ENERGY BASIS FOR MIAMI, FLORIDA, AND OTHER URBAN SYSTEMS

By

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James John Zucchetto

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Chairman: Howard T. Odum
Major Department: Environmental Engineering Sciences

This dissertation presents a systems study of Miami, Florida, with data collected for the years 1950-72, cross-correlation analysis of the data, calculation of urban indices, computer simulation of mathematical models, construction of a land use map, calculation of major economic, fossil fuel and natural energy flows, estimations of energy available from solar energy technology, and a theory relating economic competitiveness to the ratio of natural to fossil fuel energies. The urban system of Miami and Dade County, Florida, was used as a study area but the theory and approach could be used for any urban system.

An overall detailed model of the urban region of Miami, Florida, was created showing major flows and storages in the system and time series data were collected for 1950-72. Cross-correlation analysis showed significant levels of correlation between the rate of change of fossil fuel use and the rates of change of population, budget, sales tax, income,

building structure, and number of telephones. Calculation of several urban indicators for 1972 showed a fossil fuel energy density of 300 $Kcal/m^2/day$ in the urbanized area, a per capita energy consumption of 53.8×10^6 Kcal/capita/yr, a ratio of natural to fossil fuel energies of 0.25, a developed area of 260 square miles, a building growth of 150 million square feet, and a rate of development of 6.5 square miles per year. Tables and graphs of these and other variables are presented from 1950 to 1972 to identify trends.

Based on the overall model of Miami, several mathematical models for the Miami-Dade region were simulated using analog computers. These models consisted of systems of first order in time, non-linear differential equations which included fossil fuel energy flows, main economic flows, external price functions, building structure, natural energies, and population. These equations were derived from a general theory of human systems based on energetic and ecological principles. These models were simulated for several linearly increasing functions for price and several sets of available energy functions. Based on existing available energy trends and the rate of increase of price, the urban region of Miami and Dade County should reach a maximum point of growth around 1976. If additional net energy above past levels can be supplied in the future, then growth may continue until 1985 with the population leveling at about 1.6 million. Increasing prices for fuels cause structure to peak earlier and sooner while diminishing the use of fossil fuels.

Tables of economic and energy flows were constructed through calculation or estimation. To calculate the energies associated with the natural systems in the county a land use map was drawn and subsystem areas determined. Estimating the productivities of these systems on a per area basis then allowed calculation of total energy flows. The energies associated with winds, tides, waves, and fresh/salt water concentration gradient were also calculated. These energies were compared to fossil fuel energies by using the concept of energy quality and it was found that the ratio of natural to fossil fuel energies changed from 0.77 in 1950 to 0.25 in 1972. It was hypothesized that regions with higher natural to fossil fuel energy ratios can compete more effectively since they have greater natural energy subsidies.

It was calculated that recycling of garbage could produce, at most, 2.7% of the fossil fuel energy consumption while solar energy technology used for hot water heating could save, at most, 3.5% of the total fossil fuel energy used in 1972. The energy flows associated with primitive, electrical, natural, gas, and solar water heaters are presented. The relationship of prices, money, and energy flows are discussed for urban regions in general and related to the future of Dade County in particular.

As a final point of interest, an order-disorder formulation of the urbanization of South Vietnam was constructed which included main flows of money, growth of natural and urban systems, and destruction due to herbicides and general warfare. Results are presented for an herbicidal pulse lasting five years and different levels of U.S. aid.

INTRODUCTION

Perhaps the most complex and least understood systems of man are cities and urban regions which seem necessary for exchanges of energy, information, money, and goods between men and institutions. Understanding of urban systems is desperately needed for coping with the last thirty years of the twentieth century because of the intense and rapid changes occurring. The United Nations estimated that the urban populations of the underdeveloped countries will quadruple by the year 2000 and that those of the developed nations will double. Will this trend continue or will it change as a function of available world supplies of energy? Can energy predictions be used to implement accurate and adequate planning for the basic needs of these urban populations? Can economic forces driving migrations be ultimately reduced to energetic considerations and these be used to predict migrations, availability of jobs in cities, and mechanization of agriculture on the farms?

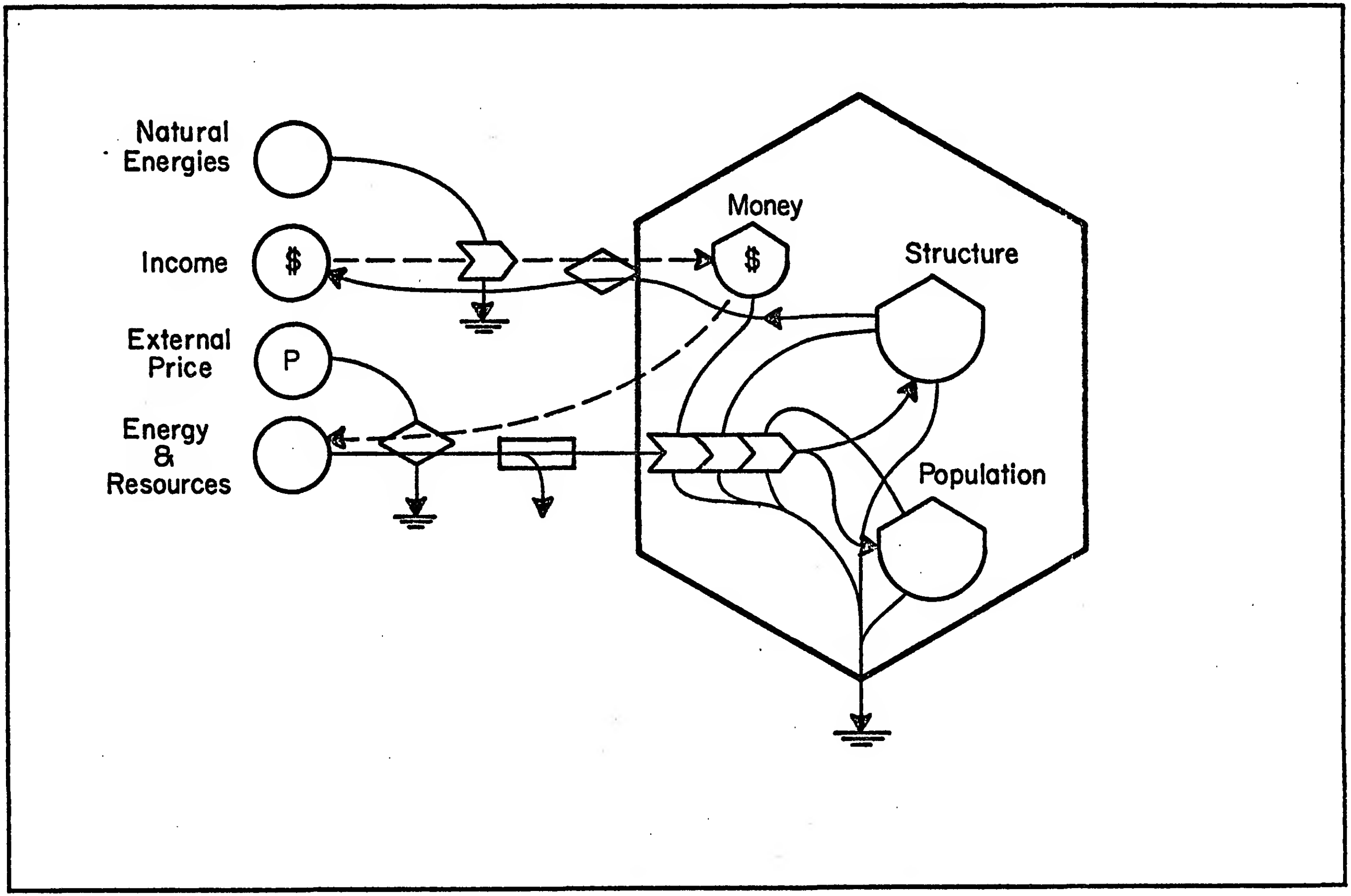
The energy crisis of 1973 dramatically outlined the dependence of the American economy and its subsystems on fossil fuel energies. In order to relate the structure and functions of cities and their supporting regions to energy, models and calculations were made to show main principles for urban growth and change considered in overview. In this study a general energy basis for cities is presented. Detailed applications, evaluations, and simulations were applied to Miami-Dade County, Florida and other cities.

The contributions of natural system energies are important in Dade County because of their multiplier effects on tourist flow and the general life support of the basic functions of maintaining air and water quality. Is there a limit to fossil fuel development in relation to natural energies above which the system loses tourist or economic viability? What is the value of these energies to a future steady-state urban system for possible energy futures? The future will be characterized either by a low level of fossil fuel availability and no net nuclear energy source or further growth based on new energy sources. By taking a macro-scale approach to the urban system this dissertation presents a theoretical framework for understanding cities.

Urban growth in the United States has accelerated in recent decades. This has facilitated competition with the rest of the world by maximizing growth rates and the utilization of unused energy reserves. Urbanization has followed the maximum power principle which says that those systems survive and compete best which maximize their power flow (Lotka, 1922). High energy components of cities have emerged and have required enormous resources for support so that the city system can continue to function. Is this trend shifting? Since there is little experience with a steady-state economy, serious study and thought are needed to determine the characteristics and behavior of a steady-state city. There is a plethora of studies on individual projects and aspects of cities including population, transportation, economics, racial distributions, housing, water supply, etc., but very few studies for an urban region as a whole with consideration of some basic parameters and with energy as a common denominator for appraisal of the basic outside forcing functions. Many have felt that a model of an entire urban region is too complicated, with thousands of parts recognized when one examines a city in micro-scale. However, if a complex system is considered at a macro-scale level by lumping components, a manageable model can be constructed to show gross effects which eventually are propagated down to the micro-scale level (Odum and Peterson, 1972).

A very simple model showing some of the basic inflows to a city along with some of the principal storages within the system is diagramed in Fig. 1 (for an explanation of the symbols, see Fig. 3 in the Methods section). The source labeled income represents the flow of money entering the system and is shown to be pumped by natural energies. This represents, for example, tourism. The source labeled resources includes all the purchased energy and materials necessary such as fossil fuels, food, water, goods and people and the source labeled free natural energies represents the work services of the natural system in support of man. The internal storages consist of structure, money available to spend,

Fig. 1. Simplified model of an urban system showing flows of money, natural energies, and fossil fuel resources into the system. Price is determined external to the system. Storages within the system are money available to spend, building structure, and number of people, all of which interact multiplicatively with external sources to generate growth.


Natural
Energies
Income
$
External
Price
P
Energy
&
Resources
Money
$
Structure
Population

and number of people. The structure, population and money storages of the system act in multiplicative action to add new structure and population to the system. Money flow from outside can come from many sources. The heat sink drains from storages represent depreciation while those at the multiplier symbols represent heat losses due to energy conversions. Can a model as simple as this with its aggregation show, through simulation, the change in the growth of structure as a function of changes in the supply of money and resources along with changes in prices occurring in the larger economy encompassing the city? Simulation results of models similar to this are presented. Theoretical studies are included to suggest a class of overview mini-models which can be generally substituted for detailed city models with similar results.

American urban systems have been characterized by rapid, successional type growth without much recycle. The model in Fig. 1 does not show any explicit recycle pathways but if this were a steady-state or declining city recycle pathways would be included. In natural ecosystems there is a cycle of growth and decay in which the dead parts are reorganized into living structure through an interaction with an outside energy source, usually sunlight. This can be thought of as a general order-disorder cycle which is representative of all processes in nature. This principle is applied later in this dissertation to the urbanization of an entire country, namely, South Vietnam.

Dissertation Research Outline

The purpose of this dissertation is the study of the energy-economic basis for urban systems with specific reference to the region of Miami-Dade County, Florida. To this end models were developed which indicated the response of the urban system to available energy and outside price functions over time. Time-series data were collected for the urban system of Miami-Dade County for as many of the gross parameters of the urban system as it was possible to collect data for. These parameters included energy consumption, building structure, population, money flows, land development, water consumption, tourist flows, transportation structure (vehicles), waste generation, etc.

The creation of conceptual and mathematical models were accomplished using the energese symbols (H. T. Odum, 1971) for detailing the overall system functions and interactions. These models are usually too complicated for simulation but indicate major pathways, interactions and, along with descriptive tables indicating numerical values, allow comparisons between the magnitudes of different pathways. Starting with the overall complex model of the urban system, several simplified models were derived and simulated in order to determine the response over time to different energy functions, price functions and money income. Although the exact numerical value of certain parameters is uncertain, e.g., available energy, simulations are conducted for parameter variation so that families of curves are generated. This at least gives an estimate of a predicted value range for variables of interest within the system. All of these models involve the solution of systems of first order, non-linear equations, which means they contain first derivatives with respect to time and products of two or more state variables, equations of the form

$$\frac{\partial Q_i}{\partial t} = \sum_{K=j}^{P} I_{iK} + f_i(Q_1; \ldots Q_N; I_1, \ldots I_j)$$
$$i = 1,2, \ldots, N$$

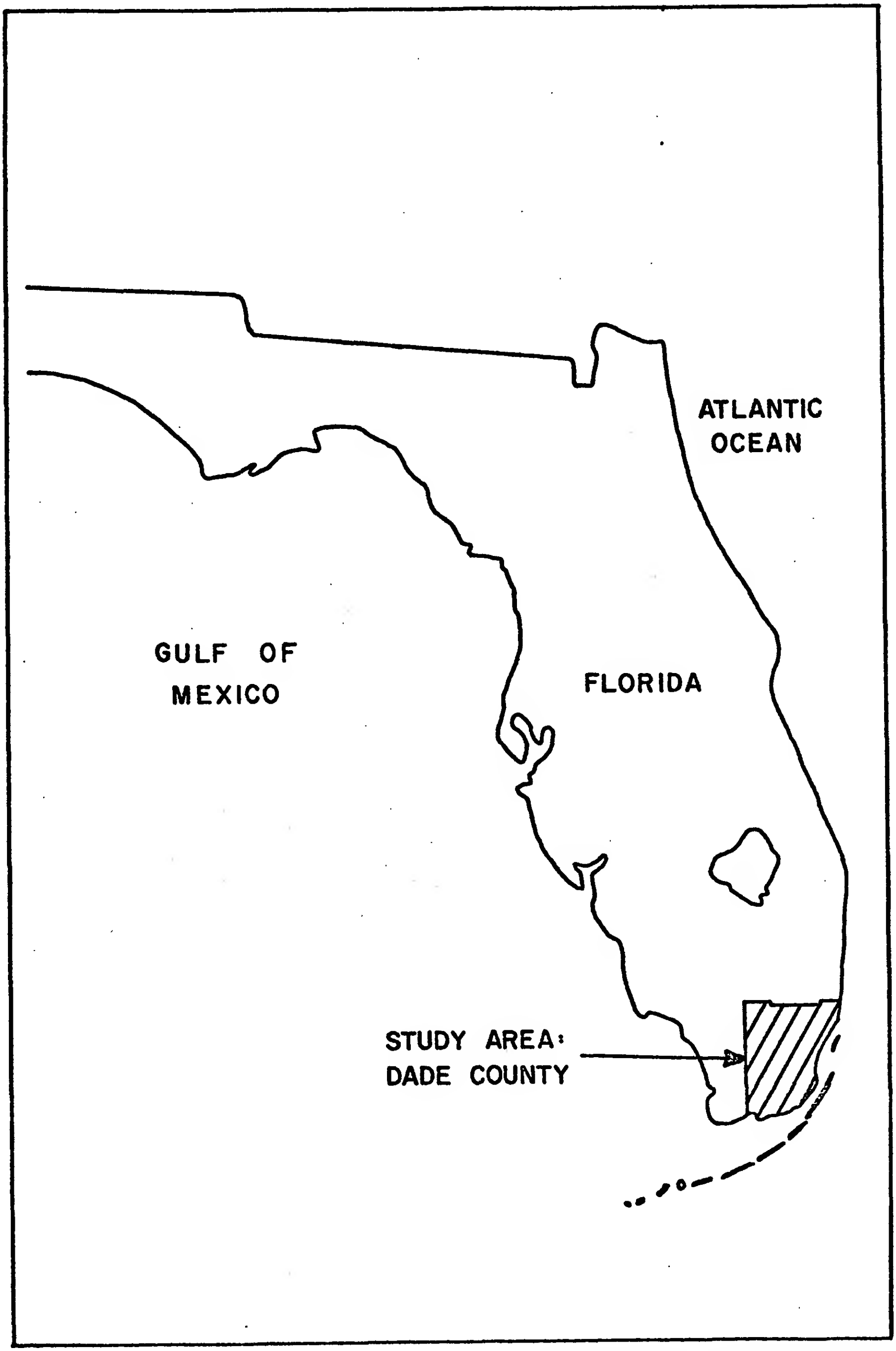
where I_j and I_{iK} are some general forcing functions, Q_i are the state variables, f_i is a non-linear function, and N is the number of equations. The combined system of equations represents a system of N^{th} order. Thus, the simulations contained herein investigate the behavior of non-linear system theory applied to urban systems along with the applicability, sensitivity and validity of such formulations. This is of importance because of the overwhelming use of linear, economic models. Aside from simulation results correlation analysis was conducted and interpretation of the time-series data was attempted. The accumulation of the data for the Miami region is important in itself for they can serve as a reference for other studies.

Land areas of subsystems contained within Dade County were calculated from land-use maps derived from aerial photographs. These subsystems included urban and natural systems such as residential and commercial areas, swamps, hardwood hammocks, and mangrove swamps. Estimates were made of the productivity of each of these systems and an energy system spectrum was calculated. The general theory of urban systems is discussed and calculations of basic energy indicators were made for the Miami-Dade system which can serve as yardsticks for comparisons with other urban systems. Energy budget calculations were also made to estimate the energetic value of money flows in the system and contributions from solar energy technology were estimated.

Description of the Study Area

Located in the southern portion of the state of Florida, latitude 25°47' North and longitude 80° West, the Miami-Dade County region is an area of approximately 2,000 square miles (see Fig. 2). Originally covered by vegetation of the type found in the Everglades National Park, it has rapidly been transformed since extensive drainage, dredge and fill operations, and agricultural and urban development began in the early 1900's. Most of the urban development has occurred along an above-sea level strip of land paralleling the east coast known as the coastal ridge. In the process of growth, many species of plants and animals have been destroyed and as much as 90% of the wildlife of the Everglades has disappeared. However, the magic of the name Miami as a subtropical paradise was maintained for a long time and tourists were attracted by the sunny beaches, mild weather, natural

Fig. 2. Map of Florida showing the location of the urban region of Dade County.


ATLANTIC
OCEAN
GULF OF
MEXICO
FLORIDA
STUDY AREA:
DADE COUNTY

subtropical ecosystems, sea breezes and moderate temperatures maintained by the offshore Gulf Stream. Summer temperatures average 81°F, winter temperatures 61°F, relative humidity is usually between 50 and 85, and 60 inches of rain fall per year. The additional diversity of luxury hotels coupled with the natural systems acted as a magnet for tourism and money income. Up until recently tourism was the main source of income with some 10 million tourists visiting the county in 1973. In recent years the economy diversified with light industry and aircraft related businesses, and Miami has become a major embarkation point to Latin America and Europe. Manufacturing plant employment increased from 29,000 in 1954 to 77,000 in 1970.

The northern portion of the county is heavily urbanized (>10 persons per acre) with this urbanization continuing northward into Broward and Palm Beach Counties; this developed coastal strip is known as the Gold Coast. Miami Beach is an island off the east coast, world famous, and intensely developed with large, high-rise hotels and apartments. The major means of transportation is the automobile with the Palmetto expressway, I-95, U.S. 1, and Old Cutler Road acting as main arteries through the region. As in most other large American cities there are concentrations of poor people in and around the downtown area with high crime rates, low income, and substandard housing. The average income level is higher in the southwest and southern portions of the developed area and is characterized by modern, single family residences. Urban development has proceeded southward, influenced directly by southbound U.S. 1. Growth is also taking place about Homestead and these two urbanized areas are creeping toward each other along the U.S. 1 route. The western and southern portions of the county are covered by extensive areas of marsh grasses with intermittent hardwood hammocks and cypress domes. The county is also covered by 238 x 10^6 sq. meters (59,000 acres) of agricultural land, tomatoes being a principal crop. Along the southern and eastern coasts are systems of mangrove trees. The major power station is located at Turkey Point.

The southern portion of Florida has long had plentiful quantities of water during the rainy season with large sheet flows occurring from areas north of the county near Lake Okeechobee to the southwestern and southern shores of Dade County. These large flows of water occur mainly along the Shark river slough. The county is also underlain by an extensive, shallow fresh water aquifer known as the Biscayne aquifer, 1,500 square miles of which lie within Dade County. Approximately 38 inches of rainfall passes through the Dade County portion of the aquifer, which is approximately 2.72 x 10^9 gallons per day. This aquifer is the result of extensive formations of permeable limestone rock; this rock is the only mineral resource in the county. The county is also underlain by a deep aquifer (approximately 800 feet deep) of brackish and salt water known as the Floridian aquifer, which is separated from the Biscayne aquifer by a layer of impermeable rock. In an attempt to control floods, manage water supplies, and develop agriculture and urban areas the Federal government has created an extensive system of canals, levees, dams and pumps to regulate water flow. The canals prevent flooding by passing water quickly to the sea, but this lowers the water table, increasing the chances for salt-water intrusion. Local pumping near the coastline has also increased salt-water intrusion. The majority of water that used to flow to the Everglades has been diverted, a major reason for the extensive decline in that ecosystem. This system of man-made water control structures has radically changed the makeup of the county. Biscayne Bay borders the county on the east and pulse discharges of water from the canals stress this aquatic habitat.

The population of Dade County in 1973 was approximately 1.3 million, starting from a mere seventeen hundred people in 1900 and net in-migration was approximately 40,000 people per year. There were large migrations of Cubans in the late 1950's and early 1960's because of the Cuban revolution. They migrated into the downtown area and the approximately 300,000 Spanish-speaking residents of the county, 200,000 of whom are Cuban, give it a distinctly Spanish flavor. Migrations of blacks from the rural areas have resulted in 189,000 blacks living mainly in the downtown areas. Politically, the county consists of 27 municipalities which were incorporated in 1957 under the Metropolitan Dade County Government, while 40% of the population still lives in unincorporated areas of the county.

Review of Previous Miami Studies

There have been many reports compiled dealing with the economic, historical, physical, and social aspects of the Miami-Dade region. The following paragraphs summarize many of the reports which have been published dealing mainly with the economic and physical aspects.

The Metropolitan Dade County Economic Survey (November, 1970) gives a brief review of the economic and social state of Dade County including statistics on business, climate, health, education, economic indicators, transportation, utilities, population and services. It focuses on the attractive aspects in order to encourage business and people to migrate into the county. The report, "Profile of Metropolitan Dade County: Conditions and Needs" (Goode, 1972), is a compilation of spatial and temporal data for population, environment, economy, housing, health, education, leisure time, public safety, transportation and social services. The report contains well-illustrated maps depicting such things as racial distributions, transportation systems, incidence of disease, parks, incidence of crime, environmental quality index, and other parameters. The report, "Facts and Figures Show How DADE DOES IT RIGHT" (1972), put out by the Miami-Metro Department of Publicity and Tourism is a compilation of information showing employment, income, indebtedness, budgets and several indicators of growth which are supposed to indicate the viability, attractiveness and growth potential of the region. Greeley and Hansen (1972) evaluated fifteen wastewater disposal plans and recommended construction plans for wastewater treatment facilities based on projected population growth. Hartwell et al. (1973) summarized the limits of water availability to Dade County and attempted to show in a general way the stress of increasing population on the water supply and other parts of the system. Studies by Klein (1957,1965,1971), Kohout and Klein (1967), Meyer and Hull (1967), Hull and Galliher (1970), Galliher and Hull (1969), Parker et al. (1944) and Leach and Grantham (1966) deal with hydrological conditions and the effects of water discharge and pumping on various areas of the county. Salt water intrusion is mapped as is fresh water head. Road and expressway development plans for midtown Miami based on anticipated growth are contained in "Multiple Use Opportunities for Midtown Miami" (1971). Several ecological studies of specific systems within Dade County have been completed by Bader and Roessler (1972), Wilson (1973), and McCoy (1973). These studies dealt with Biscayne Bay, soil arthropods, and algal mats. The Dade County Economic Base Study (1960) analyzes Dade County's personal income position. For a development just north of Dade County, Veri (1972) tried to assess the impact of the development on the surrounding area, a small-scale systems approach. It was concluded that the impact on the existing neighborhood would be undesirable and that population increases in the region should be greatly curtailed.

Several investigators have attempted to look at the problems of South Florida and Dade County in a holistic or interdisciplinary fashion. Marshall (1972) discusses the carrying capacity of South Florida and the interaction and interdependence between the Everglades and the Gold Coast. The implication is that the South Florida system is already overtaxed and as the Everglades goes, so goes South Florida. Buchanan (1973) in the RALI report has provided a sampling of information for 1,800 square miles in the southern part of Dade County which should help in creating solutions for representative problems in the county. This report seems to focus on the technological alternatives which are necessary to provide the services needed for an expanding population. First Research Corporation (1973) conducted economic studies for the state of Florida by dividing the state into five market areas. One of these areas included Dade and Broward Counties, containing the area known as the Gold Coast, a strip running along the coast. This study attempted to predict future market demand by projecting past population and economic growth into the future and thus predicting demand. No effect of outside energy and inflationary pressures was included in this analysis.

Summary of Urban Modeling Approaches

While this dissertation emphasizes an energetic-ecological approach to urban systems there are other modeling approaches which have been applied. The following paragraphs briefly describe some approaches used by other investigators.

Economic-Demographic Models

Economic based models. The external sector is the exclusive generator of growth with an assumed linear relationship between the level of external activity and that of local activity. Growth depends on external demand and supply factors are disregarded. No consideration is given to available energy (Yujnovsky, 1972).

Income expenditure models. Aggregates of components in the economy are defined based on sources of regional income and product. This goes a step beyond the previous model in that local demand is considered. There are extensive data requirements and field research necessary. For example,

$$V + M = C + I + G + X$$

where V = regional product,

M = imports,

C = regional consumption,

I = regional investment,

G = regional government expenditures, and

X = regional exports.

The method still lacks supply or available energy considerations (Yujnovsky, 1972).

Input-output analysis. Disaggregates the economy into n sectors so that production of one sector can be expressed by means of

$$X_i = \sum_{j=1}^{n} X_{ij} + Y_i \qquad (i = 1,2, \ldots n)$$

where X_i = total production of sector i,

X_{ij} = production of sector i to be used as input to sector j, and

Y_i = final demand.

Now, $X_{ij} = A_{ij}X_j$

where A_{ij} is the input-output coefficient as the minimal input required to produce a unit of a particular output. Substituting

$$x = Ax + y \qquad \text{(matrix)}$$

$$x = (I-A)^{-1}\ y$$

which is a set of linear, simultaneous equations. Basically, it is an accounting scheme to keep track of the interdependence of different sectors of the economy and is applicable for a system in equilibrium or for small changes about the reference or nominal systems.

Programming models. These consist of linear equations for which some objective function is met such as maximizing net income or minimizing the total cost of the use of resources. The market is defined in advance as a set of fixed prices for all consumption goods (Yujnovsky, 1972).

Simulation. Attempts to take into account the complex interdependence, feedbacks and non-linearity of social systems. It is assumed that the levels and rates of change of a set of components describe the state and changes of the system (Forrester, 1971). These models are usually not spatial in character although they could be used as such.

Demographic models. Population prediction models which have socio-economic variables as important parameters. The phenomenon of migration is poorly understood and usually jobs are used as a main attraction. Gravity, diffusion and probability models have been used to describe migration (Yujnovsky, 1972). This is probably where energy available to urban and agricultural regions should be considered.

Spatial Distribution Models

Location theory. Revolves about the theory that the location of a city will coincide with the least transport cost location with respect to the source and market of raw materials.

Central place theory. Central place refers to the location of a city as an area performing retail and service functions for surrounding areas. The two results of this theory are that the area served increases exponentially with the population size of the center and that the total number of establishments varies exponentially with both population size of center and total population densities (Berry, 1964).

Rent theory. Each activity in the urban area minimizes the sum of rent and transportation costs. Various schemes are developed for trade-offs between these costs and expressions are assumed for these costs as functions of distance (Yujnovsky, 1972).

Gravity models. Distributes residential population by relating places of residence to places of employment and allocates service activity by relating its employment to the spatial distribution of population. The number of trips between two areas i and j is given by

$$V_{ij} = V_i \sum_k \frac{A_i d_{ij}^{-b}}{A_k d_{ik}^{-b}}$$

where V_i = total number of trips generated at i,

d_{ik} = measure of distance between zones i and k, and

A = = a constant.

Transportation and trip generation models. These models are concerned with trip generation as a function of socio-economic variables, trip distribution, choices among different modes of transportation, estimates of travel demand and predictions of traffic volume at both micro-macro and inter-intra urban levels (Yujnovsky, 1972).

Ekistics. The term ekistics has been used extensively by Doxiadis (1963) and means the study of human settlements. Doxiadis, an architect, has chosen to look at the general spatial patterns of cities from an historical, cultural and functional point of view. Unlike most of the previous approaches mentioned above, Doxiadis chooses to rely more on intuitive judgment when trying to design a functional pattern to meet human needs. In particular, his consulting firm has proposed a transportation network and master plan for downtown Miami which relies heavily on the automobile although it has provision for the implementation of a mass transit scheme

(Doxiadis Associates, Inc., 1967). Ekistics could also be considered a holistic approach to city spatial planning.

System or Holistic Urban Models

Although the models described above have been viewed as presenting explanations of various aspects of urban systems, they all are restricted to limited parts of the city, e.g., transportation. They also suffer from an economic viewpoint of the world without consideration of some of the basic biologic-energetic laws which drive and limit natural systems and which, theoretically, are an integral part of urban systems. For the most part, use is made of linear equations for description since the techniques for the solution of linear equations are well established. The following paragraphs describe models or views of the world from a macro-system point of view in an attempt to pick out the important variables of the city, connect them into a system, and pick out some important principles which can be used to make judgments about city properties and behavior.

General system theory. It has been recognized that cities or urban areas define operating systems with interlocking parts which exhibit certain properties and perhaps obey several general laws of system behavior. Built into these system approaches may be economic, social, ecological, etc., biases. One of the distinct advantages of a general system approach is that it is not restricted to a particular field of study or a linear description of the system.

Energetic-ecological approach. Several investigators have attempted to look at several aspects of urban and human systems in terms of biological, energetic and ecological points of view deriving from the vast knowledge that has been compiled on the workings of natural systems in order to understand man and his systems, even though they are influenced in as yet unexplained cultural ways. H. T. Odum (1971) applies energy concepts and systems thinking to the systems of man and much of this approach is incorporated in this dissertation. Holling (1969) outlines the similarities between ecosystems and social systems with special reference to ecological stability. A predator-prey model is used to model land development where land acquisition is analogous to predation.

In Ian McHarg's book Design with Nature an approach is presented which attempts to combine the various properties of an area, e.g., physiography, geology, hydrology, plant associations, historical value, etc., in a systematic way in order to develop in optimum locations. Maps are created of each property indicating its value (based on a scale of 1 to 10, for example) by means of shading from black to clear. All of the maps are then overlaid and the areas which come out the darkest (or lightest, depending on the reference) are considered most suitable for development. The technique suffers from the fact that each property is assumed to be independent and if any weighting factor is used it is up to the investigator to make value judgments among the different properties. This approach is an admirable technique for trying to bring together and unite the systems of man and nature in a spatial way--no calculations are made of energetic value. Essentially, it is an architect's ecologically oriented attempt at planning which needs to have a quantitative theory wedded to it.

METHODS

Description of Modeling Language

All symbols used in the model diagrams have been established by H. T. Odum in the development of his energy language. A description, explanation and mathematical description of these symbols can be found in Odum (1971,1972). The symbols used in this thesis are summarized in Fig. 3.

Model Development

Based on previous modeling experience, urban studies, ecological principles, energetic concepts, and discussions with various people, preliminary models are constructed with the aid of the symbols described in Fig. 3. A pictured representation has advantages over mathematical equations in that it allows one to identify interactions more easily. A list of the major outside forcing functions is compiled along with the major storages (state variables) within the system. The topological structure of the model is then created by making assumptions about the interactions between the outside sources and the internal storages. This determines the pathways entering, leaving and internal to the system. The conceptualization of the model also aided in the data gathering process

Fig. 3. The symbols of the energy circuit language used in this dissertation (Odum, 1971,1972).

a. Outside source of energy supply to the system controlled from outside; a forcing function (E).

b. Constant flow source from outside; $J_2 = k_2 J_0 X/(k_r + k_1 X)$, $J_r = k_r J_0$, $J_1 = k_1 X J_0$.

c. A pathway whose flow is proportional to the quantity in the storage or source upstream ($J = k_1 E$). The heat sink represents the energy losses associated with friction and backforces along pathways of energy flow.

d. Storage of some quantity in the system. The rate of change equals inflows minus outflows ($\dot{Q} = J - kQ$).

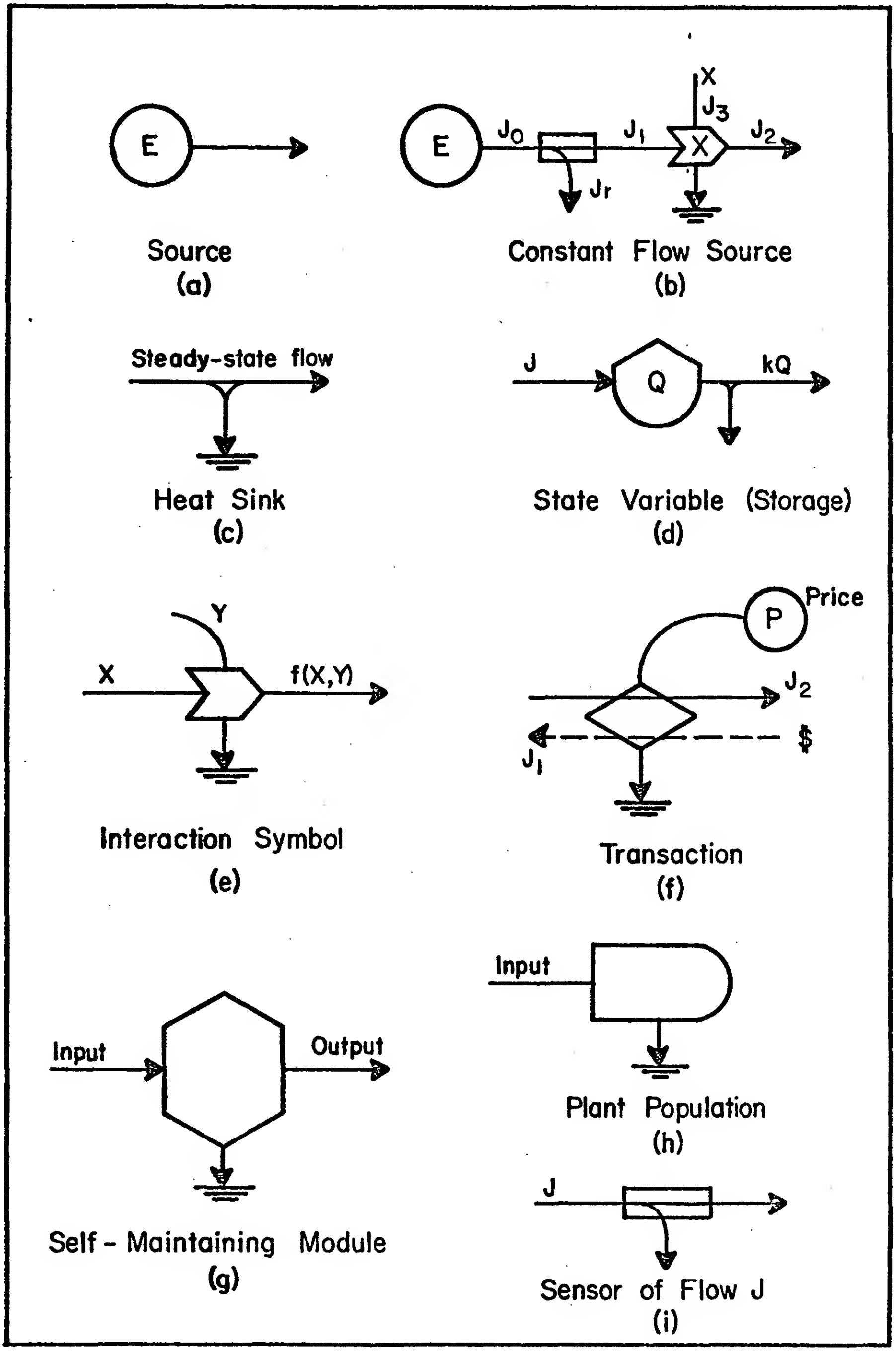
e. Interaction of two flows to produce an outflow which is some function of these flows; usually a multiplicative output, i.e., $f(X,Y) = kXY$.

f. Transactor symbol for which money flows in one direction and energy or matter in the other direction with price (P) adjusting one flow (J_1) in proportion to the other, J_2 ($J_1 = PJ_2$).

g. A combination of "active storage" and a "multiplier" by which potential energy stored in one or more sites in a subsystem is fed back to do work on the successful processing and work of that unit; autocatalytic.

h. Production and regeneration module (P-R) formed by combining a cycling receptor module, a self-maintaining module which it feeds, and a feedback loop which controls the inflow process by multiplicative and limiting actions, e.g., the green plant.

i. Sensor of the magnitude of flow, J.


E
Source
(a)
E
J_0
J_1
X
J_3
X
J_2
J_r
Constant Flow Source
(b)
Steady-state flow
Heat Sink
(c)
J
Q
kQ
State Variable (Storage)
(d)
Y
X
f(X,Y)
Interaction Symbol
(e)
P
Price
J_2
$
J_1
Transaction
(f)
Input
Output
Self - Maintaining Module
(g)
Input
Plant Population
(h)
J
Sensor of Flow J
(i)

by helping to identify important pathways. Numerical data were then compiled from the literature for the various storages, pathways and outside sources. Some of the data were approximated by using state or national average per capita data.

Data Assembly and Evaluation

Collection and Organization

By going to city agencies in Miami, state agencies in Tallahassee, and searching library reports and documents, a library of reports was gathered containing information on the urban system of Miami-Dade County. Data on such things as total energy consumption, total budget, effective buying income, population, number of telephones, building structure, retail sales, taxes, water consumption and land development were collected, graphed and tabulated by year from 1950 to 1972. Data for all years were not always available so that the most recent values found were used in the models and calculations. The consumption of fossil fuels such as natural gas and liquid fuels was estimated based on values for the state (Minerals Yearbook, Mineral Industrial Surveys). A table of fossil fuel consumption for Florida from 1950-72 is contained in Appendix I. Total, per capita, and rates of change for the variables mentioned above are also contained in Appendix I. Graphs of the data plotted as a function of time and energy are contained in the Results section. Land areas for urban and natural areas were obtained by planimetering maps (see Table 10) and aerial photographs (January, 1973).

