THE SOCIAL EFFECTS OF RESOURCE DECISIONS: A MODELING APPROACH

by

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I hereby recommend that this dissertation prepared under my direction by Eric Benjamin Oswald

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be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

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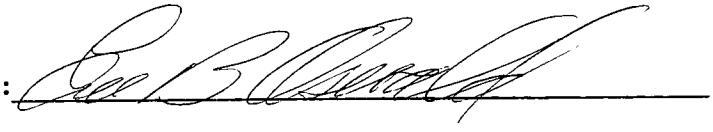
SIGNED: 

PREFACE

Research presented in this dissertation was developed within a two-year team project of the Civil Decision Quantification Program in the Department of Hydrology and Water Resources at The University of Arizona. The program is funded by the Ford Foundation to develop individuals who are capable of integrating many disciplines into civil decision processes and to apply innovative techniques which take advantage of available analytic and computational tools in considering alternative courses of action.

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Emory Sekaquaptewa, J. D., a Hopi and Assistant Professor of Anthropology and Coordinator of Indian Programs at The University of Arizona served as our co-researcher for the model of the Hopi Tribe and contributed a great deal of information and guidance to this research effort through consultation and guided field research. Dr. Samuel W. Billison, a Navajo and former member of the Navajo Tribal Government

served as a co-researcher for the Navajo social model. Dr. Billison provided both information and interpretive expertise for the research.

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ABSTRACT

Coal-fueled energy development in the Southwest has resulted in a controversy over claims of environmental damage and spiritual and social disruption to the Native American inhabitants of the region. Development has been supported through estimates of the economic benefits that will accrue to the Hopi and Navajo through the planned development. This research has developed a modeling approach to systematically and rationally assess the impacts of energy development on the Hopi and Navajo Tribes.

The model incorporates a simulation technique that describes the Indian social systems over time with and without energy development. The variations within the system without energy development and with various levels of development allow insights into impacts. Computer control allows the model to consider many different decisions relative to energy development, and incorporated graphics allow for efficient and fast impact interpretation.

The results of the model indicate that proposed impacts on the Native Americans have been exaggerated. Neither the economic impacts nor spiritual disruptions claimed are seen to occur. The model is seen to be a valuable tool for systematic analysis and the presentation of social impact information.

CHAPTER 1

INTRODUCTION

Problem Background

Projections of future energy demands, constrained by technical and economic problems of alternative energy sources, have resulted in the development and planned future development of coal-fueled power generating plants in the Colorado Plateau region of the Southwest (Table 1). These power generating facilities and their associated mines, roads, power transmission lines, etc., are having and will continue to have a wide range of impacts upon the environment and people of the region.

Environmental groups have publicly announced their concern for the impacts of this power development on the physical environment. Native American traditionalists and supporting Anglo groups have denounced some existing and planned facilities for their disruptive effects and encroachment on areas of spiritual significance to Native Americans. The Department of the Interior considered the possible effects of power development in this region to be significant enough to conduct extensive research and publish the multi-volumed Southwest Energy Study (U. S. Department of Interior, 1972).

The situation created by existing facilities and planned development and the recommendations of the Southwest Energy Study for further research provided the problem setting for a multi-disciplinary research project. The project considered the effects of coal-fueled energy

Table 1. Decision Space.

Power Plants	Units	Megawatt Capacity
Existing Plants		
1. Four Corners	(1 - 5)	2,085
2. Mohave	(1 - 2)	1,580
3. Cholla	(1)	120
4. San Juan	(2)	345
Plants Under Construction		
5. Huntington Canyon	(1)	430
6. Navajo	(1 - 3)	2,310
7. San Juan	(1)	345
8. Cholla	(2 - 3)	500
Proposed Plants		
9. San Juan	(3)	500
10. Huntington Canyon	(2)	430
11. Southern Nevada	(1 - 2)	1,600
12. Kaiparowits	(1)	1,000
13. Kaiparowits	(2)	1,000
14. Kaiparowits	(3)	1,000
TOTAL		13,245 MW

development on portions of the physical, economic, and social environments and the communication of this information to interested parties. The final report (Roefs and Gum, 1974) presents the results of the multidisciplinary team research project and the methods and models used to consider the effects of coal-fueled energy development on the relevant physical, economic and social systems. Dove (1973) specifically addressed the groundwater system and the effects of energy development on this portion of the physical environment, while Everett (1974) confronted the regional economic effects of the development. Layton (1975) addressed the problem of communicating the environmental information to prospective users with differing backgrounds and advocacy positions. As the above mentioned research efforts are linked to the Four Corners project team objectives and the final report, the modeling and research conducted to generate the social sub-system models within the team project served as a basis upon which this dissertation was developed.

Objectives of Study

The first objective of this research was to develop or find an applicable model methodology through which social sub-systems can be modeled and the effects of resource development decisions assessed. The second objective was to develop sub-models of the social systems of the Navajo and Hopi people and, using the modeling methodology, to attempt to gain insight into the social impacts of power development in the Colorado Plateau.

Many possible criteria for judging a model exist. Scientific judgment criteria of reliability and validity are possible. Political

criteria of usefulness of results to particular interest groups are also possible. While we admit the above criteria will and should be used to judge a model, our model will be discussed in terms of the policymaking process. If the modeling approach leads to a better understanding by policymakers of the social impacts of power development than now exist, it will be a success.

CHAPTER 2

SIMULATION AND MODELING

The Simulation Technique

Descriptions of the behavior of a system or process (simulation modeling) are useful in that they allow experimentation outside of the real system. These descriptions or simulation techniques allow trials to be made prior to the commitment of resources to a system, while experimentation with real systems could be risky in terms of the necessary efficacious operation of the system and costly in terms of wasted scarce resources (Thierauf, 1970).

In attempting to describe "important" mechanisms at "meaningful" levels of aggregation, one can break down complicated systems into sub-systems through the study of and operation on inputs and variables. Thierauf (1970) relates that one can evaluate and identify pertinent parameters by operating on individual inputs and variables in a system, and that breaking down complicated systems into sub-systems may allow observers to gain insights into the operation of the total system.

Forrester (1971) identifies the unexcelled ability of the human brain to perceive and categorize simple cause-effect relationships. That ability, however, does not extend to a comprehensive mental model of the complex, dynamic, nonlinear feedback system within which these simple relationships are imbedded. Computer simulations are an attempt to incorporate these many simple relationships into a model of the nonlinear

feedback system that is comprehensible, thus providing a tool for understanding complexity. As in Forrester's effort, the construction of simulation models that incorporate the relevant features of the system (subsystems) in question is the goal of the modeling approach in this research. The evaluation will also parallel Forrester's in that the effects of various policies (decisions) will be discussed in light of the changes produced in a model.

Structural Modeling

In terms of anthropological application, the models developed in this research are similar to the "Social Structure Modeling" approach described by Levi-Strauss (1967). The models consider measures of "broad structural significance" and "social relations" which are "the raw materials out of which the models making up the social structure are built." In keeping with Levi-Strauss' requirements for a model, the model satisfies the following requirements:

1. The overall structure must exhibit the characteristics of a system in that it is made up of a set of elements where one cannot change without affecting other elements.
2. In a given model, there should be a possibility of ordering a series of transformations or disaggregations resulting in a group of models.
3. The properties of a model should make it possible to predict how the model will react if one or more of its elements are submitted to modifications.

4. The model should be constituted so as to make immediately available intelligible observed facts.

With simulation as a tool and an anthropological, structural modeling approach as a guide, modeling will be used to develop the Native American social sub-system models. The modeling strategy discussed by Thompson and Van Houten (1970), in which attention is focused on the behavioral and structural aspects that are most significant to a problem setting will be utilized. Significant variables will be identified and defined and models built around interactions among these variables.

The Model Mechanism

The mechanism of our model is an adaptation of a methodology (KSIM) originally developed by Kane (1972) and modified by McDonald (1973). KSIM was developed to answer two problems suffered by most simulation models. First, they are incapable of incorporating variables which are subjective or not readily quantified. This means that the social, cultural, and personal levels of analysis are normally excluded from simulation models. Second, the technical complexity of most simulation models and language inhibits their use, understanding, and acceptance by policymakers. Kane (1972, p. 2) notes, "It was the purpose of our research to try and design a simulation procedure -- or better yet, a simulation language in which technically unsophisticated people could quickly become fluent in the logical expression of cross-impact concepts."

Simulation models which incorporate the physical level and one or more of the social levels will undoubtedly contain variables and

relationships which are subjectively determined. Because the objectivity versus subjectivity controversy tends to arouse emotional considerations, some clarification of the concepts as used here is necessary. Concerning the decision-making process, Thompson and Van Houten (1970, p. 164) provide this comparison:

> Objective rationality exists when the alternative chosen is in fact the very best one, and in a complicated world it is virtually impossible to have the kind of knowledge needed to attain it . . . Subjective rationality simply means that man makes the best choices he can within his perceptions of his situation . . . Only if man is self-sufficient (with respect to the issue at hand) and independent is there a chance of determining objectively whether he is rational. Seldom, in reality, is man either self-sufficient or independent.

The concept of general systems theory helped reveal the fact that decision-makers operate on the world as they best perceive it, not as it "really" exists. This recognition provided the impetus for the development of heuristic programming and subjective probabilities (Gore, 1964; Simon, 1960). Heuristic programming, or heuristic decision-making, is an attempt to simplify cognitive complexity. Where objective identification of relationships is not possible, substitutions such as human perception, subjective reasoning, expert opinion, and collective consensus are made. The worth of the heuristic process may be realized if the obvious faults of its total subjectivity can be controlled. Computer simulations are seen to provide the necessary control.

The simulation language (KSIM) was developed such that the following properties might be met (Kane, 1972):

1. System variables are bounded. It is now widely recognized that any variable of human significance cannot increase

indefinitely. There must be distinct limits. In an appropriate set of units these can always be set to one or zero.

2. A variable increases or decreases according to whether the net impact of the other variables is positive or negative.
3. A variable's response to a given impact decreases to zero as that variable approaches its upper or lower bound. It is generally found that bounded growth and decay processes exhibit this sigmoidal character.
4. All other things being equal, a variable will produce greater impact on the system as it grows larger.
5. Complex interactions are described by a looped network of binary interactions.

Consider the following mathematical structure used in the simulation model mechanism. Since state variables are bounded above and below, they can be rescaled to the range zero to one. Thus for each variable (x_i) we have

$$0 < x_i(t) < 1, \text{ for all } i - 1, 2, \ldots, N \text{ and all } t \geq 0. \qquad (1)$$

The mathematical calculations are carried out on an iterative basis, with Δt denoting one time iteration. $X(0)$ is a vector with entries $x_i(0)$, the initial values of the variables. $X(k\Delta t)$ is the same vector after k iterations. To preserve boundedness, successive vectors are calculated by the iterative transformation

$$x_i(t + \Delta t) = x(t)^{P_i(t)} \qquad (2)$$

where the exponent $P_i(t)$ is given by

$$P_i(t) = \frac{1 + \frac{\Delta t}{2} \sum_{j=1}^{N} \{|a_{ij} + B_{ij}| - (a_{ij} + B_{ij})\} x_j(t)}{1 + \frac{\Delta t}{2} \sum_{j=1}^{N} \{|a_{ij} + B_{ij}| + (a_{ij} + B_{ij})\ x_j(t)} \tag{3}$$

where:

N is the number of column variables;

a_{ij} is the coefficient from the cross-impact matrix, giving the direct effect of x_j upon x_i;

$$B_{ij} = b_{ij} \cdot \frac{1}{x_j(t)} \cdot \text{slope of } x_j(t); \tag{4}$$

b_{ij} is the coefficient from the cross-impact matrix, giving the derivative effect of x_j upon x_i.

