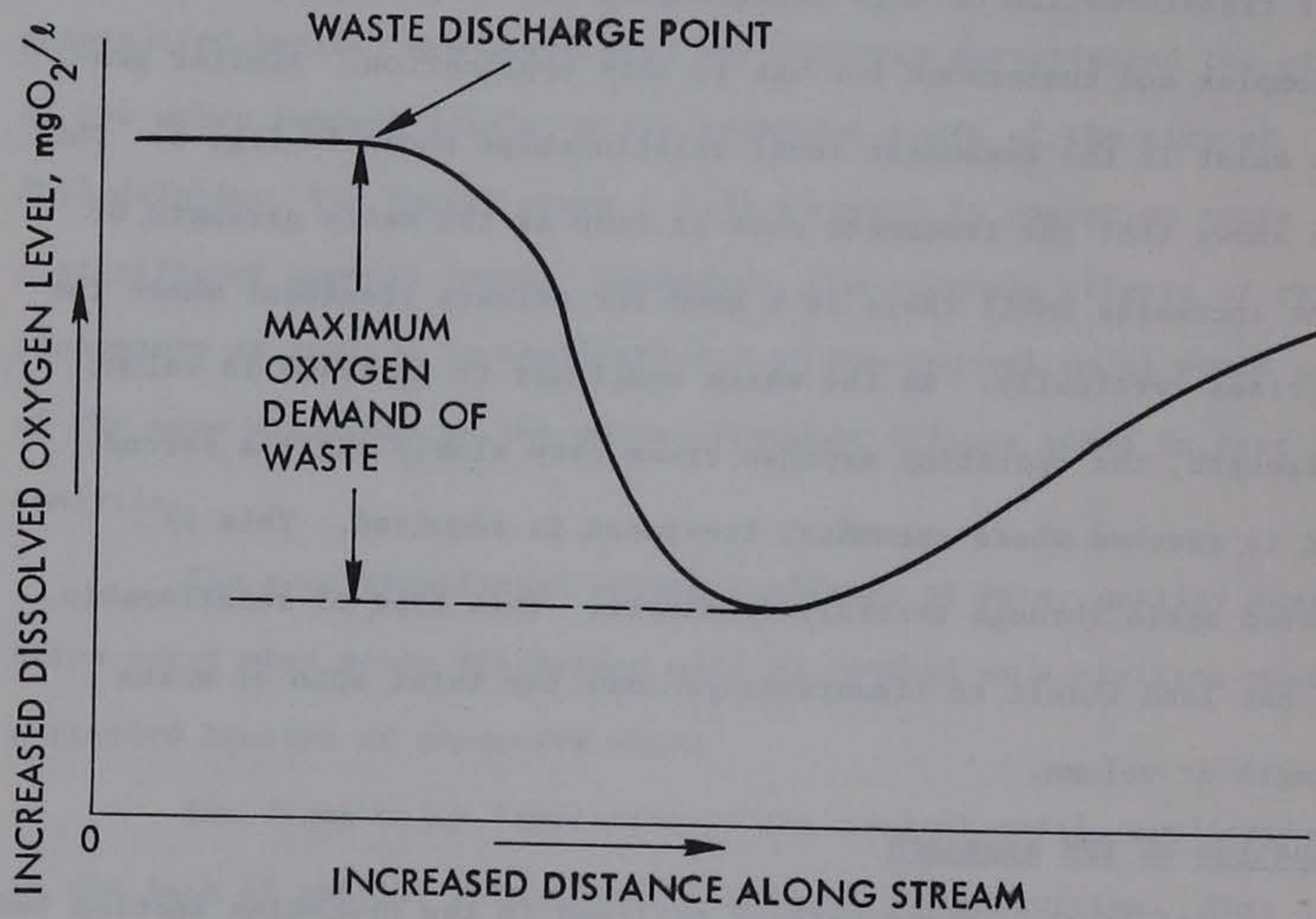


Figure 5. A TYPICAL DISSOLVED OXYGEN PROFILE ALONG A STREAM RECEIVING A BIODEGRADABLE WASTE DISCHARGE.

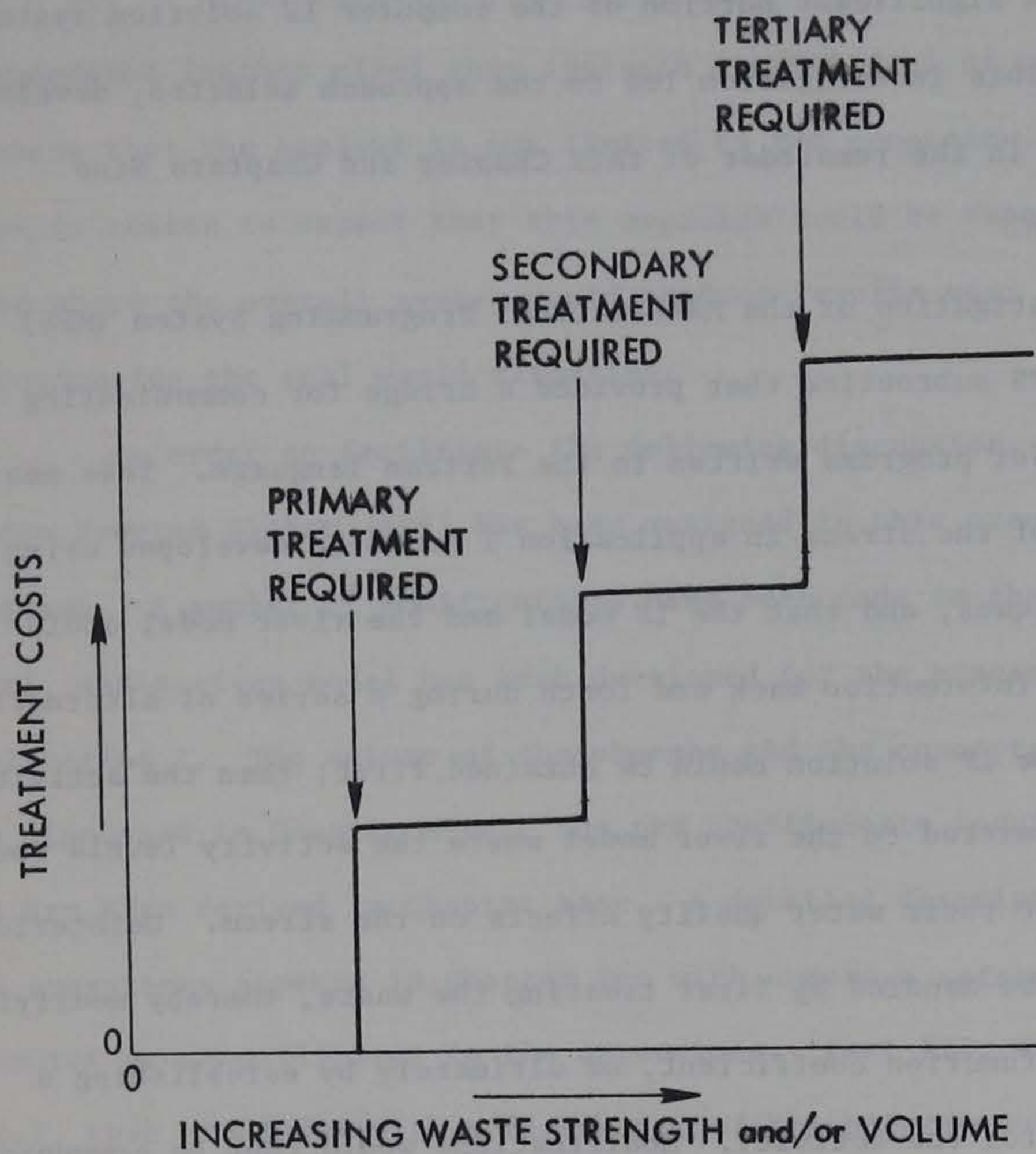


Figure 6. TYPICAL RELATIONSHIPS BETWEEN TREATMENT COSTS AND INCREASING WASTE STRENGTH AND/OR VOLUME.

A second approach began with the LP model calling a river model subroutine. Implementation of this approach would require the rewriting of a significant portion of the computer LP solution system called MPS. This investigation led to the approach selected, developed and explained in the remainder of this Chapter and Chapters Nine through Eleven.

Investigation of the Mathematical Programming System (MPS) revealed an MPS subroutine that provided a bridge for communicating with other major programs written in the Fortran language. This meant that a model of the stream in application I could be developed using Fortran techniques, and that the LP model and the river model could then transmit information back and forth during a series of alternating solutions. The LP solution could be obtained first; then the activities could be transmitted to the river model where the activity levels would be analyzed for their water quality effects on the stream. Deleterious effects would be handled by first treating the waste, thereby modifying the objective function coefficient, or ultimately by establishing a maximum bound for the activity. Modifications would then be communicated back to the LP problem which would be revised and solved again. These procedures would be repeated until an optimal solution of the LP would cause no unresolved water quality problems in the river model which would be outputted as the desired solution.

It is important to note that these two programs are independent and of equal status, even though one program initiates the sequence and

the other program is stored within the computer. Both programs contain numerous variables that must be described before analysis can begin, and only a few of these variables are communicated back and forth. This independence feature gives this approach a great deal of potential because it means that the analyst is not limited to two companion programs. There is reason to expect that this approach could be expanded to the point where the overall system would produce results very closely approximating the real world situation.

In order to facilitate the following discussion, the name Tandem Program System (TPS) has been assigned to this group of companion programs. A number of modifications have been made in the general model, and a river model has been developed for the stream found in application I. The nature of the changes and the concepts employed are discussed in Chapter Nine. The new coefficients required by the TPS are also derived in Chapter Nine. A detailed description of the TPS operations appears in Chapter Ten with numerous references to the computer program listings in the Appendices. Part III, on the TPS model, then concludes with a discussion of the program output, the example results, and some future expansion possibilities in Chapter Eleven.

CHAPTER NINE: CONCEPTS USED IN TPS

In Chapter Eight, a broad range of ideas and relationships was discussed in arriving at an approach to the problem of including water quality considerations in the general model developed in Part II of this report. This Chapter is first concerned with describing the changes required in the general model and the determination of some new objective function coefficients. The discussion then turns to the problems of building river models, a description of the concepts and assumptions employed in this application, and the derivation of several ratios and constants used in the operation of the Tandem Program System (TPS) model as described in Chapter Ten.

Modifications to the General Model--Application I

In implementing the TPS model, the water quality features included in the LP format were deleted from the general model. These deletions include the Water Treatment 2 and Pork Slaughter 2 activities and Stream II and Pork Slaughter Capacity II resource constraints.

The low flow parameter is moved to the river model in the TPS because that format allows spatial as well as temporal differentiation. The allocation of water among periods by the general model is retained so the resource constraints Stream I, Reservoir capacity, and Low Flow are continued in the LP portion of the TPS model.

The general model assumed that a certain amount of water treatment and waste water treatment capacity existed for the municipality

and that use of these resources did not affect the objective function except in the now deleted case of Water Treatment 2. A set of disposal functions was incorporated into the model to permit the model to exceed these capacities by merely calling for additional treatment. This concept is substantially altered in the TPS model.

The original assumption that municipal treatment facilities of a certain capacity already exist has been retained; however, the expense of using the waste water treatment facilities has been added to the objective function as a negative value added. Initially, the model assumes the waste is untreated. Whenever the river model calls for an increase in the level of municipal treatment, the objective function coefficient is incremented by a predetermined amount so that the coefficient represents the cost to treat one unit of activity, in this case a block of 1,000 gallons.

The original assumption that the cost of treatment of the water supply within the original capacity of the facilities would not enter the objective function is likewise not retained. A cost to operate the water treatment plant of 17.5 cents per 1,000 gallons treated was selected from Seidel and Cleasby (88) although this value is probably too low at present cost levels. Here again the capital cost of the facilities is not included.

Two new activities have been added to allow the municipality to expand either treatment facility as needed or as the river model parameters permit. These activities are called Additional Water Treatment and Additional Waste Water Treatment.

The Additional Water Treatment activity enters the objective function as negative value added with the capital cost of providing the new facilities also included with the operating cost just described. This capital cost was estimated at \$200,000 to provide one million gallons per day of additional capacity. This number is transformed into 4.4 cents per one thousand gallons treated assuming that the capital debt is amortized over 20 years at 5% interest. This method of handling costs assumes an infinite divisibility in adding additional capacity which is not attainable in reality. However, this discrepancy in the initial approach could be removed in subsequent applications.

The additional waste water treatment activity is handled in the same basic manner as the waste water treatment activity with the exception that every time the level of activity is raised, not only the cost of the higher level of treatment but also the capital cost of the facilities are added to the objective function coefficient. A cost of providing one million gallons per day of additional primary treatment was estimated at \$114,000. This figure becomes 2.5 cents per 1,000 gallons treated if the debt is amortized over 20 years at 5% interest. The same figures for secondary treatment are \$400,000 and 8.3 cents, and tertiary treatment was assumed to cost 3.0 cents per 1,000 gallons in capital expense. Tertiary treatment was assumed to include granular carbon absorption, aeration, and chlorination. The above figures were obtained from a cost study by Smith (92).

The determination of the municipal wastewater treatment operating costs involved the three levels of treatment. If the existing plant is

assumed to have a 10 million gallon per day (mgd) capacity the yearly operating cost for primary treatment would be approximately \$12,000 per mgd of capacity. This number transforms to 3.3 cents/1,000 gallons of water treated. Secondary treatment was assumed as \$18,000 per year per mgd capacity which is 4.0 cents per 1,000 gallons. The tertiary treatment process assumed has an estimated operating cost of 6.3 cents per 1,000 gallons. Once again the values have been drawn from Smith (92).

An important feature of this approach is that the volume and the strength of the waste are handled separately. It is possible to have a large volume of low strength waste requiring additional facilities but low treatment levels, or conversely, a small volume of high strength waste may require a high level of treatment, but no additional facilities. This properly mirrors real world circumstances.

Two other activities in addition to the municipal treatment activities just discussed also require the addition of treatment functions. The first, the Cattle Feedlot, is handled in a unique manner. The provision of waste treatment facilities for cattle feedlots is usually considered infeasible so if this waste is found to be excessively degrading to the stream, the entire waste is assumed to be diverted to an irrigation activity. The water is then assumed to be returned to groundwater. The cost of diverting this waste to an irrigation use was arbitrarily assumed to be 10 cents per head of cattle, and this amount is subtracted from the cattle feedlot objective function coefficient whenever the waste is so diverted. This approach was suggested by Koelliker (59).

The remaining activity concerned with water intake and waste water discharge is the pork slaughter plant. In this case, the cost for each treatment level includes the construction, debt service, operating, and maintenance expenses. Since these facilities are considerably smaller than the municipal plant, the treatment costs are higher. The primary treatment cost was estimated at 10.2 cents per 1,000 gallons, while the secondary treatment cost was 11.8 cents per 1,000 gallons.^{1/} The tertiary treatment process, consisting of carbon adsorption, re-aeration, and chlorination, was estimated at a cost of 13.9 cents per 1,000 gallons. All of these figures were taken from Smith (92). These costs were converted to units of dollars per 1,000 carcasses per day using the BOD and water usage figures developed in the next section of this chapter.

The foregoing discussion has presented the rationale and magnitudes of the revisions to the objective function coefficients as a result of needs for treatment of waste discharges. Since these objective function modifications are actually triggered in the river model portion of the TPS, this discussion could have been presented in that section of this chapter. However, moving the presentation to this section emphasizes that the actual economic impact of the treatment considerations occurs in this LP section.

A possibility exists that even tertiary treatment might not be sufficient to reduce a waste discharge to acceptable strength levels.

^{1/}The cost in secondary treatment should have been approximately 18 cents per 1,000 gallons; the erroneous figure was inadvertently used in the calculations with the result that treatment costs are somewhat understated.

Therefore, a fourth possibility was added to the model in the form of a bounds section for all of the activities. This section can be used to set maximum or minimum activity levels or to set the activity level to a predetermined number. The levels of the waste producing activities are originally set at an arbitrarily high number, 10^7 . Whenever tertiary treatment is insufficient, this upper bound is set to the maximum permissible activity level as discussed in Chapter Ten.

This bounds section was also found useful in apportioning the residential use in a reasonable manner among time periods by specifying minimum levels in each period. This could also have been accomplished by breaking the constraint value for residential use into its four time period increments.

The only major change in the constraint vector involved the summing of the time period values for Pork Slaughter 1 and Pork Slaughter 2 when the latter was deleted on the assumption that the more flexible waste treatment approach would permit full use of the slaughter plant capacity. Since Stream I and Stream II resources differed only in water quality, summing of the original constraint values was not appropriate.

This completes consideration of the LP portion of the TPS. The modified model is summarized in Fig. 4 as presented in Chapter Eight.

Concepts and Coefficients Used in the River Model Portion of TPS

The development of the river model portion of TPS could have taken any one of a number of forms. The literature is replete with recently developed river models, and new efforts are reported with increasing frequency as computer techniques develop and expand. All

of the parameters discussed in Chapter Eight have been modeled several ways, and these models can be either probabilistic or deterministic. It is very likely that any of these models could have been used in the TPS which emphasizes the versatility of this approach.

The model format chosen draws heavily on the recent work of Dougal, et al (29). This extensive study of the Skunk River near Ames, Iowa provided ample material in developing the river model, and it also provides a ready source of expansion possibilities for the TPS being presented, since many of the concepts have been simplified to aid in illustrating the approach.

The dissolved oxygen stream variable, which has been chosen from numerous possible variables (or parameters), involves a number of complex interrelationships. Whenever a waste is discharged into a stream, the distribution of the waste's oxygen demand^{2/} along, across, and down into the stream is a function of many factors such as stream flow velocity, depth, width, bottom contours, obstructions, and wind action. In addition, the exertion of the demand is influenced by the nature of the waste. Some carbon compounds exert their demand much faster than others, and demand by nitrogen compounds usually occurs days after the carbon demands have been exhausted. Aquatic organisms such as fish or algae also exert oxygen demands, at least part of the time; and sludge deposits can form which affect the exertion of the oxygen demand. And lastly, the wastes introduced as single point

^{2/}The wastes serve as food for numerous bacterial organisms in the stream, and the oxygen demand is actually the demand of these organisms.

discharges behave differently than the uniform natural waste seepages along the stream. One or more of these factors can be evaluated individually with the balance being treated as a unit, or the entire group of factors can be simultaneously evaluated in any real situation. Normally, the effect of this group of variables is represented by a 'deoxygenation coefficient.'

Oxygen is continuously entering the water resource as deoxygenation takes place. Some of the variables affecting this phenomena are stream flow characteristics, stream temperature, and the presence of algae during sunlight hours. These factors are usually summarized as the 'reoxygenation coefficient.'

For the purposes of this work these two coefficients are assumed to include all variables and to be constant. The first assumption may be possible, but the latter one is never true for more than a short period of time. One major reason for this is the role of algae. During the day, these organisms produce oxygen, thereby aiding the reoxygenation coefficient; however, at night the algae can only respire, thereby transferring their effect to the other side of the ledger.

These river coefficients were estimated from the data presented by Dougal, et. al. (29). A value of 0.400 per day was assumed for the reaeration coefficient, and a value of 0.200 per day was assumed for the deoxygenation coefficient. These values would be typical of a large stream with a low flow velocity. In an application to an actual fact situation, these values would be determined from observations taken on the stream.

The use of these simplifying assumptions in this hypothetical application permits the use of the typical dissolved oxygen profile (also called the oxygen sag curve) presented earlier in Fig. 5. This curve represents the change in the residual oxygen levels of the stream as a unit of waste moves downstream from the point of discharge.^{3/} In the early stages of the waste unit's travel, the demand is greater than the reaeration capacity of the stream so the residual level falls to a low point, and then rises as the waste demand subsides below the reaeration rate. The low point in this curve is the crucial parameter used by this river model. If the initial saturation oxygen level is assumed to be $8.5 \text{ mgO}_2/\text{l}$, and the low point is arbitrarily set at $5 \text{ mgO}_2/\text{l}$, then the stream can accommodate any waste that creates an oxygen deficit of $3.5 \text{ mgO}_2/\text{l}$ or less. The 3.5 figure is called the 'critical deficit.'

The relationship just discussed involves a time (or spatial) dimension that must be incorporated into the model. This is accomplished by adding a scale to the stream in the watershed of application I, and this is shown in Fig. 7. The distance between stations on the dimensioned stream represents the amount of waste travel in one day. While this may not approximate reality in all situations, it fits the mathematical representation of the sag curve^{4/} and eliminates the need to use fractional or decimal numbers for time of travel, t .

^{3/} The oxygen profile in the reservoir would differ from the stream profile, but this is ignored in this application.

^{4/} See Dougal; et. al. (29) page I-196, equation 45.

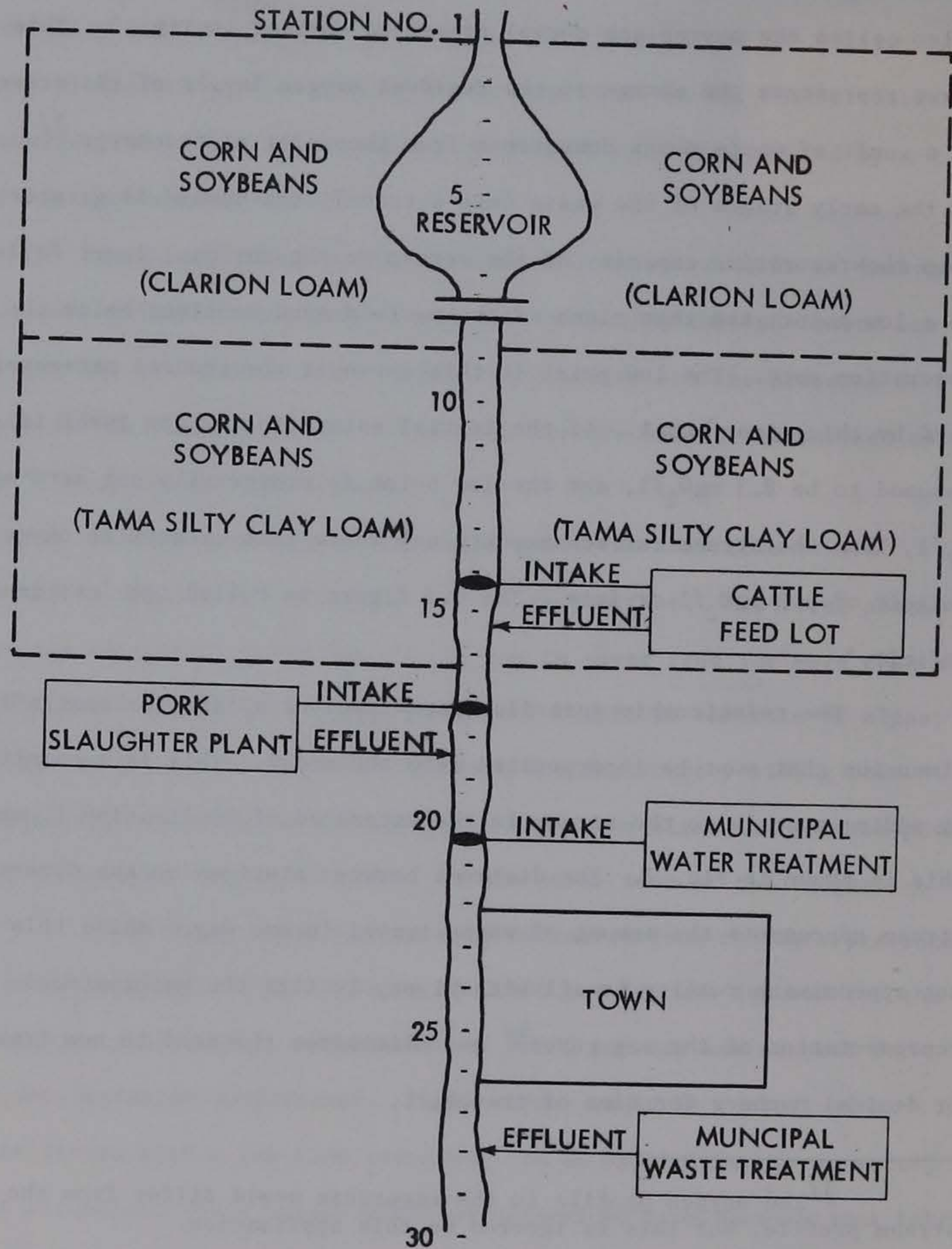


Figure 7. SPATIAL ARRANGEMENT OF ACTIVITIES IN APPLICATION I WITH STREAM DIMENSIONS ADDED.