Cross-Correlation Analysis

For two functions X and Y which are changing with time, it is sometimes desirable to know how well correlated in time these functions are. Correlation in this sense means how well two signals track each other in time. For example, if the two signals are ramps of equal slope they would be said to be well correlated; likewise, ramps of equal slope but of opposite sign would be negatively correlated. The cross-correlation function (see Lee, 1960) between two continuous signals, X and Y, is defined by

$$\phi_{XY}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} X(t)Y(t+\tau)dt$$

where the signals are considered over the interval (-T,+T). The parameter τ is the shift in time between the two signals for which the cross-correlation function is calculated. Two sinusoidal functions of equal frequency and in phase would be strongly correlated. As these two signals were shifted in time they would become less correlated until they were completely out of phase. They would then be strongly negatively correlated. The correlation function can be normalized to obtain a correlation coefficient defined by

$$r_{XY}(\tau) = \frac{\phi_{XY}(\tau)}{\sigma_X\sigma_Y} \leq |1|$$

where $\sigma_X = \sqrt{\phi_{XX}(0)}$

$\sigma_Y = \sqrt{\phi_{YY}(0)}$.

If the two functions X and Y are not continuous but discrete values of the functions are known then the correlation function is defined by

$$\phi_{XY}(\tau) = \frac{1}{K} \sum_{i=1}^{K} X_i Y_{i+\tau}$$

where τ is the shift in time between the two functions X and Y and K is the number of data points. The correlation coefficient is defined as above.

If the two functions are both non-stationary (containing a trend) then one may not necessarily "cause" the other. For example, the increasing population of New York could be correlated to the increasing price of tea in China, even though they have no relationship to each other. For Miami-Dade County all variables have been increasing up until 1972. To avoid the non-stationary nature of the functions a cross-correlation analysis was done for the first differences (rate of change) of the various parameters to see if these correlated. This cross-correlation function is given by

$$\phi_{\Delta X\text{-}\Delta Y}(\tau) = \frac{1}{K} \sum_{i=1}^{K} \left(\frac{\Delta X}{\Delta t}\right)_i \left(\frac{\Delta Y}{\Delta t}\right)_{i+\tau}$$

and this equation was used to construct Table 2. $\Delta X/\Delta t$ and $\Delta Y/\Delta t$ represent the rates of change of X and Y. Again the correlation coefficient is defined as

$$r_{\Delta X-\Delta Y}(\tau) = \frac{\phi_{\Delta X-\Delta Y}(\tau)}{\sigma_{\Delta X}\sigma_{\Delta Y}}$$

where

$$\sigma_{\Delta X} = \sqrt{\phi_{\Delta X-\Delta X}(0)}$$

$$\sigma_{\Delta Y} = \sqrt{\phi_{\Delta Y-\Delta Y}(0)} \ .$$

The program used to calculate the cross-correlation function is called CORR and is contained in the Nuclear Engineering Sciences computer center, University of Florida.

Simulation Procedure

Simulation Model

Although a very complex model containing many storages and pathways can ultimately be simulated on a digital computer, important results can be obtained by other methods. Simplifying complex models by lumping storages and eliminating small flows but maintaining the essence of the model allows analog simulation, reduces chances of error, and prevents the model from overwhelming the researcher with too much detail. After a suitable model is decided upon, the equations representing it are solved on an analog computer and output curves generated.

Writing, Scaling and Programming of Equations

Associated with each model diagram is a set of first order differential equations (N^{th} order system) which describe the rate of change of the state variables. The equations are obtained by setting the rate of change with time of a state variable equal to the inputs minus the outputs to that storage.

These pathway flows will be equal to some constant, K, times a product of state variables and sources. This coefficient can be calculated knowing the value of the flow and the state variables and sources. In order for the equations to be solved on the analog computer they must be scaled, i.e., the maximum value that a state variable will achieve should correspond to the maximum voltage output of the computer. For an example of scaled equations see the details of simulations in the appendices. An analog diagram is then drawn to represent the equations with each storage corresponding to an analog integrator. This diagram is then programmed on the computer for solution. The numerical coefficients in the differential equations are transformed into potentiometer settings on the analog computer. For example, given the equation

$$\dot{Q}_1 = .05Q_1Q_2 - .3Q_1$$

where $Q_{1max} = 10$ and $Q_{2max} = 10$. Then

$$\dot{Q}_1 = .05(10)(10)\left(\frac{Q_1}{Q_{1max}}\right)\left(\frac{Q_2}{Q_{2max}}\right) - .3(10)\left(\frac{Q_1}{Q_{1max}}\right)$$

where the ratios in brackets are now the scaled computer values and cannot exceed the maximum voltage of the computer since Q_{max} corresponds to the maximum voltage. The entire equation is then divided by Q_{1Max} in order to scale $\dot{Q}_1$ the same as Q_1. This means that one second of computer time will correspond to the unit of time which the real-world problem is expressed in. If flows are expressed as per year then one second of computer time will represent one year. The equation resulting by dividing by $Q_{1Max} = 10$ is

$$\left(\frac{\dot{Q}_1}{Q_{1Max}}\right) = .05(10)\left(\frac{Q_1}{Q_{1Max}}\right)\left(\frac{Q_2}{Q_{2Max}}\right) - .3\left(\frac{Q_1}{Q_{1Max}}\right)$$

The coefficient of the product $[Q_1][Q_2]$ is equal to .5 and is the value that a potentiometer will be set at. Likewise, the potentiometer setting for the last term is .3.

Energy-Economic Budget Calculations

Since there are no money flows in nature a method by which natural and man-made systems can be compared is to use energy flow as a measure of useful work. The gross production of natural vegetation can be estimated and used as a measure of the useful work necessary to maintain a given ecosystem. The work performed by the natural energies of wind, waves, and tides can also be calculated. Work processes in man-made systems can be measured by fossil fuel and money flows. In order to compare the energy flows associated with natural and man-made systems, a common unit of energy is necessary which measures equal ability to do useful work. For example, how much work can 1 Kcal of sunlight do compared to 1 Kcal of coal.

Energy Concentration Factor and Energy Value of Money

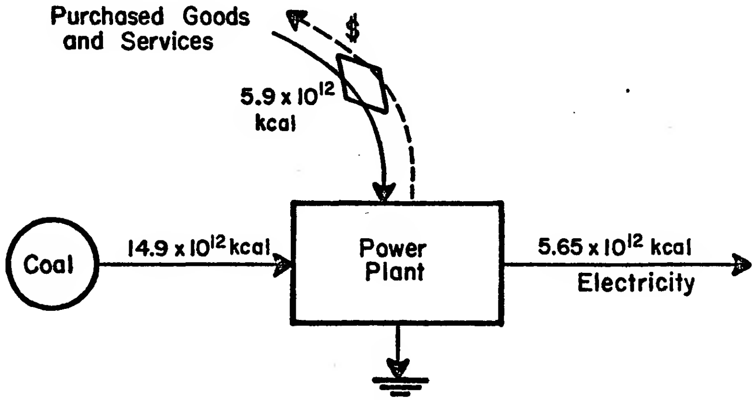
Consider Fig. 4a, which is a simplified diagram of the process of converting coal into electricity (Lem, 1973). The box represents a power plant which is driven by inputs of coal and purchased goods and services. The dollar value of goods and services has been converted to Fossil Fuel Work Equivalents[1] by using the conversion factor of 25,000 Kcal/dollar (Odum, 1974a). This ratio has been obtained by taking the ratio of total sunlight falling on the United States per year (in Fossil Fuel Work Equivalents, FFWE) plus the fossil fuel used per year and dividing by the Gross National Product of the U.S. This ratio is a measure of the fossil fuel work that one dollar can generate in the economy. There is some disagreement as to the magnitude of the dollar to kilocalorie ratio. Kylstra (1974) has calculated the ratio from 1947 to 1972 with the ratio in 1972 about 22,000 Kcal/dollar. The natural energies included in this calculation did not include the offshore marine productivities so that the ratio may be somewhat higher. The natural energies were calculated by taking the solar energy falling on the United States and converting to FFWE's by dividing by 2,000. The actual value is probably somewhere between 22,000 and 25,000 Kcal/dollar for 1972. This energy to dollar ratio has been steadily decreasing since 1947 so that the approximate figure of 25,000 Kcal/

[1]A Fossil Fuel Work Equivalent (FFWE) is the amount of useful work that 1 Kcal of fossil fuel is capable of doing.

Fig. 4. Examples illustrating the concept of energy quality. (From H. T. Odum, unpublished papers.)

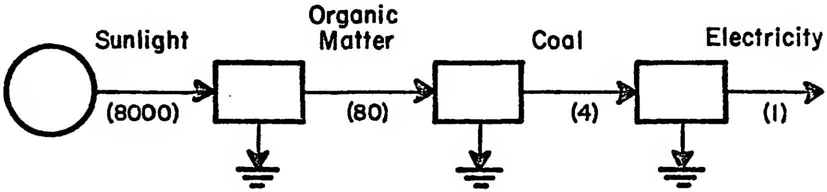
a. Diagram showing major inputs necessary to generate electricity and upgrade energy concentration (quality). It is seen that 1 Kcal of electricity is generated from approximately 4 Kcal of fossil fuel inputs.

b. Energy chain showing the upgrading of energy from dilute solar energy to concentrated electrical energy. Boxes represent energy conversion processes. Numbers in parentheses are energy concentration factors showing the number of Kcal of energy needed to generate 1 Kcal of electricity.



$$\frac{14.9 + 5.9}{5.65} = 3.7$$

(a)



(b)

dollar will introduce some error into several calculations. Since the conversion of natural energies to FFWE is also approximate, the value of 25,000 Kcal/dollar should suffice as a reasonable approximation. This number is an average value for dollar flows of goods and services which have been affected by many sectors of the economy. It can be seen from Fig. 4 that the ratio of the Kcal value of fossil fuel inputs to the Kcal value of the electrical output is 4. In the process coal has been upgraded to a higher quality and more versatile form form of energy, namely, electricity. Four Kcal units of coal are necessary to produce one Kcal of electricity. It is said that the fossil fuel work equivalent of electricity is four, or that the energy concentration factor of electricity relative to coal is four.

This same concept can be applied to other forms of energy such as sunlight and organic matter by consideration of the chain of energy processes necessary to go from sunlight to electricity. Figure 4b diagrams in simple form the energy conversions between sunlight and electricity. Tentative energy concentration factors for several types of energy are listed in Table 1. Dividing a given type of energy flow by this factor will give the energy available in Fossil Fuel Work Equivalents. This concept of energy concentration (quality) is in a theoretical phase following from the idea that energy storages must be of an upgraded higher quality. Lotka's principle also requires that energy must be upgraded and stored to accelerate inflow and effective use. The

Table 1

Energy Quality (Concentration) Factors Relating Different Work Processes

Energy Conversion Process	Energy Quality (Concentration) Factor[a]
Sunlight to Gross Production	100
Gross Production to Wood	10
Wood to Fossil Fuel	2
Wood to Electricity	8
Gross Production to Fossil Fuel	20
Sunlight to Fossil Fuel	2000
Tidal Energy to Fossil Fuel	0.3
Hydrostatic Head to Fossil Fuel	0.3
Fresh/Salt Water Concentration Gradient to Fossil Fuel	10(?)
Total Work Done in U.S. per Dollar	25000 Kcal/Dollar

[a]The Energy Quality Factor is a ratio of total energy inputs (including all subsidies) to energy output from the conversion process. By using appropriate sets of ratios, different forms of work can be converted to the same equivalent type and then compared or summed. Energy Quality Factors are preliminary and subject to readjustments. See Odum (1974a), Kemp (1974), Young *et al*. (1974), and Costanza (1975).

numbers in Table 1 should be considered approximate and preliminary.

Theoretically, then, all energy flows of man and nature can be compared by reducing them to the same common denominator of FFWE's. Likewise, the money flows of human systems can be interpreted as the work they require in the economy by the conversion factor of 25,000 Kcal/dollar (Kcal of fossil fuel work). Thus, all the work contributions of man and nature can be compared on an equal basis (see Table 11).

RESULTS

Data on Miami-Dade County

In this section data are assembled from many sources for combination in energy models toward understanding the urban system. One of the most difficult aspects of understanding cities in terms of an energy framework is getting data in energy units. In human systems the standard unit of measure is money and most data are in dollars. However, for every dollar flow in the economy there is an exchange of goods and services. These goods and services were the net result of the accumulation of processes in the economy which were dependent on energy support. In effect, a dollar can buy a number of kilocalories of useful work which was done in the general economy (see Methods; Odum, 1971). Dollar statistics give some indication of the energy intensity of the systems which they characterize. For example, the budget of a city is representative of the energy going into maintenance of those parts of the city considered public domain. Data were compiled by referring to many of the publications listed in the references (Dade County Economic Base Study, 1960; Dade County Budget; Existing Land Use Study, 1961; Economic Survey of Dade County, 1970; Dade Does It Right, 1972; see Table 6) and constructing the graphs over time given in Figs. 5-11.

The numerical data for each year used to construct these graphs are presented in Tables 20 to 21 in Appendix I with notes explaining the numbers. The graphs were constructed by connecting successive data points with straight lines. There was one data point for each year. Data points are not shown on the graphs for purposes of simplification.

Energy data for gasoline and electrical consumption were obtained from publications of the Department of Transportation and Metropolitan Dade County agencies. Numbers for natural gas, residual and distillate fuel, kerosene and liquid petroleum were based on Florida consumption of these fuels as listed in the Minerals Yearbook and Mineral Industrial Surveys. Figure 5 presents gasoline consumption and total energy consumption where total energy is the sum of gasoline, natural gas, distillate and residual fuel, kerosene, liquid petroleum and four times the electrical energy as explained in the notes to Tables 19 and 20. This energy is expressed in Kcal of fossil fuel. Population figures are shown in Fig. 6, water consumption in Fig. 7, total budget in Fig. 8, dollar flows in Fig. 9, number of telephones in Fig. 10, number of vehicles in Fig. 11, and building structure in Figs. 10 and 11. One of the most difficult parameters to find information for is physical growth of a city, either in terms of square feet or mass. Figure 11b was constructed by using the financial data available for new construction each year and dividing by the average cost per square foot ($8.50/ft^2).

Trends and Peculiarities

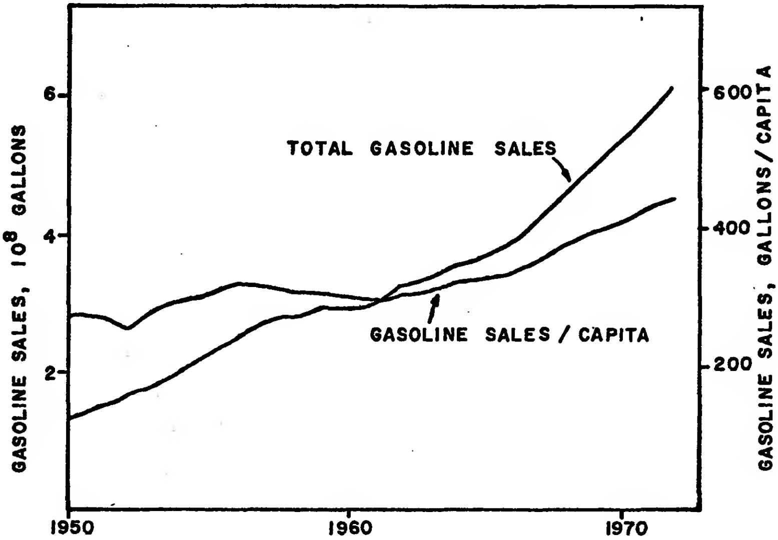
Looking at the data plotted in Figs. 5-11 it is seen that the trends are similar to those experienced in the rest of the country during a time of expanding energy, i.e., continual growth from 1950-72, except for a period during the late fifties and early sixties. If the rates of change for these parameters are looked at in Figs. 16-18 it is seen that the rates of change for total energy, effective buying income, sales tax, budget, and number of telephones have been increasing, indicating a power function for the growth of these parameters. The rates of change for water consumption, labor force, and population seem to have oscillated. Perhaps this is because these variables are subject to the random influence of weather and migrations.

There seems to have been fairly gradual growth from 1950 to about 1967 with the latter part of the sixties and early seventies characterized by rapid and accelerated growth. The birth rate (Fig. 6a) has been steadily declining since reaching a high in 1958 and the total increase in population seems to be following an oscillating curve due to migrations (Fig. 6b). It is interesting that several of the curves leveled for several years from the late fifties to the early sixties. During this period of time there were two large migrations of Cubans and the Miami Metropolitan government was created. The influx of Cubans brought in capital and created a larger tax base which may explain why the budget and sales tax leveled. There may have also been greater

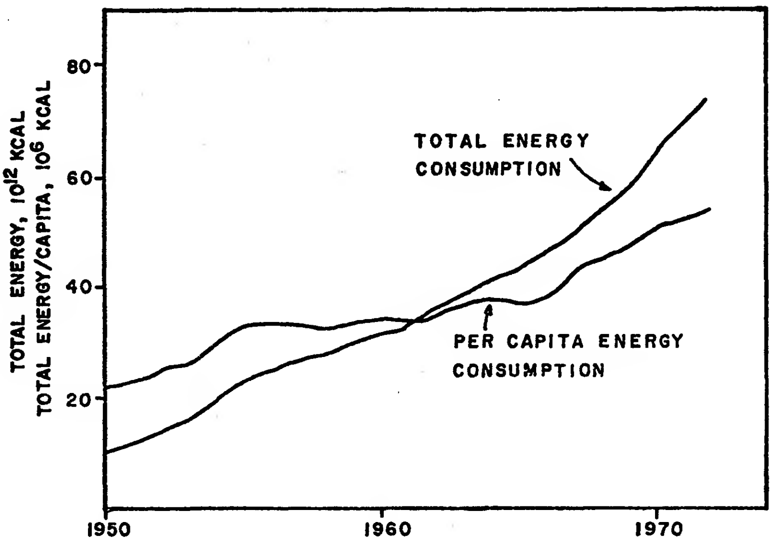
Fig. 5. Fossil fuel energy consumption for Dade County.

a. Graph of total and per capita gasoline sales in Dade County from 1950-72.

b. Total and per capita fossil fuel consumption including natural gas, liquid fuels, and electrical energy from 1950-72.


TOTAL GASOLINE SALES
GASOLINE SALES / CAPITA
GASOLINE SALES, 10^8 GALLONS
GASOLINE SALES, GALLONS / CAPITA
6
4
2
600
400
200
1950
1960
1970

(a)

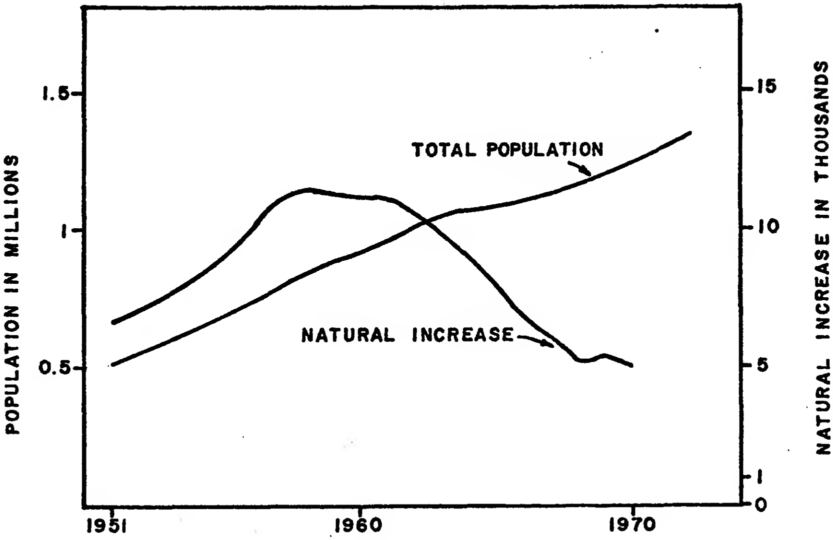

TOTAL ENERGY CONSUMPTION
PER CAPITA ENERGY CONSUMPTION
TOTAL ENERGY, 10^12 KCAL
TOTAL ENERGY/CAPITA, 10^6 KCAL
80
60
40
20
1950
1960
1970

(b)

Fig. 6. Population statistics for Dade County.

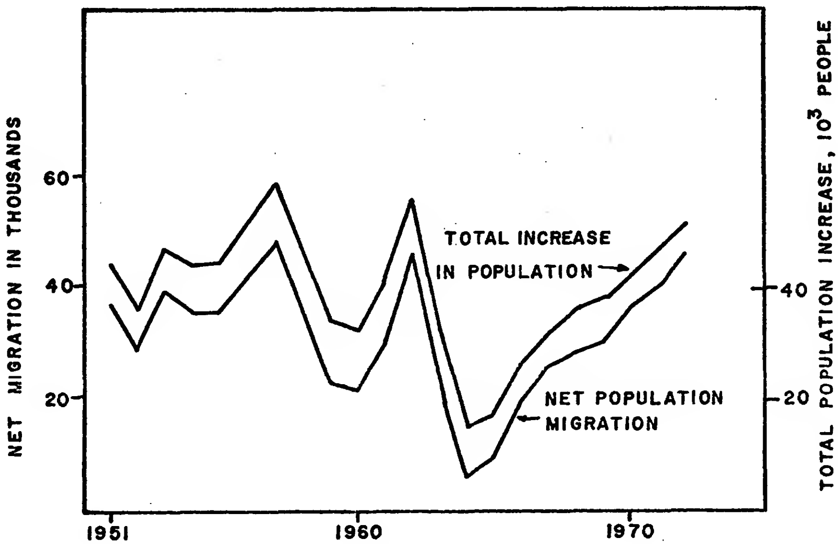
a. Total population and births (natural increase) per year for Dade County from 1950-72.

b. Net migration and total increase in population for Dade County from 1950-72.



POPULATION IN MILLIONS
NATURAL INCREASE IN THOUSANDS
TOTAL POPULATION
NATURAL INCREASE
1.5
1
0.5
15
10
5
1
0
1951
1960
1970

(a)

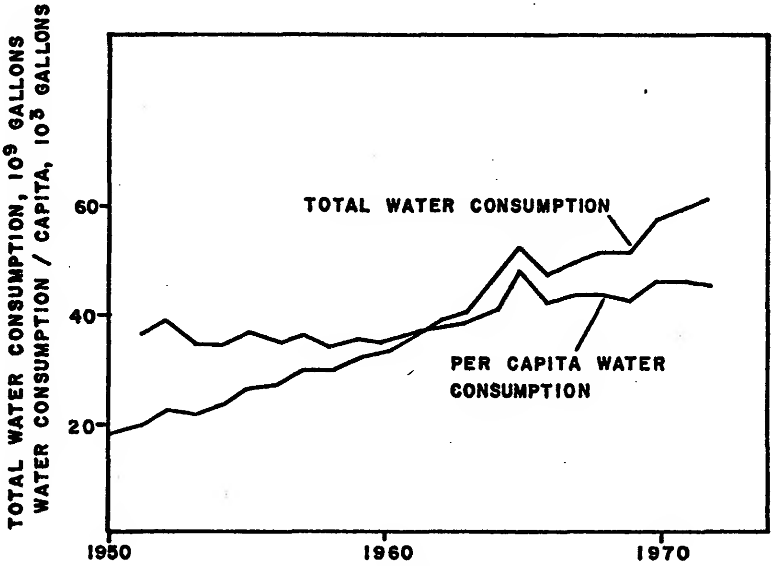


NET MIGRATION IN THOUSANDS
TOTAL POPULATION INCREASE, 10^3 PEOPLE
TOTAL INCREASE
IN POPULATION
NET POPULATION
MIGRATION
60
40
20
40
20
1951
1960
1970

(b)

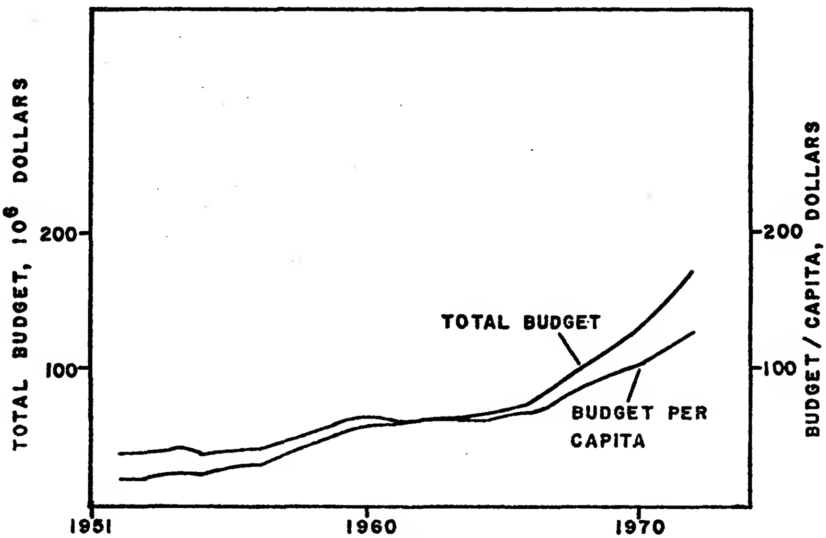
Fig. 7. Total and per capita water consumption for Dade County from 1950-72.

Fig. 8. Total and per capita budget for Dade County from 1950-72.



TOTAL WATER CONSUMPTION, 10⁹ GALLONS
WATER CONSUMPTION / CAPITA, 10³ GALLONS
60
40
20
TOTAL WATER CONSUMPTION
PER CAPITA WATER CONSUMPTION
1950
1960
1970

Fig. 7



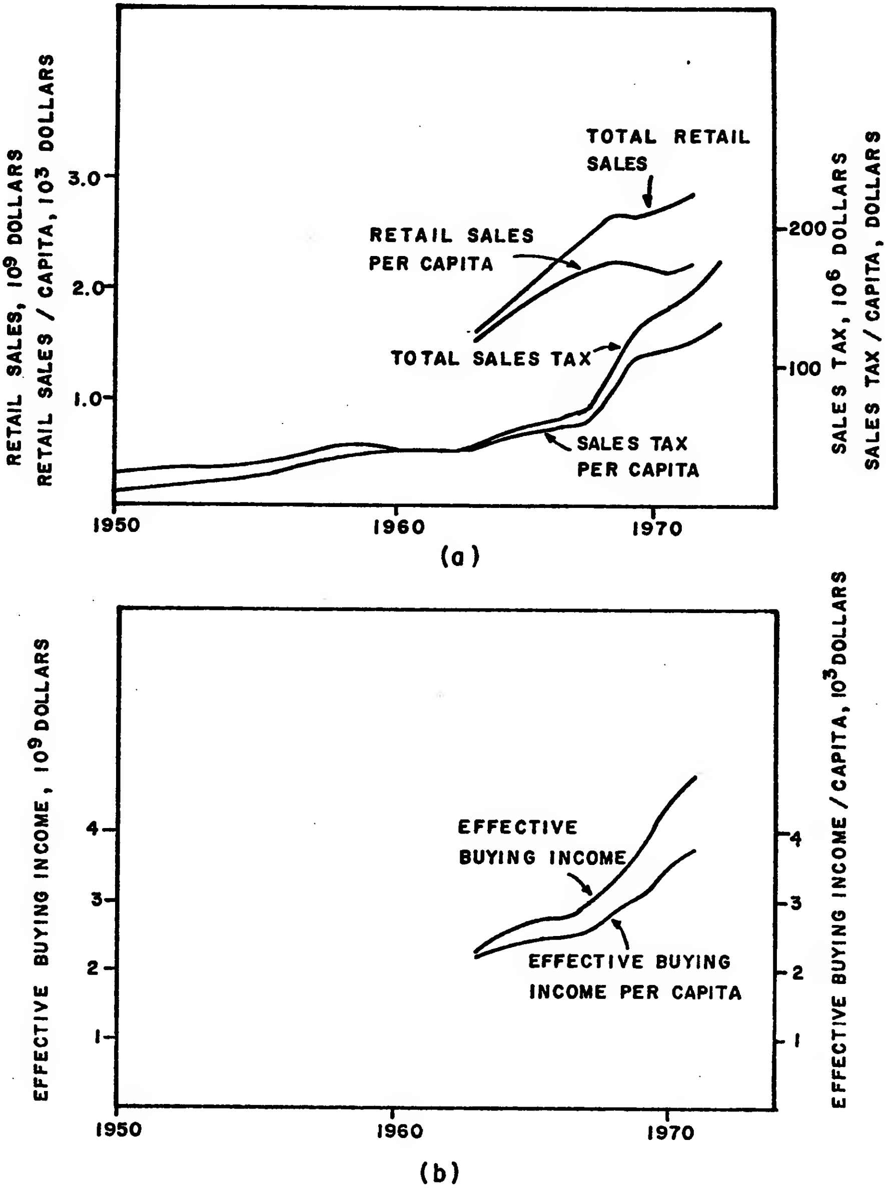
TOTAL BUDGET, 10⁶ DOLLARS
BUDGET / CAPITA, DOLLARS
200
100
TOTAL BUDGET
BUDGET PER CAPITA
1951
1960
1970

Fig. 8

Fig. 9. Economic measures for Dade County.

a. Total and per capita retail sales and sales tax collections for Dade County from 1950-72.

b. Total and per capita effective buying income for Dade County from 1950-72.

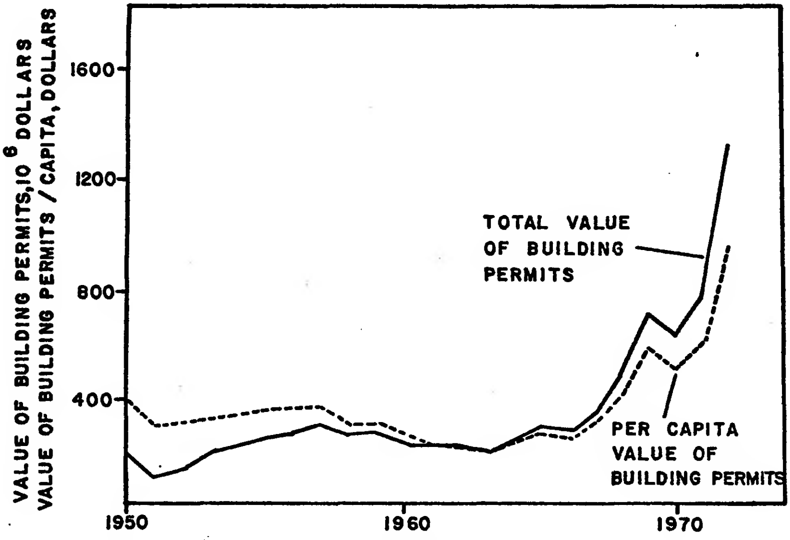


RETAIL SALES, 10^9 DOLLARS
RETAIL SALES / CAPITA, 10^3 DOLLARS
SALES TAX, 10^6 DOLLARS
SALES TAX / CAPITA, DOLLARS
TOTAL RETAIL SALES
RETAIL SALES PER CAPITA
TOTAL SALES TAX
SALES TAX PER CAPITA
3.0
2.0
1.0
200
100
1950
1960
1970
(a)
EFFECTIVE BUYING INCOME, 10^9 DOLLARS
EFFECTIVE BUYING INCOME / CAPITA, 10^3 DOLLARS
EFFECTIVE BUYING INCOME
EFFECTIVE BUYING INCOME PER CAPITA
4
3
2
1
1950
1960
1970
(b)

Fig. 10. Measures of structure for Dade County.

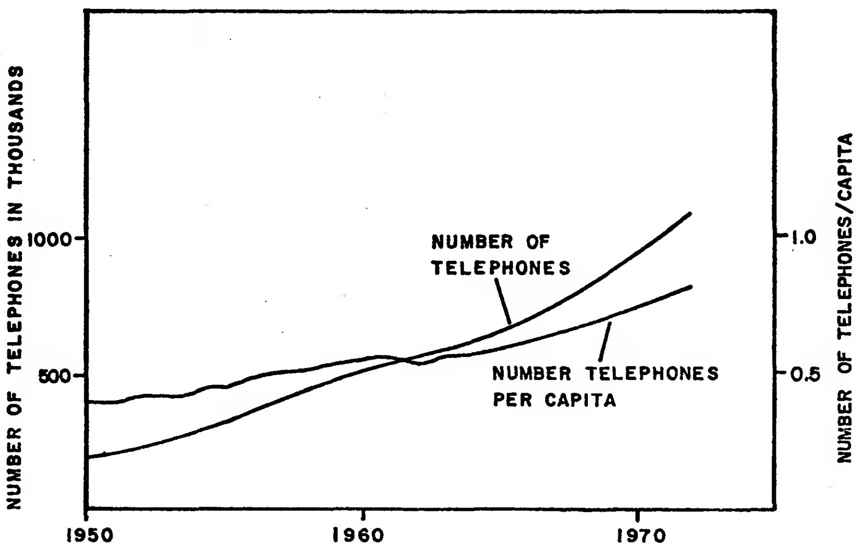
a. Total and per capita value of building permits for Dade County from 1950-72.

b. Total and per capita number of telephones for Dade County from 1950-72.



VALUE OF BUILDING PERMITS, 10^6 DOLLARS
VALUE OF BUILDING PERMITS / CAPITA, DOLLARS
1600
1200
800
400
TOTAL VALUE OF BUILDING PERMITS
PER CAPITA VALUE OF BUILDING PERMITS
1950
1960
1970

(a)



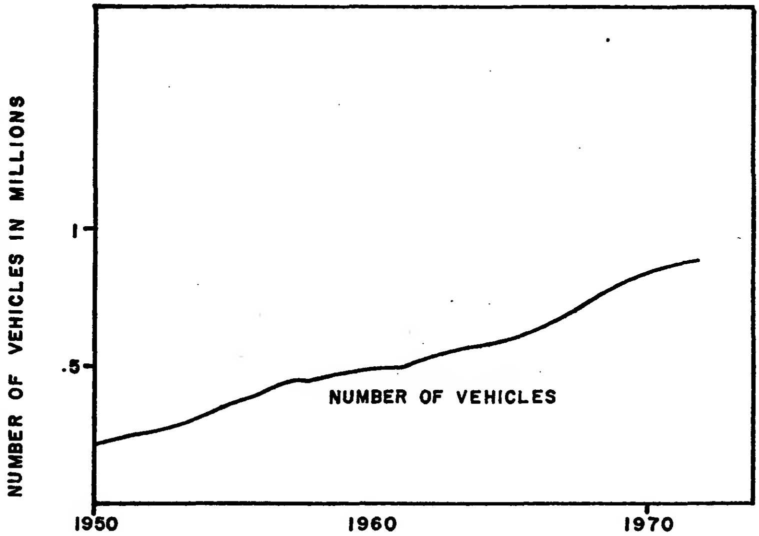
NUMBER OF TELEPHONES IN THOUSANDS
1000
500
NUMBER OF TELEPHONES
NUMBER TELEPHONES PER CAPITA
NUMBER OF TELEPHONES/CAPITA
1.0
0.5
1950
1960
1970

(b)

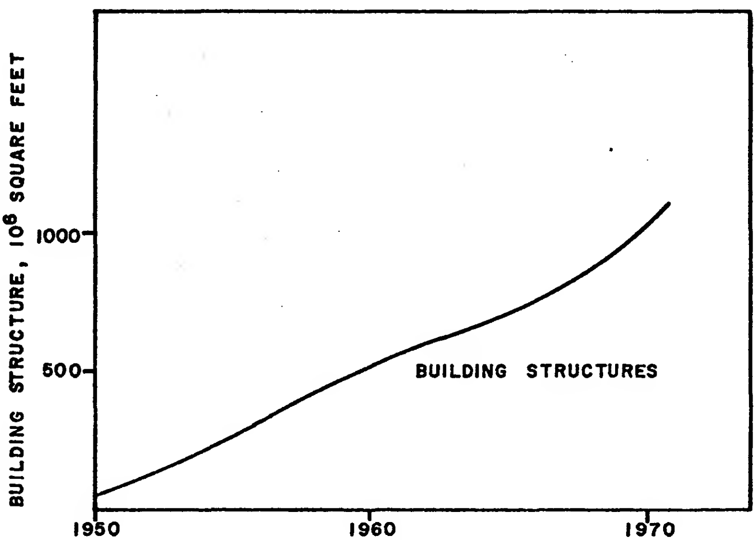
Fig. 11. Measures of structure for Dade County.

a. Number of vehicles (autos, buses, and trucks) for Dade County from 1950-72 in millions.

b. Approximate total building structure for Dade County from 1950-72 in millions of square feet.


NUMBER OF VEHICLES IN MILLIONS
1
.5
NUMBER OF VEHICLES
1950
1960
1970

(a)


BUILDING STRUCTURE, 10^6 SQUARE FEET
1000
500
BUILDING STRUCTURES
1950
1960
1970

(b)

efficiency introduced due to the consolidation of the many separate municipalities.

Cross-Correlation Analysis

Cross-correlation analysis was performed for the time series data presented in the previous section. This type of analysis gives a measure of how well two functions track each other in time. It is usually important to determine the causal variable which the other variables in a system follow. For a city or any complex system it is sometimes difficult to determine which is the cause and what are the effects. Based on thermodynamic considerations energy seems to be a necessary and primal variable for urban systems. However, once a city system is established, changes in the population or money supply could also be construed as causal actions, at least over a short period of time. Eventually, energy and resources would become the primal cause. This section attempts to give some measure to the relationship of energy and population to several urban indicators.

Since most of the data have increasing trends (non-stationary) the first differences (yearly changes) were cross-correlated (see Methods). First differences of the variables are presented in Figs. 16 to 18. The cross-correlation function used can be found in the Methods section on page 30. Table 2 presents calculated values of the cross-correlation coefficient between first differences. First differences for population and total energy were cross-correlated with the first differences of other urban variables. The greater the correlation between variables the closer the correlation coefficient is to one. Figures 16 to 18 show how many data points were used for each of the correlations since one data point was associated with each year. As can be seen from Table 2, total energy and population rates of change correlate quite well with changes in other variables except for water consumption and retail sales. The reason for the retail sales negative correlation is unknown while that of water consumption may be related to random effects of weather.

To put in perspective the change in energy consumption compared to that of other parameters, Table 3 was constructed to compare the percentage difference between 1962 and 1972 values for the number of telephones, retail sales, effective buying income, sales tax, total budget, population, building structure, number of tourists and total energy. It can be seen that a 77% increase in total fossil fuel energy has been accompanied by a 107% increase in effective buying income, a 250% increase in sales tax, a 130% increase in the budget, and a 100% increase in the number of tourists. The number of telephones, retail sales, and building structure changes have been about the same percentagewise as the change in energy consumption. Total population increased by 23.5%.

Table 2

Cross-Correlation Coefficients Between the First Differences for Selected Urban Indicators

First Differences Correlated[a]	Cross-Correlation Coefficient[b]
Population to Total Energy	0.93
Population to Water Consumption	-0.0062
Population to Total Budget	0.92
Population to Sales Tax	0.56
Population to Gasoline Consumption	0.901
Population to Effective Buying Income	0.69
Population to Retail Sales	-0.5
Population to Value of Building Permits	0.9
Population to Number of Telephones	0.92
Total Energy to Population	0.93
Total Energy to Water Consumption	-0.17
Total Energy to Total Budget	0.83
Total Energy to Sales Tax	0.65
Total Energy to Effective Buying Income	0.716
Total Energy to Retail Sales	-0.65
Total Energy to Value of Building Permits	0.79
Total Energy to Number of Telephones	0.85

[a]First differences of the variables shown in this column were correlated (see page 30 in Methods).