Notice that when the expression for B_{ij} from equation (4) is substituted in equation (3) the $1/x_j(t)$ and $x_j(t)$ will cancel. Thus, the derivative effect of x_j on x_i equals b_{ij} · slope of $x_j(t)$. And the direct effect of x_j on x_i equals $a_{ij} \cdot x_j(t)$.

Equation (3) can be made somewhat clearer by writing it in the following form.

$$P_i(t) = \frac{1 + \Delta t\ |\text{sum of negative effects on } x_i|}{1 + \text{Wt } (\text{sum of positive effects on } x_i)} \tag{5}$$

Thus, the negative direct and derivative effects are separated from the positive ones. The absolute value of the negative effects are summed in the numerator and the value of the positive effects are summed in the denominator.

To explain equations (2) through (5), consider a three variable system of x_1, x_2, and x_3. First, we want to calculate the value of $P_1(t)$ which represents the total effect of impact upon variable x_1 from both

x_2 and x_3, during some time period, t. For the effect of x_2 on x_1 assume the following:

$a_{ij} = a_{1,2} = 4.0$ (direct effect coefficient)

$x_2(t) = 0.5$ (value of $x_j(t)$)

$b_{ij} = b_{1,2} = 2.0$ (derivative effect coefficient)

slope of $x_2(t) = 1.0$ (slope of $x_j(t)$)

and for the effect of x_3 on x_1:

$a_{ij} = a_{1,3} = -3.0$ (direct effect coefficient)

$x_3(t) = 0.4$ (value of $x_j(t)$)

$b_{ij} = b_{1,3} = -1.5$ (derivative effect coefficient)

slope of $x_3(t) = 0.8$ (slope of $x_j(t)$)

and that $\Delta t = 0.1$. Substituting these values in equation (5) we have

$$P_1(t) = \frac{1.0 + 0.1 \left| (-3.0)(0.4) + (-1.5)(0.8) \right|}{1.0 + 0.1 \left((4.0)(0.5) + (2.0)(1.0) \right)} \tag{6}$$

$$P_1(t) = \frac{1.0 + 0.24}{1.0 + 0.40} = 0.89 \tag{7}$$

To find the new value of x_1 we use equation (2). For this purpose, assume that $x_1(t) = 0.5$, and upon substitution we have:

$$x_1(t = \Delta t) = (0.5)^{0.89} = 0.54$$

To summarize, the positive effects on x_1 were greater than the negative effects, thus causing $P_1(t)$ to be less than 1.0 ($P_1(t) = 0.89$). Upon substitution in equation (2), x_1 was increased from 0.5 to 0.54.

When the negative effects are greater than the positive ones, $P_i(t) > 1$ and equation (2) will decrease since $0 < x_i(t) < 1$. And if the positive effects are greater than the negative ones, $P_i(t) < 1$ and equation (2) increases. Finally, when the negative and positive effects are equal, $P_i(t) = 1$ and $x_i(t + \Delta t)$ remains constant. Thus the second condition holds.

Equation (5) guarantees that $P_i(t) > 0$ for all $i = 1, 2, \ldots, N$ and all $t \geq 0$. Thus the iterative transformation (2) maps the open interval (0,1) onto itself, preserving boundedness of the state variables (condition 1 above). From the iterative transformation it is clear that as $x_i(t) \to 0$ or 1, then $x_i(t + \Delta t) \to 0$ or 1 and the slope of $x_i(t)$, $dx_i(t)/dt \to 0$ (condition 3). From equation (3) observe that as $x_j(t)$ increases then $P_i(t) \to \infty$ or 0 (depending on the sum of the negative and positive effects) and $x_i(t + \Delta t)$ in equation (2) will receive greater impact (condition 4). Condition 5 is satisfied since the system behavior is modeled through the coefficients a_{ij} and b_{ij} each of which describes the binary interaction of x_j upon x_i (Kane, 1972).

Given the design propoerties and mathematics of the methodology, the following basic data are needed:

1. The variables (measures) that are to be included in the model;
2. the appropriate scales and starting values for the variables;
3. a description of the binary interactions between all variables.

The first step in deriving the variables for the study or modeling of any system is to list and describe the important components of the system. For the purposes of this model, three categories of social sub-system components will be considered.

1. Significant interacting structures.
2. Individual attributes.
3. Agents of change, related to power development.

Before measures of the relevant components can be selected (variables) the question of degree of aggregation must be answered. Aggregation allows simplicity in a model by using gross variables whereas disaggregation

differentiates gross variables into component parts thus adding detail and complexity. The level of aggregation is influenced by the objectives of the simulation. Relatively simple objectives call for more aggregation than more complex objectives. However, as Hamilton (1969, p. 154) notes, "If one disaggregates too extensively, he finds himself adding complexity without adding to the explanatory value of the model." For this modeling effort a high degree of aggregation was felt sufficient for the purpose.

Variable Selection

No clear, objective procedure exists for differentiating between relevant and irrelevant aggregate variables. Emshoff and Sisson (1970, p. 52) state, "A relevant variable is a characteristic or attribute of the system that is observed to take on different values and that in some way affects the measure of performance of the system over this range of values." As this statement indicates, choosing relevant variables is at present a subjective and rather undefinitive process.

To select the aggregate variables, a set of criteria were defined. The criteria are:

1. Objective analyses show the variable is significantly and directly impacted by power development in the region;
2. interest groups or policymakers believe the variable is important and related to power development;
3. our Indian co-researchers believe the variable is important and related either directly or indirectly to power development.

All of the variables in the model meet at least one of the criteria.

Scales and Starting Values

When using KSIM, it is necessary to set a starting value (0.0 - 1.0) for each variable and outline a scale by which each variable can be identified.

Starting Values. Each variable begins between 0.0 and 1.0 (vertical axis). It is necessary that a value in that range be specified and input into the programming scheme. A specific starting value can be defined quantitatively or qualitatively.

Scales. The scale is defined for all variables from a minimum value of 0.0 to a maximum value of 1.0.

Binary Interactions

KSIM is based upon binary interactions between variables. The pairwise relationships between variables must specify whether the relationship is positive or negative, as well as relate relative importance. (When determining the effect of variable A on variable B, "Does A tend to effect B positively, negatively, or not at all?"). If the effect of A on B can be identified, the effect will be in the direction specified by the sign and proportional to both the size of A and the magnitude of the interaction coefficient. The magnitude of the coefficient can be indicative of the relative importance of a relationship in the modeled system, but the size of the impacting variable and opposing effects will ultimately determine the relative importance of a single relationship.

CHAPTER 3

MODEL DEVELOPMENT

The major purpose of the research is to assess the effects on the Native American social systems of coal-fueled, electrical power producing projects in the Colorado plateau.

The social systems of the Hopi and Navajo Indian Tribes were considered to be most relevant for model application. The major criterion for this selection is that these Native Americans are the most important groups of Native American peoples in the region. In addition to the documented concern of interest groups and policymakers with these Native Americans, objective research reports (U. S. Department of the Interior, 1972) have included extensive sections discussing the impacts of proposed power development on the economic and social-cultural-spiritual systems of the Hopi and Navajo. Where land lease and coal royalty payments are being made by power producers in the Four Corners area, the Hopi and Navajo are the major payees. The physical effects of operational power production facilities from fossil fuel extraction to emissions dissapation, are largely felt on Hopi and Navajo Reservation lands. Thus, the social effects of coal fueled energy production in the Four Corners region will be assessed using the Hopi and Navajo Reservation social subsystems as models.

In developing the models, two types of variables are specified: variables with which the Indian social sub-systems are described

(endogenous variables) and variables through which the impacts of power development are related (exogenous variables). These variables and their specific definitions for each sub-system model are presented in their respective sections. The names of the endogenous variables are common and are frequently used to describe economic and social-cultural concepts and activities; however, the definitions of the variables relate the concepts to the Indian systems and may be very different from definitions used in traditional Anglo analyses due to cultural differences. For example, in describing the Indian social sub-system, the Indians' perception of health is the valid variable, not mortality and morbidity rates used to compare Indian health to Anglo health standards. Dollars per hour of wages and man-years of employment are definitions of income and employment measures used in traditional analyses, but these definitions are neither important nor applicable to the Indian due to the amount and importance of self-employment and barter activity that exists in Indian socioeconomic systems. With the aid of the co-researchers the variables were selected and defined in a manner which stressed the Indian system and provided insights into the system. These endogenous variables and the interrelationships between them comprise the simulation models of the respective Indian sub-systems. (Without aid of Indian co-researchers, little confidence could be placed in our variables and their ability to relate Indian perceptions.) In addition to making the variables meaningful in an Indian system, the co-researchers played a critical role in specifying relationships between variables and generating overall meaningful simulation models.

The exogenous variables, or the variables that relate the environmental and economic impacts of power development, enter into our analysis when the impacts of various decisions are assessed. These variables reach a maximum (1.0) when all power producing units in the decision space (Table 1) are implemented. These variables reach this maximum in 1980 and only after all plant units scheduled for operation between 1970 and 1980 are implemented. A 0.0 value would indicate no further power development and operational plants stopping their service. Unless currently operational plants are shut down, the curve representing power development starts at 0.29, the percentage of scheduled plants (capacity) presently in operation and the percentage of impacts now occurring. These exogenous variables will be discussed further in the assessment of impacts section.

The tables of binary interactions indicate the relationships among the variables which describe the Native American social sub-system and the relationships between endogenous and exogenous variables. The specification of these relationships and the mechanics of our method allow observation of the effects (of decisions about Power Development) on variables within a system that are not impacted directly from forces outside of the system, but through other variables within the system that are impacted from without. The numerical interrelationships are presented and will be discussed later. The establishment of the interrelationships can be outlined as a three part process. The first part involves identifying a relationship between sets of variables. If an interrelationship is perceived, the effect is assessed first as to its direction (+ or -) and second as to its general magnitude. The third

part of the process involves specifying a numerical value for each interrelationship. The final numerical specifications are the result of an evolutionary process that required a great deal of time and effort on the part of the research team and Indian co-researchers. This quantitative set of interactions describes the movement of the variables over time and allows the impacts of the exogenous variables to be assessed. The numbers describing the interrelationships imply relative weightings of all effects presented in the model. The use of the model necessitates specifying only the binary interrelationships and then "calibrates" the values, variable by variable, to express what the researcher and co-researchers perceive as realistic values. The model mechanism, through the computer, operates on the overall relationships, and graphically relates the results.

The Hopi Sub-System Model

The variables to be used in generating the Hopi sub-system simulation model and their starting values are presented in Table 2.

Definitions and Starting Values

Acculturation, for the Hopi model, refers to the relative intensity or frequency of contact with other culture. A value of 0.0 for Acculturation would reflect no contact with other cultures and 1.0 would indicate that no tribal activity would occur exclusive of outside participation. The assigned value of 0.2 suggests that contact exists between the Hopi and other cultures although the Hopi culture remains very distinct. The Hopi initiates contact in very few areas other than those concerned with material needs and is striving to further develop

Table 2. Variable List -- Hopi Sub-System Model.