The dissolved oxygen portion of the river model assumes that if a second waste is discharged into the stream before an upstream waste has been assimilated the effects of each waste on the oxygen profile are additive. This assumption is reasonable in most instances, but the possibility of synergistic or toxic interactions in real world applications should not be ignored.

The river model also checks to make sure a minimum low flow parameter is maintained. The operation of this facet of the program is described in detail in Chapter Ten. The minimum low flow figure used in this application is 103,367 gallons per day which was taken from the general model application I. This feature might be used, instead, to prevent the stream from falling below some predetermined level that would negate established stream standards. In Iowa this would be the "10 year 7 day"^{5/} low flow for any stream reach analyzed.

All of the activities either removing water from the stream or discharging wastes to the stream have been assigned a station on the dimensioned stream. As the river model sequences downstream each station is analyzed for water removal or waste discharge, and appropriate data are supplied to the model for use in performing these computations.

Once again the Cattle Feedlot was handled in a manner unlike the other two activity groups. The water intake quantity was assumed to be a function of the feedlot cattle population, and a figure of 15 gallons per day per head was selected. The water returned to the stream was

^{5/}The Iowa Water Quality Standards apply to waters classed as fishing streams, and the standards must be met for all flows above, or equal to, the 10 year 7 day" low flow established for each stream. This low flow is the lowest flow over a period of seven days that can be expected to occur once every ten years.

assumed to be a function of the rainfall runoff from the feedlot. This assumption is further expanded, in the interests of simplification of the model, to include a holding pond that would discharge to the stream in a continuous manner. A typical Iowa runoff amount of 20 inches per acre per year was selected, and the cattle feed lot size was assumed to be one acre for every two hundred head of cattle. The resulting discharge to the stream is 7.44 gallons per head per day.

The strength of the wastes entering the stream is calculated from this discharge quantity and an estimated figure is derived for the amount of Biochemical Oxygen Demand (BOD) generated by each animal. A reasonable strength for the waste stream flowing from the pond could be 1,000 mgO₂ demand/l. Using the 7.44 gal/head/day from above, this figure becomes 0.062 lbs BOD/head/day. These figures were suggested by Koelliker (59).

The water intake of the Pork Slaughter plant was assumed to be 225 gal/carcass, and it was further assumed that 90% of this volume would be returned to the river as waste flow. This latter figure is 202.5 gal/carcass. The strength of the waste is calculated using an assumed BOD production of 2 lbs of oxygen demand/carcass. These figures were estimated from some unpublished data supplied the Iowa State University Department of Civil Engineering, Sanitary Engineering Section, by several Iowa packing plants and represent reasonable median figures.

The intake and discharge quantities of the municipal utilities are the activity levels themselves, so these two constants assumed a value of 1 gal/gal. The strength of the waste was estimated at 350

mgO₂/l of BOD which is a typical municipal waste of intermediate strength. This number is converted to a value of 2.9 lbs. oxygen demand/1,000 gal. of waste.

This discussion has reached the point where the Tandem Program System can be assembled into an operating model. Chapter Ten discusses the assembled model in detail, using the program listings as guides. This application of the TPS required four component programs, (a) the control program, (b) the optimization program, (c) the communications program, called READCOMM, and (d) the river model program called the Water Quality Program, WQP.

CHAPTER TEN: DESCRIPTION OF TANDEM PROGRAM
SYSTEM (TPS) COMPONENTS

The component programs of this TPS approach appear in the first several appendices. This chapter of the report will describe in detail the statements in these programs so that the reader with minimal programming experience can acquire a deep enough understanding of this application to allow the use of this approach to many other and possibly quite different problems.

The controlling program uses the Mathematical Programming System/360 (hereafter referred to as MPS or MPS/360)¹. This system is described in IBM Manuals GH20-0130-3 and GH20-0290-3 current in 1970 and 1971. This controlling program consists of two parts, (a) the OS/360 Job Control Statements that appear in Appendix C, and (b) the Optimization Program that appears in Appendix D.

Control Program Job Control Cards

Statement 1, Appendix C, is the usual Job card required for every job run at the I.S.U. Computation Center. Statements 2, 3, and 4 transfer control to the compiler and call for the compilation of the input program that immediately follows statement 4, in this case the Optimization Program. The unnumbered statements beginning with an x are control statements contained within the MPS and are generated automatically by the system.

¹There is a later version now available and known as MPSX.

Statement 5 overrides the builtin MPS STEPLIB procedure and allows creation of a library of programs, which is done with Statements 6 and 7 (Note, the unnumbered cards beginning with // are merely continuations of the preceding card). Statement 6 adds the READCOMM program (Appendix E) under the name of PROG.U3583.D, and statement 7 adds the Water Quality program under the code name PROG.U3583.H.

Statements 8 through 11 link both data sets 03 and 06 to the printer. Both sets are specified in this application because midway through the development of this program, the I.S.U. Computation Center switched the standard printed output data set from 03 to 06. To avoid confusion during the change both sets were specified. Statements 12 through 19 specify that data sets 08 through 12 are direct access files that are located in disc packs. These data sets are used in the READCOMM and Water Quality programs.

The final statement, number 20, instructs the computer to commence executing the Optimization program previously compiled using the input data immediately following this statement. The input data must be followed by an ENDDATA statement and /* card.

Optimization Program

This program begins with the required opening PROGRAM statement. The parameter 'ND' stands for 'no diagnostics' and it prevents the abnormal ending of the program for compilation errors. The next statement sets up the standard system demand implementation and their addresses.

Statement 3 calls for the reading of the first data card and specifies that this card must have the name DAVE in column field 15-19.

Statement 4 allocates space in the MPS to this problem file and labels it MAY. Statement 5 then calls for the reading of the balance of the data cards and the storing of the data in proper form in the problem file just defined.

Statement 6, with the address MORE, identifies data set 08 as the communications file to be used by READCOMM in carrying information to the Water Quality program. This file is labeled COMMFMT. Statement 7 positions the disc to the beginning of the communications data set and opens the file for output.

Statement 8 instructs the computer to print out the input data as read. This output appears in Appendix G as the original data and also as the intermediate data output in Appendix H.

The next two cards are included for precautionary reasons. Whenever the number of iterations through the Tandem Program System equals XFREQZ, in this case, 50, the program branches to the statement labeled ITR (number 33). The five statements, 33 through 37, then transfer the existing solution to a portion of the problem file MAY and then return control to Statement 11. The computations then continue, and the intermediate solution just saved can be recovered if the tandem program comes to an abnormal end within the next fifty iterations. Statement 11 initiates the solution of the optimization portion of the problem. The arguments specify that a set of 'bounds' called 'XMAX' are to be used, and the solution is to be a maximum value for the objective function. This card also specifies an initial basis. Statement 12 instructs the computer to use the data vector 'C' from the problem file as the coefficients for the objective function. Statement 13 calls for the data vector 'bl' to be used as the constraints (or the Right Hand Side, RHS).

Statement 14 causes the computer to skip statement 15 on the first iteration. The variable L3 is initially defined as 1 by statement 40. This variable is incremented one unit by statement 26 on each iteration, eliminating the subsequent bypassing of statement 15. This maneuver keeps a record of the number of iterations and enables all later solutions of the optimization program to begin with the last 50th basis or the last optimal solution that has been saved in the problem file, eliminating a great deal of computation time.

The next statement (16) specifies the algorithm to be used in the solution, in this case, the primal algorithm. Statements 17 and 18 specify the output activities for the solution. The first statement calls for a printed output of all non zero columns and all rows. The second statement calls for this same solution to be transferred to the communications file, COMMFMT.

Statement 19 then calls for the saving of the optimal solution in the problem file replacing any optimal or 50th iteration solution previously saved.

The three statements, 20 through 22, release the core work area used in solving the optimization problem; execute the READCOMM program, codenamed DAVE (See Appendix E); and then again release the core work area used for this operation.

Statements 23 and 24 call for the solution of the Water Quality program (WQP), codenamed HUBLY (See Appendix F). The IDEX argument is the variable indicating the number of iterations of the TPS, and is used by the WQP to tell the optimization program when to stop. When control is returned to the optimization program this variable is evaluated

by statement 25, and the system either branches to 'QUIT' or begins the revision of the input data to the optimization program in preparation for a new solution.

If the decision is to continue with another solution, the counter L3 is incremented one unit by statement 26. The next statement identifies the problem file MAY as the file to be revised. The statement, number 28, then takes the input data from data set 11, modifies the problem file MAY, and stores the revised model back on the problem file. This command also creates the output shown in Appendix H, page VI-7.

The final revision of the problem is accomplished by statements 29 and 30. The first of these commands calls for a new setup as in statement 11, only this time the revised bounds are setup. Similarly, the objective function is revised by statement 30.

Statement 31 is another safety precaution designed to prevent the TPS from continuously oscillating because the solutions do not converge. The variable I4 is set equal to a number one-unit greater than the maximum number of iterations that can be tolerated. When that number of iterations is reached, the tandem program branches to QUIT. Otherwise, the control is returned to the statement with the address MORE, statement 6, and a new optimal solution is begun.

Statements 38 through 43 initially define the variables and arguments used in the statements described above. The final card is a signal to the computer that this is the end of the program to be compiled and that control is to return to the OS 360 job control statements discussed in the preceding section.

The READCOMM Program

This program (Appendix E) transfers the solution (the optimal levels for each activity) from the communication file in MPS to data sets on a disc, in this case sets 09 and 10. This program also makes the necessary statements available to transmit the arguments ISTOP and IDEX between the optimization program and the WQP.

The first two statements are straightforward Fortran definition statements and the second pair of statements position the disc data sets 09 and 10 to position 1.

Statement 5 equates the word FILE to the integer 08, used in this context to denote disc data set 08 which is the MPS communications file. Statement 6 instructs the computer to position itself to read this file from the beginning. The argument INDIC is used throughout this program to indicate when the end of a data set is reached, at which time it assumes a value of 1.

The next three statements, 7, 8, and 9, call for the program to read the first array in the file, which happens to be a standard array. Statements 10 and 11 call for the computer to position itself to the next array. If this array does not exist the program branches to the RETURN statement which returns the control to the optimization program. If the array exists, then the program reads the column names, data type, and then the individual values of each row vector as a result of the statements 12 through 14. The column names are stored in the vector array COLUMN and each set of values is stored in a vector array VALUES.

The READCOMM program must read the output arrays from the communications file in the same order as they are entered by MPS.

Therefore, it is necessary to read these first two arrays even though they do not contain data to be transmitted to the WQP. The second array appears in the TPS output, Appendix H page 241. Since the reading of these arrays is not followed by writing the arrays onto a disc data set, they are actually discarded or ignored.

This process is repeated a third time by statements 15 through 19, with this third array containing the information to be transmitted to the WQP. This array also appears in Appendix H, page 242. The transmission is accomplished by writing these values onto two disc data sets, 09 and 10, as called for by statements 20 through 23.

Statement 24 returns control to the last CALL VECTOR statement until that statement branches to the RETURN command, at which time control is returned to the optimization program. The END command is for compiler use only.

The commands GETARG and PUTARG that are used by the WQP are also a part of READCOMM. The first command transfers the arguments IDEX and ISTOP to the WQP, and the latter command returns these two variables to the optimization program.

Since this program must reside in the system's library if this program is to be made available in the Control program, a set of input procedures is listed in the record part of Appendix E. Statement 1 is the customary job card. The next four statements, 2 through 5, scratch any program using this program name that has previously been created in the system's library. This is not necessary, of course, if the program has never been cataloged or has not been recataloged after being scratched. But

inclusion of this procedure under these two conditions does not cause an abnormal end to the cataloging procedure so the scratch portion is simply included for every run whether or not it is needed.

The balance of the statements make up the catalog procedure. Statements 6 and 7 instruct the computer to compile the program using the input stream following statement 7.

Statements 8 through 11 instruct the Linkage-Editor to concatenate the SYS1.FORTLIB data set with the MPS 360.SUBRTNES data set, to add the new program to this data set, and to refer to the whole set as PROG.U3583. Statements 11 through 15 are instructions to the Linkage-Editor, and it is here that the name DAVE is attached to this program.

The Water Quality Program (WQP)

This program appears in Appendix F. A complete listing of the program statements is found in sections 1 through 10. These ten groups represent the major function areas of the program. Also included in Appendix F are the input and revise procedures (section 11), a set of definitions for the program variables (section 12), and a simple flow chart (Section 13).

It is acknowledged that some programming inefficiencies exist in the program as presented. Some of the areas for improvement would require major changes in the program. Other areas do not offer enough additional benefits to warrant making the change. An example of the first type involves a more judicious choice in the units of measurement chosen for some of the variables, but to make the change in the program would involve rewriting many statements in both the optimization and the

WQP. Since the major purpose of this study is to develop techniques, and not solve a particular problem, efforts to further streamline the Tandem Program System are not justified in this project.

The first group of statements, section 1, is the definition statements usually found at the beginning of a Fortran program. An example of an inefficiency as just discussed can be seen in statements 1 and 2. In the beginning, the variables JX and JXMAX were established as integers, and this fits the definition statement 1. However, later in the program's development, it was necessary to switch these variables to real numbers, and statement 2 was a much simpler method than rewriting all of the statements containing JX and JXMAX.

Another point of interest in this section is the use of double precision numbers. Toward the end of the program's development, a problem was encountered with variables being modified even when the program had not sequenced through the appropriate modification procedures. This trouble was eventually traced to machine error resulting from the use of values too close to the maximum size for single precision numbers. A switch to double precision numbers solved the problem.

In the next section (2), a group of fixed ratios and constants needed to analyze the river water quality and to evaluate the cost of treatment are read into the computer in WQP format.^{2/} These real life variables and relationships are assumed to be constant during the TPS analysis, and the roles of most of these entities have already been discussed.

^{2/} See page 162, line 10 this chapter.

However, the variables F and JP have been omitted from previous description because the need for them first arises in the Water Quality Program. Withdrawals and discharges to a waterway often are related. For instance, the pork slaughter operation can be expected to discharge about the same volume as it takes in; and, similarly, the municipality will discharge less than its intake volume. Coordinating these intake and discharge quantities does not occur naturally in the TPS so these two variables have been added to correct this problem. The variable JP identifies the location of any intake that is related to a particular discharge. In this application, JP is a vector array because there is only one intake point for each discharge source; but in a more complex application a JP matrix array could be used to handle multiple interdependent intakes and discharges. The variable F describes the quantitative relationship between the discharge and intake volumes.

The variable is:

$$F = \frac{\text{Volume in} - \text{Volume out}}{\text{Volume out}}$$

Using these two variables, the WQP can assure that the model will not permit an unrealistic disappearance of quantities of water.

In section 3, statements 29 through 39, the names and the values of all of the model's activities are read into the WQP from the disc data sets created by the READCOMM program. The names are stored in the array IN and the values in the array X.

In section 4, statements 40 through 85, the data which may be modified during the execution of the TPS are read into the WQP in MPS

format.^{3/} Statement 40 instructs the computer to obtain the arguments IDEX and ISTOP from the optimization program via READCOMM. The argument IDEX is then used in statement 41 to determine which data set to use. On the first execution of the WQP the original input data, statements 48 through 79, are used; and in all subsequent executions of the WQP, the modified data set is used that has been stored on disc data set 12 in a previous execution. This latter operation is accomplished with statements 81 through 83.

The statements 42 through 47 zero the storage arrays and statement 80 causes the program to bypass data set 12 on the first execution. Statement 84 returns data set 12 to the beginning of the set in preparation for the expected input of data later in the WQP.

The statements in section 5, 86 through 101, begin the analysis of the river's water quality. The first statement initially sets KOUNTA equal to zero. At the end of the analysis this variable is examined, and if it is greater than zero, then the WQP instructs the optimization program to solve the problem again and return to the WQP for another analysis.

Statement 87 begins a loop that contains one complete analytical sequence. This loop allows repetition of the river analysis for as many time periods as needed. The loop test value, in this case 4, equals the number of time periods to be analyzed.

Statements 88 through 98 set the working arrays of the WQP equal to zero, or, in the case of JXMAX, to a very large number.

^{3/} See page 162, line 10 in this chapter.

The last three statements, 99 through 101, initialize three variables that are used later to speed up execution of the program. The use of these variables is explained below.

Section 6, statements 102 through 191, converts all of the data that have been entered in MPS format into the WQP format. This manipulation is necessary for all data that are either stored or carried between the optimization program and the WQP.

The differences between these two formats occur in the activity numbering sequence and in some of the variable units.

The need to convert from one numbering sequence to another arises because of the basic differences in the two problems being solved and in the computational approach to each problem. The following discussion of these two formats should clarify this point.

In the optimization program the MPS format is used which is essentially a consecutive numbering of all the activities in the order that the coefficients were entered into the computer. Furthermore, in the case where it is wished to solve the problem over several time periods (as is done in this application), each time period's activities are entered in one long vector. In other words, if the first time period contained x activities, then those activities would be numbered from one through x . If a second time period with y activities was also to be analyzed these activities would be numbered from $x + 1$ through $x + y$. The next time periods activities would then begin with number $x + y + 1$, and so forth.

This method of setting up the problem allows MPS to solve the

problem over the total time span and within each time period in one execution of the solution algorithm. This can be easily seen in this application.

A number of the resource constraint equations have separate limiting values for each time period, and the MPS sets up separate constraint inequalities, specific to the appropriate time period, for each of these limiting values. In these situations there is no apportioning of a resource between time periods. However, some resource constraints have only one limiting value, and for these constraints the MPS sets up one long inequality. The solution includes an apportionment of these resources between time periods.

However, the WQP is faced with a different situation. In this operation, concern exists only with those activities using the river water either as a source or a waste sink, but in order to analyze the river's water quality it is necessary to first be able to locate the water users. Therefore, the numbers assigned to variables in WQP format denote their location by station on the river as previously discussed.

Furthermore, since water quality cannot be apportioned between time periods, there is no need to solve the water quality problem for all time periods simultaneously. In fact, an approach involving a simultaneous solution makes the program considerably more complicated than the sequential solution approach used.

Essentially, the conversion from MPS format to WQP format involves equating the level of some water using activity designated

by its location on the river to an MPS activity level that is designated by its location in the MPS activity vector. Furthermore, in the WQP this must be done each time a new water quality analysis is undertaken. Thus, every time period solution begins by selecting from the MPS activity vector the appropriate values.

The first three statements, 102 through 104, in section 6 cause the program to branch to the format conversion blocks for the first three time periods with the loop variable, k, representing the time period number. When time period 4, the last time period in this application, is analyzed the format conversion block on cards 105 through 126 is used.

If all of the time periods contain the same number of activities, and these activities are arranged in the same relative order in each period, the program coding in this section can be dramatically simplified. However, in this application the corn and soybean activities do not occur in the first time period so the bulkier method was used, but here again some opportunity is seen for future streamlining of this approach. If all time periods had originally been set up with identical sequences of activities and with the activities that we wished to exclude fixed at a level of zero, a simpler coding approach for this section could have been used.

Another group of conversions is necessary in moving from MPS format to WQP format. In this application the WQP requires different units on some of the variables in contrast to the optimization program. The most common conversion involves converting from units of activity per time period to units of activity per day. Statement 108 is an

example of this type of conversion where the number of hogs butchered per time period is divided by TD, the number of days in time period 4 (or D). This statement also represents a conversion in quantity of activity units. The general model described in Part Two measured this activity in blocks of 1,000 units, and the WQP uses this activity in terms of single units. This type of conversion should be avoided in future applications of this approach by better coordinating the optimization and water quality models. This type of conversion led to the need to use double precision numbers in this application.

One additional conversion activity is illustrated in statement 114, where it was necessary to combine two MPS format activities at the same WQP location. (there is also a time factor conversion in this statement.) In this case, the two water treatment activities are combined.

At the completion of the format conversion operation the program returns from the appropriate conversion block to a common CONTINUE statement, statement 192.

The program now commences the analysis of the river's water quality, and the program listing for this module is section 7, statement 192 through 276. For discussion purposes, this section has been broken into five subsections.

Subsection 7a is called a control module; its function is to shorten significantly the computation time of this section. Whenever the water quality analysis identifies a need for waste water treatment and alters the quality of the effluent accordingly, the computation of

the oxygen deficit must begin anew at the point farthest upstream that is affected by such modification. Whenever the modification involves an increase in the degree of waste treatment, the analysis recycles to the station of the offending effluent's discharge. However, after the available levels of treatment have been applied and the effluent still creates unsatisfactory water quality conditions, the WQP establishes a maximum activity level; and this may require a change in the dependent intake volume simultaneously. Originally, the program recycled to station 1 after this type of modification; however, the control module statements now permit the program to begin anew at the station of the upstream intake. This simple modification resulted in a great saving of computation time. The module functions by allowing the key loop variables N1 and N2 to retain their initial values of 1 and 2, (statements 99 and 100) on the first entry to this section, but subsequent returns to this module during any single water quality analysis causes these variables to be set equal to J, the station of the dependent intake.

Statements 197 through 199 call for the removal from the array of calculated waste contributions, all values for discharges downstream from the recycled starting point. This eliminates the possibility of any previous downstream discharge values affecting the new analysis.

The last statement in this subsection, number 200 initiates the major loop in the water quality analysis. This statement calls for the analysis to begin at station 2 (Station 1 is the beginning point in the reach being analyzed; there is no station 0.) At each station the

river is analyzed for low flow and a waste discharge to the river, which is subsection 7b. If there are no flow problems or waste discharges, this loop moves to the next station. If there are problems, the program moves through the appropriate subsections as discussed below and then returns to this loop where the analysis is moved again downstream one station. In this application, it was decided arbitrarily to continue the analysis twenty two stations past the last discharge point, which is station 28. Therefore, this loop test value is set equal to 50, the number of stations to be analyzed.

After entering the analysis loop, the program moves to subsection 7b, statements 201 through 209. This module figures the flow level at the new station, checks to see if the minimum flow conditions are maintained (the program branches to subsection 7c if the minimum flow level is not maintained), and determines if a waste is discharged to the river. In this latter activity the waste strength is calculated, and the program branches to the dissolved oxygen analysis subsection (7d) if this strength is greater than zero. Otherwise the program continues advancing downstream as described above.

Upon entering this module, a variable L is set equal to the number of the preceding upstream station by statement 201. Then another variable QOUTA is set equal to the amount of water withdrawn from the river per unit of activity for the station being analyzed. This variable is used later in subsection 7e. Statement 203 compares the river flow at the preceding station with the minimum flow parameter. If this upstream flow is found to be less than or equal to the minimum flow the program branches to statement 210 in subsection 7c where the

new flow level is computed as the previous flow plus any waters discharged to the stream. This equation, statement 210, assumes that waters just discharged to the stream cannot be reused at the same station should the river flow rise above the minimum because of the discharge. Statement 211 then sets the amount of water withdrawn per unit of activity equal to zero, and statement 212 returns the analysis to statement 207, the waste strength calculation.

However, if the upstream flow is sufficient then the program sequences to statement 204, which calculates the new river flow as the sum of the previous station's flow plus the amount of water discharged, and minus the amount of water withdrawn. If some water has been withdrawn, the fulfillment of the low flow parameter is checked in statement 206, and if the flow is too low the program branches to statement 213 in subsection 7c. This card increments KOUNTA one unit because an activity level must be bounded at a maximum level because of the low flow parameter. Statement 214 then calculates this maximum level as the amount of water available divided by the net withdrawal per unit of activity at that station. This calculation assumes that an activity both withdrawing and discharging water will not discharge during low flow crises. The variable QOUTA is then modified to represent the net rate of water intake per unit activity, and the river flow is set equal to the minimum flow parameter by statement 216. Lastly, the activity level is set equal to the maximum bound, and the program returns to the waste strength calculation of statement 207.