[b]Cross-correlation coefficient given by equations on page of Methods section. This coefficient is a measure of how well two functions track each other in time. The maximum value of the coefficient is one and indicates high correlation. The time shift, τ, between the two functions was equal to zero for the coefficients calculated for this table (see page 29 in Methods section).

Table 3

Percentage Difference Between 1963 and 1971 Values for Several Urban Parameters

Item	Percent Difference[a]
Total Energy	77.0
Number of Telephones	67.1
Retail Sales	78.5
Effective Buying Income	107.0
Sales Tax	250.0
Budget	130.0
Population	23.5
Building Structure	76.0
Number of Tourists	100.0

[a]Percent difference was calculated by subtracting the value in 1963 from the value in 1971 and dividing by the value in 1963. This was multiplied by 100 to convert to percent.

Urban Indicators

The description of an urban system requires numerical information for parameters which indicate the state of the system. Traditionally, such things as population, area, population density, labor force, number of jobs and economic information have been tabulated. Recently, since the increase in environmental awareness, measures of environmental health and pollution have been introduced. Such things as number of comfort days and rainfall indexes are used to indicate weather conditions. These measures are used to compare different urban systems and build models.

Several other measures are needed and may possibly replace some of the above-mentioned ones for some purposes. For example, energy density (total energy consumed/unit area) may give a more realistic picture of the intensity of urbanization than population density. As can be seen from Table 4 the energy density of the Miami-Dade urban area is 300 Kcal/m^2/day compared to a New York City value of 4,000 Kcal/m^2/day (Odum and Peterson, 1972). Anyone who has visited these two areas can perceive the difference in intensity of these cities. Energy density could also be used to classify different types of subsystems within the city (Wetterqvist _et al._; Brown, 1973). Total energy use per capita is a succinct measure of the activity in the city; this parameter can reflect the economic vitality of a population in a city.

Although most cities don't contain many large natural ecosystems, they do contain parks, open spaces, and trees. The ratio of the gross photosynthesis of this vegetation to the total energy consumption is an indication of the level of development of the city and the support from free natural work. The productive energies of vegetation, the natural energies of winds, water, waves, and sun provide free work services in a region. The ratio of all natural energies (vegetation and physical) to total energy (fossil fuel) use is important and may be a measure of tourist competitiveness with other competing urban regions.

Other indicators of urban areas include number of telephones (a measure of the communication web), retail sales, effective buying income (income left after taxes), sales tax collections, water consumption, budget, number of vehicles, net migration, square feet of buildings built (measure of structure), total energy consumed, and money incomes and expenditures. Another interesting measure is the ratio of floor space area built to that of the urbanized area, i.e., the ratio of growth in the vertical direction to that in the horizontal direction. In Table 4 it is referred to as the vertical/horizontal growth ratio. This ratio is an indication of three-dimensional growth. Table 4 is a list of the main urban indicators used for Miami-Dade County with their numerical values for 1971 or 1972 (see Tables 20 and 21 in Appendix I and Table 11 for more complete information on these parameters).

Table 4

Urban Indicators

Item	Total for 1972	Per Capita for 1972
Budget[a]	$\$173x10^6$	$126
Developed Area[b]	260 $mile^2$	.00019 $mile^2$
Economic Subsidies[c]	$\$1.48x10^9$	$1080
Effective Buying Income[a]	$\$5x10^9$	$3722
Energy Density in Developed Area[d]	300 $Kcal/m^2/day$	
Expenditures[e]	$\$6.8x10^9$	$4964
Fossil Fuel Consumption[a]	$74x10^{12}$ Kcal	$53.8x10^6$ Kcal
Labor Force[a]	$643x10^3$	.47
Net Migration[a]	$47x10^3$	.034
Number of Telephones[a]	$1.093x10^6$	.814
Number of Vehicles[a]	$880x10^3$	.64
Population[a]	$1.37x10^6$	
Population Density in Developed Area[f]	$5.27x10^3/mile^2$	
Retail Sales[a]	$\$2.82x10^9$	$2183
Ratio of Total Natural Energies to Fossil Fuel Consumption[g]	0.25	
Sales Tax Collections[a]	$\$179x10^6$	$133
Structure Built in a Year[h]	$150x10^6$ ft^2	110 ft^2
Structure Existing[i]	$1100x10^6$ ft^2	800 ft^2
Total Natural Energies[j]	$18.9x10^{12}$ FFWE	
Vertical/Horizontal Growth Ratio[k]	0.365	
Water Consumption[a]	$60x10^9$ gal	$44.4x10^3$ gal

[a]These items can be found in the Data section by looking at the graphs of these variables. Values can also be found in Tables 20 and 21 in the Appendix.

[b]Planimetered from aerial photographs (see Table 10).

Footnotes to Table 4 - continued

[c]Consists of transfer payments plus federal subsidies to agencies. See notes 6 and 7 to Table 6.

[d]Calculated by taking total fossil fuel use and dividing by the developed area:

$$\text{Energy density} = \frac{73.63\text{x}10^{12}\ \text{Kcal/yr}}{260\ \text{mile}^2} \text{ x } \frac{1\ \text{mile}^2}{2.59\text{x}10^6\ \text{m}^2}$$

$$\text{x } \frac{1\ \text{year}}{365\ \text{days}}$$

$$\text{Energy density} = 300\ \text{Kcal/meter}^2\text{/day}$$

[e]See Table 9.

[f]Calculated by taking total population and dividing by developed area:

$$\text{Population density} = \frac{1.37\text{x}10^6\ \text{people}}{260\ \text{mile}^2} = 5.27\text{x}10^3\text{/mile}^2$$

[g]See Table 11 for a list of productivities for the natural and developed areas. The total energy of the natural systems is $18.9\text{x}10^{12}$ FFWE. In units of chemical energy this would be 20 times as great or $275\text{x}10^{12}$ Kcal. The ratio of natural energies in FFWE to total fossil fuel consumption is 18.9/73.63 = .25.

[h]See note 22 to Table 6.

[i]See note 23 to Table 6.

[j]See Table 11. An FFWE is equivalent to 1 Kcal of fossil fuel.

[k]This was calculated by taking the approximate growth in square feet of structure and dividing it by the increase in developed land area from 1960 to 1972. This is a measure of vertical vs. horizontal growth. Thus, the ratio from 1960 to 1972 was

$$\text{Vertical/horizontal growth ratio} =$$

$$= \frac{1110\text{x}10^6\ \text{ft}^2 - 520\text{x}10^6\ \text{ft}^2}{(260-202)\ \text{mile}^2}$$

$$= \frac{590\text{x}10^6\ \text{ft}^2}{58\ \text{mile}^2 \text{x} \left(\frac{27.88\text{x}10^6\ \text{ft}^2}{\text{mile}^2}\right)}$$

$$\text{Vertical/horizontal growth ratio} = .365$$

Many of the above-mentioned indicators are only parts of the overall Miami-Dade County system. Indicators of long-range growth for the system are those which reflect the growth of the system as a whole. Two of these parameters are developed land and population, both of which are plotted in Fig. 12 from approximately 1900 to 1972. The graph of developed land was constructed by planimetering maps from the Dade County Planning Department, Research Division, 1973. The shape of the curve is suggestive of logistic growth. The data which were used to construct these curves are presented in Table 5, which also includes the rate (velocity) of development computed by taking the total development over ten-year increments and dividing by ten to get an average yearly rate of development. Another indicator of long-range growth is total fossil fuel energy consumed, a plot of which is presented in Fig. 5b from 1950-72. It should be possible to determine various storages and flows in the system if the total energy needed to support a given level of structure is known. Figures 13 to 15 show effective buying income, retail sales, total budget, number of telephones, number of tourists, sales tax, and building structure as a function of the total fossil fuel energy supporting the system and as a function of the sum of electrical and gasoline energy consumption. Several of these curves are almost straight-line growth curves while others are close to piecewise linear; the slope of the curve for sales tax in Fig. 15 seems to be increasing,

Table 5

Long-Range Urban Indicators

Year	Developed Land, Square Miles	Population, Millions	Population Density, People/Square Mile	Rate of Development, Square Miles/Year[a]	Fossil Fuel Energy Density, Kcal/meter^2/day
1920	13	0.05	3846		
				2.1	
1930	34	0.125	3676		
				3.0	
1940	64	0.275	4297		
				4.5	
1950	109	0.495	4541		109
				9.3	
1960	202	0.94	4653		170
				4.5	
1970	247	1.27	5142		285
				6.5	
1972	260	1.37	5269		300

[a]Rate of development was calculated by taking the change in developed land over a ten-year period and dividing by ten to put it on a yearly basis.

Fig. 12. Total population and developed land for Dade County from 1920-72. Developed land in units of square miles; total population in millions.

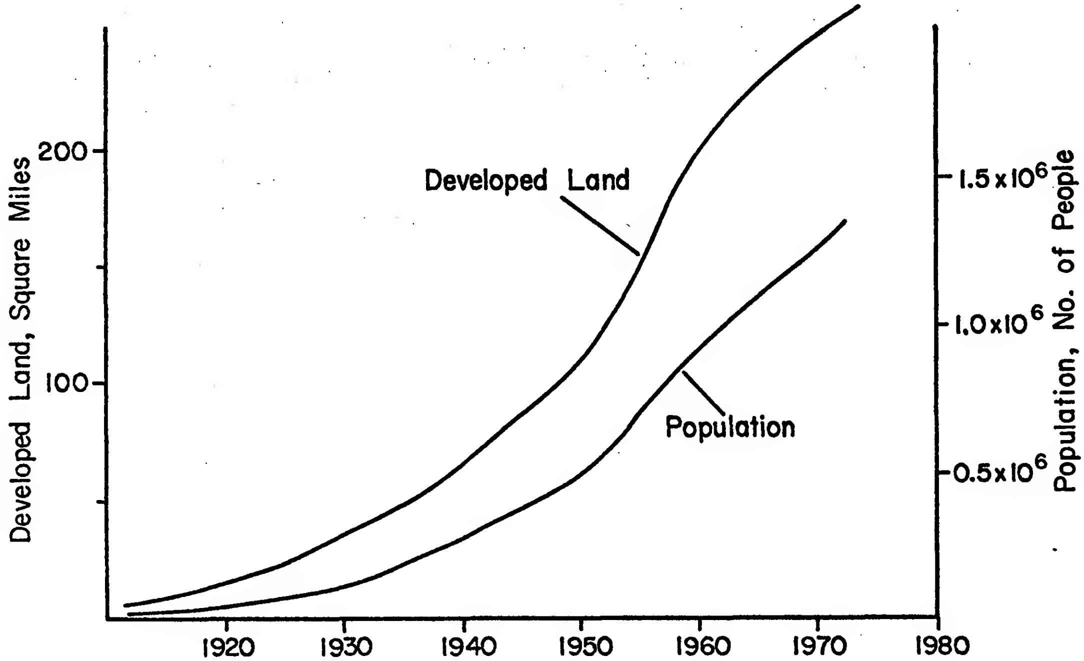
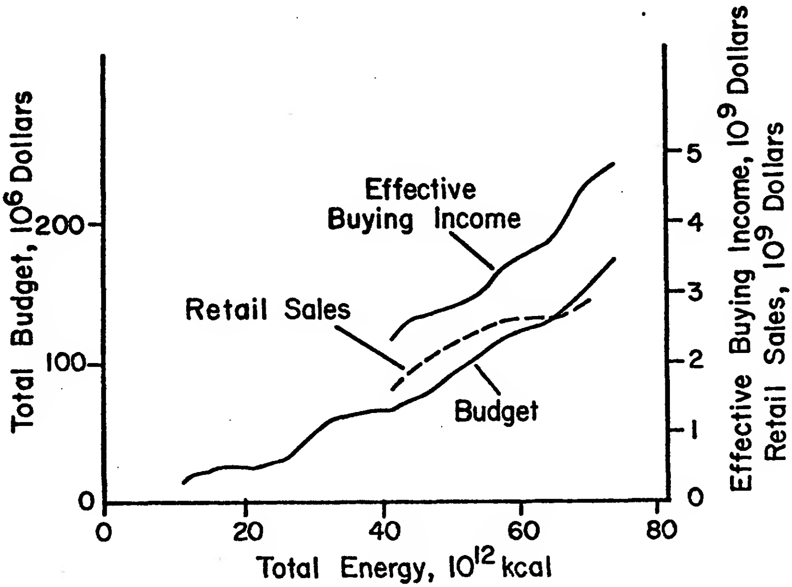

Developed Land, Square Miles
200
100
Developed Land
Population
1.5 x 10^6
1.0 x 10^6
0.5 x 10^6
Population, No. of People
1920
1930
1940
1950
1960
1970
1980

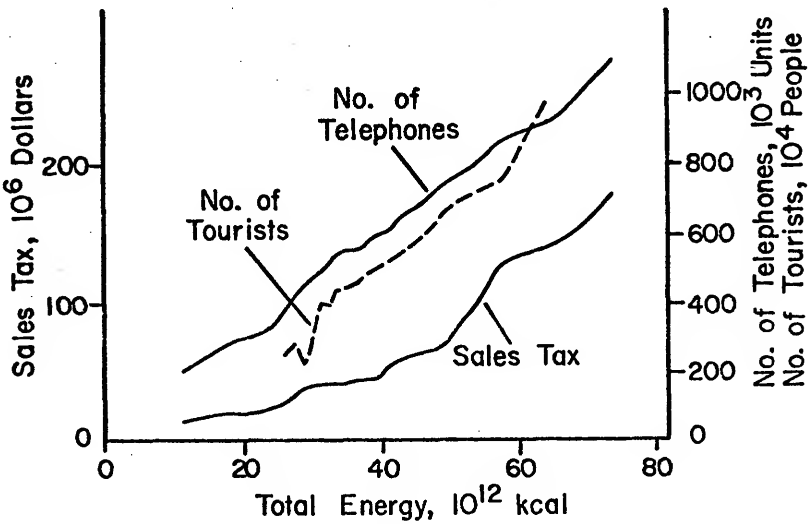
Fig. 13. Several parameters in Dade County as a function of total fossil fuel energy.

a. Total budget, retail sales, and effective buying income as a function of total fossil fuel energy supporting the system of Dade County.

b. Number of tourists, number of telephones, and sales tax collections as a function of total fossil fuel energy supporting the system of Dade County.


Effective
Buying Income
Retail Sales
Budget
Total Budget, 10^6 Dollars
Effective Buying Income, 10^9 Dollars
Retail Sales, 10^9 Dollars
0
100
200
0
1
2
3
4
5
0
20
40
60
80
Total Energy, 10^{12} kcal

(a)

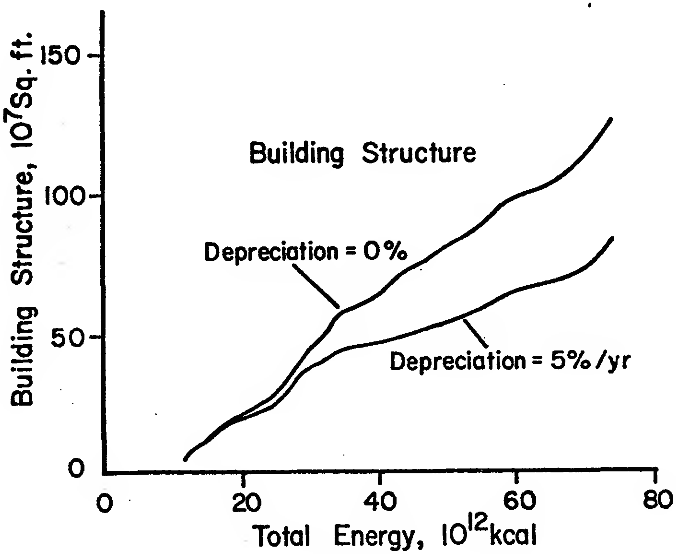

No. of
Telephones
No. of
Tourists
Sales Tax
Sales Tax, 10^6 Dollars
No. of Telephones, 10^3 Units
No. of Tourists, 10^4 People
0
100
200
0
200
400
600
800
1000
0
20
40
60
80
Total Energy, 10^{12} kcal

(b)

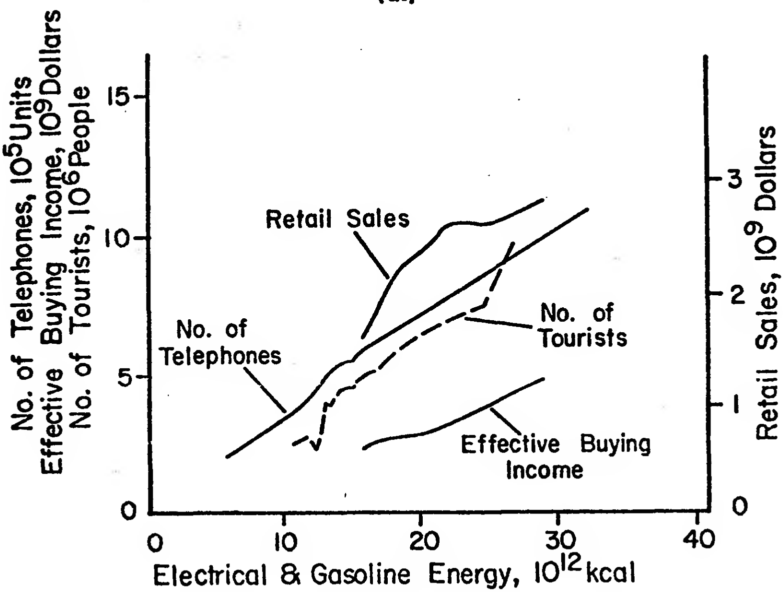
Fig. 14. Building structure and economic flows as functions of fossil fuel energies.

a. Building structure as a function of total fossil fuel energy supporting the system of Dade County for two different rates of depreciation.

b. Effective buying income, number of tourists, number of telephones, and retail sales as functions of electrical plus gasoline energy supporting the system of Dade County.


Building Structure, 10^7 Sq. ft.
150
100
50
0
Building Structure
Depreciation = 0%
Depreciation = 5%/yr
0
20
40
60
80
Total Energy, 10^{12} kcal

(a.)


No. of Telephones, 10^5 Units
Effective Buying Income, 10^9 Dollars
No. of Tourists, 10^6 People
15
10
5
0
Retail Sales
No. of Telephones
No. of Tourists
Effective Buying Income
3
2
1
0
Retail Sales, 10^9 Dollars
0
10
20
30
40
Electrical & Gasoline Energy, 10^{12} kcal

(b.)

Fig. 15. Effective buying income, sales tax collections, and total budget as functions of electrical plus gasoline energy supporting the system of Dade County.

Fig. 16. Rate of change per year for total energy, electrical energy, and gasoline energy for yearly intervals from 1950-51 to 1971-72. All units in 10^{12} Kcal (FFWE).

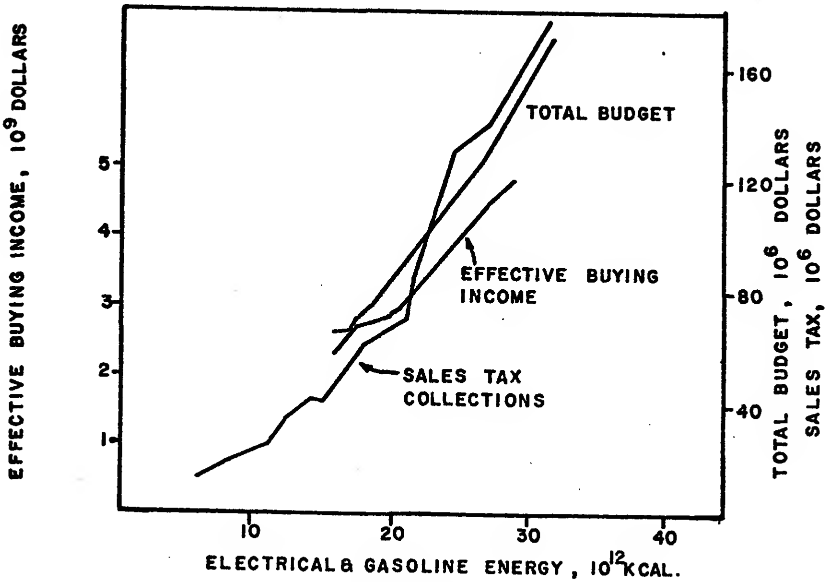

EFFECTIVE BUYING INCOME, 10^9 DOLLARS
TOTAL BUDGET
EFFECTIVE BUYING INCOME
SALES TAX COLLECTIONS
TOTAL BUDGET, 10^6 DOLLARS
SALES TAX, 10^6 DOLLARS
ELECTRICAL & GASOLINE ENERGY, 10^{12} KCAL.

Fig. 15

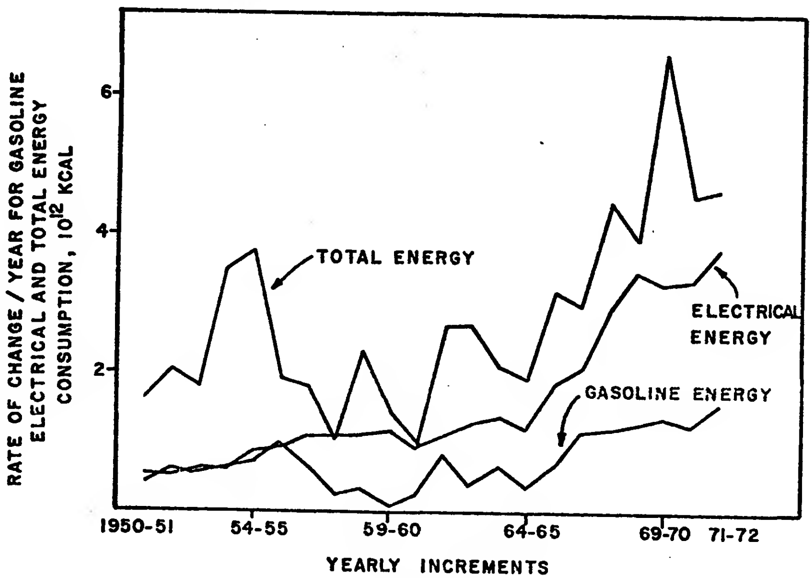
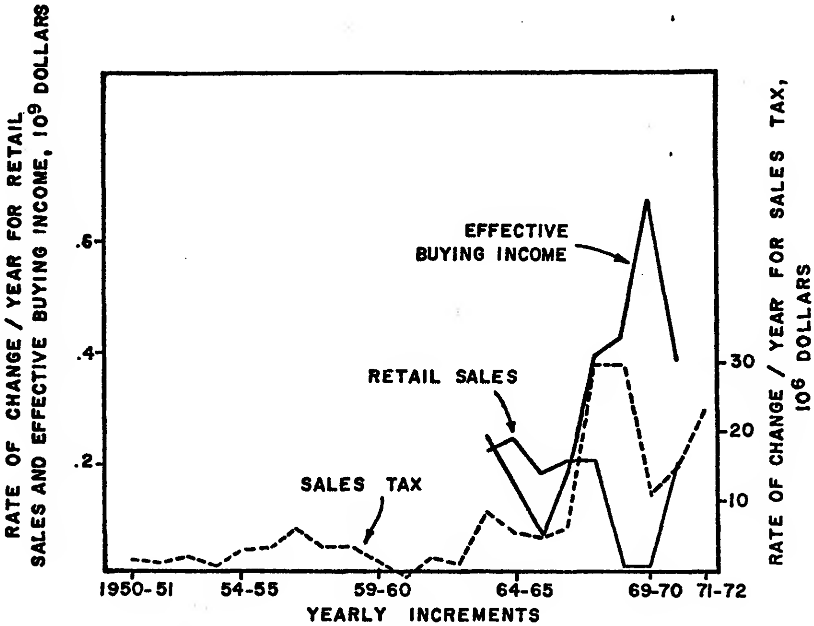

RATE OF CHANGE / YEAR FOR GASOLINE ELECTRICAL AND TOTAL ENERGY CONSUMPTION, 10^{12} KCAL
TOTAL ENERGY
ELECTRICAL ENERGY
GASOLINE ENERGY
1950-51
54-55
59-60
64-65
69-70
71-72
YEARLY INCREMENTS

Fig. 16

Fig. 17. Rates of change for economic flows and water consumption in Dade County.

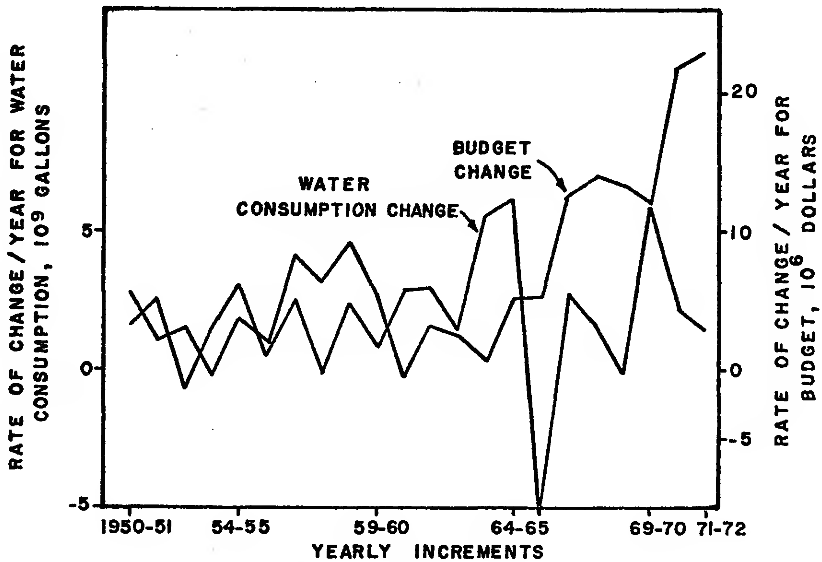
a. Rate of change per year for effective buying income, retail sales and sales tax for yearly intervals from 1950-51 to 1971-72.

b. Rate of change per year for total budget and water consumption for yearly intervals from 1950-51 to 1971-72.



RATE OF CHANGE / YEAR FOR RETAIL SALES AND EFFECTIVE BUYING INCOME, 10^9 DOLLARS
.6
.4
.2
EFFECTIVE BUYING INCOME
RETAIL SALES
SALES TAX
1950-51
54-55
59-60
64-65
69-70
71-72
YEARLY INCREMENTS
30
20
10
RATE OF CHANGE / YEAR FOR SALES TAX, 10^6 DOLLARS

(a)



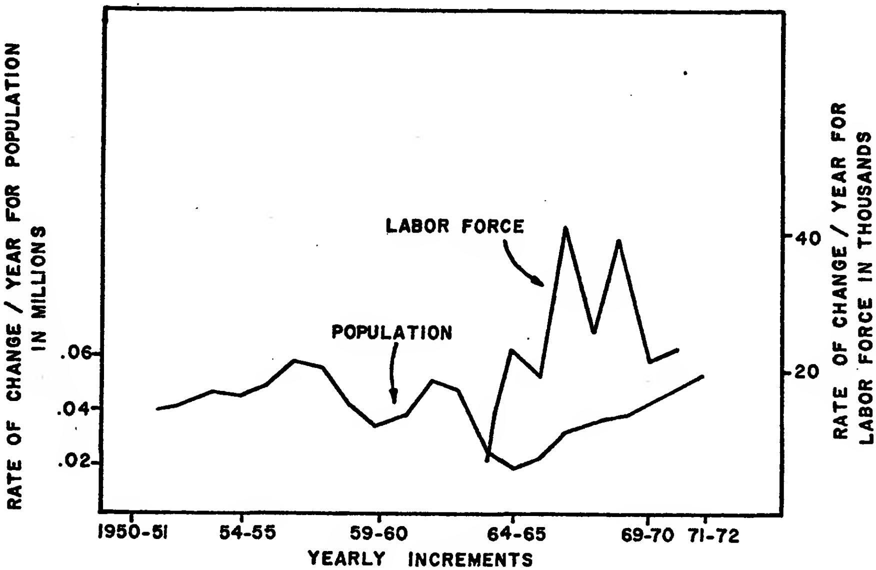
RATE OF CHANGE / YEAR FOR WATER CONSUMPTION, 10^9 GALLONS
5
0
-5
BUDGET CHANGE
WATER CONSUMPTION CHANGE
1950-51
54-55
59-60
64-65
69-70
71-72
YEARLY INCREMENTS
20
10
0
-5
RATE OF CHANGE / YEAR FOR BUDGET, 10^6 DOLLARS

(b)

Fig. 18. Rates of change for labor force, population and number of telephones in Dade County.

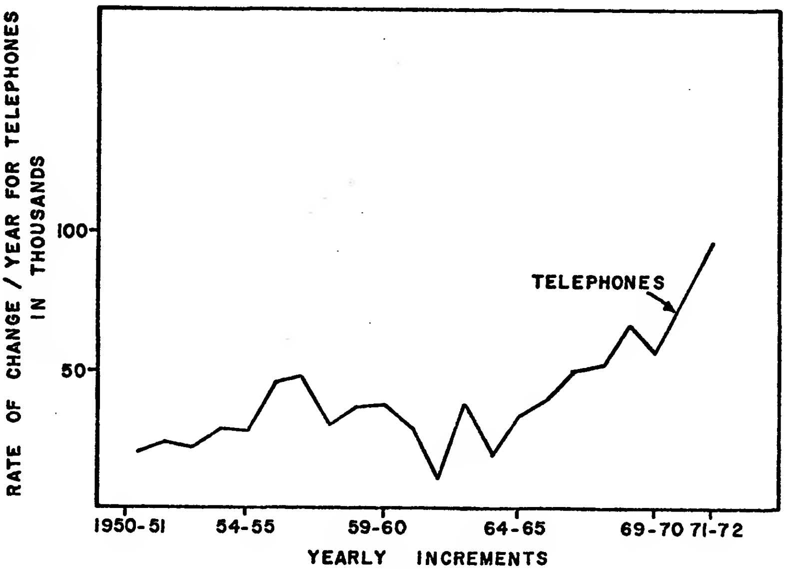
a. Rate of change per year for labor force and population for yearly intervals from 1950-51 to 1971-72.

b. Rate of change per year for number of telephones for yearly intervals from 1950-51 to 1971-72.



LABOR FORCE
POPULATION
RATE OF CHANGE / YEAR FOR POPULATION IN MILLIONS
.06
.04
.02
RATE OF CHANGE / YEAR FOR LABOR FORCE IN THOUSANDS
40
20
1950-51
54-55
59-60
64-65
69-70
71-72
YEARLY INCREMENTS

(a)



TELEPHONES
RATE OF CHANGE / YEAR FOR TELEPHONES IN THOUSANDS
100
50
1950-51
54-55
59-60
64-65
69-70
71-72
YEARLY INCREMENTS

(b)

indicating a power function relation to the sum of electrical and gasoline energies in the system.

If the city indicators discussed above are plotted on a graph as a function of time (Figs. 5 to 11), then trends (rates of change) can be identified. This is further needed information when comparing different urban systems in addition to Table 4 of city indicators. The rate of change (velocity) of flows and storages in the system can be derived from the graphs over time. The rates of change of all the urban parameters are graphed in Figs. 16 to 18 from 1950-72. These graphs are further discussed and analyzed in the Data section.

General Overall Model of Miami-Dade County

This section presents an overall macro-model of the Miami-Dade system for purposes of describing system components, interactions, and numerical values of flows and storages. Figure 19 is the diagrammatic representation of the system with accompanying Table 6, which delineates numerical values and associated calculations and assumptions. The circled numbers of Fig. 19 refer to pathway numbers in Table 6. The outside forcing functions have been grouped into three main categories, namely, fossil-fuel energy and goods, natural energies, and money inputs. This grouping was chosen so that Fig. 19 represents a general urban model since all urban regions depend on these outside forcing functions to greater

Fig. 19. Overall detailed model of the Miami-Dade urban system showing values for flows and storages.

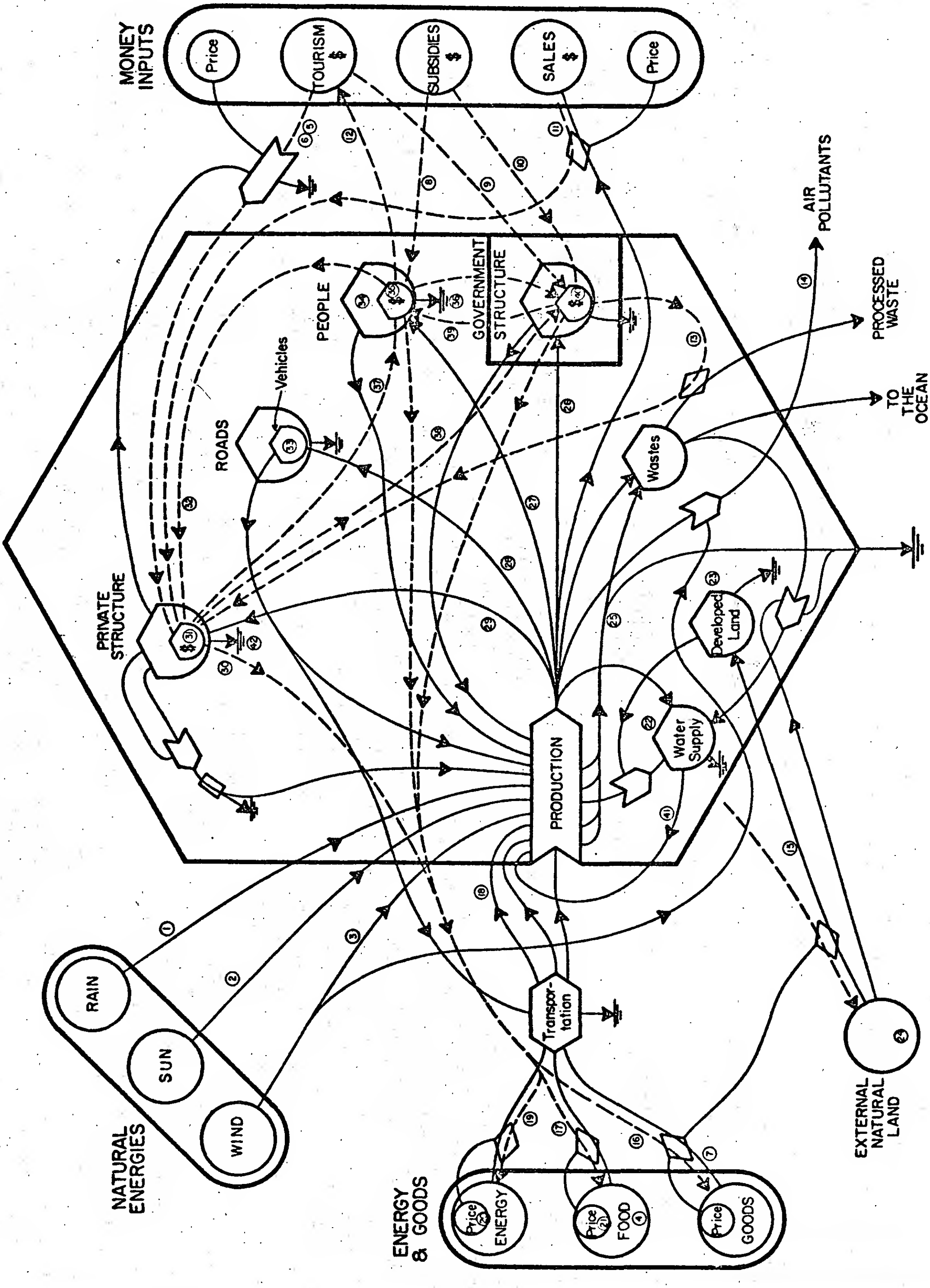

NATURAL ENERGIES
RAIN
SUN
WIND
ENERGY & GOODS
Price
ENERGY
Price
FOOD
Price
GOODS
MONEY INPUTS
Price
TOURISM $
SUBSIDIES $
SALES $
Price
PRIVATE STRUCTURE
ROADS
Vehicles
PEOPLE
GOVERNMENT STRUCTURE
Wastes
Developed Land
Water Supply
PRODUCTION
Transportation
EXTERNAL NATURAL LAND
AIR POLLUTANTS
PROCESSED WASTE
TO THE OCEAN

Table 6

Storages and Flows for Model in Figure 19

Pathway No. on Fig. 19[a]	Note[b]	Description	Numerical Value	Reference[c]
1	1	Rainfall	222×10^{10} gal/yr	Windham
2	2	Sunlight	73.6×10^{14} Kcal/yr	How Dade Does It Right, MDPT, 1972; Mineral Industrial Surveys, 1950-72; Annual Report of Fla. Gas Transmission Co., 1971
3	3	Wind Energy Dissipated to Ground	$.38 \times 10^{12}$ Kcal	
4	4	Food Consumption	$.3 \times 10^{12}$ Kcal/yr	U.S. Census of Agriculture, 1972
5		Tourists	10^{7}/yr (1973)	Annual Financial Report of Metropolitan Dade County, MDCP, 1971
6		Tourist Dollar Flow	3×10^{9} dollars/yr	Ibid.; The Dade County Economy, MDCP, 1971
7	5	Imports of Motor Vehicles	29,000 vehicles/yr (1972-73)	Dade County Dept. of Transportation
8	6	Transfer Payments and Property Income	$\$1.4 \times 10^{9}$	Dade County Economic Base Study, MDCP,1960; Fla. Statistical Abstract, 1973

Table 6 - Continued

Pathway No. on Fig. 19[a]	Note[b]	Description	Numerical Value	Reference[c]
9		Income to Gov't from Tourists	$\$7.86\text{x}10^6$	Dade County Economic Base Study, MDCP, 1960; The Dade County Economy, MDCP, 1973; Conversation with Jay Yelton, State Economist
10	7	External Federal Subsidies	$\$856\text{x}10^6$	Federal Information Exchange System County Summaries, 1970
12	8	Taxes	$\$1.36\text{x}10^9$ (1972)	Dade County Economic Base Study, MDCP, 1960; Annual Financial Report, MDCP, 1971; Fla. Statistical Abstract, 1973; The Dade County Economy, MDCP, 1973
13		Expenditures for Air Pollution Control and Solid Waste Control	$\$.45\text{x}10^6$ (1971-72)	Dade County Budget, Bd. of County Commissioners, 1971-72
14	9	Air Pollutants Generated	915,453 tons	
15	10	Rate of Land Development from Natural to Developed	4.8 sq. miles per year	Urban Environmental Changes, MDCP, 1972; Aerial photographs, 1973; see Table 10
16	11	Money Spent for Vehicles	$\$2.75\text{x}10^9$ (1972)	Fla. Statistical Abstract, 1973
17	12	Money Paid for Food	$\$1.19\text{x}10^9$ (1972)	Ibid.