Variable List	Starting Values	Output Code
Endogenous Sector (1-10)		
1. Acculturation	0.2	ACCU
2. Individual Stress	0.2	STRS
3. Tribal Government Unity	0.6	TGU
4. Social Structure Unity	0.7	SSU
5. Federal Involvement	0.5	FEDI
6. Health	0.5	HEAL
7. Population	0.6	POP
8. Indian Employment	0.5	IEMP
9. Indian Income	0.5	IINC
10. Tribal Income	0.3	INC
Exogenous Sector (11, 12)		
11. Environmental Impact	--	ENV
12. Economic Impact	---	ECON

and strengthen cultural traits. The fact that the graphically displayed acculturation process is seen to increase over time relative to starting levels is due to the pressure for contact applied on the Hopi from outside cultures.

Individual stress, or mental tension resulting from the alteration of existing equilibrium can be viewed as a gauge of an individual Indian's discomfort with an imposed situation. The assigned starting value of 0.2 indicates the existence of individual stress mainly due to social pathologies attributable to contact with outside cultures, and the pressures applied by other cultures. A value of 0.0 would indicate a totally undisturbed existence while 1.0 would be illustrative of total breakdown.

Tribal Government Unity relates the degree to which the tribal government constitutes a whole and promotes an undivided total effect with symmetry and consistendy. A value of 0.0 would indicate that a Tribal government was not serving as a representative institution and had little influence on the tribe. A maximum value of 1.0 would indicate an active and representative body, able to reflect and carry out the tribe's wishes. The assigned value of 0.6 reflects that a relatively high degree of representation and strength exists with the Hopi tribal government.

The extremes of social structure unity can be seen to range from tightly knit family units with strong leaders to situations where no consistent character of philosophy, leadership, action, or inaction exists. With 1.0 and 0.0 indicative of the extremes, a strong and unified social structure (0.7) is seen within the Hopi Tribe. The definition that we will specify for social structure unity is the degree to which the tribal

social structure and its parts maintain and demonstrate consistency of character, leadership, and philosophy.

Federal Government Involvement is a variable defined as the degree to which the tribe has become associated with or obliged to interact with the Federal government (and assigned the purpose of describing the interaction between the federal and tribal governments). The starting value of 0.5 assigned to Federal Involvement reflects a situation where the tribe is neither independent nor totally dependent on the federal government (but operates in a fairly equal mix of independence and aid).

The Hopi perception of Health is a very difficult concept to describe since it has as much to do with the Hopis' perceptions of themselves and their environment as with how they actually feel. Thus, the variable is defined simply as a description of the Hopis' perception of their general health. If they judged their state to be unhealthy (0.0) near or distant environmental problems and individual mobility problems may predominate, as well as disease. Perceptions of perfect health (1.0) would relate to mobility within and the ability to reach out into their environment, as well as incidence of morbidity and mortality. The starting value of 0.5 relates a median state of happiness with their environment and decreasing rates of morbidity.

The Population variable describes the number of Indians on the reservation. Considering the current distribution of land use and ownership, the socioeconomic situation with respect to employment, and the general ability of the reservation to provide for its people, a maximum population could be hypothesized. This maximum (1.0) could be compared to a situation of no on-reservation population (0.0). The 0.6

value attempts to relate the present population of 6,500 as a proportion of a theoretical maximum.

Indian Employment is defined as the potential numbers of Indian wage earners, including those self-employed. A given static or inter-temporal demographic structure within the reservation boundaries would avail a number of workers to a mix of available employment opportunities. No employment potential (0.0) reflects the absence of workers and jobs. A potential of 1.0 would indicate positions exist for all workers and workers for all positions. The potential employment description is an attempt to relate a valid concept within the Hopi social-cultural sub-system to the impacts of power development, without defining a new non-Anglo measure of employment meaningful to the Hopi system. It is not meaningful to relate employment opportunities to the Hopi in terms of dollars added to the reservation economy or in man-years of labor. The Hopi interpretation of a unit of employment opportunity, as provided by an Anglo resource development project, may be somewhat less than a man-year of labor or may not be an opportunity at all. (The employment variable allows the employment impacts of power development to be considered as well as the income effects.) The real response of the sub-system to employment is reflected in the relationship between employment potential and Indian Income. There is not a 1:1 relationship between these variables in the Hopi sub-system (and this is perceived as the response of the Hopi to a unit of employment opportunity).

Indian Income is defined as a description of the total income paid to and generated by the Hopi, including wages, welfare and other transfer payments, and self-employment. As noted previously, personal

income is important to the Hopi, but determining what its value would be is difficult. If an individual income figure were estimated, it would likely imply that Anglo welfare standards are meaningful, which would be against our belief and purpose. For the Indian Income variable, 0.0 and 1.0 define minimum and maximum possible incomes. The 0.5 starting value provides a point from which the impacts can be assessed.

Tribal Income describes the total income to the tribe from sources such as royalties, lease payments, and direct payments. The minimum and maximum values of Tribal Income are zero (0.0) and the maximum that could be theoretically generated (1.0). The current maximum amount budgeted in a given year is 700,000.00 and 0.3 is the relative position of current tribal budgets.

The exogenous variables, vectors of economic and environmental impact, are defined below, but will be discussed further in the assessment of impacts.

Environmental Impact

Environmental impact provides a description of the elements of coal-fueled energy development and facility operation that affect the physical environment. This description includes the concepts of air pollution, water pollution, and use, and land use for all of the plant, mine, and transmission facilities. Where information was not available on planned facilities, estimates were made from existing technology and specifications presented in the Southwest energy study.

Economic Impact

The economic impact variable consists of a description of the facets of coal-fueled energy development that affect the relevant economic sub-systems. The description includes available jobs, incomes, lease payments, coal royalty payments, and water use payments. Where royalty, lease payments, and other economic impact information is not available for existing and planned facilities, estimates were based on location and planned capacity of the facilities.

Binary Interrelationships

Table 3 illustrates the direct binary interrelationships specified by researcher and Indian co-researcher. These relate the variable with which we have described the Hopi sub-system and provide a way to relate the impacts of power development. Growth of the Hopi population (Variable Number 7) is seen to have a positive effect on the relative intensity or frequency of contact with other cultures. The existence of employment potential for the Hopi, regardless of the degree to which off-reservation jobs are taken, has been assessed as having a positive effect on the acculturation process. Row Number 2, which represents the Individual Stress variable, is impacted by Variable Number 1 and Variable Number 11. The positive impact of Acculturation on Individual Stress suggests inter-cultural contact tends to increase stress. Increases in social pathologies have occurred and can be attributed to contact with the Anglo culture; tensions resulting from land disputes and other inter-cultural pressures are evident. The positive effect of Environmental Impacts associated with power development (Variable Number 11) on

Table 3. Hopi Sub-System Model, Table of Binary Interactions.[a]

	1	2	3	4	5	6	7	8	9	10	11	12
1							.1	.1				
2	.2										-.1	
3	.1			-.01							-.05	
4	.01	-.05	-.01			.02						
5			-.01	-.05		-.01						
6	.05	-.05		.05	.05					.1	-.01	
7						.5						
8	.08	-.01	.04		.02		-.02			.05		.05
9	.1							.2			-.01	.02
10			.05		.1							.03
11												
12												

a. Impact is Column to Row. Numbered rows and columns correspond to numbered variables on variable list. A blank element in the table indicates that either no relationship exists or none has been specified.

Individual Stress indicates that individuals are concerned about environmental effects of the power production facilities which will alter existing environmental equilibrium.

The positive direct effect of inter-cultural contact (acculturation) on Unity of the Tribal Government (Variable 3) reflects that although some Hopi do not recognize the Tribal Government officially, more and more look to it for help in dealing with inter-tribal and cultural problems. Even though more people rely on the Tribal Government in some areas, the existence of unified clans with strong social leadership tends to exert a negative pressure on the tribal governments' effectiveness and unity. Further, any environmental effect of power development is illustrated as having a negative impact on the Tribal Government unity, suggesting that self-proclaimed traditionalists and other Indian groups that are against any encroachment on the environment pressure the Tribal government when such encroachment occurs.

The positive impact of the acculturative process on the social structure and its unity (Variable 4) represents the movement of the Hopi back into their culture and Social Structure. The reverse relationship logically should exist, but apparently there is a movement of the young and institutionally and professionally trained Hopi back to the reservation and the Tribe. These Hopi have experienced a great deal of inter-cultural contact, but have chosen to return to the Tribe, work at developing traditional arts and crafts, play active roles in the social system and rituals, and promote the significance and distinctness of their culture.

Stress has a negative effect on the unity of the social structure. The existence of stress is exemplified in social pathologies, such as drinking, and tends to decrease participation in traditional ritual and the social system.

As the existence of strong clans and leadership tends to have a negative influence on the unity of the Tribal Government, a unified tribal government tends to negate strengths within social units. The unified and effective government supplants the need for the social units in areas other than spiritual ones. Better health (Variable 6) on the other hand, tends to have a positive effect on the social system.

Variable 5, as defined as Federal Involvement, is only discouraged by the impacting variables in the sub-system. The existence of a unified Tribal government and social structure, as well as a perception of health and welfare in general, all tend to discourage interaction with and obligation to the federal government, while encouraging cash financing of tribal and local programs.

Improvement of health conditions has been accelerated by intercultural contact, interactive and monetary Federal involvement and Tribal Income distributions. The existence of strong social units and structures have also had a positive impact on general health outlooks. Conversely, stress and resulting problems along with the environmental impacts of Power development are seen to have negative effects on health and perceptions. The environmental impacts of Power development include particulate air pollution, water pollution, and the dispersion of compounds that cannot be readily traced or easily assessed. These environmental impacts may impair the health of the Hopi.

Population (Variable 7) is seen to be impacted in the direct effect category by Health. Health care and perceptions of health seem to have a positive effect on the reservation population.

Where new jobs are identified and learned, the measure of Potential Employment (Variable 8) is positively effected by Acculturation. The Tribal and Federal governments provide employment opportunities and tribal income pays the wages for many on-reservation jobs. Stress and the existence of a large population both tend to negate potential employment, from the labor supply side and job supply side, respectively. The economic impact of power development is positive as more jobs are made available to Indians.

Indian Incomes (Variable 9) are enhanced by Acculturation and by the new markets and methods of income generation gained through intercultural contact. There is a positive relationship between potential employment and income. Power development effects the income of the Indian through both the environmental and economic impact categories. Land use and general environmental pollution are seen to have a negative impact on Indian Income through self-employment areas such as agriculture.

Tribal Income is impacted positively by a unified Tribal government. An effective Tribal government is able to generate monies independently and in conjunction with the Federal government. Involvement of the Federal government has always meant programs and funding (which is being administered through the Tribal government). There is a direct positive impact of power development on Tribal income. Part of the total economic impact of power development is brought into the analysis through

the Tribal Income variable, and this impact can be documented in terms of royalty, lease and water use payments.