This waste strength calculation, to which the program always returns after satisfying the flow parameters, is simply the activity level at Station I multiplied by the oxygen demand per unit of activity level and divided by the flow in the river. The constants in the equation convert the units of the answer to milligrams of oxygen demand per liter. As previously stated, a positive result here causes the program to branch to subsection 7d for a dissolved oxygen (DO) analysis of the river after the addition of this waste.

This DO analysis begins at the initial or the last recycle starting point, and moves downstream one station at a time. At each station the program first initializes the variables DT and DNT to zero in statements 221 and 222; and then statement 223 calculates the oxygen demand remaining from the initial background demand using the equation:^{4/}

$$D_s = D_0 e^{-rt}$$

where D_s equals the demand at the subject station, D_0 equals the initial background demand (coded as DB), r equals the stream's reaeration coefficient, and t is time in days (in this application, t equals the number of stations separating the subject station from the initial station).

This subsection next computes the oxygen demands resulting from any waste discharges upstream from the station at which it is computing the demand. This is accomplished with the loop described by statements 224 through 228. The equation for calculating the oxygen demand of the

^{4/} See Dougal (29), p. I-196, equation 45, second term.

waste discharged at station N on the river at station M is:^{5/}

$$D_M = \frac{kL_N}{y - k} [e^{-kt} - e^{-rt}]$$

where D_M is the demand at station M in mgO_2 per liter, L_N is the oxygen demand of the waste discharged at station N, k is the deoxygenation coefficient for the river, r is the reaeration coefficient for the river, and t is time measured in days (or in the case of this application, the difference in station numbers). The values for each of the various waste discharges are summed into the variable DNT, and when all of the discharges upstream from station M have been summed, N equals M, and the program branches to statement 229 where the background demand, DBA, and the waste discharge demands, DNT, are summed into DT, the total demand.

The statements 230 and 231 are used to truncate the total demand, DT, and the critical demand, DC, to four decimal places. This is accomplished by moving the decimal point four places to the right and converting the numbers to integers. The two values are then compared by statement 232; and, if the critical demand is exceeded, the program branches to subsection 7e, the treatment level determination section discussed below. If the critical demand is not exceeded, the total demand is stored in the array DTR for station M, and the program loops to the next downstream station beginning again at statement 220.

This process continues until an oxygen demand profile has been calculated for the entire reach of the river being analyzed. This

^{5/}See Dougal (29), p. I-196, equation 45, first term.

analysis includes the effects of all wastes discharged at station I and at stations further upstream. The program then returns to statement 200, and the search downstream continues for additional waste discharges and low flow problems starting with station $(I + 1)$. When the final station on the stream has been analyzed completely, the array DTR contains the final oxygen demand profile for the stream.

However, in reaching this point of departure from the Water Quality analysis section, the program will probably have branched several times to the treatment level determination section, 7e, statements 236 through 275. This section begins by incrementing the counter KOUNTA by one unit. Next the value in the array KT for station I is incremented one unit. This array is used to indicate the degree of treatment to be provided. A value of 0 indicates no treatment is provided, one denotes primary treatment, two denotes secondary treatment, three denotes tertiary treatment, and numbers greater than three indicate the activity has been bounded at a maximum level, possibly several times at successively lower values. This new value for KT indicates the treatment level to be implemented in that particular pass through subsection 7e.

The next statement, 238, branches to a special treatment section for the cattle feed lot, statements 260 through 263. As was discussed earlier, this waste is diverted to irrigation use if it violates the water quality parameters of the river. The treatment level section for this waste then sets the BOD contribution and the activity level for the waste discharge equal to zero. The cost to irrigate per unit of activity, CTI, is also subtracted from the objective function coefficient.

For all other waste discharges, the desired level of treatment is determined by statements 239 through 241, and the program branches to the appropriate group of statements. The primary treatment level, for example, is implemented by statements 264 through 267. This group of statements first reduces the BOD of the waste to 65% of the original strength with statement 264. The next card computes a new objective function coefficient by subtracting the cost per unit of activity to provide primary treatment. Statement 266 creates another objective function coefficient which is used specifically for the activity, "additional waste water treatment," by not only subtracting the cost of treating the waste but also the cost of constructing the additional structures needed for the additional treatment.

Secondary treatment is handled similarly by statements 268 through 271, and tertiary treatment is implemented by statements 272 through 275. The BOD of the secondary treatment effluent is 23% of the primary treatment effluent, and tertiary treatment effluent is only 33% as strong as the secondary effluent.

All of these treatment level blocks return the program to statement 201, where the analysis of the river's water quality for the wastes and flows for station I and points upstream is begun again with the checking of low flow parameters and the computation of the waste load addition at station I, and proceeding through the several sequences described above.

If the waste still demands too much oxygen after tertiary treatment, the program will not branch at any of the statements 239

Through 241, and will then enter the block of statements in subsection 7e establishing a maximum allowable upper bound for the offending activity using statements 242 through 259.

The equation used to compute JXMAX in statements 242 through 244 is derived in the following manner. The amount of oxygen demand, D, available for the waste discharged at station I is equal to the critical demand, DC, minus the oxygen demand of the wastes discharged upstream from station I. This latter quantity is equal to the total demand just computed minus the demand for the station I waste that was just computed, or

$$D(I)' = DC - (DT - D(I)).$$

Substituting this equation and the equation for RL, from statement 207, into the equation for D(N) in statement 225 yields:

$$DC - DT + D(I) = \frac{RK * JX(I) * BOD(I) * 10^6 * (e^{-RKt} - e^{-RRt})}{(8.33) (QRIV(L) + JX(I) (QIN(I) - JX(I) * QOUTA) (RR - RK))} \quad \textcircled{1}$$

where the following relationship has been substituted for ORIV(I) because of this quantity's dependence on JX.

$$QRIV(I) = QRIV(L) + JX(I) * QIN(I) - JX(I) * QOUTA$$

Solving equation 1 for JX and substituting the difference in station numbers between station I and the station with the oxygen shortage, M, for time t yields the equation in statements 242-244. This equation is first set equal to JXMAX and then in statement 245 to JX.

Statement 246 sets J equal to the station number of the dependent intake or 0 if none exists. In this latter case, the analysis then

continues, statement 247, in the same manner as described above for the treatment level calculations. However, if a dependent intake exists, the relationship between the intake volume and the discharge volume is examined by statements 248 through 250. If the intake quantity is less than or equal to the value calculated from the discharge volume, the analysis again continues in the same manner as above for the treatment levels. This assumes that if the activity's water intake is less than the calculated value, the difference will be made up from another source, such as a well.

However, if the intake-discharge relationship shows that water has been taken into the activity that cannot be discharged as waste because of JXMAX, a new value for JXMAX must be calculated that will coordinate the intake-discharge volumes. This new situation modifies the river flow at station L immediately upstream from I. The new relationship is:

$$QRIV(L)' = QRIV(L) + JX(JP) (QOUT(JP) - QIN(JP) - JX(I)(1 + F(I)) \\ (QOUT(JP) - QIN(JP))).$$

This equation takes the previous flow at L, adds the original net withdrawal, and subtracts the modified net withdrawal expressed in terms of JX at station I. This relationship is then substituted for QRIV(L) in equation 1 and is again solved for JX with (M - I) substituted for t as before. This manipulation yields the equation on statements 252 through 254, which is set equal to JXMAX for the station I activity. The station J activity is then calculated, and the appropriate JX's are equated to the JXMAX'S, using statements 255 through 257. The control

module variable N3 is then set equal to J, a number greater than zero, and the program returns to the control module for the recycled analysis start discussed above.

This completes discussion of the water quality analysis section although this may not be apparent because of the numerous branches and loops. A simplified flow diagram of the program is presented in section 13 of Appendix F which may clarify the analytical pathways of the WQP.

However, the program still has some work to do after completing the water quality analysis. At the end of each time period's analysis, a number of variables must be converted back into MPS format. This is essentially the reverse of the conversion procedures described previously, however, the subject variables differ. Two of the variables, vectors C and XMAX, are returned to the optimization program and used to revise the input data. In addition, these two variable vectors plus XBOD and IKT are stored for subsequent iterations of the WQP as discussed previously.

The calculation of the bounds, XMAX, for the water treatment and wastewater treatment activities requires additional discussion. Statement 282 is a typical calculation for an "additional water treatment" activity. The resulting value is examined for negativity by statement 283; and, if the value is negative, a bound is then established on the activity "water treatment" by statement 284. This calculation is repeated several times in this section for each of the appropriate activities.

After each time period has been analyzed, and the data have been converted back into MPS format, the program moves to the section

where the WQP output is initiated. The WQP output is shown in Appendix H in conjunction with the balance of the TPS output. The output resulting from statements 356 through 365 appears on pages 243, 244, 245, 246, 257, 258, 259, and 260.

After the program has analyzed all of the time periods and created the output just described the program moves out of the major outer loop bounded by the CONTINUE statement 366 into the area where the decision to continue or stop the TPS analysis is made.

Statement 368 examines the KOUNTA variable for an indication of any activity level or objective function coefficient modifications in the just completed analysis. A positive indication results in the program branching to statement 375 to begin the exit procedures to the optimization program with the intent of continuing the TPS analysis. However, a negative indication results in the output called for by statements 369 through 372. This output appears on page 261, Appendix H. The program then sets ISTOP equal to one which will instruct the optimization program to stop and then branches to statement 416, the communications link with the optimization program.

However, the exit procedures, when the analysis is to continue, are somewhat more complex. The program first, in statement 375, prepares data set 11 to receive the revised data being returned. The next two statements, 376 and 377, are debugging procedures that were inadvertently left in the deck for the run that produced the output in Appendix H. The output from these statements is the bottom row of numbers on page 246 and is of no importance.

Statement 378 sets the variable NCOLS equal to the number of activities in the MPS format data vectors. This variable is used as a test value in subsequent loops.

Statements 379 through 411 prepare the output and the data for the Optimization program "REVISE" command. This output appears on page H-7 of Appendix H. The revised input data to the optimization program also appears on pages 248, 249, 250, 251, 252, 253 and 254 of Appendix H.

There are two significant manipulations of the data occurring within this group of statements. The first of these involves statements 394 through 399. Since we want to revise only the bounds which have been altered by the WQP, we wish to bypass any XMAX values still equal to their original values. This is accomplished with statement 394. Furthermore, negative bounds cannot be inputted to the optimization program, so any negative XMAX values found are set equal to zero, and that activity is fixed at the zero level by statements 397 through 399.

The second manipulation involves statements 402 through 406 where XMAX is truncated to three decimal places.

Statement 412 prepares data set 11 for entry by the REVISE command.

The storage of the WQP variables to be used in subsequent iterations is accomplished by statements 413 through 415. The data are stored on disc data set 12.

Statement 416 returns the TPS to the optimization program via READCOMM with instructions to continue or stop.

The last statement, 417, tells the compiler that the end of the WQP has been reached.

A set of input procedures is also needed for this program, and these statements are listed in section 11. These procedures are identical to the input procedures for the READCOMM program described previously, with the exception of the program name. The WQP uses the DSNAME of PROG.U3583.H, and the READCOMM name HUBLY.

Section 12 of Appendix 6 contains a listing of the various codes used in the WQP and units of the variables. The flow chart mentioned previously appears in section 13.

This discussion of the TPS has been directed towards those readers wishing to apply this technique to their own problem areas; and, at this point, that mission has been fulfilled. However, Part III continues in Chapter 11 with a closing discussion of the analysis results obtained in this application and a discussion of a few expansion possibilities for the TPS.

CHAPTER ELEVEN: RESULTS OF TANDEM PROGRAM SYSTEM MODEL

Two remaining discussion areas are incorporated into this closing chapter of Part III. The results obtained in applying the TPS to application I are presented first, to illustrate the output format and to show how the water quality portion of TPS affected the final solution. The last section of this chapter briefly discusses some potential improvements and expansions in the TPS approach.

Application I Results Using TPS

An acceptable optimal solution to application I was found on the second iteration of the TPS. The computer output containing the two optimal solutions, the two river analyses, and the communicated variables has been presented in Appendix H. The computer printout has been rearranged into the actual solution sequence. The results of the initial optimization program solution appear on pages 241 and 242 of Appendix H, followed by the WQP river analyses for each of the four time periods. The WQP modifications to the objective function coefficients and bounds appear on page 247, and the next seven pages of that appendix contain the revised data set used by the optimization program in its second solution. The results of the subsequent optimization solution follow on pages 255 and 256. The final set of four WQP river analyses is followed by the PROBEND message indicating that an acceptable optimal solution has been found.

An idea of the effects of altering the general model to fit the TPS and then allowing the water quality parameters to enter the

solution can be seen in a comparison of optimal object function values, as shown in Table 15.

Table 15. Comparison of Optimal Objective Function Values

General Model--Application I--unbounded solution	\$17,480,640
TPS initial solution	\$17,649,333
TPS final solution	\$17,379,973

Surprisingly, the optimal values obtained before and after the general model was modified differ by less than 1%, indicating that most of the original features of the model have not been disturbed. The effect of imposing water quality standards was a relatively small 1.5% decrease which is less than was expected.

The various activities and their values entering the four time periods of the initial and final TPS solutions have been tabulated in Table 16 presented below. The corresponding values found in the initial general model solution of application I are also included in the table for those activities that are comparable. The activities that were bounded by the WQP have been marked with an asterisk along with the changes in the balance of the activities resulting indirectly from the treatment and bounding activities of the WQP. The waste water treatment activity in time period C has been marked with a double asterisk because this activity was also bounded, but the final solution did not exhaust the amount of treatment still available.

The river analyses for the first TPS iteration show that tertiary treatment was required for both the Pork Slaughter and Waste Water

Table 16. Initial and Final Optimal Activity Levels for Application I Using TPS.

<u>Time Period</u>	<u>Activity</u>	<u>Level of Activity</u>		
		General Model Application I Unbounded sol.	TPS Initial Solution	TPS Final Solution
A	Pork Slaughter	318.411	318.411	318.411
	Other Non-durable Goods	0	736.897	701.119
	Wholesale & Retail Trade	781.400	0	586.676
	Other services	-	2,207.472	2,163.686
	Water Treatment	-	195,529.598	195,529.598
	Add'l Water Treatment	-	78,180.428	78,180.428
	Waste Water Treatment	-	187,847.973	188,500.227
	Residential Use	89,959.632	132,349.127	132,349.127
	Low Flow	629.989	629.989	629.989
B	Pork Slaughter	103.470	103.470	103.470
	Regulated Industries	0	329.571	295.456
	Other Services	-	113.231	711.720
	Water Treatment	-	65,896.715	65,896.715
	Add'l Water Treatment	-	154,651.003	155,762.017
	Waste Water Treatment	-	63,720.600	63,720.597
	Add'l Waste Water Treatment	-	6,567.041	8,886.773
	Residential Use	30,313.089	44,603.849	44,603.849
	Storage	100.000	1,265.000	0
Low Flow	1,259.979	1,259.979	1,259.979	
C	Pork Slaughter	119.448	119.448	116.784*
	Other Non-Durable Goods	0	0	35.777
	Other Machinery	995.646	995.647	995.647
	Finance, Insurance & Real Estate	2,757.000	2,757.021	2,757.021
	Other Services	-	589.988	0
	Water Treatment	-	66,976.989	66,976.989
	Add'l. Water Treatment	-	21,040.482	1,099.896*
	Waste Water Treatment	-	61,951.937	55,045.032**
	Storage	0	0	1,265.000
	Residential Use	89,790.000	45,335.061	45,335.061
	Low Flow	504.044	504.044	504.044
D	Pork Slaughter	103.470	103.470	102.640*
	Other Services	-	1,009.158	1,044.442
	Water Treatment	-	65,896.715	65,896.715
	Add'l Water Treatment	-	10,664.137	11,781.493
	Waste Water Treatment	-	43,594.924	43,949.533
	Recreation Use	12,625.000	11,385.000	11,385.000
	Residential Use	56,829.164	44,603.849	44,603.849
	Low Flow	251.890	251.890	251.890

Treatment activities in all time periods in addition to the bounding described above. The revised objective function coefficients for these activities can be found on page 247, Appendix H, among the revisions transmitted back to the optimization program. As a result of the increased treatment costs the municipal Waste Water Treatment activity decreased by 5,900,044 gallons in the final solution. However, the addition of treatment costs did not curtail the Pork Slaughter activity since all of the available capacity was utilized even after these costs were considered.

The bounding of the Waste Water Treatment activity in period C resulted in the bounding of the Additional Water Treatment activity through the use of the F and GP variables discussed earlier. This action caused the model to leave 20,197,527 gallons of the stream resource unused which probably is the reason the storage activity moved from time period B to period C.

As in the general model solution of application I, the agricultural group of activities and the construction and mining activities never entered the solution so there was no opportunity to observe any water quality effects in these areas. However, the aggregated industries of the municipality produced 98,080 units less value added after the application of water quality criteria.

Improvement and Expansion Possibilities for the TPS

A number of potential improvement areas in the TPS model have been noted at various points in the preceding discussions; however, the results just presented illustrate a few additional areas in need of attention.

Several of the bound revisions listed on page 247 of Appendix H appear to contain very minute revisions, such as revising 63720.600 to 63720.597. This is the type of problem mentioned early in Chapter Ten that required switching to double precision numbers. Obviously part of that problem still remains and probably should be debugged out of the model. Since aberrations of this sort do not significantly affect the solution when they occur in the bounds section (the earlier problem included the objective function revisions), these machine problems were allowed to remain temporarily in the TPS.

The improbable free time period allocation of residential water use existing in the general model is clearly shown by the data in Table 16. The assumed constant consumption of the TPS model (731,210 gallons per day) resulted in the figures shown for the initial and final TPS solutions. There obviously is a difference between these allocations and the general model allocations also shown. The daily residential use of the general model figures are:

Period A	497,015 gallons per day
Period B	496,936 gallons per day
Period C	1,448,226 gallons per day
Period D	931,626 gallons per day

This problem is resurrected at this point because the TPS model still contains a number of areas where events such as the practically impossible tripling of residential water use in period C can occur. The all or nothing use of many of the activities, as seen in Table 16, illustrates this type of problem and needs to be corrected.

The TPS approach to the problem of dependent intakes and discharges works well in a single industry situation, e. g. the Pork

Slaughter activity. However, the use of a constant discharge/intake ratio is inconsistent with the municipality situation. The data in Table 16 have ratios of 0.69, 0.32, 0.70, and 0.57 for the four time periods, and this problem area is the probable cause of the 20 million gallon stream surplus in period 3.

These areas of needed improvement are all directed towards building more realism into this particular application, and the list could be expanded to include many more than these few examples. However, these problems are insignificant when compared to the multitude of expansion possibilities available to the TPS. The versatility now possible in linear programming optimization problems through use of the TPS is limited only by the user's imagination.

The expansion methods available fall into two large categories. A point of initial endeavor might involve the expansion of the Water Quality Program to increasing levels of complexity including additional water quality criteria and physical variables. Or, in this same manner, the Water Quality program portion of TPS might be diverted to some other area of interest to the analyst.

A second approach to TPS expansion involves the use of multiple programs, each possibly quite different from the others. The system might be set up to solve an initial problem of the type just described, but instead of stopping when the solution is reached, the problem could then be reformed by another Fortran program and a new TPS solution could be started.

The potential for application of this new tool should be obvious to the reader at this point.

PART IV

CHAPTER TWELVE: SUMMARY, CONCLUSIONS AND SUGGESTIONS
FOR FURTHER RESEARCH

This study was undertaken with three objectives, each of which has been met with some success. The first objective, to determine by analysis of Iowa's water permit system how the system would allocate water in times of scarcity, was accomplished in Chapter Three. It was shown in that chapter that the permit system acknowledges only two consistently identified points on a water user's production function, the point of zero output and zero water use and the point of maximum total physical product, where the marginal physical product of water becomes zero. The second objective was the construction of a model which would show optimum water use in particular situations. This model is discussed in Chapters Five and Six. The accomplishment of these first two objectives enabled partial accomplishment of the third.

The third objective was to compare optimal water allocation and permit system allocation in a particular situation. Such a comparison was described in Chapter Seven. In Part III, the general model was extended and refined to include detailed water quality considerations using linear programming and simulation. The resulting Tandem Program System (TPS) Model makes possible adjustments in producing activities based upon their waste producing character.

As was noted in the discussion of this comparison, it is not possible to predict what allocation will result from operation of the permit system; it is possible only to estimate limits between which

permit system allocations might range, given certain assumptions concerning waste and total water use.

Related to all three of these objectives is the hypothesis developed in Chapter Four. The hypothesis states that Iowa's permit system will optimally allocate scarce water resources. It is possible to say, as illustrated by the results described previously in this chapter, that although the permit system might allocate water optimally, it is also likely that it will not. The hypothesis is therefore rejected on the grounds that no systematic bias toward finding optimum allocations can be presumed in the permit system. Note that the strict alternative hypothesis, that Iowa's permit system will not optimally allocate a scarce water resource, cannot be accepted without modification. An acceptable alternative hypothesis is that the permit system will not always allocate scarce water resources optimally. It is defensible to state that the current statutory criteria for water allocation in Iowa are less than adequate given the optimality assumptions herein.

Having reached the objectives of the study, certain conclusions can be drawn which are of perhaps greater import than the rejection of the hypothesis. The permit system in Iowa cannot be relied on to optimally allocate scarce water resource without modification; this study proposes models which can be instruments of such a modification. No vast change in the present permit system is required. It is necessary, however, that two further objectives be accomplished. First, data must be generated which will allow the models to be more accurate in describing area water use problems. Second, a system must be devised whereby solutions of the model can be obtained simply by transferring from the data bank to the model the activity vectors appropriate to the situation

under study. This system, if accurate, specific data were on call, would provide timely information in the form of priority lists among relevant activities, to those responsible for permit allocation decisions. The conclusion to which these suggestions point is that it would be possible to decrease the economic uncertainty of permit allocation by minimizing the element of randomness resulting from lack of information. Using the models would also assist the State of Iowa in finding that allocation which will provide the greatest feasible return to the state's water resources.

The form taken by the required data referred to above is critical. The discussion of the model in Chapter Five pointed out that a trade-off exists between greater detail in information and greater awkwardness of computation as the model and its data requirements grow. The suggested data set should then be composed of information which describes the characteristics of the model's activities and constraints as accurately as ease of manipulation will allow.

Such information can be envisioned with little difficulty. For example, any one of the aggregate producing sectors used in this study could be further broken down into a number of smaller, more homogeneous industry types. Linear production functions for these industry types could be estimated by sampling among them. It appears that the data so estimated could be allowed a large error tolerance, since the previous analysis in this chapter has shown that relatively small changes in the shadow price of water occur with large changes in water use. This insensitivity implies that the opportunity cost of inaccurate data may not be high.

The development of a system for utilizing this data would not be inordinately difficult. Linear programming routines have been developed and can be made an integral part of any computer installation. Data files could be established in some form of computer storage, such as magnetic tape or magnetic disc, and the required coefficients would be a part of the model's solution system.

It is apparent, therefore, that models such as those developed in this study, when utilized with the appropriate data, could be of continuing value in the administration of Iowa's permit system. It is not improbable that models and data systems such as those suggested here could be easily maintained and updated once the data files had been established, thus providing an analytical tool which could be used to good purpose in more efficiently administering Iowa's water resources.

Suggestions for Further Research

As the conclusions of this study indicate, further research in at least three specific directions is required in order that the models developed in this study can be of maximum usefulness to those who are responsible for water quality management in Iowa. The first, and most urgent, direction is the development of more accurate information from which the coefficients and parameters of the models can be estimated. A data bank could be developed, in which production information could be stored. This information would be more specific than that derived from the aggregate sectors used herein. The increased specificity could come through subdividing sectors into a number of more narrow industry types and sampling within those types to derive more complete and representative descriptions of these production functions. With these data on file, a decision maker faced with determining a question

of water allocation could utilize the model simply by withdrawing from the data banks those activities involved in the allocation.

Research could also be conducted in a second area. Models which describe the hydrologic system under consideration can be linked with this study's linear programming model, which describes the economic system making use of the water. In this way, changes in water resource parameters could be determined as changes in the hydrologic system took place, either as a result of water use or of changes in water supply.