Table 6 - Continued

Pathway No. on Fig. 19[a]	Note[b]	Description	Numerical Value	Reference[c]
18	13	Total Fossil Fuel Energy Used in System	73.63×10^{12} Kcal/yr (1972)	Fla. Statistical Abstract, 1973; Dade County Economic Base Study, MDCP, 1960; Annual Financial Report, MDCP, 1971; The Dade County Economy, MDCP, 1973; Minerals Yearbook; Fla. Gas Transmission Co.'s Annual Report, 1971
19	14	Money Paid for Fuels	$\$59.2 \times 10^{7}$ (1972)	*Ibid.*
20	15	Price of Fossil Fuel Energy	$\$.8 \times 10^{-5}$/Kcal	*Ibid.*
21	16	Price of Food	$\$.834 \times 10^{-3}$/Kcal	Fla. Statistical Abstract, 1973
22	17	Water Supply	9×10^{12} gal	Windham
23	18	Developed Land Area	260 sq. miles	Aerial photography, Jan., 1973; see Table 10.
24	19	Land Area with Natural Self-maintaining Systems	1690 sq. miles	*Ibid.*
25	20	Solid Waste Generated	1600 lbs/person/yr Total=1.07×10^{6} tons	

Table 6 - Continued

Pathway No. on Fig. 19[a]	Note[b]	Description	Numerical Value	Reference[c]
26	21	Rate of Building Growth in Public Sector	1.53×10^6 sq. ft (1972)	Annual Financial Report, MDCP, 1971; How Dade Does It Right, MDPT, 1972; Economic Survey, MDCP, 1970
27		Births and Net Migration	50800 (1972)	U.S. Census, 1970
28		No. of Vehicles Bought	26,987 vehicles for 1970	Dade County Dept. of Transportation; Fla. Statistical Abstract, 1973
29	22	Rate of Building Growth in Private Sector	1.53×10^8 sq. ft (1972)	Annual Financial Report, MDCP, 1971; How Dade Does It Right, MDPT, 1972; Economic Survey, MDCP, 1970
30	23	Total Structure of County Excluding Gov't Structure	1.09×10^9 sq. ft	Ibid.
31	24	Money Held by Business	$\$1.46 \times 10^9$	Fla. Statistical Abstract, 1973
32	25	Retail Sales	$\$2.5 \times 10^9$ (1972)	Dade County Economic Base Study, MDCP, 1960; Annual Financial Report, MDCP, 1971; Fla. Statistical Abstract, 1973; The Dade County Economy, MDCP, 1973
33		No. of Vehicles	850×10^3 (1971-72)	Dade County Dept. of Transportation

Table 6 - Continued

Pathway No. on Fig. 19[a]	Note[b]	Description	Numerical Value	Reference[c]
34		Total Population	1.37×10^{6} people	U.S. Census, 1970; How Dade Does It Right, MDPT, 1972
35	26	Money Held by People	$\$1.46 \times 10^{9}$	Fla. Statistical Abstract, 1973
36		Deaths	14627 (1972)	U.S. Census, 1970
37	24	Private Income	$\$4.75 \times 10^{9}$ (1972)	Dade County Economic Base Study, MDCP, 1960; Annual Financial Report, MDCP, 1971; Fla. Statistical Abstract, 1973; The Dade County Economy, MDCP, 1973
38		Sales Tax	$\$178.6 \times 10^{6}$ (1972)	Ibid.
39	27	Government Structure	$\$1.09 \times 10^{7}$ sq. ft	Ibid.
40		Money Held by Government	$\$3.26 \times 10^{8}$	Fla. Statistical Abstract, 1973; Dade County Budget, Bd. of County Commissioners, 1971
41		Water Consumption	59.6×10^{9} gal (1972)	How Dade Does It Right, MDPT, 1972
42		Depreciation	5%/yr	

[a]Pathways on Fig. 19 are circled.
[b]Notes are contained in Appendix II.
[c]MDCP stands for Metropolitan Dade County Planning Department; MDPT stands for Miami-metropolitan Department of Publicity and Tourism.

or lesser degree. For example, for an industrial city an industry storage and outflow of industrial goods in exchange for money would be substituted for tourism. As can be seen from the diagram, the major forcing functions for the Miami-Dade region include fossil fuel and food energies, tourist dollar flow, federal economic subsidies, sales of goods, population migration, natural energies, and external land available for development. The flow of tourists in and out of the region has been represented by the tourist money coming into the system which is inversely proportional to the price of goods and services in the external (U.S.) economy. In fact, all prices have been assumed to be determined by the economy of the United States as a whole, which reflects world-wide fuel availability and inflation.

The main storages which have been chosen to represent the system are private structure, roads and vehicles, population, government structure, water supply, developed land, wastes, and money. It can be seen that the production of structure and people is dependent on an interaction of all segments of the system, i.e., complex systems are highly integrated. This interaction depends on the natural energies of the system which are necessary for survival and provide work services for man. The wind energies of the system are especially important in maintaining the air quality of the system which serves as an attraction for people and tourists. Depreciation on all structures has been included to represent decay and is assumed to be 5%/year for a mean building life of 20 years. The entire system is enclosed in the hexagonal symbol representing an autocatalytic system.

Another main aspect of the model are the pathways of money flows. These include the external sources and sinks of money along with the internal cycles of wages and sales which account for distribution within the system. It is seen that developed land is generated by available monies within the system for purchase of external land. In a sense the model is the superimposition of two models, one depicting the flow of energy, people and goods through the system while the other describes the money flows. These two systems are connected through price interaction equations (see Fig. 3 and later simulated models).

Urban Mini-Model Driven by External Storage of Fossil Fuels and Linear Price Functions

In Fig. 20 is a simple model which aggregates the structure of the city (meaning square feet of buildings) into one storage and the money available for spending into another storage. It is assumed that the growth of structure, represented by J_2, is a product function of the structure Q_1, the money storage, M, and the fossil fuel, F, which means that all three variables are necessary for growth to occur. If, for example, money flows out of the system M will decrease with a resulting decrease in the rate of growth, a consequence of limited capital. Compensating for the growth of structure is an assumed depreciation rate of 5% per year, represented by a flow out of the storage, Q_1. Because of the simplicity of this model the money flows are broken into three main types. The inflow of money, K_1I_2, is that derived from tourism and transfer payments; the outflow, J_1P_1, is the money spent for energy; the remaining outflow, K_5MP_1, is money spent for goods and services and can be looked upon as the money necessary to keep the economic system functioning including interchange between people. This model could be used for any urban system provided the flows are known or approximated.

Since this model considers the energy source as a storage, the response of the model will vary depending on the amount of fuel assumed available. For this simulation the total proven fossil fuel reserves have been used (Auer, 1974) with a 40% recovery rate (Ballentine, 1974). Other available energy sources will be considered in later models. Monies spent for fuels and goods and services are a function of the price, P_1, so that the response of the model becomes dependent on the price function. This price is assumed to be determined external to the system, generated by the interactions of the U.S. and world economies.

Since there is so much uncertainty in the nature of future prices, several price functions are used in order to generate families of curves. The inflow of money, K_1I_2, is assumed to increase at a rate of \$.012 billion/yr, which is the average rate of increase from 1950-72. This is probably unrealistic but is an optimistic assumption in terms of a supply of money to the system. Four cases of a price function are used, namely, P_c = constant price, $.1P_c$ increase per year after 1973, $.2P_c$ increase per year, and $.5P_c$ increase per year after 1973. P_c was the existing price of fuel from 1952 to 1973. It is assumed that fuel prices are constant before 1973, an assumption which agrees well with the facts (Minerals Yearbook). Prices for goods and services are assumed to be some constant multiple of fuel prices.

Simulation output results are presented in Figs. 21 to 23. Figures 21 and 22a show the overall response of the three state variables and the money flow for fuels, J_1P_1, for four different price functions. The effect of different rates of increasing prices is clearly illustrated in Figs. 22b and 23 where families of curves are plotted for Q_1, M, F and J_1P_1. In Fig. 22b it is seen that for $dP/dt > 0$ (inflation rate greater than 0), structure peaks earlier and at a lower level than for $dP/dt = 0$ where dP/dt is the rate of price increase. The percentage difference in maximum structure between $dP/dt = 0$ and $dP/dt = .5\ P_c/yr$ is approximately (.65-.4)/.65 or 38.5%, separated in time by eight years, the result of greater outlays of money for fuels, goods, and services. Figure 23a shows the response of the money tank. It is seen that for P_1 = constant the money available continues to grow because of the assumed continuing input from outside the system. Each of the cases for $dP/dt \neq 0$ gives an eventual steady-state value with the $dP/dt = .5\ P_c/yr$ condition 33% less than the $dP/dt = .1\ P_c/yr$ condition in 1990. The fuel curves shown in Fig. 23b are extremely interesting and show, in

Fig. 20. Simplified urban model of Miami-Dade County driven by outside storage of fossil fuels, external income, and linear price functions. The equations used to simulate the model were as follows:

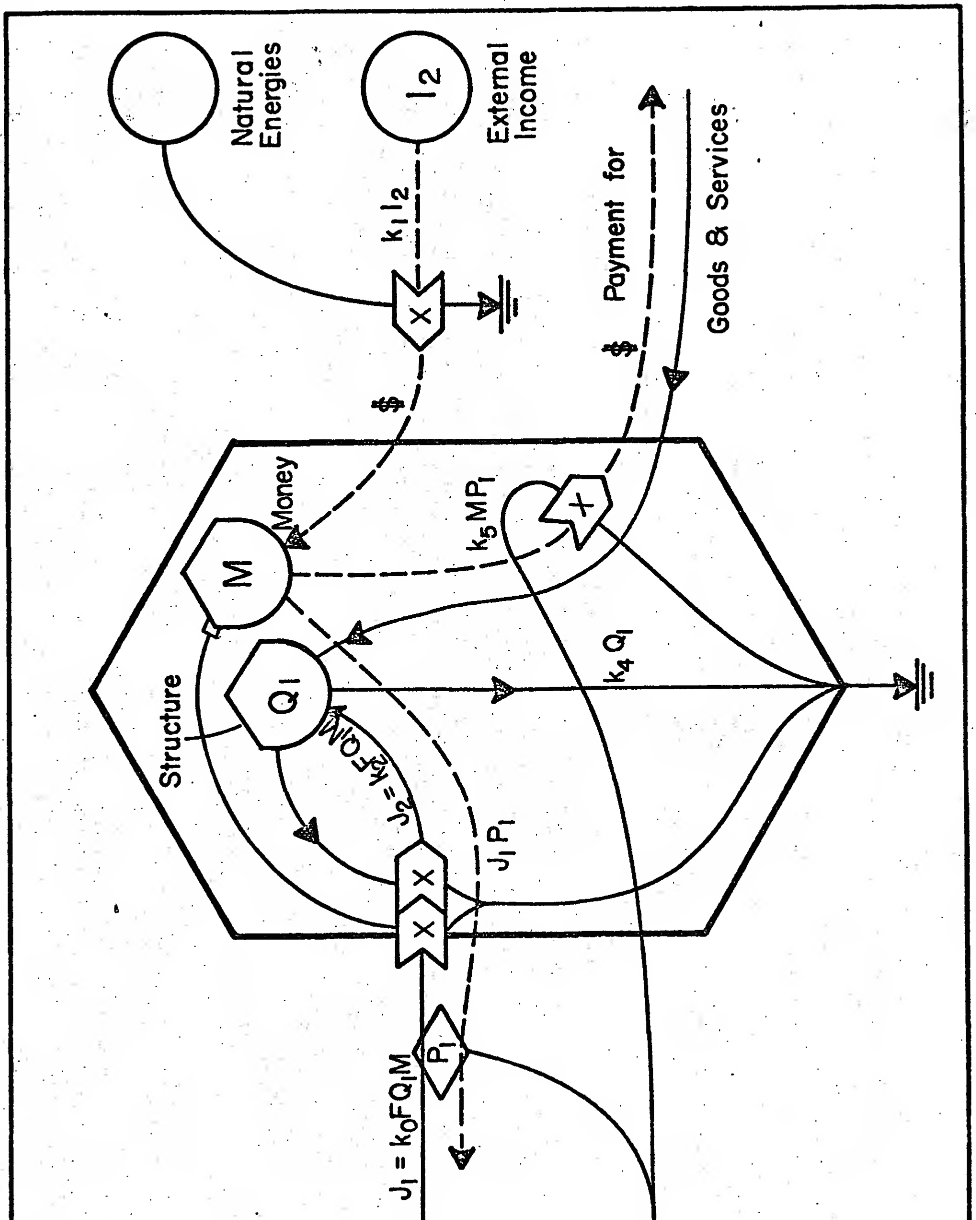
$$\dot{F}_1 = -K_0FQ_1M$$

$$\dot{Q}_1 = K_2FQ_1M - K_4Q_1$$

$$\dot{M} = K_1I_2 - K_0FQ_1MP_1 - K_5MP_1$$

$$\dot{P}_1 = 0 \text{ before } 1973$$

$$\dot{P}_1 = \text{constant after } 1973$$



Natural Energies
I_2
External Income
$k_1 I_2$
X
\$
Payment for
Goods & Services
Money
M
$k_5 M P_1$
X
Structure
Q_1
$k_4 Q_1$
$J_2 = k_2 F Q_1 M$
$J_1 P_1$
X
X
P_1
$J_1 = k_0 F Q_1 M$
F
Fossil Fuels
P_1
Price

Table 7

Flows and Storages for Model in Figure 20

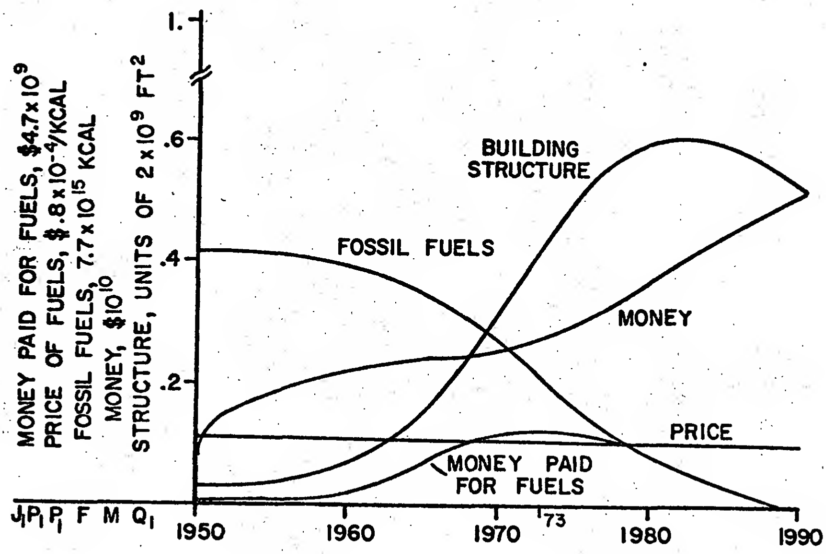
Mathematical Quantity	Note[a]	Description	Numerical Value	Reference
F	1	United States' Fossil Fuel Supply Available for Residents of Dade County	3.08×10^{15} Kcal	Auer, 1974
Q_1	2	Building Structure in Square Feet	app. 850×10^6 ft^2 (1972)	See Data section and Table 20
M	3	Monies Available for Purchasing	\$$2.737 \times 10^9$	"
$J_1 = K_0 F Q_1 M$	4	Fuel Consumption in Dade County	73.63×10^{12} Kcal (1972)	"
$J_2 = K_2 F Q_1 M$	5	Building Growth Rate	55×10^6 ft^2/yr	"
$K_1 I_2$	6	Income from Tourism and Transfer Payments	\$$4.0 \times 10^9$/yr (1970)	"
$J_1 P_1$	7	Money Paid for Fuels	\$$59.2 \times 10^7$	"
$K_4 Q_1$	8	Depreciation of Structure	5%/yr	"
$K_5 M P_1$	9	Money Paid for Goods & Services	\$$3.4 \times 10^9$/yr	"
P_1	10	Price for Fuels	\$$0.804 \times 10^{-5}$/Kcal	"

[a]Notes are contained in Appendix II.

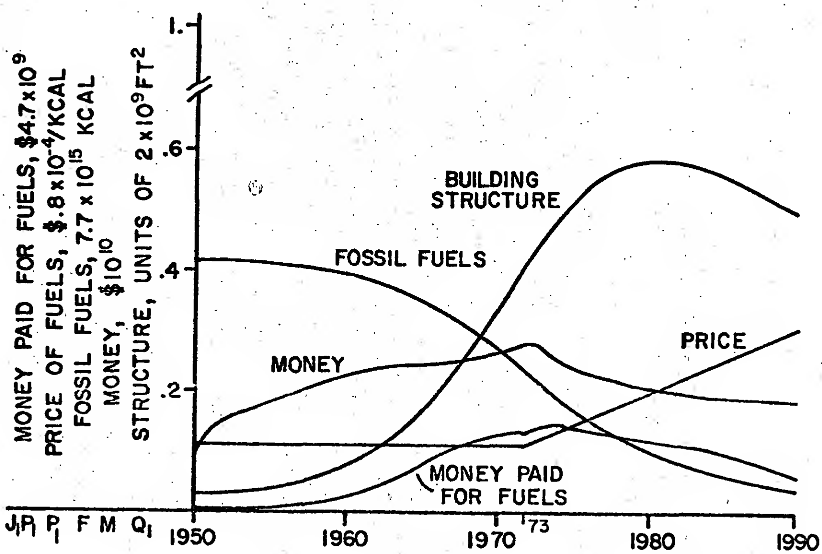
Fig. 21. Simulation results for model in Fig. 20.

a. Simulation results for model in Fig. 20 with price constant. Numbers on vertical axis indicate units that variables are expressed in.

b. Simulation results for model in Fig. 20 with price increasing 10% per year after 1973. Numbers on vertical axis indicate units that variables are expressed in.


MONEY PAID FOR FUELS, $4.7x10^9
PRICE OF FUELS, $.8x10^-4/KCAL
FOSSIL FUELS, 7.7x10^15 KCAL
MONEY, $10^10
STRUCTURE, UNITS OF 2x10^9 FT^2
BUILDING STRUCTURE
FOSSIL FUELS
MONEY
PRICE
MONEY PAID FOR FUELS
J1 P1 P1 F M Q1
1950
1960
1970
'73
1980
1990

(a.)

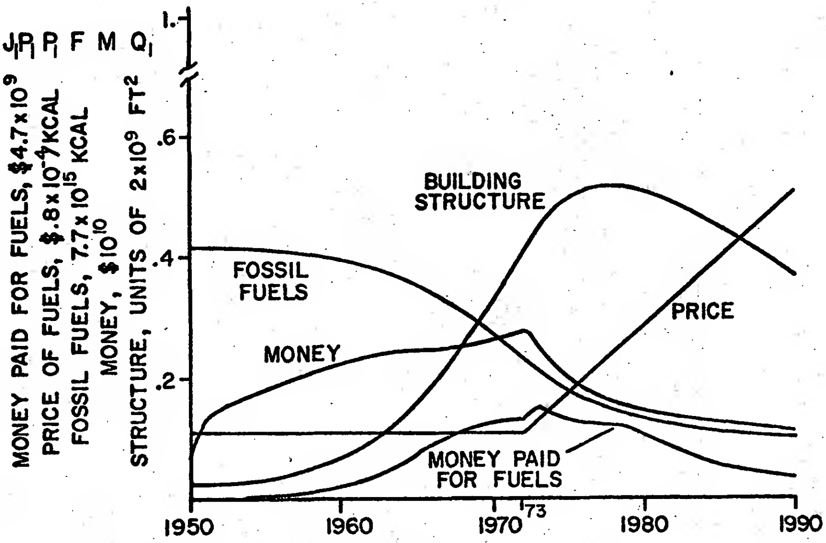

MONEY PAID FOR FUELS, $4.7x10^9
PRICE OF FUELS, $.8x10^-4/KCAL
FOSSIL FUELS, 7.7x10^15 KCAL
MONEY, $10^10
STRUCTURE, UNITS OF 2x10^9 FT^2
BUILDING STRUCTURE
FOSSIL FUELS
MONEY
PRICE
MONEY PAID FOR FUELS
J1 P1 P1 F M Q1
1950
1960
1970
'73
1980
1990

(b.)

Fig. 22. Simulation results for model in Fig. 20.

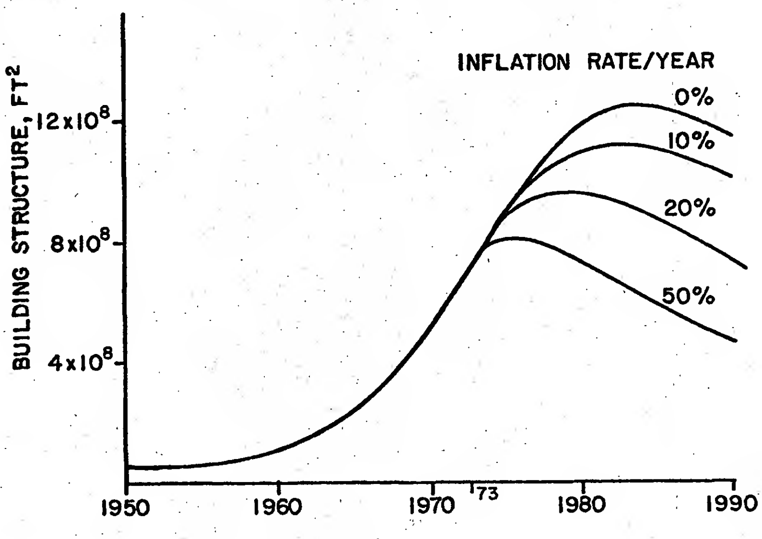
a. Simulation results for model in Fig. 20 with price increasing 20% per year. Numbers on vertical axis are units that variables are expressed in.

b. Simulation results for model in Fig. 20 showing a family of curves for building structure as a function of four different inflation rates. Inflation rate is the percentage increase of 1973 price occurring each year.



J₁ P₁ P₁ F M Q₁
MONEY PAID FOR FUELS, $4.7x10^9
PRICE OF FUELS, $.8x10^-4/KCAL
FOSSIL FUELS, 7.7x10^15 KCAL
MONEY, $10^10
STRUCTURE, UNITS OF 2x10^9 FT^2
1.
.6
.4
.2
BUILDING STRUCTURE
FOSSIL FUELS
PRICE
MONEY
MONEY PAID FOR FUELS
1950
1960
1970
'73
1980
1990

(a)



BUILDING STRUCTURE, FT^2
12x10^8
8x10^8
4x10^8
INFLATION RATE/YEAR
0%
10%
20%
50%
1950
1960
1970
'73
1980
1990

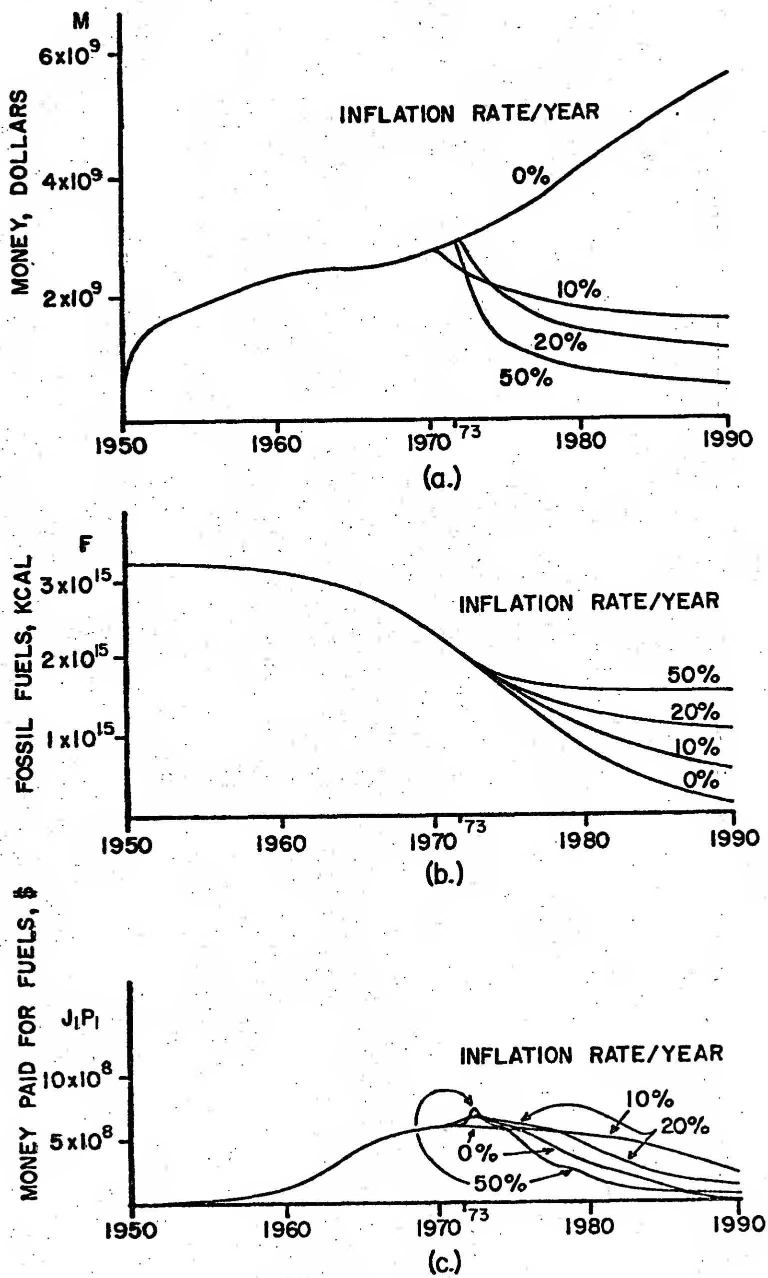
(b)

Fig. 23. Simulation results for the model in Fig. 20.

a. Simulation results for model in Fig. 20 showing a family of curves for money supply for four different rates of inflation. Inflation rate is the percentage increase of 1973 price occurring each year.

b. Simulation results for model in Fig. 20 showing a family of curves for fossil-fuel supply for four different inflation rates.

c. Simulation results for model in Fig. 20 showing a family of curves for money paid for fuels for four different inflation rates.


M
6x10⁹
4x10⁹
2x10⁹
MONEY, DOLLARS
INFLATION RATE/YEAR
0%
10%
20%
50%
1950
1960
1970
'73
1980
1990
(a.)
F
3x10¹⁵
2x10¹⁵
1x10¹⁵
FOSSIL FUELS, KCAL
INFLATION RATE/YEAR
50%
20%
10%
0%
1950
1960
1970
'73
1980
1990
(b.)
MONEY PAID FOR FUELS, $
J₁P₁
10x10⁸
5x10⁸
INFLATION RATE/YEAR
10%
20%
0%
50%
1950
1960
1970
'73
1980
1990
(c.)

effect, the results of supply and demand. It is seen that higher price levels lead to smaller consumption of fuels and an eventual higher level of fuel remaining. In fact, in 1990 there is 10 times as much fuel remaining for $dP/dt = .5\ P_c/yr$ than for $dP/dt = .1\ P_c/yr$. Finally, in Fig. 23c is shown the different outlays of money for fuels and it is seen that higher prices lead to a higher pulse in fuel purchases followed by a lower level of monies spent for fuels, probably because of a lower level in money supply, M. As can be seen from Fig. 23a the $.1\ P_c/yr$ price function triggered slightly earlier than 1973, which would introduce some small error into the 10% curve in Fig. 23c for fuel expenditures.

What the results of this and other models in this dissertation mean for life in the city is discussed later on in the Discussion section. How will fewer cars, buildings, and little or no net growth affect the life-style of the inhabitants?

Urban Mini-Model Driven by External Linear Functions for Energy and Price

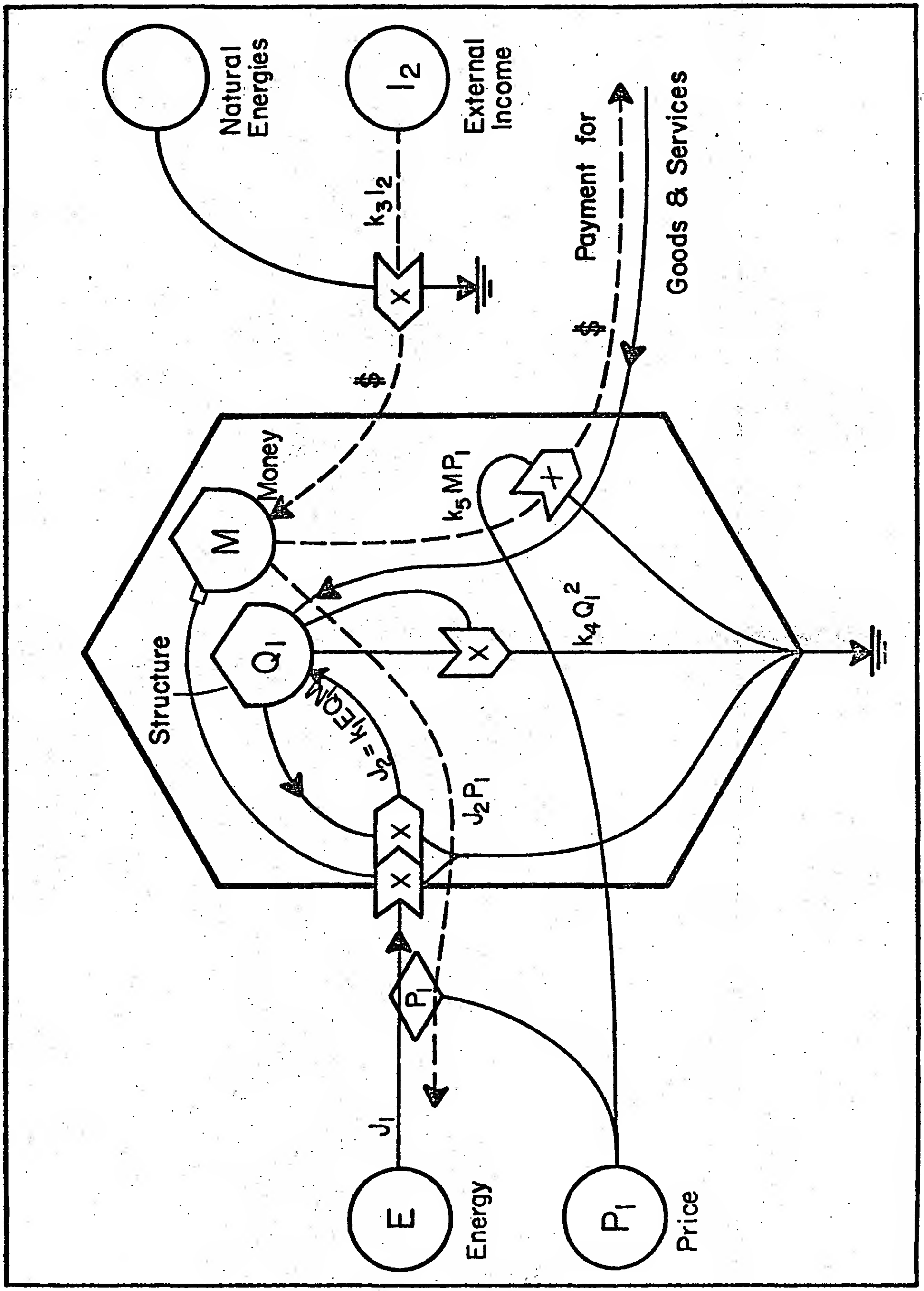
In Fig. 24 is a model similar to the model in Fig. 20 except that, instead of a storage of fossil fuel as an energy source, an arbitrary function may be programmed to drive the model. All the money flows are the same functionally as in the previous model. Maintenance energies are assumed to be a square drain on structure because of the increased interaction between parts as the system gets larger (Lamm, 1973). The model diagram and associated equations are shown in Fig. 24. For numerical values of the flows see Table 7.

As in the previous model the price function, P_1, is variable but so also is the energy function, E. Again, it is difficult to assess how P_1 and E will change in the future, especially since they are probably coupled in some way, so several cases are considered. If there are more fossil fuel reserves than is generally assumed and nuclear power is a net-yielder of energy, then the available energy can continue to grow. In order to simplify the simulations, linear functions were used for E as well as P_1. The first case considered is a linear increase of E from 1950 to 2000 with the values at 1950 and 1973 corresponding to actual energy usage. This corresponds to an increase of approximately .24 E_0/yr where E_0 is the energy consumption for 1950 (approximately 11.24×10^{12} Kcal). A less optimistic energy outlook is portrayed by the same linear increase from 1950-73 followed by a leveling at the 1973 value. In order to maintain this level of energy consumption a net-yielding nuclear technology will have to be developed. As a last case, it is assumed that energy consumption peaks in 1973 and decreases linearly to the 1950 level by the year 2000. The price function was 20% of the 1973 level per year after 1973, i.e., $dP/dt = .2\ P_c/\text{yr}$. Figure 25 depicts the overall behavior of the model for an assumed price function which increases at the rate of $dP/dt = .2\ P_c/\text{yr}$ for the three different available energy functions discussed above. It is seen that even for steadily increasing energy the structure, Q_1, levels while the money supply decreases as monies spent for fuels increase almost in a

Fig. 24. Simplified urban model of Miami-Dade County with inflows of fossil fuel energy and external income with linear external price function. The equations describing the simulation model are:

$$\dot{Q}_1 = K_1EQ_1M - K_4Q_1^2 \qquad \dot{P}_1 = 0 \text{ before } 1973$$

$$\dot{M} = K_3I_2 - K_2EQ_1MP - K_5MP_1 \qquad \dot{P}_1 = \text{constant after } 1973$$



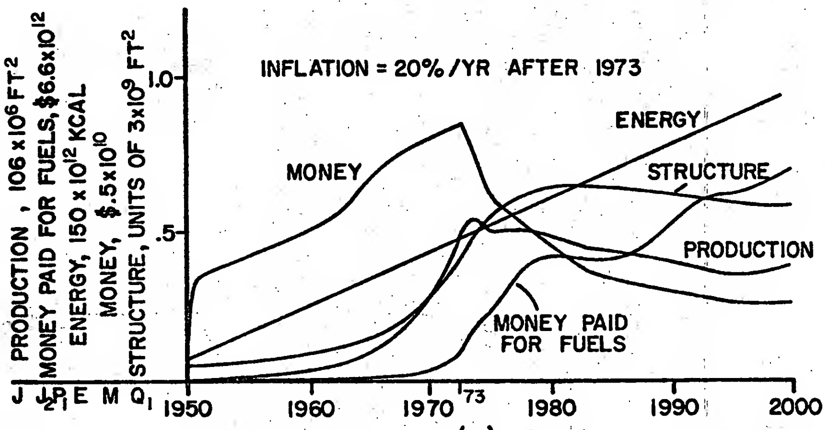
Natural Energies
I_2
External Income
$k_3 I_2$
X
$
Payment for
Goods & Services
$
Money
M
$k_5 M P_1$
X
Structure
Q_1
X
$k_4 Q_1^2$
$J_2 = k_1 E Q_1 M$
X
X
$J_2 P_1$
P_1
J_1
E
Energy
P_1
Price

Fig. 25. Simulation results for model in Fig. 24.

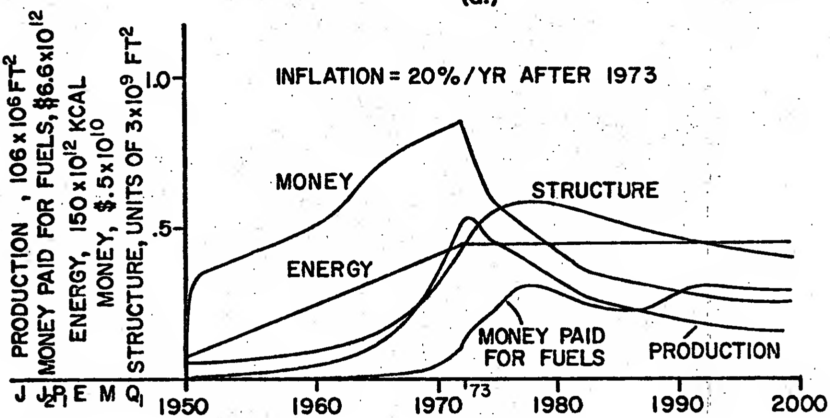
a. Simulation results for model in Fig. 24 with energy increasing from 1950 to 2000 at the rate of 2.7×10^{12} Kcal/yr. Numbers on vertical axis are in units that variables are expressed in.

b. Simulation results for model in Fig. 24 with energy increasing from 1950 to 1973 at the rate of 2.7×10^{12} Kcal/yr and level from 1973 to 2000.

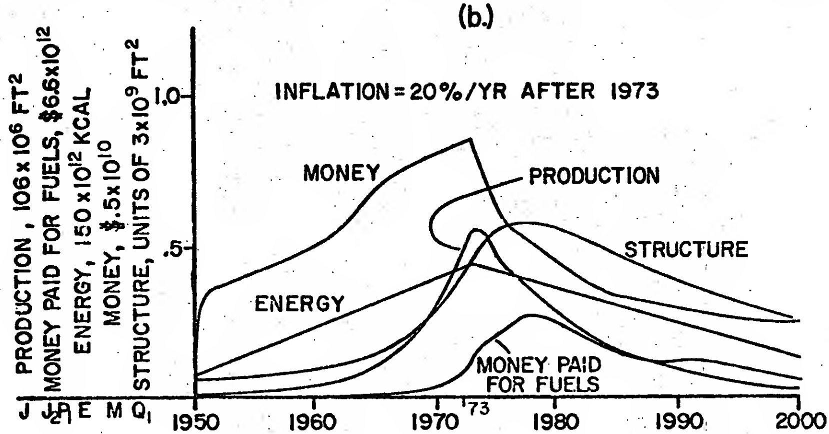
c. Simulation results for model in Fig. 24 with energy increasing from 1950 to 1973 at the rate of 2.7×10^{12} Kcal/yr and then decreasing at this rate from 1973 to 2000.


INFLATION = 20%/YR AFTER 1973
PRODUCTION, 106 x 10^6 FT^2
MONEY PAID FOR FUELS, $6.6x10^12
ENERGY, 150 x 10^12 KCAL
MONEY, $.5x10^10
STRUCTURE, UNITS OF 3x10^9 FT^2
1.0
.5
MONEY
ENERGY
STRUCTURE
PRODUCTION
MONEY PAID FOR FUELS
J J2P1 E M Q1
1950
1960
1970
'73
1980
1990
2000

(a.)


INFLATION = 20%/YR AFTER 1973
PRODUCTION, 106 x 10^6 FT^2
MONEY PAID FOR FUELS, $6.6x10^12
ENERGY, 150 x 10^12 KCAL
MONEY, $.5x10^10
STRUCTURE, UNITS OF 3x10^9 FT^2
1.0
.5
MONEY
STRUCTURE
ENERGY
MONEY PAID FOR FUELS
PRODUCTION
J J2P1 E M Q1
1950
1960
1970
'73
1980
1990
2000

(b.)

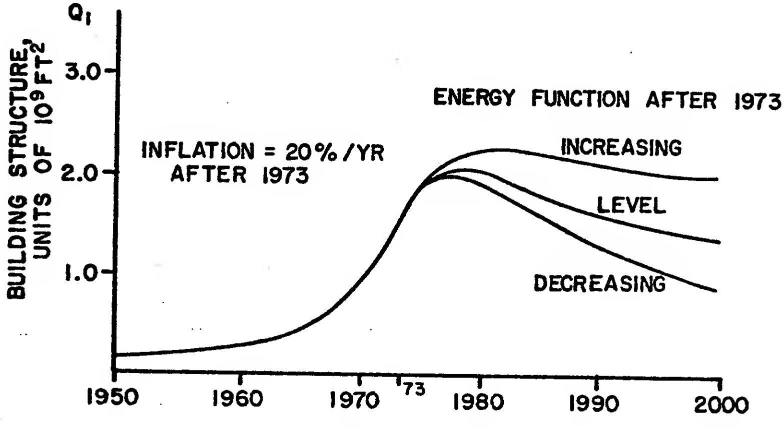

INFLATION = 20%/YR AFTER 1973
PRODUCTION, 106 x 10^6 FT^2
MONEY PAID FOR FUELS, $6.6x10^12
ENERGY, 150 x 10^12 KCAL
MONEY, $.5x10^10
STRUCTURE, UNITS OF 3x10^9 FT^2
1.0
.5
MONEY
PRODUCTION
STRUCTURE
ENERGY
MONEY PAID FOR FUELS
J J2P1 E M Q1
1950
1960
1970
'73
1980
1990
2000

(c.)