Figure 1 is the graphically displayed model of the Hopi sub-system. The specified binary interrelationships and the model mechanism have allowed the variables to be extended from their starting points into the future (2020) and now represent trends in the variables over the period, given the assumption of no power development. This composite or simulation model of our sub-system provides a base upon which the impacts of power development can be assessed. Given these trends, questions can be asked as to the impacts of power development due to plant specific, area specific, or capacity specific decisions. The insights that the modeling method can provide in terms of changes in directions and/or rate of change in graphically displayed variables over time can help answer the decision specific questions.

The Navajo social sub-system model will be presented separately from the Hopi model. The variables used to describe the Navajo sub-system are the same as those used in the Hopi model but many definitions are different and the relationships between the variables are very different.

The Navajo Sub-System Model

The variables to be used in describing the Navajo social sub-system and generating a simulation model are presented in Table 4. (The definitions of the variables are related within the discussions of starting values.) The definitions, starting values, and the binary interrelationships between the variables were established with the aid

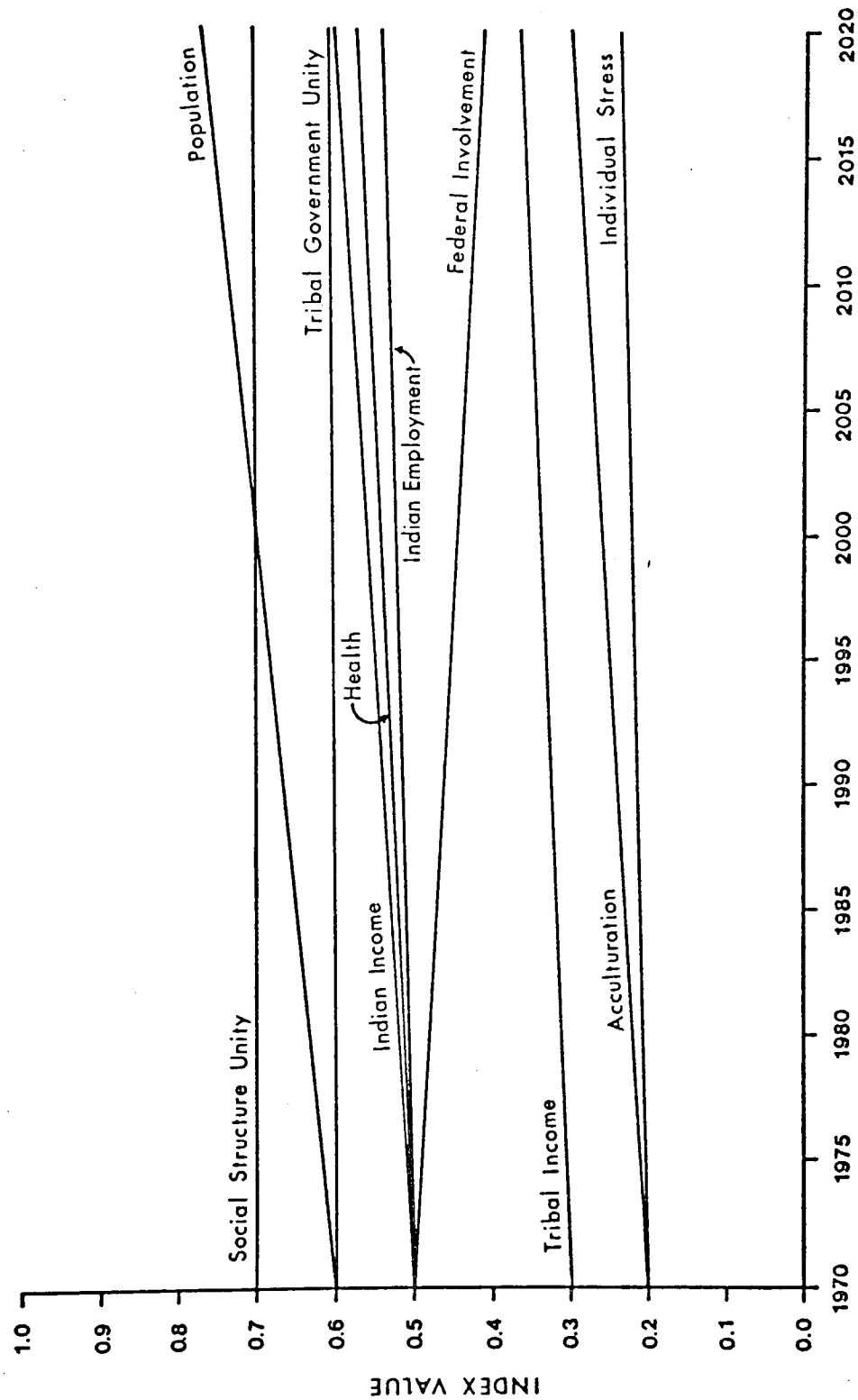

Figure 1. Hopi Simulation Model Composite Graphic Display.

Table 4. Variable List -- Navajo Sub-System Model.

Variable List	Starting Values
Endogenous Sector (1-10)	
1. Acculturation	0.3
2. Individual Stress	0.2
3. Tribal Government Unity	0.5
4. Social Structure Unity	0.6
5. Federal Involvement	0.5
6. Health	0.5
7. Population	0.6
8. Indian Employment	0.5
9. Indian Income	0.4
10. Tribal Income	0.5
Exogenous Sector (11, 12)	
11. Environmental Impact	--
12. Economic Impact	--

of Dr. Billison, a Navajo and former member of the Tribal government (and the basic model to predict the movement of the variables over time.)

Definitions and Starting Values

Acculturation (Incorporation) is a description of the degree to which elements of other cultures are incorporated in such a way that the structural framework (institutional core) is maintained, and borrowed elements are fitted into place and elaborated in terms of pre-existing patterns (Kluckhohn and Spicer, 1961). The above definition is seen to relate the acculturative process to the Navajo. A starting value of 0.0 for Acculturation would reflect that no elements of other cultures are being incorporated or the Navajo cease to be a "borrowing" type of culture. A value of 1.0 would indicate the incorporation of all possible elements of all relevant cultures or we would interpret it to indicate that the Navajo would cease to have a distinct culture of their own. The assigned value of 0.3 reflects that the tribe has remained distinct from surrounding cultures in ritual, language and social patterns, while many material elements of outside cultures have been incorporated.

Individual Stress, or mental tension resulting from factors that tend to alter an existing equilibrium, is a variable that concerns non-physical, personal discomfort and problems experienced by the Navajo. A value of 0.0 for individual stress would represent a completely undisturbed existence for an individual, while 1.0 indicates a total mental breakdown. The 0.2 value illustrates the opinion that problems exist, but that the mental tension generated is small to the Navajo.

Tribal Government Unity is the degree to which the tribal government constitutes a whole, promoting an undivided total effect with symmetry and consistency. The minimum value (0.0) for tribal government unity represents an ineffective, powerless, and unrepresentative institution, existing physically, but having no influence on the tribe or intercultural relations. A maximum of 1.0 would indicate a powerful governing body representative of the tribe and able to promote the tribes' wishes consistently and decisively. The 0.5 starting value is meant to represent an active governing body, effective in many ways, but lacking in the support necessary to make it a powerful tool of the Indian people.

Social Structure Unity is the degree to which the tribal social structure and its parts maintain and demonstrate consistence of character, leadership, and philosophy. A unified social structure does not imply adherence to "old" or traditional structure. A structure of unified clans with strong leadership and consistent philosophy would be reflected in a maximum value of 1.0, as would a situation in which there is a high degree of concern for tribe and tribal member welfare and the maintenance of the mechanisms by which the tribe remains culturally distinct. A situation described by a minimum value (0.0) of unity is one in which no consistent character of philosophy, leadership, or action or inaction is maintained. The starting value of 0.6 reflects a situation where many strong and powerfully led clans and social groups exist, but they are split into progressive and nonprogressive camps, maintaining different philosophies.

A maximum value (1.0) for Federal Government Involvement would reflect that the Navajo reservation and people were wards of the federal

government. A minimum (0.0) would indicate autonomous operation of the tribe. The starting value of 0.5 attempts to describe a situation where the tribe governs itself and initiates programs under a veil of funds, services, and consultation with the federal government. Federal Government Involvement, then, is the degree to which the tribe has become associated with or obliged to interact with the Federal government.

Health is a description of the Indians' perception of their general health. The Indians' perception has as much to do with his ability to reach into his natural environment and utilize its aesthetic and physical resources. The reservation way of life has generally decreased the Indian perception of health and vitality. A 1.0 value would reflect that no health problems are perceived, and 0.0 would represent an unhealthy state. Current assessments, as represented by the 0.5 value, indicate an increased response on the part of the individuals to available public and private medical facilities. The Navajo are concerned with disease prevention and hygiene.

The Population variable describes the numbers of Indians on the reservation. A value of 1.0 for the population variable would indicate a maximum number of Indians on the reservation and 0.0 no Navajo residing on the reservation. An estimate of 0.6 of how the present population of about 130,000 relates to a maximum and minimum reservation population. This estimate considers current land use, ownership, and occupancy and the ability of the reservation and local areas to provide jobs and income for reservation residents.

Indian Employment describes the potential numbers of Indians employed in wage earning positions, as well as those self-employed.

Population distribured by age and sex determines the potential number of Navajo available for wage earning positions and self-employment. There is also a given supply of employment opportunities in the same time frame. A value of 1.0 for Indian employment would reflect a situation there are jobs for all Navajo and a worker for each job, while 0.0 a situation of no employment potential. There is an employment ethic among the Navajo. It is important to be working or have worked recently and it is obvious that the employment concept has a role in the description of the social sub-system. Traditional measures of employment do not apply directly to the Navajo employment situations. Potential employment was used so that a new measure of employment, applicable to the Navajo, would not have to be developed. Through this variable employment impacts (jobs available) of power production can be introduced and the endogenous interaction with the population variable related. The specification of the relationship between employment potential and Indian income represents how the Navajo responds to employment potential in terms of income. The starting value of 0.5 indicates that both the population and employment opportunities are about 50 percent of potential.

Indian Income describes the total income paid to and generated by the Navajo, including wages, welfare payments, self-employment, and barter. Indian Income cannot be easily measured by techniques normally employed in the Anglo culture. The maximum (1.0) and minimum (0.0) scale values are defined only in relation to power development, i.e., the maximum and minimum values indicate the trend of Indian incomes due to power development. The starting value of 0.4 is an estimate of the current income level as compared to a maximum.

Tribal Income is a variable that describes an important factor in the reservation economic and social systems, the total income to the Tribe from sources such as royalties, lease payments, and direct payments. As opposed to Indian Income, this variable can be estimated fairly accurately, from tribal budgets and reserves. A minimum value of 0.0 represents a zero income. Specifying a maximum (1.0) income is more difficult. The current annual budget of $20,000,000 has been specified as 0.5 without defining 1.0 more specifically than as a relative maximum. Simulating the growth trends tribal income with and without power development is the goal of the variable.

The following definitions are those of the exogenous variables through which the impacts of power development decisions are related. These variables will be discussed further in the assessment of impacts section.

Exogenous Variables

Environmental Impact. The elements of coal-fueled energy development and facility operations that affect the physical environment. This description includes the concepts of air pollution, water pollution, and use and land use for all of the plant, mine, and transmission facilities. Where impacts estimates were specified and were not available concerning planned facilities, estimates were made from existing technology and specifications presented in the Southwest Energy Study (U. S. Department of Interior, 1972).