A third area of study is indicated by the following facts. The value of marginal product of a unit of water is also the share of product which accrues to water as an input to production. This value represents the marginal cost to the State of Iowa in surrendering water for use. The marginal benefit from use, however, is being realized privately, and marginal private cost is zero since only the \$15 application fee is charged for water used. This divergence between private and social marginal cost could be rectified if a fee were charged, equal to value of marginal product, for water use. This fee would also be an aid in allocation, since, in perfect competition, it represents the market clearing price of water. On the basis of what has been shown in this study with regard to the permit system and water allocation, collection of such a fee is justified. However, the assumptions of perfect competition and homogeneous water supplies relied on in the study must be relaxed and the resulting conclusions studied prior to any recommendation on the structure of a system of fees for water use.

Whichever of these three directions of research is taken, it is apparent that this type of water resources research is an inter-

disciplinary field of endeavor. The inherently hybrid nature of the tools which will be needed for water resource management in the future requires that research efforts be conducted in the multi-faceted interfaces of economics and such disciplines as the physical sciences, law, and engineering.

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APPENDIX A

Year	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1. Average rainfall (inches)	31.11	32.57	31.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50	30.50
2. Average temperature (degrees F)	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73	57.73
3. Average relative humidity (%)	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73	78.73
4. Average wind speed (miles per hour)	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
5. Average number of days with precipitation	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
6. Average number of days with snow	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
7. Average number of days with fog	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
8. Average number of days with ice	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
9. Average number of days with hail	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
10. Average number of days with sleet	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
11. Average number of days with drizzle	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
12. Average number of days with rain	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
13. Average number of days with snowfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
14. Average number of days with sleetfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
15. Average number of days with drizzle	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
16. Average number of days with rain	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
17. Average number of days with snowfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
18. Average number of days with sleetfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
19. Average number of days with drizzle	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
20. Average number of days with rain	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
21. Average number of days with snowfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
22. Average number of days with sleetfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
23. Average number of days with drizzle	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
24. Average number of days with rain	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
25. Average number of days with snowfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
26. Average number of days with sleetfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
27. Average number of days with drizzle	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
28. Average number of days with rain	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
29. Average number of days with snowfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
30. Average number of days with sleetfall	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

2011 C&G

Page 18 - Installation data and associated cost for the cable system to be installed

Table 19. Fertilization rates and expected crop yields on soil types used in application I

Soil type	Corn		Soybeans	
	yield ^a (bushels/acre)	fertilization rate ^b (lb./acre)	yield ^a (bushels/acre)	fertilization rate ^b (lb./acre)
I. Tama silty clay loam	98		34	
Fertilizer:				
Nitrogen		100		0
Phosphorus		18		18
Potassium		15		0
II. Clarion loam	90		29	
Fertilizer:				
Nitrogen		80		0
Phosphorus		36		26
Potassium		15		35

^a(50, Table 1.10, p. 15)

^b(50, Table 1.9, p. 14)

Table 20. Rainfall and runoff by time period for three levels of rainfall

	Rainfall ^a (in)	Runoff (in) ^b	Runoff (gallons per square mile drainage area)
Average rainfall			
annual	32.12	6.572	62,105,173.4
period 1	9.37	2.74	47,639,466.8
period 2	8.60	2.188	38,042,026.7
period 3	7.46	0.874	15,195,946.7
period 4	6.69	0.768	13,352,960.0
Below normal rainfall			
annual	21.47	2.172	37,763,840.1
period 1	6.06	0.906	15,752,320.0
period 2	6.08	0.732	12,727,040.0
period 3	4.90	0.289	5,024,746.7
period 4	4.43	0.254	4,416,213.3
Above normal rainfall			
annual	37.79	10.02	174,214,400.3
period 1	11.11	4.18	72,676,266.8
period 2	10.52	3.34	58,071,466.8
period 3	8.89	1.33	23,124,266.7
period 4	7.27	1.17	20,342,400.0

^a(80, p. 6)

^b $\log(\text{annual runoff}) = -3.1 + 2.6$

$\log(\text{annual rainfall}):$

runoff in period 1: 41.7% of annual total;

period 2: 33.3% of annual total;

period 3: 13.3% of annual total;

period 4: 11.7% of annual total.

See Bennion (6, p.11).

Table 21. Crop water requirements by time period for three levels of rainfall

	Water required (gallons/acre) ^a	Rainfall (gallons/acre) ^b			Supplemental irrigation required ^c (gallons/acre)			Assumed yield ^d (bushels/acre)	Supplemental water requirements per bushel		
		below normal	average	above normal	below normal	average	above normal		below normal	average	above normal
Period 1:		16,463.2	25,455.5	30,182.5							
Corn I	13,276.5				0	0	0	98	0	0	0
Corn II	13,276.5				0	0	0	90	0	0	0
Soybeans I	13,276.5				0	0	0	34	0	0	0
Soybeans II	13,276.5				0	0	0	29	0	0	0
Period 2:		16,517.5	23,363.6	28,579.7							
Corn I	19,361.9				2,844.3	0	0	98	29.0	0	0
Corn II	19,361.9				2,844.3	0	0	90	31.6	0	0
Soybeans I	19,361.9				2,844.3	0	0	34	83.7	0	0
Soybeans II	19,361.9				2,844.3	0	0	29	98.1	0	0
Period 3:		13,311.8	20,266.6	24,151.5							
Corn I	29,139.3				15,827.5	8,872.7	4,987.8	98	161.5	90.1	50.9
Corn II	29,139.3				15,827.5	8,872.7	4,987.8	90	175.9	98.1	55.4
Soybeans I	29,139.3				15,827.5	8,872.7	4,987.8	34	465.5	259.6	146.7
Soybeans II	29,139.3				15,827.5	8,872.7	4,987.8	29	545.8	304.4	172.0
Period 4		12,035.0	18,174.7	19,750.4							
Corn I	13,754.6				1,719.6	0	0	98	17.6	0	0
Corn II	13,754.6				1,719.6	0	0	90	19.1	0	0
Soybeans I	13,754.6				1,719.6	0	0	34	50.6	0	0
Soybeans II	13,754.6				1,719.6	0	0	29	59.3	0	0

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^aBased on data given in Shaw, et. al. (80a).

^bBased on data given in Shaw, (80).

^cFor any time period, supplemental irrigation required = water required - rainfall. negative irrigation requirements, implying an abundance of rainfall relative to crop use, are considered as zero.

^dBased on data in James (51). See Table 1, supra.

Table 22. Definition of aggregate sectors by Standard Industrial Classification code

Sector ^a	Standard Industrial Classification codes included
1. Livestock agriculture	
2. Crop agriculture	
3. Meat products	201
4. Other food and kindred products	20 (except 201)
5. Other non-durables	22, 23, 26 - 31
6. Farm machinery	352
7. Other machinery	35 (except 352), 36
8. Other durables	19, 24, 25, 32 - 34, 37 - 39
9. Regulated industries	40, 42, 44 - 47, 481, 482, 49
10. Wholesale and retail trade	50 - 59
11. Finance, insurance, and real estate	60 - 67
12. Other services	70 - 89 (except public education), 483, 0722
13. Construction and mining	15 - 17, 12, 14

^a(66, Table 1, 8 - 32)

Table 23. 1960 capital-output, output per worker, and capital-labor ratios by sector

Sector	1960 capital per dollar output ^a	1960 output per worker ^b	1960 capital per per worker ^c	1960 employed ^d
1. Livestock agriculture	0.6295	15,775	\$ 9,930.4	140,394
2. Crop agriculture	1.6114	16,274	\$26,233.9	75,473
3. Meat products	0.1423	52,455	\$ 7,464.3	27,313
4. Other food and kindred products	0.3497	32,898	\$11,504.4	29,731
5. Other non-durables	0.5389	15,766	\$ 8,496.3	36,999
6. Farm machinery	0.4150	15,838	\$ 6,572.8	22,060
7. Other machinery	0.4945	11,361	\$ 5,618.0	34,133
8. Other durables	0.5015	12,745	\$ 6,391.6	44,259
9. Regulated industry	2.2621	13,456	\$30,438.8	66,016
10. Wholesale and retail trade	0.6523	5,817	\$ 3,794.4	203,648
11. Finance, Insurance, and real estate	1.0471	30,995	\$32,454.9	37,492
12. Other services.	0.9451	4,333	\$ 4,095.1	161,906
13. Constructing & mining	0.1909	17,102	\$ 3,280.0	56,770

^a(3, Table 8, p. 53)

^b(66, Table 29, p. 127)

^cCapital/dollars of output X output/worker = capital/worker

^d(66, Table 31, p. 129)

Table 24. Direct purchases and imports per dollar of gross output by sector, 1960

Sector	Direct purchases per dollar of gross output ^a	Imports per dollar of gross output ^b	Total materials cost per dollar of gross output
1. Livestock agriculture	0.364713	0.174749	0.539462
2. Crop agriculture	0.540987	0.001549	0.542536
3. Meat products	0.131098	0.000902	0.132000
4. Other food and kindred products	0.231319	0.008886	0.240205
5. Other non-durables	0.411381	0.016417	0.427798
6. Farm machinery	0.560502	0.121950	0.682452
7. Other machinery	0.639259	0.061198	0.700457
8. Other durables	0.588157	0.090549	0.686706
9. Regulated industries	0.689875	0.011813	0.701688
10. Wholesale and retail trade	0.765675	0.004516	0.770191
11. Finance, insurance,	0.613211	0.004679	0.617890
12. Other services	0.745066	0.002981	0.748047
13. Construction and mining	0.421439	0.044192	0.465631

^a(66, Table 26, p. 124)

^b(3, Table 22, pp. 95-96)

Table 25. Capital per worker and estimated capital stock by major industry groups, application I

Major industry group ^a	Activities included	Capital ^b worker	Estimated employment ^c	Capital stock
Non-durable goods manufacturing	X ₈ , X ₉	\$ 3,373.9	128	\$ 431,859.2
Durable goods manufacturing	X ₁₀ , X ₁₁ , X ₁₂	\$ 3,186.8	116	\$ 369,668.8
Regulated industries	X ₁₃	\$30,438.8	123	\$ 3,743,972.4
Wholesale and retail trade	X ₁₄	\$ 3,794.4	438	\$ 1,661,947.2
Finance, insurance, and real estate	X ₁₅	\$32,454.9	62	\$ 2,012,203.8
Other services	X ₁₆	\$ 4,095.1	439	\$ 1,797,748.9
Construction and mining	X ₁₇	\$ 3,280.0	121	\$ 396,880.0

^aThese major industry groups are defined in U. S. Census of Population (96, Table 70, p. 17-199).

^bCapital/Worker = Capital/Output X Output/Worker . Capital-output ratio from Barnard (3, Table 8, p. 53); output per worker from MacMillan (66, Table 29, p. 127).

^cTotal model employment was allocated among major industry groups in the same proportions in which total state employment is divided among the same major industry groups in urban places of 2,500 to 10,000 population.

Table 26. Actual 1960 county and municipal employment, by sector and estimated 1967 county and municipal employment, by sector

major industry group	1960 ^a county employment	1960 ^b municipal employment	percentage of county employment located in municipality	1967 ^c estimated county employment	1967 ^d estimated municipal employment
Agriculture	2,368	85	3.6	2,002	72
Manufacturing	213	120	56.3	448	351
Regulated Industries	251	121	48.2	273	128
Wholesale and Retail Trade	1,000	544	54.4	1,112	619
Finance, Insurance, and Real Estate	163	102	62.6	195	123
Services	971	385	39.6	1,326	533
Construction	292	150	51.4	351	188
Total					2,014

^a(96, Table 85, p. 17-268)

^b(96, Table 81, p. 17-234)

^cDr. Marvin Julius, Department of Economics, Iowa State University, Ames, Iowa. Data from a study in progress of employment and output in Iowa counties. June, 1969.

^dMunicipal employment by sector is assumed to be in the same proportion to total municipal employment as county employment by sector is to total county employment.

Table 27. Capital per worker and estimated 1967 capital stock, by major industry groups

major industry group	capital per worker ^a	estimated 1967 employment ^b	estimated 1967 capital stock
Agriculture	\$ 15,620.3	72	\$ 1,124,662
Manufacturing	\$ 7,606.7	351	\$ 2,669,952
Regulated Industries	\$ 30,428.8	128	\$ 3,896,166
Wholesale Retail Trade	\$ 3,794.4	619	\$ 2,348,734
Finance, Insurance and Real Estate	\$ 32,454.9	123	\$ 3,991,953
Services	\$ 4,095.1	533	\$ 2,182,688
Construction	\$ 3,280.0	188	\$ 616,640

^aCapital/Worker = Capital/Output X Output/Worker . Capital-output ratio from Barnard (3, Table 8, p. 53); output per worker from MacMillan (66, Table 29, p. 127).

^bFor sources and derivation, see Table 26, Appendix B .

APPENDIX C

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Control Program OS/360 Job Control Statements

Statement

No.

```

1 //C428B50 JOB 'U3583,TIME=2,REGION=144K',VINCE,MSGLEVEL=1
2 //STEP1 EXEC MPS360,TIME.MPSCOMP=(1,0),TIME.MPSEEXEC=(1,0),
// REGION.MPSEEXEC=144K
XXMPSCOMP EXEC PGM=COMPILER
XXSTEPLIB DD DSN=SYS1.MPSMVT,DISP=SHR
XXSCRATCH1 DD UNIT=SYSDA,SPACE=(TRK,(5,2)),DSNAME=&SYSUT1
XXSCRATCH2 DD UNIT=SYSDA,SPACE=(TRK,(5,2)),DSNAME=&SYSUT2
XXSCRATCH3 DD UNIT=SYSDA,SPACE=(TRK,(5,2)),DSNAME=&SYSUT3
XXSCRATCH4 DD UNIT=SYSDA,SPACE=(TRK,(5,2)),DSNAME=&SYSUT4
3 //MPSCOMP.SYSMLCP DD DSN=&&SSDA,SPACE=(TRK,(5,2))
X/SYSMLCP DD UNIT=SYSDA,SPACE=(TRK,(5,2)),DISP=(NEW,PASS)
XXSYSPRINT DD SYSOUT=A
4 //MPSCOMP.SYSIN DD *
```

(The Optimization Program cards are located here and the compiler prints the program, as read, at this point.)

```

XXMPSEEXEC EXEC PGM=EXECUTOR,COND=(0,NE,MPSCOMP)
5 //MPSEEXEC.STEPLIB DD DSN=SYS1.MPSMVT,DISP=(SHR,PASS)
X/STEPLIB DD DSN=SYS1.MPSMVT,DISP=SHR
6 // DD DSN=PROG.U3583.D,DISP=(SHR,PASS),
// UNIT=DISK,VOLUME=SER=LIBPAK
7 // DD DSN=PROG.U3583.H,DISP=(SHR,PASS),
// UNIT=DISK,VOLUME=SER=LIBPAK
XXETA1 DD UNIT=SYSDA,SPACE=(TRK,(200),,CONTIG)
XXMATRIX1 DD UNIT=SYSDA,SPACE=(CYL,(10),,CONTIG)
XXSCRATCH1 DD UNIT=SYSDA,SPACE=(CYL,(10),,CONTIG),DSNAME=&SYSUT1
XXSCRATCH2 DD UNIT=SYSDA,SPACE=(CYL,(10),,CONTIG),DSNAME=&SYSUT2
XXPROFILE DD UNIT=SYSDA,SPACE=(CYL,(10),,CONTIG)
XXSYSMLCP DD UNIT=SYSDA,DSNAME=*.MPSCOMP.SYSMLCP,DISP=(OLD,DELETE)
XXSYSPRINT DD SYSOUT=A
XXSYSPUNCH DD SYSOUT=B
XXSYSIN DD DDNAME=SYSIN,DCB=BLKSIZE=80
8 //MPSEEXEC.FT03F001 DD SYSOUT=A,
9 // DCB=(RECFM=FBA,LRECL=133,BLKSIZE=3325,BUFNO=1)
10 //MPSEEXEC.FT06F001 DD SYSOUT=A,
11 // DCB=(RECFM=FBA,LRECL=133,BLKSIZE=3325,BUFNO=1)
12 //MPSEEXEC.FT08F001 DD UNIT=DISK,SPACE=(CYL,(50),,CONTIG)
13 //MPSEEXEC.FT09F001 DD UNIT=DISK,SPACE=(CYL,(50),,CONTIG),
14 // DCB=(RECFM=FB,LRECL=130,BLKSIZE=2600)
15 //MPSEEXEC.FT10F001 DD UNIT=DISK,SPACE=(CYL,(50),,CONTIG),
16 // DCB=(RECFM=FB,LRECL=80,BLKSIZE=7200)
17 //MPSEEXEC.FT11F001 DD UNIT=DISK,SPACE=(CYL,(50),,CONTIG),
18 // DCB=(RECFM=FB,LRECL=80,BLKSIZE=7200)
19 //MPSEEXEC.FT12F001 DD UNIT=DISK,SPACE=(CYL,(10),,CONTIG)
20 //MPSEEXEC.SYSIN DD *
//
```

APPENDIX D

District of Columbia

Case No.	City	Year	Population
1	Washington	1850	25,000
2	Washington	1860	32,000
3	Washington	1870	45,000
4	Washington	1880	65,000
5	Washington	1890	85,000
6	Washington	1900	110,000
7	Washington	1910	135,000
8	Washington	1920	165,000
9	Washington	1930	200,000
10	Washington	1940	230,000
11	Washington	1950	260,000
12	Washington	1960	300,000
13	Washington	1970	350,000
14	Washington	1980	400,000
15	Washington	1990	450,000
16	Washington	2000	500,000
17	Washington	2010	550,000
18	Washington	2020	600,000
19	Washington	2030	650,000
20	Washington	2040	700,000
21	Washington	2050	750,000
22	Washington	2060	800,000
23	Washington	2070	850,000
24	Washington	2080	900,000
25	Washington	2090	950,000
26	Washington	2100	1,000,000
27	Washington	2110	1,050,000
28	Washington	2120	1,100,000
29	Washington	2130	1,150,000
30	Washington	2140	1,200,000
31	Washington	2150	1,250,000
32	Washington	2160	1,300,000
33	Washington	2170	1,350,000
34	Washington	2180	1,400,000
35	Washington	2190	1,450,000
36	Washington	2200	1,500,000
37	Washington	2210	1,550,000
38	Washington	2220	1,600,000
39	Washington	2230	1,650,000
40	Washington	2240	1,700,000
41	Washington	2250	1,750,000
42	Washington	2260	1,800,000
43	Washington	2270	1,850,000
44	Washington	2280	1,900,000
45	Washington	2290	1,950,000
46	Washington	2300	2,000,000
47	Washington	2310	2,050,000
48	Washington	2320	2,100,000
49	Washington	2330	2,150,000
50	Washington	2340	2,200,000
51	Washington	2350	2,250,000
52	Washington	2360	2,300,000
53	Washington	2370	2,350,000
54	Washington	2380	2,400,000
55	Washington	2390	2,450,000
56	Washington	2400	2,500,000
57	Washington	2410	2,550,000
58	Washington	2420	2,600,000
59	Washington	2430	2,650,000
60	Washington	2440	2,700,000
61	Washington	2450	2,750,000
62	Washington	2460	2,800,000
63	Washington	2470	2,850,000
64	Washington	2480	2,900,000
65	Washington	2490	2,950,000
66	Washington	2500	3,000,000
67	Washington	2510	3,050,000
68	Washington	2520	3,100,000
69	Washington	2530	3,150,000
70	Washington	2540	3,200,000
71	Washington	2550	3,250,000
72	Washington	2560	3,300,000
73	Washington	2570	3,350,000
74	Washington	2580	3,400,000
75	Washington	2590	3,450,000
76	Washington	2600	3,500,000
77	Washington	2610	3,550,000
78	Washington	2620	3,600,000
79	Washington	2630	3,650,000
80	Washington	2640	3,700,000
81	Washington	2650	3,750,000
82	Washington	2660	3,800,000
83	Washington	2670	3,850,000
84	Washington	2680	3,900,000
85	Washington	2690	3,950,000
86	Washington	2700	4,000,000
87	Washington	2710	4,050,000
88	Washington	2720	4,100,000
89	Washington	2730	4,150,000
90	Washington	2740	4,200,000
91	Washington	2750	4,250,000
92	Washington	2760	4,300,000
93	Washington	2770	4,350,000
94	Washington	2780	4,400,000
95	Washington	2790	4,450,000
96	Washington	2800	4,500,000
97	Washington	2810	4,550,000
98	Washington	2820	4,600,000
99	Washington	2830	4,650,000
100	Washington	2840	4,700,000

Optimization Program

Control Program Compiler - MPS/360

Statement No.	Statement Address	
1		PROGRAM('ND')
2		INITIALZ
3		MOVE(XDATA,'DAVE')
4		MOVE(XPBNAME,'MAY')
5		CONVERT
6	MORE	ASSIGN('COMMFMT','FT08F001','COMM')
7		PREPOJT('COMMFMT')
8		BCDOUT
9		XFREQ2=50
10		MVADR(XDOFREQ2, ITR)
11		SETUP('BOUNDS','XMAX','MAX')
12		MOVE(XOBJ,'C')
13		MOVE(XRHS,'B1')
14		IF(L3,EQ.1,SKIP)
15		RESTORE
16	SKIP	PRIMAL
17		SOLUTION('ACTIVE')
18		SOLUTION('FILE','COMMFMT')
19		SAVE
20		FREECORE
21		DAVE
22		FREECORE
23		IDEX=L3
24		HUBLY(IDEX,ISTOP)
25		IF(ISTOP.EQ.L1,QUIT)
26		L3=L3+1
27		MOVE(XOLDNAME,'MAY')
28		REVISE('FILE','FT11F001')
29		SETUP('BOUNDS','XMAX','MAX')
30		MOVE(XOBJ,'C')
31		IF(L3.NE.L4,MORE)
32	QUIT	EXIT
33	ITR	L1=L1+50
34		IF(L1.LT.L2,JUMP)
35		SAVE
36		L1=1
37	JUMP	CONTINUE
38	L1	DC(1)
39	L2	DC(50)
40	L3	DC(1)
41	L4	DC(4)
42	IDEX	DC(1)
43	ISTOP	DC(0)
44		PEND

APPENDIX E

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READCOMM Program and Input Procedures

1. The READCOMM Program

Statement No.	Statement Address
1	INTEGER FILE,INDIC,N,TYPE(30)
2	DOUBLE PRECISION NAME,COLUMN(30),VALUES(30)
3	REWIND 9
4	REWIND 10
5	FILE = 8
6	CALL POSITN (FILE,INDIC)
7	CALL ARRAY (FILE,INDIC,NAME)
8	CALL COLNAM (FILE,TYPE,COLUMN,NUMBER)
9	CALL VECTOR (FILE,INDIC,VALUES)
10	CALL ARRAY(FILE,INDIC,NAME)
11	IF(INDIC-1) 31,31,22
12	22 CALL COLNAM(FILE,TYPE,COLUMN,NUMBER)
13	24 CALL VECTOR(FILE,INDIC,VALUES)
14	IF(INDIC-1) 41,41,24
15	41 CALL ARRAY(FILE,INDIC,NAME)
16	IF(INDIC-1) 31,31,42
17	42 CALL COLNAM(FILE,TYPE,COLUMN,NUMBER)
18	44 CALL VECTOR(FILE,INDIC,VALUES)
19	IF(INDIC-1) 31,31,25
20	25 WRITE(9,26) VALUES(3)
21	26 FORMAT(D15.8)
22	WRITE(10,66) VALUES(1)
23	66 FORMAT(A9)
24	GO TO 44
25	31 RETURN
26	END

2. Input Procedures

Statement

No.

a. Job Card

1 //C428V83 JOB 'U3583,REGION=128K,TI=4',VINCE,CLASS=D

b. Scratch Procedure

2 //STEP 2 EXEC MOD
 3 //MOD.SYSIN DD *
 4 SCRATCH DSNAME=PROG.U3583.D,VOL=2314=LIBPAK,PURGE
 5 /*

c. Catalogue Procedure

6 //S1 EXEC FORTGCL,REGION.LKED=128K
 7 //FORT.SYSIN DD*

The READCOMM Program is read and the compiler outputs the program as read at this point.