Fig. 26. Simulation results for model in Fig. 24.

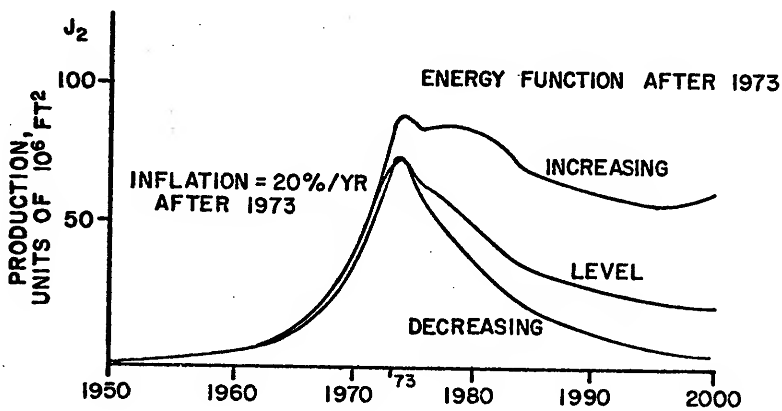
a. Simulation results for model in Fig. 24 showing a family of curves for building structure as a function of three different energy functions.

b. Simulation results for model in Fig. 24 showing a family of curves for growth rate as a function of three different energy functions.



Q_1
BUILDING STRUCTURE, UNITS OF 10^9 FT^2
3.0
2.0
1.0
ENERGY FUNCTION AFTER 1973
INFLATION = 20%/YR AFTER 1973
INCREASING
LEVEL
DECREASING
1950
1960
1970
'73
1980
1990
2000

(a)



J_2
PRODUCTION, UNITS OF 10^6 FT^2
100
50
ENERGY FUNCTION AFTER 1973
INFLATION = 20%/YR AFTER 1973
INCREASING
LEVEL
DECREASING
1950
1960
1970
'73
1980
1990
2000

(b)

step-wise manner. The next two cases of energy leveling and declining result in lower levels of each parameter. It is interesting that in each figure, production, J_2, peaks in 1973 and declines thereafter while the peak in structure occurs about 3 to 6 years later, depending on the energy function. Figures 26a and 26b allow better comparison of the structure, Q_1, and production, J_2, for the three different energy functions. It is seen that increasing energy results in structure being approximately 45% higher. The energy added from 1973-2000 is given by

$$\int_{23}^{50} (6.8+2.9t) \times 10^{12}\, dt = 3040 \times 10^{12} \text{ Kcal}$$

while for energy level from 1973-2000 the energy added is 1990×10^{12} Kcal. While the structure is 45% higher the energy maintenance of the city is approximately 53% higher. The production rate of the city, J_2, is much lower in the year 2000, being about 36% of the value for the energy increasing case. What alternative growth futures will mean for urban life is considered in the Discussion section.

Tourist Mini-Model for Miami-Dade County

In Fig. 27 is a model similar to those already presented but simulated in greater detail and containing features appropriate for Dade County. The money flows were separated into four major flows. The flow of tourist dollars was assumed to be directly dependent on available fossil fuels, structure in the county, and natural energies in the system. It was reasoned that as fossil fuels decline so will tourist travel. Low levels of natural energies or man-made structure to provide services would also limit tourist allocation. Finally, it was assumed that tourist flow was inversely proportional to the price of travel where the price of travel was thought to be closely related to the price of fuels. It was reasoned that even if the cost of travel became very high there would still be some tourism. This tourist flow could have been programmed with a $(1-P_2)$ term but this would go to zero at some critical price. Thus, the inverse function was used. The flow of taxes out of the system was assumed proportional to the money storage while the inflow of transfer payments and government subsidies was assumed proportional to the population. The flow of money through the price transactor, with price P_1, was the difference between money to purchase food, fuels and goods minus profits from manufacturing and property income.

Two storages were included in this model which were not present in previous models, namely, natural energies and population. A stress on natural energies was assumed to be proportional to developed structure. The flow of population into the population storage was assumed to be dependent on fossil fuels, money supply, and structure, all of which contribute to the increase in population. This increase in population consisted of natural increase plus migration. Most of the recent population increase can be accounted for by migration (see Fig. 6). As in previous models, the production of structure is also assumed to be dependent on these variables. Also included in this model were two price functions; P_2 is representative of the price of travel and P_1 is some mixed price for goods and fuels. Of course, P_1 is related to P_2 since they are both dependent on energy sources.

It was desired to find the response of the model to a step increase in the price of travel. To account for this the model was programmed with a step input for the price of travel, P_2, and a linearly increasing function for P_1. It was assumed that P_1 was increasing 20% of the 1973 level each year as in previous simulations. In summary, then, the rationale for using two different price functions was that the price of travel was closely associated with fuel prices and so this flow was programmed with a step input for P_2. The general price for goods, services, and fuels which connects the urban system to the outside economy was assumed to have a more gradual increase so that a linearly increasing function was programmed for P_1. Both of these price functions are assumed to be created external to the system.

The results of the simulations are presented in Figs. 28 to 30. Figures 28 and 29 show results for building structure, natural energies, population, tourist dollars and money supply. The curves generated for prices constant assume that prices remain constant until 1990. For the price increasing curves the price functions shown in Fig. 29c were used where the rate of increase of P_1 was 20% per year and P_2 was a step

Fig. 27. Tourist model for Miami-Dade County with major money flows. The equations used to simulate the model were as follows:

$$\dot{Q}_1 = K_6 FMQ_1 - K_7 Q_1$$

$$\dot{Q}_2 = K_8 Q_2 J_R - K_9 Q_1 - K_{10} Q_2$$

$$\dot{Q}_3 = K_{12} FMQ_1 - K_{13} Q_3$$

$$\dot{M} = K_1 \frac{Q_1 Q_2 F}{P_2} + K_{11} Q_3 - K_4 MQ_1 FP_1 - K_5 M$$

$$\dot{F} = -K_4' FMQ_1$$

$$J_R = J_0 K_0 J_R Q_2$$

$\dot{P}_1 = 0$ before 1973

$\dot{P}_1 =$ constant after 1973

P_2 is a step function with step increase at 1973

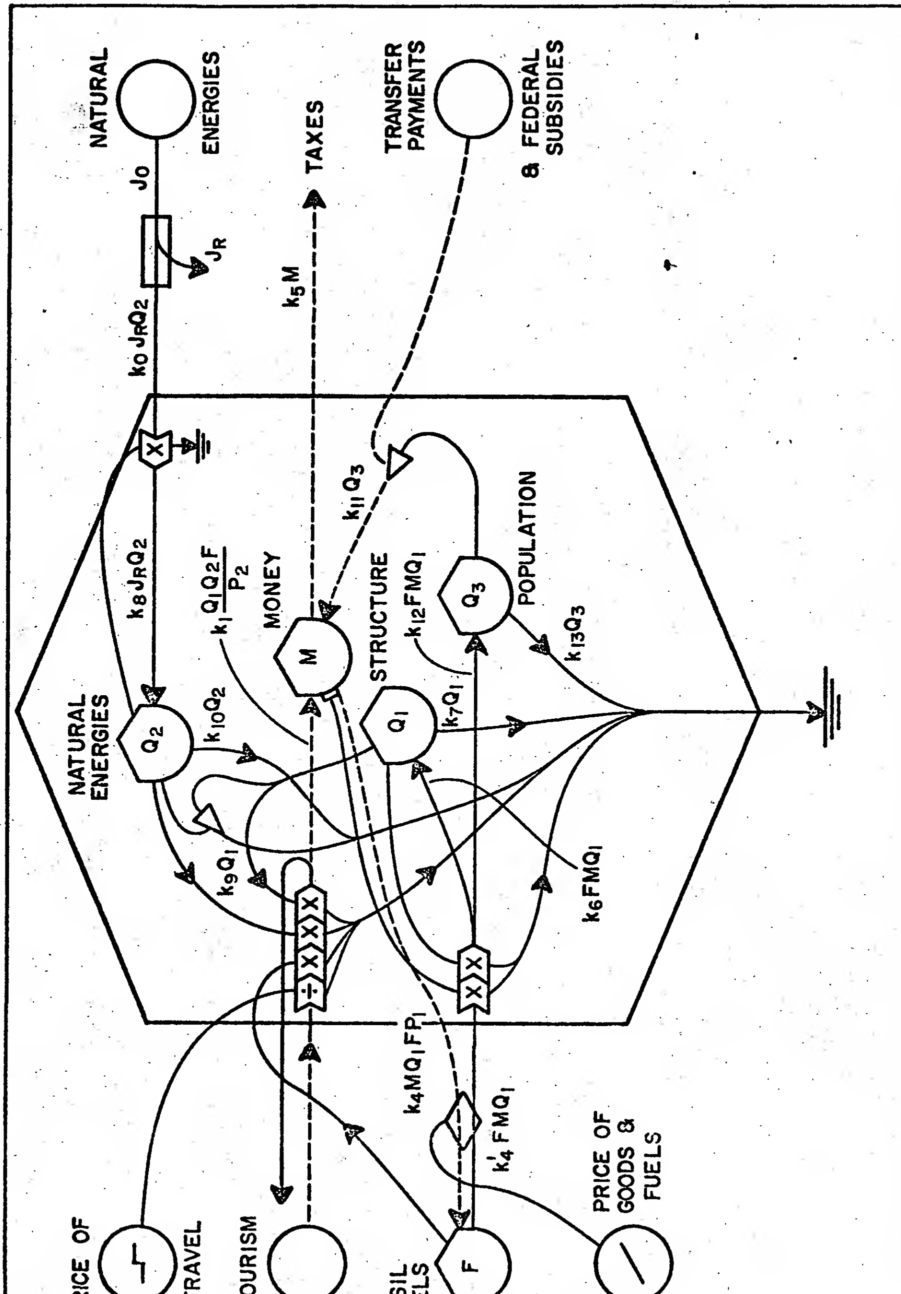

NATURAL ENERGIES
J_0
J_R
$k_0 J_R Q_2$
TAXES
$k_5 M$
TRANSFER PAYMENTS & FEDERAL SUBSIDIES
$k_8 J_R Q_2$
$k_1 \frac{Q_1 Q_2 F}{P_2}$
MONEY
M
$k_{11} Q_3$
STRUCTURE
$k_{12} FMQ_1$
Q_3
POPULATION
$k_{13} Q_3$
NATURAL ENERGIES
Q_2
$k_{10} Q_2$
Q_1
$k_7 Q_1$
$k_9 Q_1$
$k_6 FMQ_1$
$k_4 MQ_1 FP_1$
$k_4' FMQ_1$
PRICE OF TRAVEL
P_2
TOURISM
FOSSIL FUELS
F
PRICE OF GOODS & FUELS
P_1

Table 8

Storages and Flows for Tourist Model in Figure 27

Mathematical Quantity	Note	Description	Numerical Value[a]	Reference
F	1	United States Fossil Fuel Supply Available to Residents of Dade County	3.08×10^{15} Kcal	Auer, 1974
Q_1	2	Building Structure in Square Feet	850×10^{6} ft^2 (1972)	See Data section and Table 20
Q_2	3	Natural Energies	13.9×10^{12} Kcal (1972)	"
Q_3	4	Population	1.37×10^{6} (1972)	"
M	5	Money Available for Purchasing	$\$2.74 \times 10^{9}$ (1972)	"
K'_4FMQ_1	6	Fuel Consumption in Dade County	73.63×10^{12} Kcal (1972)	"
K_6FMQ_1	7	Building Growth Rate	55×10^{6} ft^2/yr	"
$K_{12}FMQ_1$		Population Growth	50800/yr (1972)	"
$K_{13}Q_3$		Death Rate	14627/yr (1972)	"
$K_4MQ_1FP_1$	8	Money for Food, Fuels and Goods minus Manufacturing and Property Income	$\$2.65 \times 10^{9}$ (1972)	"
K_7Q_1	9	Depreciation of Structure	5%/yr	"

Table 8 - Continued

Mathematical Quantity	Note	Description	Numerical Value[a]	Reference
$K_1 \frac{Q_1 Q_2 F}{P_2}$	10	Tourist Money Flow	$\$3.2 \times 10^9$ (1972)	"
$K_5 M$	11	Outflow of Tax Money	$\$1.36 \times 10^9$ (1972)	"
$K_{11} Q_3$	12	Transfer Payments plus Federal Subsidies	$\$1.48 \times 10^9$ (1972)	"
$K_8 J_R Q_2$	13	Natural System Production	13.9×10^{12} Kcal	"
$K_{10} Q_2$	14	Natural System Decay	13.9×10^{12} Kcal	"
$K_9 Q_1$	15	Stress on Natural Systems	$.05 \times 10^{12}$ Kcal/yr	"

[a] All Kcal values are in Fossil Fuel Work Equivalents (FFWE).

NOTE: Notes are contained in Appendix II.

Fig. 28. Simulation results for tourist model in Fig. 27.

a. Building structure for two different price situations. One result is for prices constant; the other result is for the programmed price functions shown in Fig. 29c.

b. Natural system energies for two different price situations.

c. Total population for two different price situations.

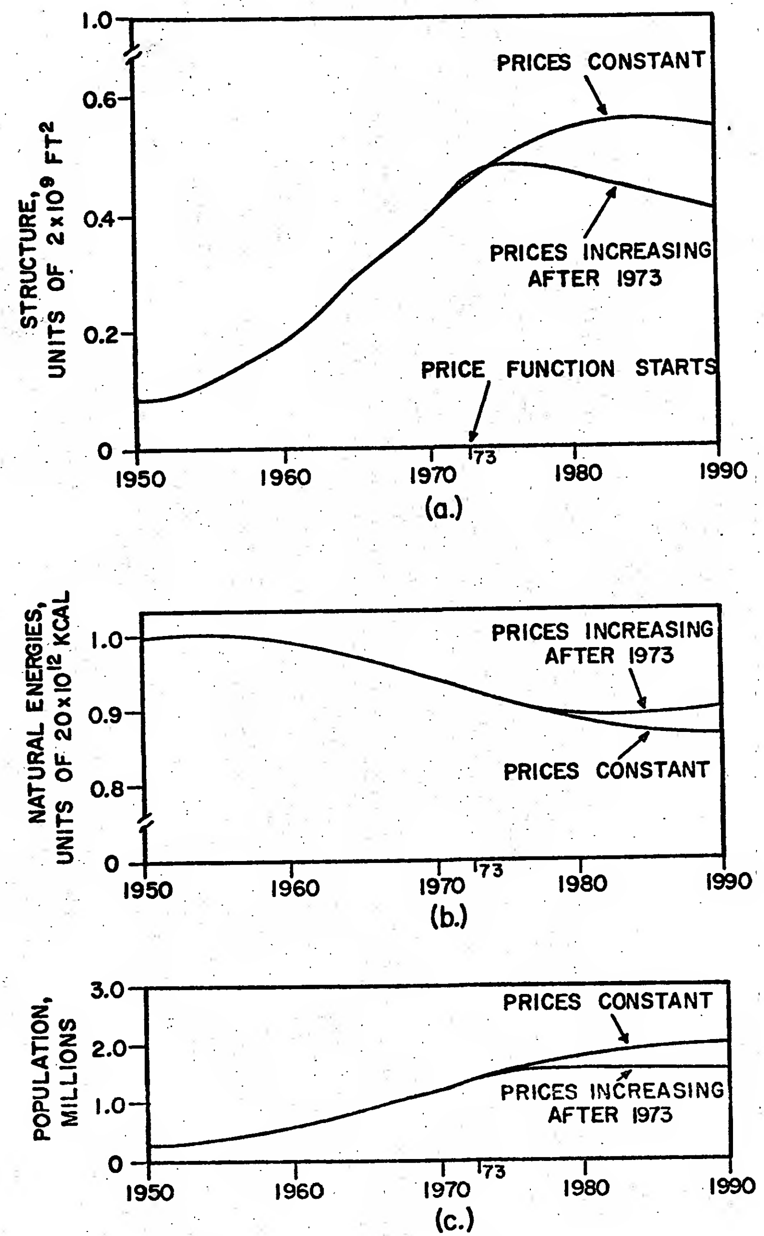
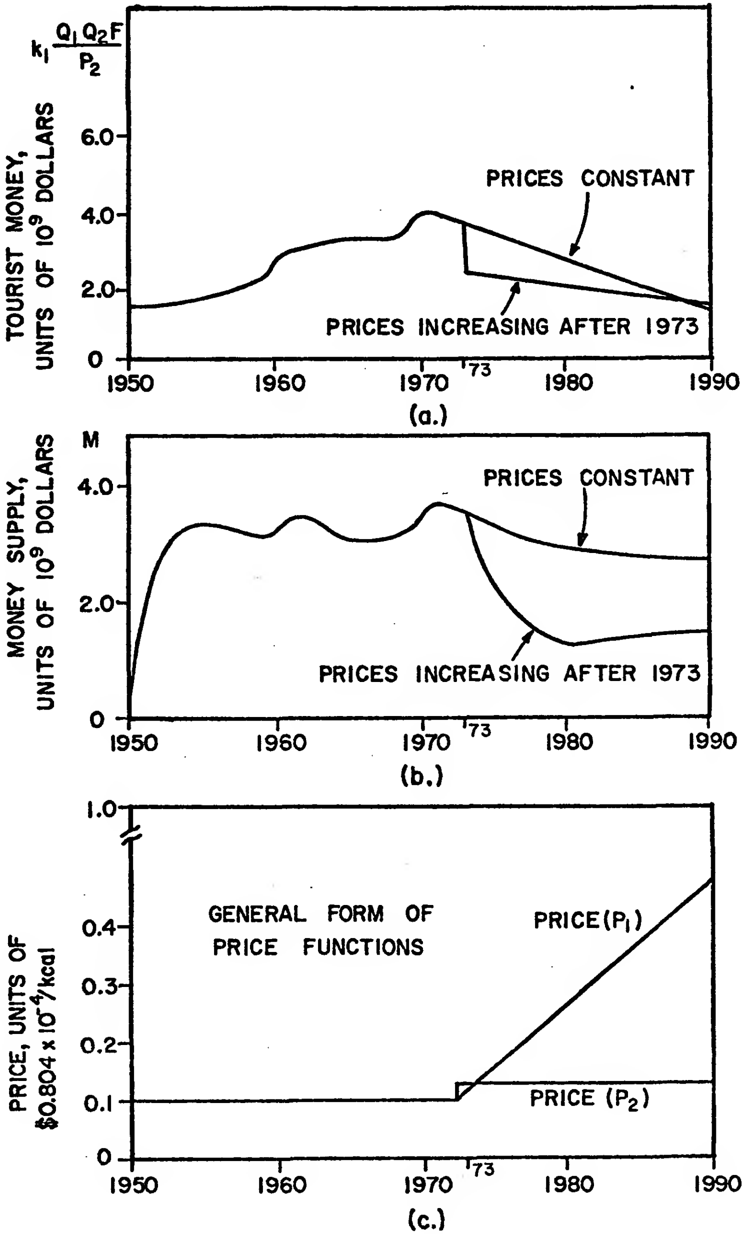

STRUCTURE, UNITS OF 2x10⁹ FT²
1.0
0.6
0.4
0.2
0
PRICES CONSTANT
PRICES INCREASING AFTER 1973
PRICE FUNCTION STARTS
1950
1960
1970
'73
1980
1990
(a.)
NATURAL ENERGIES, UNITS OF 20x10¹² KCAL
1.0
0.9
0.8
0
PRICES INCREASING AFTER 1973
PRICES CONSTANT
1950
1960
1970
'73
1980
1990
(b.)
POPULATION, MILLIONS
3.0
2.0
1.0
0
PRICES CONSTANT
PRICES INCREASING AFTER 1973
1950
1960
1970
'73
1980
1990
(c.)

Fig. 29. Simulation results for tourist model in Fig. 27.

a. Tourist dollar flow for two different price situations. One result is for prices assumed constant; the other result is for the programmed price functions shown in Fig. 29c.

b. Money supply for two different price situations.

c. General form of the price functions programmed for simulations. P_1 represented some mixed price for goods and fuels for the urban system, whereas P_2 represented a price more directly related to tourist travel.

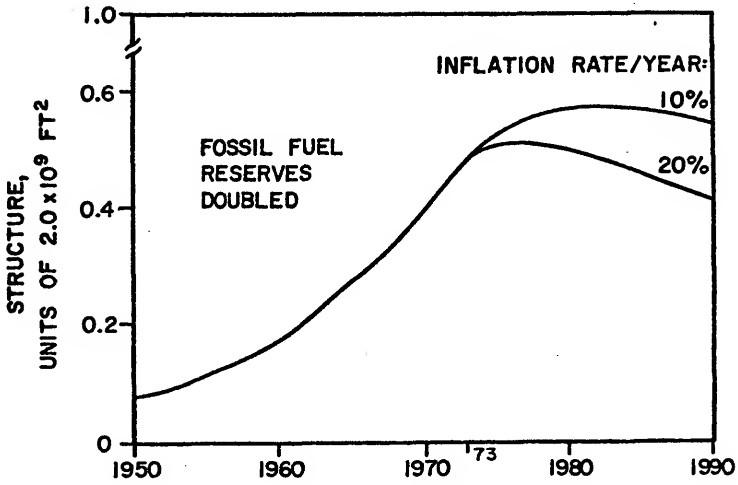


$k_1 \frac{Q_1 Q_2 F}{P_2}$
TOURIST MONEY, UNITS OF 10^9 DOLLARS
6.0
4.0
2.0
0
PRICES CONSTANT
PRICES INCREASING AFTER 1973
1950
1960
1970
'73
1980
1990
(a.)
M
MONEY SUPPLY, UNITS OF 10^9 DOLLARS
4.0
2.0
0
PRICES CONSTANT
PRICES INCREASING AFTER 1973
1950
1960
1970
'73
1980
1990
(b.)
PRICE, UNITS OF $0.804 x 10^{-4}/kcal
1.0
0.4
0.3
0.2
0.1
0
GENERAL FORM OF PRICE FUNCTIONS
PRICE (P_1)
PRICE (P_2)
1950
1960
1970
'73
1980
1990
(c.)

Fig. 30. Simulation results for tourist model in Fig. 27 with fossil-fuel storage double that used for simulation results shown in Figs. 28 and 29.

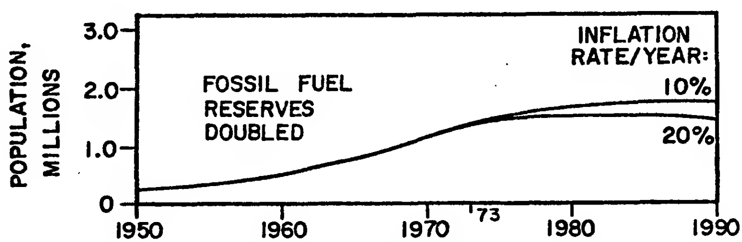
a. Building structure for two different rates of inflation after 1973. The rate of increase of price refers to the slope of the P_1 price function after 1973 as shown in Fig. 29c. The P_2 price function is assumed to remain the same.

b. Total population for two different rates of inflation after 1973.



1.0
0.6
0.4
0.2
0
STRUCTURE, UNITS OF 2.0 x 10⁹ FT²
INFLATION RATE/YEAR:
10%
20%
FOSSIL FUEL RESERVES DOUBLED
1950
1960
1970
'73
1980
1990

(a.)



3.0
2.0
1.0
0
POPULATION, MILLIONS
INFLATION RATE/YEAR:
10%
20%
FOSSIL FUEL RESERVES DOUBLED
1950
1960
1970
'73
1980
1990

(b.)

function. It can be seen from the curves that increasing prices inhibit the growth of structure, population, tourism, and money supply whereas the natural system energies recover and end up at a higher level by the year 1990. It is interesting to note that this type of model formulation results in oscillations in the money supply as can be seen from Fig. 29b. There seems to be an upturn just after the recession of 1960 and again in the late sixties until 1972. This kind of fluctuating behavior in the economic system is well known. This oscillation may also have been caused by the initial state of the system.

In Fig. 30 are presented results for doubling the initial storage of fossil fuels and seeing the responses for two different rates of inflation for the price function, P_1. The structure and populations do not grow as much as would be anticipated and this is attributable to a limited supply of money.

Energy-Economic Calculations

This section brings together the systems of man and nature through the common denominator of energy. As explained in the Methods section it is theoretically possible to convert the useful work of natural systems and human systems to a common denominator of Fossil Fuel Work Equivalents (FFWE). To this end, areas of different systems in Dade County have been measured or calculated. This allows a budget of all these flows to be constructed.

Fossil-Fuel and Money Flows

Close inspection of the table of data in Appendix I shows the use and breakdown of fossil fuels from 1950 to 1972. For clarity the distribution of fossil fuels has been illustrated in Fig. 31 with pie diagrams for the years 1950, 1960 and 1972. It can be seen that high quality electrical energy has increased percentagewise while liquid fuels and gasoline have decreased. Notice that gasoline has gone from 45.5% of the fossil fuels used in 1950 to 29.5% in 1972.

The main money flows for 1972 in the Miami-Dade system are summarized in Table 9. These numbers were obtained from the various references cited in the data section and in Appendix I. The notes to Table 9 detail the calculations used to arrive at the value of the flows.

Subsystems of Dade County

Following from the Center for Wetlands, University of Florida, study of South Florida, Table 10 was constructed to give values for areas of different systems (see Fig. 32b). As can be seen from the table, the top seven categories are man-made systems, the next three are agricultural, and the rest are natural, self-maintaining systems. It can be seen that the overwhelming majority of land is covered by marsh or wet prairies. The areas were calculated by planimetering

Fig. 31. Pie diagrams illustrating the distribution of fossil fuels for 1950, 1960, and 1972.

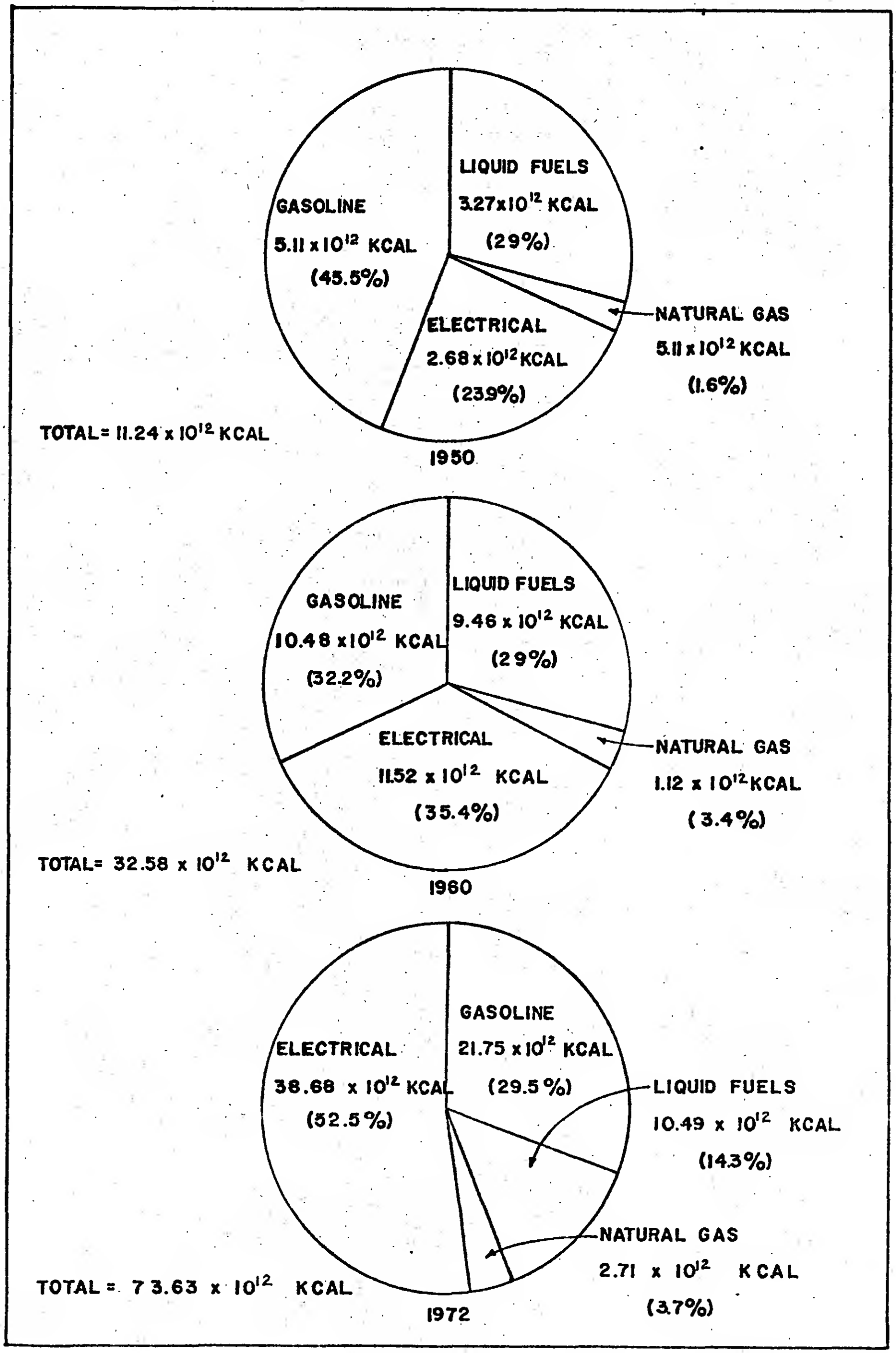

LIQUID FUELS
3.27x10^12 KCAL
(29%)
GASOLINE
5.11 x 10^12 KCAL
(45.5%)
ELECTRICAL
2.68 x 10^12 KCAL
(23.9%)
NATURAL GAS
5.11 x 10^12 KCAL
(1.6%)
TOTAL= 11.24 x 10^12 KCAL
1950
LIQUID FUELS
9.46 x 10^12 KCAL
(29%)
GASOLINE
10.48 x 10^12 KCAL
(32.2%)
ELECTRICAL
11.52 x 10^12 KCAL
(35.4%)
NATURAL GAS
1.12 x 10^12 KCAL
(3.4%)
TOTAL= 32.58 x 10^12 KCAL
1960
GASOLINE
21.75 x 10^12 KCAL
(29.5%)
ELECTRICAL
38.68 x 10^12 KCAL
(52.5%)
LIQUID FUELS
10.49 x 10^12 KCAL
(14.3%)
NATURAL GAS
2.71 x 10^12 KCAL
(3.7%)
TOTAL = 73.63 x 10^12 KCAL
1972

Table 9

Major Money Flows in the Miami-Dade Urban System for 1972

Major Incomes, Billions of Dollars		Major Expenses, Billions of Dollars	
Tourism[a]	3.23	Expenditures for Fuels[g]	0.59
Government Subsidies[b]	0.856	Expenditures for Goods[h]	3.6
Transfer Payments[c]	0.62	Expenditures for Food[i]	1.25
Property Income[d]	0.79	Taxes[j]	1.36
Manufacturing[e]	2.0	Total	6.8
Agriculture[f]	0.14		
Total	6.65		

[a]Tourists spent $3 billion in 1970 (see Table 6, pathway no. 6). Multiply this by ratio of population in 1972 to 1970 to obtain approximate figure for 1972:

$$\$3 \times \frac{1.3676}{1.267} \text{ billion} = \$3 \times 1.079 \text{ billion} = \$3.23 \text{ billion}$$

[b]Multiply government subsidies in 1970 (see note 7, Table 6) by 1.079 to obtain $.856 billion for 1972.

[c]See note 6, Table 6.

[d]See note 6, Table 6.

[e]This was the approximate value of industry shipments (Florida Statistical Abstract, 1973).

Footnotes to Table 9 - continued

[f]Agricultural income accounted for approximately 2% of the total income (Buchanan, 1973).

[g]See note 14, Table 6.

[h]Money spent for vehicles was approximately $2.6 billion (see note 11, Table 6). Money spent for manufacturing goods was approximately $1.02 billion (Florida Statistical Abstract, 1973). The sum of these two is $3.6 billion.

[i]See note 12, Table 6.

[j]See note 8, Table 6.

Table 10

Land Areas Within Dade County in Units of Square Kilometers[a]

	Area	Percent of Total
Power Plants	17	.31
Man-made Lakes & Reservoirs	12	.22
Cleared and/or Prepared with Roads	26	.47
Open Space and Recreation	71	1.3
Transportation Terminals	28	.51
Commercial, Industrial & Institutional	76	1.39
Residential	461	8.4
Orchards, Groves and Treecrops	8	.15
Vegetable Crops	335	6.11
Improved Pasture	69	1.26
Rivers, Streams and Lakes	50	.9
Fresh Water Marsh/Sloughs	1229	22.42
Salt Water Marsh	30	.55
Mangroves	302	5.51
Pinelands	217	3.96
Cypress Trees	108	1.97
Hardwood Trees	60	1.09
Sawgrass Marsh	551	10.05
Exposed Marl Prairies & Salt Flats	43	.78
Wet Prairies	1290	23.53
Estuary (Biscayne Bay)	499	9.12
Total	5482	100.00

[a]Planimetered from aerial photographs flown January, 1973 (Mark Hurd. Black and White Infrared and NASA False Color Mosaic U-2. Scale: 1 inch = 2 miles).

Fig. 32a. Aerial map of Miami-Dade County.

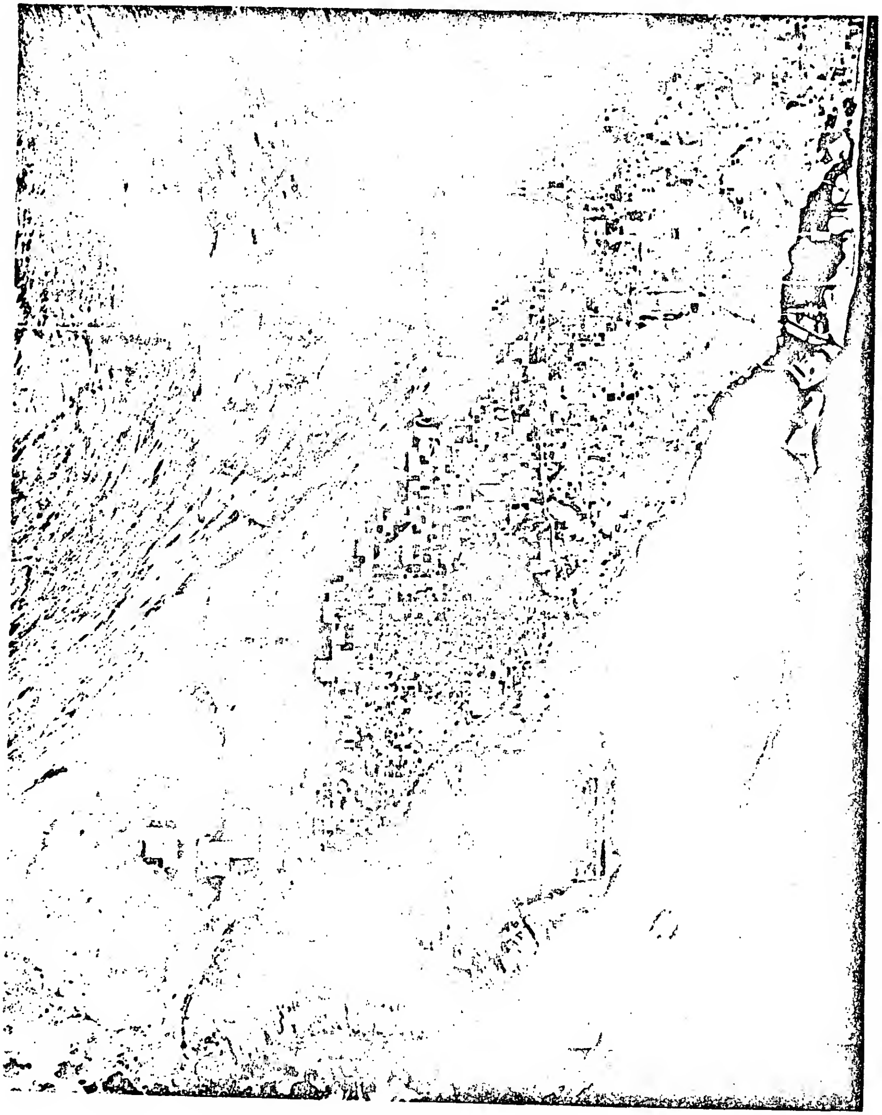
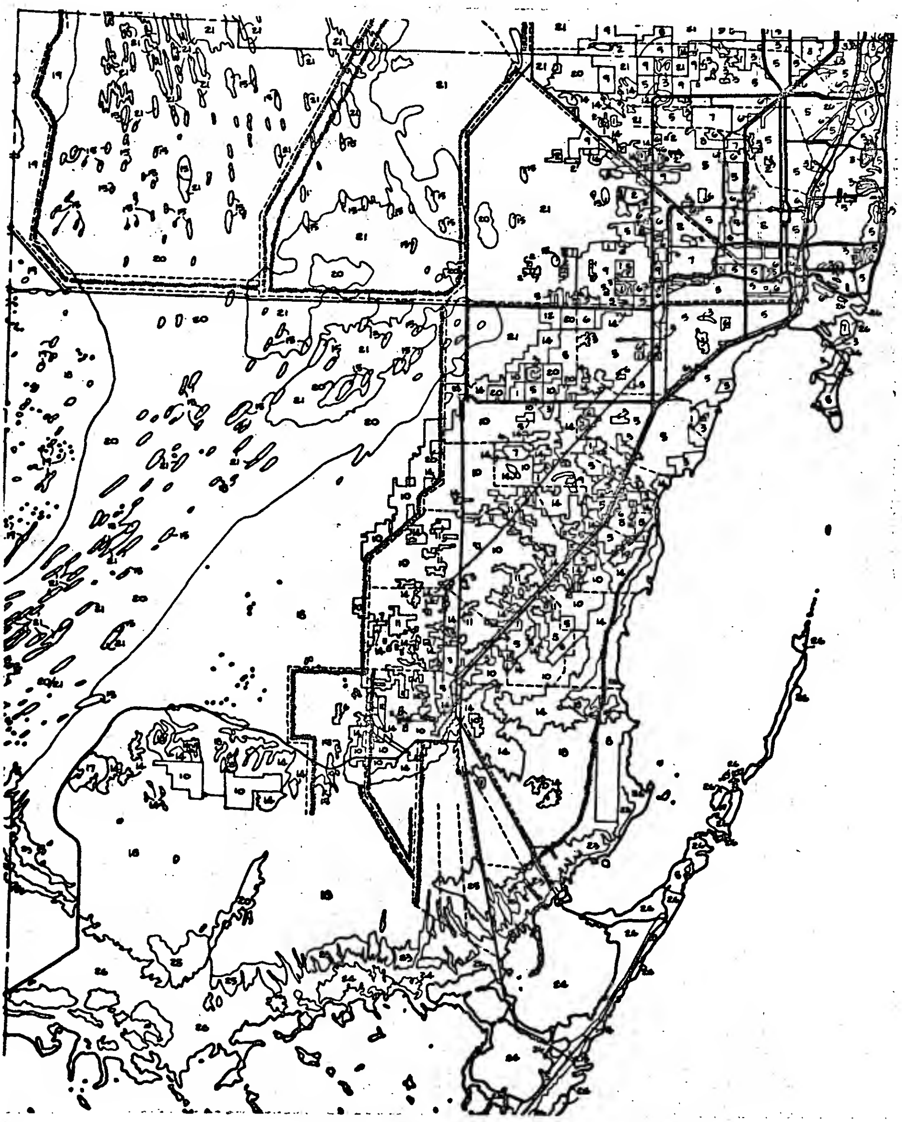


Fig. 32b. Land use map* of the Miami-Dade urban region derived from aerial photograph. The key to the map is as follows:

1 Cleared Land	14 Pinelands
2 Lakes & Reservoirs	15 Hardwoods
3 Recreation; Open Space	16 Rivers & Lakes
4,5 Residential	17 Cypress
6 Commercial & Industrial	18 Wet Prairie
7 Transportation	19 Scrub Cypress
8 Power Plants	20 Fresh Water Marsh
9 Pasture	21 Sawgrass Marsh
10 Vegetable Crops	22 Beach & Dune
11 Tree Crops	23 Salt Flats
12 Sugar Cane	24 Estuarine Bays
13 Dry Prairie	25 Salt Water Marsh
	26 Mangroves

*Land use map constructed by Bob Costanza, Center for Wetlands, University of Florida.



aerial photographs flown January, 1973 (see footnote to Table 10).