Economic Impact. The facets of coal-fueled energy development that affect the relevant economic sub-systems. The description includes

available jobs, incomes, lease payments, coal royalty payments, and water use payments. Where economic information was not available, estimates were made using facility location and planned capacity as a guide.

Binary Interrelationships

In Table 5, the numerical values of the direct binary interrelationships are presented. These interrelationships are based on literature search, field research, and consultation with Indian co-researchers.

Acculturation is seen to be directly impacted by the Population and Indian Employment variables. Population (Variable 7) has been determined to have a positive effect on Acculturation (Variable 1). This determination reflects that with on reservation population trends, the sheer numbers of elements incorporated will increase. In addition contact with other culture will increase, thereby increasing incorporation of new elements. The employment potential for the Navajo (Variable 8) is seen to have a positive effect on the Acculturation process. This determination reflects the most job supply changes in potential employment are associated with "Anglo-oriented jobs," which require the incorporation of certain work habits and duties.

The Acculturation process tends to increase individual stress. The movement of the Indian away from home and, possibly, off the reservation for the purpose of employment is an example of the incorporation process; such movement does not appear to be a historical trait of the Navajo, but one illustrative of the present day Anglo culture. The distances involved in this travel as well as the characteristics of this "Anglo oriented" employment tend to create stress on the individual. The

Table 5. Navajo Sub-System Model, Table of Binary Interactions.[a]

	1	2	3	4	5	6	7	8	9	10	11	12
1							.10	.20				
2	.20										.20	
3				-.01							-.05	
4		-.05	-.01		-.05			.01				
5			.10	-.10		.08	.10					
6					.10					.10	-.01	
7						.5						
8		-.01	.01	.10	.10		.03			.05		.10
9	.20							.30			-.01	.04
10			.30	-.01	.10							.10
11												
12												

a. Impact is column to row. Numbered rows and columns correspond to numbered variables in variable list. A blank element in the table indicates that either no relationship exists or none has been specified.

distance itself may make it impossible or difficult for the individual to participate in the relevant rituals and ceremonials. The type of employment, most likely, will not be structured so that the Indian is free to leave the job at times when traditional activities occur. The result could be the loss of job or the disfavor of the clan or family. The environmental impact of power development (Variable 11) on individual stress is a positive binary interrelationship and an entry point for the impacts of the power development (exogenous) sector into the Navajo social-cultural sub-system (endogenous sector). The positive effect of the existence of environmental impacts with power development on individual stress, reflects that many concerned and "traditionalist" Navajo are, and will be stressed by the pollution, mining, and transmission lines associated with the power producing facilities. Long standing environmental equilibriums will be altered and some individuals will be effected.

The negative relationship between social structure unity and the effectiveness of the tribal government describes the conflict between centralized government and clan oriented social structure. The strong social and spiritual leaders tend to disagree with the concept of the tribal government unless directly related to it. In general, where powerful social leaders exist the efficacy of the tribal governments operations has been reduced.

The existence of active, non-progressive factions within the tribe tends to bring the environmental effects of power development to the surface as an issue that effects the tribal government. Therefore,

the environmental impacts of power development will have a negative impact on the effectiveness and unified operation of the tribal government.

Stress, tribal government unity, and federal involvement all have a negative impact on the unity of the tribal social structure. The negative effect of stress describes the fact that tension alienates one from traditional philosophy. The existence of a strong, clan oriented social structure negates the effectiveness of the tribal government. These two significant interacting structures within the Navajo system, vie for leadership and tend to negate the effectiveness and degree of unity of each other. The existence of federal government input into reservation affairs has a negative effect on the social units within the tribe. There is a general distaste for federal intervention into Tribal affairs although apparent acceptability is evidenced by the acceptance of monetary payments, food, and durables by the tribal members. There are disagreements as to whether federal government monies and gifts should be accepted but little disagreement where general government intervention is the issue.

The existence of a work ethic among the Navajo is described by the specification of the positive relationship between employment and the social structure unity. It is important to the family and clan to either be working or have worked recently.

Federal involvement, as defined, is positively effected by a unified tribal government. Although the federal government may not become more evident, an efficient Tribal government is able to utilize more available federal programs and monies for its benefit. As opposed to this concept, the existence of unified social units or a unified social

structure has a negative effect on federal government involvement. The philosophies of most social leaders and units do not include the recognition of the federal government or the acceptance of its programs and proposed benefits.

The existence of health problems and a perception for the need of better health by the individual tends to increase federal involvement through the activities of the Indian Health Service. This situation is described by the positive relationship between the variables. The population on the reservation tends to have a positive effect on federal involvement. A zero population would have no effect, but realistically, a given population has demands for more services of the federal government such as health, education, and training services.

General perceptions of health have been positively impacted by federal involvement and Tribal income. Federal health services are being increasingly used by the Navajo as the value of these services becomes more evident. Tribal monies have been and are continuing to be used for advertising the value of health care, promoting the use of available facilities and providing transportation to and from medical facilities. Through the health variable, an entry point for the effects of power development (exogenous sector) is provided. Although the precise health related effects of specific pollutants emitted by the coal-fueled power production process are not known, a negative effect is specified. The particulates, NO_4, SO_2, and heavy metals in emissions are not good for health or a healthy environment and the negative impacts of these environmental effects on perceptions of health is obvious.

Within this endogenous system, the population is seen to be impacted by health. The positive, direct relationship reflects current levels of the health variable and their impacts on the reservation population.

Indian employment is impacted by variables (endogenous and exogenous) that affect the supply of employment opportunities and the supply of workers. Stress is specified to have a negative effect on employment by moving workers away from jobs and the job market in general. The tribal government has a positive effect on the availability of employment opportunities, by providing jobs and encouraging the establishment of business enterprise. The existence of federal involvement includes funded projects with job opportunities as well as training programs. This positive effect on employment is both in the direction of job supply and worker supply.

A unified social structure exhibits the before mentioned work ethic in a manner that has a definite effect on the positive supply of labor and a positive effect on Indian employment as defined. The population, as such, provides a labor supply and has a positive effect on employment regardless of its size. Another variable that has a positive effect on employment is the income of the tribal government. This income has, characteristically, meant jobs and services to the tribe. Indian employment is an important variable in the social sub-system in that it has both social and economic implications. Through the employment variable, we can relate the exogenous economic effects of power development to jobs available to the Navajo. The positive relationship

indicates that decision that will have an economic impact and will avail jobs to the Navajo, either through the plant or supporting facilities.

The Navajo acculturative process has an effect on individual Indian incomes. The movement into new employment areas and business practices with expansion into larger extra-tribal markets are examples of the incorporative process and illustrate why a positive relationship has been specified between acculturation and Indian Income. The existence of employment potential is seen to positively impact on Indian Income. The less than unity impact of employment potential on income attempts to illustrate the gap between employment potential and income generalization. This gap or lack of actual employment is very common where the employment opportunities are Anglo-oriented jobs with seniorities, pecking orders, and rigorous work-time structures.

A small negative impact is perceived upon Indian income through the exogenous environmental impact of power development variable. This describes the effect of attitudes and self-employment activity on Income, in an area where there are spiritual ties to the environment as well as commercial and private agrarian activity. There is a positive exogenous economic impact on Indian Incomes due to power development. Excluding employment and job related impacts, many payments are made to individuals for land leases and royalties.

The Tribal government has a positive impact on its own income since its relevance as a structure depends on income generation. Many social units and leaders, conversely, have attempted continually to direct monies to individuals and areas thus having a negative effect on the size of the tribal income. The federal government is the main source

of tribal monies, which are usually earmarked for specific programs and activities. The interaction between the Tribal and Federal governmental structures results in positive income for the tribe.

The final endogenous variable through which the impacts of power development are assessed is Tribal Income. The Navajo Tribe receives royalties and direct payments concomitant with the construction and operation of specific producing units and supporting facilities. There is a positive effect specified between the exogenous economic impact of power development and Tribal income that describes the impact of the current and potential payments.

Figure 2 is the model results, graphically displayed, of the Navajo social sub-system. It is a result of the model mechanism operating with the binary interactions specified in Table 5 without any power development. The mechanism extended the specified interactions into the future for fifty years (time periods) as an estimate of long term trends in the variables.

The establishment of this simulation model prepares the base upon which the impacts of power development can be assessed. Given that these curves describe the feasible trend of a variable from now to the year 2020, what are the impacts of power development as assessed through changes in the direction and/or rate of movement in the graphically displayed variables over time?

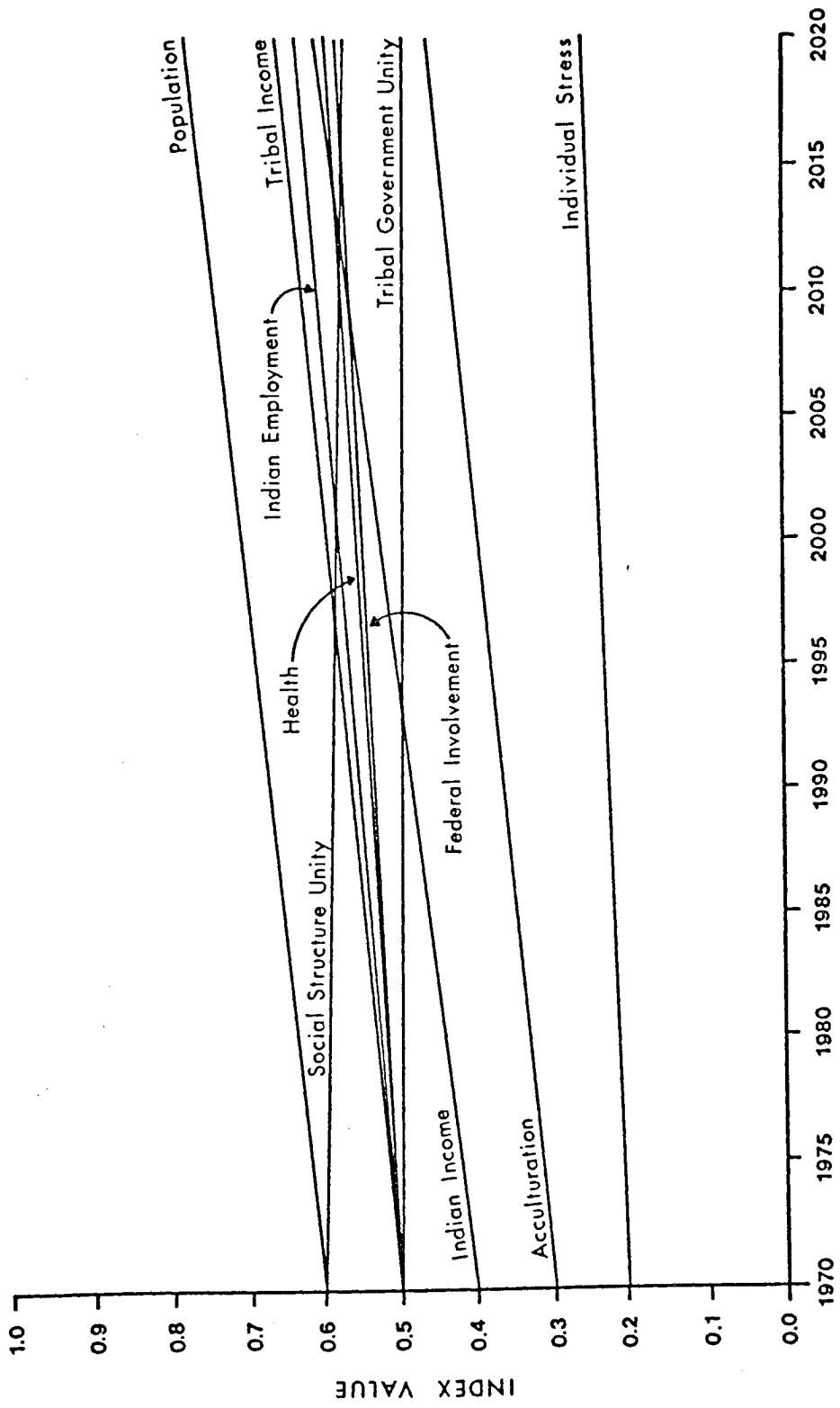

Figure 2. Navajo Simulation Model Composite Graphic Display.