8 //LKED.SYSLIB DD DSNAME=MPS360.SUBRTNES,DISP=SHR,UNIT=PACK,
 VOLUME=(PRIVATE,SER=MPS002)
 9 // DD DSNAME=SYS1.FORTLIB,DISP=SHR
 10 //LKED.SYSLMOD DD DSNAME=PROG.U3583.D,UNIT=DISK
 VOLUME=SER=LIBPAK,DISP=(NEW,CATLG),
 SPACE=(1024,(100,1,1),RLSE),LABEL=RETPD=100
 11 //LKED.SYSIN DD*
 12 INSERT READCOMM
 13 ENTRY MAIN
 14 NAME DAVE(R)
 15 /*

APPENDIX F

[The following table contains extremely faint and illegible text, likely representing a table of contents or index. The text is too light to transcribe accurately.]

Water Quality Program and Input Procedures

Statement
No. Addr.

1. DEFINITION STATEMENTS

```

1      IMPLICIT REAL*8(A-H,O-Z)
2      REAL*8 JX,JXMAX
3      DOUBLE PRECISION V,IN(200)
4      DIMENSION RL(50),QRIV(50),QIN(50),QOUT(50),BOD(50),JX(50),TL1(50),
5      CTL2(50),TL3(50),JXMAX(50),CS(50),KT(50),TLIC(50),TL2C(50),TL3C(50)
6      C,CSA(50), D(50),X(200),XMAX(200),C(200),DTR(50),F(50),JP(50)
7      DIMENSION XBOD(200),IKT(200)

```

2. FIXED RATIOS AND CONSTANTS

```

8      DATA F/27*0.D0,0.33D0,22*0.D0/
9      DATA JP/14*0,14,2*0,17,9*0,20,22*0/
10     DATA QIN/14*0.D0,7.44D0,2*0.D0,202.5D0,9*0.D0,1.D0,22*0.D0/
11     DATA QOUT/13*0.D0,15.D0,2*0.D0,225.D0,2*0.D0,1.D0,30*0.D0/
12     DATA TL1/17*0.D0,.023D0,9*0.D0,.33D0,22*0.D0/
13     DATA TL2/17*0.D0,.024D0,9*0.D0,.05D0,22*0.D0/
14     DATA TL3/17*0.D0,.028D0,9*0.D0,.063D0,22*0.D0/
15     DATA TL1C/27*0.D0,.025D0,22*0.D0/
16     DATA TL2C/27*0.D0,.083D0,22*0.D0/
17     DATA TL3C/27*0.D0,.03D0,22*0.D0/
18     RR= 0.400
19     RK= 0.200
20     DB= 0.0
21     DC= 3.5
22     DT=0.0
23     QMIN = 103367.0
24     CTI = 0.10
25     TA = 181
26     TB = 61
27     TC = 62
28     TD = 61

```

3. TRANSFER ACTIVITY LEVELS FROM OPTIMIZATION PROGRAM

```

29     REWIND 9
30     REWIND 10
31     DO 66 I=1,200
32     READ(9,26,END=67) V
33 66   X(I)=V
34 67   DO 68 I=1,200
35     READ(10,27,END=69) IN(I)
36 68   CONTINUE
37 69   CONTINUE
38 26   FORMAT(D15.8)
39 27   FORMAT(A9)

```

4. VARIABLE RATIOS AND CONSTANTS

Statement
No. Addr.

```

40      CALL GETARG(IDEX,ISTOP)
41      IF(IDEX.GT.1) GO TO 9971
42      DO 11 I=1,200
43      XMAX (I) =1.E7
44      XBOD(I)=0.0
45      IKT(I)=0
46      C(I)=0.0
47      11 CONTINUE
48      XBOD(1)=0.062
49      XBOD(21)=0.062
50      XBOD(45)=0.062
51      XBOD(69)=0.062
52      C( 1)=36.25
53      C(21)=36.25
54      C(45)=36.25
55      C(69)=36.25
56      XBOD( 2)=2.0
57      XBOD(26)=2.0
58      XBOD(50)=2.0
59      XBOD(74)=2.0
60      C( 2)=13130.0
61      C(26)=13130.0
62      C(50)=13130.0
63      C(74)=13130.0
64      XBOD(14)=2.90
65      XBOD(38)=2.90
66      XBOD(62)=2.90
67      XBOD(86)=2.90
68      C(16)=-0.0001
69      C(40)=-0.0001
70      C(64)=-0.0001
71      C(88)=-0.0001
72      XMAX(13)=222630.
73      XMAX(14)=189072.6
74      XMAX(37)=75030.
75      XMAX(38)=63720.6
76      XMAX(61)=76260.
77      XMAX(62)=64765.2
78      XMAX(85)=75030.
79      XMAX(86)=63720.6
80 9971  IF(IDEX.EQ.1) GO TO 9975
81      DO 9972 I=1,200
82 9972  READ(12,9973)XBOD(I),IKT(I),C(I),XMAX(I)
83 9973  FORMAT(F12.6,I6,F12.6,E20.12)
84      REWIND 12
85 9975  CONTINUE

```

5. INITIALIZE WORKING VARIABLES

Statement No. Addr.	
86	KOUNTA=0
87	DO 1100 K=1,4
88	DO 10 I=1,50
89	JX(I)=0.0
90	JXMAX(I)=1.E7
91	D(I)=0.0
92	QRIV(I)=0.0
93	KT(I)=0
94	DTR(I)=0.0
95	BOD(I)=0.0
96	CS(I)=0.0
97	CSA(I)=0.0
98	10 CONTINUE
99	N1 = 1
100	N2 = 2
101	N3 = 0

6. CONVERT OPTIMIZATION PROGRAM FORMAT TO WATER QUALITY PROGRAM FORMAT

102	IF(K.EQ.1)GO TO 110
103	IF(K.EQ.2)GO TO 120
104	IF(K.EQ.3)GO TO 130
105	QRIV(1) =1447938.8
106	JX(14) = X(69)
107	JX(15) = X(69)
108	JX(17) = X(74)*1000./TD
109	JX(18) = X(74)*1000./TD
110	JX(20) = (1/TD)*(X(85)+X(87))
111	JX(28) = (1/TD)*(X(86)+X(88))
112	JXMAX(15)=XMAX(69)
113	JXMAX(18)=XMAX(74)*1000./TD
114	JXMAX(20)=(XMAX(87)+XMAX(85))/TD
115	JXMAX(28)=(XMAX(88)+XMAX(86))/TD
116	BOD(15)=XBOD(69)
117	BOD(18)=XBOD(74)
118	BOD(28)=XBOD(86)
119	CS(15)=C(69)
120	CS(18)=C(74)/1000.
121	CS(28)=C(86)
122	CSA(28)=C(88)
123	KT(15)=IKT(69)
124	KT(18)=IKT(74)
125	KT(28)=IKT(86)
126	GO TO 140
127	110 QRIV(1) = 1740587.8
128	JX(14) = X(1)
129	JX(15) = X(1)
130	JX(17) = X(2)*1000./TA
131	JX(18) = X(2)*1000./TA
132	JX(20) = (1/TA)*(X(13)+X(15))

Statement
No. Addr.

```

133      JX(28) = (1/TA)*(X(14)+X(16))
134      JXMAX(15)=XMAX( 1)
135      JXMAX(18)=XMAX( 2)*1000./TA
136      JXMAX(20)=(XMAX(15)+XMAX(13))/TA
137      JXMAX(28)=(XMAX(16)+XMAX(14))/TA
138      BOD(15)=XBOD( 1)
139      BOD(18)=XBOD( 2)
140      BOD(28)=XBOD(14)
141      CS(15)=C( 1)
142      CS(18)=C( 2)/1000.
143      CS(28)=C(14)
144      CSA(28)=C(16)
145      KT(15)=IKT( 1)
146      KT(18)=IKT( 2)
147      KT(28)=IKT(14)
148      GO TO 140
149  120  QRIV(1) =4172800.0
150      JX(14) = X(21)
151      JX(15) = X(21)
152      JX(17) = X(26)*1000./TB
153      JX(18) = X(26)*1000./TB
154      JX(20) = (1/TB)*(X(37)+(39))
155      JX(28) = (1/TB)*(X(38)+(40))
156      JXMAX(15)=XMAX(21)
157      JXMAX(18)=XMAX(26)*1000./TB
158      JXMAX(20)=(XMAX(39)+XMAX(37))/TB
159      JXMAX(28)=(XMAX(40)+XMAX(38))/TB
160      BOD(15)=XBOD(21)
161      BOD(18)=XBOD(26)
162      BOD(28)=XBOD(38)
163      CS(15)=C(21)
164      CS(18)=C(26)/1000.
165      CS(28)=C(38)
166      CSA(28)=C(40)
167      KT(15)=IKT(21)
168      KT(18)=IKT(26)
169      KT(28)=IKT(38)
170      GO TO 140
171  130  QRIV(1) = 1620886.0
172      JX(14) = X(45)
173      JX(15) = X(45)
174      JX(17) = X(50)*1000./TC
175      JX(18) = X(50)*1000./TC
176      JX(20) = (1/TC)*(X(61)+X(63))
177      JX(28) = (1/TC)*(X(62)+X(64))
178      JXMAX(15)=XMAX(45)
179      JXMAX(18)=XMAX(50)*1000./TC
180      JXMAX(20)=(XMAX(63)+XMAX(61))/TC
181      JXMAX(28)=(XMAX(64)+XMAX(62))/TC
182      BOD(15)=XBOD(45)
183      BOD(18)=XBOD(50)

```

Statement
No. Addr.

```

184      BOD(28)=XBOD(62)
185      CS(15)=C(45)
186      CS(18)=C(50)/1000.
187      CS(28)=C(62)
188      CSA(28)=C(64)
189      KT(15)=IKT(45)
190      KT(18)=IKT(50)
191      KT(28)=IKT(62)

```

7. WATER QUALITY ANALYSIS

a. Control Module

```

192  140  CONTINUE
193      IF(N3.EQ.0)GO TO 9876
194      N1 = J
195      N2 = J
196  9876  CONTINUE
197      DO 9991 IKL = N1,50
198      RL(IKL)=0.0
199  9991  CONTINUE
200  150  DO 1000 I=N2,50

```

b. Check Flow Level and Organic Load

```

201  149  L = I-1
202      QOUTA=QOUT(I)
203      IF(QRIV(L).LE.QMIN)GO TO 160
204      QRIV(I)=QRIV(L)+QIN(I)*JX(I)-QOUT(I)*JX(I)
205      IF(QOUT(I).EQ.0.0) GO TO 159
206      IF (QRIV(I).LT.QMIN) GO TO 170
207  159  RL(I)=JX(I)*BOD(I)*10**6/(8.33*QRIV(I))
208      IF(RL(I).GT.0.0) GO TO 180
209      GO TO 1000

```

c. Low Flow Protection

```

210  160  QRIV(I) = QRIV(L) + QIN(I)*JX(I)
211      QOUTA=0.0
212      GO TO 159
213  170  KOUNTA = KOUNTA + 1
214      JXMAX(I)=(QMIN-QRIV(L))/(QIN(I)-QOUT(I))
215      QOUTA=(QRIV(L)-QMIN)/JXMAX(I)
216      QRIV(I)=QMIN
217      JX(I) = JXMAX(I)
218      GO TO 159

```

Statement
No. Addr.

d. Check Effect of Waste on River Dissolved Oxygen

```

220 180 DO 900 M=N2,50
221      DNT=0.0
222      DT=0.0
223      DBA=DB/DEXP(RR*(M-1))
224      DO 800 N=2,50
225      D(N)=RK*RL(N)*(1./DEXP(RK*(M-N))-1./DEXP(RR*(M-N)))/(RR-RK)
226      DNT=DNT+D(N)
227      IF(M.EQ.N)GO TO 805
228 800 CONTINUE
229 805 DT=DNT+DBA
230      IDT = DT*10000
231      IDC = DC*10000
232      IF(IDT.GT.IDC) GO TO 190
233      DTR(M)=DT
234 900 CONTINUE
235      GO TO 1000

```

e. Treatment Level Determination

```

236 190 KOUNTA = KOUNTA + 1
237      KT(I) = KT(I) + 1
238      IF (I.EQ.15) GO TO 210
239      IF (KT(I).EQ.1) GO TO 220
240      IF (KT(I).EQ.2) GO TO 230
241      IF (KT(I).EQ.3) GO TO 240
242      JXMAX(I)=8.33*(DC-DT+D(I))*(RR-RK)*QRIV(L)/(RK*(1./DEXP(RK*(M-I)))
243      C-1./DEXP(RR*(M-I)))*BOD(I)*10**6-(QIN(I)-QOUTA)*8.33*
244      C(DC-DT+D(I))*(RR-RK))
245 195 JX(I) = JXMAX(I)
246      J = JP(I)
247      IF(J.EQ.0)GO TO 149
248      IJXJ=JX(J)
249      IJXI=JX(I)
250      IF(IJXJ.GT.IJXI*(F(I)+1)) GO TO 197
251      GO TO 149
252 197 JXMAX(I)=(QRIV(L)+JX(J)*(QOUT(J)-QIN(J)))/(RK*BOD(I)*10**6*(1/DEXP
253      C(RK*(M-I))-1/DEXP(RR*(M-I)))/((DC-DT+D(I))*8.33*(RR-RK))+(F(I)+1)*
254      C(QOUT(J)-QIN(J))-QIN(I)+QOUTA)
255      JXMAX(J ) = JXMAX(I) *(F(I)+1)
256      JX(J ) = JXMAX(J )
257      JX(I) = JXMAX(I)
258      N3 = J
259      GO TO 140
260 210 BOD(15) =0.0
261      CS(15) = CS(15) - CTI
262      JX(15) = 0
263      GO TO 149
264 220 BOD(I)=BOD(I)*0.65
265      CS(I)=CS(I)-TL1(I)
266      CSA(I) = CSA(I)-TL1(I)-TL1C(I)
267      GO TO 149

```

Statement
No. Addr.

```

268 230 BOD(I) = BOD(I)*0.23
269      CS(I) = CS(I) - TL2(I)
270      CSA(I) = CSA(I) - TL2(I) - TL2C(I)
271      GO TO 149
272 240 BOD(I) = BOD(I)*0.33
273      CS(I) = CS(I) - TL3(I)
274      CSA(I) = CSA(I) - TL3(I) - TL3C(I)
275      GO TO 149
276 1000 CONTINUE

```

8. CONVERT WATER QUALITY PROGRAM FORMAT TO OPTIMIZATION PROGRAM FORMAT

```

277 250 IF(K.EQ.1) GO TO 260
278      IF(K.EQ.2) GO TO 270
279      IF(K.EQ.3) GO TO 280
280      XMAX(69) = JXMAX(15)
281      XMAX(74) = JXMAX(18)/1000*TD
282      XMAX(87)=(JXMAX(20)-1230.)*TD
283      IF(XMAX(87).GE.0.0)GO TO 251
284      XMAX(85)=1230.*TD+XMAX(87)
285 251 XMAX(88)=(JXMAX(28)-1044.6)*TD
286      IF(XMAX(88).GE.0.0)GO TO 252
287      XMAX(86)=1044.6*TD+XMAX(88)
288 252 C(69) = CS(15)
289      C(74) = CS(18)*1000.
290      C(86) = CS(28)
291      C(88) = CSA(28)
292      XBOD(69)=BOD(15)
293      XBOD(74)=BOD(18)
294      XBOD(86)=BOD(28)
295      IKT(69)=KT(15)
296      IKT(74)=KT(18)
297      IKT(86)=KT(28)
298      GO TO 300
299 260 XMAX(1)  = JXMAX(15)
300      XMAX(2)  = JXMAX(18)/1000*TA
301      XMAX(15)=(JXMAX(20)-1230.)*TA
302      IF(XMAX(15).GE.0.0)GO TO 261
303      XMAX(13)=1230.*TA+XMAX(15)
304 261 XMAX(16)=(JXMAX(28)-1044.6)*TA
305      IF(XMAX(16).GE.0.0)GO TO 262
306      XMAX(14)=1044.6*TA+XMAX(16)
307 262 C(1)      = CS(15)
308      C( 2) = CS(18)*1000.
309      C(14)  = CS(28)
310      C(16)  = CSA(28)
311      XBOD( 1)=BOD(15)
312      XBOD( 2)=BOD(18)
313      XBOD(14)=BOD(28)
314      IKT( 1)=KT(15)
315      IKT( 2)=KT(18)
316      IKT(14)=KT(28)
317      GO TO 300

```


Statement
No. Addr.

```

318 270 XMAX(21) = JXMAX(15)
319      XMAX(26) = JXMAX(18)/1000*TB
320      XMAX(39)=(JXMAX(20)-1230.)*TB
321      IF(XMAX(39).GE.0.0)GO TO 271
322      XMAX(37)=1230.*TB+XMAX(39)
323 271 XMAX(40)=(JXMAX(28)-1044.6)*TB
324      IF(XMAX(40).GE.0.0)GO TO 272
325      XMAX(38)=1044.6*TB+XMAX(40)
326 272 C(21) = CS(15)
327      C(26) = CS(18)*1000.
328      C(38) = CS(28)
329      C(40) = CSA(28)
330      XBOD(21)=BOD(15)
331      XBOD(26)=BOD(18)
332      XBOD(38)=BOD(28)
333      IKT(21)=KT(15)
334      IKT(26)=KT(18)
335      IKT(38)=KT(28)
336      GO TO 300
337 280 XMAX(45) = JXMAX(15)
338      XMAX(50) = JXMAX(18)/1000*TC
339      XMAX(63)=(JXMAX(20)-1230.)*TC
340      IF(XMAX(63).GE.0.0)GO TO 281
341      XMAX(61)=1230.*TC+XMAX(63)
342 281 XMAX(64)=(JXMAX(28)-1044.6)*TC
343      IF(XMAX(64).GE.0.0)GO TO 282
344      XMAX(62)=1044.6*TC+XMAX(64)
345 282 C(45) = CS(15)
346      C(50) = CS(18)*1000.
347      C(62) = CS(28)
348      C(64) = CSA(28)
349      XBOD(45)=BOD(15)
350      XBOD(50)=BOD(18)
351      XBOD(62)=BOD(28)
352      IKT(45)=KT(15)
353      IKT(50)=KT(18)
354      IKT(62)=KT(28)
355 300 CONTINUE

```

9. PRINT WORKSHEET FOR EACH TIME PERIOD OR PROBEND MESSAGE

```

356      WRITE(6,301)K,INDEX
357 301 FORMAT('1',///,' RIVER CONDITIONS FOR THE TIME PERIOD',I2,',',
358      CSOLUTION NUMBER',I2)
359      WRITE(6,302)
360 302 FORMAT('0',T4,'STA',T12,'RIVER FLOW',T30,'DEFICIT',T39,'ACT. LEVEL
361      C',T52,'TRT. LEVEL')
362      DO 1300 I=1,50
363      WRITE(6,305) I,QRIV(I),DTR(I),JX(I),KT(I)
364 305 FORMAT(' ',I5,F15.1,F15.5,F12.0,I10)
365 1300 CONTINUE
366 1100 CONTINUE

```

Statement
No. Addr.

```

367      ISTOP=0
368      IF (KOUNTA.GT.0) GO TO 310
369      WRITE(6,306)IDEX
370 306  FORMAT('1',////,'      THE OPTIMAL SOLUTION NUMBER',I2,' ALSO ALLOWS
371      C ACHIEVEMENT OF',/, '      THE WATER QUALITY AND FLOW PARAMETERS SPEC-
372      CIFIED.',/, '      THIS IS PROBEND.')
```

10. EXIT PROCEDURES TO OPTIMIZATION PROGRAM

```

375 310  REWIND 11
376      WRITE(6,7779)C(2),C(74),CS(18)
377 7779  FORMAT(3D20.12)
378      NCOLS=91
379      WRITE(11,51)
380 51    FORMAT('NAME',10X,'DAVE')
381      WRITE(11,52)
382 52    FORMAT(' COLUMNS')
383      WRITE(11,53)
384 53    FORMAT('  MODIFY')
385      DO 54 I=1,130
386      IF(C(I).EQ.0.0) GO TO 54
387      WRITE(11,55) IN(I),C(I)
388 55    FORMAT(3X,A9,2X,'C  ',5X,F12.5)
389 54    CONTINUE
390      WRITE(11,56)
391 56    FORMAT(' BOUNDS')
392      WRITE(11,53)
393      DO 58 I=1,NCOLS
394      IF(XMAX(I).GE.1.E7) GO TO 58
395      IF(XMAX(I).LT..000009) GO TO 9985
396      GO TO 5888
397 9985  XMAX(I)=.000000
398      WRITE(11,60) IN(I),XMAX(I)
399 60    FORMAT(' FX XMAX',5X,A9,2X,F12.8)
400      GO TO 58
401 5888  CONTINUE
402      L=XMAX(I)
403      DD=XMAX(I)-L
404      ID=DD*1000.
405      YID=ID/1000.
406      XMAX(I)=L+YID
407      WRITE(11,59) IN(I),XMAX(I)
408 59    FORMAT(' UP XMAX',5X,A9,2X,F12.3)
409 58    CONTINUE
410      WRITE(11,599)
411 599   FORMAT(' ENDDATA')
412      REWIND 11
413      DO 9974 I=1,200
414 9974  WRITE(12,9973)XBOD(I),IKT(I),C(I),XMAX(I)
415      REWIND 12
416 5019  CALL PUTARG(IDEX,ISTOP)
417      END
```

Statement
No.