Energy Calculations

The previous sections have presented numerical data for fossil fuel flows, money flows, and land areas of various systems in the county. The metabolism of the urban areas can be obtained directly from fossil fuel and money data. In order to generate the complete energy picture of the county, contributions from natural ecosystems must be calculated. The useful work that an ecosystem performs in maintenance, survival, and growth is measured by its gross production. A measurement of this would result in an energy flow expressed in Kcal of chemical energy (sugar). As explained in Methods, these work services of nature need to be converted to fossil fuel work equivalents so that the systems of man and nature can be compared on an equal basis.

Table 11 tabulates all the major energy flows for the Miami-Dade system. Areas of natural systems were obtained from Table 10. These multiplied by work per unit area gave total work. Multiplying by a suitable factor expressed this work in FFWE's. The notes to the table explain the calculations and assumptions made. Energy flows per year were converted into equivalent dollar flows through the conversion factor of 25,000 Kcal/dollar (see Table 1). These systems were those that were contained within the Dade County lines (see Fig. 2). Dade County extends about halfway into the

Table 11

Major Energy Flows in Dade County for 1972

Name of Energy Flow	(A) Area of System[1] in 10^6 sq.meters	(B) Annual Work of that Type[2] 10^3 Kcal/m^2/yr	(C) Energy Concentration Factor[3]	(D) County's Annual Work[4] 10^{12} Kcal/yr	(E) Dollar Equivalent for Human Work[5] 10^6 \$/yr
Flows of Metabolic Work by Natural Ecosystems					
Fresh Water Marsh, Sawgrass Marsh[6] and Wet Prairies	3070.0	67.3	20.0	10.33	413.0
Salt Water Marsh and Marl Prairies[7]	73.0	34.6	20.0	0.13	5.2
Rivers, Streams & Lakes[8]	50.0	4.6	20.0	0.013	0.52
Pinelands[9]	217.0	11.5	20.0	0.12	4.99
Cypress Hardwoods[10]	108.0	20.0	20.0	0.11	4.4
Hardwoods[11]	60.0	38.3	20.0	0.11	4.4
Estuary (Biscayne Bay)[12]	499.0	20.0	20.0	0.5	20.0
Mangroves[13]	302.0	29.5	20.0	0.45	18.0
Subtotal				11.76	470.5

Table 11 - Continued

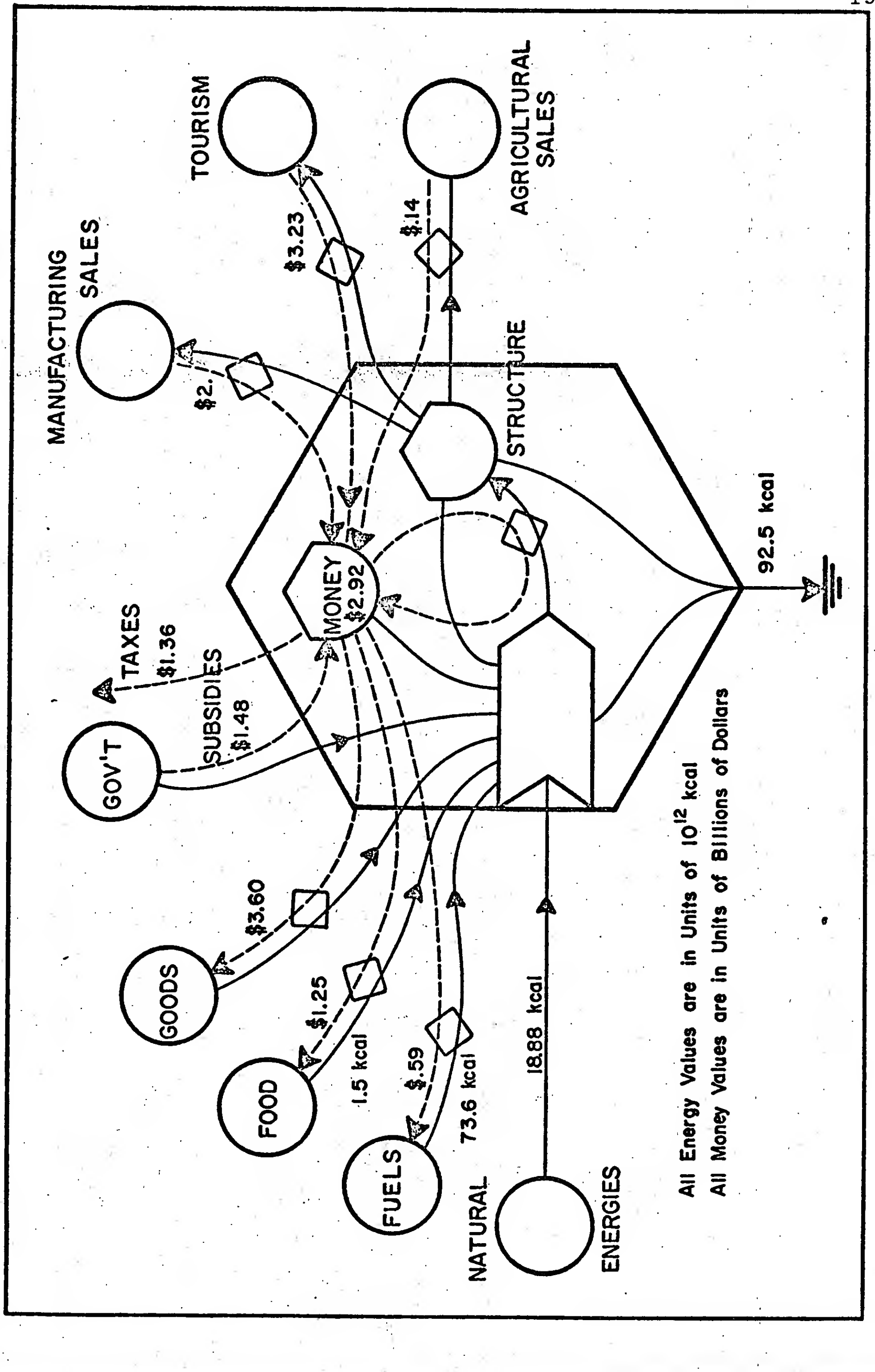
Name of Energy Flow	(A) Area of System[1] in 10^6 sq.meters	(B) Annual Work of that Type[2] 10^3 Kcal/m^2/yr	(C) Energy Concentration Factor[3]	(D) County's Annual Work[4] 10^{12} Kcal/yr	(E) Dollar Equivalent for Human Work[5] 10^6 \$/yr
Other Contributing Natural Flows					
Tides in Biscayne Bay[14]	499.0	0.32	0.3	0.53	21.2
Beach Wave Energy[15,16]	1.75	516.0	1(?)	0.9	36.2
Wind Energy Dissipated to Ground[17]	5482.0	0.21	3(?)	0.38	15.3
Potential Energy of Water[18]	4983.0	0.0018	0.3	0.03	1.2
Potential Energy of Fresh/ Salt Water Concentration Gradient[19]	5482.0	9.14	10.0(?)	5.0	200.0
Subtotal				6.81	272.7
Nature's Metabolic Work on Managed Areas					
Improved Pasture[20]	69.0	21.8	20.0	0.08	3.2
Vegetable Crops[21]	335.0	12.8	20.0	0.22	8.6
Orchards, Groves, and Tree Crops[22]	8.0	14.1	20.0	0.006	0.24
Subtotal				0.31	12.0
Total Natural Energies				18.88	755.2

Table 11 - Continued

Name of Energy Flow	(A) Area of System[1] in 10^6 sq.meters	(B) Annual Work of that Type[2] 10^3 Kcal/m^2/yr	(C) Energy Concentration Factor[3]	(D) County's Annual Work[4] 10^{12} Kcal/yr	(E) Dollar Equivalent for Human Work[5] 10^6 \$/yr
Fossil Fuel and Economic Flows					
Fuel Flows[23]					
Electricity			0.25	38.68	1547.0
Gasoline			1.0	21.75	870.0
Natural Gas			1.0	2.71	108.0
Liquid Fuels			1.0	10.49	420.0
Total Fossil Fuels				73.63	2945.0

NOTE: Notes 1 through 23 are contained in Appendix II. These notes show detailed calculations.

Fig. 33. Diagram showing major energy and economic flows for Dade County.


MANUFACTURING SALES
TOURISM
AGRICULTURAL SALES
$2.
$3.23
$.14
STRUCTURE
MONEY $2.92
TAXES $1.36
SUBSIDIES $1.48
GOV'T
92.5 kcal
GOODS
$3.60
FOOD
$1.25
1.5 kcal
FUELS
$.59
73.6 kcal
18.88 kcal
NATURAL ENERGIES
All Energy Values are in Units of 10^12 kcal
All Money Values are in Units of Billions of Dollars

Everglades on the west, is bounded by the shoreline on the south, and extends several miles into Biscayne Bay on the east.

Natural to Fossil Fuel Energy Ratio

If all energies are put in units of Fossil Fuel Work Equivalents, then the ratio of natural to fossil fuel energies can be a measure of the extent of development in a region. Specifically, the ratio

$$\frac{\text{Total Work}}{\text{Fossil Fuel}} = \frac{\text{Fossil Fuel} + \text{Natural}}{\text{Fossil Fuel}} = 1 + \frac{\text{Natural}}{\text{Fossil Fuel}}$$

has a minimum value of one for no natural energies and attains high values for small fossil fuel flows. If the ratio is high for a region in comparison to neighboring regions, then more natural energies are available to subsidize investments of fossil fuel development. The ratio for Dade County since 1950 is tabulated in Table 12, where it can be seen that it has dropped significantly during the last twenty years. The overall ratio for the United States is approximately 1.4 (Odum, 1974; Kylstra, 1974). Approximate ratios for the United States are also included in Table 12 for comparison with the Miami region. The approximate ratio for Florida is approximately 1.25 while that for the region of South Florida is about 1.4 (Fontaine and Brown, 1975).

Table 12 is of immense interest since it can be seen that the ratio for Dade County and the United States were approximately equal in 1960. In about 1966-67 Dade County began to have sharp increases in budget, taxes, and fossil

Table 12

Fossil Fuel Energy, Total Natural Energy and Their Ratio from 1950 to 1972[a]

Year	Natural Area,[b] Square Kms	Primary Production,[c] 10^{12} Kcal/yr	Other Natural Energies,[d] 10^{12} Kcal/yr	Total Natural Energies,[e] 10^{12} Kcal/yr	Fossil Fuels,[f] 10^{12} Kcal/yr	Fossil Fuel+Natural / Fossil Fuel: Dade County[g]	Fossil Fuel+Natural / Fossil Fuel: United States[h]
1950	5180	13.05	6.81	19.86	11.2	2.77	1.78
1960	4940	12.45	6.81	19.26	32.6	1.6	1.6
1970	4824	12.16	6.81	18.97	64.3	1.3	1.4
1972	4790	12.07	6.81	18.88	73.6	1.26	1.37

[a]All energy units in FFWE (see Table 1).

[b]Computed as total area in Table 10 minus developed area given in Table 5.

[c]See Table 11. This is the sum of metabolic work on natural ecosystems plus managed areas. An average productivity of

$$\frac{12.07\text{x}10^{12}\ \text{Kcal/yr}}{4.79\text{x}10^{9}\ \text{m}^2} = 2.52\text{x}10^3\ \text{Kcal/m}^2\text{/yr}$$

was calculated for 1972 and this number was used to calculate photosynthetic production in each year knowing the natural land area.

[d]See Table 11. These energies include such things as winds and tides.

[e]This is the sum of primary production and other natural energies.

Footnotes to Table 12 - continued

[f]See Table 20 in Appendix I.

[g]The fossil fuels used in this ratio are the energy value in FFWE of the fossil fuels consumed. It assumes that the energy value of goods and services coming into the system is equal to the energy value of the goods and services flowing out. Another way of calculating this ratio is to include the energy value of the bought goods and services by multiplying this dollar flow by 25000 Kcal/dollar. It is assumed that only imports and not exports should be included in the determination of external selling price (see Fig. 37). Calculated in this way the ratio for 1972 would have been

$$\text{Ratio} = 1 + \frac{\text{Natural}}{\text{Fossil fuel}+\$(\text{fossil fuel}+\text{goods}+\text{food})\text{x}25000\ \text{Kcal/dollar}}$$

$$\text{Ratio} = 1 + \frac{18.88}{73.6+(.59+3.6+1.25)\text{x}25}$$

$$\text{Ratio} = 1.09$$

which indicates that Dade County is still less competitive than South Florida.

[h]As calculated by Kylstra (1974) this ratio is total fossil fuels in the U.S. plus natural energies divided by fossil fuels. It was assumed that this ratio is the value that an average subregion of the country, in competition with Dade County, would have.

fuel energy use, which may be signs of the increasing costs of overdevelopment. Thus, the time-delay for this ratio to affect the system may be on the order of six or seven years. The theory behind this ratio is further discussed in the Discussion section.

Recycle of Energy from Urban Wastes

There has been much discussion recently of using garbage as a means of tapping extra energy. With this in mind, a calculation was made of the possible energy potential of the urban refuse produced in Dade County if it is incinerated and the heat energy derived from the organic matter used as fuel in electrical power plants. An estimate of the organic urban refuse produced in 1971 for the United States was .63 tons/person/yr (Anderson, 1972). It was estimated that solid waste can produce 2.52×10^6 Kcal/ton of energy (Hirst, 1973), so that the energy that could be produced in Dade County amounts to .63 tons/person/yr $\times$ 1.37×10^6 people $\times$ 2.52×10^6 Kcal/ton = 2.18×10^{12} Kcal/yr. The energy cost of solid waste collection, transportation, and disposal is approximately $.076 \times 10^6$ Kcal/ton $\times$ .63 tons/person/yr $\times$ 1.37×10^6 people = $.066 \times 10^{12}$ Kcal/yr, while the energy cost of incineration is approximately 10 kwh/ton $\times$ 860 Kcal/kwh $\times$ 1.37×10^6 people $\times$ .63 $\times$ 4 Kcal FFWE/Kcal(electrical) = $.03 \times 10^{12}$ Kcal/yr. Thus, the net energy of the process is $(2.18-.066-.03) \times 10^{12}$ Kcal/yr = 2.08×10^{12} Kcal/yr. In comparison to the total fossil fuel energy use in Dade County for 1972, it amounts to 2.7% of the total.

The above calculation assumes that the garbage collection system will remain as it is with the exception that the garbage will be used for generating energy rather than landfill. As the energy level of the system gets lower, garbage, and therefore potential recycle, will be reduced. At some level will garbage collection be drastically curtailed? In order to do a complete net energy analysis of garbage collection the money expenses and their associated energy costs would also have to be included. Then a comparison to alternative methods of recycle could be made.

Food Production

Looking at Table 11, it can be seen that the total agricultural output amounts fo 4.4 x 10^{12} Kcal/yr or vegetable crops and groves. If it is assumed that the net productivity is 50% and that 20% of this is edible, then .44 x 10^{12} Kcal/yr is available for consumption (E. P. Odum, 1971). Since 1.5 x 10^{12} Kcal/yr of food is needed for the county, of which 1.3 x 10^{12} Kcal/yr is carbohydrate, these crops can supply approximately one-third of the carbohydrate requirements of the Dade County population.

The total gross production of improved pasture amounts to 1.6 x 10^{12} Kcal/yr (see Table 11). Assuming that net production is 50% of this and that the conversion into beef results in a 10% conversion, the protein production was calculated to be .08 x 10^{12} Kcal/yr. An average person needs approximately 600 Kcal of protein per day, which makes for a requirement of .3 x 10^{12} Kcal/yr of protein for the Dade County population, and which is approximately four times as much as can be produced within the county.

Energy to Money Ratios Expressed in Energy Units

Many ratios may be of interest for a theoretical and conceptual understanding of the function of urban regions. One of these is the ratio of total direct energy use (fossil fuel + natural) to the gross regional product. In 1972 this ratio for Dade County was 92.5 x 10^{12} Kcal/(1.25 x \$5.45 x 10^9) = 13580 Kcal/dollar (gross regional product = 1.25 times the expenditures for goods and services; see Brown, 1973). This ratio can be compared to the ratio of the total energies of the U.S. to its gross national product. This ratio was 25000 Kcal/dollar. The lower ratio for Dade County indicates that more dollars are generated per unit of fossil fuel consumed. This may be characteristic of high consumer and service oriented economies whereas industrial areas may have a high energy to dollar ratio. This ratio might be used as an index for comparison of urban systems.

The actual energy value of the food consumed in the system is fairly small but the money spent was approximately \$1.25 billion. If this is converted to energy expended somewhere else in the country by the 25000 Kcal/dollar ratio, it is seen that 31.2 x 10^{12} Kcal of energy are required to deliver the food to the urban region. The ratio of this to the total energy flow is .34.

The Role of Solar Energy Technology in the Miami-Dade Urban System[1]

Energy Calculations for Water Heaters

In order to evaluate and compare competing water heating systems such as solar, natural gas, electrical, and wood, all energy subsidies to each of the systems must be identified and quantified. Much ado about solar energy as a new energy source has been made recently. The only way to decide this issue is to determine how much fossil fuel subsidy is required to make a solar device operate as compared to competing fossil fuel systems. Not only are energy flows quantified in this section, but so also are capital requirements.

Located in one of the most southern areas of the United States with an average incident solar radiation flux of 4500 Kcal/m^2/day (Bennett, 1965), the Miami-Dade County region is a desirable area for evaluating the effectiveness of solar energy technology. Presented in Figs. 34 and 35 are two diagrams illustrating the main pathways involved in solar, electric, and gas water heaters (Odum, 1975). The size of the water heaters and the flows are those which would be necessary for an average family of four under the present standard of living. The solar water heater uses incident solar energy coupled with large area collectors to heat water. The manufacture of equipment for storage and collection required fossil fuel energy in the main U.S. economy as an initial

[1]Done in collaboration with Sandra Brown, Department of Environmental Engineering Sciences, University of Florida.

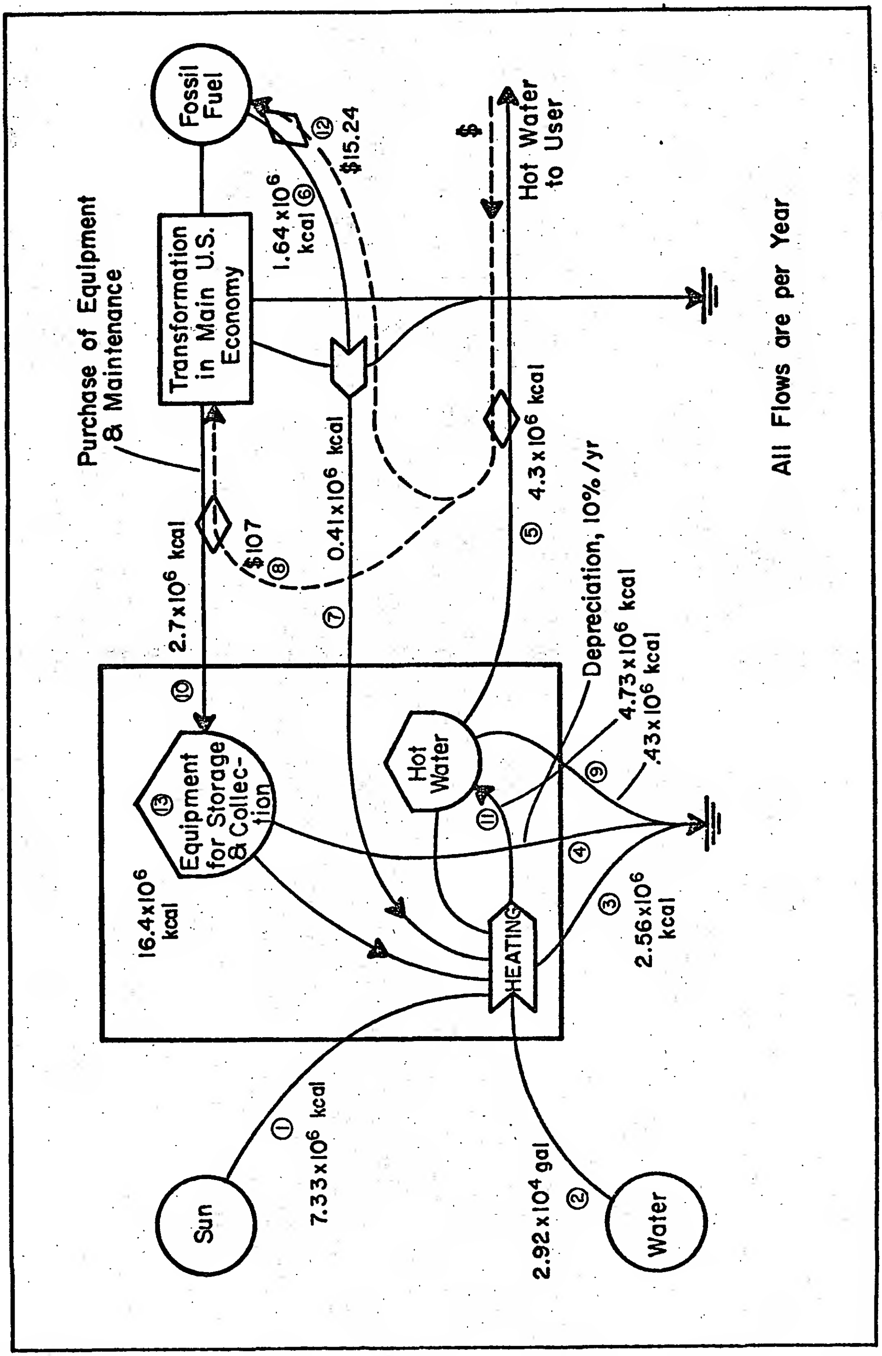
investment. This is depicted as pathway 10 in Fig. 34. The only other fossil fuel energy necessary for running this system is electricity for an electric immersion heater during the months of low solar radiation (pathway 6 in Fig. 34).

The electric and gas water heater systems use electrical and natural gas energy, respectively, to heat water. Initial equipment also requires fossil fuels in the main U.S. economy for manufacture (pathway 10 in Fig. 35). The initial investment for the solar heater is greater than for the electric or gas heaters but less fossil fuel is used directly. Tables 13 and 14 describe the flows in Figs. 34 and 35 with notes detailing the calculations. Dollar costs were converted to fossil fuel energy costs through the conversion factor of 25000 Kcal/dollar (see Table 1).

Calculations based on the flows in Figs. 34 and 35 were made to assess the fuel savings and capital savings of replacing electrical and gas heaters with solar water heaters in the Miami-Dade region. The results are summarized in Table 15. It can be seen that both systems result in a savings of fossil fuel energy. Fuel savings offset capital requirements if a solar water heater is used instead of an electrical system, resulting in a net capital savings. On the other hand, even though a solar heater uses less energy than a gas heater, the difference is small and loss of capital would be incurred if gas were replaced by solar.

Table 16 presents the results of calculations assuming that all the electrical water heaters were replaced in Dade

Fig. 34. Major energy and money flows for a solar water heater. Pathway numbers in circles refer to numerical values and footnotes in Table 13. (From S. Brown and J. Zucchetto, unpublished paper.)



Fossil Fuel
Purchase of Equipment & Maintenance
Transformation in Main U.S. Economy
1.64 x 10^6 kcal ⑥
⑫ $15.24
$
Hot Water to User
④.3 x 10^6 kcal
⑤ 4.3 x 10^6 kcal
0.41 x 10^6 kcal
⑦
$107 ⑧
2.7 x 10^6 kcal
⑩
Depreciation, 10% /yr
4.73 x 10^6 kcal
.43 x 10^6 kcal
⑨
All Flows are per Year
⑬ Equipment for Storage & Collec-tion
16.4 x 10^6 kcal
Hot Water
⑪
HEATING
④
③ 2.56 x 10^6 kcal
Sun
① 7.33 x 10^6 kcal
Water
② 2.92 x 10^4 gal

Table 13

Flows and Storages for Solar Water Heater for a Family of Four in Dade County

Pathway on Fig. 34	Note[a]	Description	Numerical Value	Reference
1	1	Average Incident Solar Radiation on 4.46 m^2 Collector	7.33×10^6 Kcal/yr	Bennett, 1965
2	2	Annual Cold Water Consumption	2.92×10^4 Gal/yr	
3	3	Losses Due to Inefficiency of Solar Heater	2.56×10^6 Kcal/yr	Aimone, 1974
4	4	Depreciation of Solar Equipment	10%/yr	Solar Water Heater Co., Miami, Fla.
5	5	Heat Energy for Hot Water	4.3×10^6 Kcal/yr	
6	6	Fossil Fuel Needed to Heat Water	1.64×10^6 Kcal/yr	
7	7	Electrical Energy Needed	$.41 \times 10^6$ Kcal/yr	
8	8	Initial and Maintenance Costs of Equipment Prorated Over 10 Years	$107/yr	
9	9	Loss of Heat from Tank	$.43 \times 10^6$ Kcal/yr	
10	10	Energy Cost for Equipment	2.7×10^6 Kcal/yr	_Ibid._
11	11	Energy Needed for Heating Water	4.73×10^6 Kcal/yr	
12	12	Cost of Fuel	$15.24/yr	Florida Power & Light Corp.
13	13	Cost of Solar Equipment	16.4 or 20×10^6 Kcal/yr	

[a]Notes are contained in Appendix II.

Fig. 35. Major energy and money flows for an electrical and natural gas water heater. There are pathways which have two numerical values associated with them: the first number refers to an electrical water heater whereas the second one refers to a gas water heater. Pathway numbers in circles refer to numerical values and footnotes in Table 14. (From S. Brown and J. Zucchetto, unpublished paper.)

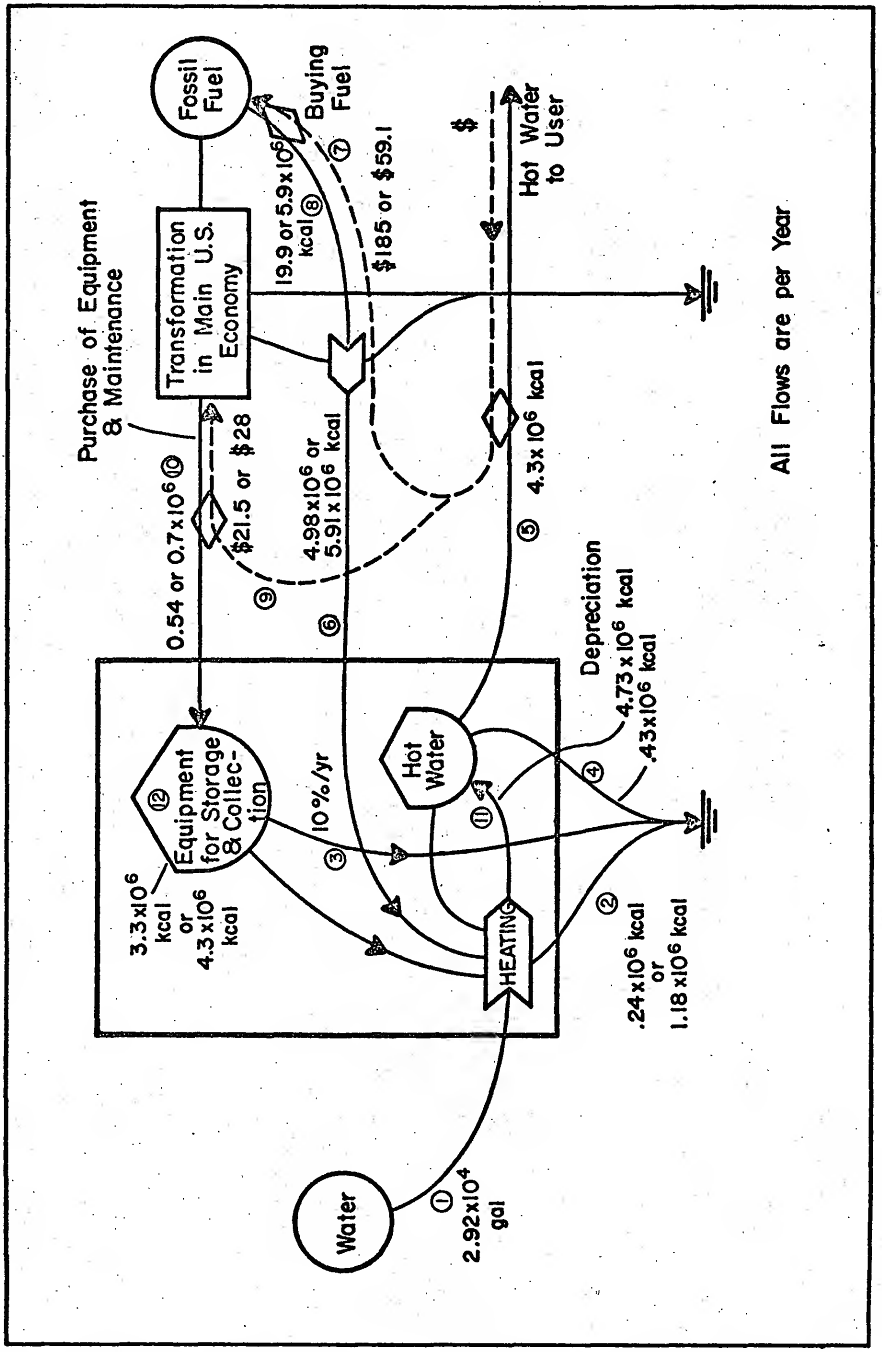

Water
① 2.92x10⁴ gal
HEATING
⑫ Equipment for Storage & Collection
3.3x10⁶ kcal or 4.3x10⁶ kcal
10%/yr
③
Hot Water
⑪
④
Depreciation
4.73x10⁶ kcal
.43x10⁶ kcal
②
.24x10⁶ kcal or 1.18x10⁶ kcal
Purchase of Equipment & Maintenance
0.54 or 0.7x10⁶ ⑩
$21.5 or $28
⑨
Transformation in Main U.S. Economy
4.98x10⁶ or 5.91x10⁶ kcal
⑥
Fossil Fuel
19.9 or 5.9x10⁶ kcal ⑧
Buying Fuel
⑦
$185 or $59.1
$
Hot Water to User
⑤ 4.3x10⁶ kcal
All Flows are per Year

Table 14

Flows and Storages for Electric and Gas Water Heaters for a Family of Four

Pathway on Fig. 35	Note[a]	Description	Numerical Values for Electric Heater	Numerical Values for Gas Heaters
1	1	Annual Cold Water Consumption	2.92×10^{4} Gal/yr	2.92×10^{4} Gal/yr
2	2 & 13	Heat Loss Due to Inefficiency of Heater	$.24\times10^{6}$ Kcal/yr	1.18×10^{6} Kcal/yr
3	3	Depreciation of Equipment	10%/yr	10%/yr
4	4	Heat Loss from Tank	$.43\times10^{6}$ Kcal/yr	$.43\times10^{6}$ Kcal/yr
5	5	Heat Energy for Hot Water	4.3×10^{6} Kcal/yr	4.3×10^{6} Kcal/yr
6	6 & 14	Electrical Energy Use or Natural Gas Use	4.98×10^{6} Kcal/yr or 5.79×10^{3} Kwh/yr	5.91×10^{6} Kcal/yr
7	7 & 15	Cost of Electricity or Natural Gas	$185.3/yr	$59.1/yr
8	8 & 14	Fossil Fuel Needed to Heat Water	19.9×10^{6} Kcal/yr	5.91×10^{6} Kcal/yr
9	9 & 16	Cost of Equipment	$21.5/yr	$28/yr
10	10 & 16	Energy Cost for Equipment	$.54\times10^{6}$ Kcal/yr	$.7\times10^{6}$ Kcal/yr
11	11	Number of Kcal Needed for Producing Hot Water	4.73×10^{6} Kcal/yr	4.73×10^{6} Kcal/yr
12	12 & 17	Cost of Equipment (Total Initial Cost)	3.3×10^{6} Kcal	4.3×10^{6} Kcal

[a]Notes are contained in Appendix II.

Table 15

Difference in Per Capita Fossil Fuel and Capital Expenditures Between Solar Water Heaters and Electrical or Gas Water Heaters for Dade County

	Fuel Savings, 10^6 Kcal/capita/yr	Savings in Fuel Expenditures, $/capita/yr	Capital Outlay Required, $/capita/yr	Net Capital Savings, $/capita/yr
1) Solar Water Heater vs. Electric Water Heater	4.57[a]	34.7[b]	21.4[c]	13.3[d]
2) Solar Water Heater vs. Gas Water Heater	1.07[e]	10.7[f]	19.8[g]	-9.1[h]

[a]The actual fuel savings of a solar heater over an electrical heater in Dade county would be pathway 8 in Fig. 35 for an electrical heater minus pathway 6 in Fig. 34 which amounts to

$$\frac{(19.9-1.64)\text{x}10^6 \text{ Kcal/yr}}{4 \text{ people}} = 4.57\text{x}10^6 \text{ Kcal/capita/yr.}$$

[b]Savings in fuel expenditures is the fuel saved multiplied by an average cost for 1974 per Kcal for fossil fuel in Dade county or

$$4.57\text{x}10^6 \text{ Kcal/capita/yr x } \$.76\text{x}10^{-5}\text{/Kcal} = \$34.7\text{/capita/yr.}$$

[c]The difference in cost between solar and electric water heaters is pathway 8 in Fig. 34 minus pathway 9 in Fig. 35 or

$$\frac{(\$107-\$21.5)\text{/yr}}{4 \text{ people}} = \$21.4\text{/capita/yr.}$$

Footnotes to Table 15 - continued

[d]Net capital savings is the amount of money saved in fuel expenditures minus the capital outlay required or

$$\$34.7 - \$21.4 = \$13.3/\text{capita/yr.}$$

[e]The actual fuel savings of a solar heater vs. a gas heater in Dade county would be pathway 8 in Fig. 35 for a gas heater minus pathway 6 in Fig. 34 for a solar heater or

$$\frac{(5.91-1.64)}{4 \text{ people}} \times 10^6 \text{ Kcal/yr} = 1.07 \text{ Kcal/capita/yr.}$$

[f]Savings in fuel expenditures is the fuel saved multiplied by the price or

$$1.07\times10^6 \text{ Kcal/capita/yr} \times \$1.\times10^{-5}/\text{Kcal} = \$10.7/\text{capita/yr.}$$

[g]The difference in capital outlay is the cost of a solar water heater minus the cost of a gas heater or pathway 8 in Fig. 34 minus pathway 9 in Fig. 35 or

$$\frac{\$(107-28)}{4 \text{ people}} = \$19.8/\text{capita/yr.}$$

[h]Net capital savings is savings in fuel expenditures minus capital outlay required. In this case there are no savings but a net deficit which is

$$\$(10.5-19.8)/\text{yr} = -\$11.8/\text{capita/yr.}$$

Table 16

Fossil Fuel Savings and Capital Expenditures for the Replacement of Electric Water Heaters by Solar Water Heaters Over a Ten-Year Period in Dade County[a]

	Fuel Savings,[b] 10^{12} Kcal/yr	Savings in Fuel Expenditures, $\$10^6$/yr	Capital Outlay Required, $\$10^6$/yr	Net Capital Savings,[c] $\$10^6$/yr
1) Solar Water Heaters Installed Over a Period of 10 Years. Prices Assumed to Remain Constant.	2.6	19.8[d]	12.1[e]	+7.7
2) Solar Water Heaters Installed Over a Period of 10 Years. Inflation Rate Assumed to be 10%/yr.	2.6	35.[f]	17.35[g]	+17.65

[a]Two cases are considered: 1) Prices remain constant over a 10-year period and 10%/yr of the population is provided with solar equipment. 2) Prices inflate at the rate of 10%/yr and 10%/yr of the population is provided with solar equipment. For both cases it was assumed that the population remains at the level of 1.36×10^6 people. Since approximately 75% of Dade county households (Fla. Statistical Abstract, 1973) use electricity for water heating, the number of people affected is $.75 \times 1.36 \times 10^6 = 1.02 \times 10^6$ people.

[b]If it were possible to instantaneously replace all the electric water heaters by solar water heaters then the actual fuel savings in Dade county would be pathway 8 in Fig. 35 minus pathway 6 in Fig. 34 which amounts to

Footnotes to Table 16 - continued

$$\frac{(19.9-1.64)\text{x}10^6 \text{ Kcal/yr}}{4 \text{ people}} = 4.57\text{x}10^6 \text{ Kcal/person/yr.}$$

Since it is assumed that 10% of the system for heating water is replaced each year the total fuel savings the first year would amount to

$$.1\text{x}4.57 \text{ Kcal/person/yr x } 1.02\text{x}10^6 \text{ people} = .46\text{x}10^{12} \text{ Kcal.}$$

The second year fuel savings would amount to $.93\text{x}10^{12}$ Kcal and savings would increase each year until the 10th year. The total savings over the 10-year period amounts to $25.6\text{x}10^{12}$ Kcal for an average of $2.6\text{x}10^{12}$ Kcal/yr.

[c]Net capital savings is the amount of money saved in fuel expenditures minus the capital outlay required.