The Assessment of Impacts

The simulation models of the Hopi and Navajo social sub-systems, presented in the previous section, serve as the basis upon which the impact assessments will be made.

The Exogenous Variables

The simulation models are the result of the interaction of the endogenous variables (1-10) within the limits of the model mechanics. The relationships between the endogenous and exogenous (11 and 12) variables have been specified but these relationships are not a part of the interactive computational process until a decision is made, input into the system and the environmental impact and economic impact variables, thereby, assigned a value other than zero.

The value assigned to the exogenous variables (environmental impact and economic impact) is a result of two steps. Table 6 presents the percentage of total capacity (MW) each plant in the decision space (Table 1) is projected to produce and the time period in which the plant is projected to begin operation. From this array the exogenous variables are assigned a value, depending on the decision made (power plant or combination of plants) with which to start and a value in each of the time periods. The decision for full development of power (full impact), for example, would involve selecting decision units 1 through 14. This selection would assign a starting value of 0.29 to the exogenous variables in time period number 1 and, following the cumulative totals in Table 6 for each time period, would assign a maximum value of 1.00 to the variables in time periods 10 to 50. A decision for power plant unit

Table 6. Generating Capacity as a Percentage of Total Projected Capacity; by Year, Period 1970-1980, by Plant (Unit) Number.[a]

Power Plant (Unit Number)	Year Period (Time Period)									
	(1) 1970-71	(2) 1971-72	(3) 1972-73	(4) 1973-74	(5) 1974-75	(6) 1975-76	(7) 1976-77	(8) 1977-78	(9) 1978-79	(10) 1979-80
1	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
2	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4			0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
5				0.025	0.025	0.025	0.025	0.025	0.025	0.025
6				0.20	0.20	0.20	0.20	0.20	0.20	0.20
7							0.02	0.02	0.02	0.02
8					0.03	0.03	0.03	0.03	0.03	0.03
9									0.03	0.03
10							0.025	0.025	0.025	0.025
11									0.12	0.12
12										0.08
13										0.08
14										0.08
Cumulative	0.29	0.29	0.31	0.535	0.565	0.565	0.61	0.61	0.76	1.00

a. See Decision Space.

numbers 1, 2, 3, 8, and 11 to be implemented, would result in a starting value of 0.29, subsequent values of 0.29, 0.29, 0.29, 0.32, 0.32, 0.32, 0.32, 0.44, and a value of 0.44 for time periods 10 to 50. With a value relating power development assigned to the exogenous variables, the second step involves relating the specific level of development and impact to the Indian systems. The arrays in Tables 7, 8, 9, and 10 relate, for a tribe and an exogenous variable, the effect of a specific power plant unit. These arrays illustrate that certain power plant units have no effect on the environmental or economic impact variables for a tribe and that others have a high proportion of the total effect. For a decision, the economic and environmental impacts variables would be assigned a value that is the product, in a time period, of the sum of the percentages of total projected capacity (Table 6) and the sums of the percentages of total effect on a Tribe. Using the decision of full power development, (full impact) as an example, the sum of the percentages of total projected capacity in a time period would be reflected by the cumulative total. The sums of percentages of total effect on a tribe would also be the cumulative totals, in a time period, for the economic or environmental effect on a given tribe. At full power development the value of the economic impact variable in time period 1 for input into the Hopi model would be 0.29 x 0.4 or 0.116. The value of the variable in time period 10 would be 1.00 x 1.00 or 1.00.

The values that are computed and assigned to the exogenous variables are then input into the simulation mechanism through the specified relationships between them and the endogenous variables. The relative size of the values meter the magnitude of the impacts and where impacts

Table 7. Percentage of Total Economic Effect on the Hopi Generated by Each Plant Unit, by Time Period and Cumulative.

Power Plant (Unit Number)	Time Period									
	1	2	3	4	5	6	7	8	9	10
1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4			0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
5				0.0	0.0	0.0	0.0	0.0	0.0	0.0
6				0.35	0.35	0.35	0.35	0.35	0.35	0.35
7							0.05	0.05	0.05	0.05
8					0.1	0.1	0.1	0.1	0.1	0.1
9									0.05	0.05
10							0.0	0.0	0.0	0.0
11									0.0	0.0
12										0.0
13										0.0
14										0.0
Cumulative	0.4	0.4	0.45	0.8	0.9	0.9	0.95	0.95	1.0	1.0

Table 8. Percentage of Total Environmental Effect on the Hopi Generated by Each Plant Unit, by Time Period and Cumulative.

Power Plant (Unit Number)	Time Period									
	1	2	3	4	5	6	7	8	9	10
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
4			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5				0.0	0.0	0.0	0.0	0.0	0.0	0.0
6				0.3	0.3	0.3	0.3	0.3	0.3	0.3
7							0.0	0.0	0.0	0.0
8					0.2	0.2	0.2	0.2	0.2	0.2
9									0.0	0.0
10							0.0	0.0	0.0	0.0
11									0.0	0.0
12										0.0
13										0.0
14										0.0
Cumulative	0.5	0.5	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0

Table 9. Percentage of Total Environmental Effect on the Navajo Generated by Each Plant Unit, by Time Period and Cumulative.

Power Plant (Unit Number)	Time Period									
	1	2	3	4	5	6	7	8	9	10
1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
3	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
4			0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
5				0.0	0.0	0.0	0.0	0.0	0.0	0.0
6				0.2	0.2	0.2	0.2	0.2	0.2	0.2
7							0.05	0.05	0.05	0.05
8					0.05	0.05	0.05	0.05	0.05	0.05
9									0.05	0.05
10							0.0	0.0	0.0	0.0
11									0.0	0.0
12										0.05
13										0.05
14										0.05
Cumulative	0.45	0.45	0.5	0.7	0.75	0.75	0.8	0.8	0.85	1.0

Table 10. Percentage of Total Economic Effect on the Navajo Generated by Each Plant Unit, by Time Period and Cumulative.

Power Plant (Unit Number)	Time Period									
	1	2	3	4	5	6	7	8	9	10
1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5				0.0	0.0	0.0	0.0	0.0	0.0	0.0
6				0.3	0.3	0.3	0.3	0.3	0.3	0.3
7							0.1	0.1	0.1	0.1
8					0.0	0.0	0.0	0.0	0.0	0.0
9									0.1	0.1
10							0.0	0.0	0.0	0.0
11									0.0	0.0
12										0.0
13										0.0
14										0.0
Cumulative	0.4	0.4	0.5	0.8	0.8	0.8	0.9	0.9	1.0	1.0

are generated, insights can be gained from the relative differences in magnitudes of effects between decisions.

The Impacts of Full Power Development

Figure 3 presents the individual graphic variable comparisons for the Hopi sub-systems. Table 11 exhibits the numerical output for the variables in the Hopi model, in a comparative setting. Figure 4 presents the graphic comparisons and Table 12 the numerical output for the Navajo sub-system. The graphic comparison offer information for general insights while the numerical output allows for closer analysis. The Hopi model illustrates only six of its variables being impacted by the decision, with individual stress showing the greatest change, while the Navajo model shows a greater number of variables being impacted by the full power development decision.

Any other decision within our defined decision space can be made and its impacts on the social sub-systems models of the Hopi and Navajo assessed. The basic software used in this research allows the outputs to be retrieved as numerical listings and composite graphic displays. Each decision requires a separate computer run and graphic variable comparisons and numerical comparisons must be made manually. The recent availability of an interactive CRT terminal has made it possible to instantaneously illustrate graphic comparisons. With this interactive mode, the decision, Indian tribe, and variable are manually selected, and the machine makes the calculations and outputs the comparative graphic display as one observes. The interactive mode increases the usefulness of the model in its ability to isolate the impact of a decision on a

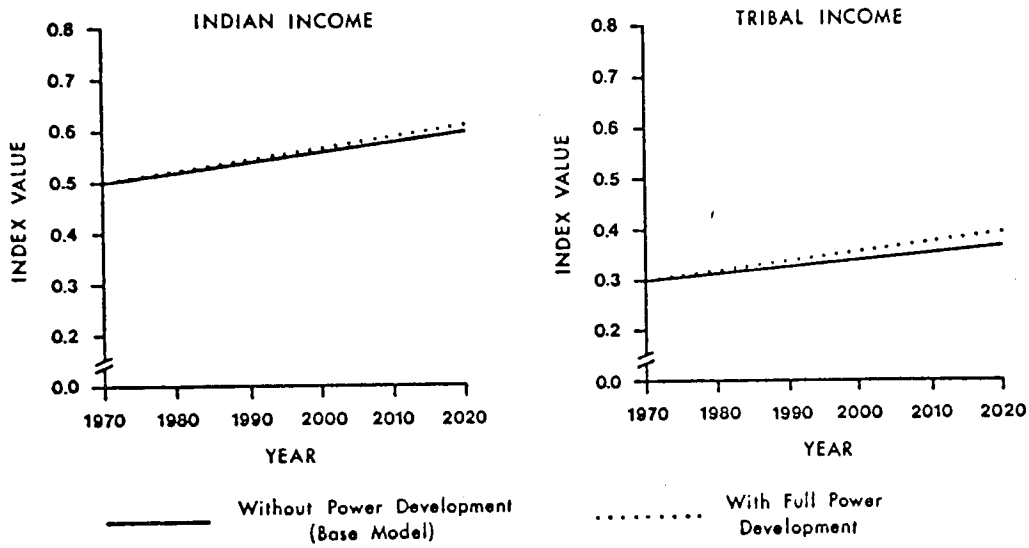

Figure 3. Hopi Social Sub-System Model.

