January 1981

Energy Siting in Utah: A Programming Model

Donald L. Snyder

John E. Keith

Terrence F. Glover

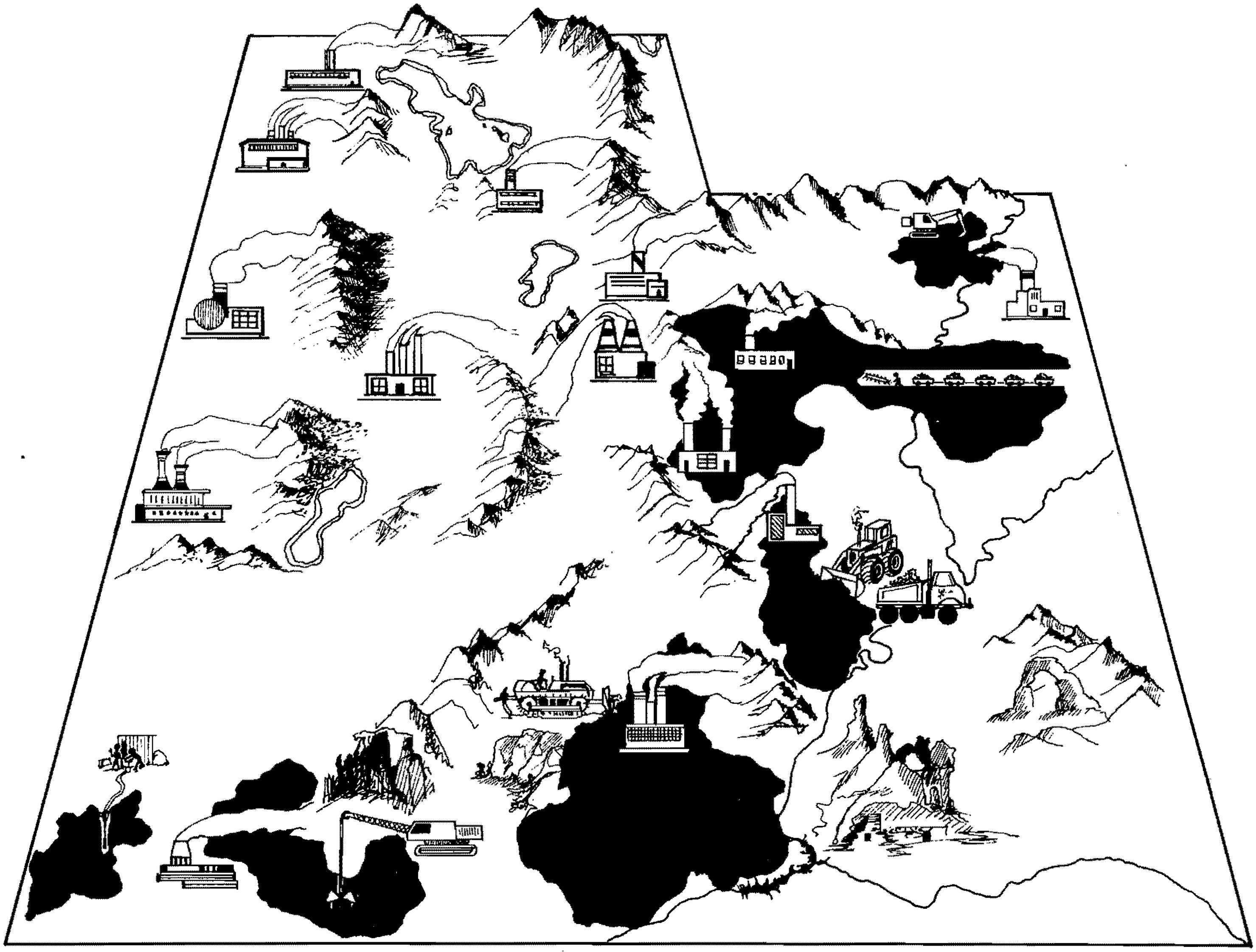
Gene L. Wooldridge

Recommended Citation

Snyder, Donald L.; Keith, John E.; Glover, Terrence F.; and Wooldridge, Gene L., "Energy Siting in Utah: A Programming Model" (1981). *Reports.* Paper 76.
https://digitalcommons.usu.edu/water_rep/76

ENERGY SITING IN UTAH: A PROGRAMMING MODEL

Donald L. Snyder
John E. Keith
Terrence F. Glover
Gene L. Wooldridge



Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

WATER RESOURCES PLANNING SERIES
UWRL/P-81/04

June 1981

ENERGY SITING IN UTAH: A PROGRAMMING MODEL

by

Donald L. Snyder
John E. Keith
Terrence F. Glover
Gene L. Wooldridge

The work upon which this publication is based was supported in part by funds provided by the Office of Water Research and Technology (A-047-UTAH, 14-34-0001-9047), U.S. Department of the Interior, Washington, D. C., as authorized by the Water Research and Development Act of 1978.

WATER RESOURCES PLANNING SERIES
UWRL/P-81/04

Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

June 1981

ABSTRACT

Using a conceptual model of a multiple-product firm, the necessary conditions for an optimal input and output allocation were determined for a region constrained by resource availabilities and/or policy constraints.

A linear programming model was developed to determine the optimal allocation of water between agricultural and coal-fired electrical generating entities as well as the trade offs which could occur if electrical generation were increased. Other areas of potential trade offs such as coal source restrictions and air quality regulations were also examined. Coal mining and transportation costs were included as were SO_2. NO_x, and particulate emission rates on a coal and plant basis.

Few trade offs between electrical power generation and irrigated agriculture were noted. However, substantial changes within the energy sector were discovered as coal capacities and air quality standards were changed. Net revenues declined sharply as air costs after and/or pollution and coal capacity restrictions were imposed and/or increased. It was determined that substantial changes in regional economic activity occurred as a result of these restrictions on development.

ACKNOWLEDGMENTS

This study was financed, in part, by the U.S. Department of the Interior, Office of Water Research and Technology, and the Utah Center for Resources Research, under contract no. A-47-UTAH 14-34-0001-9047.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

CHAPTER I

INTRODUCTION

The official energy position of the United States as expressed in the National Energy Plan (Federal Energy Administration 1974) is that this nation should become energy independent as soon as possible. The primary resource identified as the means to achieve that independence is coal. While conceding that a need exists for the increased production of energy via coal, the Council on Environmental Quality (1976) suggested that energy production should not occur at the expense of a clean environment, which prompted an interest in the low sulfur coal which is found throughout much of the Rocky Mountain area (Science and Public Policy Program 1975). In Utah there are several coal-fired power plants planned using various local and out-of-state coal sources. If this intended development actually occurs, other economic sectors within the state, particularly agriculture, may be effected. These issues raise some difficult questions: What trade offs will occur between energy or agricultural production and the environment? What are some of the costs associated with maintaining a clean environment? How might energy production affect the current levels of agricultural production? This study was undertaken to address some of these questions.

Statement of the Problem

In a semiarid state such as Utah (Figure 1), water availability may have a significant impact on all forms of production, particularly agriculture and energy. Of the almost nine million acre-feet of water withdrawn for use by Utah in 1975, 65 percent was utilized in agriculture (Utah Division of Water Resources 1978). It is projected that by the year 2000, less than 60 percent will go for agricultural production. In that same time frame, energy water use is expected to increase substantially. For example, oil shale production planned for Uintah County in 1985 could require more than 30,000 acre-feet annually (Bishop et al. 1975; U.S. Department of the Interior 1977). A coal slurry pipeline proposed from the Alton coal field to Arrow Canyon, Nevada, would require almost 10,000 acre-feet of water per year. The Intermountain Power Project (IPP) will utilize approximately 30,000 acre-feet of water annually.

In addition to the vast quantity of water used by energy and agriculture, the production of electrical power, shale oil, and agricultural produce may cause undesirable effects on the quality of the water supply. For instance, it has been estimated that at least one-seventh of the total salt outflow from the Duchesne River basin can be attributed to irrigated agriculture (Utah State University 1975). The electrical power industry within Utah is expected to follow a total containment policy with respect to the water they withdraw, which could increase salinity concentration of remaining streamflows.

Clean air is another resource which may be adversely affected by increased power production. In 1974, the Environmental Protection Agency (EPA) established regulations designed to prevent the significant deterioration of air quality (Federal Register 1974). Areas of the nation were differentiated into three air classes, I, II, III. Class I is the most restrictive standard. Initially, all clean areas were designated as Class II with the provision that reclassification could occur. Recently, all national parks within the state have been designated as Class I, with much of the remaining land still categorized as Class II (Federal Register 1978). Since a 1,000 megawatt (1,000 mw) plant could emit up to 120 tons of sulfur dioxide per day (Perkins 1974), there is considerable concern about power plant location as well as abatement technologies and costs. These air quality regulations may force a trade off between air quality and power plant operation.

One purpose of this study is to determine the optimal combination of agriculture and energy given the constraints on water quantity and air and water quality. Another purpose is to determine the trade offs which may occur.

Finally, as energy and agriculture trade offs emerge from plant sitings, the regional economies of the state will be affected. Sectors of these economies which provide goods and services to the energy and agriculture industries will have changed demands. Thus, indirectly the constraints on air and water quality will have important indirect effects on the whole economy and on resident households.

Description of the Area

Utah has been divided into several hydrologic study units (HSU's) as shown in

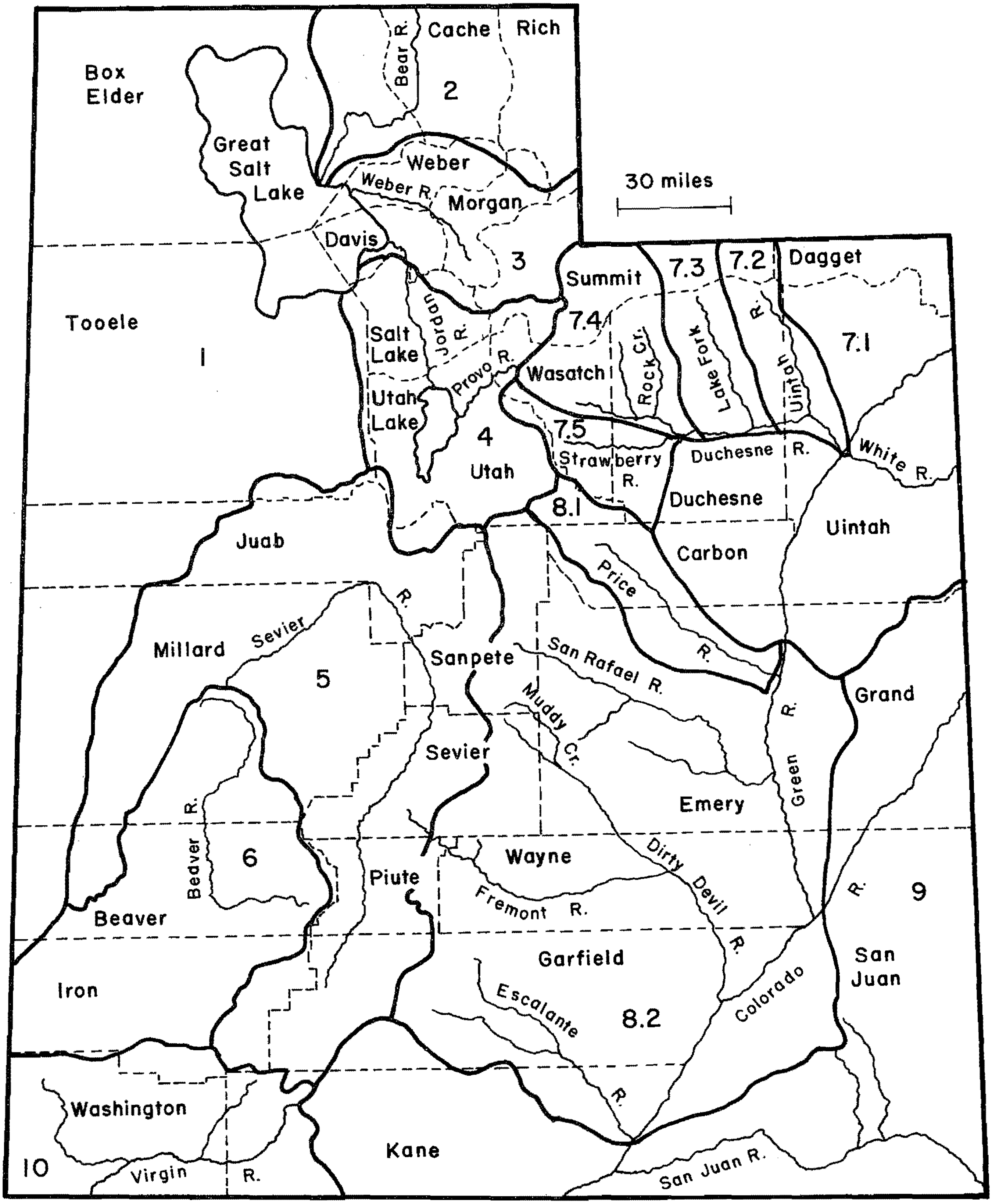


Figure 1. County boundaries, major drainage systems, and hydrologic study units of Utah.

Figure 1 (Glover et al. 1979; Keith et al. 1978). These areas are portions of two major drainages of the West: Colorado River drainage and the Great Basin drainage. The Great Basin drainage consists of the Western Desert (HSU 1); Bear River basin (HSU 2); Weber River drainage (HSU 3); Jordan River basin (HSU 4); Sevier River basin (HSU 5); and the Cedar-Beaver drainage (HSU 6). The Colorado River basin includes the Green River drainage (HSU 7.1); Uintah River basin (HSU 7.2); Lake Fork basin (HSU 7.3); Rock Creek drainage (HSU 7.4); headwaters of the Duchesne and Strawberry Rivers (HSU 7.5); Price River basin (HSU 8.1); remainder of the drainage system west of the Colorado River and east of the Wasatch Mountain Range (HSU 8.2); South and East Colorado River basins (HSU 9); and the Virgin River drainage (HSU 10).

These HSUs generally correspond to somewhat larger air sheds depicted in Figure 2. These air sheds are similar to those identified by previous plume modeling efforts of Anderson (1977) and Lewis et al. (1977) and describe only the general areas involved in the study's plume models. The Castle Valley air shed is comprised of the Castle Valley, San Rafael Valley, and San Rafael Swell of Wasatch, Carbon, Emery, Sanpete, and Sevier Counties. The Uintah Basin air shed includes Duchesne and Uintah Counties. San Juan County is included in the Four Corners air shed which also incorporates parts of Northeastern Arizona and Northwestern New Mexico. The St. George air shed includes Iron and Washington Counties. The Wasatch Front area as well as the northern Utah Mountains are included in the Wasatch Front air shed. Finally, the Western Desert air shed includes the vast Western Desert region of Utah.[1] Specific plume impingement points used in the dispersion model are shown within each air shed.

The state is divided into four economic regions: the Wasatch Front (HSUs 1, 2, 3, and 4), the Southwest (HSUs 5, 6, and 10), the Uintah Basin (HSU 7.1, 7.2, 7.3, 7.4, and 7.5), and the Southeast (HSUs 8.1, 8.2, and 9). These regions generally correspond to county boundaries, particularly with respect to economic activity. County data are the smallest units which can be identified for delineating economic regions.

Objectives of the Study

This study examines the economically efficient allocation of resources between existing and proposed production entities given resource and environmental constraints. The specific objectives of the study are:

1. To formulate theoretical and empirical models which address the optimal input (water and other resources) and output (agriculture and electrical power) combinations in a regional setting.

2. To determine the changes in the efficient output mix of agriculture and energy given new or modified environmental constraints.

3. To determine the economic costs associated with these constraints and/or policies.

4. To determine the indirect effects of the changes in the agriculture and energy sectors on regional economics.

Procedures and Methodology

A theoretical production possibilities model is formulated which provides the basis for an empirical model. The empirical model is set in a mathematical programming framework and takes into account the existing environmental restrictions, seasonal water variations, and coal and water transportation costs. The results and implications of the model are presented and discussed.

---

[1] Research is continuing to determine appropriate air shed boundaries in the Western Desert Region of Utah (Glover et al. 1979).

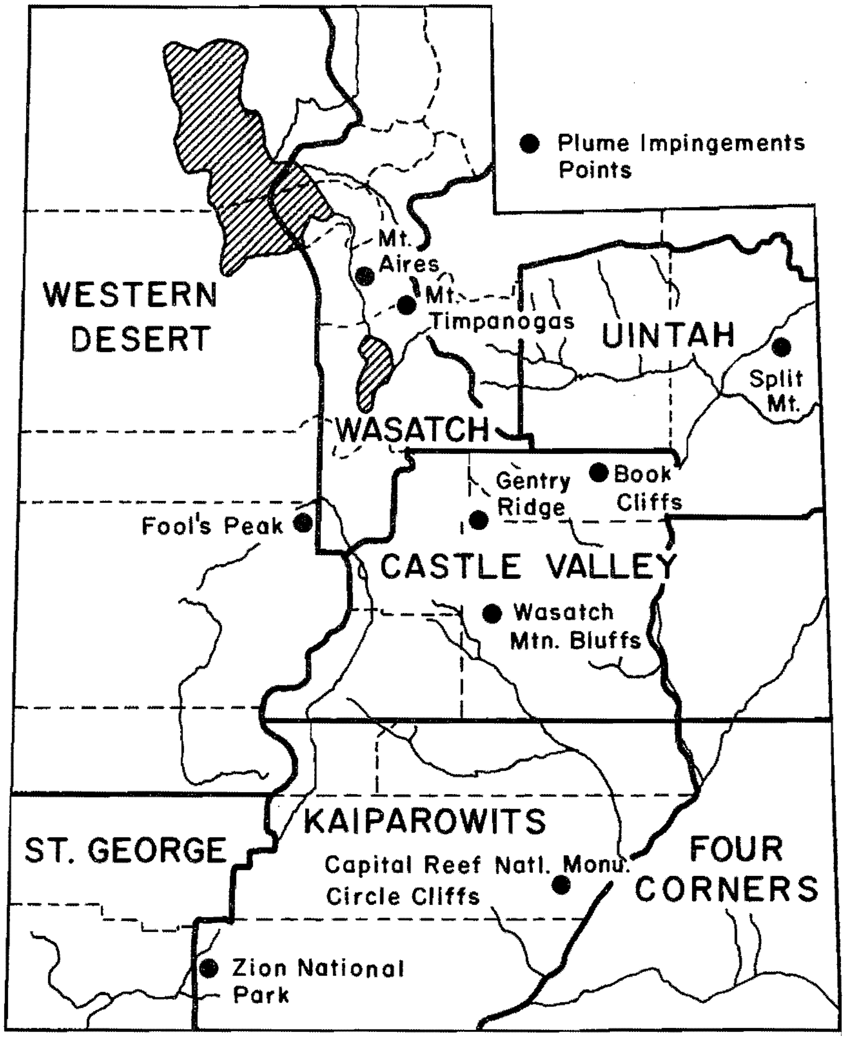


Figure 2. Plume modeling air sheds and impingement points for Utah.

CHAPTER II

REVIEW OF LITERATURE

Production Theory and an Optimal Product Mix

Efficient factor/product allocation is derived from the study of production economics. Hicks (1939) generated a mathematical model of a firm in which the following major assumptions were maintained:

1. The firm possessed a productive process capable of transforming n unlimited variable factors into m final products.

2. Perfect competition existed.

3. The firm attempted to maximize profits subject to its continuous production function.

4. The exact nature of the production function had been predetermined and was fixed.

5. The production function was also characterized by a decreasing marginal rate of technical substitution between factors, a decreasing marginal product for all factor-product relationships, and an increasing marginal rate of product transformation between products.

6. Prices and parameters were known with certainty and remained constant.

Through the use of classical optimization techniques, the following conditions emerged:

1. The price ratio of any two products (P_i/P_{i+1}) equal the marginal rate of product transformation (MRPT) between the two products, or

$$MRPT_{Q_iQ_{i+1}} = P_i/P_{i+1} \quad . \; . \; . \; . \; . \; . \qquad (1)$$

2. The price ratio of any two factors (C) equal the marginal rate of technical substitution (MRTS) between the two factors, or

$$MRTS_{X_jX_{j+1}} = C_j/C_{j+1} \quad . \; . \qquad . \; . \; . \qquad (2)$$

3. The price ratio of any factor-product combination equal the marginal product (MP) for that factor-product combination,

$$MP_j = C_j/P_i \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (3)$$

These conditions are demonstrated graphically in Figure 3 for the two output cases.

Pfouts (1961) developed a model in which fixed factors of production were included in the firm's cost minimizing calculations. Pfouts' contribution was that there is a conversion cost associated with factors fixed to the multiproduct firm but variable within the firm. Naylor (1965) extended Pfouts' work to include the profit maximization case.