[d]The savings in money spent for fuel would be (see Table 6, note 15)

$$2.6\text{x}10^{12} \text{ Kcal/yr x } \$.76\text{x}10^{-5}\text{/Kcal} = \$19.8\text{x}10^6\text{/yr.}$$

[e]The difference in cost between solar and electric water heaters is pathway 8 in Fig. 34 minus pathway 9 in Fig. 35 or \$(107-21.5)/yr or dividing by a family of four to get \$21.35/person/yr. This number assumes an interest rate of 10%/yr, an equipment lifetime of 10 years and 1974 prices. In the first year $.1\text{x}\$21.35\text{x}1.02\text{x}10^6$ people = $\$2.2\text{x}10^6$ would have to be provided. The second year would require twice as much since the heaters bought in the first year are still being paid for plus 10% new heaters are added. This would continue for each year and the total money expended over 10 years would be

$$\sum_{n=1}^{10} \$2.2\text{x}10^6 \; n = \$121\text{x}10^6$$

or an average of $\$12.1\text{x}10^6$/yr. Much more money would be spent in the last few years than at the beginning. After this 10-year period is over there would still be money left to pay remaining from the loans for the last 9 years of the period. This would amount to

$$\sum_{n=1}^{9} \$2.2\text{x}10^6 \; n = \$99\text{x}10^6$$

or an average of $\$11\text{x}10^6$/yr for a period of 9 years after the initial 10-year installation period.

Footnotes to Table 16 - continued

[f]Savings in fuel the first year are $.46 \times 10^{12}$ Kcal (see footnote b), which amounts to

$$.46 \times 10^{12} \text{ Kcal} \times \$.76 \times 10^{-5}/\text{Kcal} = \$3.5 \times 10^{6}.$$

The second year twice as much fuel would be saved at a price 10% higher which would amount to

$$.92 \times 10^{12} \text{ Kcal} \times \$.836 \times 10^{-5}/\text{Kcal} = \$7.76 \times 10^{6}.$$

Continuing in this way for 10 years the total money saved is $\$350.6 \times 10^{6}$ for an average of $\$35. \times 10^{6}$/yr.

[g]If the initial cost rises by 10% each year then the money paid each year will be $\$2.20 \times 10^{6}$ the first year (see footnote d), $\$(2.42+2.2) \times 10^{6}$ the second year, $\$(2.84+2.42+2.2) \times 10^{6}$ the third year, etc., since each year's outlays are a summation of earlier plus present prices. The total amount expended over a 10-year period would be $\$173.5 \times 10^{6}$ for an average of $\$17.35 \times 10^{6}$/yr.

County over a ten-year period. Approximately three-quarters of the households in Dade County use electrical water heaters (Florida Statistical Abstract, 1973). Two cases were considered, namely, prices constant for ten years and prices increasing with a 10% per year inflation rate. It can be seen that fuel savings are realized and capital savings accrue. This quantity of fuel saved, however, still only represents about 3.5% of the total fossil fuel budget of the county.

Investment Alternatives to Water Heaters

The question now arises as to whether solar water heaters should be substituted for electrical heaters. What feedback and work contribution does hot water provide to a society by keeping its members clean? This function may not be necessary in a low energy society. Thus, if our society is to rapidly decline, putting capital and energy into water heaters will constitute a wasteful action. This money could be used to buy Middle Eastern oil, for example, and perhaps provide some competitive advantage to the United States.

To obtain a measure of comparison between several alternatives, divide the Kcal of heat output for each type of heater by the dollars invested. For the gas heater this ratio is 4.3×10^6 Kcal/\$87.1 = 49500 Kcal/dollar; for the solar heater this ratio is 4.3×10^6 Kcal/\$122.24 = 35200 Kcal/dollar; for the electrical heater this ratio is 4.3×10^6 Kcal/\$206.5 = 20800 Kcal/dollar. Now, if Middle Eastern oil is assumed to be \$12/barrel and there are 1.015×10^6

Kcal/barrel, then this oil has a value of 96000 Kcal/dollar. The question then arises as to whether it would be economically and energetically more advantageous to purchase Middle Eastern oil and use oil-burning water heaters or use the oil for more directly productive activities.

At the individual level is also the question of discount rate. If the energy level declines rapidly many individuals may decide to invest in some part of the economy which is growing rather than buying a new water heater. If it is assumed that money can be earned at the rate of 5%/yr and the cost of a new solar water heater is $800 (see Table 13, note 14), then an amount equal to $392 could be earned over ten years for a family of four.

Tables 15 and 16 represent the savings in fuel within Dade County, whereas work done outside the county is reflected by dollar flows. If the energy requirements in the entire U.S. economy are considered, the simple diagram in Fig. 36 may be drawn to show the relative magnitude of flows for each system. Included in Fig. 36 is also the primitive wood-burning system for which wood is collected from a steady-state forest and burned to heat water. It was assumed that this forest grew at the rate of .1 $gm/m^2/day$ and the energy value of the wood was 4.5 Kcal/gm. The acreage necessary could then be calculated.

It is seen that the issue of solar energy technology is complex and even if the society has enough extra energy to diversify into such a technology the savings in energy are

Fig. 36. Diagram summarizing energy flows for four different types of water heaters.

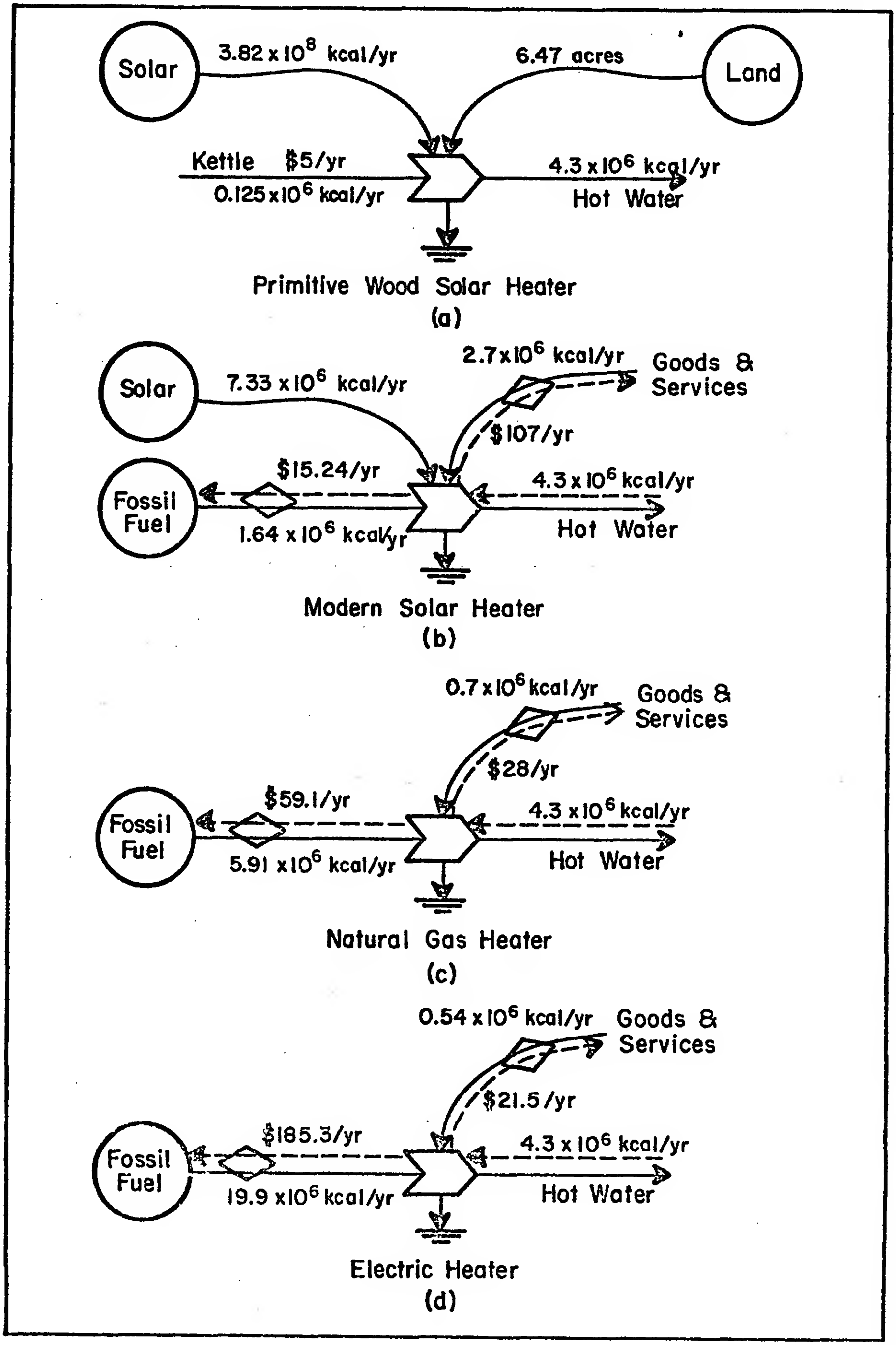
a. Primitive solar water heater for which wood is collected from a steady-state forest. The only capital investment is a small kettle or stove.

b. Modern solar water heater utilizing a flat plate solar collector.

c. Natural gas water heater.

d. Electrical water heater.

(From S. Brown and J. Zucchetto, unpublished paper.)


Solar
3.82 x 10^8 kcal/yr
6.47 acres
Land
Kettle $5/yr
0.125 x 10^6 kcal/yr
4.3 x 10^6 kcal/yr
Hot Water
Primitive Wood Solar Heater
(a)
2.7 x 10^6 kcal/yr
Goods & Services
Solar
7.33 x 10^6 kcal/yr
$107/yr
$15.24/yr
Fossil Fuel
4.3 x 10^6 kcal/yr
1.64 x 10^6 kcal/yr
Hot Water
Modern Solar Heater
(b)
0.7 x 10^6 kcal/yr
Goods & Services
$28/yr
$59.1/yr
Fossil Fuel
4.3 x 10^6 kcal/yr
5.91 x 10^6 kcal/yr
Hot Water
Natural Gas Heater
(c)
0.54 x 10^6 kcal/yr
Goods & Services
$21.5/yr
$185.3/yr
Fossil Fuel
4.3 x 10^6 kcal/yr
19.9 x 10^6 kcal/yr
Hot Water
Electric Heater
(d)

only a few percent. How fast the energy level of the system declines will determine whether solar heaters will be used on a wide basis.

DISCUSSION

This sections brings together in overview the results of this dissertation and the implications and questions to which they lead. Some of these include the nature of the models presented, the effects of energy and price on the general behavior of the urban variables, and some theoretical discussion. Consideration of energy calculations including those of natural, agricultural, recycled garbage, and solar energy technology are considered. The future of Dade County in light of these calculations is also discussed. The next few paragraphs discuss the similarities between urban and natural ecosystems.

Comparison Between Urban and Natural Systems

Theoretically, a system will build a mass-energy structure for internal and external interactions. The maintenance, growth, and stability of these systems require the capture of energy and mass from the outside. Based on this, models of city systems can be constructed using storages and flows, the flows being some function of external forcing functions and internal storages and flows (see Fig. 3 for a description of the components used for these models). Since this work was derived from previous modeling directed towards natural ecosystems, Table 17 has been constructed to point out the similarities between natural ecosystems without man and human systems. Both systems obey the conservation of energy and mass, responding to external sources of these parameters. Both systems need information and structure for control, require maintenance, recycle structure, establish communication pathways, diversify, produce, consume, establish cycling pathways, and exhibit successional development. Human systems contain libraries and culture for information storage and transmission, government, institutions and communications for control, industry for production, and people for consumption. Recycle of structure is accomplished through repair and reprocessing of materials. Successional development can be seen taking place in neighborhoods with invasions of ethnic groups and urban renewal programs. All of these processes are energetically costly and must be constantly maintained. Money in the human system acts as the distribution mechanism for energy, materials and information, and aids in keeping the system alive and functioning, in the process establishing cycles of money flow, balance of payments, and a basis for exchange value (see sections on urban indicators and data for a discussion and compilation of the variables which are a measure of the properties discussed in the above paragraph).

Table 17

Similarities Between Natural Ecosystems and Urban Systems

Category	Natural Ecosystems	Urban Systems
Energy	Solar; Natural Energies	Solar; Natural Energies; Fossil Fuels
Materials	Nutrients; Trace Metals	Resources
Information	Genes; Chemical Systems	Genes; Memory; Libraries; Computers
Structure	Biomass	Square Feet of Buildings
Maintenance	Repair; Replacement	Repair; Replacement; Renewal
Entropy Generation	Death; Heat	Death; Depreciation; Heat
Diversity	Species	Occupations; Businesses; Ethnicity
Production	Photosynthesis	Industrial Production
Consumers	Animals; Microbes	Government; Industry; People
Cycles	Nutrients	Money
Temporal Processes	Succession; Climax	Succession of Neighborhoods; Urban Renewal; Steady-state

Effects of Available Fossil Fuel Energy

As in other sciences the axiom of the conservation of energy and mass has evolved through experience and is accepted as self-evident so then energy has been accepted in this dissertation as a primary forcing function for all human systems. This is a good assumption based on experience with our highly mechanized society (Odum, 1971). The high fossil fuel energy density (300 Kcal/m^2/day) necessary to support the variety of functions in the Miami-Dade urban system is necessarily dependent on sources of energy, especially fossil fuels. The availability of high quality electrical energy made possible the high density of structure in cities because of its cleanliness and versatility. In the lower density, residential parts of cities it has also made possible the use of a diversity of appliances which contribute to a high energy consumption per person. At present densities, lighting and heating skyscrapers with oil, coal, and gas would constitute a very dirty proposition in terms of releasing hydrocarbons to the city environment. Even the proposed uses of solar energy for heating and lighting would be prevented under high densities because of shading. Since almost 4 Kcal of fossil fuel energy are necessary to generate 1 Kcal of electrical energy (see Fig. 4), high density urban systems are necessarily dependent on large supplies of fossil fuels. The increasing use of electrical energy in the urban system is graphically shown in Fig. 31.

Since the entire urban system is so highly interconnected and subsystems mutually dependent, several parameters have been plotted as a function of total fossil fuel energy driving the entire system in Figs. 13 and 14. The number of telephones, effective buying income, and tourists seemsto be increasing in a piecewise linear manner. The curves of money costs such as the budget and sales tax have increasing slopes with increasing energies. This reflects the increasing costs with size as is pointed out so well by Lamm (1973), who shows the increasing costs of services as cities become larger. The curve for retail sales has a plateau which corresponds to leveling in the curves of effective buying income, budget, number of telephones, sales tax, and building structure. This decrease in activity compared to preceding years lasted from an energy level of 58 to 64 x 10^{12} Kcal which corresponds to the year 1969. Beyond the 64 x 10^{12} Kcal energy level the curves begin to increase at a greater rate. Looking at Fig. 16 it can be seen that a pulse of energy entered the system from 1969-70 followed by an increase in the rates of growth for effective buying income, retail sales, number of telephones, sales tax, and building structure. This is a nice example of the influence of energy in the urban system. Furthermore, the slowdown in growth during 1969 may have been due to the decrease in the rate of energy use from 1968-69 which can be seen in Fig. 16. Further discussion of correlation between energy and urban variables can be found in the Data section.

In Figs. 14b and 15 are graphs of the urban variables discussed above plotted as a function of the sum of gasoline and electrical energies. The units of energy in this case are expressed as actual Kcal of gasoline and electrical energy without conversion to Fossil Fuel Work Equivalents. Using electrical plus gasoline energy as the independent parameter suggested that these energies were more directly involved in the actual mechanical workings of the economy whereas petroleum oils and natural gas would be used for cooking and heating. Several of the curves such as number of telephones, total budget, and sales tax collections are almost perfectly piecewise linear while the other curves are approximately so. These graphs suggest the direct impact of fossil fuel energies on urban parameters.

The quantitative relationships for several urban parameters in Dade County can be seen in Table 3. Total energy increased 77% from 1963 to 1971. Those variables which increased in approximately the same proportion were number of telephones (67%), retail sales (78.5%), and building structure (76%), while those which increased in greater proportion were number of tourists (100%), effective buying income (107%), budget (130%), and sales tax (250%). Population increased by a smaller percentage (23.5%).

The previous discussion was based on actual data for the Miami-Dade urban system. In addition, consider the simulation models depicted in the Results section and the effect of different energy functions on the output of the models. The model in Fig. 20 shows the city system being driven by a storage of fossil fuels representing the proven fossil fuel reserves in the United States available to the residents of Dade County. The characteristic curve of city structure is one which starts out slowly in the beginning, goes through a period of steep growth, peaks, and then begins to fall. This can be seen in Figs. 21 and 22. The storage of fossil fuels resembles an inverse sigmoid curve whose greatest rate of decrease corresponds to the greatest rate of increase of the structure curve.

Rather than a storage of fossil fuels the model in Fig. 24 depicts an urban model driven by an arbitrary outside energy function and depreciation of structure assumed to be a square function of structure. Three energy functions were considered: linearly increasing after 1972; level after 1972; linearly decreasing after 1972. The increasing energy function could represent a net nuclear energy technology. For the energy increasing case structure peaks and then drops slightly and levels off. The production of structure peaks and then changes erratically. The case where energy levels after 1972 shows a sharper peak in structure than the previous case and one for which the production of structure peaks and declines thereafter. The energy declining case results in structure peaking and declining as does the production of structure.

As a final consideration of the effect of fossil fuel energy, the tourist model in Fig. 27 was simulated for two initial values of fossil fuel energy, one being twice as large as the other. This case was considered in order to understand an increase in available energy due to a net energy coal technology. Comparing Figs. 28a and 30a it is seen that for prices increasing 20% per year, structure peaks approximately 4% higher with initial fuel storage doubled. This is smaller than would be expected and might be explained by the fact that the model doesn't include increasing the money supply in relation to the amount of available energy. The decrease in tourism and the increase in prices combine to limit the capital for growth. A sudden input of Federal subsidies could result in a surge of growth followed by decline as fuels were exhausted.

Effects of External Price

For the models simulated in the Results section, money transactions with the outside world occur through the price transactor, the mathematics for which is shown in Fig. 3. It represents the fact that for every flow of energy, goods, or services in the human system, there is a counter-current flow of money. As depicted in the models in Figs. 19, 20, 24, and 27, the price is shown to be determined external to the urban system, the net result of the complex interactions in the U.S. and world economic systems. Since the early fifties the western world has not been subjected to very severe rates of inflation. Prices of energy have remained fairly constant from 1950-72 (Minerals Yearbook) as have many other prices for basic goods which were all dependent on energy for their existence. However, as the reserves of fossil fuels become depleted, it becomes more expensive for a unit of energy to be delivered to where it is needed: a greater amount of capital and energy is required and this is reflected in the price system as an increase in the price of fuel. This increase in price is propagated through the economic system and affects the costs of goods and services. Rapidly increasing costs occurred for the prices of fuels in 1973 as the era of cheap and easily accessible fuels came to an end. The situation was aggravated by the fourfold increase in the price of Middle Eastern oil. Since these events the industrialized countries have been subjected to double-digit inflation.

In order to simulate this rapid inflation the price functions for some of the models were programmed to remain constant from 1950 to 1972 and then linearly increase from then on. Since the exact shape and magnitude of the future price function is unknown, simulations were conducted for several price functions. The effects of these are discussed in the following paragraphs.

Fossil Fuels

The storage of fossil fuels responds in a very interesting manner as can be seen from Fig. 23b. As the inflation rate (price) increases, the amount of fossil fuel remaining in 1990 increases. This result seems to agree well with the notion of the price system regulating supply and demand forces. As prices increase more money is spent for goods, services, and fuels, leaving less money in storage for further spending: fewer kilocalories of fuel can be purchased with a dollar. The amount of fuel remaining in 1990 is not linearly related to the inflation rate, i.e., a 50% inflation rate does not result in five times as much fuel remaining as a 10% inflation rate.

Fuel Expenditures

As can be seen from Fig. 23c, fuel expenditures peak rather sharply in 1973 for a 50% inflation rate and then descend more rapidly than the other rates as the money supply is used up faster until it reaches a low level in 1990. There doesn't seem to be any general pattern to the curves except for an initial pulse of spending at the onset of inflation.

Money Supply

As would be expected, the money supply decreases with increasing prices as can be seen from Fig. 23a. This implies that there will be less capital for growth if a greater and greater proportion of money continues to go for fuels. This may be one of the primary limiting factors to growth that Dade County and other urban regions will experience.

Structure

The characteristic curve of structure changes as a function of the inflation rate (Fig. 22b). As the inflation rate increases structure peaks earlier and at a lower level due to the increasing costs and unavailability of capital for new structure. This seems to be the current situation in the United States in 1974 with high interest rates, lower productivity, and falling GNP.

Population

As can be seen from the results of the tourist model in Fig. 28c, increasing prices inhibit the growth of population as well as the other storages in the system. The 1990 population is decreased approximately 25% to a level of 1.6 million people. This comes about because the model assumes that both migration and reproduction are functions of energy supply, structure, and money. In essence, this says that if there is no growth of the city then population growth will also become zero. By combining population growth to available energy as in Fig. 27 a more realistic prediction method is obtained as compared to extrapolation of population data into the future.

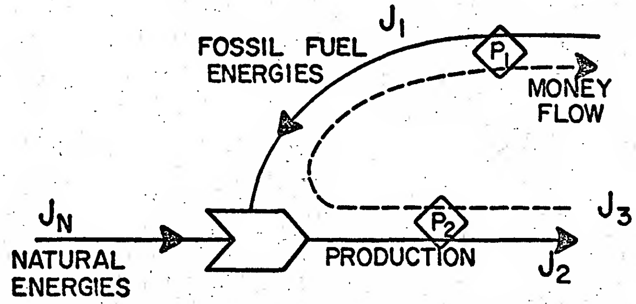
In general, then, the effect of increasing prices is to inhibit the growth of the system and prolong the supply of fossil fuel. The models seem to generate results which are in agreement with notions of supply and demand.

Competitiveness of Miami-Dade County

In Table 12 the ratio of the total work for Miami-Dade County to the fossil fuel work was tabulated from 1950 to 1972. The total work was considered to be composed of the sum of natural energies and fossil fuel energies, where both are expressed in units of Fossil Fuel Work Equivalents. The natural work of nature includes winds to reduce air pollution, waves to build and maintain beaches, tides, photosynthetic productivity, etc., all of which contribute to the vitality of a region. A region which is low in these energies will be outcompeted by a region high in these energies if both systems have the same economic mix, since the system with low natural energies will have to subsidize work functions that would otherwise be provided free. Thus, a higher ratio of total work to fossil fuel work for a region will allow this region to outcompete regions with a lower ratio.

Consider the diagram in Fig. 37 which shows the main energy and money flows in a region, with selling price, P_2, and external price, P_1. It can be seen that the larger J_1+J_N/J_1 is, the smaller P_2 is compared to P_1, which means that the region will sell at lower prices and outcompete other regions that have a smaller ratio. Classical economics leaves out the component of natural energy and arrives at the condition that the ratio of flows should be inversely proportional to the ratio of prices ($J_1/J_2 = P_2/P_1$) in order to maximize profits (Bishop and Toussaint, 1958).

Fig. 37. Diagram showing relationships of energy flows to prices. (From H. T. Odum and J. Zucchetto, unpublished paper.)



$J_1 = 73.6 \times 10^{12}$ kcal

$J_2 = 92.5 \times 10^{12}$ kcal

$J_3 = \$6.8 \times 10^{9}$

$J_N = 18.9 \times 10^{12}$ kcal

$$J_2 = J_1 + J_N$$

$$J_3 = J_2 P_2 = J_1 P_1$$

$$P_2 = \frac{J_1}{J_2} P_1$$

$$P_2 = \frac{J_1}{J_1 + J_N} P_1$$

Classical Economics Didn't Consider Natural Energies so that $J_N = 0$

and $\dfrac{P_2}{P_1} = \dfrac{J_1}{J_2}$

For Dade County, then, the ratio is 1.25 as compared to 1.25 for Florida (Kylstra, 1974) and 1.4 for the region of South Florida (Fontaine and Brown, 1975). It would be expected that these neighboring regions will receive the bulk of new investment for they will outcompete Dade.

Future Outlook and Recommendations for Miami-Dade County

Population and Growth

As can be seen from the model simulation results, the system structure and population is limited. As discussed in previous paragraphs the factors interacting which result in limited growth are available energy, inflation, limited capital, maintenance costs of complex structure, and the destruction of natural system energies which are vital to the economic competitiveness of the region (see Fig. 37). Based on the tourist model in Fig. 27 the population curves in Fig. 28 show the population leveling at about 1.6 million with structure peaking about 1978. These results assume that 40% of the proven fossil fuel reserves in the United States are available for consumption (see note 1 to Table 7). Even for an increasing energy function as shown in Fig. 25a, the structure still peaks around 1980 but remains at a high level. This is due to the square drain maintenance costs of the system structure and increasing money expenditures for energy.

There are other considerations for predicting a leveling of the urban system as discussed in the paragraphs accompanying Fig. 37 showing the natural energy contributions to the competitiveness of a region. Those systems which have a larger ratio of natural to fossil fuel energies will outcompete systems with a smaller ratio because of the free work services of nature. Under these criteria Dade County is overdeveloped and therefore less competitive compared to other regions in South Florida so that any new investment should be attracted to regions other than Dade. This is a quantitative way of saying that a hotel will more likely be put on a clean, extensive beach than on an eroded and polluted one.

Agricultural Areas

Is it a prudent policy to develop the remaining agricultural areas in Dade County as some developers would like to do? As presented in the Energy-Economic Calculations section the agricultural areas as they exist now could provide approximately one-third of the carbohydrate and one-fourth of the protein requirements of the Dade County population. This is for the present food consumption of 3000 Kcal/person/day. If fossil fuels become limiting at a national scale, then putting the last energies into development while destroying the contributions of agricultural energies could prove to be disastrous. Putting energies into development would decrease the natural to developed energy ratio and make the region even less competitive as the price of services goes up. If the United States is entering a depression in 1975, then the availability of food-producing lands is a survival factor for the county.

Another aspect to consider is the diversity of the region. If the agricultural lands are developed, then the county is headed for extensive urban sprawl, high cost of services, congestion and decay that is characteristic of practically every other urbanized region in the United States. Leaving the agricultural sector maintains a diversity of labor and land and provides a buffer during hard times. This is especially true with regard to the shipment of food, for as energy prices go up external food supplies will also increase in price. Thus, a local supply of food will be economically advantageous. There is also the question of how further development will affect water quality and supply. If there are extra funds and energy for growth perhaps these are more wisely invested in redevelopment, maintenance, and adaptation to a lower energy society.

Alternative Energy Sources

This dissertation has presented the fossil fuel and natural energy contributions to the Dade County urban system. There has been much speculation that other energy processes can supply additional energy to human systems. Recycling of garbage to produce additional fossil fuel energy has been suggested but, as calculated in this dissertation, this would only be a savings of about 2.7% of the total energy budget at most and with possible hidden costs not considered.

Likewise, the use of solar energy to produce low grade energy (heat) to perform such functions as heating water would amount to a 3.5% savings in fuel if all electric water heaters were replaced over a period of 10 years, but there may be other greater energy effective uses of capital than for water heaters in a warm climate in a declining energy situation. Net energy calculations cast doubt on the question of whether solar energy technology could produce net energy in the form of electricity. Thus, the two methods discussed above for tapping some extra energy are at most small and not sufficient for running a high energy system. The recycling of materials from urban garbage can certainly provide a source of raw materials in short supply but it must be determined if it is energetically cheaper to recycle or produce these materials anew. Other sources of energy which may provide for further growth are Middle Eastern oil, coal, and nuclear energy if they provide net energy to the system of the United States. However, they will most likely have high costs associated with them.

The above discussion has concentrated on technological alternative energy sources. As the energy level of a society comes down, these diverse sources may be selected against. For example, less garbage will be produced and with it less potential for recycle. Similarly, useful work processes will probably outcompete hot water heaters for fuel use. However, the solar input to Dade County which drives the natural systems will still have a tourist multiplier effect, especially if these energies increase as fossil fuel energies decrease.

Energy Cost Benefit Considerations

It is recommended that any proposed changes or developments in the county be subjected to energy cost benefit calculations (Odum, 1974) in order to determine whether a proposed project will yield a higher energy value as compared to other alternatives. This type of analysis will be especially important as energy sources become limiting and natural energies must contribute vital energies for system survival. This will be especially true if the water management of the region is considered. The natural water system of the area has been totally altered by man through the construction of water management structures. This alteration of the natural water system coupled with extensive urban development has resulted in significant salt water encroachment, especially during periods of drought. Methods have been proposed for water conservation and recharge of the aquifer to prevent salt water intrusion such as backpumping from the outlet of the canals upstream to the conservation districts. How much energy these plans will require plus the energy required to maintain the water system functioning should be determined for the future, especially in light of decreasing energy supplies and increasing prices.

Many of the numbers presented and calculated in this dissertation can be used in the study of future proposals in Dade County. The Doxiadis Associates' (1967) master plan for downtown Miami should be examined with consideration of available energy and costs for building this structure along with that associated with the transportation technology which is necessary for providing access to this area. If this plan is anticipating future automobile growth and use based on past trends, then it must be rethought and revised as energy becomes more expensive.

Dade County Master Plan Approach

The Comprehensive Development Master Plan for Metropolitan Dade County prepared by the Metropolitan Dade County Planning Department (1973) is in many ways startling in that its tone and outlook is much different than studies previous to 1971. Most previous studies extrapolated existing growth into the future and thus predicted continued growth and development. Growth was good and the question was how to manage this growth. The General Land Use Master Plan had predicted a population of 2.5 million by 1985 but now the master plan is predicting somewhere between 1.6 and 1.8 million people. The tourist model in Fig. 27 predicted about 1.6 million people in 1985 (see Fig. 28c). Thus, the planners are beginning to respond to the reality of the energy situation as they monitor indicators such as tourism, migration, building growth, quality of life, carrying capacity, energy availability, and prices. If population modeling had been tied to energy sources in the sixties, perhaps the growth would have been seen to be limited.

It is also interesting that the Master Plan sets out such goals as:

a) A population ceiling should be determined.

b) Foster economic growth that will improve the standard of living both on an absolute and relative scale.

c) To achieve a harmonious relationship between man and his environment.

d) Recycle urban wastes.

e) Urban growth should be constrained by the carrying capacity of the Dade County environment.

f) Insure the preservation of beaches and wetlands.

g) Determine limitation on withdrawal from the Biscayne aquifer.

All of these goals point to the fact that more energies are going to be put into maintenance of the system and that consideration of the carrying capacity will result in logistic growth. In a sense this change in outlook of the planners is a validation of the model results presented in this dissertation. Further evidence for changes in the Miami urban system was a drop in tourism of about 30% for 1974 compared to 1972-73 and virtually no new construction permits with several large developments going bankrupt (Littlejohn, 1975). Construction is continuing on some developments which were already partially constructed.

Implications for Urban Living Patterns

There are many ways in which living styles and customs may change with adaptation to lower available energies and less urban structure. Less structure implies fewer automobiles, luxuries and buildings. People may migrate out of the urban regions to rural areas. The pace of life will probably slow down with less change, more stable communities, fewer machines and more labor intensive jobs. Perhaps the business district will decentralize to avoid the energy use of commuting and become dispersed throughout the urban region. Communication will be maintained through telephones and televisions. Extensive automobile use may be replaced by greater use of buses, bicycles, and certainly more walking. Extensive walking will provide much-needed exercise for large portions of the population and increase the number of people on the streets. This, coupled with the need for manual labor and more stable communities, may help to decrease crime.

Even if some net energy is provided to the cities for the next few decades, the establishment of a pleasing and attractive human habitat will require channeling of energies into maintenance of buildings, streets, parks and all services. This may result in the achievement of an aesthetically pleasing architecture with diversity of structure. Rather than displacing old, stable communities with gigantic high-rise buildings, these communities may be renovated with local people serving as the labor force. The acquisition of material things and planned obsolescence may be replaced by an appreciation of a simple life style with mechanisms maintained rather than replaced. There will be growth and change in some areas of the economy and depression in others while, on the average, the whole economy will maintain a nearly constant level of activity. There will be change and development but at a slower pace.

Implementation for the Transition Period

The perennial problem of interfacing scientific and technical research and development to society is of special interest when considering the work in this dissertation. It seems as though the difficulty of introducing new ideas or innovations is directly related to the scale of the research since large-scale projects affect many people and groups. Resistance is greater. The research presented in this dissertation presents ideas and results which may affect and challenge existing values of the society.

Ideas can be circulated in the public arena through books, magazines, and educational institutions so that they will influence values and policies if they survive competition with other ideas. However, this process may take a long time so that federal, state, and local government can be looked to for implementing these ideas in the form of policies, laws, zoning, and taxation. Whether these governmental agencies have the power to make such changes in the face of powerful concentrations of energy and power (e.g., corporations) is an important question. Changes in policy can also be brought about through advocacy planning, consumer groups, and the courts.

As the energy level of society shifts the distribution of energy, and therefore of money and political power, will shift and redistribute. The key question is how this political power will be redistributed. In Dade County lower energy levels may shift power to agricultural areas and diminish manufacturing growth and power. Tourism will probably still exist as an important source of income but greatly diminished. In Florida, the counties control development through zoning and permits. The county agencies are, in turn, heavily influenced by local economic interests.

Other Urban Patterns

Whereas the Miami urban region, like other American urban systems, has been a fast-growing, successional system characterized by a high ratio of net growth to recycle, other cities have energy constraints which require recycle of materials and a low ratio of net growth to recycle. As an example of a recycle model, the following paragraphs describe an order-disorder model for the urbanization of South Vietnam.

Urbanization Model for South Vietnam*

Perhaps the most striking example of the disordering process in the rapid development of an urbanized society has occurred in South Vietnam during the war years 1963-72. As in other under-industrialized countries, the rapid transformation from an agrarian to an urbanized society has resulted in various kinds of disruptions and disorderings in the social and physical systems. The intense conflict between United States military forces and Communist forces resulted in

*Sponsored by National Research Council Subcontract BA 23-72-28.

widespread destruction due to combat troops, intense bombing, and widespread herbiciding. American aid in the form of fuel and material which, along with the natural system energies, operate on the destruction to maintain and develop the agricultural and urban sectors. Figure 38 presents a macro-model of the processes taking place in Vietnam. The ecosystem and agricultural system are destroyed by herbicides for a period of five years, along with other forms of war destruction for 15 years. The natural ecosystem also loses by being developed and converted into agricultural and urban land through an interaction with fuels and disordered parts. Disordered parts are created from the natural, agricultural and urban compartments by virtue of the war and normal deterioration. This represents an order-disorder cycle. The rates of development were estimated from 1965-66 data and are summarized in Table 18. Unknown flows such as the natural deterioration or depreciation rate were approximated to be 2% per year, which is a conservative figure. The equations representing the model are on the legend to Fig. 38.