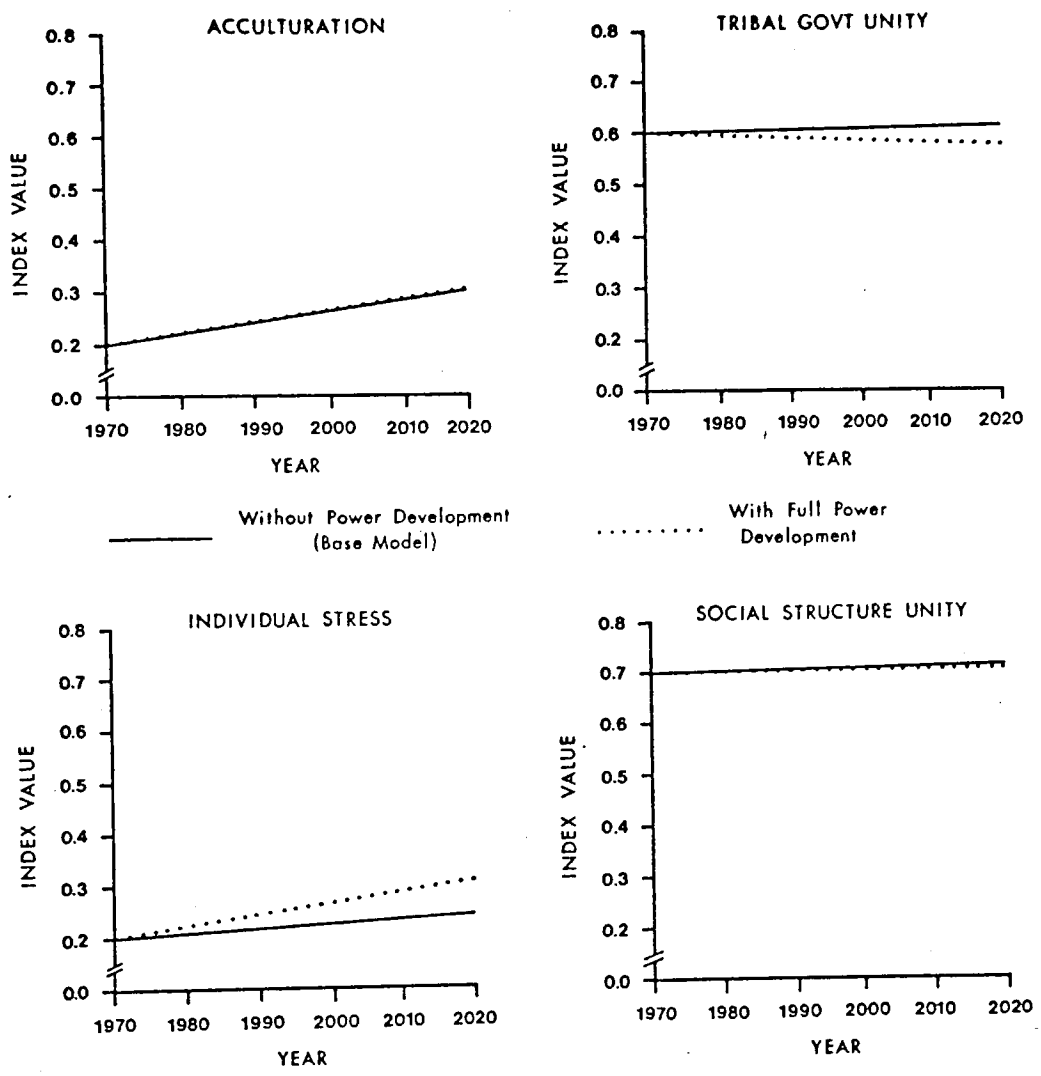

Figure 3. (continued)

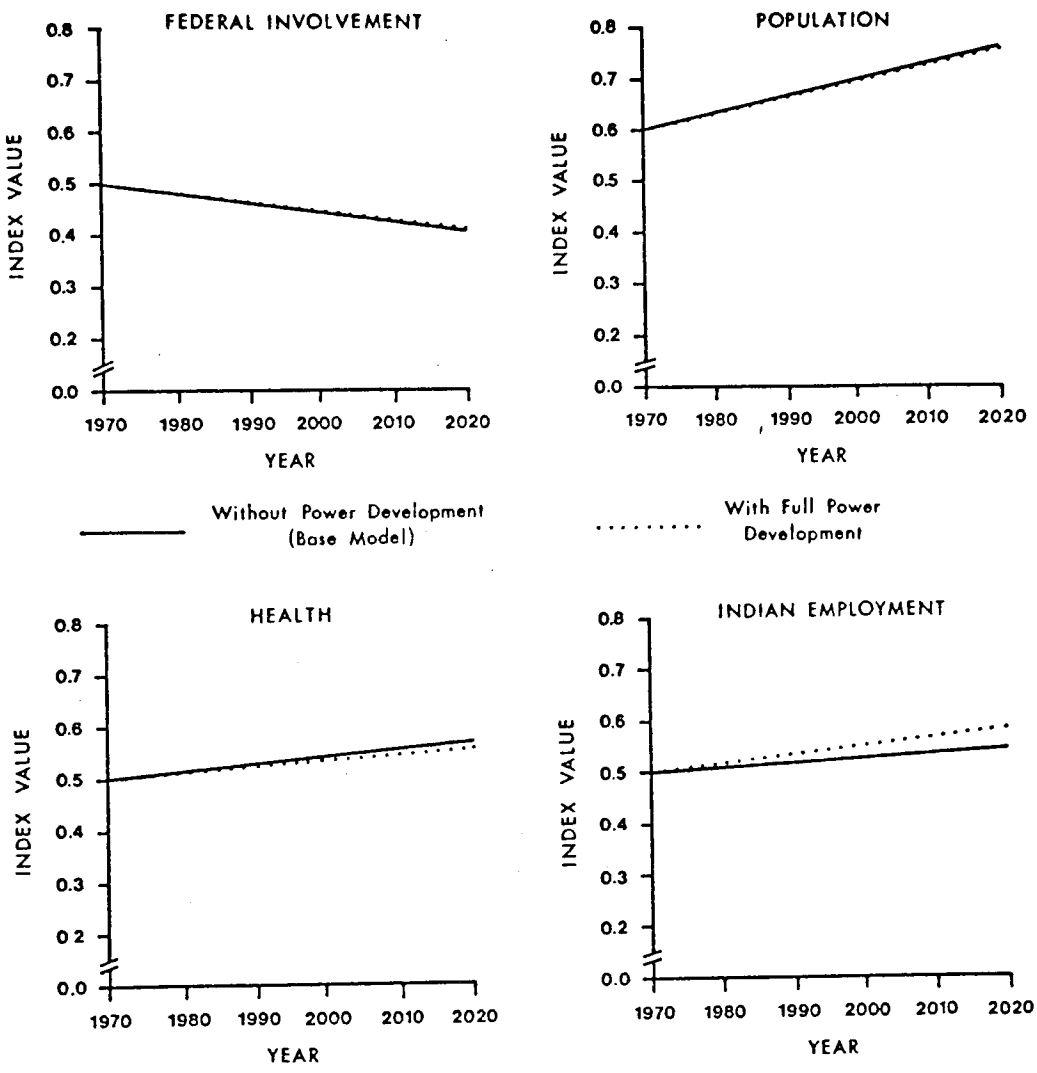

Figure 3. (continued)

Table 11. Hopi Social Sub-System Model.

Variable	Numerical Output Comparison: Full Impact Year					
	1970	1980	1990	2000	2010	2020
Acculturation						
Simulation	.200	.216	.236	.257	.279	.302
Full Impact	.200	.216	.236	.257	.279	.303
Individual Stress						
Simulation	.200	.206	.213	.222	.231	.240
Full Impact	.200	.213	.237	.263	.290	.318
Tribal Government Unity						
Simulation	.600	.602	.604	.607	.610	.613
Full Impact	.600	.599	.593	.588	.584	.579
Social Structure Unity						
Simulation	.700	.701	.702	.703	.704	.705
Full Impact	.700	.701	.702	.703	.703	.704
Federal Involvement						
Simulation	.500	.486	.469	.452	.435	.417
Full Impact	.500	.486	.469	.452	.435	.418
Health						
Simulation	.500	.514	.530	.545	.560	.576
Full Impact	.500	.513	.527	.541	.555	.568
Population						
Simulation	.600	.634	.670	.704	.736	.767
Full Impact	.600	.634	.670	.704	.736	.766
Indian Employment						
Simulation	.500	.508	.517	.526	.535	.545
Full Impact	.500	.512	.529	.546	.563	.580
Indian Income						
Simulation	.500	.519	.540	.561	.582	.603
Full Impact	.500	.519	.542	.565	.589	.612
Tribal Income						
Simulation	.300	.313	.327	.341	.355	.368
Full Impact	.300	.315	.335	.354	.373	.392

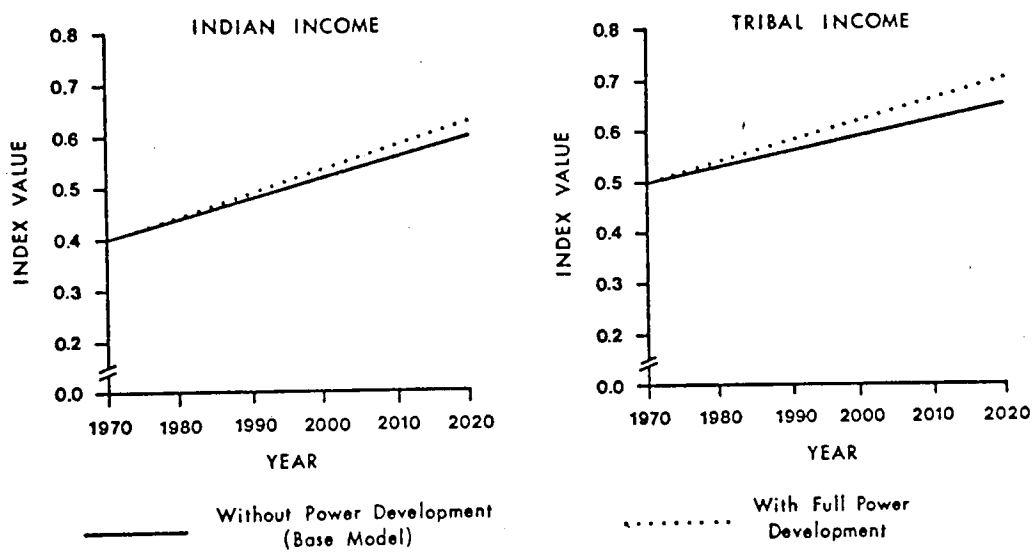

Figure 4. Navajo Social Sub-System Model.