Naylor's and Pfouts' modifications necessitated the use of a more general mathematical structure than had been employed previously. They determined that the Kuhn-Tucker conditions (Pfouts 1961) could be applied to a modified classical optimization problem. In essence, their theory of the multiple-input, multiple-output firm was framed in a mathematical programming setting based on the following assumptions:

1. The firm had v independent activities in which n variable factors were combined with a maximum of k fixed factors to produce m products.

2. Perfect competition existed.

3. The firm attempted to maximize profit subject to the constraints imposed by the nature of its activities and the available fixed factors.

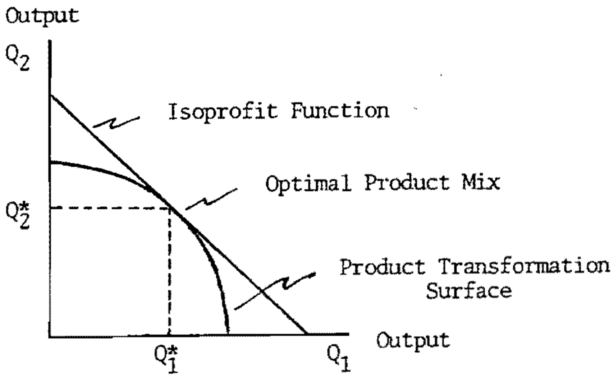


Figure 3. Optimal allocation of output under the Hicksian assumptions.

4. The firm's production functions were homogeneous of degree one.

5. Two or more activities could be used simultaneously subject to the available fixed factors.

6. All factors and products were perfectly divisible.

7. Prices and parameters were known with complete certainty and remained constant.

The conclusions derived from this model specification as demonstrated in Figure 4 were:

1. The unit price of each activity needed to be less than or equal to the sum of the imputed costs of the fixed and variable factors used to produce one unit of that activity.

2. For each variable-activity combination, the unit price of the factor was greater than or equal to the marginal value imputed to that variable factor with regard to that activity.

3. The cost of converting one unit of a given fixed factor for use in a given activity was greater than or equal to the net marginal value imputed to that fixed factor-activity combination.

4. The firm's total profit after paying the costs of its scarce resources equaled zero.

5. The total value imputed to the scarce resources available to the firm was equal to the imputed value of the scarce resources used by the firm.

The marginal analysis of the firm is concerned primarily with alternative factor-product combinations given very small changes in resource availabilities. In general, the programming production problem for the firm is one of finding the optimal values of some objective function subject to a set of concave constraints imposed on the variables of the objective function. Elements from the classical as well as the programming approaches will be utilized in the theoretical and empirical portions of this study.

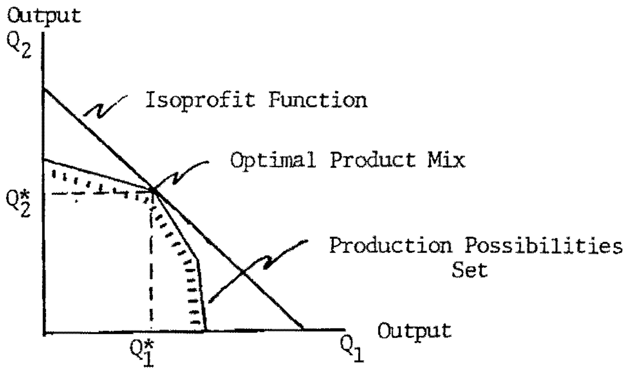


Figure 4. Optimal allocation of output under the programming assumptions.

Production Theory and Market Imperfections[1]

The efficient allocation of inputs and outputs can be adversely affected by several market distortions or imperfections. Of special theoretical interest in this study is the behavior of a firm under regulatory constraints such as an energy utility company (Averch and Johnson 1962). Most regulatory agencies employ a "fair rate of return" criterion to determine the pricing policy of the firm. Generally, the firm is allowed to subtract its operating expenses from gross revenues with the remaining net revenue sufficient to allow a normal rate of return on its investment. Since the firm does not equate marginal rates of factor substitution to the ratio of factor costs, the firm operates inefficiently in an economic sense.

Factor immobilities may distort the price system such that a deviation from optimality may occur (Fishlow and David 1961). The existence of factor payment differentials implies that there is a cost associated with resource movement due to imperfect knowledge and/or the existence of time lags. The direction of the differential will be determined by the demand conditions such that the output sector facing the greatest demand must pay the higher factor prices in order to bid the factors away from competing uses. The output sector which benefits from the lower priced factor will use more of it, the other sector less. Johnson (1966) identifies two additional sources of distortions--taxation and unionization. If the distortions are severe enough, the product transformation function may become convex.

Melvin (1971) and Hsiao (1971) recognized the important effect that the elasticity of substitution in production can have on the shape of the transformation function, although they arrive at different conclusions. Scarth and Warne (1973) and Kraus et al. (1973) contend that the curvature of the transformation function is indeterminate on theoretical grounds. Finally, Melvin (1968), Stewart (1971), and Vanek and Bertrand (1971) conclude that production is indeterminate if the number of products

---

[1] An excellent summary of the effects of imperfect competition on the multiproduct firm is provided by Mauer and Naylor (1964).

exceed the number of inputs. In summary, it is recognized that distortions may exist which could prevent an efficient allocation of output. Further research would be helpful in determining how many of these imperfections are present and the degree to which the efficient allocation of output is affected.

Empirical Allocation Models

Empirical allocation models have consistently relied on mathematical programming techniques (Pfouts 1961; Dorfman 1951) because:

1. Economic variables are usually assumed to be nonnegative.

2. If the objective function and constraints are linear, then the partial derivatives are constant and conditions for a maximum occurs at a boundary point.

3. One or more of the constraints may take the form of an inequality.

Classical optimization techniques are not helpful to identify the optimal solution.

The mathematical programming technique is only one of many procedures relating to the multiple-objective, decision-making process outlined by Cochrane and Zeleny (1973) and Keith et al. (1977). The programming method reduces one or more of the objectives to a constraint. The strength of this approach lies in its ability to provide a fairly simple, yet complete, set of efficient solutions.

The constrained multiple-objective approaches to date have relied on either a cost minimization or profit maximization framework placed in a variety of programming models. Bishop et al. (1975) employed a separable programming model to provide an efficient allocation of water with the stated objective of minimizing cost. Finney et al. (1977) discussed the application of mixed integer programming models to the cost minimizing allotment of water. King et al. (1972) employed a parametric linear programming approach in a least cost water allocation model.

Keith (1973) and Keith et al. (1973, 1977) maximized annual net profit of agriculture and energy sectors in a linear programming framework. Morris (1977) formulated an optimization model by incorporating input-output results into a linear programming representation. Keith et al. (1978) examined the allocation of water under the assumption of profit maximization. Most recently Glover et al. (1979) discussed the optimal distribution of output (energy and agriculture) in a regional setting by maximizing profit and examined some of the impacts associated with energy development.

This research examines of the costs associated with pollution control for energy and agriculture in greater detail. Also, the plume modeling will incorporate the 1977 restrictions and air quality classifications. Alternative coal sources with their associated transportation routes and costs will be modeled. The model will be framed in a seasonal context to determine the full impact of seasonal water flows on agricultural and energy production. Finally, input-output tables were developed for each regional economy using a mathematical process, and these technical relationships were included in the programming model. The input-output tables indicate the economic impact of changes in the agricultural and energy sectors on other sectors in the economy.

CHAPTER III

THEORETICAL MODEL

In the specification of a linear production model for a multiple-input, multiple-output firm the following specific technical assumptions are made:

1. The firm will attempt to maximize profit subject to its production function and associated constraints.

2. The profit and production functions are linear or can be reduced to linear segments which implies that the second-order partial derivatives are equal to zero or do not exist.

3. The production functions are homogeneous of degree one.

4. All factors and products are perfectly divisible.

5. Prices are known with complete certainty.

6. Production coefficients are known with complete certainty and are fixed.

7. Restricted quantities of the region's limited factors are available to the firm and variable to each product.

8. The product transformation curve is concave to the origin.

9. The quantity of each factor used is greater than or equal to zero.

10. All production processes are additive (Christensen et al. 1973a).

The production possibilities frontier for this firm can be represented in implicit form as:

$$F(Q_i; X_{ji}; B_{ki}) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

in which

Q_i = level of the ith product $(i=1,\ldots,m)$

X_{ji} = quantity of the jth variable factor used in the production of the ith output $(j=1,\ldots,n)$

B_{ki} = quantity of the kth limited factor converted into the production of the ith output $(k=1,\ldots,p)$

However, given the assumptions of linearity and fixed coefficients noted above, this implicit production function can be reduced to

$$X_{ji} = a_{ji}Q_i \quad (i=1,\ldots,m)(j=1,\ldots,n) \quad . \quad . \quad . \quad (5)$$

$$B_{ki} = b_{ki}Q_i \quad (i=1,\ldots,m)(k=1,\ldots,p) \quad . \quad . \quad . \quad (6)$$

$$\sum_{i=1}^{m} B_{ki} \le B_k \quad (k=1,\ldots,p) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Equations 5 and 6 are formal statements of the assumption that the production functions are homogeneous of degree one. Equation 7 merely restates assumption 6. Utilizing the specifications given above, an efficient allocation of inputs and outputs on a regional basis can be determined by maximizing regional profit while constrained by fixed production coefficients and limited factor availabilities. The profit function for a region could be represented as

$$\Pi_R = \sum_{i=1}^{m} P_iQ_i - \sum_{i=1}^{m}\sum_{j=1}^{n} (P_j+P_j^t)\,X_{ji}$$

$$- \sum_{i=1}^{m}\sum_{k=1}^{p} (P_k+P_k^t)B_{ki} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

in which

P_i = price of the ith output

P_j = cost of the jth variable factor

P_j^t = cost of transporting the jth variable factor

P_k = cost of converting a small amount of the kth limited factor into the production of the ith output

P_k^t = cost of transporting the kth limited factor

The modified, constrained optimization problem would appear as

Maximize: Π_R

Subject to:

$$X_{ji} = a_{ji}Q_i \quad (i=1,\ldots,m)(j=1,\ldots,n)$$

$$B_{ki} = b_{ki}Q_i \quad (i=1,\ldots,m)(k=1,\ldots,p)$$

$$\sum_{i=1}^{m} B_{ki} \leq B_k \quad (k=1,\ldots,p) \quad . \quad . \quad . \quad (9)$$

The Lagrangean function would then be

$$L = \Pi_R + \sum_{i=1}^{m} \sum_{j=1}^{n} \theta_{ji} \; (X_{ji} - a_{ji}Q_i)$$

$$+ \sum_{i=1}^{m} \sum_{k=1}^{p} \lambda_{ki} \; (B_{ki} - b_{ki}Q_i) + \sum_{k=1}^{p} \lambda_k \; (B_k$$

$$- \sum_{i=1}^{m} B_{ki}) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (10)$$

where θ_{ji}, λ_{ki}, and λ_k are the Lagrangean multipliers for the use of the jth variable input, used in the production of the ith output, the kth limited factor used in the production of the ith output, and the total kth limited factor, respectively.

Prior to determining the optimality conditions for the fixed coefficient regional model, it is necessary to briefly review the major conclusion of the Kuhn-Tucker theorem (Kuhn and Tucker 1951) which is that optimality conditions can be determined for functions constrained by equalities and inequalities rather than just equalities if and only if the objective function and constraint set are concave and differentiable. Note that if all the constraints are effective (that is, are equalities) then the conditions derived by Hicks (refer to page 5) are met. Since both the objective function and constraints are linear, the concavity requirements are fulfilled.

After taking the first derivative of the Lagrangean function and by imposing the Kuhn-Tucker framework, the following optimality conditions[1] result:

$$P_i = \sum_{j=1}^{n} \theta_{ji}a_{ji} + \sum_{k=1}^{p} \lambda_{ki}b_{ki} \quad (i=1,\ldots,m) \quad . \quad . \quad (11)$$

$$-P_j - P_j^t < \theta_{ji} \quad (i=1,\ldots,m)(j=1,\ldots,n) \quad . \quad . \quad . \quad . \quad (12)$$

$$-P_k - P_k^t + \lambda_{ki} \leq \lambda_k \quad (i=1,\ldots,m)(k=1,\ldots,p) \quad . \quad . \quad (13)$$

$$\sum_{i=1}^{m} P_iQ_i^o - \sum_{i=1}^{m} \sum_{j=1}^{n} (P_j+P_j^t) \; X_{ji}^o - \sum_{i=1}^{m} \sum_{k=1}^{p} (P_k+P_k^t) \; B_{ki}^o$$

$$= \sum_{i=1}^{m} \sum_{k=1}^{p} \lambda_k\lambda_{ki}Q_i^o \quad . \; . \; . \; . \; . \; . \; . \quad (14)$$

$$\sum_{k=1}^{p} \lambda_k^o B_k = \sum_{k=1}^{p} \sum_{i=1}^{m} B_{ki}\lambda_k^o \quad . \; . \; . \; . \; . \; . \quad (15)$$

$$Q_i^o,\ X_{ji}^o,\ B_{ki}^o,\ \theta_{ji}^o,\ \lambda_{ki}^o,\ \lambda_k^o \geq 0 \quad (i=1,\ldots,m)(j=1,\ldots,n)(k=1,\ldots,p) \quad . \; . \; . \; . \; . \; . \; . \quad (16)$$

$$\sum_{k=1}^{m} B_{ki} \leq B_k \quad (k=1,\ldots,p) \quad . \; . \; . \; . \; . \; . \; . \; . \quad (17)$$

$$X_{ji} \geq a_{ji}Q_i \quad (i=1,\ldots,m)(j=1,\ldots,n) \quad . \; . \; . \; . \quad (18)$$

$$B_{ki} \geq b_{ki}Q_i \quad (i=1,\ldots,m)(k=1,\ldots,p) \quad . \; . \; . \; . \quad (19)$$

These necessary and sufficient conditions for profit maximization have the following interpretation. The Lagrangean multipliers (λ_k, λ_{ki}, θ_{ji}) are the "shadow" prices of the production factors. θ_{ji} and λ_{ki} represent the value of an additional unit of input to the firm while λ_k represents the value of the marginal product of the factor limited to the region.

Condition 11 states that the price per unit of the ith product must be less than or equal to the sum of the imputed costs of the factors used in the production of that product. If the inequality holds, the ith product will not be produced. If the equality holds for all inputs, the product is being produced at the appropriate level. If the equality holds for each output, the Hicksian solution that the $MRPS_{Q_iQ_{i+1}} = P_i/P_{i+1}$ prevails. For instance, profits within a region may be derived from two major products. The condition given above merely states that the price per unit of each product must be less than or equal to the sum of the costs associated with that product.

Condition 12 could be rearranged such that

$$P_j + P_j^t \geq \theta_{ji} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (20)$$

which asserts that the jth factor cost plus its transportation must be greater than or equal to the value imputed to the jth variable factor used in the ith product. If the inequality holds, the factor will not be employed in that product. When the equality holds, the ith product is employing the jth variable factor in the appropriate quantities. Obviously, if the price of the jth variable factor (e.g., the wage rate

---

[1] The superscript o (i.e., X_{ji}^o) represents the optimal amount.

of labor) plus the cost of transporting that factor is greater than the value received from that factor, it should not be employed. If the price of the factor plus transportation costs are less than its imputed value, more of the variable factor should be used. Only when a stationary equality is achieved does the product employ just the right amount of the variable factor. When the equality holds for each factor, the familiar Hicksian condition that $MP_{X_{ji}} = P_j/P_i$ emerges.

Condition 13 states that the marginal value of the kth limited factor used in the ith product minus the cost of converting and transporting one unit of the kth limited factor to the ith product must be less than or equal to the marginal value imputed to that unit of the kth limited factor. The inequality implies that none of the limited factor should be used in the ith product. For instance, if the marginal value (price) of water minus the cost of converting water so that it can be used in agriculture (e.g., de-salting process) minus the cost of transporting the water (e.g., pipelines, canals, or laterals) such that it can be used is less than the value imputed to water in agriculture, it should not be employed.

Condition 14 states that the firm's profits after paying the imputed costs to its scarce resources must equal zero. Condition 15 indicates that the value of the scarce resources available to the firm must be equal to the value of those resources used in production. Given the assumptions imposed earlier in Equations 5 and 6, the equalities will hold for conditions 17 and 18. Finally, condition 16 meets the assumption of nonnegativity or economic feasibility. This theoretical model is used as a basis for the empirical model developed in the next chapter.

CHAPTER IV

EMPIRICAL MODEL

The Programming Model

The theoretical model can be applied by using mathematical programming. However, the optimality conditions determined for the theoretical model will change because activities become the "output" rather than products in the programming model. Thus, the Hicksian condition that the marginal rate of product transformation must equal the price ratio of those products holds only if each activity is directly related to a specific product. Given a functional relationship between activities and products, the optimality conditions determined previously will hold in general (Naylor 1966).

For large scale, complex problems such as this study examines, nonlinear classical programming is infeasible. For this reason a linear programming model is utilized in this study. A linear programming approach requires the acceptance of some rather stringent assumptions: 1) marginal and average costs are assumed constant and equal, and 2) average and marginal revenue are likewise constant and equal. With no resource constraints, production would either not occur or would be nonunique and unlimited. The use of demand and cost functions would be desirable, but the data required to estimate such functions is overwhelming. In the absence of such data, it will be assumed that the size of the existing and projected electrical power facilities proposed by the power companies are made in response to the actual and anticipated demand. The projected capacities will function as proxies for demand and will serve to constrain production accordingly.

The profit maximizing objective function will include agriculture and electrical power generation only. The basic model structure is adapted from Glover et al. (1979). The notation to be used is:

$$
\begin{aligned}
\text{Maximize } Z = {} & \sum_{i=1}^{L} \sum_{j=1}^{M} \sum_{r=1}^{N} b_{ij}^{r} X_{ij}^{r} - \sum_{q=1}^{S} \sum_{r=1}^{N} \theta_{q}^{r} WA_{q}^{r} \\
& - \sum_{q=1}^{S} \sum_{\substack{k=1 \\ k \neq r}}^{N} \sum_{r=1}^{N} d_{qk}^{r} MA_{qk}^{r} + \sum_{t=1}^{H} \sum_{r=1}^{N} W_{t}^{r} \,|_{t}^{r} \\
& - \sum_{h=1}^{G} \sum_{t=1}^{H} \sum_{k=1}^{T} \sum_{r=1}^{N} (\phi_{h}^{r} + \Pi_{ht}^{kr}) Y_{ht}^{kr} \\
& - \sum_{q=1}^{S} \sum_{r=1}^{N} \sigma_{q}^{r} WE_{q}^{r} - \sum_{q=1}^{S} \sum_{\substack{k=1 \\ k \neq 1}}^{N} \sum_{r=1}^{N} \mu_{qk}^{r} ME_{qk}^{r} \\
& - \sum_{w=1}^{C} \sum_{r=1}^{N} J_{w} TR_{rw} - \sum_{x=1}^{D} \sum_{r=1}^{N} J_{x} TR_{rx}
\end{aligned}
\qquad . \; . \; . \; . \; . \; . \; . \; . \; (21)
$$

subject to:

Water Constraints

groundwater availability

$$
\sum_{q=1}^{S} \underset{(k=r)}{P_{qk}^{r}} (WA_{q}^{r} + WE_{q}^{r}) + \sum_{q=1}^{S} \partial_{q}^{r} WTLG_{q}^{r} - (RFA^{r}) \leq GW^{r}
$$

$$
r = 1, \ldots, N \quad . \; . \; . \; . \; . \; . \; . \; . \; (22)
$$

surface water availability

$$
\begin{aligned}
& \sum_{q=1}^{S} WN_{q}^{r} (WA_{q}^{r} + WE_{q}^{r}) - \sum_{q=1}^{S} \sum_{\substack{k=1 \\ k \neq r}}^{N} V_{qk}^{r} (MA_{qk}^{r} + ME_{qk}^{r}) \\
& + \sum_{q=1}^{S} \underset{(k=r)}{P_{qk}^{r}} WTLS_{q}^{r} + S_{k}^{r} OF_{k}^{r} \\
& + \sum_{q=1}^{S} \sum_{\substack{k=1 \\ k \neq r}}^{N} \sum_{r=1}^{N} 0_{qk}^{r} (EXA_{qk}^{r} + EXE_{qk}^{r}) \\
& - (1-\lambda)^{r} (RFA^{r} + RFE^{r}) \leq SW^{r} \quad r = 1, \ldots, N
\end{aligned}
$$

$$
. \; . \; . \; . \; . \; . \; . \; . \; (23)
$$

return flow from agriculture

$$
\sum_{q=1}^{S} (1-\eta)_{q}^{r} WA_{q}^{r} + \sum_{q=1}^{S} \sum_{\substack{k=1 \\ k \neq r}}^{N} (1-\eta)_{qk}^{r} MA_{qk}^{r} - RFA^{r} = 0
$$

$$
r = 1, \ldots, N
$$

$$
. \; . \; . \; . \; . \; . \; . \; . \; (24)
$$

wetland requirements

$$
\sum_{q=1}^{S} J_{q}^{r} WTLS_{q}^{r} + \sum_{q=S+1}^{B} \nabla_{q}^{r} WTLG_{q}^{r} = WLREQ^{r}
$$

$$
r = 1, \ldots, N
$$

$$
. \; . \; . \; . \; . \; . \; . \; . \; (25)
$$

Table 1. Variable notation.