11. INPUT PROCEDURES

a. Job Card

1 // C428V8 JOB 'U3583,REGION=144K, TI=2',VINCE,CLASS=D

b. Scratch Procedure

2 // STEP4 EXEC MOD
3 // MOD.SYSIN DD*
4 SCRATCH DSNAMES=PROG.U3583.H,VOL=2314=LIBPAK,PURGE
5 /*

c. Catalogue Procedure

6 //S1 EXEC FORTGCL,REGION.FORT=128K,REGION.LKED=128K
7 //FORT.SYSIN DD*

(Water Quality Model Program Entered Here)

8 //LKED.SYSLIB DD DSNAMES=MPS360.SUBRTNES,DISP=SHR,UNIT=PACK,
// VOLUME=(PRIVATE,SER=MPS002)
9 // DD DSNAMES=SYS1.FORTLIB,DISP=SHR
10 //LKED.SYSLMOD DD DSNAMES=PROG.U3583.H, UNIT=DISK,
VOLUME=SER=LIBPAK,DISP=(NEW,CATLG),
SPACE=(1024,(100,1,1),RLSE),LABEL=RETPD=100

11 //LKED.SYSIN DD*
12 INSERT READCOMM
13 ENTRY MAIN
14 NAME HUBLY (R)
15 /*

12. DEFINITIONS OF VARIABLES USED IN WATER QUALITY PROGRAM

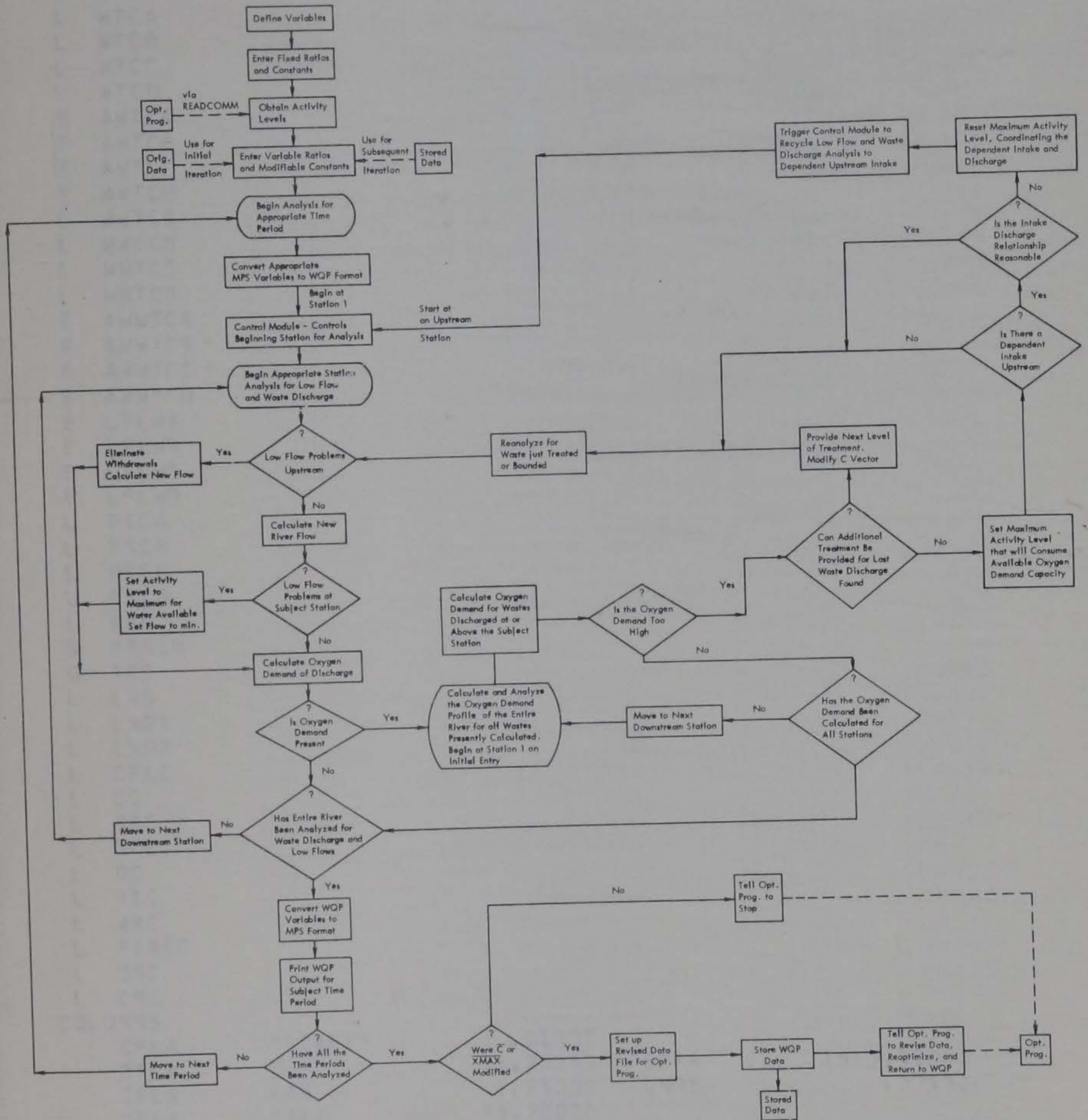
Code	Definition	Units	Format
BOD	Biochemical Oxygen Demand generated by each activity per unit of activity.	$\frac{\#O_2}{UA^1}$	WQP
C	The objective function coefficients in MPS format.	$\frac{\$ \text{ Value added}}{UA}$	MPS
CS	The objective function coefficients in WQP format with the exception of the values for additional waste water treatment.	"	WQP
CSA	The objective function coefficients for additional waste water treatment in WQP format.	"	WQP
CTI	The cost of diverting the feed lot waste to irrigation.	$\frac{\$}{UA}$	---
D	A working variable array used in determining the river oxygen demand at the various stations of the river.	$\frac{Mg O_2}{liter}$	WQP
DB	The oxygen demand of the river at Station 1.	$\frac{Mg O_2}{liter}$	---
DC	The maximum allowable oxygen demand in the river.	$\frac{Mg O_2}{liter}$	---
DT	Total oxygen demand at each station of the river.	$\frac{Mg O_2}{liter}$	---
DTR	The storage array for all the DT's along the river.	$\frac{Mg O_2}{liter}$	WQP
F	The ratio of the water withdrawn from the river and not returned per unit of water discharged.	None	WQP
IN	An array used to store the MPS names for the activities.	None	MPS
IKT	An array of integers indicating the level of treatment called for by the WQP. 0 =None 1 =Primary 2 =Secondary 3 or more=Tertiary	None	MPS

¹UA = a unit of activity

Code	Definition	Units	Format
JP	An array of integers that indicate if an activity waste flow is linked to an upstream river intake. The integer gives the station of the upstream link.	None	WQP
JX	The levels of the various activities.	Units/day	WQP
JXMAX	The maximum level of the various activities that can be allowed.	Units/day	WQP
KOUNTA	A counter used to signal if a change in a treatment level has been made during each WQP run.	None	---
KT	The same as IKT only in WQP format.	None	WQP
RK	The river deoxygenation coefficient.	days ⁻¹	---
RL	The oxygen demand load being added to the river at each station.	$\frac{\text{Mg O}_2}{\text{liter}}$	WQP
RR	The river reaeration constant.	days ⁻¹	---
QIN	The volume of water released by each unit of activity at each station per day.	$\frac{1000\text{gal}}{(\text{UA})(\text{days})}$	WQP
QMIN	The minimum acceptable flow in the river.	$\frac{1000\text{gal}}{\text{day}}$	---
QRIV	The flow in the river at each station.	$\frac{1000\text{gal}}{\text{day}}$	WQP
QOUT	The volume of water withdrawn for each unit of activity at each station per day.	$\frac{1000\text{gal}}{(\text{UA})(\text{day})}$	WQP
TA, TB, TC, TD	The number of days in each of the time periods.	days	---
TL1, TL2, TL3	The cost of providing each additional level of treatment per unit of activity.	$\frac{\$}{\text{UA}}$	WQP
TL1C, TL2C, TL3C	The cost of providing the additional capital expenditures required for the additional waste water treatment.	$\frac{\$}{\text{UA}}$	WQP
X	The levels of the various activities.	Units	MPS

Code	Definition	Units	Format
XBOD	Biochemical Oxygen Demand generated by each activity per unit of activity.	$\frac{\#O_2}{UA}$	MPS
XMAX	The maximum allowable level for each activity.	Units	MPS

13. FLOW CHART FOR WATER QUALITY PROGRAM.



APPENDIX G: ORIGINAL INPUT TO OPTIMIZATION PROGRAM

EXECUTOR. MPS/360 V2-M9

NAME DAVE

- ROWS
- N C
 - L STRA
 - L STRB
 - L STRC
 - L STRD
 - L WTCA
 - L WTCB
 - L WTCC
 - L WTCO
 - E AWTCA
 - E AWTCB
 - E AWTCC
 - E AWTCD
 - L WWTCA
 - L WWTCB
 - L WWTCC
 - L WWTCD
 - E AWWTCA
 - E AWWTCB
 - E AWWTCC
 - E AWWTCD
 - E LFLWA
 - E LFLWR
 - E LFLWC
 - E LFLWD
 - L PSCA
 - L PSCB
 - L PSCC
 - L PSCD
 - L RES
 - G RESID
 - G REC
 - L LAB
 - L LND1
 - L LND2
 - L CFLC
 - L CC
 - L SBC
 - L NDC
 - L DC
 - L RIC
 - L WRC
 - L FIREC
 - L OSC
 - L CMC

COLUMNS

Variable	Scale	Value	Variable	Value
CFLA	'SCALE'	.01000	STRA	1810.00000
CFLA	C	36.25000	LND1	.00400
CFLA	LAB	1.25000		
CFLA	CFLC	33.20000		
PSA	C	13130.00000	STRA	3700.00000
PSA	LAB	.13800	PSCA	1000.00000

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DF-KA	C	1000.00000	AWTCA	119136.00000
DF-KA	AWWTCA	- 5170.00000	LAB	.13190
DF-KA	NDC	1572.20000		
DN-DA	C	1000.00000	AWTCA	96970.00000
DN-DA	LAB	.13460	NDC	1264.40000
DN-DA	AWWTCA	-90109.00000		
FMA	C	1000.00000	AWTCA	59281.00000
FMA	AWWTCA	-59281.00000	LAB	.14480
FMA	DC	946.20000		
DMA	C	1000.00000	AWTCA	12135.00000
DMA	AWWTCA	-11216.00000	LAB	.15280
DMA	DC	870.60000		
DDA	C	1000.00000	AWTCA	80268.00000
DDA	AWWTCA	-70668.00000	LAB	.13430
DDA	DC	1024.20000		
RIA	C	1000.00000	AWTCA	522978.00000
RIA	AWWTCA	-108312.00000	LAB	.08190
RIA	RIC	3266.90000		
W-PA	C	1000.00000	AWTCA	8277.00000
W-PA	AWWTCA	- 7257.00000	LAB	.21000
W-PA	WRC	857.00000		
FIREA	C	1000.00000	AWTCA	2602.00000
FIREA	AWWTCA	- 2413.00000	LAB	.05100
FIREA	FIREC	1706.20000		
DSA	C	1000.00000	AWTCA	31667.00000
DSA	AWWTCA	-10050.00000	LAB	.20210
DSA	DSC	1272.50000		
CDNA	C	1000.00000	AWTCA	1261749.00000
CDNA	AWWTCA	-883582.00000	LAB	.14120
CDNA	CMC	506.00000		
WTA	C	- .17500	STRA	1138.60000
WTA	WTCA	1138.60000	AWTCA	- 1000.00000
WWTA	WWTCA	1000.00000	AWWTCA	1000.00000
AWTA	C	- .21900	STRA	1138.60000
AWTA	AWTCA	- 1000.00000		
AWWTA	C	- .00010	AWWTCA	1000.00000
STORA	STRA	1000.00000	STRB	- 1000.00000
STORA	RES	1000.00000		
RECA	RES	1000.00000	REC	1000.00000
RESIDA	AWTCA	1000.00000	AWWTCA	- 750.00000
RESIDA	RESID	1000.00000		
LFLWA	STRA	1000.00000	LFLWA	1000.00000
CFLB	'SCALE'	.01000		
CFLB	C	36.25000	STRB	1910.00000
CFLB	LAB	1.25000	LND1	.00400
CFLB	CFLC	33.20000		
CRN1B	'SCALE'	.01000		
CRN1B	C	58.00000	STRB	29.00000
CRN1B	LAB	.20000	LND1	1.02000
CRN1B	CC	45.41000		
CRN2B	'SCALE'	.01000		
CRN2B	C	58.00000	STRB	31.60000
CRN2B	LAB	.20000	LND2	1.10000
CRN2B	CC	48.55000		

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SB1B	'SCALE'	.01000		
SB1B	C	153.00000	STRB	92.70000
SB1B	LAB	.55000	LND1	2.90000
SB1B	SBC	113.77000		
SB2B	'SCALE'	.01000		
SB2B	C	153.00000	STRB	92.10000
SB2B	LAB	.78000	LND2	3.40000
SB2B	SBC	132.57000		
PSR	C	13130.00000	STRB	8700.00000
PSB	LAB	.13800	PSCB	1000.00000
DF-KB	C	1000.00000	AWTCB	112136.00000
DF-KB	AWTCB	- 5170.00000	LAB	.13150
DF-KB	NDC	1572.20000		
DN-DB	C	1000.00000	AWTCB	96970.00000
DN-DB	LAB	.12450	NDC	- 1364.40000
DN-DB	AWTCB	-90109.00000		
FMB	C	1000.00000	AWTCB	59281.00000
FMR	AWTCB	-59281.00000	LAB	.14480
FMB	DC	946.20000		
DMB	C	1000.00000	AWTCB	12135.00000
JMR	AWTCB	-11216.00000	LAB	.15280
JMB	DC	870.60000		
JDR	C	1000.00000	AWTCB	80263.00000
JDR	AWTCB	-70668.00000	LAB	.13430
JDR	DC	1024.30000		
RIR	C	1000.00000	AWTCB	522978.00000
RIR	AWTCB	-108313.00000	LAB	.08190
PIR	RIC	2266.90000		
W-RR	C	1000.00000	AWTCB	8277.00000
W-RR	AWTCB	- 7357.00000	LAB	.21000
W-RR	WRC	857.00000		
FIREB	C	1000.00000	AWTCB	2608.00000
FIREB	AWTCB	- 2413.00000	LAB	.05100
FIREB	FIREC	1706.90000		
JSB	C	1000.00000	AWTCB	31467.00000
JSB	AWTCB	-10050.00000	LAB	.20210
OSB	DSC	1273.50000		
CONB	C	1000.00000	AWTCB	1261769.000
CONB	AWTCB	-883582.00000	LAB	.14120
CONB	CMC	506.00000		
WTR	C	- .17500	STRB	1138.60000
WTR	WTCB	1138.60000	AWTCB	- 1000.00000
WWTB	WWTB	1000.00000	AWTCB	1000.00000
AWTR	C	- .21900	STRB	1138.60000
AWTB	AWTCB	- 1000.00000		
AWWTB	C	- .00010	AWTCB	1000.00000
STDRB	STRB	1000.00000	STRC	- 1000.00000
STDRB	RES	1000.00000		
RECB	RFS	1000.00000	REC	1000.00000
RESIDB	AWTCB	1000.00000	AWTCB	- 750.00000
RESIDB	RESID	1000.00000		
LFLWB	STRB	1000.00000	LFLWB	1000.00000
CFLC	'SCALE'	.01000		
CFLC	C	36.25000	STRC	1810.00000

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CFLO	CFLO	33,20000	LAB	1,25000
CFLO	LND1	,00400		
CRN1C	'SCALE'	,01000		
CRN1C	C	58,00000	STRO	29,00000
CRN1C	LAB	,20000	LND1	1,02000
CRN1C	CC	45,41000		
CRN2C	'SCALE'	,01000		
CRN2C	C	58,00000	STRO	31,50000
CRN2C	LAB	,23000	LND2	1,10000
CRN2C	CC	48,55000		
SB1C	'SCALE'	,01000		
SB1C	C	153,00000	STRO	33,70000
SB1C	LAB	,66000	LND1	2,90000
SB1C	SBC	113,77000		
SB2C	'SCALE'	,01000		
SB2C	C	153,00000	STRO	33,10000
SB2C	LAB	,78000	LND2	3,40000
SB2C	SBC	132,57000		
PSC	C	13130,00000	STRO	3700,00000
PSC	LAB	,13800	PSCC	1000,00000
DF-KC	C	1000,00000	AWTCC	119136,00000
DF-KC	AWWTCC	- 5170,00000	LAB	,13100
DF-KC	NDC	1572,20000		
DN-DC	C	1000,00000	AWTCC	35970,00000
DN-DC	LAB	,13460	NDC	1354,40000
DN-DC	AWWTCC	-20109,00000		
FMC	C	1000,00000	AWTCC	59281,00000
FMC	AWWTCC	-59281,00000	LAB	,14480
FMC	DC	946,20000		
DMC	C	1000,00000	AWTCC	12135,00000
DMC	AWWTCC	-11216,00000	LAB	,15980
DMC	DC	870,60000		
DDC	C	1000,00000	AWTCC	90268,00000
DDC	AWWTCC	-70668,00000	LAB	,13430
DDC	DC	1024,30000		
RIC	C	1000,00000	AWTCC	522978,00000
RIC	AWWTCC	-108313,00000	LAB	,08190
PIC	RIC	3266,90000		
W-RC	C	1000,00000	AWTCC	8277,00000
W-RC	AWWTCC	- 7357,00000	LAB	,21000
W-RC	WRC	857,00000		
FIREC	C	1000,00000	AWTCC	2608,00000
FIREC	AWWTCC	- 2413,00000	LAB	,05100
FIREC	FIREC	1706,90000		
DSC	C	1000,00000	AWTCC	31667,00000
DSC	AWWTCC	-10050,00000	LAB	,20210
DSC	DSC	1273,50000		
CONC	C	1000,00000	AWTCC	1261769,000
CONC	AWWTCC	-983583,00000	LAB	,14120
CONC	CMC	506,00000		
WTC	C	- ,17500	STRO	1138,60000
WTC	WTCC	1138,60000	AWTCC	- 1000,00000
WWTC	WWTCC	1000,00000	AWWTCC	1000,00000
AWTC	C	- ,21900	STRO	1138,60000

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AWTC	AWTCC	- 1000.00000		
AWWTC	C	- .00010	AWWTCC	1000.00000
STJRC	STRC	1000.00000	STRD	- 1000.00000
STORC	RES	1000.00000		
RECC	RES	1000.00000	REC	1000.00000
RESIDC	AWTCC	1000.00000	AWWTCC	- 750.00000
RESIDC	RESID	1000.00000		
LFLWC	STRC	1000.00000	LFLWC	1000.00000
CFLD	'SCALE'	.01000		
CFLD	C	36.25000	STRD	1810.00000
CFLD	LAB	1.25000	LND1	.00400
CFLD	CFLC	33.20000		
CRN1D	'SCALE'	.01000		
CRN1D	C	58.00000	STRD	29.00000
CRN1D	LAB	.20000	LND1	1.02000
CRN1D	CC	45.41000		
CRN2D	'SCALE'	.01000		
CRN2D	C	58.00000	STRD	31.50000
CRN2D	LAB	.23000	LND2	1.10000
CRN2D	CC	48.55000		
SB1D	'SCALE'	.01000		
SB1D	C	153.00000	STRD	83.70000
SB1D	LAB	.66000	LND1	2.90000
SB1D	SBC	113.77000		
SB2D	'SCALE'	.01000		
SB2D	C	153.00000	STRD	98.10000
SB2D	LAB	.78000	LND2	3.40000
SB2D	SBC	132.57000		
PSD	C	13130.00000	STRD	3700.00000
PSD	LAB	.13800	PSCD	1000.00000
DF-KD	C	1000.00000	AWTCD	119136.0000
DF-KD	AWWTCD	- 5170.00000	LAB	.13190
DF-KD	NDC	1572.20000		
DN-DD	C	1000.00000	AWTCD	96970.00000
DN-DD	LAB	.13460	NDC	1364.40000
DN-DD	AWWTCD	-90109.00000		
FMD	C	1000.00000	AWTCD	59281.00000
FMD	AWWTCD	-59281.00000	LAB	.14480
FMD	DC	945.20000		
DMD	C	1000.00000	AWTCD	12135.00000
DMD	AWWTCD	-11216.00000	LAB	.15980
DMD	DC	870.60000		
ODD	C	1000.00000	AWTCD	80268.00000
ODD	AWWTCD	-70668.00000	LAB	.13430
ODD	DC	1024.30000		
RID	C	1000.00000	AWTCD	522978.0000
RID	AWWTCD	-108313.0000	LAB	.08190
RID	RIC	3266.90000		
W-RD	C	1000.00000	AWTCD	8277.00000
W-RD	AWWTCD	- 7357.00000	LAB	.21000
W-RD	WRC	857.00000		
FIREC	C	1000.00000	AWTCD	2608.00000
FIREC	AWWTCD	- 2413.00000	LAB	.05100
FIREC	FIREC	1705.90000		

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OSD	C	1000.00000	AWTCD	31667.00000
OSD	AWWTCO	-10050.00000	LAB	.20210
OSD	OSC	1273.50000		
COND	C	1000.00000	AWTCD	1261769.000
COND	AWWTCO	-883583.0000	LAB	.14120
COND	CMC	506.00000		
WTD	C	- .17500	STRD	1138.60000
WTD	WTCD	1138.60000	AWTCD	- 1000.00000
WWTD	WWTCD	1000.00000	AWWTCO	1000.00000
AWTD	C	- .21900	STRD	1138.60000
AWTD	AWTCD	- 1000.00000		
AWWTD	C	- .00010	AWWTCO	1000.00000
RECD	RES	1000.00000	REC	1000.00000
RESIDD	AWTCD	1000.00000	AWWTCO	- 750.00000
RESIDD	RESID	1000.00000		
LFLWD	STRD	1000.00000	LFLWD	1000.00000
RHS				
B1	STRA	315046400.0	STRB	254540800.0
B1	STRC	100494934.0	STRD	88324266.00
B1	WTCA	222630000.0	WTCB	75030000.00
B1	WTCC	76260000.00	WTCD	75030000.00
B1	WWTCA	189072600.0	WWTCB	63720600.00
B1	WWTCC	64765200.00	WWTCD	63720600.00
B1	RES	12650000.00	RESID	266891886.0
B1	REC	11385000.00	LFLWA	629989.0000
B1	LFLWB	1259979.000	LFLWC	504044.0000
B1	LFLWD	251890.0000	LAB	1427.00000
B1	LND1	500.00000	LND2	500.00000
B1	PSCA	318411.0000	PSCB	103470.0000
B1	PSCC	119448.0000	PSCD	103470.0000
B1	CFLC	33200.00000	CC	44330.00000
B1	SBC	39620.00000	NDC	1005422.000
B1	DC	865810.0000	RIC	3743972.000
B1	WRC	3904438.000	FIREC	4705960.000
B1	OSC	4991927.000	CMC	928240.0000
BOUNDS				
UP XMAX	CFLA	10000000.00		
UP XMAX	PSA	10000000.00		
UP XMAX	AWTA	10000000.00		
UP XMAX	AWWTA	10000000.00		
LD XMAX	RESIDA	132349.1270		
UP XMAX	CFLB	10000000.00		
UP XMAX	PSB	10000000.00		
UP XMAX	AWTB	10000000.00		
UP XMAX	AWWTB	10000000.00		
LD XMAX	RESIDB	44603.84900		
UP XMAX	CFLC	10000000.00		
UP XMAX	PSC	10000000.00		
UP XMAX	AWTC	10000000.00		
UP XMAX	AWWTC	10000000.00		
LD XMAX	RESIDC	45335.06000		
UP XMAX	CFLD	10000000.00		
UP XMAX	PSD	10000000.00		
UP XMAX	AWTD	10000000.00		

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UP XMAX AWWTD 10000000.00
 LD XMAX RESIDD 44603.84900
 ENDATA

Line	Module	Code	Value
1	...	...	...
2	SPR0	...	...
3	SPR0	...	...
4	SPR0	...	...
5	SPR0	...	...
6	SPR0	...	...
7	SPR0	...	...
8	SPR0	...	...
9	SPR0	...	...
10	SPR0	...	...
11	SPR0	...	...
12	SPR0	...	...
13	SPR0	...	...
14	SPR0	...	...
15	SPR0	...	...
16	SPR0	...	...
17	SPR0	...	...
18	SPR0	...	...
19	SPR0	...	...
20	SPR0	...	...
21	SPR0	...	...
22	SPR0	...	...
23	SPR0	...	...
24	SPR0	...	...
25	SPR0	...	...
26	SPR0	...	...
27	SPR0	...	...
28	SPR0	...	...
29	SPR0	...	...
30	SPR0	...	...
31	SPR0	...	...
32	SPR0	...	...
33	SPR0	...	...
34	SPR0	...	...
35	SPR0	...	...
36	SPR0	...	...
37	SPR0	...	...
38	SPR0	...	...
39	SPR0	...	...
40	SPR0	...	...
41	SPR0	...	...
42	SPR0	...	...
43	SPR0	...	...
44	SPR0	...	...
45	SPR0	...	...