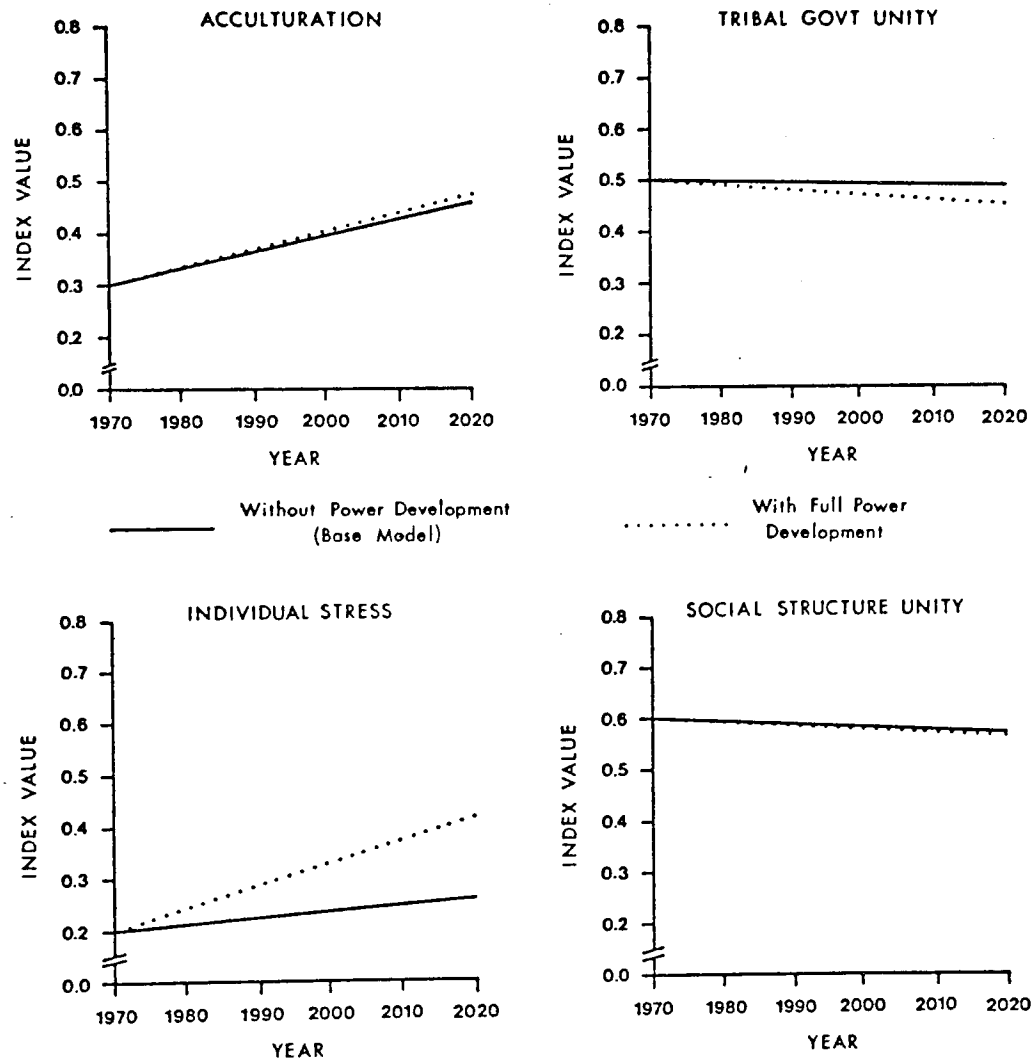

Figure 4. (continued)

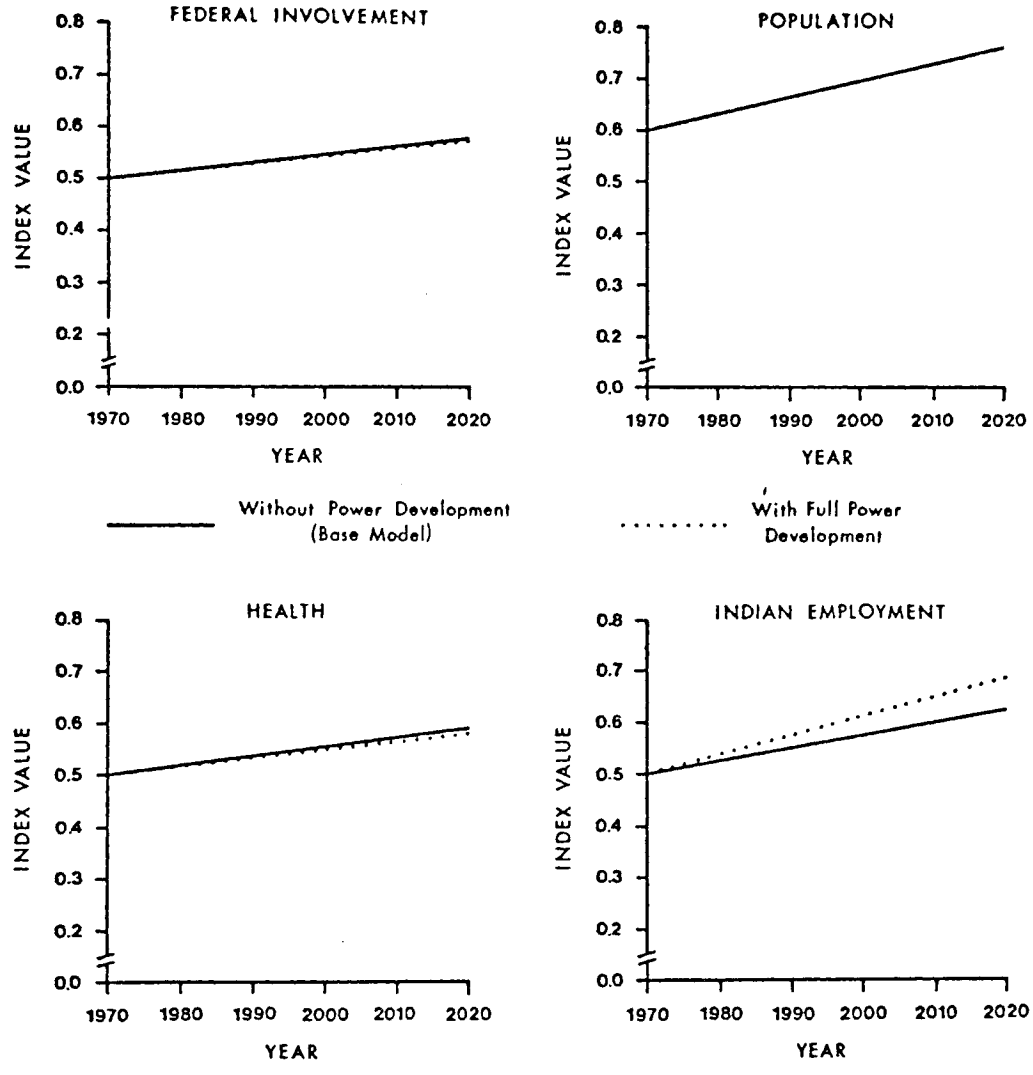

Figure 4. (continued)

Table 12. Navajo Social Sub-System Model.

Variable	Numerical Output Comparison: Full Impact Year					
	1970	1980	1990	2000	2010	2020
Acculturation						
Simulation	.300	.327	.358	.391	.426	.461
Full Impact	.300	.327	.359	.393	.429	.466
Individual Stress						
Simulation	.200	.209	.220	.233	.247	.262
Full Impact	.200	.223	.269	.318	.369	.421
Tribal Government Unity						
Simulation	.500	.499	.498	.497	.496	.495
Full Impact	.500	.495	.486	.476	.466	.456
Social Structure Unity						
Simulation	.600	.595	.589	.584	.577	.571
Full Impact	.600	.595	.589	.583	.576	.569
Federal Involvement						
Simulation	.500	.514	.531	.548	.565	.583
Full Impact	.500	.514	.531	.547	.564	.582
Health						
Simulation	.500	.516	.534	.552	.571	.590
Full Impact	.500	.515	.532	.549	.567	.585
Population						
Simulation	.600	.634	.670	.705	.737	.768
Full Impact	.600	.634	.670	.704	.737	.768
Indian Employment						
Simulation	.500	.524	.551	.577	.603	.629
Full Impact	.500	.531	.574	.614	.653	.689
Indian Income						
Simulation	.400	.435	.476	.518	.561	.603
Full Impact	.400	.438	.484	.532	.581	.629
Tribal Income						
Simulation	.500	.530	.562	.593	.623	.652
Full Impact	.500	.537	.584	.628	.668	.705

specific tribe and variable quickly, and provide for the selective sifting of all possible model outputs. Layton (1975) utilized the interactive mode in presenting the Hopi and Navajo models as well as many other categories of impact models within the context of the information system. User feedback rated the system very high in terms of quickness and ease of information retrieval, and when compared to other modes, users of Layton's system were impressed by the wide range of information that could be retrieved from this single source.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

Assessing the effects of coal-fired energy development on the natural and cultural environments of the Southwest and communicating information on those impacts to interested groups and individuals were the main objectives of the Four Corners Program.

The portion of the research described in this dissertation is that related to the assessment of social and economic impacts on Native Americans. A description of impacts on groundwater can be found in Dove (1973). Regional economic impacts are described in Everett (1974) and a description and analysis of an information system combining all categories of impacts is in Layton (1975).

The conclusions of this research fall into two categories: First, the conclusions of the modeling process and second, conclusions related to the acceptance and usefulness of the results when presented in the context of a comprehensive information system.

The modeling is an approach to make an objective analysis of an emotional issue, and gain insights into the impacts of energy development on Native Americans. The magnitude of impacts on Native Americans of environmental and economic consequences of energy development were found to be minor. Both the economic benefits claimed by proponents of the developments and the social disruptions claimed by opponents of the developments were found to be exaggerations.

Specifically, the difference in the value of the Individual Stress variable between no development and full power development was projected by the model to be 0.078 and 0.159 for the Hopi and Navajo, respectively. Since the scale ranges from 0.000 to 1.000, these differences represent 8 and 16 percent of the maximum value. Projected differences in the value of the Individual Income variable between no development and full power development are 0.009 for the Hopi and 0.026 for the Navajo. As demonstrated by the model results, the impacts are greater for the Navajo than the Hopi. These projections are, of course, completely dependent upon the structure and coefficients in the model. While the model is a set of interacting coefficients, the most important coefficients are the ones relating the environmental impacts of power development on Individual Stress, and the impact of Indian Employment on Indian Income. In the Hopi model, for example, the Individual Stress variable is related to the environmental impacts of power development by a coefficient equal to 0.1. This reflects the fact that no power plants or related facilities are in a close proximity to the Hopi Reservation and the judgment that mining activities on Black Mesa are not of great concern to the Hopi. If a greater concern was detected and documented, a larger coefficient would have been employed, an increased impact related through the model and thus greater impact displayed through the Individual Stress variable and other variables impacted by Individual Stress. The impact of Indian Employment on Indian Income is characterized by a coefficient of 0.2. This relates that the Hopi will not respond to employment potentials created by power development. This conclusion by the researchers is a result of past Hopi propensity to not take

employment in similar job categories and the distances between the Hopi Reservation and the power plants in the decision space. If the Hopi were likely to accept employment opportunities such as those made available through power development, the coefficient would have been larger. A marked increase in the Indian Income variable would result from a larger coefficient and would relate that for the same increase in employment potential due to power development, the Hopi were accepting the positions and experiencing increased incomes. Corresponding coefficient values for the Navajo are 0.2 and 0.3. These higher values reflect that the Navajo are in a closer proximity to planned and existing energy development, stand to be more directly impacted by the environmental effects of the development and have a greater propensity to accept employment opportunities like those created by energy development.

The results of the modeling approach were included in an information system developed as part of the Four Corners Program by Layton (1975). The system, all of the impact categories developed during the Four Corners Program, was demonstrated to prospective users and their reactions recorded. Within the context of the information system, the models were considered useful, convenient, and as credible as the primary sources of information (i.e., impact statements, periodicals, and personal contacts), and more credible than the mass media. When compared to the other impact categories, Layton (1975) relates that the Native American model was considered unbiased. Users spent more time interacting with the Native American simulation model than any other category and rated the clarity and completeness of the model highly. It is significant to note that the modeling application developed in this research was rated in a very

positive manner by users of the system. This supports the premise that models of the social impacts of resource development are useful and will be accepted by persons involved in making resource decisions. Since such models facilitate objective analysis, their application should lead to better decisions.

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