Z	regional profit function
i	land class
j	type of crop grown
r,k	study region
α	seasons
q	source of water
b_{ij}	net revenue per acre of j^{th} crop grown on i^{th} land class exclusive of water cost
X_{ij}	j^{th} crop grown on land class i
θ_q	unit cost of water delivery from q^{th} source to agricultural use
WA_q	amount of water used by agriculture from q^{th} source
d_{qk}	unit cost of transferring water from q^{th} source in region k to agriculture
MA_{qk}	amount of water imported from q^{th} source in region k
h	raw energy product
t	converted energy product
W_t	price of the t^{th} final energy product
F_t	amount of the final energy product
ϕ_h	unit cost of extraction and conversion of h^{th} raw energy product
Π_{ht}	unit cost of transporting h^{th} raw product to t^{th} conversion process
Y^{rk}_{ht}	amount of h^{th} raw product transported to the t^{th} conversion process from the r^{th} region to the k^{th} region
σ_q	unit cost of delivering water from source q to energy use
WE_q	amount of water used from source q to energy
μ_{qk}	unit cost of transferring water from q^{th} source in region k to energy
ME_{qk}	amount of water imported from source q in region k to energy
W	agricultural effluents
∂_w	treatment cost for effluents from agriculture
TR_w	amount of agricultural effluent treated
X	energy effluents
O_x	treatment cost for effluents from energy
TR_x	amount of energy effluent treated
a_{ij}	percent of j^{th} crop grown on i^{th} land class
PTL_i	total acres of presently irrigable land of class i
$PCDL_i$	total acres of presently cultivated dry land of class i
$POIL_i$	total acres of potentially irrigable land of class i
$POCDL_i$	total acres of potentially cultivated dry land of class i
E_{ij}	rotational coefficient of j^{th} crop on i^{th} land class
$WTLS_q$	wetland requirements met from surface water of q^{th} source
$WTLG_q$	wetland requirements met from ground water of q^{th} source
$WTLREQ$	total wetland water requirements
F^r_h	amount of h^{th} raw energy product in the r^{th} region
I^r_h	total amount of h^{th} output in the r^{th} region
B_{ht}	efficiency of conversion process for h^{th} raw product
F_t	amount of t^{th} final energy product
EMA_h	amount of h^{th} raw energy material available
S_{ij}	consumptive use water requirements in acre feet per acre of the j^{th} crop on the i^{th} land class
η_q, η_{qk}	efficiency parameter of water used by agriculture
$(1-\eta)_q$, $(1-\eta)_{qk}$	return flow coefficients of water in agriculture
RFA	return flows from agriculture
GW	total amount of ground water available
OF_k	stream outflow of local surface water from region k
EXA_{qk}, EXE_{qk}	amount of water exported from source q in region k to agriculture and energy, respectively
λ	ground water recharge coefficient
$(1-\lambda)$	portion of return flow which augments surface water availabilities
SW	total amount of surface water available
EMA_w	agricultural w^{th} effluent emissions
EME_x	energy x^{th} effluent emissions
F_{th}	tons of effluent that occur from the use of the h^{th} raw product in the t^{th} conversion process
$NTEMA_w$	net effluent of w^{th} pollutant from agriculture
$NTEME_x$	net effluent of x^{th} pollutant from energy
$MAXEA_w$	allowable maximum for w^{th} effluent from agriculture
$MAXED_x$	allowable maximum for x^{th} effluent from energy

J_q, q, e_{ht}, P_h, F_h, M_h, n_h, U_h, P_q, ∂_q, P_{qk}, W_q, V_{qk}, F_q, S_k, O_{qk}, E_n, and E_m are the coefficients associated with given variables.

land availability

$$\sum_{j=1}^{M} a^{r}_{ij}\, X^{r}_{ij} \le PIL^{r}_{i} \qquad \begin{array}{l} i = 1,\ldots, L \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (26)$$

$$\sum_{j=1}^{M} a^{r}_{ij}\, X^{r}_{ij} \le PCDL^{r}_{i} \qquad \begin{array}{l} i = 1,\ldots, L \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (27)$$

$$\sum_{j=R+1}^{M} a^{r}_{ij}\, X^{r}_{ij} \le POIL^{r}_{i} \qquad \begin{array}{l} i = 1,\ldots, L \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (28)$$

$$\sum_{j=1}^{M} a_{ij}\, X^{r}_{ij} \le POCDL^{r}_{i} \qquad \begin{array}{l} i = 1,\ldots, L \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (29)$$

Agricultural Production

crop rotation

$$\sum_{j=1}^{M} E^{r}_{ij}\, X^{r}_{ij} \gtreqless 0 \qquad \begin{array}{l} i = 1,\ldots, L \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (30)$$

agriculture water requirements

$$\sum_{i=1}^{L} \sum_{j=1}^{M} \delta^{r}_{ij}\, X^{r}_{ij} - \sum_{q=1}^{S} \eta^{r}_{q}\, WA^{r}_{q} - \sum_{\substack{k=1 \\ k\ne r}}^{N} \sum_{q=1}^{S} \eta^{r}_{qk}\, MA^{r}_{qk} = 0$$

$$r = 1,\ldots, N \quad . \quad . \ (31)$$

Energy Production

intermediate energy flow and final outputs

$$\sum_{t=1}^{H} \sum_{k=1}^{T} \ell^{kr}_{dt}\, Y^{kr}_{ht} - f^{r}_{ht}\, |^{r}_{t} = 0$$

$$\begin{array}{l} h = 1,\ldots, G \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (32)$$

efficiency of conversion process

$$\sum_{t=1}^{H} \sum_{k=1}^{T} \beta^{kr}_{ht}\, Y^{kr}_{ht} - M^{r}_{t}\, |^{r}_{t} = 0$$

$$\begin{array}{l} h = 1,\ldots, G \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (33)$$

capacity of the plants, resource availability, and transmission facilities

$$\eta^{r}_{t}\, |^{r}_{t} \le MEMA^{r}_{t} \qquad \begin{array}{l} h = 1,\ldots, G \\ r = 1,\ldots, N \end{array} \quad . \quad . \ (34)$$

energy water requirement

$$\sum_{t=1}^{H} U^{r}_{t}\, |^{r}_{t} - \sum_{q=1}^{S} P^{r}_{\substack{qk \\ k=r}}\, WE^{r}_{q} - \sum_{q=1}^{S} \sum_{\substack{k=1 \\ k\ne r}}^{T} P^{r}_{qk}\, ME^{r}_{qk} = 0$$

$$r = 1,\ldots, N \quad . \quad . \ (35)$$

gross emissions

agriculture

$$\sum_{w=1}^{C} (EMA_{rw} - \Sigma E^{r}_{w}\, RFA^{r}) = 0$$

$$r = 1,\ldots, N \quad . \quad . \ (36)$$

energy

$$\sum_{x=1}^{D} (EME_{rx} - \sum_{t=1}^{H} E^{r}_{xt}\, |^{r}_{t})$$

$$r = 1,\ldots, N \quad . \quad . \ (37)$$

emission treatment level

agriculture

$$\sum_{w=1}^{C} EMA_{rw} - \sum_{w=1}^{C} TR_{rw} - \sum_{w=1}^{C} NTEMA_{rw} = 0$$

$$r = 1,\ldots, N \quad . \quad . \ (38)$$

energy

$$\sum_{x=1}^{D} EME_{rx} - \sum_{x=1}^{D} TR_{rx} - \sum_{x=1}^{D} NTEME_{rx} = 0$$

$$r = 1,\ldots, N \quad . \quad . \ (39)$$

environmental constraints

$$\sum_{w=1}^{C} NTEMA_{rw} \le \sum_{w=1}^{C} MAXE_{A_{rw}}$$

$$r = 1,\ldots, N \quad . \quad . \ (40)$$

$$\sum_{x=1}^{D} NTEME_{rx} \le \sum_{x=1}^{D} MAXE_{D_{rx}}$$

$$r = 1,\ldots, N \quad . \quad . \ (41)$$

Definition of variables and terms:

i = class of land (I, II, III, IV, ...)

j = type of crop grown

r,k = study regions

q = source of water (present surface and groundwater and new development surface and groundwater, etc.)

b^{r}_{ij} = net revenue associated with one acre of the jth crop grown in the ith class of land in region r, excluding water costs

θ^{r}_{q} = unit cost of delivering water from qth source in region r to agriculture use

WA_q^r = amount of water used by agriculture from qth source in region r to agriculture use

d_{qk}^r = unit cost of transferring water from region k to region r of qth type (present and new transfer for agriculture use)

MA_{qk}^r = amount of imported water from region k to region r of qth type for agriculture use

a_{ij}^r = the coefficient associated with X_{ij}

PIL_i^r = available total acres of presently irrigable dry land i in region r

$PCDL_i^r$ = available total acres of presently cultivated dry land i in region r

$POIL_i^r$ = available total acres of potentially irrigable land i in region r

$POCDL_i^r$ = available total acres of potentially cultivated dry land i in region r

E_{ij}^r = the rotational coefficient of the jth crop with ith land class in region r

$WTLS_q^r$ = wetland water requirements met from surface water of qth type in region r

$WTLC_q^r$ = wetland water requirements met from groundwater of qth type in region r

$WLREQ^r$ = wetland water requirements in region r

X_{ij}^r = jth crop acreage grown in ith land class in region r

h = the raw energy product (coal, crude oil, tar sands, oil shale, natural gas, etc.)

t = the converted energy product (gasified coal, liquified coal, coal slurry, electricity, refined oil, etc.)

W_t^r = price of the tth final product in region r

F_t^r = amount of the tth final product in region r

ϕ_h^r = unit cost of extraction and conversion of the hth energy product in region r

Π_{ht}^{kr} = unit cost of transporting the hth product to the tth conversion process plant from region r to region k

Y_{ht}^{kr} = amount of the hth product transported to the tth conversion process plant from region r to region k

σ_q^r = unit cost of delivering water from source q to energy use in region r

WE_q^r = amount of water used from source q to energy use in region r

μ_{qk}^r = unit cost of transferring water from source q in region k to energy use in region r

ME_{qk}^r = amount of imported water from source q in region k to energy use in region r

f_{ht}^r = input requirements for the hth input per unit of the tth output

$|_t$ = total amount of tth final output in region r (note that for some regions, a final output may be a raw energy product)

β_{ht}^{kr} = the efficiency of the tth conversion process for the hth raw product in region r

$MEMA_t^r$ = amount of the tth energy material available in region r

ℓ_{ht}^{kr} = the coefficient associated with Y_{ht}^{kr}

α_i = the augmented M & I water requirements

δ_{ij}^r = consumptive use water requirements per acre in acre feet of jth crop in the ith land class in region r

η_q^r, η_{qk}^r = efficiency parameter of water use by agriculture in region r

g_t^r = consumptive use water requirement in acre feet to produce one unit of the tth energy product

RFA^r, RFE^r = return flows from agriculture and energy in region r, respectively

GW^r = total amount of groundwater available in region r

SW^r = total amount of local surface water available in region r

OF_k^r = stream outflow of local surface water from region r to k

$WTLG_q^r$ = wetland requirement taken from groundwater availability in region r

$WTLS_q^r$ = wetland requirement taken from local surface water availability in region r

$\mathrm{EXA}_{qk}^{r}, \mathrm{EXE}_{qk}^{r}$ = amount of water exported from source q in region r to agriculture and energy production in region k, respectively

λ^{r} = the recharge coefficient of groundwater from return flow in region r

$(1-\lambda)^{r}$ = the recharge coefficient of local surface water from return flow in region r

$(1-\eta)^{r}$ = the return flow coefficients of agriculture and energy in region r, respectively

$\mathcal{J}_{q}^{r}, \mathcal{Y}_{q}^{r}, S_{k}^{r}, M_{t}^{r}, N_{h}^{r}, U_{t}^{r}, P_{qk}^{r}, \partial_{q}^{r}, WN, V_{qk}^{r}, \Gamma_{q}^{r}, O_{qk}^{r}$ = the efficiency of use coefficients associated with the given activity in region r

E_{w}^{r} = emission rate for the wth pollutant from agricultural return flow in region r

E_{xt}^{r} = emission rate for the xth pollutant from the tth energy product in the rth region

x = energy effluents

w = agricultural effluents

EMA_{rw} = agricultural wth emissions for the rth region

$J_{w(\mathrm{or}\ x)}$ = cost of treatment per unit emissions of the wth or xth pollution

EMC_{rx} = energy emissions of xth pollution for rth region

$\mathrm{TR}_{rw(\mathrm{or}\ x)}$ = treatments of wth or xth pollutant for region r

NTEMA_{rw} = net effluent of wth pollutant for agriculture in region r

NTEME_{rx} = net effluent of xth pollutant for energy for region r

MAXEA_{rw} = allowable maximum for the wth effluent for agriculture in region r

MAXEE_{rx} = allowable maximum for the xth effluent for energy in region r

Note that the maximum for each sub or superscript can vary as the scope of the model is expanded or narrowed.

The Electricity Sector

The following equations further detail the electrical generation sector and associated coal activity.

Objective function

$$\sum_{k}^{N}\sum_{r}^{N}\sum_{d}^{Q} \mathrm{EPROFIT}_{dr}^{k} + \sum_{k}^{N}\sum_{r}^{N}\sum_{d=1}^{Q}\sum_{m=1}^{R}\left(W_{c}^{r}\, \mathrm{CM}_{dr}^{km} - \sum_{m=1}^{R} \phi_{c}^{r}\, \mathrm{CLCST}_{dr}^{km}\right) \quad . \; . \; . \; . \; . \tag{42}$$

electricity profit

$$\sum_{k}^{N}\sum_{r}^{N}\Big(W_{e}^{k}\, \mathrm{ELEC}_{dr}^{k} - \phi_{e}^{k}\, \mathrm{ELEC}_{dr}^{k} - W_{c}^{k}\, \mathrm{CM}_{dr}^{km} - \sum_{z} \Pi_{ce}^{rk}\, \mathrm{CT}_{drz}^{km} - \sum_{z=1}^{Z} \Pi_{ee}^{rk}\, \mathrm{TRM}_{dr}^{k} - \theta_{q}^{dk}\, \mathrm{ENWREQ} - J_{ex}\, \mathrm{TR}_{exr}\Big) = \sum_{k}^{N}\sum_{r}^{N} \mathrm{EPROFIT}_{dr}^{k} \quad . \; . \tag{43}$$

coal requirement

$$\mathrm{ELEC}_{dr}^{k} - \sum_{m=1}^{R}\sum_{z=1}^{Z} \beta_{ce}^{rk}\, \mathrm{CM}_{dr}^{km} = 0 \quad . \; . \; . \; . \tag{44}$$

(Note that the coal requirement, or conversion ratio, may vary for each coal source, but it is constant for a given coal source.)

water requirement

$$g_{e}^{r}\, \mathrm{ELEC}_{dr}^{k} = \mathrm{ENWREQ}_{dr}^{k} \quad . \; . \; . \; . \; . \; . \; . \tag{45}$$

(Includes M and I augmented water requirement.)

electricity transmission (each MWH produced must be transmitted)

$$\mathrm{ELEC}_{dr}^{k} = \mathrm{TRM}_{dr}^{k} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \tag{46}$$

coal transport

$$\beta_{ce}^{rk}\, \mathrm{ELEC}_{dr}^{k} = \sum_{z=1}^{Z} \mathrm{CT}_{drz}^{km} \quad . \; . \; . \; . \; . \; . \; . \tag{47}$$

demand constraints

$$\sum_{r=1}^{N}\sum_{d=1}^{Q} \mathrm{ELEC}_{dr}^{k} \le \mathrm{DMND}_{k} \quad . \; . \; . \; . \; . \; . \tag{48}$$

coal mining constraints

$$\sum_{z=1}\sum_{d=1}^{Q}\sum_{k=1}^{N} \mathrm{CT}_{drz}^{km} = \mathrm{CM}_{r}^{m} \quad . \; . \; . \; . \; . \; . \tag{49}$$

$$\mathrm{CM}_{r}^{m} \le \mathrm{CMMAX}_{r}^{m} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \tag{50}$$

coal transportation constraints

$$\mathrm{CT}_{drz}^{k} \le \mathrm{CTMAX}_{drz}^{km} \quad . \; . \; . \; . \; . \; . \; . \tag{51}$$

transmission constraints

$$\sum_{d=1}^{Q}\sum_{r=1}^{N} \mathrm{TRM}_{dr}^{k} \le \mathrm{TRMMAX}_{drz}^{k} \quad . \; . \; . \; . \; . \tag{52}$$

gross pollution

$$\sum_{k=1}^{N} E_{xe}\ ELEC_{dr}^{k} + W_k CM_{dr}^{km} = EME_{xer} \quad . \quad . \quad . \quad (53)$$

(Note the adjustment of pollutant produced based on the coal used as compared to a standard coal.)

treatment of pollution

$$EME_{xer} - TR_{exr} = NTEME_{exr} \quad . \quad . \quad . \quad . \quad . \quad . \quad (54)$$

(Treatment levels are incremented.)

maximum allowable pollution

$$NTEME_{exr} \leq MAXE_{E_{exr}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (55)$$

fixed investment levels (by plant)

$$\sum_{n=1}^{N} N_{(trm)}\ TRM_{dr}^{k} + N_{(trt)}\ TR_{dr} + \sum_{k=1}^{N} N_e\ ELEC_{dr}^{k}$$

$$= INV_{edr} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (56)$$

(Fixed investment is determined for output (per MWH), transmission (per MWH), and treatment (per ton removed).)

minimum profitability constraint

$$\sum_{k=1}^{N} EPROFIT_{dr}^{k} - PCT_e\ INV_{edr} \quad . \quad . \quad . \quad . \quad (57)$$

(A plant must meet or exceed an exogenously specified return to fixed investment.)

Super and subscripts are the same as those listed above with the following exceptions:

e,c = electricity and coal production, respectively (would be subsumed under subscript t or h)

d = electricity plant identification number (d = 1, ..., Q)

m = mine identification number (m = 1, ..., R)

N_e = investment cost per MWH produced

$N_{(trm)}$ = investment cost of transmission per MWH

$N_{(trt)}$ = investment cost per ton of pollutant treated

PCT_e = established rate of return on investment for electrical generation

z = coal transportation route and/or type (z = 1, ..., Z)

w_k = coefficient of pollution adjustment for each coal source

$EPROFIT_{dr}^{k}$ = profit to the dth plant from the rth region from sales to the kth region

CM_{dr}^{km} = coal mined in the mth mine in the rth region sent to the dth electrical plant in the kth region

$CLCST_{dr}^{km}$ = cost of coal from the mth mine in the rth region to the dth plant in the kth region

$ELEC_{dr}^{k}$ = electrical production in the dth plant in the rth region sold in the kth region

CT_{drz}^{km} = coal transportation from the mth mine in the rth region to the dth plant in the kth region by the zth route

$ENWREQ_{dr}$ = water required for the dth plant in the rth region

TRM_{drz}^{k} = transmission of electricity from the dth plant in the rth region to the kth region by the zth route

$DMND_k$ = maximum demand for electricity in region k

$CMMAX_r^m$ = maximum coal available annually from the mth mine in the rth region

$CTMAX_{drz}^{km}$ = maximum transportation capacity of the zth route to the dth plant in the kth region from the mth mine in the rth region (note that the capacity may involve sums of transport in some cases)

$TRMMAX_{drz}^{k}$ = maximum electrical transmission capacity of the zth line from the rth region to the kth region

INV_{edr} = investment cost of the dth electrical plant in the rth region

θ_q^{dk} = cost of water from source q by plant k

W_e^k = gate price of electricity at plant k

ϕ_e^k = variable cost of production excluding coal, water from and pollution treatment at generating plant k

π_{ce}^{rk} = transport cost for coal from mine C in region r to plant k

π_{ee}^{rk} = transmission cost for energy from plant k to region k

The coal sector is composed primarily of the revenues from mine mouth sales less the production costs in the objective function (Equation 42) and the water requirements associated with coal mining (almost entirely M and I demand increases). For each coal source, there exists a conversion rate to electricity based on a 10,000 Btu heat rate adjusted for coal quality (Equation 44). This configuration implicitly assumes a constant conversion rate for each coal irrespective of plant size at any one site. Since coal conversion rates are the major component of production cost savings to larger plants (i.e., decreasing production costs and plant size increases) the model assumes constant cost production relationship for a given coal source.