EXECUTOR, MPS/360 V2-M9

SOLUTION 1

SECTION 1 - ROWS

NUMBER	...ROW...	AT	...ACTIVITY...	SLACK ACTIVITY	...LOWER LIMIT.	...UPPER LIMIT.	...DUAL ACTIVITY
1	C	BS	17649333.5453	17649333.5453-	NONE	NONE	1.00000
2	STRA	UL	315046400.000	.	NONE	315046400.000	.00084-
3	STRB	UL	254540800.000	.	NONE	254540800.000	.00084-
4	STRC	UL	100494934.000	.	NONE	100494934.000	.00084-
5	STRD	JL	88324266.0000	.	NONE	88324266.0000	.00084-
6	WTCA	UL	222630000.000	.	NONE	222630000.000	.00004-
7	WTCB	JL	75030000.0000	.	NONE	75030000.0000	.00004-
8	WTCC	JL	76260000.0000	.	NONE	76260000.0000	.00004-
9	WTCD	JL	75030000.0000	.	NONE	75030000.0000	.00004-
10	AWTCA	EQ	.	.	.	.	.00117-
11	AWTCB	EQ	.	.	.	.	.00117-
12	AWTCC	EQ	.	.	.	.	.00117-
13	AWTCD	EQ	.	.	.	.	.00117-
14	WWTCA	BS	187847972.934	1224627.05547	NONE	189072600.000	.
A 15	WWTCB	JL	63720600.0000	.	NONE	63720600.0000	.
16	WWTCC	BS	61951936.8701	2813263.12994	NONE	64755200.0000	.
17	WWTCD	BS	43594923.8299	20125676.1701	NONE	63720600.0000	.
A 18	AWWTCA	EQ	.	.	.	.	.
A 19	AWWTCB	EQ	.	.	.	.	.
A 20	AWWTCC	EQ	.	.	.	.	.
A 21	AWWTCD	EQ	.	.	.	.	.
22	LFLWA	EQ	529989.00000	.	529989.00000	629989.00000	.00084
23	LFLWB	EQ	1259979.00000	.	1259979.00000	1259979.00000	.00084
24	LFLWC	EQ	504044.00000	.	504044.00000	504044.00000	.00084
25	LFLWD	EQ	251890.00000	.	251890.00000	251890.00000	.00084
26	PSCA	JL	318411.00000	.	NONE	318411.00000	12.47195-
27	PSCB	UL	103470.00000	.	NONE	103470.00000	12.47195-
28	PSCC	UL	119448.00000	.	NONE	119448.00000	12.47195-
29	PSCD	UL	103470.00000	.	NONE	103470.00000	12.47195-
A 30	RES	JL	12650000.0000	.	NONE	12650000.0000	.
31	RESID	LL	266891886.000	.	266891886.000	NONE	.00117
A 32	REC	LL	11385000.0000	.	11385000.0000	NONE	.
33	LAB	JL	1427.00000	.	NONE	1427.00000	4715.64609-
34	LND1	BS	.	500.00000	NONE	500.00000	.
35	LND2	BS	.	500.00000	NONE	500.00000	.
36	CFLC	BS	.	33200.00000	NONE	33200.00000	.
37	CC	BS	.	44330.00000	NONE	44330.00000	.
38	SBC	BS	.	39620.00000	NONE	39620.00000	.
39	NDC	JL	1005422.00000	.	NONE	1005422.00000	.18430-
40	DC	JL	866810.00000	.	NONE	866810.00000	.26671-
41	RIC	BS	1075674.26023	2667297.73977	NONE	3743972.00000	.
42	WRC	BS	489411.42453	3415026.57547	NONE	3904438.00000	.
43	FIREC	JL	4705960.00000	.	NONE	4705960.00000	.44317-
44	DSC	UL	4991927.00000	.	NONE	4991927.00000	.00770-
45	CMC	BS	.	928240.00000	NONE	928240.00000	.

EXECUTOR. MPS/360 V2-49

SOLUTION 1
SECTION 2 - COLUMNS

NUMBER	COLUMN.	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT.	..UPPER LIMIT.	..REDUCED COST.
47	PSA	BS	318.41100	13130.00000	.	10000000.0000	.
49	DN-DA	BS	736.89680	1000.00000	.	NONE	.
56	JSA	BS	2207.47199	1000.00000	.	NONE	.
58	WTA	BS	195529.59775	.17500-	.	NONE	.
59	WWTB	BS	187847.97293	.	.	NONE	.
60	AWTA	BS	78180.42798	.21900-	.	10000000.0000	.
A 64	RESIDA	LL	132349.12700	.	132349.12700	NONE	.
65	LFLWA	BS	629.98900	.	.	NONE	.
71	PSB	BS	103.47000	13130.00000	.	10000000.0000	.
77	RIB	BS	329.57062	1000.00000	.	NONE	.
80	OSB	BS	113.23097	1000.00000	.	NONE	.
82	WTB	BS	65896.71526	.17500-	.	NONE	.
83	WWTB	BS	63720.60000	.	.	NONE	.
84	AWTB	BS	154651.00299	.21900-	.	10000000.0000	.
85	AWWTB	BS	5557.04055	.00010-	.	10000000.0000	.
86	STORB	BS	1265.00000	.	.	NONE	.
88	RESIDB	LL	44603.84900	.	44603.84900	NONE	.00004-
89	LFLWB	BS	1259.97900	.	.	NONE	.
95	PSC	BS	119.44800	13130.00000	.	10000000.0000	.
99	OMC	BS	995.64668	1000.00000	.	NONE	.
102	W-RC	BS	571.07517	1000.00000	.	NONE	.
103	FIREC	BS	2757.02150	1000.00000	.	NONE	.
104	DSC	BS	589.98756	1000.00000	.	NONE	.
106	WTC	BS	66976.98929	.17500-	.	NONE	.
107	WWTB	BS	61951.93687	.	.	NONE	.
108	AWTC	BS	21040.48164	.21900-	.	10000000.0000	.
112	RESIDC	BS	45335.06100	.	45335.06000	NONE	.
113	LFLWC	BS	504.04400	.	.	NONE	.
119	PSD	BS	103.47000	13130.00000	.	10000000.0000	.
128	JSD	BS	1009.15792	1000.00000	.	NONE	.
130	WTD	BS	65896.71526	.17500-	.	NONE	.
131	WWTB	BS	43594.92383	.	.	NONE	.
132	AWTD	BS	10664.13754	.21900-	.	10000000.0000	.
134	RECD	BS	11385.00000	.	.	NONE	.
A 135	RESIDD	LL	44603.84900	.	44603.84900	NONE	.
136	LFLWD	BS	251.89000	.	.	NONE	.

RIVER CONDITIONS FOR THE TIME PERIOD 1, SOLUTION NUMBER 1

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	1740587.8	0.0	0.	0
2	1740587.8	0.0	0.	0
3	1740587.8	0.0	0.	0
4	1740587.8	0.0	0.	0
5	1740587.8	0.0	0.	0
6	1740587.8	0.0	0.	0
7	1740587.8	0.0	0.	0
8	1740587.8	0.0	0.	0
9	1740587.8	0.0	0.	0
10	1740587.8	0.0	0.	0
11	1740587.8	0.0	0.	0
12	1740587.8	0.0	0.	0
13	1740587.8	0.0	0.	0
14	1740587.8	0.0	0.	0
15	1740587.8	0.0	0.	0
16	1740587.8	0.0	0.	0
17	1344773.2	0.0	1759.	0
18	1701006.3	0.0	1759.	3
19	1701006.3	1.81806	0.	0
20	1699494.1	2.70719	1512.	0
21	1699494.1	3.03336	0.	0
22	1699494.1	3.03110	0.	0
23	1699494.1	2.84871	0.	0
24	1699494.1	2.57838	0.	0
25	1699494.1	2.27592	0.	0
26	1699494.1	1.97393	0.	0
27	1699494.1	1.69022	0.	0
28	1700532.0	1.43351	1038.	3
29	1700532.0	2.76263	0.	0
30	1700532.0	3.32696	0.	0
31	1700532.0	3.43785	0.	0
32	1700532.0	3.29326	0.	0
33	1700532.0	3.01710	0.	0
34	1700532.0	2.68524	0.	0
35	1700532.0	2.34262	0.	0
36	1700532.0	2.01461	0.	0
37	1700532.0	1.71419	0.	0
38	1700532.0	1.44688	0.	0
39	1700532.0	1.21371	0.	0
40	1700532.0	1.01321	0.	0
41	1700532.0	0.84262	0.	0
42	1700532.0	0.69865	0.	0
43	1700532.0	0.57788	0.	0
44	1700532.0	0.47707	0.	0
45	1700532.0	0.39323	0.	0
46	1700532.0	0.32372	0.	0
47	1700532.0	0.26622	0.	0
48	1700532.0	0.21876	0.	0
49	1700532.0	0.17964	0.	0
50	1700532.0	0.14743	0.	0

RIVER CONDITIONS FOR THE TIME PERIOD 2, SOLUTION NUMBER 1

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	4172800.0	0.0	0.	0
2	4172800.0	0.0	0.	0
3	4172800.0	0.0	0.	0
4	4172800.0	0.0	0.	0
5	4172800.0	0.0	0.	0
6	4172800.0	0.0	0.	0
7	4172800.0	0.0	0.	0
8	4172800.0	0.0	0.	0
9	4172800.0	0.0	0.	0
10	4172800.0	0.0	0.	0
11	4172800.0	0.0	0.	0
12	4172800.0	0.0	0.	0
13	4172800.0	0.0	0.	0
14	4172800.0	0.0	0.	0
15	4172800.0	0.0	0.	0
16	4172800.0	0.0	0.	0
17	3791148.4	0.0	1696.	0
18	4134634.8	0.0	1696.	3
19	4134634.8	0.72119	0.	0
20	4131019.3	1.07390	3616.	0
21	4131019.3	1.20329	0.	0
22	4131019.3	1.20239	0.	0
23	4131019.3	1.13004	0.	0
24	4131019.3	1.02280	0.	0
25	4131019.3	0.90282	0.	0
26	4131019.3	0.78302	0.	0
27	4131019.3	0.67048	0.	0
28	4132171.6	0.56865	1152.	3
29	4132171.6	1.18958	0.	0
30	4132171.6	1.45926	0.	0
31	4132171.6	1.52005	0.	0
32	4132171.6	1.46258	0.	0
33	4132171.6	1.34363	0.	0
34	4132171.6	1.19806	0.	0
35	4132171.6	1.04657	0.	0
36	4132171.6	0.90088	0.	0
37	4132171.6	0.76709	0.	0
38	4132171.6	0.64782	0.	0
39	4132171.6	0.54365	0.	0
40	4132171.6	0.45400	0.	0
41	4132171.6	0.37756	0.	0
42	4132171.6	0.31319	0.	0
43	4132171.6	0.25910	0.	0
44	4132171.6	0.21393	0.	0
45	4132171.6	0.17635	0.	0
46	4132171.6	0.14519	0.	0
47	4132171.6	0.11941	0.	0
48	4132171.6	0.09813	0.	0
49	4132171.6	0.08058	0.	0
50	4132171.6	0.06614	0.	0

RIVER CONDITIONS FOR THE TIME PERIOD 3, SOLUTION NUMBER 1

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	1620886.0	0.0	0.	0
2	1620886.0	0.0	0.	0
3	1620886.0	0.0	0.	0
4	1620886.0	0.0	0.	0
5	1620886.0	0.0	0.	0
6	1620886.0	0.0	0.	0
7	1620886.0	0.0	0.	0
8	1620886.0	0.0	0.	0
9	1620886.0	0.0	0.	0
10	1620886.0	0.0	0.	0
11	1620886.0	0.0	0.	0
12	1620886.0	0.0	0.	0
13	1620886.0	0.0	0.	0
14	1620886.0	0.0	0.	0
15	1620886.0	0.0	0.	0
16	1620886.0	0.0	0.	0
17	1197072.1	0.0	1884.	0
18	1578504.6	0.0	1884.	4
19	1578504.6	2.09774	0.	0
20	1577256.9	3.12364	1248.	0
21	1577256.9	3.50000	0.	0
22	1577256.9	3.49739	0.	0
23	1577256.9	3.28694	0.	0
24	1577256.9	2.97502	0.	0
25	1577256.9	2.62604	0.	0
26	1577256.9	2.27759	0.	0
27	1577256.9	1.95024	0.	0
28	1578195.0	1.65404	938.	5
29	1578195.0	2.90789	0.	0
30	1578195.0	3.42224	0.	0
31	1578195.0	3.50000	0.	0
32	1578195.0	3.33352	0.	0
33	1578195.0	3.04293	0.	0
34	1578195.0	2.70161	0.	0
35	1578195.0	2.35284	0.	0
36	1578195.0	2.02082	0.	0
37	1578195.0	1.71784	0.	0
38	1578195.0	1.44890	0.	0
39	1578195.0	1.21471	0.	0
40	1578195.0	1.01360	0.	0
41	1578195.0	0.84265	0.	0
42	1578195.0	0.69848	0.	0
43	1578195.0	0.57761	0.	0
44	1578195.0	0.47676	0.	0
45	1578195.0	0.39292	0.	0
46	1578195.0	0.32342	0.	0
47	1578195.0	0.26595	0.	0
48	1578195.0	0.21852	0.	0
49	1578195.0	0.17943	0.	0
50	1578195.0	0.14726	0.	0

RIVER CONDITIONS FOR THE TIME PERIOD 4, SOLUTION NUMBER 1

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	1447938.8	0.0	0.	0
2	1447938.8	0.0	0.	0
3	1447938.8	0.0	0.	0
4	1447938.8	0.0	0.	0
5	1447938.8	0.0	0.	0
6	1447938.8	0.0	0.	0
7	1447938.8	0.0	0.	0
8	1447938.8	0.0	0.	0
9	1447938.8	0.0	0.	0
10	1447938.8	0.0	0.	0
11	1447938.8	0.0	0.	0
12	1447938.8	0.0	0.	0
13	1447938.8	0.0	0.	0
14	1447938.8	0.0	0.	0
15	1447938.8	0.0	0.	0
16	1447938.8	0.0	0.	0
17	1069345.5	0.0	1683.	0
18	1410079.5	0.0	1683.	4
19	1410079.5	2.09774	0.	0
20	1408824.4	3.12364	1255.	0
21	1408824.4	3.50000	0.	0
22	1408824.4	3.49739	0.	0
23	1408824.4	3.28694	0.	0
24	1408824.4	2.97502	0.	0
25	1408824.4	2.62604	0.	0
26	1408824.4	2.27759	0.	0
27	1408824.4	1.95024	0.	0
28	1409539.0	1.65404	715.	3
29	1409539.0	2.68505	0.	0
30	1409539.0	3.09042	0.	0
31	1409539.0	3.12820	0.	0
32	1409539.0	2.96200	0.	0
33	1409539.0	2.69377	0.	0
34	1409539.0	2.38558	0.	0
35	1409539.0	2.07388	0.	0
36	1409539.0	1.77888	0.	0
37	1409539.0	1.51067	0.	0
38	1409539.0	1.27320	0.	0
39	1409539.0	1.06678	0.	0
40	1409539.0	0.88974	0.	0
41	1409539.0	0.73941	0.	0
42	1409539.0	0.61272	0.	0
43	1409539.0	0.50659	0.	0
44	1409539.0	0.41805	0.	0
45	1409539.0	0.34448	0.	0
46	1409539.0	0.28352	0.	0
47	1409539.0	0.23312	0.	0
48	1409539.0	0.19153	0.	0
49	1409539.0	0.15726	0.	0
50	1409539.0	0.12905	0.	0
0.13055000000000 05 0.13055000000000 05 0.13055000000000 02				

EXECJTOR. MPS/360 V2-M9
 REVISIONS TO OPTIMIZATION PROGRAM AFTER SOLUTION I
 REVISE MAY TO MAY ACCORDING TO DAVE

TIME = 1.29

FILE = FT11F001

2- COLUMNS SECTION.

MODIFY		
CFLA	C	36.25000
PSA	C	13055.00000
WTA	C	-0.44300
AWTA	C	-0.58110
CFLB	C	36.25000
PSB	C	13055.00000
WTB	C	-0.44300
AWTB	C	-0.58110
CFLC	C	36.25000
PSC	C	13055.00000
WTC	C	-0.44300
AWTC	C	-0.58110
CFLD	C	36.25000
PSD	C	13055.00000
WTD	C	-0.44300
AWTD	C	-0.58110

0 MINOR ERROR(S) - 0 MAJOR ERROR(S)

5- BOUNDS SECTION.

MODIFY		
UP XMAX	PSA	9999999.999
UP XMAX	WTA	222630.000
UP XMAX	WTA	189072.562
UP XMAX	AWTA	9999999.999
UP XMAX	AWTA	9999999.999
UP XMAX	PSB	9999999.999
UP XMAX	WTB	75030.000
UP XMAX	WTB	63720.597
UP XMAX	AWTB	9999999.999
UP XMAX	PSC	116.784
UP XMAX	WTC	75260.000
UP XMAX	WTC	58165.335
UP XMAX	AWTC	1099.896
FX XMAX	AWTC	0.0
UP XMAX	PSD	102.640
UP XMAX	WTD	75030.000
UP XMAX	WTD	63720.597
UP XMAX	AWTD	9999999.999

0 MINOR ERROR(S) - 0 MAJOR ERROR(S)

PROBLEM STATISTICS - 45 ROWS, 136 VARIABLES, 426 ELEMENTS, DENS

EXECUTOR. MPS/360 V2-M9

REVISED INPUT

NAME DAVE
ROWS

- N C
- L STRA
- L STRB
- L STRC
- L STRD
- L WTCA
- L WTCB
- L WTCC
- L WTCD
- E AWTCA
- E AWTCB
- E AWTCC
- E AWTCD
- L WWTCA
- L WWTCB
- L WWTCC
- L WWTCD
- E AAWTCA
- E AAWTCB
- E AAWTCC
- E AAWTCD
- F LFLWA
- F LFLWB
- E LFLWC
- E LFLWD
- L PSCA
- L PSCB
- L PSCC
- L PSCD
- L RES
- G RESID
- G REC
- L LAB
- L LND1
- L LND2
- L CFLC
- L CC
- L SBC
- L NDC
- L DC
- L RIC
- L WRC
- L FIREC
- L DSC
- L CMC

COLUMNS

CFLA	'SCALE'	.01000		
CFLA	C	36.25000	STRA	1810.00000
CFLA	LAB	1.25000	LND1	.00400
CFLA	CFLC	33.20000		
PSA	C	13055.00000	STRA	8700.00000
PSA	LAB	.13800	PSCA	1.000.00000

EXECUTOR. MPS/360 V2-M9

DF-KA	C	1000.00000	AWTCA	119136.00000
DF-KA	AWWTCA	- 5170.00000	LAB	.13190
DF-KA	NDC	1572.20000		
DN-DA	C	1000.00000	AWTCA	95970.00000
DN-DA	LAB	.13460	NDC	1364.40000
DN-DA	AWWTCA	-90109.00000		
FMA	C	1000.00000	AWTCA	59281.00000
FMA	AWWTCA	-59281.00000	LAB	.14480
FMA	DC	946.20000		
GMA	C	1000.00000	AWTCA	12135.00000
GMA	AWWTCA	-11216.00000	LAB	.15980
GMA	DC	870.60000		
ODA	C	1000.00000	AWTCA	80269.00000
ODA	AWWTCA	-70668.00000	LAB	.13430
ODA	DC	1024.30000		
RIA	C	1000.00000	AWTCA	522978.00000
RIA	AWWTCA	-108313.00000	LAB	.08190
RIA	RIC	3266.90000		
W-RA	C	1000.00000	AWTCA	8277.00000
W-RA	AWWTCA	- 7357.00000	LAB	.21000
W-RA	WRC	857.00000		
FIREA	C	1000.00000	AWTCA	2608.00000
FIREA	AWWTCA	- 2413.00000	LAB	.05100
FIREA	FIREC	1706.90000		
OSA	C	1000.00000	AWTCA	31667.00000
OSA	AWWTCA	-10050.00000	LAB	.20210
OSA	OSC	1273.50000		
CONA	C	1000.00000	AWTCA	1261769.00000
CONA	AWWTCA	-883583.00000	LAB	.14120
CONA	CMC	506.00000		
WTA	C	- .17500	STRA	1138.60000
WTA	WTCA	1138.60000	AWTCA	- 1000.00000
WTA	WWTCA	1000.00000	AWWTCA	1000.00000
WTA	C	- .44300		
AWTA	C	- .21900	STRA	1138.60000
AWTA	AWTCA	- 1000.00000		
AWTA	C	- .58110	AWWTCA	1000.00000
STORA	STRA	1000.00000	STRB	- 1000.00000
STORA	RES	1000.00000		
RECA	RES	1000.00000	REC	1000.00000
RESIDA	AWTCA	1000.00000	AWWTCA	- 750.00000
RESIDA	RESID	1000.00000		
LFLWA	STRA	1000.00000	LFLWA	1000.00000
CFLB	'SCALE'	.01000		
CFLB	C	36.25000	STRB	1810.00000
CFLB	LAB	1.25000	LND1	.00400
CFLB	CFLC	33.20000		
CRN1B	'SCALE'	.01000		
CRN1B	C	58.00000	STRB	29.00000
CRN1B	LAB	.20000	LND1	1.00000
CRN1B	CC	45.41000		
CRN2B	'SCALE'	.01000		
CRN2B	C	58.00000	STRB	31.60000
CRN2B	LAB	.23000	LND2	1.10000

EXECUTOR.		MPS/360 V2-M9	
CRN2B	CC	48,55000	
SB1B	'SCALE'	.01000	
SB1B	C	153,00000	STRB 83,70000
SB1B	LAB	.65000	LND1 2,90000
SB1B	SBC	113,77000	
SB2B	'SCALE'	.01000	
SB2B	C	153,00000	STRB 98,10000
SB2B	LAB	.78000	LND2 3,40000
SB2B	SBC	132,57000	
PSB	C	13055,00000	STRB 8700,00000
PSB	LAB	.13800	PSCB 1000,00000
DF-KB	C	1000,00000	AWTCB 119136,00000
DF-KR	AWTCB	- 5170,00000	LAB .13190
DF-KB	NDC	1572,20000	
DN-DB	C	1000,00000	AWTCB 96970,00000
DN-DB	LAB	.13460	NDC 1364,40000
DN-DB	AWTCB	-90109,00000	
FMB	C	1000,00000	AWTCB 59281,00000
FMB	AWTCB	-59281,00000	LAB .14480
FMB	DC	946,20000	
DMB	C	1000,00000	AWTCB 12135,00000
DMB	AWTCB	-11216,00000	LAB .15980
DMB	DC	870,60000	
ODB	C	1000,00000	AWTCB 80263,00000
ODB	AWTCB	-70668,00000	LAB .13430
ODB	DC	1024,30000	
RIB	C	1000,00000	AWTCB 522978,00000
RIB	AWTCB	-108313,00000	LAB .08190
RIB	RIC	3266,90000	
W-RB	C	1000,00000	AWTCB 8277,00000
W-RB	AWTCB	- 7357,00000	LAB .21000
W-RB	WRC	857,00000	
FIREB	C	1000,00000	AWTCB 2608,00000
FIREB	AWTCB	- 2413,00000	LAB .05100
FIREB	FIREC	1706,90000	
DSB	C	1000,00000	AWTCB 31667,00000
DSB	AWTCB	-10050,00000	LAB .20210
JSB	JSC	1273,50000	
CONB	C	1000,00000	AWTCB 1261769,000
CONB	AWTCB	-883583,00000	LAB .14120
CONB	CMC	506,00000	
WTB	C	- .17500	STRB 1138,60000
WTB	WTCB	1138,60000	AWTCB - 1000,00000
WWTB	WWTB	1000,00000	AWTCB 1000,00000
WWTB	C	- .44300	
AWTR	C	- .21900	STRB 1138,60000
AWTB	AWTCB	- 1000,00000	
AWWTB	C	- .58110	AWWTB 1000,00000
STDRB	STRB	1000,00000	STRC - 1000,00000
STDRB	RES	1000,00000	
RECR	RES	1000,00000	REC 1000,00000
RESIDB	AWTCB	1000,00000	AWWTB - 750,00000
RESIDB	RESID	1000,00000	
LFLWB	STRB	1000,00000	LFLWB 1000,00000

EXECUTOR. MPS/360 V2-M9

CFLC	'SCALE'	.01000		
CFLC	C	36.25000	STRC	1810.00000
CFLC	CFLC	33.20000	LAB	1.25000
CFLC	LND1	.00400		
CRN1C	'SCALE'	.01000		
CRN1C	C	58.00000	STRC	29.00000
CRN1C	LAB	.20000	LND1	1.02000
CRN1C	CC	45.41000		
CRN2C	'SCALE'	.01000		
CRN2C	C	58.00000	STRC	31.60000
CRN2C	LAB	.23000	LND2	1.10000
CRN2C	CC	48.55000		
SB1C	'SCALE'	.01000		
SB1C	C	153.00000	STRC	83.70000
SB1C	LAB	.66000	LND1	2.90000
SB1C	SBC	113.77000		
SB2C	'SCALE'	.01000		
SB2C	C	153.00000	STRC	98.10000
SB2C	LAB	.78000	LND2	3.40000
SB2C	SBC	132.57000		
PSC	C	13055.00000	STRC	8700.00000
PSC	LAB	.13800	PSCC	1000.00000
DF-KC	C	1000.00000	AWTCC	119136.0000
DF-KC	AWWTCC	-5170.00000	LAB	.13190
DF-KC	NDC	1572.20000		
DN-DC	C	1000.00000	AWTCC	96970.00000
DN-DC	LAB	.13460	NDC	1364.40000
DN-DC	AWWTCC	-90109.00000		
FMC	C	1000.00000	AWTCC	59281.00000
FMC	AWWTCC	-59281.00000	LAB	.14480
FMC	DC	946.20000		
DMC	C	1000.00000	AWTCC	12135.00000
DMC	AWWTCC	-11216.00000	LAB	.15980
DMC	DC	870.60000		
DDC	C	1000.00000	AWTCC	80268.00000
DDC	AWWTCC	-70668.00000	LAB	.13430
DDC	DC	1024.30000		
RIC	C	1000.00000	AWTCC	522978.0000
RIC	AWWTCC	-108313.0000	LAB	.08190
RIC	RIC	3266.90000		
W-RC	C	1000.00000	AWTCC	8277.00000
W-RC	AWWTCC	-7357.00000	LAB	.21000
W-RC	WRC	857.00000		
FIREC	C	1000.00000	AWTCC	2608.00000
FIREC	AWWTCC	-2413.00000	LAB	.05100
FIREC	FIREC	1706.90000		
JSC	C	1000.00000	AWTCC	31667.00000
JSC	AWWTCC	-10050.00000	LAB	.20210
JSC	JSC	1273.50000		
CONC	C	1000.00000	AWTCC	1261769.000
CONC	AWWTCC	-883583.0000	LAB	.14120
CONC	CMC	506.00000		
WTC	C	- .17500	STRC	1138.60000
WTC	WTCC	1138.60000	AWTCC	- 1000.00000