Input-Output Model

Final demand (export)

$$FD_{ar} + \alpha_{ar} W_t^r |_t^r + W_t^r X_{ij}^r = TFD_{ar} \quad . \quad . \quad . \quad (58)$$

Input-output constraints

$$\sum_{a=1}^{A} \sum_{b=1}^{B} \psi_{abr} TFD_{ar} = RGO_{ar} \quad . \quad . \quad . \quad . \quad (59)$$

Regional gross output

$$\sum_{a=1}^{A} RGO_{ar} = TRGO_r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (60)$$

in which

a,b = economic sector

FD_{ar} = existing final demand in the ath sector in the rth region

TFD_{ar} = total (augmented) final demand in the ath sector of the rth region

RGO_{ar} = regional gross output (sales) in the ath sector of the rth region

$TRGO_r$ = total regional gross output in the rth region

ψ_{abr} = proportion of each dollar of output sold to the bth sector by the ath sector

Objective Function Coefficients[1]

Water Costs

Water costs (Table 2) specific to each HSU were obtained from King (1972) and Glover et al. (1980) and updated to 1977 prices using irrigation and water cost indices found in the Engineering News Record (1978). The cost per acre foot of delivering water to agricultural production for both existing and new water are included for surface water sources as well as groundwater supplies. The cost per acre foot of water imports, both present and new, are also shown for each HSU. Similar information is included for the energy sector.

Agricultural Costs and Revenues

Net revenue coefficients from agriculture for the entire 1977 season are shown in Table 3. Crop productivities by county had been previously determined by Christensen et al. (1973b) and updated by Davis et al. (1975). Productivity rates by HSU were then multiplied by appropriate crop prices[2] to determine gross revenue per acre. Variable costs (Glover et al. 1979; U.S. Department of Agriculture 1978a), excluding water transfer and application costs, were then subtracted from gross revenue figures to determine net revenue on a per acre basis.

In order to determine the impact of seasonal water availabilities, seasonal net revenue was also computed (Table 4) by assuming productivity to be directly proportional to the quantity of water consumptively used (Office of the State Engineer 1962). For example, if alfalfa consumed 31 percent of its annual water requirement within the first 6 months, productivity was assumed to be 31 percent of the annual production rate also. Production costs were divided between seasons proportional to the growing periods for all crops except barley and nurse crops where costs were assumed proportional to production.

The new land development costs on an annual basis shown in Table 5 were obtained from Keith et al. (1978) and modified utilizing information from the U.S. Department of Agriculture (1969a, 1969b, 1978b) and the Engineering News Record Construction Index (1978). While these costs include charges for land clearing and leveling, no attempt has been made to include the expenditures necessary to raise the actual productivity of the new land to a level consistent with land currently under production. The net revenue associated with new agricultural land was therefore, at a level somewhat higher than would actually prevail in the market. Another possible complication is that land ownership, whether state, federal, or private, is not taken into account so that all land suited for crop production is made available for production. These development costs were then subtracted from both the full-season and partial-season net revenue figures to determine the net revenue for new land development.

---

[1] A printout of the model and coefficients is available from the writers upon request.

[2] An 8-year price average was determined for each crop to eliminate the annual variability which often is found in agricultural prices.

Table 2. Cost components for supplying water to agriculture and energy in Utah for 1977 (annual cost in $/ac-ft).

	AGRICULTURE								ENERGY							
	Local Surface Water		Groundwater		Surface Water Transfers				Present Water		New Water		Surface Water Transfers			
HSU	Present	New	Present	New	To HSU	Present	To HSU	New	Surface	Ground	Surface	Ground	To HSU	Present	To HSU	New
1	2.27	15.77	3.74	4.55	4	5.58			51.09	72.13	135.39	126.98	4	65.53		
2	2.27	14.30	5.28	6.02			1	60.87	51.09	72.13	135.39	126.98			3	210.263
							3	77.55								
3	2.27	16.50	6.02	6.75	2	5.58	4	66.90	60.11	90.16	177.32	148.43	4	63.66	4	246.298
					4	3.76										
4	2.27	15.77	8.22	9.02			5	55.17	60.11	90.16	177.32	148.43			5	246.298
5	2.27	14.30	5.28	6.02			6	67.63	54.10	72.13	156.28	126.98			6	200.637
6	2.27	13.57	6.75	7.48					54.10	72.13	156.28	126.98				
7.1	2.27	15.77	3.08	3.74	4	3.76			54.10	72.13	156.28	126.98	4	63.66		
7.2	2.27	15.77	3.08	3.74	4	3.76			54.10	72.13	156.28	126.98	4	63.66		
7.3	2.27	15.77	3.08	3.74	4	3.76	3	95.58	54.10	72.13	156.28	126.98	4	63.66	3	264.930
							4	84.91					7.4	2.27	5	248.609
							5	79.21								
							7.4	2.27								
7.4	2.27	15.77	3.08	3.74	4	3.76			54.10	72.13	156.28	126.98	4	63.66		
7.5	2.27	15.77	3.08	3.74	4	3.76	4	75.91	54.10	72.13	156.28	126.98	4	63.66	5-Ute	254.682
															5-Bonn	245.359
8.1	2.27	15.77			5	5.58			66.12		201.37		5	63.66		
8.2	2.27	15.77			5	5.58	4	78.92	66.12		201.37		5	63.66	4	248.466
							5	52.16							5	248.466
9	2.27	15.77							60.11		177.32					
10	2.27	15.77	3.74	4.55	6	3.76	6	67.63	60.11	72.13	177.32	126.98	6	57.447	6	218.344

Table 3. Net revenue for full season agricultural production by land class and HSU in Utah, 1977, ($/acre).

Crop	Land Class				Land Class				Land Class			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	HSU #1				HSU #2				HSU #3			
Alfalfa (Full)	85.40	67.23	57.19		98.39	78.20	60.82		103.46	92.57	73.39	
Alfalfa (Partial)	60.51	44.65	41.93		75.03	62.05	58.38		80.11	69.96	68.06	
Barley	97.72	76.98	64.44		99.30	83.70	69.86		100.30	92.08	72.60	
Nurse Crop	47.92	31.39	23.51		58.00	42.58	32.69		45.34	50.03	38.30	
Corn Grain	111.02	76.35	40.52		104.92	73.68	37.06		104.92	73.68	78.39	
Corn Silage	192.02	180.18	149.52		183.88	178.73	155.47		185.01	184.98	168.08	
Apple (N)[a]	576.96	518.03	435.54		569.32	544.50	432.90		569.32	512.38	432.90	
Apple (M)[b]	2912.76	2380.18	2228.99		2906.20	2374.68	2223.25		2906.20	2374.68	2223.25	
Peach (N)	596.12	471.21	399.20		592.90	469.84	393.58		571.30	469.84	393.58	
Peach (M)	2642.94	2228.51	2089.35		2633.31	2224.39	2085.92		2633.31	2224.39	2085.92	
St. Cherry (N)	(143.07)[d]	(132.41)	(133.94)		(147.64)	(136.93)	(136.22)		(147.64)	(136.93)	(136.22)	
St. Cherry (M)	857.52	634.00	432.78		845.70	628.84	427.74		845.70	628.84	427.74	
Sr. Cherry (N)	205.80	99.34	85.70		141.90	98.48	83.08		141.90	98.48	83.08	
Sr. Cherry (M)	1261.03	1030.16	965.43		1256.20	1027.15	959.70		1256.20	1027.15	959.70	
Dry Wheat				11.70				11.12				15.20
Dry Beans												
Alfalfa (Full)-(P)[c]			37.94				32.50				44.08	
Alfalfa (Partial)-(P)			27.27				19.88				28.00	
Barley-(P)			28.72				36.65				46.85	
Nurse Crop-(P)			9.60				14.19				17.10	
	HSU #4				HSU #5				HSU #6			
Alfalfa (Full)	105.16	88.66	71.81			77.41	64.96		92.54	69.91	70.60	
Alfalfa (Partial)	81.80	68.83	56.39			53.88	45.67		67.58	63.06	60.62	
Barley	100.30	89.93	73.41			75.93	61.10		90.78	76.62	62.88	
Nurse Crop	55.34	49.86	36.19			30.75	19.45		32.85	31.45	21.55	
Corn Grain	122.15	70.99	44.55			69.48	33.71		111.44	65.89	28.59	
Corn Silage	185.01	183.49	157.57			188.27	163.44		208.18	188.64	172.75	
Apple (N)	569.32	512.38	432.90									
Apple (M)	2906.20	2374.68	2223.25									
Peach (N)	571.30	469.84	393.58									
Peach (M)	2633.31	2224.39	2085.92									
St. Cherry (N)	(147.64)	(136.93)	(136.22)									
St. Cherry (M)	845.70	628.84	427.74									
Sr. Cherry (N)	141.90	98.48	83.08									
Sr. Cherry (M)	1256.20	1027.15	959.70									
Dry Wheat				8.52				8.24				8.68
Dry Beans												
Alfalfa (Full)-(P)			40.31				40.63				40.16	
Alfalfa (Partial)-(P)			28.58				22.48				26.16	
Barley-(P)			37.06				34.86				32.22	
Nurse Crop-(P)			15.34				10.28				12.46	

Table 3. Continued.

Crop	Land Class I	II	III	IV	Land Class I	II	III	IV	Land Class I	II	III	IV
	HSU #7.$_i$ (i=1,...,5)				HSU #8.$_j$ (j=1,2)				HSU #9			
Alfalfa (Full)		72.28	65.61		97.54	87.93	80.41		110.23	86.24	73.65	
Alfalfa (Partial)		59.31	43.37		73.59	69.89	72.10		84.59	55.08	39.53	
Barley		78.20	72.55		94.19	84.30	70.08		102.64	79.46	62.70	
Nurse Crop		30.56	18.86		44.63	36.65	26.33		51.16	31.81	18.90	
Corn Grain		75.06	30.26		97.02	62.26	35.46		76.14	51.82	30.26	
Corn Silage		185.47	156.98		190.41	184.48	161.80		188.29	188.87	163.08	
Apple (N)[a]												
Apple (M)[b]												
Peach (N)												
Peach (M)												
St. Cherry (N)												
St. Cherry (M)												
Sr. Cherry (N)												
Sr. Cherry (M)												
Dry Wheat				7.48				7.56				5.22
Dry Beans												33.14
Alfalfa (Full)-(P)			46.80				52.87				48.31	
Alfalfa (Partial)-(P)			21.70				43.05				23.81	
Barley-(P)			35.05				32.84				23.62	
Nurse Crop-(P)			11.16				14.37				11.98	

Crop	HSU #10 I	II	III	IV
Alfalfa (Full)	143.59	103.40	70.69	
Alfalfa (Partial)	69.45	47.75	31.39	
Barley	85.54	73.24	57.80	
Nurse Crop	32.59	24.12	12.68	
Corn Grain	145.74	98.26	65.06	
Corn Silage	241.50	244.79	195.84	
Apple (N)	520.72	472.32	402.14	
Apple (M)	2867.14	2295.90	2162.77	
Peach (N)	558.76	441.69	371.98	
Peach (M)	2574.10	2175.21	2048.17	
St. Cherry (N)				
St. Cherry (M)				
Sr. Cherry (N)				
Sr. Cherry (M)				
Dry Wheat				9.98
Dry Beans				
Alfalfa (Full)-(P)			23.00	
Alfalfa (Partial)-(P)			3.03	
Barley-(P)			17.71	
Nurse Crop-(P)			(0.86)	

[a] N = Nurse crop.

[b] M = Mature crop.

[c] P = Pasture.

[d] Negative values are enclosed in parentheses.

Table 4. Net revenue in first-half season for selected crops by land class and HSU in Utah, 1977 ($/acre).

Crop	Land Class				Land Class				Land Class			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	HSU #1				HSU #2				HSU #3			
Alfalfa (Full)	4.41	1.25	1.94		18.31	12.87	9.68		20.42	18.78	16.81	
Alfalfa (Partial)	0.64	(1.79)[a]	1.08		13.82	10.93	12.48		15.94	14.46	17.74	
Barley	53.76	42.30	35.44		69.56	58.59	48.91		70.21	64.45	50.82	
Nurse Crop	26.36	17.27	12.93		38.08	29.81	22.89		38.73	35.67	25.44	
Corn Grain	(14.09)	(20.27)	(26.15)		(14.36)	(19.95)	(26.27)		(6.00)	(12.85)	(20.68)	
Corn Silage	18.02	21.46	18.75		12.25	21.09	21.51		22.60	31.94	33.42	
Dry Wheat				11.70				11.12				15.20
Dry Beans												
Alfalfa (Full)-(P)[b]			1.28				5.17				10.10	
Alfalfa (Partial)-(P)			0.70				4.25				7.30	
Barley-(P)			17.03				31.72				39.47	
Nurse Crop-(P)			6.63				7.54				17.10	
	HSU #4				HSU #5				HSU #6			
Alfalfa (Full)	20.85	17.04	14.54			4.86	4.98		6.92	5.63	6.32	
Alfalfa (Partial)	16.36	13.47	12.33			1.34	2.74		3.33	4.24	7.04	
Barley	70.21	62.96	50.39			53.16	42.76		50.84	42.91	35.23	
Nurse Crop	38.73	36.66	25.34			21.53	13.61		15.62	17.61	12.08	
Corn Grain	(1.02)	(13.49)	(18.52)			(12.67)	(20.01)		(13.88)	(22.63)	(28.60)	
Corn Silage	22.60	31.34	(29.58)			35.36	32.44		22.56	24.56	25.12	
Dry Wheat				8.52				8.24				8.68
Dry Beans												
Alfalfa (Full)-(P)			8.16				3.11				3.59	
Alfalfa (Partial)-(P)			6.25				1.35				3.04	
Barley-(P)			31.65				30.42				19.70	
Nurse Crop			15.34				10.28				9.24	

Table 4. Continued.

Crop	Land Class				Land Class				Land Class			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	HSU #7.$_i$ (i=1,...,5)				HSU #8.$_j$ (j=1,2)				HSU #9			
Alfalfa (Full)		5.68	7.21		12.81	12.02	14.82		14.92	9.91	9.75	
Alfalfa (Partial)		5.54	3.26		8.87	10.19	14.26		10.99	4.27	2.84	
Barley		44.57	41.35		52.75	47.21	39.23		57.48	44.50	35.10	
Nurse Crop		17.41	10.75		25.85	20.52	14.70		28.65	17.81	10.58	
Corn Grain		(17.57)	(25.47)		(9.65)	(16.62)	(20.83)		(19.93)	(23.39)	(25.47)	
Corn Silage		25.52	23.26		26.22	30.63	29.07		19.70	26.37	24.82	
Dry Wheat				7.48				7.56				5.22
Dry Beans												33.14
Alfalfa (Full)-(P)			2.33				9.74				6.40	
Alfalfa (Partial)-(P)			1.63				8.51				1.71	
Barley-(P)			18.45				19.67				23.62	
Nurse Crop-(P)			11.16				9.95				11.98	
	HSU #10											
Alfalfa (Full)	53.18	36.47	23.92									
Alfalfa (Partial)	22.45	13.93	7.87									
Barley	74.42	63.71	50.29									
Nurse Crop	28.38	20.99	11.02									
Corn Grain	63.82	41.82	26.61									
Corn Silage	107.99	110.91	89.06									
Dry Wheat				9.98								
Dry Beans												
Alfalfa (Full)-(P)			7.78									
Alfalfa (Partial)-(P)			3.03									
Barley-(P)			17.71									
Nurse Crop-(P)			(0.86)									

[a] Negative values are enclosed in parentheses.

[b] P = Pasture.

Table 5. Annualized costs of preparing potentially irrigable land for production by land class in Utah for 1977 ($/acre).

HSU	Land Class			
	I	II	III	IV
1	22.17	25.06	27.25	30.39
2	24.59	27.48	29.67	32.80
3	27.00	29.90	32.08	37.64
4	29.42	32.31	34.50	37.64
5	-	27.48	29.67	32.80
6	27.00	29.90	32.08	37.67
7.1	-	25.06	27.25	30.39
7.2	-	25.06	27.25	30.39
7.3	-	25.06	27.25	30.39
7.4	-	25.06	27.25	30.39
7.5	-	25.06	27.25	30.39
8.1	22.17	25.06	27.25	30.39
8.2	22.17	25.06	27.25	30.39
9	22.17	25.06	27.25	30.25
10	22.17	25.06	27.25	30.25

The energy sector consists mainly of electrical generation and the associated coal use.

Energy Resource Costs and Revenues

Coal mining costs and coal revenues were determined for 21 mines or mine areas in Utah, Wyoming, and Colorado. Mine specific extraction costs were not available. Costs vary among mines with overburden depth, seam thickness, in-mine flooding, actual coal conditions, and coal mine capacities. The estimates of coal mining costs as shown in Table 6 were determined from information found in Anderson (1977, 1979), Stradley (1977), the U.S. Department of Energy (1978a, 1979), and the U.S. Department of the Interior (1975, 1976b, 1976c). Where necessary, these costs have been updated using mining cost indices prepared by the U.S. Department of Commerce (1978). The f.o.b. mine selling price estimates specifically allow for mine types, current or projected output rates, mining methods, sulfur content, and Btu heat value (U.S. Department of Energy 1978a).

Transportation methods include belt, truck, rail, and slurry. Coal transportation costs from vaious mines to power plants by alternative methods were estimated in earlier research (Glover et al. 1979). Some adjustments were made for distances and tonnages by using specific observations from the sources cited above as well as current negotiated rates furnished by Union Pacific Railroad (1979). These costs are displayed in Table 7. It should be noted that these costs are only estimates. Truck transportation rates are sensitive to mileages and tonnages. Railroad rates are dependent upon the load turn-around time, car ownership, and new construction requirements, as well as distances and tonnages. Given the large potential increases in transportation, existing shipments are seldom comparable to the proposed shipments. Slurry transportation rates are very sensitive to volumes shipped and substantially less sensitive to distances (Anderson 1979). Belt shipments are restricted to mine mouth generating facilities only. New facilities construction was included where applicable.

Electricity Costs and Revenues

Electricity costs, prices, and net revenues by HSU (Table 8) were obtained from the Utah Division of Public Utilities (1979) and the U.S. Department of Energy (1978b). Variable costs excluding fuel were determined on a plant by plant basis. Revenue is available only as a company-wide average price of approximately $21.41 per MWH. Proposed power plants are assumed to experience costs and profitability similar to the latest Huntington unit. The Huntington unit was chosen because it is the only major Utah power plant which contains a sizable amount of pollution control equipment.

The Huntington plant is currently experiencing a variable cost of $2.56 per MWH, which generates an average net revenue of $18.85 per MWH.

Salinity Abatement Costs

Agricultural pollution abatement costs per ton of salt removed (Table 9) were obtained from Glover et al. (1979) and updated using appropriate cost indices for canal lining and sprinkler systems (Engineering News Record 1978). The term "salinity" is used as a proxy for total dissolved solids (TDS). Agriculture contributes to salinity through irrigation. First, there is some direct loading from fertilizers being applied to the soil. Second, the natural salts found within the soil are added to the stream flows through the leaching process and return flows. Salinity concentrations are also increased by consumptive water use. The principal methods of salinity control in agriculture are the installation of sprinklers (Treatment 1) and canal lining (Treatment 2). It is assumed that producers of coal-fired electrical power will follow a total containment policy (i.e., pond evaporation), even though there is some evidence that they might not continue to do so. For instance, the water from the Huntington units is currently being used to irrigate a variety of crops under a project initiated by Utah Power and Light Company (Hanks et al. 1977; Hanks et al. 1978).

Air Pollution Abatement Costs

Estimated pollution treatment costs for electrical power plants expressed in dollars per ton of effluent removed are shown for the removal of SO_2 (Table 10). Costs ranged from $1067/ton removed to $209/ton removed (Martin 1976). The emission rates

Table 6. Estimated mining costs and at mine selling prices for coal mines in Utah, Wyoming, and Colorado ($/ton).

COAL SOURCE	MINE OR COAL FIELD INFORMATION						MINING COST AND COAL PREMIUM			SELLING PRICE FOR MINE
	Mine Type	Seam Depth	Btu Content/ lb.	Planned Mine Capacity in mmtpy	% Sulfur Content	Mine Method	Mining Cost/Ton	Premium for Low Sulfur	Premium for Btu Content	
Utah										
1. Alton	S	12	10,772	9.5	1.3	strip	6.39	-	1.00	7.39
2. Bookcliffs	U	7-10	12,762	5.0	0.5	C/L[a]	10.94	1.62	3.00	15.56
3. Braztah	U	10*	12,300	6.5	0.5	C/L	10.94	1.62	3.00	15.56
4. Carbon Fuel	U	10*	12,850	4.0	0.2	C/L	10.94	3.24	3.00	17.18
5. Castlegate	U	10*	12,870	4.0*	0.2	C/L	10.94	3.24	3.00	17.18
6. Deer Creek	U	13	12,800	2.2	0.5	C/L	10.94	1.62	3.00	15.56
7. Deseret	U	10-13	12,830	4.0*	0.6	C/L	10.94	0.81	3.00	14.75
8. Henry Mtns. (Emery)	U	6	12,480	4.0*	0.96	C[b]	16.59	-	3.00	19.59
9. Henry Mtns. (General)	U	10	12,833	10.0	2.03	C/L	10.94	-	3.00	13.94
10. Hiawatha Quads	U	10-20	12,744	2.0	0.59	C/L	12.40	1.62	3.00	17.02
11. Huntington Canyon	U	5-14	13,300	2.0	0.6	C/L	12.40	0.81	4.00	17.21
12. Kaiparowits	U	12	11,999	6.0	0.87	C/L	10.94	-	2.00	12.94
13. Kolob	S	11	11,700	6.0	2.51	strip	6.39	-	2.00	8.39
14. Salina Canyon	U	10*	11,360	2.0	0.45	C/L	10.94	2.43	2.00	15.37
15. Swisher	U	6-10	12,700	4.0	0.6	C/L	10.94	0.81	3.00	14.75
16. Wasatch Plateau	U	10	12,589	4.0	0.6	C	10.94	0.81	3.00	14.75
17. Wilberg	U	13	12,280	2.2	0.5	C/L	10.94	1.62	3.00	15.56
Wyoming										
1. Evanston	U	9-11	10,450	2.0	0.4	C/L	12.40	2.43	1.00	15.83
2. Kemmerer	S	25	9,683	5.0	0.5	strip	6.39	1.62	-	8.01
3. Powder River	S	20	8,360	5.0	0.5	strip	6.39	1.62	-	8.01
4. Rock Springs	a.U	9-11	9,210	1.5	0.6	C/L	13.86	0.81	-	14.67
	b.S	40	9,210	8.0	0.6	strip	6.39	0.81	-	7.20
Colorado										
1. Yampa	S	25-50	10,598	3.0	0.47	strip	6.51	2.43	1.00	9.94

* = estimates due to poor data

[a] C/L = combination of continuous and longwall techniques

[b] C = continuous mining technique only

Table 7. Range of transport costs for coal per ton mile, 1977 ($/t mi).

	Max. Cost	Min. Cost
Truck	$0.090	$0.065
Rail	0.030	0.018
Slurry	0.035	0.030
Belt	0.07	0.07

Table 8. Estimated electricity costs, price, and net revenue of existing or proposed power plants by HSU for 1977 ($/MWH).

HSU	Plant	Price Average	Average Variable Costs	Average Net Revenue
1	Lucin	21.41	2.56	18.85
	Kelton	21.41	2.56	18.85
4	Gadsby (#1,#2)	21.41	2.77	18.64
	Hale	21.41	3.27	18.14
	Nephi	21.41	2.56	18.85
5	Axtell-Gunnison	21.41	2.56	18.85
	IPP	21.41	2.56	18.85
6	Milford-Black Rock	21.41	2.56	18.85
	Beryl-Lund	21.41	2.56	18.85
7	Moon Lake	21.41	2.56	18.85
8.1	Carbon (#1,#2)	21.41	2.56	18.85
	Helper	21.41	2.56	18.85
8.2	Huntington	21.41	2.56	18.85
	Emery	21.41	3.02	18.39
	Garfield	21.41	2.56	18.85
10	Warner Valley	21.41	2.56	18.85

Table 9. Agricultural pollution abatement methods and costs by HSU for 1977 ($/ton of salt removed).

HSU	Sprinkler Cost	Canal Lining Cost
1	41.91	29.09
2	41.91	29.09
3	41.91	29.09
4	41.91	29.09
5	15.23	21.85
6	15.23	29.09
7.1	33.38	29.09
7.2	61.64	29.09
7.3	8.29	30.75
7.4	21.19	30.75
7.5	15.23	30.75
8.1	72.60	21.85
8.2	10.48	23.04
9	27.41	26.95
10	21.09	30.75

Table 10. SO_2, NO_x, and particulate emissions and control costs per ton removed.

	(Tons/Hour)		$/Ton Removed	
	Max.	Min.	"Acceptable Control"	Maximum Removal
SO_2	0.015	0.0019	$757.00	$770.00
NO_x	0.0056	0.0031		$133.00
Particulates	0.046	0.019		$151.00

were calculated under the assumption that the power plants would operate at only 80 percent of their nameplate capacity to allow for boiler shut-downs. Treatment costs for SO_2 removal depend on site conditions, quantity of sulfur to be removed, plant capacity and whether the system is new or in production. Since the majority of Utah, Wyoming, and Colorado coal has a low sulfur content, the costs per ton removed are fairly high. The few cases of high sulfur content coal found in Utah are adjusted accordingly (Martin 1976; Battelle 1978). NO_x and particulate emissions are also listed in Table 10. Cost per ton of NO_x removal at 20 percent control was estimated to be $133/ton while removal of particulates at 99 percent control was estimated at $151/ton (Glover et al. 1979; Martin 1976).

Matrix A Coefficients

Agriculture

The rotational constraints listed in Keith et al. (1978) were modified to include only those crops currently grown. For instance, sugar beet processing has declined significantly since the closure of the Garland beet processing facility (Decker 1979). The modified rotational constraints are listed in Table 11.

The consumptive use of water by selected crops on a seasonal basis is shown in Table 12. Crop productivity was adjusted seasonally according to these consumption rates. Irrigation efficiency coefficients and agricultural water return flow coefficients (Table 13) for each HSU were obtained from Keith et al. (1978). The irrigation coefficients indicate the percent of water applied to the crops that is consumed on the average by the crops or other vegetation. The return flow coefficients represent the distribution of water that is not consumed by the crop.

As discussed previously, the return flow of water from agriculture generally carries an increased concentration of salinity which increases the salt carried by a region's surface and groundwater. Coefficients used to measure the impact of irrigated agriculture on these water flows (Table 13) were obtained from Glover et al. (1979).

Table 11. Rotational constraints for selected crops in Utah.

1. Alfalfa full + Alfalfa partial ≥ Barley
2. Barley ≥ Nurse crop
3. Alfalfa full + Alfalfa partial ≤ 5 (Nurse crop)
4. Alfalfa full + Alfalfa partial + Barley + Nurse crop ≥ 7 (Corn grain + Corn silage)
5. Mature applies ≥ 2.3 (Nurse apples)
6. Mature peaches ≥ 2.0 (Nurse peaches)
7. Mature sweet cherries ≥ 2.0 (Nurse sweet cherries)
8. Mature sour cherries ≥ 2.6 (Nurse sour cherries)
9. Alfalfa full + Alfalfa partial + Barley + Nurse crop + Corn grain + Corn silage ≥ 30 (Mature apples)
10. Alfalfa full + Alfalfa partial + Barley + Nurse crop + Corn grain + Corn silage ≥ 15 (Mature peaches)
11. Alfalfa full + Alfalfa partial + Barley + Nurse crop + Corn grain + Corn silage ≥ 27 (Mature sweet cherries)
12. Alfalfa full + Alfalfa partial + Barley + Nurse crop + Corn grain + Corn silage ≥ 25 (Mature sour cherries)

Energy

Levels of output and plant efficiencies determine the quantity of energy material that is required. The amount of coal required for a specific coal-fired electrical power plant depends on the heat rate (Btu required per megawatt hour) of the plant and the Btu content of the coal. Existing or proposed power plants have heat rates which varied from 9400 to 12,000 Btu per MWH. Given that each coal has a different Btu content, each power plant was matched with one or more possible coal sources with the appropriate average Btu content by coal source (Anderson 1977, 1979; U.S. Department of the Interior 1975, 1977). The coal feed rate for each plant was determined under the assumption that the plant is operating at 100 percent of nameplate capacity (Perkins 1974; Painter 1974). Any other operating capacity can be found by multiplying these feed rates by the percentage of operation time.

Water requirements for the production of electricity used were 0.1258×10^{-2} acre feet per MWH (Keith et al. 1978).

Emission factors measured in tons per hour per megawatt for each coal source were calculated using a method similar to that employed by Painter (1974), Perkins (1974), and the Federal Energy Administration (1976) (Appendix B). Emission calculations depend on plant heat rates, the Btu content of the coal, the actual chemical composition of the coal, and the plant operating time.

Right-hand Side Values

The right-hand side (RHS) values are those values which serve as limits on the resources within a region.

Water Resources

The total surface water available within a region (net of municipal and industrial requirements) was obtained from King et al. (1972) and Keith et al. (1978). These availabilities were then modified to reflect the seasonal flows which occur throughout the year, as recorded by Utah State University (1968). Regional water flows were further adjusted for existing storage facilities (United States Department of Agriculture 1978b, 1978c). Surface water availabilities for Season 1 (January - June) and Season 2 (July - December) as shown in Table 14 exclude water used in the current production of petroleum (Keith et al. 1978).

Groundwater availability (Keith et al. 1978) was modeled such that any or all pumping could occur in either of the two seasons (Table 14). Finally, wetland requirements and present or new imports (King 1972) were divided equally between the two seasons.

Agricultural Land

The land available in each of four land classes (Table 15) by HSU was obtained from Keith et al. (1978) with an allowance made for potentially irrigable land as well as presently irrigated land. Land class IV included all presently and potentially cultivable land net of present or potentially irrigable land within the optimal solution set in order to allow dry land crops to be grown on any land if unprofitable in other uses. Fruit crops were restricted to present acreages of 630 acres in HSU 1, 1,633 acres in HSU 2, 1,422 acres in HSU 3, 8,021 acres in HSU 4, and 383 acres in HSU 10 (Keith et al. 1978; Utah Department of Agriculture 1978).

Coal Resources

Coal production projections for Utah, Wyoming, and Colorado were obtained from the U.S. Department of the Interior (1975, 1977) and were reduced to account for coal currently committed to other uses such as coking and household use (Table 16). The two levels of coal are related to an accelerated and a more likely mining rate scenario. The levels were used to examine the effects of coal availability. Approximate coal source locations are shown in Figure 5.

Clean Water Resources

Agriculture can have an adverse impact on the quality of the water used in its production processes (Utah State University 1975). It was assumed that a nondegradation restriction on salinity would be imposed.

Table 12. Seasonal consumptive use of water by selected crops in Utah (ac-ft).

HSU	Alfalfa Full Season		Alfalfa Partial Season		Barley Season		Nurse Crop Season		Corn Grain Season		Corn Silage Season		Nurse Apples Season		Mature Apples Season		Nurse Peaches Season		Mature Peaches Season	
	1[a]	2[b]	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	0.62	1.38	0.465	1.035	0.66	0.54	0.88	0.72	0.35	1.05	0.325	0.975	0.8	1.7	1.152	2.448	0.896	1.904	1.248	2.652
2	0.576	1.024	0.36	0.64	0.49	0.21	0.432	0.768	0.286	0.814	0.26	0.74	0.912	1.488	1.33	2.17	1.206	1.674	1.444	2.356
3	0.576	1.024	0.36	0.64	0.49	0.21	0.77	0.33	0.348	0.852	0.319	0.781	0.912	1.488	1.33	2.17	1.206	1.674	1.444	2.356
4	0.72	1.28	0.468	0.832	0.63	0.27	1.05	0.45	0.435	1.065	0.406	0.994	1.026	1.674	1.444	2.356	1.14	1.86	1.596	2.604
5	0.682	1.518	0.341	0.759	0.84	0.36	1.12	0.48	0.435	1.065	0.406	0.994	-	-	-	-	-	-	-	-
6	0.651	1.449	0.465	1.035	0.56	0.44	0.896	0.704	0.375	1.125	0.35	1.05	-	-	-	-	-	-	-	-
7.1	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688	0.40	1.2	0.315	1.125	-	-	-	-	-	-	-	-
7.2	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688	0.40	1.2	0.315	1.125	-	-	-	-	-	-	-	-
7.3	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688	0.40	1.2	0.315	1.125	-	-	-	-	-	-	-	-
7.4	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688	0.40	1.2	0.315	1.125	-	-	-	-	-	-	-	-
7.5	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688	0.40	1.2	0.315	1.125	-	-	-	-	-	-	-	-
8.1	0.672	1.428	0.352	0.748	0.728	0.572	0.896	0.704	0.432	1.168	0.405	1.095	-	-	-	-	-	-	-	-
8.2	0.672	1.428	0.352	0.748	0.728	0.572	0.896	0.704	0.432	1.168	0.405	1.095	-	-	-	-	-	-	-	-
9	0.713	1.587	0.403	0.897	0.784	0.616	1.008	0.792	0.5	1.5	0.475	1.425	-	-	-	-	-	-	-	-
10	1.628	2.072	1.32	1.68	1.305	0.195	1.74	0.26	1.128	1.272	1.081	1.219	1.32	1.68	1.76	2.24	1.496	1.904	1.936	2.464

HSU	N. Sweet Cherries Season		M. Sweet Cherries Season		N. Sour Cherries Season		M. Sour Cherries Season		Alfalfa F. Pasture Season		Alfalfa P. Pasture Season		Barley Pasture Season		N. Crop Pasture Season	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	0.864	1.836	1.216	2.584	0.864	1.836	1.216	2.584	0.62	1.38	0.465	1.035	0.66	0.54	0.88	0.72
2	0.988	1.612	1.406	2.294	0.988	1.612	1.406	2.294	0.576	1.024	0.36	0.64	0.49	0.21	0.432	0.768
3	0.988	1.612	1.406	2.294	0.988	1.612	1.406	2.294	0.576	1.024	0.36	0.64	0.49	0.21	0.77	0.33
4	1.102	1.798	1.558	2.542	1.102	1.798	1.558	2.542	0.72	1.28	0.468	0.832	0.63	0.27	1.05	0.45
5	-	-	-	-	-	-	-	-	0.682	1.518	0.341	0.759	0.84	0.36	1.12	0.48
6	-	-	-	-	-	-	-	-	0.651	1.449	0.465	1.035	0.56	0.44	0.896	0.704
7.1	-	-	-	-	-	-	-	-	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688
7.2	-	-	-	-	-	-	-	-	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688
7.3	-	-	-	-	-	-	-	-	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688
7.4	-	-	-	-	-	-	-	-	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688
7.5	-	-	-	-	-	-	-	-	0.651	1.449	0.341	0.759	0.741	0.559	0.912	0.688
8.1	-	-	-	-	-	-	-	-	0.64	1.36	0.352	0.748	0.672	0.528	0.896	0.704
8.2	-	-	-	-	-	-	-	-	0.64	1.36	0.352	0.748	0.672	0.528	0.896	0.704
9	-	-	-	-	-	-	-	-	0.713	1.587	0.403	0.897	0.784	0.616	1.008	0.792
10	-	-	-	-	-	-	-	-	1.628	2.072	1.32	1.68	1.305	0.195	1.74	0.26

Note: N = Nurse, M = Mature, P = Partial, F = Full.

[a] Season 1: January-June; [b] Season 2: July-December.

Table 13. Irrigation efficiency and agricultural return flow coefficients and salt loading attributable to agriculture by HSU in Utah.

HSU	Irrigation Efficiency Coefficients (%)	To Surface (%)	To Ground (%)	Salt Loading (t/ac ft Return Flow)
1	0.4758	0.4742	0.0500	0.34
2	0.3423	0.6077	0.0500	0.34
3	0.3667	0.5833	0.0500	0.34
4	0.3891	0.5609	0.0500	0.34
5	0.3250	0.6250	0.0500	0.89
6	0.4553	0.4947	0.0500	0.89
7.1	0.3712	0.6288	0.0000	0.78
7.2	0.3712	0.6288	0.0000	0.58
7.3	0.3712	0.6288	0.0000	0.34
7.4	0.3712	0.6288	0.0000	0.34
7.5	0.3712	0.6288	0.0000	0.47
8.1	0.3750	0.6250	0.0000	1.49
8.2	0.3750	0.6250	0.0000	1.09
9	0.2000	0.8000	0.0000	0.58
10	0.5000	0.4500	0.0500	1.26

Table 14. Average seasonal surface water and groundwater availabilities by HSU in Utah.

HSU	Season 1 Jan. - June ac-ft x 10^3	Season 2 July - Dec. ac-ft x 10^3	Ground-water ac-ft x 10^3
1	424.85	188.15	184.00
2	519.37	413.63	94.00
3	445.78	320.06	62.00
4	273.00	265.69	127.00
5	196.60	213.40	335.00
6	41.30	37.70	127.00
7.1	2216.60	1148.80	1.49
7.2	166.74	92.91	6.98
7.3	685.39	360.09	11.65
7.4	314.08	168.81	13.59
7.5	296.85	286.64	6.47
8.1	122.45	79.54	-
8.2	4829.70	1820.20	-
9	1427.70	714.25	-
10	173.49	70.12	10.00

Table 15. Presently (1977) cultivated and potentially cultivable land acreage available by HSU in Utah (acres).

HSU	PILND I	PILND II	PILND III	PILND3P	PCLND IV	POILND I	POILND II	POILND III	POILND3P	POCLND IV
1	3,100	15,300	21,600	2,882	47,600	98,900	487,300	611,000	479,200	1,676,400
2	13,600	75,000	78,400	70,547	246,000	14,900	78,000	68,400	127,700	289,000
3	29,400	51,900	56,200	6,866	169,700	700	8,000	21,800	26,200	56,700
4	17,500	58,900	88,400	14,678	224,600	24,500	92,400	100,600	79,200	296,700
5	-	186,300	85,900	10,500	298,000	-	221,900	308,100	446,000	976,000
6	300	49,300	21,900	4,366	80,000	200	233,500	274,100	344,700	852,500
7.1	-	1,653	2,447	500	4,600	-	16,126	23,873	10,590	38,752
7.2	-	7,257	10,743	3,000	21,000	-	1,420	10,985	7,875	22,818
7.3	-	18,545	27,454	17,000	36,000	-	13,150	19,467	13,957	51,070
7.4	-	10,815	16,010	1,085	42,000	-	16,274	24,091	17,272	63,200
7.5	-	34,470	51,029	14,500	20,000	-	13,184	19,517	13,992	51,200
8.1	-	7,719	9,141	6,400	18,000	-	20,400	22,400	15,800	58,600
8.2	933	19,689	30,887	25,750	62,500	7,000	92,400	96,400	50,000	245,800
9	976	2,050	1,500	4,160	1,900	5,400	132,000	290,000	106,000	533,000
10	3,200	11,900	5,200	620	21,000	7,800	37,600	103,400	95,300	244,100

PILND I = presently irrigated class I land.
PILND II = presently irrigated class II land.
PILND III = presently irrigated class III land.
PILND3P = presently irrigated pasture, class III.
PCLND IV = presently cultivated class IV land.

POILND I = potentially irrigable class I land.
POILND II = potentially irrigable class II land.
POILND III = potentially irrigable class III land.
POILND3P = potentially irrigable pasture, class III.
POCLND IV = potentially cultivable class IV land.

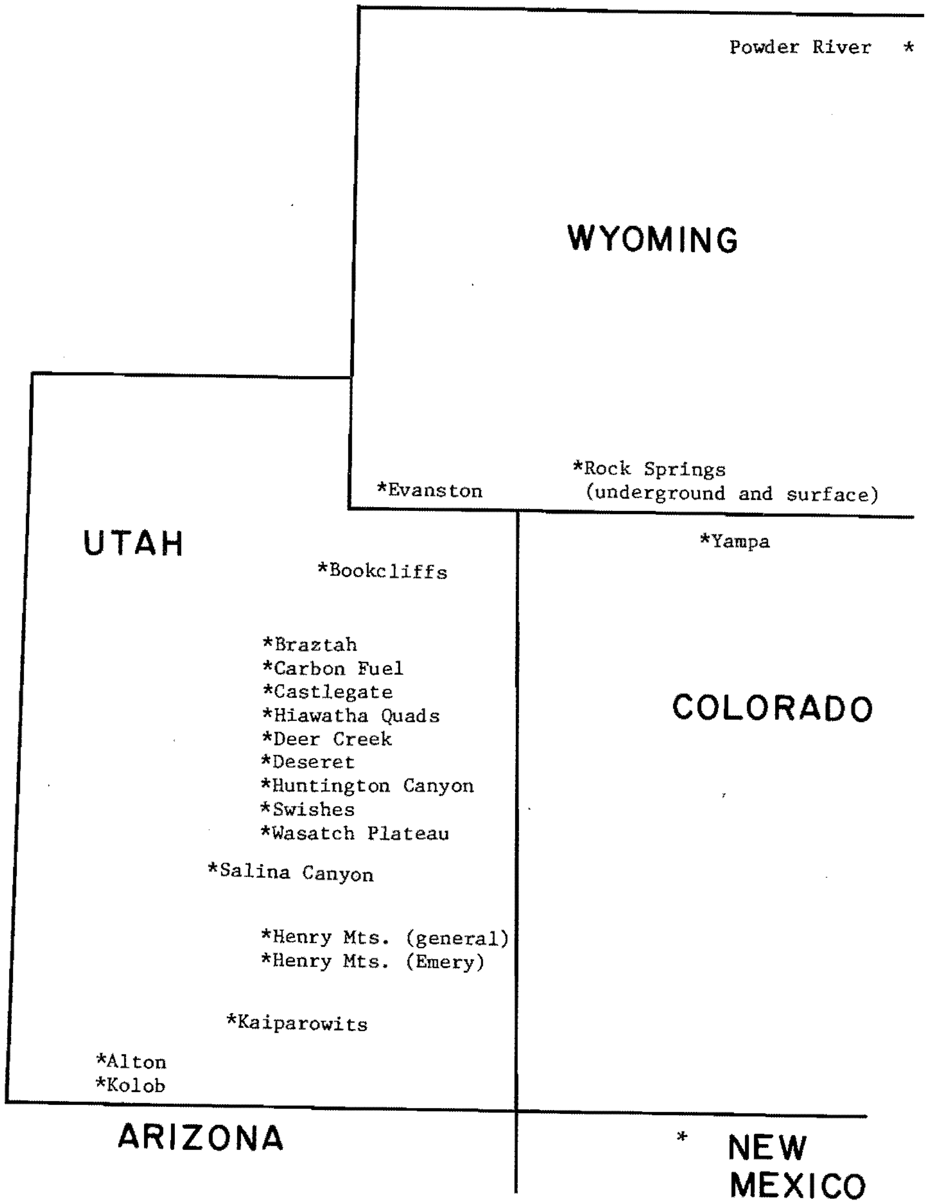


Figure 5. Coal source locations.