EXECUTOR. MPS/360 V2-M9

WWTC	WWTCC	1000.00000	AWWTCC	1000.00000
WWTC	C	- .44300		
AWTC	C	- .21900	STRC	1138.60000
AWTC	AWTCC	- 1000.00000		
AWWTCC	C	- .58110	AWWTCC	1000.00000
STORC	STRC	1000.00000	STRD	- 1000.00000
STORC	RES	1000.00000		
RECC	RES	1000.00000	REC	1000.00000
RESIDC	AWTCC	1000.00000	AWWTCC	- 750.00000
RESIDC	RESID	1000.00000		
LFLWC	STRC	1000.00000	LFLWC	1000.00000
CFLD	'SCALE'	.01000		
CFLD	C	36.25000	STRD	1810.00000
CFLD	LAB	1.25000	LND1	.00400
CFLD	CFLC	33.20000		
CRN1D	'SCALE'	.01000		
CRN1D	C	58.00000	STRD	29.00000
CRN1D	LAB	.20000	LND1	1.02000
CRN1D	CC	45.41000		
CRN2D	'SCALE'	.01000		
CRN2D	C	58.00000	STRD	31.60000
CRN2D	LAB	.23000	LND2	1.10000
CRN2D	CC	48.55000		
SB1D	'SCALE'	.01000		
SB1D	C	153.00000	STRD	83.70000
SB1D	LAB	.66000	LND1	2.90000
SB1D	SBC	113.77000		
SB2D	'SCALE'	.01000		
SB2D	C	153.00000	STRD	98.10000
SB2D	LAB	.78000	LND2	3.40000
SB2D	SBC	132.57000		
PSD	C	13055.00000	STRD	8700.00000
PSD	LAB	.13800	PSCD	1000.00000
DF-KD	C	1000.00000	AWTCD	119136.0000
DF-KD	AWWTCD	- 5170.00000	LAB	.13190
DF-KD	NDC	1572.20000		
DN-DD	C	1000.00000	AWTCD	96970.00000
DN-DD	LAB	.13460	NDC	1364.40000
DN-DD	AWWTCD	-90109.00000		
FMD	C	1000.00000	AWTCD	59281.00000
FMD	AWWTCD	-59281.00000	LAB	.14480
FMD	DC	946.20000		
DMD	C	1000.00000	AWTCD	12135.00000
DMD	AWWTCD	-11216.00000	LAB	.15980
DMD	DC	870.60000		
ODD	C	1000.00000	AWTCD	80268.00000
ODD	AWWTCD	-70668.00000	LAB	.13430
ODD	DC	1024.30000		
RID	C	1000.00000	AWTCD	522978.0000
RID	AWWTCD	-108313.0000	LAB	.08190
RID	RIC	3266.90000		
W-RD	C	1000.00000	AWTCD	8277.00000
W-RD	AWWTCD	- 7357.00000	LAB	.21000
W-RD	WRC	857.00000		

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FIRED	C	1000.00000	AWTCD	2608.00000
FIRED	AWWTCD	- 2413.00000	LAB	.05100
FIRED	FIREC	1706.90000		
DSD	C	1000.00000	AWTCD	31667.00000
DSD	AWWTCD	-10050.00000	LAB	.20210
DSD	DSC	1273.50000		
COND	C	1000.00000	AWTCD	1261759.000
COND	AWWTCD	-883583.0000	LAB	.14120
COND	CMC	506.00000		
WTD	C	- .17500	STPD	1138.60000
WTD	WTCD	1138.60000	AWTCD	- 1000.00000
WWTCD	WWTCD	1000.00000	AWWTCD	1000.00000
WWTCD	C	- .44300		
AWTD	C	- .21900	STRD	1138.60000
AWTD	AWTCD	- 1000.00000		
AWWTCD	C	- .58110	AWWTCD	1000.00000
RECD	RES	1000.00000	REC	1000.00000
RESIDD	AWTCD	1000.00000	AWWTCD	- 750.00000
RESIDD	RESID	1000.00000		
LFLWD	STRD	1000.00000	LFLWD	1000.00000
RHS				
B1	STRA	315046400.0	STRB	254540800.0
B1	STRC	100494934.0	STRD	88324266.00
B1	WTCA	222630000.0	WTCB	75030000.00
B1	WTCC	76260000.00	WTCD	75030000.00
B1	WWTCA	189072600.0	WWTCB	63720600.00
B1	WWTCC	64765200.00	WWTCD	63720600.00
B1	RES	12650000.00	RESID	266891886.0
B1	REC	11385000.00	LFLWA	629989.0000
B1	LFLWB	1259979.000	LFLWC	504044.0000
B1	LFLWD	251890.0000	LAB	1427.00000
B1	LND1	500.00000	LND2	500.00000
B1	PSCA	318411.0000	PSCB	103470.0000
B1	PSCC	119448.0000	PSCD	103470.0000
B1	CFLC	33200.00000	CC	44330.00000
B1	SBC	39620.00000	NDC	1005422.000
B1	DC	866810.0000	RIC	3743972.000
B1	WRC	3904438.000	FIREC	4705960.000
B1	DSC	4991927.000	CMC	928240.0000
BOUNDS				
UP XMAX	CFLA	10000000.00		
UP XMAX	PSA	9999999.999		
UP XMAX	WTA	222630.0000		
UP XMAX	WWTB	189072.5620		
UP XMAX	AWTB	9999999.999		
UP XMAX	AWWTB	9999999.989		
LD XMAX	RESIDA	132349.1270		
UP XMAX	CFLB	10000000.00		
UP XMAX	PSB	9999999.999		
UP XMAX	WTB	75030.00000		
UP XMAX	WWTB	63720.59700		
UP XMAX	AWTB	9999999.999		
UP XMAX	AWWTB	10000000.00		
LD XMAX	RESIDB	44603.84900		

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UP XMAX	CFLC	10000000.00
UP XMAX	PSC	116.78400
UP XMAX	WTC	76260.00000
UP XMAX	WWTC	58165.33500
UP XMAX	AWTC	1099.89600
FX XMAX	AWWTC	.
LD XMAX	RESIDC	45335.06000
UP XMAX	CFLD	10000000.00
UP XMAX	PSD	102.64000
UP XMAX	WTD	75030.00000
UP XMAX	WWTD	63720.59700
UP XMAX	AWTD	9999999.999
UP XMAX	AWWTD	10000000.00
LD XMAX	RESIDD	44603.84900

ENDATA

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SOLUTION 2
SECTION 1 - ROWS

NUMBER	...ROW..	AT	...ACTIVITY...	SLACK ACTIVITY	..LOWER LIMIT.	..UPPER LIMIT.	..DUAL ACTIVITY
1	C	BS	17379972.5261	17379972.5261-	NONE	NONE	1.00000
2	STRA	UL	315046400.000	.	NONE	315046400.000	.00077-
3	STRB	UL	254540800.000	.	NONE	254540800.000	.00073-
4	STRC	BS	80297406.3856	20197527.6144	NONE	100494934.000	.
5	STRD	UL	88324266.0000	.	NONE	88324266.0000	.00077-
6	WTCA	UL	222630000.000	.	NONE	222630000.000	.00004-
7	WTCB	UL	75030000.0000	.	NONE	75030000.0000	.00004-
8	WTCC	UL	76260000.0000	.	NONE	76260000.0000	.00081-
9	WTCD	UL	75030000.0000	.	NONE	75030000.0000	.00004-
10	AWTCA	EQ	.	.	.	.	.00110-
11	AWTCB	EQ	.	.	.	.	.00106-
12	AWTCC	EQ	.	.	.	.	.00110-
13	AWTCD	EQ	.	.	.	.	.00110-
14	WWTCA	BS	188500226.555	572373.43491	NONE	189072600.000	.
15	WWTCB	BS	63720596.9999	3.00007	NONE	63720600.0000	.
16	WWTCC	BS	55045032.4297	9720167.57033	NONE	64765200.0000	.
17	WWTCD	BS	43949533.4558	19771066.5442	NONE	63720600.0000	.
18	AWWTCA	EQ	.	.	.	.	.00044
19	AWWTCB	EQ	.	.	.	.	.00058
20	AWWTCC	EQ	.	.	.	.	.00044
21	AWWTCD	EQ	.	.	.	.	.00044
22	LFLWA	EQ	629989.00000	.	629989.00000	629989.00000	.00077
23	LFLWB	EQ	1259979.00000	.	1259979.00000	1259979.00000	.00073
24	LFLWC	EQ	504044.00000	.	504044.00000	504044.00000	.
25	LFLWD	EQ	251890.00000	.	251890.00000	251890.00000	.00077
26	PSCA	UL	318411.00000	.	NONE	318411.00000	12.39925-
27	PSCB	UL	103470.00000	.	NONE	103470.00000	12.39959-
28	PSCC	BS	116784.00000	2664.00000	NONE	119448.00000	.
29	PSCD	BS	102640.00000	830.00000	NONE	103470.00000	.
30	RES	UL	12650000.0000	.	NONE	12650000.0000	.00077-
31	RESID	LL	266891886.000	.	266891886.000	NONE	.00143
32	REC	LL	11385000.0000	.	11385000.0000	NONE	.00077
33	LAB	UL	1427.00000	.	NONE	1427.00000	4703.06518-
34	LND1	BS	.	500.00000	NONE	500.00000	.
35	LND2	BS	.	500.00000	NONE	500.00000	.
36	CFLC	BS	.	33200.00000	NONE	33200.00000	.
37	CC	BS	.	44330.00000	NONE	44330.00000	.
38	SBC	BS	.	39620.00000	NONE	39620.00000	.
39	NDC	UL	1005422.00000	.	NONE	1005422.00000	.16159-
40	DC	UL	866810.00000	.	NONE	866810.00000	.26435-
41	RIC	BS	965224.27579	2778747.72421	NONE	3743972.00000	.
42	WRC	BS	502781.37034	3401656.62966	NONE	3904438.00000	.
43	FIREC	UL	4705960.00000	.	NONE	4705960.00000	.44303-
44	DSC	UL	4991927.00000	.	NONE	4991927.00000	.00805-
45	CMC	BS	.	928240.00000	NONE	928240.00000	.

A

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SOLUTION 2
SECTION 2 - COLUMNS

NUMBER	COLUMN.	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT.	..UPPER LIMIT.	REDUCED COST.
	47	PSA	BS	318.41100	13055.00000	9999999.99900	.
	49	DN-DA	BS	701.11935	1000.00000	NONE	.
	54	W-RA	BS	586.67604	1000.00000	NONE	.
	56	DSA	BS	2163.68578	1000.00000	NONE	.
	58	WTA	BS	195529.59775	.17500-	222530.00000	.
	59	WWTB	BS	188500.22657	.44300-	189072.56200	.
	60	AWTA	BS	78180.42798	.21900-	9999999.99900	.
A	64	RESIDA	LL	132349.12700	.	132349.12700	NONE
	65	LFLWA	BS	629.98900	.	NONE	.
	71	PSB	BS	103.47000	13055.00000	9999999.99900	.
	77	RIB	BS	295.45572	1000.00000	NONE	.
	80	DSB	BS	711.72021	1000.00000	NONE	.
	82	WTB	BS	65896.71527	.17500-	75030.00000	.
	83	WWTB	UL	63720.59700	.44300-	63720.59700	.13810
	84	AWTB	BS	155762.01651	.21900-	9999999.99900	.
	85	AWWTB	BS	8886.77270	.58110-	10000000.00000	.
	88	RESIDB	LL	44603.84900	.	44603.84900	NONE
	89	LFLWB	BS	1259.97900	.	NONE	.
	95	PSC	UL	116.78400	13055.00000	116.78400	12405.97700
	97	DN-DC	BS	35.77745	1000.00000	NONE	.
	99	DMC	BS	995.64668	1000.00000	NONE	.
	103	FIREC	BS	2757.02150	1000.00000	NONE	.
	106	WTC	BS	66976.98929	.17500-	75250.00000	.
	107	WWTC	BS	55045.03243	.44300-	58165.33500	.
	108	AWTC	UL	1099.89600	.21900-	1099.89600	.88009
	110	STORC	BS	1265.00000	.	NONE	.
	112	RESIDC	BS	45335.06100	.	45335.06000	NONE
	113	LFLWC	BS	504.04400	.	NONE	.
	119	PSD	UL	102.64000	13055.00000	102.64000	12399.25228
	128	DSD	BS	1044.44246	1000.00000	NONE	.
	130	WTD	BS	65896.71527	.17500-	75030.00000	.
	131	WWTB	BS	43949.53346	.44300-	63720.59700	.
	132	AWTD	BS	11781.49306	.21900-	9999999.99900	.
	134	RECD	BS	11385.00000	.	NONE	.
A	135	RESIDD	LL	44603.84900	.	44603.84900	NONE
	136	LFLWD	BS	251.89000	.	NONE	.

RIVER CONDITIONS FOR THE TIME PERIOD 1, SOLUTION NUMBER 2

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	1740587.8	0.0	0.	0
2	1740587.8	0.0	0.	0
3	1740587.8	0.0	0.	0
4	1740587.8	0.0	0.	0
5	1740587.8	0.0	0.	0
6	1740587.8	0.0	0.	0
7	1740587.8	0.0	0.	0
8	1740587.8	0.0	0.	0
9	1740587.8	0.0	0.	0
10	1740587.8	0.0	0.	0
11	1740587.8	0.0	0.	0
12	1740587.8	0.0	0.	0
13	1740587.8	0.0	0.	0
14	1740587.8	0.0	0.	0
15	1740587.8	0.0	0.	0
16	1740587.8	0.0	0.	0
17	1344773.2	0.0	1759.	0
18	1701006.3	0.0	1759.	3
19	1701006.3	1.81805	0.	0
20	1699494.1	2.70719	1512.	0
21	1699494.1	3.03337	0.	0
22	1699494.1	3.03110	0.	0
23	1699494.1	2.84871	0.	0
24	1699494.1	2.57838	0.	0
25	1699494.1	2.27593	0.	0
26	1699494.1	1.97393	0.	0
27	1699494.1	1.69022	0.	0
28	1700535.6	1.43352	1041.	3
29	1700535.6	2.76802	0.	0
30	1700535.6	3.33499	0.	0
31	1700535.6	3.44685	0.	0
32	1700535.6	3.30226	0.	0
33	1700535.6	3.02555	0.	0
34	1700535.6	2.69289	0.	0
35	1700535.6	2.34939	0.	0
36	1700535.6	2.02047	0.	0
37	1700535.6	1.71921	0.	0
38	1700535.6	1.45113	0.	0
39	1700535.6	1.21729	0.	0
40	1700535.6	1.01621	0.	0
41	1700535.6	0.84512	0.	0
42	1700535.6	0.70072	0.	0
43	1700535.6	0.57960	0.	0
44	1700535.6	0.47849	0.	0
45	1700535.6	0.39440	0.	0
46	1700535.6	0.32468	0.	0
47	1700535.6	0.26702	0.	0
48	1700535.6	0.21941	0.	0
49	1700535.6	0.18018	0.	0
50	1700535.6	0.14787	0.	0

RIVER CONDITIONS FOR THE TIME PERIOD 2, SOLUTION NUMBER 2

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	4172800.0	0.0	0.	0
2	4172800.0	0.0	0.	0
3	4172800.0	0.0	0.	0
4	4172800.0	0.0	0.	0
5	4172800.0	0.0	0.	0
6	4172800.0	0.0	0.	0
7	4172800.0	0.0	0.	0
8	4172800.0	0.0	0.	0
9	4172800.0	0.0	0.	0
10	4172800.0	0.0	0.	0
11	4172800.0	0.0	0.	0
12	4172800.0	0.0	0.	0
13	4172800.0	0.0	0.	0
14	4172800.0	0.0	0.	0
15	4172800.0	0.0	0.	0
16	4172800.0	0.0	0.	0
17	3791148.4	0.0	1696.	0
18	4134634.8	0.0	1696.	3
19	4134634.8	0.72120	0.	0
20	4131001.1	1.07390	3634.	0
21	4131001.1	1.20329	0.	0
22	4131001.1	1.20239	0.	0
23	4131001.1	1.13004	0.	0
24	4131001.1	1.02280	0.	0
25	4131001.1	0.90282	0.	0
26	4131001.1	0.78302	0.	0
27	4131001.1	0.67048	0.	0
28	4132191.4	0.56865	1190.	3
29	4132191.4	1.21303	0.	0
30	4132191.4	1.49418	0.	0
31	4132191.4	1.55918	0.	0
32	4132191.4	1.50168	0.	0
33	4132191.4	1.38038	0.	0
34	4132191.4	1.23132	0.	0
35	4132191.4	1.07593	0.	0
36	4132191.4	0.92635	0.	0
37	4132191.4	0.78890	0.	0
38	4132191.4	0.66632	0.	0
39	4132191.4	0.55922	0.	0
40	4132191.4	0.46703	0.	0
41	4132191.4	0.38852	0.	0
42	4132191.4	0.32222	0.	0
43	4132191.4	0.26658	0.	0
44	4132191.4	0.22011	0.	0
45	4132191.4	0.18145	0.	0
46	4132191.4	0.14939	0.	0
47	4132191.4	0.12287	0.	0
48	4132191.4	0.10097	0.	0
49	4132191.4	0.08292	0.	0
50	4132191.4	0.06806	0.	0

RIVER CONDITIONS FOR THE TIME PERIOD 3, SOLUTION NUMBER 2

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	1620886.0	0.0	0.	0
2	1620886.0	0.0	0.	0
3	1620886.0	0.0	0.	0
4	1620886.0	0.0	0.	0
5	1620886.0	0.0	0.	0
6	1620886.0	0.0	0.	0
7	1620886.0	0.0	0.	0
8	1620886.0	0.0	0.	0
9	1620886.0	0.0	0.	0
10	1620886.0	0.0	0.	0
11	1620886.0	0.0	0.	0
12	1620886.0	0.0	0.	0
13	1620886.0	0.0	0.	0
14	1620886.0	0.0	0.	0
15	1620886.0	0.0	0.	0
16	1620886.0	0.0	0.	0
17	1197073.1	0.0	1884.	0
18	1578504.7	0.0	1884.	4
19	1578504.7	2.09774	0.	0
20	1577406.7	3.12364	1098.	0
21	1577406.7	3.49999	0.	0
22	1577406.7	3.49738	0.	0
23	1577406.7	3.28694	0.	0
24	1577406.7	2.97501	0.	0
25	1577406.7	2.62604	0.	0
26	1577406.7	2.27758	0.	0
27	1577406.7	1.95023	0.	0
28	1578294.5	1.65404	888.	5
29	1578294.5	2.82550	0.	0
30	1578294.5	3.30105	0.	0
31	1578294.5	3.36422	0.	0
32	1578294.5	3.19783	0.	0
33	1578294.5	2.91542	0.	0
34	1578294.5	2.58619	0.	0
35	1578294.5	2.25095	0.	0
36	1578294.5	1.93246	0.	0
37	1578294.5	1.64218	0.	0
38	1578294.5	1.38473	0.	0
39	1578294.5	1.16069	0.	0
40	1578294.5	0.96837	0.	0
41	1578294.5	0.80495	0.	0
42	1578294.5	0.66716	0.	0
43	1578294.5	0.55167	0.	0
44	1578294.5	0.45532	0.	0
45	1578294.5	0.37523	0.	0
46	1578294.5	0.30885	0.	0
47	1578294.5	0.25395	0.	0
48	1578294.5	0.20867	0.	0
49	1578294.5	0.17133	0.	0
50	1578294.5	0.14061	0.	0

RIVER CONDITIONS FOR THE TIME PERIOD 4, SOLUTION NUMBER 2

STA	RIVER FLOW	DEFICIT	ACT. LEVEL	TRT. LEVEL
1	1447938.8	0.0	0.	0
2	1447938.8	0.0	0.	0
3	1447938.8	0.0	0.	0
4	1447938.8	0.0	0.	0
5	1447938.8	0.0	0.	0
6	1447938.8	0.0	0.	0
7	1447938.8	0.0	0.	0
8	1447938.8	0.0	0.	0
9	1447938.8	0.0	0.	0
10	1447938.8	0.0	0.	0
11	1447938.8	0.0	0.	0
12	1447938.8	0.0	0.	0
13	1447938.8	0.0	0.	0
14	1447938.8	0.0	0.	0
15	1447938.8	0.0	0.	0
16	1447938.8	0.0	0.	0
17	1069348.6	0.0	1683.	0
18	1410079.8	0.0	1683.	4
19	1410079.8	2.09772	0.	0
20	1408806.4	3.12362	1273.	0
21	1408806.4	3.49997	0.	0
22	1408806.4	3.49736	0.	0
23	1408806.4	3.28692	0.	0
24	1408806.4	2.97500	0.	0
25	1408806.4	2.62602	0.	0
26	1408806.4	2.27757	0.	0
27	1408806.4	1.95022	0.	0
28	1409526.9	1.65403	720.	3
29	1409526.9	2.69556	0.	0
30	1409526.9	3.10607	0.	0
31	1409526.9	3.14575	0.	0
32	1409526.9	2.97953	0.	0
33	1409526.9	2.71025	0.	0
34	1409526.9	2.40050	0.	0
35	1409526.9	2.08705	0.	0
36	1409526.9	1.79030	0.	0
37	1409526.9	1.52045	0.	0
38	1409526.9	1.28149	0.	0
39	1409526.9	1.07376	0.	0
40	1409526.9	0.89559	0.	0
41	1409526.9	0.74429	0.	0
42	1409526.9	0.61677	0.	0
43	1409526.9	0.50993	0.	0
44	1409526.9	0.42082	0.	0
45	1409526.9	0.34677	0.	0
46	1409526.9	0.28540	0.	0
47	1409526.9	0.23467	0.	0
48	1409526.9	0.19280	0.	0
49	1409526.9	0.15830	0.	0
50	1409526.9	0.12991	0.	0

PROBEND MESSAGE

THE OPTIMAL SOLUTION NUMBER 2 ALSO ALLOWS ACHIEVEMENT OF
THE WATER QUALITY AND FLOW PARAMETERS SPECIFIED.
THIS IS PROBEND.

ISWRRI - 12 The effect of photosynthesis on the oxygen balance in a mid-western stream. D. B. McDonald, W. L. Paulson, and C. A. Merritt. (A-016-IA) 27 p. 1968.

*ISWRRI - 13 Competitive recreational uses of selected Iowa lakes. Arnold O. Haugen, and Arnold J. Sohn. (A-005-IA) 173 p. 1968. (Available from NTIS as PB 194 800)

ISWRRI - 14 Model flood plain zoning ordinance. N. William Hines. (A-019-IA) 2 p. 1968.

ISWRRI - 15 Collection, characterization, and study of biodegradability and chemical oxidation of carbon-absorbed materials from effluents from sewage treatment plants. R. L. Johnson, and Owen Sletten. (A-007-IA) 96 p. 1968.

ISWRRI - 16 The valleys of Iowa -1: valley width and stream discharge relationships in the major streams. Neil E. Salisbury, James C. Knox, and Richard A. Stephenson. (A-006-IA) 137 p. 1968.

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