That is, salinity concentrations would be allowed to stay at current levels but could not exceed those levels if new irrigated agriculture were developed. These nondegradation limits (expressed in tons/year emitted) were obtained from Glover et al. (1979) as shown in Table 17. The model allowed an increase (decrease) in these limits associated with an increase (decrease) in surface flows.

Clean Air Resources

The coal-fired production of electricity emits substantial quantities of air pollutants. The Environmental Protection Agency (EPA) has established tolerances for particulates and SO_2 (Federal Register 1978) as shown in Table 18. These air quality restrictions were taken into account by utilizing a "limited mixing" atmospheric dispersion model (Wooldridge 1979a). The recent study by Glover et al. (1979) had utilized the concepts of "an air shed carrying capacity" as well as "source to high terrain" limitations.[3] That model employed the following assumptions: 1) the existence of a persistent upper temperature inversion which remained in place for three days; 2) the

---

[3] Limited mixing models project plume characteristics and associated ambient air quality (carrying capacity). High terrain models simulate the air quality degradation which occurs on a high terrain impediment to air flow.

Table 16. Projected coal source capacities.

Coal Source	Projected Coal Source Yearly Capacity (MM tons)	Estimated Coal Sources Capacity for Production of Electrical Power Level 1	Level 2
Alton	9.50	4.00	2.00
Bookcliffs	5.00	2.00	1.00
Braztah	6.50	2.50	1.25
Carbon Fuel	4.00	4.00	2.00
Castlegate	4.00[a]	4.00	2.00
Deer Creek	2.20[a]	2.00	1.00
Deseret	2.00[a]	2.00	1.00
Henry Mts. (E)	4.00[a]	4.00	2.00
Henry Mts. (G)	10.00	10.00	5.00
Hiawatha Quads	2.00	2.00	1.00
Huntington Canyon	2.00	2.00	1.00
Kaiparowits	6.00	6.00	3.00
Kolob	6.00	6.00	3.00
Salina Canyon	2.00	2.00	1.00
Swisher	4.00	4.00	2.00
Wasatch Plateau	4.00	4.00	2.00
Wilberg	2.20	2.20	1.10
Evanston	2.00	2.00	1.00
Kemmerer	5.00	5.00	2.50
Powder River	5.00	5.00	2.50
Rock Springs (A) underground	1.50	1.50	0.75
Rock Springs (B) surface	8.00	4.00	2.00
Yampa	4.00	4.00	2.00
New Mexico	5.9	5.9	5.9

[a] Estimated annual output levels.

Table 17. Salinity loading limits for a nondegradation criterion at outflow of HSU.

HSU	Maximum Salinity Level (tons/tear)
1	21,000
2	21,000
3	21,000
4	21,000
5	36,000
6	36,000
7.1	10,000
7.2	30,000
7.3	51,000
7.4	51,000
7.5	36,000
8.1	36,000
8.2	33,000
9	34,000
10	51,000

Table 18. Maximum allowable increase in effluents measured in micrograms per cubic meter by air quality classifications for 1977.

	Particulates		Sulfur Dioxide		
	Annual Geometric Mean	24-Hour Maximum	Annual Geometric Mean	24-Hour Maximum	3-Hour Maximum
Class I	5	10	2	5	25
Class II	19	37	20	91	512
Class III	37	75	40	182	700

wind speed of 4 knots; and 3) a well-mixed air below the inversion. The limiting air quality factor was based on the 24-hour SO_2 criterion.

This study assumed given power plant locations so that a plume model utilizing the concept of "source to high terrain" would be most effective in determining limitations on power production (Figure 6). Furthermore, the 3-hour SO_2 effluent limit, the most limiting case, has been utilized (Wooldridge 1979b). The discharge of SO_2 was believed to be more restrictive than the discharge of particulates or NO_x throughout most of the state. Particulate control is effective at 95 percent control or better and is not considered a major problem. NO_x control on a commercial level has been limited to only 15 to 20 percent (Martin 1976) and is not expected to be a problem except for the Wasatch Front area which has already been designated as a nonattainment region. A nonattainment area is one in which no additional effluents can be emitted. The extent to which current emissions must be controlled is uncertain at this time.

The model used for the calculation of SO_2 effluent limitations (Appendix C) assumed the plume to be normally distributed with complete reflection at the earth's surface and at the top of a "mixed" layer. This represents a conservative approach (Wooldridge 1979b). Power production restrictions within each air shed were calculated for specific plants and coal sources. The annual maximum tonnage of SO_2 allowed was calculated, as well as SO_2 required to be removed; particulates were assumed to be controlled at the 99 percent level and nitrogen oxides are assumed controlled at the 20 percent level.

Regional Economic Impacts

For each of the four economic regions identified on page 3, a 21 sector input-output table was constructed. The 1972 State of Utah I-O table developed by the University of Utah Bureau of Economic and Business

Research (Bradly 1972) was aggregated to 21 sectors which represent the major activities in the state. These transactions, or flows, were reduced for each sector in each region by the ratio of regional to state employment. For sectors in which no regional employment existed, the sector was eliminated. For sectors for which no specific regional employment was available, a ratio of region to state total employment was used. The four resulting regionalized tables were "balanced" to assure that row and column sums (output and outlays), including value added and final demands, were equal. This mechanical process is known as the RAS method and has been used and documented widely by several U.S. government agencies and other researchers. The regional I-0 tables produced by the RAS method may be inaccurate if regional economics differ significantly with structure from the state table.

Given the limited project budget, a full account of interregional flows was not accomplished. However, for the energy sectors, flows of resources and final products from one region to another were treated as export demands. Use within a given region was not treated as export. Thus, for various electrical generation facilities, that portion of the electrical production which is anticipated to be exported to other Utah regions, or out of the state, was treated as additions to final demand. New crop production was also treated as export activity, although this assumption may not be warranted. These input-output tables are available on request from the writers.

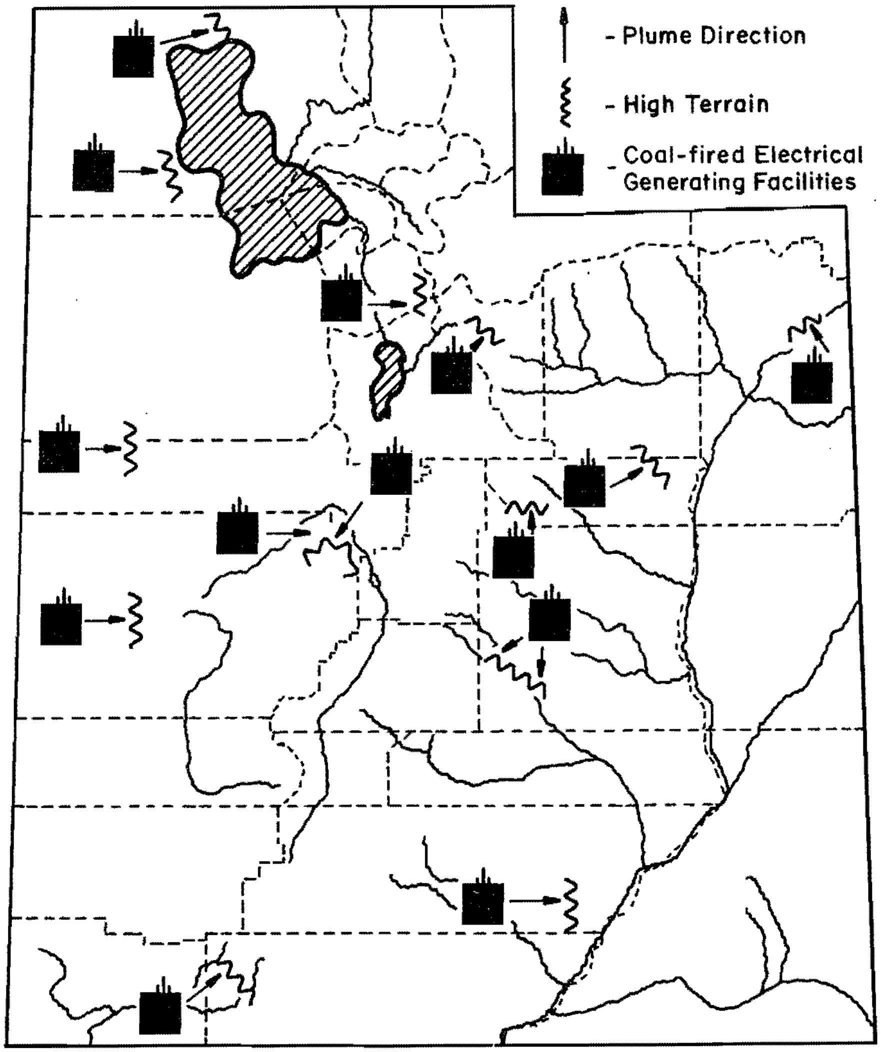


Figure 6. Effluent vectors and impingement points utilized in plume model.

CHAPTER V

RESULTS OF THE ANALYSIS

The Base Model

The base solution includes only current and potential agricultural development given water availabilities net of all other existing energy production and other M and I water use. Total crop acreages for the initial solution (Table 19) were generated for each HSU. These acreages are somewhat larger than the crop land currently existing within the state due to the assumptions and data employed, as discussed in Chapter IV. Alfalfa under full irrigation came into production only in areas of high water availability (HSUs 7.1, 7.2, 7.3, 7.4, and 7.5) or in areas of high profitability (HSU 10). Corn grain failed to enter the solution basis in any HSU. Fruit acreages were limited to the production of apples and peaches. In most regions, corn silage and nurse crops entered the solution at the maximum level allowed by the crop rotation restrictions.

Land classes under production by HSU were distinguished by presently irrigated land (PILND) (Table 20) and potentially irrigable land (POILND) (Table 21) of Class I, II, and III. Where available, land of Class I was always brought into the solution prior to land of Class II or III. Presently irrigated land was brought into production before new land was developed except for land in HSU 7.5. Other than nurse crops, full season crops consistently entered the solution (Table 22) prior to partial season production. Even in areas of restricted water supply, partial season cropping patterns were of limited importance. Minor exceptions were found within HSUs 4 and 6, where half-season alfalfa acreage under partial irrigation nearly equaled full-season partially irrigated alfalfa, and HSUs 8.1 and 10 where half-season barley acreage equaled the acreage under full-season production. Pasture areas entered the solution only in regions of relatively high water availability.

For the base solution, the available (net) water supply was used only in agriculture. The shadow prices of this surface and groundwater on a seasonal basis are shown in Table 23. Water used for agricultural production within HSU 1 represented the highest shadow price and the largest seasonal price variation, i.e. second season water was most constraining in HSU 1. With this exception, the imputed values of seasonal water supplies by HSU were roughly equivalent to those derived from a full season model (Anderson et al. 1973). Present surface water on a seasonal basis and groundwater on an annual basis by HSU were utilized in varying degrees (Table 24). The greatest level of use for both new and present groundwater sources was noted in season 2. The seasonal flows in to the Great Salt Lake or from HSU to HSU showed no unexpected char-

Table 19. Total crop acreages by HSU in base (agriculture only) solution.

HSU	Alfalfa (full)	Alfalfa (partial)	Barley	Nurse Crop	Corn Grain	Corn Silage	Apples	Peaches	Sweet Cherries	Sour Cherries
1	-	4,041	4,041	808	-	1,270	485	144	-	-
2	-	129,924	129,924	25,984	-	40,833	1,633	-	-	-
3	-	60,741	60,741	12,148	-	19,090	1,422	-	-	-
4	-	106,836	106,836	56,793	-	38,638	8,021	-	-	-
5	-	74,096	74,096	14,819	-	23,287	-	-	-	-
6	-	28,437	28,437	5,687	-	8,937	-	-	-	-
7.1	6,918	10,352	17,270	3,454	-	5,356	-	-	-	-
7.2	14,829	2,207	17,036	3,407	-	3,801	-	-	-	-
7.3	33,635	-	33,635	6,727	-	8,577	-	-	-	-
7.4	35,068	-	35,068	7,013	-	6,587	-	-	-	-
7.5	42,933	-	8,586	8,586	-	6,985	-	-	-	-
8.1	-	22,227	22,227	4,445	-	4,445	-	-	-	-
8.2	-	66,637	54,811	13,273	-	19,207	-	-	-	-
9	-	6,498	6,498	1,299	-	2,042	-	-	-	-
10	13,870	-	13,870	2,774	-	5,325	-	-	-	-

Table 20. Presently irrigated (PILND) land under production by Land Class I, II, and III by HSU in base solution (acres).

HSU	PILND I	PILND II	PILND III
1	3,100	-	-
2	13,600	75,000	78,400
3	29,400	51,900	56,200
4	17,500	58,900	88,400
5	-	186,300	-
6	300	49,300	21,900
7.1	-	1,653	2,447
7.2	-	7,257	10,743
7.3	-	18,545	17,454
7.4	-	10,815	16,010
7.5	-	20,000	-
8.1	-	7,719	9,141
8.2	933	19,689	30,887
9	976	2,050	1,500
10	3,200	11,900	5,200

Table 21. Potentially irrigated (POILND) land under production by Land Class I, II, and III by HSU in base solution (acres).

HSU	POILND I	POILND II	POILND III
1	7,690	-	-
2	14,900	78,000	68,400
3	700	8,000	7,943
4	24,500	92,900	35,426
5	-	-	-
6	-	-	-
7.1	-	16,126	22,625
7.2	-	1,420	10,985
7.3	-	13,150	19,467
7.4	-	16,274	24,091
7.5	-	13,184	19,517
8.1	-	20,400	18,626
8.2	7,000	92,400	2,749
9	5,400	6,412	-
10	7,800	8,123	-

acteristics compared to present average conditions.

The salinity levels of the base solution are given in Table 29. The maximum salinity level allowable under the nondegradation assumption of the model was reached in HSUs 1, 5, 7.4, 9, and 10, which in turn limited agricultural development in those HSUs as well as in areas into which their water flowed. For instance, the salinity levels in HSU 9 were a function of salinity levels of each HSU in the Colorado River basin. Sprinkler irrigation (treatment 1) and canal or ditch lining (treatment 2) were used to ameliorate the salinity loading problem. The acreages which came under either treatment are also shown in Table 25. To achieve an optimal solution, almost 600 acres in HSU 5 and 40,000 acres in HSU 7.4 were irrigated with a sprinkler system. Additional ditch lining took place in HSU 1 on almost 8,000 acres.

A sensitivity analysis was performed on the base solution to determine which constraints were most critical on agricultural production. For those HSUs in which currently irrigated and potentially irrigable lands were at their upper bounds, water availabilities and salinity treatment levels were constraining. Crop acreages were affected primarily by the rotational constraints and occasionally salinity treatment levels, particularly in HSU 5. Crop levels in the downstream portion of the Colorado River were limited by salinity levels found in the upstream return flows. For example, crop acreages in HSU 7.1 were adversely affected by salt loading from HSU 7.5. Salinity treatment levels were determined by maximum salinity levels allowable and new water sources.

Table 26 indicates the regional gross output for each economic region for the existing 1977 case, and for the changes in agricultural production indicated by the base model solution. The household sector was treated externally. It is clear that even with substantial changes in irrigated acreages, total economic activity changes relatively little (a total of $31 million or 0.4 percent of state gross output). The implication is that agriculture induces relatively little additional economic activity.

Agriculture and Energy

The energy sectors, coal and electricity generation, were then added to the base agricultural model. Provision for water system development for energy production was made, based on the least-cost water delivery method to each energy activity. In addition, the increased demand for culinary water associated with mines and power plants was included. Electricity was initially assumed to sell in all markets for $21.41. An initial run was made which included the investment costs for developing transmission facilities to each market for each site. The maximum profit site for each market was determined by the model. The investment cost was then shifted to that site's electricity profit constraint, and removed from the profit function. Thus, the variable transmission cost (hookup and wheeling cost) in the objective function for the least-cost site was assumed to be zero. Transmission costs for all other sites were determined by calculating their hookup and wheeling costs to the optimal transmission facilities of the initial maximum profit site. This procedure was followed for each of the alternative constraints analyzed, but no change in least-cost plant occurred. This procedure is

Table 22. Full-season and half-season crops by HSU in the base solution (acres).

HSU	Alfalfa (Full)		Alfalfa (Full) Pasture		Alfalfa (Partial)		Barley		Barley Pasture		Nurse Crop		Nurse Crop Pasture		Corn Grain		Corn Silage	
	Full Season	Half Season	Full Season	Half Season	Full Season	Half Season	Full Season	Half Season	Full Season	Half Season	Full Season	Half Season	Full Season	Half Season	Full Season	Half Season	Full Season	Half Season
1	-	-	-	-	4,041	-	4,041	-	-	-	-	807	-	-	-	-	1,269	-
2	-	-	-	-	129,923	-	129,923	-	-	-	-	25,983	-	-	-	-	40,833	-
3	-	-	-	-	60,191	548	60,740	-	-	-	-	12,146	-	-	-	-	19,089	-
4	-	-	-	-	63,123	43,712	106,835	-	-	-	35,426	21,366	-	-	-	-	42,946	-
5	-	-	-	-	74,096		74,096	-	-	-	-	14,819	-	-	-	-	23,287	-
6	-	-	-	-	15,975	12,461	28,437	-	-	-	-	5,687	-	-	-	-	8,937	-
7.1	6,560	-	357	-	10,352	-	17,198	-	71	-	2,070	1,312	-	71	-	-	5,356	-
7.2	7,060	-	7,767	-	2,207	-	15,483	-	1,553	-	1,852		1,553	-	-	-	3,800	-
7.3	23,664	-	9,969	-	-	-	31,641	-	1,993	-	4,732	-	1,993	-	-	-	8,577	-
7.4	21,954	-	13,112	-	-	-	32,445	-	2,622	-	4,389	-	2,622	-	-	-	8,407	-
7.5	32,938	-	9,994	-	-	-	6,587	-	1,998	-	6,587	-	1,998	-	-	-	6,587	-
8.1	-	-	-	-	22,226	-	11,190	11,036	-	-	-	4,445	-	-	-	-	6,985	-
8.2	-	-	-	-	66,366	-	54,810	-	-	-	-	13,272	-	-	-	-	19,206	-
9	-	-	-	-	5,197	1,250	7,687	-	-	-	27	1,260	-	-	-	-	2,022	-
10	9,535	4,333	-	-	-		7,689	6,180	-	-	137	2,635	-	-	-	-	5,325	-

based on the logic that the maximum profit site will be the first constructed so that transmission facilities will be available to other plants at the hookup and wheeling cost. Given the fixity of investment in the transmission lines, the initial site recovers a return to its fixed investment, rather than experiencing the variable hookup and wheeling charges.

Table 23. Shadow prices of agricultural water availabilities by HSU for 1977 in base solution ($/ac-ft).

HSU	Surface Water		Groundwater
	Season 1	Season 2	Full Season
1	57.56	151.98	89.88
2	29.77	29.77	29.77
3	29.77	29.77	41.30
4	33.20	29.77	29.77
5	13.55	13.55	11.16
6	38.40	38.40	39.23
7.1	4.61	4.61	4.61
7.2	0.64	0.64	0.64
7.3	-	-	-
7.4	-	-	-
7.5	-	-	-
8.1	10.55	10.55	-
8.2	3.49	3.49	-
9	2.60	2.60	-
10	-	-	-

Table 27 indicates electrical production activity associated with the imposition of ambient air standards, and given projected demands of 2000 MW in California, 1500 MW in Utah, 1000 MW in Nevada, and 250 MW in Idaho. The coals used are also listed in Table 27. Given the power production, the only treatment of emissions occurred at the Black Rock (85 percent treatment), Barstow (90 percent level), and Cadiz (90 percent level). Changes in agricultural production were small, where they were indicated at all. Only in HSU 8.2 (south of the Price River basin) were acreages lost, and the only 37 acres of potentially irrigable land were removed from production. Other changes involved reducing the intensity of irrigation of alfalfa from full season to partial season on 403 acres in HSU 4, on 12,424 acres in HSU 6, and on 15 acres in HSU 8.2. In HSU 8.1, barley irrigation was reduced on 2310 acres. These reductions in irrigation were the result of water transfers between the agriculture sector and the energy sector in each HSU. In general, the model indicated that during the early runoff period, sufficient water for energy production and irrigation were available, but in the late season low-water period, water would be transferred from agriculture to energy. However, no new storage was indicated, because the marginal user of water (agriculture) generated less value (net profit) than new water storage development would cost on a per-acre-foot basis. Salinity level increased in HSU 2 to 154,167 tons (a change of 63,975 tons), and in HSU 8.1 to 26,476 (a change of 14 tons). Sprinkling increased by 81 acres to 669 acres in HSU 5, and canal lining increased on 321 acres for a total of 8,268 acres.

Table 24. Presently developed and/or newly developed surface and groundwater to agriculture by HSU in base solution (ac-ft).

HSU	Present Surface Water		Present Groundwater		New Surface Water		New Groundwater	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
1	13,327	-	-	16,846	-	-	-	-
2	392,179	385,560	-	19,000	-	-	-	15,652
3	187,579	139,215	-	32,900	-	-	-	15,996
4	332,382	211,449	28,232	54,967	-	-	-	16,681
5	302,875	123,399	-	-	-	-	35,193	164,613
6	17,068	14,889	63,514	68,019	-	-	-	-
7.1	69,934	94,253	-	-	-	-	-	-
7.2	74,256	105,892	-	-	-	-	-	-
7.3	151,326	220,415	-	-	-	-	-	-
7.4	157,223	228,156	-	-	-	-	-	-
7.5	-	41,305	-	-	120,187	175,098	-	-
8.1	82,181	81,805	-	-	-	-	-	-
8.2	221,163	81,783	-	-	-	190,289	-	-
9	49,971	58,264	-	-	-	-	-	-
10	47,600	20,400	-	-	56,177	36,761	-	-

Table 25. Salinity loading (tons/year) and treatment (acres/year) by HSU in base solution.

HSU	Salinity Levels	Treatment by Sprinkler	Treatment by Lining
1	57,851	-	7,947
2	90,191	-	-
3	66,389	-	-
4	105,417	-	-
5	600,415	588	-
6	80,712	-	-
7.1	19,626	-	-
7.2	-	-	-
7.3	24,630	-	-
7.4	27,676	39,382	-
7.5	17,459	-	-
8.1	26,461	-	-
8.2	261,642	-	-
9	509,600	-	-
10	42,840	-	-

Table 26. Regional gross output by region for the base model.

Region	Regional Gross Output (x 10^6)	
	Without New Ag (1977)	Percent Change With New Ag (Model Solution)
Southeast	51.81	57.35
Southwest	423.42	424.88
Uintah	375.83	381.97
Wasatch Front	7061.01	7078.83
Total	7912.07	7943.03

Regional gross output changed rather drastically in the areas in which new energy was produced, as can be seen in Table 28. It is obvious that new electrical power generation and the associated coal production have much more impact on the regional economies than the increases in irrigated agriculture (about double for most HSUs).

Two alternatives to the initial energy solution were examined, to determine the sensitivity of power plant siting and coal use in the model, as well as regional economic impacts, to air quality constraints. The first alternative was a reduction of allowable emissions by 90 percent. While these numbers are not necessarily commensurate with a regulated 90 percent treatment, they do reflect a much more stringent control of ambient air quality. Table 29 indicates the power production and coals used by each plant under the tighter air standards.

Note that most power production was reduced by the emission factor (90 percent), with the exception of Black Rock. Treatment remained the same for all plants except for Black Rock, Barstow, and Cadiz plants which increased treatment to 95 percent levels. Only these plants were profitable enough to allow treatment at higher intensities.

The reduced generation levels allowed an acreage increase of 25 acres of potentially irrigable land in HSU 8.2. Only 41 acres of alfalfa were reduced to partial season irrigation in HSU 4, which was a 90 percent increase in full season alfalfa. The changes were similar for HSU 6, in which an increase of 8,596 acres of alfalfa on full irrigation was indicated; and HSU 8.2, in which an increase to full irrigation occurred on 15 acres. Barley was increased to full irrigation on 2,295 acres in HSU 8.1.

Table 27. Electricity and coal production for the ambient air standard case.

HSU	Plant	MWH Produced	Face-Plate Capacity (MW)	Mine	Tons/yr
4	Gadsby	77,458	12	Deseret	26,168
	Hale	174,444	25	Salina Canyon	73,605
	Nephi	265,958 (to Nevada)	40	Book Cliffs	83,263
6	Black Rock	8,299,088 (to Utah)	(1185)	Alton	2,000,000
		4,086,714 (to California)	(590)	Book Cliffs	1,663,261
		12,385,802 (total)	1175		
8.1	Helper	70,100	10	Castle Gate	23,445
8.2	Emery	352,545	50	Wasatch Plateau	111,920
	Garfield	286,040	40	Emery	95,347
	Huntington	136,731	20	Huntington Canyon	40,214
California	Barstow	5,017,136	725	Salina Canyon	850,410
				Book Cliffs	270,885
				Gallup (N.M.)	653,325
	Cadiz	4,912,149	700	Gallup	1,846,673

Salinity remained unchanged from the introduction of energy, but sprinkling was reduced on 31 acres in HSU 5, and canal lining was reduced on all the 8,268 acres in HSU 8.1.

Regional gross outputs fell, as might be expected, since the effects of the increase in agricultural profits are small and relatively insignificant compared to the effects of a reduction of output in the energy sector. Table 30 indicates changes in regional gross output from the initial energy.

The final alternative was to examine the effect of an increased price of electricity in California, coupled with the 90 percent reduction in allowable ambient air standards. California sale price was raised to $40 per MWH. Note that, given the model's structure, Colorado basin energy output and the related agricultural production were not affected by the price change because Colorado basin power plants were assumed to provide electricity for Utah, Idaho, and Colorado only. Electrical generation in the Great basin and in the Virgin River basin (HSU 10) were effected. Table 31 lists the power and coal production.

Table 28. Regional gross output by region with energy for ambient air standard solution.

Region	RGO	Change in RGO (x 10^6) From Base Model	Percent Change in RGO (x 10^6)
Southeast	746.42	689.07	1200
Southwest	645.90	221.02	52
Uintah	448.13	66.16	17
Wasatch Front	9,338.35	2,259.52	32
Total	11,178.80	3,235.77	41

The increased sale price of electricity provides sufficient revenue to pay for treatment of effluents by plants selling to California, which, in turn, increases the capacity of power plants to produce for markets which have heretofore not been attractive, such as the increased sale of electricity to Utah. Treatment levels are indicated in Table 32. In fact, six new zones are indicated as coming "on line," including Kelton and Lucin (HSU 1), IPP and Axtell (HSU 5), Lund (HSU 6), and Warner Valley (HSU 10).

Since no changes in generation occurred in the Colorado basin, agricultural production was unchanged as well. No land was taken out of production in HSUs 4, 5, 6, or 10; however, significant changes did occur in the irrigation activity. In HSU 4, a total of 4,580 acres of alfalfa were shifted from partial irrigation for a full season to partial irrigation for the early season, an increase of 4,539 acres from the lower electricity price solution. In HSU 6, an increase of 3,558 acres in partial irrigation from the 90 percent reduction solution is evident. In addition, sprinkling in HSU 5 increases on 22,527 acres to a total of 23,196 acres, and water imports to HSU 5 from HSU 8.1, through the Bonneville Unit of the Central Utah Project increased by approximately 2,000 acre feet. Changes from the 90 percent reduction solution include an increase of HSU 6 by 2,000 tons and a slight decrease of salinity of 4,000 tons in HSU 6.

Table 29. Electrical generation and coal production with 90 percent reduction in allowable emissions.

HSU	Plant	MWH Produced	Face Plate Capacity (MW)	Mine	Tons/yr
4	Gadsby	7,746	1.1	Deseret	2,617
	Hale	174,444	25	Salina Canyon	7,360
	Nephi	26,596 (to Nevada)	3.8	Book Cliffs	6,585
6	Black Rock	3,816,358 (to California)	544	Alton	708,327
				Book Cliffs	416,816
8.1	Helper	7,010	1	Castle Gate	2,344
8.2	Emery	35,255	5	Wasatch Plateau	11,192
	Garfield	28,604	4	Emery	9,534
	Huntington	20,763	3	Huntington Canyon	4,022
California	Barstow	491,215	70	Gallup	184,667
	Cadiz	491,215	70	Gallup	184,667

Regional gross outputs are reported in Table 33. The increased price for electricity in California caused a significant increase in RGO for the Southwest region, as electrical production increases, while the tighter air standards reduced the generation and therefore, RGO in the Southeast region.

Table 30. Regional gross output (x 10^6) and changes from ambient air standards case for 90 percent reduction in allowable emissions.

Region	RGO	Change Due to Tighter Air Quality Standards	Percent Change Due to Tighter Air Quality Standards
Southeast	74.64	- 671.78	-90
Southwest	64.59	- 581.31	-90
Uintah	448.13	0	0
Wasatch	9335.08	3.27	0.03
Total	9922.44	-1249.82	-11.2

Conclusions and Recommendations

Several conclusions can be drawn from these results. First, if air quality is tightly constrained either in terms of ambient air standards or required treatment practices, a higher price of electricity will be required to induce larger scale electrical generation increases. Second, water availability is not a constraint on electrical production, although some decreases in agricultural production might be expected in Utah, particularly in the form of decreased irrigation of crops such as alfalfa. Third, electrical energy production, and the concomitant coal production, will have a very significant impact on the energy rich, but relatively undeveloped subregions of Utah (the Southwest and Southeast regions) with somewhat lesser effect on the other subregions of the state. Fourth, there is a significant trade off between clean air and regional economic development, although increasing demand and higher prices may offset the economic impacts of more stringent air quality standards. Finally, given the structure of the model, no new storage and only very limited interregional water transfers are indicated, because the marginal user (agriculture) does not generate sufficiently high value of marginal product to

Table 31. Electrical and coal production with 90 percent reduction in allowable emissions and \$40.00/MWH price in California.

HSU	Plant	MWH Produced	Face Plate Capacity (MW)	Coal Source	Tons/yr
1	Kelton	398,347 (to Nevada)	(57)	Kemmerer	204,860
		97,416 (to Calif.)	(14)		
		495,763 (Total)	71		
	Lucin	302,597 (to Nevada)	(43)	Kemmerer	159,336
		82,996 (to Calif.)	(12)		
		385,593 (Total)	55		
4	Gadsby	7,746	1.1	Deseret	2,617
	Hale	174,444	25	Salina Canyon	7,360
	Nephi	1,842,538 (to Nevada)	(263)	Hiawatha Quads	711,932
		428,525 (to Calif.)	(61)		
		2,271,063 (Total)	324		
5	IPP (Lynndyl)	6,920,076 (to Utah)	(990)	Book Cliffs	427,433
		4,464,518 (to Nevada)	(640)	Salina Canyon	580,108
		4,641,457 (to Calif.)	(660)	Wasatch Plateau	3,988,808
		16,026,051 (Total)	2290	Rock Springs (surface)	183,790
5	Axtell	3,591,925 (to Utah)	(513)	Salina Canyon	1,412,531
		419,664 (to Calif.)	(60)		
		4,011,589 (Total)	573		
6	Black Rock	5,199,278 (to Calif.)	742	Alton	57,500
				Book Cliffs	1,572,567
	Lund	2,164,235 (to Calif.)	310	Evanston	829,209
10	Warner Valley	5,667	0.8	Alton	1,940
California	Barstow	491,215	70	Gallup	184,667
	Cadiz	491,215	70	Gallup	184,667

compensate for high water development costs. This conclusion, however, neglects political and institutional constraints on water transfers which, if they exist, may cause the energy sectors with their high marginal values of water to develop storage. In addition, only average seasonal flows was used in this study and the effects of low flow years on water allocation was not examined.

Table 32. Treatment levels by plant for $40.00/MWH California price and 90 percent reduction in ambient or allowable emissions standards.

HSU	Plant	Level
1	Kelton	85%
	Lucin	85%
4	Nephi	95%
5	IPP	85%
	Axtell	95%
6	Black Rock	95%
	Lund	95%
10	Warner Valley	70%
California	Barstow	95%
	Cadiz	95%

The study has produced a relatively general model for evaluating the effects of water and air quality standards, water availability, and other coal-fired resource limitations on the development of electrical power plants in Utah. However, several model improvements would make a more refined analysis possible. First, a more complete and accurate assessment of Colorado River basin energy markets and transportation systems should be made. Second, a more sophisticated air quality model which relates locationally specific air quality standards currently extant to allowable emissions should be used for more precise identification of potential sites. Third, coal requirements for electrical production should be modeled to include declining best rate requirement functions. Fourth, the efficiency and costs of salinity treatment activities should be carefully examined. Fifth, storage should be addressed more precisely in the model, with respect to both location and seasonal water availability. Sixth, the stochastic nature of seasonal water availability should be included in the model.

Table 33. Regional gross output (x 10^6) with 90 percent reduction in allowable emissions and $40.00/MWH price change of electricity--California.

Region	RGO	Change from Low Priced 90% Solution	Percent Change from Low Priced 90% Solution	Change from Initial Energy Solution	Percent Change from Initial Energy Solution
Southeast	196.19	121.55	163	-550.23	-73.7
Southwest	1,873.10	1,808.51	2900	1227.2	190
Uintah	448.13	0	0	0	0
Wasatch Front	9,372.61	37.53	6.4	34.26	4.6
Total	11,890.03	1,967.59	19.9	714.5	6.4

SELECTED BIBLIOGRAPHY

Anderson, Mark H., Jay C. Andersen, John E. Keith, and Calvin G. Clyde. 1973. The demand for agricultural water in Utah. Logan, Utah: Utah Water Research Laboratory, Utah State University, PRWG100-4.

Anderson, Orsen L. 1977. Study of alternative locations of coal-fired electric generating plants to supply energy from western coal to the Department of Water Resources. Los Angeles, California: The Institute of Geophysics and Planetary Physics, University of California.

Anderson, Orsen L. 1979. Rocky Mountain coal for Southern California's coal-fired electric power generation. Los Alamos, New Mexico: Los Alamos Scientific Laboratory.

Averch, Harvey, and Leland L. Johnson. 1962. Behavior of the firm under regulatory constraint. American Economic Review. 52(5):1052-1069.

Battelle Columbus Laboratories. 1978. Analysis of variations in costs of FGD systems - Final Report (RP209-2). Palo Alto, California Research Reports Center.

Bishop, A. Bruce, M. D. Chambers, W. O. Mace, and D. W. Mills. 1975. Water as a factor in energy development. Logan, Utah: Utah Water Research Laboratory, Utah State University, PRJER028-1.

Christensen, Lauritis R., Dale W. Jorgenson, and Lawrence J. Lau. 1973a. Transcendental logarithmic production frontiers. Review of Economic Studies. 55(1):28-45.

Christensen, Rondo A., Lynn H. Davis, and Stuart H. Richards. 1973b. Enterprise budgets for farm and ranch planning in Utah. Logan, Utah: Research Report 5, Agricultural Experiment Station, Utah State University.

Cochrane, James L., and Milan Zeleny, Editors. 1973. Multiple criteria decision making. Columbia, South Carolina: University of South Carolina Press.

Council on Environmental Quality. 1976. Environmental quality - 1976. Washington, D.C.: Government Printing Office.

Davis, Lynn H., Rondo A. Christensen, and Max Jensen. 1975. Enterprise budgets for farm and ranch planning in Utah, 1969-73. Logan, Utah: Agricultural Economics Series 75-7, Economics Research Institute, Utah State University.

Decker, Carl. U and I, Incorporated, Salt Lake City, Utah. Interview on March 6, 1979.

Dorfman, Robert. 1951. Application of linear programming to the theory of the firm. Berkeley, California: University of California Press.

Engineering News Record. 1978. Irrigation and hydro cost indexes for the west. 200(12):97.

Federal Energy Administration. 1974. Project independence: Final task force report. Washington, D.C.: Government Printing Office.

Federal Energy Administration. 1976. Coal and electric utility conventions for PIES. Washington, D.C.: Government Printing Office. 13(FEA/N-76/423).

Federal Register. 1974. Air quality classifications. 38(235).

Federal Register. 1978. Prevention of significant air quality deterioration. 43(118).

Fishlow, Albert, and Paul A. David. 1961. Optimal resource allocation in an imperfect market setting. Journal of Political Economy. 69(6):529-546.

Finney, Brad, William J. Grenney, A. Bruce Bishop, and Trevor C. Hughes. 1977. Mixed integer programming models for water resources management. Logan, Utah: Utah Water Research Laboratory, Utah State University, PRWG198-1.

Frontier Transport, Salt Lake City, Utah. Interview with company personnel on March 12, 1979.

Glover, Terrence F., John E. Keith, W. Cris Lewis, and Gene Wooldridge. 1979. The economics of energy development - environmental quality trade-offs. Socioeconomic Impacts of Energy in Utah. Draft Final Report of the Utah Consortium of Energy Resource Education submitted to U.S. Department of Energy.

Hanks, John R., Rex F. Nielson, Lyman S. Willardson, Raymond L. Cartee, Steven E. Ging, and Paul McNeil. 1978. Potential for using waste water from electrical power plants for irrigation. Report prepared for Utah Power and Light Company. Logan, Utah: Utah State University.

Hanks, John R., Lyman S. Willardson, Rex F. Nielson, Raymond L. Cartee, and Steven E. Ging. 1977. Potential for using waste water from electrical power plants for irrigation. Report prepared for Utah Power and Light Company. Logan, Utah: Utah State University.

Hicks, J. R. 1939. Value and capital. London: Oxford University Press.

Hsiao, Frank S. T. 1971. The contract curve and the production possibility curve. Journal of Political Economy. 79(4): 919-923.

Johnson, Harry G. 1966. Factor market distortions and the shape of the transformation curve. Econometrica. 34(3): 686-698.

Keith, John E. 1973. The economic efficiency of inter-basin transfers of agricultural water in Utah: A mathematical programming approach. Unpublished Dissertation, Department of Economics, Utah State University, Logan, Utah.

Keith, John E., Jay C. Andersen, Alton B. King, Mark H. Anderson, Thomas C. Anderson, Calvin G. Clyde, and Daniel H. Hoggan. 1973. Interregional planning of water resources applications by systems analysis approach: A summary report. Logan, Utah: Utah Water Research Laboratory, Utah State University, PRWG100-5.

Keith, John E., Trevor C. Hughes, and Daniel H. Hoggan. 1977. The Virgin River Basin study: A regional approach to multiobjective planning for water and related resources. Logan, Utah: Utah Water Research Laboratory, Utah State University, PRWG146-1.

Keith, John E., K. S. Turna, Sumol Padunchai, and Rangesan Narayanan. 1978. The impact of energy resource development on water resource allocations. Logan, Utah: Utah Water Research Laboratory, Utah State University, UWRL/P-78/05.

King, Alton B. 1972. Development of regional supply functions and a least-cost model for allocating water resources in Utah: A parametric linear programming approach. Unpublished Dissertation, Department of Civil Engineering, Utah State University, Logan, Utah.

King, Alton B., Jay C. Andersen, Calvin G. Clyde, and Daniel H. Hoggan. 1972. Development of regional supply functions and a least-cost model for allocating water resources in Utah: A parametric linear programming approach. Logan, Utah: Utah Water Research Laboratory, Utah State University, PRWG100-2.

Kraus, Melvin B., Harry G. Johnson, and Thanos Skouras. 1973. On the shape and location of the production possibilities curve. Economica. 40(August):305-310.

Kuhn, H. W., and A. Tucker. 1951. Nonlinear programming. In: Proceedings of the Second Berkeley Symposium of Mathematical Statistics and Probability. Edited by J. Neyman. Berkeley, California: University of California Press.

Lewis, W. Cris, Jay C. Andersen, Delworth B. Gardner, Terry F. Glover, Bartell C. Jensen, John E. Keith, and H. Craig Petersen. 1977. Macroeconomic effects of coal and oil shale development in the intermountain west. Logan, Utah: Economics Department, Utah State University Foundation.

Los Angeles Department of Water and Power. 1976. Intermountain Power Project: Preliminary engineering and feasibility study. City of Los Angeles, California, Volume 2, Part 1.

Martin, Patrick J. 1976. Effects of environmental regulations on energy cost, use, and availability. Part II: Emission control technology discussions. Menlo Park, California: Stanford Research Institute, Project 5326.

Mauer, William A., and Thomas H. Naylor. 1964. Monopolistic-monopsonistic competition: The multi-product, multifactor firm. Southern Economic Journal. 31(July):38-43.

Melvin, James R. 1968. Production and trade with two factors and three goods. American Economic Review. 58(5):1249-1268.

Melvin, James R. 1971. On the derivation of the production possibilities curve. Economica. 38(August):287-294.

Morris, Glen E. 1977. An optimization model of energy related economic development in the Upper Colorado River Basin under conditions of water and energy resource scarcity. Los Alamos, New Mexico: Los Alamos Scientific Laboratory, LA-6732-T.

Naylor, Thomas H. 1965. A Kuhn-Tucker model of the multi-product, multi-factor firm. Southern Economic Journal. 31(October): 650-658.

Naylor, Thomas H. 1966. The theory of the firm: A comparison of margianl analysis and linear programming. Southern Economic Journal. 32(January):263-274.

Painter, Dean E. 1974. Air pollution technology. Reston, Virginia: Reston Publishing Company.

Perkins, Henry E. 1974. Air pollution. New York: McGraw-Hill Book Company.

Pfouts, Ralph W. 1961. The theory of cost and production in the multi-product firm. Econometrica. 29(4):650-658.

Olsen, Gordon. Savage Bros., Inc., American Fork, Utah. Interview on March 12, 1979.

Scarth, William M., and Robert D. Warne. 1973. The elasticity of substitution and the shape of the transformation curve. Economica. 40(August):299-304.

Science and Public Policy Program. 1975. Energy alternatives: A comparative analysis. Norman, Oklahoma: University of Oklahoma.

Stewart, Douglas B. 1971. Production indeterminacy with three goods and two factors: A comment on the pattern of trade. American Economic Review. 61(1):241-244.

Stradley, Scot Arthur. 1977. Human resource implications of the production process in underground bituminous extraction, especially for Utah. Unpublished Dissertation, Department of Economics, University of Utah, Salt Lake City, Utah.

Union Pacific Railroad. 1979. Response letter from the Department of Traffic Marketing. April 20, 1979.

U.S. Department of Agriculture. 1969a. Agricultural incomes and the impacts of potential development: Sevier River, Utah. Salt Lake City, Utah: Economic Research Service.

U.S. Department of Agriculture. 1969b. Water and related land resources: Sevier River Basin, Utah. Salt Lake City: Economic Research Service.

U.S. Department of Agriculture. 1978a. Agricultural prices annual summary. Washington, D.C.: Government Printing Office.

U.S. Department of Agriculture. 1978b. Utah farm report. Salt Lake City, Utah: Economics, Statistics, and Cooperatives Service. (May 1-12).

U.S. Department of Agriculture. 1978c. Utah farm report. Salt Lake City, Utah: Economics, Statistics, and Cooperatives Service. (January 1-12).

U.S. Department of Commerce. 1974. 1974 census of agriculture. Washington, D.C.: Government Printing Office.

U.S. Department of Commerce. 1978. Statistical abstract of the United States. Washington, D.C.: Government Printing Office.

U.S. Department of Energy. 1978a. Monthly report: Cost and quality of fuels for electric utility plants, DOE/EIA-0075/3(78). Washington, D.C.: Government Printing Office.

U.S. Department of Energy. 1978b. Steam-electric plant construction cost and annual production expenses 1977, DOE/EIA-0033/3(77).

U.S. Department of Energy. 1979a. Basic estimated capital investment and operating costs for underground bituminous coal mines utilizing a continuous mining system, FE/EES-79/1. Washington, D.C.: Government Printing Office.

U.S. Department of Energy. 1979b. Basic estimated capital investment and operating costs for subbituminous and lignite coal strip mines (Preliminary Report). Washington, D.C.: Government Printing Office.

U.S. Department of the Interior. 1976a. Basic estimated capital investment and operating costs for underground bituminous coal mines developed for longwall mining, IC8715. Washington, D.C.: Government Printing Office.

U.S. Department of the Interior. 1976b. Basic estimated capital investment and operating costs for underground bituminous coal mines developed for longwall mining IC8720. Washington, D.C.: Government Printing Office.

U.S. Department of the Interior. 1976c. Fuels and energy data: United States by States and Census Divisions - 1973, IC8722. Washington, D.C.: Government Printing Office.

U.S. Department of the Interior. 1977. A listing of proposed, planned, or under construction energy projects in federal region III, IC8772. Washington, D.C.: Government Printing Office.

Utah Department of Agriculture. 1978. Utah agricultural statistics. Salt Lake City, Utah: State of Utah, Department of Agriculture.

Utah Division of Public Utilities. 1979. Response letter from Carl L. Mower, Assistant Manager of Accounts and Finance. April 13, 1979.

Utah Division of Water Resources. 1978. The State of Utah water - 1978. Salt Lake City, Utah: Department of Natural Resources.

Utah State Engineer, Water Division. 1962. Water consumption in Utah. Salt Lake City, Utah: Office of the State Engineer.

Utah State University. 1975. Colorado River - regional assessment study. Prepared for the National Commission on Water Quality Logan, Utah.

Utah State University - Utah Division of Water Resources. 1968. Hydrologic atlas of Utah. Logan, Utah: Utah Water Research Laboratory, PRWG40-5.

Vanek, Jaroslav, and Trent J. Bertrand. 1971. Trade and factor prices in a multi-commodity world. In: Trade, Balance of Payments and Growth. Edited by Jagdish Bhagwati, Ronald Jones, Robert Mundell and Jaroslav Vanek. New York: American Elsevier Publishing Company, Inc.

Vlandy, T. A. United States Fuel Company. 1979. Interview on March 14, 1979.

Wooldridge, Gene L. 1979a. Mapping of coal-fired electrical power generation potential in the Great Basin Region of Utah. Prepared for the Utah Consortium for Energy Research Education. Logan, Utah: Department of Soil Science and Biometeorology, Utah State University.

Wooldridge, Gene L. 1979b. Power plant operation under effluent restrictions. Prepared by Donald L. Snyder and John E. Keith under Project JER-047, Power Plant Siting. Logan, Utah: Department of Soil Science and Biometeorology, Utah State University.

APPENDIX A

AGRICULTURE MATRIX VARIABLE NOTATION

i = land class
r = HSU
( ) = variable numerical values other than integers

Rows

TALFAFr = total alfalfa (full) acreage
TALFAPr = total alfalfa (partial) acreage
TBARLYr = total barley acreage
TNURSECr = total nurse crop acreage
TCORNGr = total corn grain acreage
TCORNSr = total corn silage acreage
TAPPLEr = total apple acreage
TPEACHr = total peach acreage
TSTCHr = total sweet cherry acreage
TSRCHr = total sour cherry acreage
FRUITACr = total fruit acreage
PILNDir = presently irrigated land
PCLNDir = presently cultivated land
ROTABr = alfalfa and barley rotation
ROTBNr = barley and nurse crop rotation
ROTANri = alfalfa and nurse crop rotation
ROTCr = corn rotation
ROTNAPPir = nurse apple rotation
ROTNPEir = nurse peach rotation
ROTNSTir = nurse sweet cherry rotation
ROTNSRir = nurse sour cherry rotation
ROTMAPP = mature apple rotation
ROTMPEA = mature peach rotation
ROTMSTC = mature sweet cherry rotation
ROTMSRC = mature sour cherry rotation
AGWRQ1r = season 1 agricultural water requirement
AGWRQ2r = season 2 agricultural water requirement

Columns

ALFFir = full-season alfalfa (full) acreage
ALF1ir = partial-season alfalfa (full) acreage
ALPFir = full-season alfalfa (partial) acreage
ALP1ir = partial-season alfalfa (partial) acreage
BRLFir = full-season barley acreage
BRL1ir = partial-season barley acreage
NRCFir = full-season nurse crop acreage
NRC1ir = partial-season nurse crop acreage
CRNGFir = full-season corn grain acreage
CRNG1ir = partial-season corn grain acreage
CRNSFir = full-season corn silage acreage
CRNS1ir = partial-season corn silage acreage
DBEANSir = dry bean acreage
DWHEATir = dry wheat acreage
NAPPLir = nurse apple acreage
NPEACir = nurse peach acreage
NSTCHir = nurse sweet cherry acreage
NSRCHir = nurse sour cherry acreage
MAPPLir = mature apple acreage
MPEACir = mature peach acreage
MSTCHir = mature sweet cherry acreage
MSRCHir = mature sour cherry acreage

	Agriculture Sector											
	ALFFir	ALFlir	ALPFir	ALPLir	BRLFir	BRLlir	NRCFir	NRClir	CRNGFir	CRNGlir	CRNSFir	CRNSlir
Profit	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()
TALFAFr	1	1										
TALFAPr			1	1								
TBARLYr					1	1						
TNURSCr							1	1				
TCORNGr									1	1		
TCORNSr											1	1
TAPPLEr												
TPEACHr												
TSTCHr												
TSRCHr												
FRUITACr												
PILNDir	1	1	1	1	1	1	1	1	1	1	1	1
PCLNDir	1	1	1	1	1	1	1	1	1	1	1	1
ROTABr	1	1	1	1	-1	-1						
ROTBNr					1	1	-1	-1				
ROTANri	1	1	1	1			-5	-5				
ROTCr	1	1	1	1	1	1	1	1	-7	-7	-7	-7
ROTNAPir												
ROTNPEir												
ROTNSTir												
ROTNSRir												
ROTMAPPr												
ROTMPEAr												
ROTMSTCr												
ROTMSRCr												
AGWRQ1r	()	()	()	()	()	()	()	()	()	()	()	()
AGWRQ2r	()		()		()		()		()		()	

	DBEANSir	DWHEATir	NAPPLir	NPEACir	NSTCHir	NSRCHir	MAPPLir	MPEACir	MSTCHir	MSRCHir	Row Type
Profit	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	+/-()	N
TALFAFr											N
TALFAPr											N
TBARLYr											N
TNURSECr											N
TCORNGr											N
TCORNSr											N
TAPPLEr			1				1				N
TPEACHr				1				1			N
TSTCHr					1				1		N
TSRCHr						1				1	N
FRUITACr			1	1	1	1	1	1	1	1	L
PILNDir	1	1	1	1	1	1	1	1	1	1	L
PCLNDir	1	1	1	1	1	1	1	1	1	1	L
ROTABr											G
ROTBNr											G
ROTANri											L
ROTCr											G
ROTNAPir			-2.3				1				E
ROTNPEir				-2				1			E
ROTNSTir					-2				1		E
ROTNSRir						-2.6				1	E
ROTMAPPr							-30				G
ROTMPEAr								-15			G
ROTMSTCr									-27		G
ROTMSRCr										-25	G
AGWRQ1r			()	()	()	()	()	()	()	()	E
AGWRQ2r			()	()	()	()	()	()	()	()	E

ADDITIONAL MATRIX VARIABLE NOTATION FOR AGRICULTURE WATER/TREATMENT SECTOR

Rows

ARF1rTk = season 1 return flow
ARF2rTk = season 2 return flow
SWAVL1r = surface water available in season 1
SWAVL2r = surface water available in season 2
GWAVILr = groundwater available
WTLRQ1r = wetland requirement in season 1
WTLRQ2r = wetland requirement in season 2
PSWAE1r = present surface water to agriculture and energy in season 1
PSWAE2r = present surface water to agriculture and energy in season 2
PGWAEr = present groundwater to agriculture and energy
PMA1rTk = present imports in season 1
PMA2rTk = present imports in season 2
NM1rTk = new imports in season 1
NM2rTk = new imports in season 2
EVLOSSr = evaporation loss
CHSWOFr = change of surface water outflow
TWTLRQGr = total wetland requirements met from ground source
NDIUCrE = total consumptive use
OUTFrL = total water outflow
RAGSLTr = gross salt loading
RNSLTr = net salt loading
MAGSLTr = maximum salt loading allowable

Columns

PSWAGr = present surface water to agriculture
NSWAGr = new surface water to agriculture
PGWAGr = present groundwater to agriculture
NGWAGr = new groundwater to agriculture
PIArTk = present imports to agriculture
NIArTk = new imports to agriculture
WTLRSr = wetland requirements met from surface source
WTLRGr = wetland requirements met from ground source
OFSWrTk = outflow of surface water
AWRFk = agricultural water return flow
EVLFCAGr = agricultural evaporation from canals
CUROFr = current outflow
CHOFSWr = change of surface water outflow
AGSLTr = gross salt loading
T1SLTr = salinity treatment 1
T2SLTr = salinity treatment 2
NTSLTr = net salt loading

ENERGY MATRIX VARIABLES

i = mine source
j = power plant
r = HSU
k = treatment
s = state
( ) = variable numerical values other than integers

Rows

EWRQr = energy water requirement
AMWRr = augmented municipal water requirement for energy
CPCLir = coal source capacity
FLCRir = flow of coal
CCSTir = cost of coal
CLEQir = coal (equality)
SCEQir = sell coal (equality)
CPELjr = plant capacity
CCij = coal conversion factor
SELRjr = sell electricity row
RSijr = gross SO_2 emissions
RNijr = gross NO_x emissions
RPijr = gross particulate emissions
NSijr = net SO_2 emissions
NNijr = net NO_x emissions
NPijr = net particulate emissions
MJSijr = maximum level of SO_2 allowable
MJNijr = maximum level of NO_x allowable
MJPijr = maximum level of particulate allowable

Columns

sCMir = coal mined
CMir = coal for sale
CTirjr = coal transported
CEirjr = coal transported to electricity
Elijr = electricity produced
SELjr = electricity sold
PSWENr = present surface water to energy
NSWENr = new surface water to energy
PGWENr = present groundwater to energy
NGWENr = new groundwater to energy
PIErTk = present imports to energy
NIErTk = new imports to energy
AUMWENr = augmented municipal water requirement for energy
ELSijr = gross SO_2 emissions
ELNijr = gross NO_x emissions
ELPijr = gross particulate emissions
ENSijr = net SO_2 emissions
ENNijr = net NO_x emissions
ENPijr = net particulate emissions
TkSijr = treatment k for SO_2
TkNijr = treatment k for NO_x
TkPijr = treatment k for particulates

	Water Sector for Agriculture													
	Crops	Season 1,2 PSWAGr	Season 1,2 NSWAGr	Season 1,2 PGWAGr	Season 1,2 NGWAGr	Season 1,2 PIArTk	Season 1,2 NIArTk	Season 1,2 WTLRS	Season 1,2 WTLRG	Season 1,2 OFSWrTk	Season 1,2 AWRFkr	EVLFCAGr	CUROFr	CHOFSWr	Row Type
Profit	+/-()	-()	-()	-()	-()	-()	-()								N
AGWRQ1r	+()	-()	-()	-()	-()	-()	-()	1							E
AGWRQ2r	and/or +()	-()	-()	-()	-()	-()	-()	1							E
ARF1rTk		()	()	()	()	()	()				-1				E
ARF2rTk		()	()	()	()	()	()				-1				E
SWAVL1r		()	()			()	()			(+/-)1	-1				E/L
SWAVL2r		()	()			()	()			(+/-)1	-1				E/L
GWAVLr				1	1				1						L
WTLRQ1r								1	1						E
WTLRQ2r								1	1						E
PSWAE1r		1													L
PSWAE2r		1													L
PGWAEr				1											L
PMA1rTk						1									L
PMA2rTk						1									L
NM1rTk							1								L
NM2rTk							1								L
EVLOSS		()	()			()						-1			E
CHSWOFr										-1			1	-1	E
TWTLRQGr									1						L
NDIUCrE						1	1								E
OUTFrL										()					G

	Salinity Loading/Treatment Sector						
	Season 1,2 AWRFr	CHOFSWr	AGSLTr	T1SLTr	T2SLTr	NTSLTr	Row Type
Profit				-()	-()		N
RAGSLTr	()		-1				E
RNSLTr		()	1	-1	-1	-1	E
MAGSLTr						1	L

	Energy Sector						
	sCMir	CMir	CTirjr	CEirjr	ELijr	SELjr	Row Type
Profit	-()	()	-()	-()	-()	()	N
EWRQr	0.00005				0.00126		E
AMWRr	$7.75\text{x}10^{-9}$				$9.436\text{x}10^{-8}$		E
CPCLir	1						L
FLCLir	-1		1				E
CCSTir			-1	1			E
CLEQir	-1	1					E
SCEQir	1		-1				E
CPELjr					1		L
CCirjr			()		-1		E
SELRjr					-1	1	E

	Water Sector for Energy							
	Season 1,2 PSWEN_r	Season 1,2 NSWEN_r	Season 1,2 PGWEN_r	Season 1,2 NGWEN_r	Season 1,2 PIErTk	Season 1,2 NIErTk	AUMWEN_r	Row Type
Profit	-()	-()	-()	-()	-()	-()		N
SWAVL1r	1	1			()	()		E/L
SWAVL2r	1	1			()	()		E/L
GWAVLr			1	1				L
PSWAE1r	1							L
PSWAE2r	1							L
PGNAEr			1					L
PMA1rTk					1			L
PMA2rTk					1			L
NM1rTk						1		L
NM2rTk						1		L
EWRQr	-1	-1	-1	-1	-1	-1		E
AMWRr							-1	E
NDIUCrE	1	1			1	1		E

	Energy Pollution/Treatment Sector										
	ELijr	ELSijr	ELNijr	ELPijr	ENSijr	ENNijr	ENPijr	TkSijr	TkNijr	TkPijr	Row Type
Profit	-()							-()	-()	-()	N
RSijr	()	-1									E/G
RNijr	()		-1								E/G
RPijr	()			-1							E/G
NSijr		1			-1			-1			E
NNijr			1			-1			-1		E
NPijr				1			-1			-1	E
MJSijr					1						L
MSNijr						1					L
MJPijr							1				L

APPENDIX B

CALCULATION OF COAL FEED RATES AND EMISSION FACTORS

The Calculation of a Coal Feed Rate

The calculation of a coal feed rate requires information concerning the plant heat rate and the Btu content of the fuel. The formula used to calculate the coal requirement of a plant is:

$$\text{Feed rate in tons per hour per megawatt (MW)} = \text{FRtph}$$

$$= \frac{(1\text{x}10^6 \text{ watts/MW}) \times 3.41152815 \text{ Btu's/watt}}{\text{TEF/hr.} \times \text{Btu's/lb.} \times 2000 \text{ lbs./ton}}$$

where

TEF = thermal efficiency factor calculated as

$$= \frac{3412}{\text{plant heat rate}}$$

and

Btu/lb. varies by coal source

The Calculation of Pollution

$$\text{1. Particulates in tph/MW} = \frac{(\text{emission}) \times (\text{\% ash/lb.}) \times \text{FRtph factor}^{a}}{2000 \text{ lbs.}}$$

[a] Emission factors vary as boiler types vary, but some common factors are:

General boiler = 16
Wet bottom boiler = 13
Dry bottom boiler = 17
Cyclone boiler = 2

$$\text{2. } SO_2 \text{ emissions in tph/MW} = \frac{(38) \times (\text{\% sulfur/lb.}) \times \text{FRtph}}{2000 \text{ lbs.}}$$

$$\text{3. } NO_x \text{ emissions in tph/MW} = \frac{(\text{emission factor}^{b}/\text{lb.}) \times \text{FRtph}}{2000 \text{ lbs.}}$$

[b] Some common emission factors are:

General boiler = 18
Wet bottom boiler = 30
Dry bottom boiler = 17
Cyclone boiler = 55

APPENDIX C

PLUME MODELING

The purpose of plume modeling is to measure the concentration of an effluent discharged in a continuous stream. Factors affecting the results of a modeling attempt include the turbulence of the atmosphere, the height the effluent is released, the surface roughness, the wind speed and distance from the emissions source.

The model used in the calculation of the SO_2 concentrations found in this study was a limited mixing model (Wooldridge 1979b). The plume was assumed to be normally distributed with complete reflection at both the earth's surface and the inversion layer. Since some mixing or attachment would normally be expected to occur, this model represents a conservative approach. The inversion layer was expected to be fairly stable. Distance from the emissions source to the nearest class I or class II air quality zone was calculated. The inversion layer was assumed to be 350 meters above the earth's surface. The actual model appeared as

$$X \text{ point} = \frac{Q}{2\Pi \; \mu \; \sigma_y \sigma_z} g_1 g_2$$

where

X point = concentration at the receptor point
Q = uniform emission rate of pollutants
y = line perpendicular to direction of plume flow
z = vertical extension of emission's source
μ = wind speed
H = effective emissions height
$g_1 = \exp \{-\frac{1}{2} (y/\sigma y)^2\}$

$$g_2 = \sum_{n=-4}^{+4} \{\exp \left|-\tfrac{1}{2}(\frac{Z-H}{\sigma_Z})^2\right| + \exp \left|-\tfrac{1}{2}(\frac{Z+H+2nL}{\sigma_Z})\right|\}$$

L = thickness of mixing surface layer
n = index number representing the reflection at the earth's surface and the inversion layer