Figure 39a shows the result of a simulation run with a 5-year herbicide pulse and a 15-year war pulse with a recycle of disordered parts to the natural ecosystem. Perturbations are produced during the initial 10-15 years but the system has enough stability as a result of input of natural and fossil fuel energies to quickly recover and achieve a steady-state. The results in Fig. 39b come about if it is assumed that there is no recovery of disordered lands to natural

Fig. 38. Urbanization model for the country of South Vietnam showing major sectors including natural ecosystems, agricultural systems, and urban systems. There is a recycle pathway of destroyed areas through a storage of disordered parts. Equations describing the model are:

$$\dot{Q}_1 = S+K_0Q_2-K_3Q_1CW-K_1Q_1-K_{31}Q_1H-K_2Q_1Q_2M$$

$$\dot{Q}_2 = K_4M+K_5CW(Q_1+Q_3+Q_4)+K_{21}H(Q_1+Q_3)-K_6Q_1Q_2M$$

$$\dot{Q}_3 = K_7Q_1Q_2M-K_8Q_3CW-K_9Q_3-K_{30}Q_3H$$

$$\dot{Q}_4 = K_{11}Q_1Q_2M-K_{12}Q_4-K_{13}Q_4CW$$

$$\dot{M} = K_4Q_3+A-K_{15}M-K_{16}M+W$$

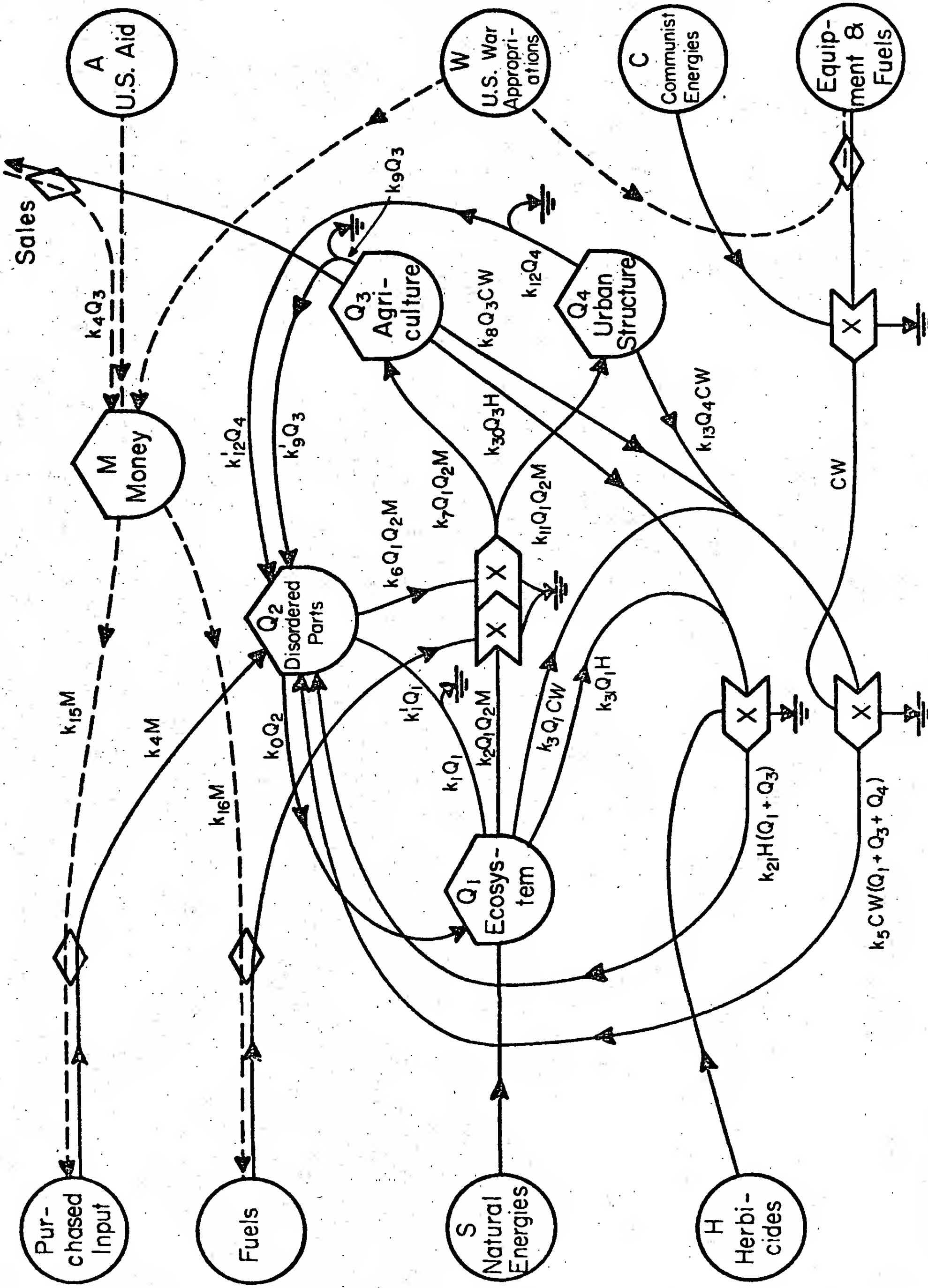

A
U.S. Aid
W
U.S. War Appropri-ations
C
Communist Energies
Equip-ment & Fuels
Sales
k_4Q_3
M
Money
k_9Q_3
Q_3
Agri-culture
$k_{12}Q_4$
k_8Q_3CW
Q_4
Urban Structure
$k_{13}Q_4CW$
CW
$k'_{12}Q_4$
k'_9Q_3
$k_7Q_1Q_2M$
$k_{30}Q_3H$
$k_6Q_1Q_2M$
$k_{11}Q_1Q_2M$
Q_2
Disordered Parts
$k_{15}M$
k_4M
$k_{16}M$
k_0Q_2
k'_1Q_1
k_1Q_1
$k_2Q_1Q_2M$
k_3Q_1CW
$k_{31}Q_1H$
$k_{21}H(Q_1+Q_3)$
$k_5CW(Q_1+Q_3+Q_4)$
Q_1
Ecosys-tem
Pur-chased Input
Fuels
S
Natural Energies
H
Herbi-cides

Table 18

Storages and Flows for South Vietnam Model

Mathematical Quantity	Note[a]	Description	Numerical Values	Reference
Q_1	1	Ecosystem Lands (Upland Forest and Mangrove)	19.19×10^6 acres	Vietnam Statistical Yearbook, 1970
Q_2	2	Disordered Parts (Forest, Agriculture and City)	25×10^4 acres	U.S. Congress House Committee on Appropriations, 1970
Q_3	3	Agricultural Land	7.31×10^4 acres	
Q_4	4	Urban Land	2.47×10^4 acres	Odum, Sell, *et al.*, 1974
M	5	Capital in City	$281 million	
H	6	Herbicide Use	644×10^3 gal/yr	
C	7	Communist Energies	$555 million/yr	
$K_{11}Q_1Q_2M$	8	Rate of Growth of Urban Land	1235 acres/yr	
$K_7Q_1Q_2M$	9	Bare Forest Land Returning to Agriculture	5600 acres/yr	
K_8Q_3CW	10	Replanted Agricultural Land	4.5×10^4 acres/yr	
K_3Q_1CW	11	Ecosystem Land Destroyed	7.95×10^3 acres/yr	
W	12	U.S. War Appropriations	$200 million/yr	

Table 18 - Continued

Mathematical Quantity	Note[a]	Description	Numerical Value	Reference
A	13	U.S. Aid	\$250 million/yr	
K_4M	14	Purchased Input	\$50.3 million/yr	
$K_5CW(Q_1+Q_3+Q_4)$	15	Structure Destroyed	40×10^3 acres/yr	
$K_{14}Q_3$	16	Money in Due to Sales	\$40.5 million/yr	
$(K_{15}+K_{16})M$	17	Money to Purchase Goods and Fuels	\$130.5 million/yr	
$K_{16}M$	17	Money to Purchase Fuels	\$80.5 million/yr	
$K_6Q_1Q_2M$	18	Bare Land Returning to Agriculture	14500 acres/yr	
$K_{11}Q_1Q_2M$	19	Natural Land → Urban Land	1235 acres/yr	
$K_7Q_1Q_2M$	20	Natural Land → Agricultural Land	5600 acres/yr	
K_8Q_3CW	21	Rural Destruction	4.5×10^4 acres/yr	
K_0Q_2	22	Rate of Return of Disordered Land to Natural Land	1.25×10^4 acres/yr	
$K_{31}Q_1H$	23	Ecosystem Herbicide Destruction	1.5×10^5 acres/yr	
$K_{30}Q_3H$	24	Agricultural Herbicide Destruction	5.94×10^4 acres/yr	

Table 18 - Continued

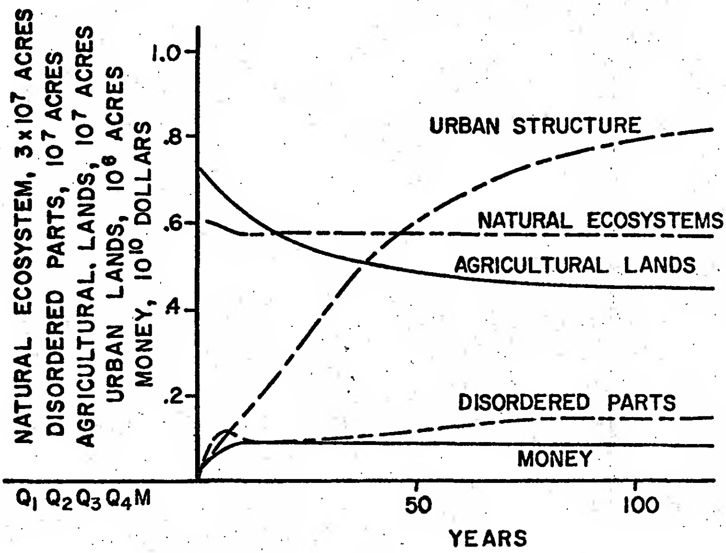
Mathematical Quantity	Note[a]	Description	Numerical Values	Reference
$K_{21}H(Q_1+Q_3+Q_4)$	25	Total Herbicide Destruction	21×10^4 acres/yr	
$K_{13}Q_4CW$	26	Urban Bomb Destruction	890 acres/yr	
$K_2Q_1Q_2M$	27	Total Ecosystem Transformation Into Rural and Urban	6835 acres/yr	
K_9Q_3	28	Depreciation	.02 Q_3/yr	
$K_{12}Q_4$	28	Depreciation	.02 Q_4/yr	

[a]Notes are contained in Appendix II.

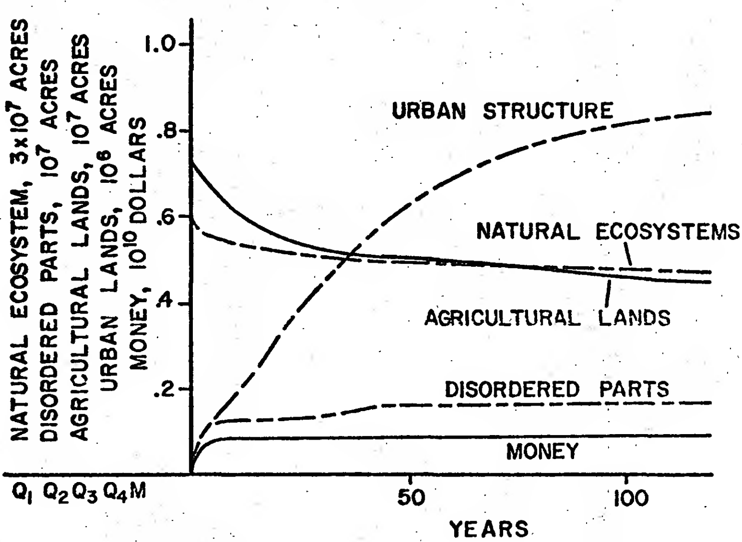
Fig. 39. Simulation results for Vietnam model.

a. Simulation results for model in Fig. 38 with recovery of natural lands ($k_0Q_2 \neq 0$).

b. Simulation results for model in Fig. 38 with no recovery of natural lands ($k_0Q_2 = 0$).

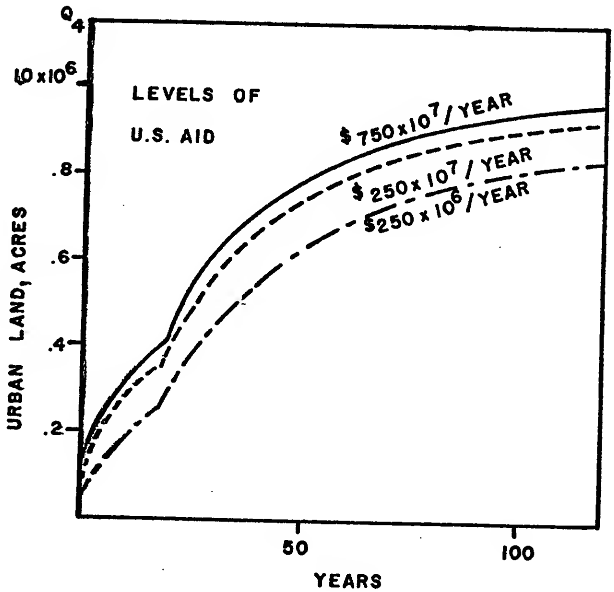

NATURAL ECOSYSTEM, 3x10^7 ACRES
DISORDERED PARTS, 10^7 ACRES
AGRICULTURAL LANDS, 10^7 ACRES
URBAN LANDS, 10^6 ACRES
MONEY, 10^10 DOLLARS
1.0
.8
.6
.4
.2
URBAN STRUCTURE
NATURAL ECOSYSTEMS
AGRICULTURAL LANDS
DISORDERED PARTS
MONEY
Q1 Q2 Q3 Q4 M
50
100
YEARS

(a.)


NATURAL ECOSYSTEM, 3x10^7 ACRES
DISORDERED PARTS, 10^7 ACRES
AGRICULTURAL LANDS, 10^7 ACRES
URBAN LANDS, 10^6 ACRES
MONEY, 10^10 DOLLARS
1.0
.8
.6
.4
.2
URBAN STRUCTURE
NATURAL ECOSYSTEMS
AGRICULTURAL LANDS
DISORDERED PARTS
MONEY
Q1 Q2 Q3 Q4 M
50
100
YEARS

(b.)

Fig. 40. Simulation results for model in Fig. 38 showing urban sector as a function of three different levels of U.S. aid.


Q4
1.0 x 10^6
.8
.6
.4
.2
URBAN LAND, ACRES
LEVELS OF
U.S. AID
$ 750 x 10^7 / YEAR
$ 250 x 10^7 / YEAR
$ 250 x 10^6 / YEAR
50
100
YEARS

ecosystems (k_0Q_2). This might come about if a political decision is made to develop the devastated natural areas. Ecosystem lands end up at a value approximately 16% lower than in Fig. 39a. It is interesting to note that in all the graphs urban development follows a kind of pseudo-logistic curve even though there is only a linear depreciation outflow and a constant yearly rate of energy input. Since U.S. aid is one of the primary ordering energies the response of the system to different levels of aid is of interest. Figure 40 presents urban growth for three different levels of U.S. aid which shows there is not a linear correspondence between U.S. aid and growth. This may indicate a process of diminishing returns in that the percentage increase in growth is decreasing with equal increments of U.S. aid.

Examination of the simulation curves suggests magnitudes of impact of the herbicide spraying period on the total energy flow of the Vietnam system. As shown in Fig. 39a, the percentage of energy lost, as a fraction of the area under the disordered parts curve until steady-state is reached, is approximately 5-6%. The impact of herbicides exerts a short-range effect, damping out within a period of 5 years, as long as foreign aid is stimulating reordering.

Summary

In summary, then, this dissertation dealt with aspects of the urban system in terms of an energetic formulation. Although the theory presented here could be used for any urban region, the area of Dade County was used as a study area since it is extensively urbanized and one for which data were available. Time series data from 1950 to 1972 were collected for many urban parameters and the rates of change of these variables correlated well with the rates of change for fossil fuel energy use. Based on the data and energy concepts, a set of urban indicators were calculated which could be used when making comparisons to other urban systems. Borrowing from ecosystem modeling, a detailed model of Miami and Dade County was constructed (Fig. 19) to show values of flows including natural energies. Based on this model several simplified models were constructed and analog computer simulated to show the effects of available energy and price on the growth of the system. These models included two generalized models (Figs. 20 and 24) and a tourist model (Fig. 27) which were subjected to different functions of available energy and price. The results show that the higher the rate of increase in price, the sooner and lower the urban structure peaks. Different price functions also affect fossil fuel reserves, fuel expenditures, and money storage differently. Higher prices inhibit the use of fossil fuels and decrease the money available for purchasing. Changes in the energy input function to the urban system also resulted in different responses. The tourist model indicated the effect of changes in tourist dollars on urban and natural parts of the system. If there are not any sudden discoveries of available energy in the country, Dade County structure should peak in the next few years and level with the population perhaps reaching 1.6 million in the next ten years. This population increase may be offset if there are migrations back to rural areas. If new net energy sources are developed, then growth will continue and peak at a later date and a higher level.

Calculations were made for the major economic and energy flows in the system, especially the major sources of fossil fuel and those associated with the natural areas in the county. In order to calculate these natural system energies, subsystems in the county were identified, their areas measured, and a land use map was constructed. A table of energy flows was also constructed.

In order to compare natural system and fossil fuel energies the concept of energy quality was employed, which allows theoretical assessment of the ability of energy flows with different energy concentrations to do useful work. The ratio of total energy flow to fossil fuel flow changed from 2.77 in 1950 to 1.25 in 1972, compared to a value of 1.4 in 1972 for the region of South Florida. An estimate of the energy recoverable from garbage in Dade County, assuming that the level of the system remains the same, was calculated as 2.08×10^{12} Kcal/yr, which represents 2.7% of the 1972 fossil fuel consumption. It was also estimated that the agricultural lands in the county could provide one-third of the carbohydrate and one-fourth of the protein requirements of the population for existing levels of population and consumption. Several energy to money ratios were also calculated.

An analysis of solar energy technology applied to water heating was also conducted, with results showing that a solar system would save both money and energy over an electrical system. This was not true when compared to a natural gas water heater. The question still remains, however, whether capital and energy should be invested in a luxury such as water heating rather than a more survival-related activity. This technology applied to water heating would have saved 3.5% of the total energy consumed in 1972. The results presented in this dissertation for the future of Dade County seem to agree with the new outlook and predictions of the Dade County Planning Department, which sees much smaller growth than previously predicted along with a consideration of logistic growth effects. Their population predictions are similar to those presented in this dissertation.

Finally, an order-disorder urbanization model was constructed for the country of South Vietnam to show the effects of foreign aid, energy, and war on the development of an entire country. The model shows diminishing returns on foreign aid invested in the country. This system between order and recycling parts and lands is a future of cities and countries as well as of forests and seas.

APPENDIX I

TABLES OF DATA FOR FLORIDA AND DADE COUNTY

Table 19

Energy Data for Florida Not Including Electrical Utilities[1]

Year	Natural Gas, 10^6 Ft.^{3}	Liquid Petroleum Fuel, 10^6 Barrels	Distillate, Residual and Kerosene Fuel, 10^6 Barrels	Population, 10^6 People
1950	8346	1.481	10.59	2.81
51	7789	1.605	12.45	2.967
52	9202	1.873	15.09	3.118
53	10656	2.187	16.25	3.284
54	14783	2.652	22.334	3.462
55	18467	3.139	28.432	3.67
56	23529	3.589	27.795	3.941
57	27670	3.655	27.453	4.245
58	33960	4.73	25.678	4.57
59	40945	4.76	28.245	4.79
1960	49357	4.935	28.183	4.999
61	59129	4.936	26.75	5.205
62	68716	5.405	27.16	5.392
63	81953	6.001	28.7	5.541
64	92855	6.373	29.0	5.781
65	101389	5.67	30.6	5.954
66	114588	6.095	31.4	6.104
67	117716	6.22		6.242
68	127968	6.344		6.433
69	126838	7.32	26.9	6.641
1970	133886	7.837	32.2	6.845
71	136698	7.539	30.84	7.041
72	122957	7.871	30.56	7.495

NOTE: Note 1 is contained in Appendix II.

Table 20

Dade County Data for Selected Urban Indicators[2-7]

Year	Budget, $\$10^6$	Building Permits, $\$10^6$/yr	Building Structure Growth, 10^6 ft^2/yr	Building Structure (Total) Above 1949 Level,[3] 10^6 ft^2	Distillate, & Kerosene 10^6 Barrels	Residual Fuel,[4] 10^{12} Kcal	Effective Buying Income $\$10^9$
1950	14.65	194.58	46	46	1.86	3.01	
51	20.13	161.68	37	83	2.26	3.66	
52	22.32	174.53	38	121	2.78	4.50	
53	25.41	204.99	44	165	3.07	4.97	
54	24.79	226.49	47	212	4.29	6.95	
55	28.59	256.2	52	264	5.49	8.89	
56	30.65	273.15	54	318	5.36	8.68	
57	38.94	303.3	58	376	5.29	8.57	
58	45.24	266.29	50	426	4.88	7.90	
59	54.41	282.09	51	477	5.30	8.58	
1960	59.89	241.93	43	520	5.27	8.53	
61	59.43	227.97	39	559	5.016	8.12	
62	62.66	225.33	38	597	5.198	8.42	
63	65.11	200.6	33	630	5.516	8.93	2.315
64	65.79	239.72	39	669	5.417	8.77	2.554
65	71.00	290.53	44	713	5.637	9.13	2.715
66	76.27	274.99	41	754	5.778	9.36	2.78
67	88.87	334.58	48	802			2.962
68	102.79	479.09	67	869			3.351
69	116.03	691.96	87	956	4.96	8.03	3.77
1970	128.07	613.19	72	1028	5.96	9.65	4.435
71	149.87	760.0	83	1110	5.761	9.33	4.809
72	172.65	1300.0	150(?)		5.576	9.03	5(?)

NOTE: Notes 2-7 are contained in Appendix II.

Table 20 - Continued

Year	Electrical Energy, 10^9 Kwh	Electrical Energy, 10^{12} Kcal	Gasoline Energy,[5] 10^8 gal	Gasoline Energy,[5] 10^{12} Kcal	Electrical & Gasoline Energy, 10^{12} Kcal	Labor Force, 10^3 people	Liquid Petroleum, 10^6 Barrels	Liquid Petroleum, 10^{12} Kcal
1950	0.78	2.68	1.42	5.11	7.79		0.26	0.264
51	0.943	3.24	1.53	5.51	8.75		0.29	0.294
52	1.099	3.78	1.70	6.12	9.9		0.345	0.35
53	1.283	4.42	1.86	6.7	11.12		0.413	0.419
54	1.464	5.04	2.04	7.35	12.39		0.51	0.518
55	1.714	5.92	2.25	8.1	14.02		0.61	0.62
56	1.994	6.88	2.53	9.1	15.98		0.69	0.70
57	2.319	8.00	2.72	9.8	17.8		0.71	0.72
58	2.666	9.16	2.79	10.05	19.21		0.9	0.91
59	3.002	10.32	2.89	10.4	20.72		0.89	0.90
1960	3.344	11.52	2.91	10.48	22.0		0.92	0.934
61	3.62	12.48	2.98	10.72	23.2		0.926	0.94
62	3.959	13.64	3.22	11.6	25.24		1.035	1.05
63	4.357	15.0	3.33	11.98	26.98	426.4	1.153	1.17
64	4.763	16.4	3.51	12.63	29.0	434.8	1.19	1.21
65	5.121	17.6	3.61	13.0	30.6	458.5	1.044	1.06
66	5.676	19.52	3.80	13.68	33.2	478.2	1.121	1.14
67	6.295	21.6	4.13	14.88	36.48	519.8		1.16
68	7.154	24.64	4.47	16.1	40.74	545.5	1.173	1.19
69	8.166	28.08	4.84	17.4	45.48	586.3	1.35	1.4
1970	9.134	31.4	5.23	18.82	50.22	608.2	1.45	1.47
71	10.118	35.0	5.59	20.1	55.1	631.6	1.408	1.43
72	11.238	38.68	6.04	21.75	60.43	643.3	1.44	1.46

Table 20 - Continued

Year	Natural Gas, 10^6 ft^3	Natural Gas, 10^{12} Kcal	Net Migration, 10^3 people/yr	Population (Total) 10^6 people	Retail Sales, \$$10^9$	Sales Tax Collections, \$$10^6$	Telephones (Total), 10^3 units
1950	652.2	0.177		0.495		12.76	200.68
51	628.1	0.171	37.0	0.5388		14.78	221.25
52	751.7	0.204	28.5	0.5476		16.28	245.29
53	894.1	0.243	39.0	0.6215		18.52	267.63
54	1260.3	0.343	35.0	0.6653		19.52	297.17
55	1582.5	0.43	35.5	0.7098		22.62	325.85
56	2016.3	0.548	41.5	0.7613		26.37	371.72
57	2371.0	0.645	48.0	0.8204		32.64	419.93
58	2864.8	0.779	37.0	0.8686	1.366	36.31	450.39
59	3417.8	0.93	22.5	0.9025	1.509	39.79	488.16
1960	4097.9	1.115	21.5	0.935		41.67	516.72
61	4922.4	1.34	29.5	0.9758		40.37	546.82
62	5839.5	1.59	46.0	1.0322		43.01	556.97
63	6993.7	1.90	22.5	1.065	1.58	44.44	595.53
64	7701.4	2.09	6.0	1.08	1.797	53.1	615.1
65	8292.0	2.26	9.0	1.097	2.035	58.94	649.46
66	9361.4	2.55	20.0	1.1237	2.214	63.7	689.94
67	9679.7	2.63	26.0	1.1558	2.413	69.8	740.54
68	10505.6	2.86	28.5	1.1896	2.61	99.7	792.65
69	10390.3	2.83	30.5	1.2255	2.614	129.24	859.68
1970	11009.3	2.99	37.0	1.267	2.62	140.23	918.13
71	11337.5	3.08	41.0	1.3154	2.82	155.0	995.5
72	9974.3	2.71	46.5	1.3676	3(?)	178.57	1093.0

Table 20 - Continued

Year	Total Fossil Fuel Energy, 10^{12} Kcal	Tourist Flow, 10^{6}/yr	Vehicles, (Total), 10^{3} units	Water Consumption, 10^{9} gal
1950	11.241		222.84	18.08
51	12.875		247.18	19.69
52	14.954		262.6	22.29
53	16.752		292.48	21.52
54	20.201		322.82	23.01
55	23.96		377.09	26.07
56	25.908	2.56	405.36	26.57
57	27.735	2.856	448.74	29.29
58	28.8	2.248	457.31	29.16
59	31.13	4.0	480.51	31.59
1960	32.58	3.95	493.0	32.44
61	33.6	4.4	502.08	35.33
62	36.3	4.6	529.17	38.25
63	38.98	5.0	550.9	39.64
64	41.1	5.2	556.0	45.16
65	43.05	5.5	603.35	51.31
66	46.25	6.0	633.4	45.96
67	49.28	6.6	671.21	48.6
68	53.79	7.2	730.92	50.13
69	57.74	7.5	796.46	50.04
1970	64.33	10.0	823.44	55.88
71	68.94			58.07
72	73.63			59.56

Table 21

Dade County Per Capita Data for Selected Urban Variables[8]

Year	Budget, Dollars	Building Permits, Dollars	Building Structure Growth ft^2/yr	Building Structure (Total) Above 1949 Level, ft^2	Distillate, & Kerosene Barrels	Residual Fuel, 10^6 Kcal	Effective Buying Income, $\$10^3$
1950	29.6	393.1	92.9	93.0	3.76	6.08	
51	37.4	300.0	68.7	154.0	4.19	6.79	
52	40.8	318.7	69.4	221.0	4.84	7.83	
53	40.9	329.8	70.8	265.0	4.94	7.80	
54	37.3	340.4	70.6	318.0	6.45	10.45	
55	40.3	360.9	73.3	372.0	7.73	12.52	
56	40.3	358.8	70.9	418.0	7.04	11.40	
57	47.5	369.7	70.7	458.0	6.45	10.45	
58	52.1	306.6	57.6	490.0	5.62	9.10	
59	60.3	312.6	56.5	529.0	5.87	9.51	
1960	64.0	263.31	46.0	556.0	5.64	9.12	
61	60.9	238.61	40.0	573.0	5.14	8.32	
62	60.7	224.43	36.8	578.0	5.04	8.16	
63	61.1	191.23	31.0	592.0	5.18	8.38	2.207
64	60.9	223.62	36.1	619.0	5.02	8.12	2.382
65	64.7	266.79	40.1	650.0	5.14	8.32	2.493
66	67.9	247.74	36.5	671.0	5.14	8.33	2.505
67	76.9	293.49	41.5	694.0		7.79	2.598
68	86.4	408.43	56.3	730.0		7.57	2.857
69	94.7	572.8	71.0	780.0	4.05	6.55	3.121
1970	101.0	491.73	56.8	811.0	4.70	7.61	3.557
71	113.9	588.24	63.0	844.0	4.38	7.09	3.722
72	126.2	968.7			4.08	6.60	

NOTE: Note 8 is contained in Appendix II.

Table 21 - Continued

Year	Electrical 10^3 Kwh	Energy, 10^6 Kcal	Gasoline Gallons	Energy, 10^6 Kcal	Labor Force	Liquid Petroleum, Barrels	10^6 Kcal	Natural Gas, ft^3	10^6 Kcal
1950	1.58	5.41	281.0	10.30		0.53	0.533	1318	0.358
51	1.75	6.01	264.0	10.23		0.54	0.546	1166	0.317
52	1.91	6.58	294.0	11.18		0.60	0.609	1308	0.355
53	2.06	7.11	304.0	10.58		0.66	0.674	1439	0.391
54	2.20	7.58	313.0	10.83		0.77	0.779	1894	0.516
55	2.41	8.34	327.0	11.25		0.86	0.873	2230	0.606
56	2.62	9.04	326.0	11.78		0.91	0.919	2648	0.720
57	2.83	9.75	317.0	11.73		0.87	0.878	2890	0.786
58	3.07	10.55	317.0	11.41		1.04	1.048	3298	0.897
59	3.33	11.43	309.0	11.41		0.99	1.0	3787	1.03
1960	3.58	12.32	302.0	11.12		0.98	0.99	4383	1.19
61	3.71	12.79	309.0	10.88		0.95	0.96	5044	1.37
62	3.84	13.20	313.0	11.12		1.00	1.02	5657	1.54
63	4.15	14.08	326.0	11.25	0.40	1.08	1.1	6567	1.78
64	4.44	15.19	330.0	11.73	0.40	1.10	1.12	7131	1.94
65	4.70	14.95	339.0	11.88	0.42	0.95	0.966	7557	2.06
66	5.11	17.37	358.0	12.20	0.43	1.00	1.015	8331	2.27
67	5.52	18.69	377.0	12.90	0.45		1.004	8375	2.28
68	6.10	20.70	396.0	13.58	0.46	0.99	1.0	8831	2.40
69	6.76	22.90	412.0	14.25	0.48	1.10	1.14	8478	2.31
1970	7.32	24.77	425.0	14.83	0.48	1.14	1.16	8684	2.36
71	7.83	26.60	441.0	15.30	0.48	1.07	1.09	8619	2.34
72	8.37	28.28		15.90	0.47	1.05	1.07	7293	1.98

Table 21 - Continued

Year	Retail Sales, $\$10^3$	Sales Tax Collections, Dollars	Telephones	Total Fossil Fuel Energy, 10^6 Kcal	Vehicles	Water Consumption, 10^3 Gallons
1950		25.77	0.405	22.7	0.45	36.52
51		27.43	0.411	23.9	0.46	36.54
52		28.33	0.427	26.03	0.48	38.8
53		29.8	0.431	26.95	0.47	34.6
54		29.34	0.447	30.36	0.49	34.59
55		31.87	0.459	33.76	0.53	36.73
56		34.64	0.488	34.03	0.53	34.9
57		39.79	0.512	33.81	0.55	35.7
58	1.573	41.8	0.519	33.16	0.53	33.57
59	1.67	44.09	0.541	34.5	0.53	35.0
1960		44.56	0.553	34.84	0.53	34.7
61		41.37	0.56	34.4	0.51	36.2
62		41.67	0.54	35.17	0.51	37.06
63	1.506	42.36	0.568	36.6	0.52	37.79
64	1.676	49.53	0.574	38.06	0.51	42.13
65	1.869	54.12	0.596	37.46	0.55	47.12
66	1.995	57.39	0.622	38.3	0.56	41.41
67	2.117	61.23	0.65	42.64	0.58	42.63
68	2.225	85.0	0.676	45.22	0.61	42.74
69	2.164	106.99	0.712	47.12	0.65	41.42
1970	2.10	112.45	0.736	50.74	0.65	44.81
71	2.183	119.97	0.771	52.41		44.95
72	2.26(?)	133.06	0.814	53.84		44.38

Table 22A

Rate of Change per Year for
Selected Urban Variables in Dade County

Year Interval	Budget, $\$10^6$	Budget per Capita, Dollars	Effective Buying Income, $\$10^9$	Electrical Energy 10^{12} Kcal	Gasoline Energy, 10^{12} Kcal	Labor Force, 10^3 People	Population, 10^6 People
1950-51	5.48			0.56	0.4		0.0438
51-52	2.19	1.15		0.54	0.612		0.0398
52-53	3.09	2.4		0.63	0.576		0.0413
53-54	-0.62	-3.96		0.62	0.648		0.0454
54-55	3.8	3.06		0.88	0.756		0.0441
55-56	2.06	0.08		0.96	1.01		0.0481
56-57	8.29	7.57		1.12	0.684		0.0553
57-58	6.3	4.33		1.16	0.252		0.0536
58-59	9.17	7.88		1.16	0.36		0.041
59-60	5.48	3.73		1.2	0.072		0.033
1960-61	-0.46	-2.98		0.96	0.252		0.0366
61-62	3.23	0.21		1.16	0.865		0.0486
62-63	2.45	-0.34		1.36	0.396		0.045
63-64	0.68	-0.7	0.239	1.4	0.648	8.4	0.023
64-65	5.21	3.83	0.161	1.23	0.37	23.7	0.017
65-66	5.27	3.51	0.065	1.9	0.684	19.7	0.021
66-67	12.6	9.25	0.182	2.13	1.198	41.6	0.03
67-68	13.92	9.67	0.389	2.95	1.222	25.7	0.033
68-69	13.24	8.42	0.419	3.48	1.33	40.8	0.035
69-70	12.04	6.65	0.665	3.33	1.402	21.9	0.039
1970-71	21.8	13.3	0.374	3.38	1.295	23.4	0.045
71-72	22.78	12.7	0.39(?)	3.85	1.62	11.7	0.05

Table 22B

Rate of Change or First Differences for Selected Urban Variables[9]

Year Interval	Retail Sales, $\$10^9$	Sales Tax Collections, $\$10^6$	Telephones, 10^3 Units	Total Fossil Fuel Energy, 10^{12} Kcal	Water Consumption, 10^9 Gallons
1950-51		2.02	20.57	1.63	1.61
51-52		1.5	24.04	2.08	2.6
52-53		2.24	22.34	1.8	-0.77
53-54		1.0	29.54	3.5	1.49
54-55		3.1	28.68	3.76	3.06
55-56		3.75	45.87	1.95	0.5
56-57		6.27	48.21	1.83	2.72
57-58	0.143	3.67	30.46	1.07	-0.13
58-59		3.48	37.77	2.33	2.43
59-60		1.88	28.56	1.45	0.85
1960-61		-1.3	30.1	1.02	2.89
61-62		2.64	10.15	2.7	2.92
62-63		1.43	38.56	2.68	1.39
63-64	0.217	8.66	19.6	2.12	5.52
64-65	0.238	5.84	34.4	1.95	6.15
65-66	0.179	4.76	40.4	3.2	-5.35
66-67	0.199	6.1	50.6	3.03	2.64
67-68	0.197	29.9	52.2	4.51	1.53
68-69	0.004	29.54	67.0	3.95	-0.09
69-70	0.006	10.99	58.4	6.6	5.84
1970-71	0.20	14.77	77.4	4.6	2.19
71-72	0.10	23.57	97.5	4.7	1.49

NOTE: Note 9 is contained in Appendix II.

APPENDIX II

NOTES TO TABLES 6, 7, 8, 11, 13, 14, 18, 19, 20, 21, and 22

Notes to Table 6

1. Approximately 10^{12} gallons/yr recharges aquifer (Windham).

2. Sunlight energy falling on Dade County approximately equal to

$$\text{sunlight} = 4000 \text{ Kcal/m}^2\text{/day} \times 365 \text{ days/yr}$$
$$\times\ 1924 \text{ mile}^2 \times \frac{2.59\times10^6 \text{ m}^2}{\text{mile}^2}$$
$$= 73.6 \times 10^{14} \text{ Kcal/yr}$$

3. See note 17 to Table 11.

4. It was assumed that the average intake/person is 3000 Kcal/day which is

$$3000 \text{ Kcal/capita /day} \times 1.37 \times 10^6 \text{ people} \times \frac{365 \text{ days}}{\text{yr}}$$
$$= 15 \times 10^{11} = 1.5 \times 10^{12} \text{ Kcal/yr}$$

5. Based on percentage increase in no. of vehicles from 1969-70 which was approximately 3.4%. This comes out to be 29,000 vehicles/yr for 1972-73 if number of vehicles in 1971 is multiplied by .034:
.034 x 851,000 = 29,000.

6. Transfer payments = $\$.57 \times 10^9$ for 1970. Property income = $\$.73 \times 10^9$ for 1970. Assume values for 1972 are those of 1970 corrected by the ratio of 1972 to 1970 population:

$$\frac{\text{Population (1972)}}{\text{Population (1970)}} = \frac{1.368}{1.267} = 1.079$$

Transfer payments (1972) = \$.57x(1.079)B = \$.62 Billion
Property income (1972) = \$.73x(1.079)B = \$.79 Billion
Total =\$1.41 Billion

7. Major Federal subsidies include:

1) Dept. of Commerce = $\$6 \times 10^6$
2) H.E.W. = $\$334 \times 10^6$
3) Dept. of Housing & Urban Development = $\$30.4 \times 10^6$
4) Dept. of the Interior = $\$3.4 \times 10^6$
5) Dept. of Justice = $\$5.2 \times 10^6$
6) Dept. of Labor = $\$8.3 \times 10^6$
7) General Services Admin. = $\$4 \times 10^6$
8) Post Office Dept. = $\$47.1 \times 10^6$
9) All other except transportation = $\$355 \times 10^6$

Total = $\$793 \times 10^6$

Multiply by ratio of 1972 to 1970 population to get $\$856 \times 10^6$.

8. Taken as a total income minus effective buying income for 1970. Taxes = $\$5.7 \times 10^9$ minus $\$4.44 \times 10^9$ = $\$1.26 \times 10^9$. For 1972 multiply by ratio of 1972/1970 population to get $\$1.36 \times 10^9$.

9. The sum of hydrocarbons, CO, NO_2, SO_2, NO_3, particulates, aldehydes, organic acids and other organics amounts to 915,453 tons for 1970.

10. The amount of developed land was 260 square miles in 1972 and 202 square miles in 1960 (see Table 5). The average rate of development is

$$\frac{260\text{-}202 \text{ miles}^2}{12 \text{ years}} = 4.8 \text{ miles}^2/\text{year}$$

11. Money spent in 1967 for vehicles was $\$2.099 \times 10^9$ (Fla. Statistical Abstract, 1973). Ratio of vehicles in 1972 to that in 1967 was approximately 1.31. Therefore, assume money spent for vehicles in 1972 was approximately $\$2.0 \times 10^9 \times 1.31 = \$2.6 \times 10^9$.

12. Approximately 25% of family budget is used to buy food (Fla. Statistical Abstract, 1973). Total effective buying income of Dade County for 1972 was approximately $\$5 \times 10^9$ so that money spent for food was approximately $\$1.25 \times 10^9$.

13. Energy flow is the sum of electrical energy, gasoline, natural gas, distillate, residual and kerosene. Fossil fuel equivalent of electrical energy = 4 x (kwh used) because conversion of fuel into electrical energy requires an energy ratio of 4:1 (see Table 1). Thus,

    Electrical energy = $4 \times 9.67 \times 10^{12}$ Kcal = 38.68×10^{12} Kcal

    Gasoline energy = 6.04×10^8 gal x 3.6×10^4 Kcal/gal

    = 21.75×10^{12} Kcal

    Natural gas = 2.71×10^{12} Kcal

    Distillate + Residual + Kerosene = 8.07×10^{12} Kcal

    Total ≈ 73.63×10^{12} Kcal.

14. Average price of fuel calculated to be $.804 \times 10^{-3}$ cents/Kcal (see note 15 below).

    Total money = $.804 \times 10^{-3}$ cents/Kcal x 73.63×10^{12} Kcal

    Total money = 59.2×10^7 dollars

15. 1971-72 prices of fuels were (Minerals Yearbook, Fla. Statistical Abstract, 1973):

    Natural gas: $\$1.39/10^3\ ft^3$

    or $.003676\ ft^3/\text{Kcal} \times \$1.39/10^3\ ft = \$.51 \times 10^{-5}/\text{Kcal}$

    Distillate fuel: 11.9¢/gallon

    $$\text{or } 11.9¢/\text{gal} \times \frac{42\ \text{gal}}{\text{barrel}} \times \frac{1\ \text{barrel}}{1.6192 \times 10^6\ \text{Kcal}}$$

    $$= \$.31 \times 10^{-5}/\text{Kcal}$$

Residual fuel: \$4.51/barrel

$$\text{or } \$4.51/\text{barrel} \times \frac{1 \text{ barrel}}{1.6192\text{x}10^6 \text{ Kcal}} = \$.28 \times 10^{-5}/\text{Kcal}$$

LP gas: 11.6¢/gal

$$\text{or } \frac{11.6¢}{\text{gal}} \times \frac{42 \text{ gal}}{\text{barrel}} \times \frac{1 \text{ barrel}}{1.6192\text{x}10^6 \text{ Kcal}} = \$.3 \times 10^{-5}/\text{Kcal}$$

Gasoline: 40¢/gal

$$\text{or } \frac{40¢}{\text{gal}} \times \frac{1 \text{ gal}}{3.6\text{x}10^4 \text{ Kcal}} = \$1.1 \times 10^{-5}/\text{Kcal}$$

Electricity: 2.6¢/kwh

$$\text{or } 2.6¢/\text{kwh} = \frac{1 \text{ kwh}}{859.85 \text{ Kcal}} = \$3.02 \times 10^{-5}/\text{Kcal (of high quality energy)}$$

$$= \$3.02/4 \times 10^{-5}/\text{Kcal}$$

$$= \$.76 \times 10^{-5}/\text{Kcal of fossil fuel energy used to generate electricity}$$

The average price for all fuel is a weighted average of the above prices:

$$\text{Average price} = \$.51 \times 10^{-5}\ \frac{2.71}{73.63} + \frac{\$(.31+.28)}{2} \times 10^{-5}\ \frac{9.03}{73.63} + \$.3 \times 10^{-5}\ \frac{1.46}{73.63} + \$1.1 \times 10^{-5}\ \frac{21.75}{73.63} + \$.76 \times 10^{-5}\ \frac{38.68}{73.63}$$

$$\text{Average price} = \$.804 \times 10^{-5}/\text{Kcal}$$

16. Price of food taken as money spent for food (see note 12) divided by Kcal value (see note 4):

$$\text{Price} = \frac{\$1.25\text{x}10^9}{1.5\text{x}10^{12} \text{ Kcal}}$$

$$= \$.834 \times 10^{-3}/\text{Kcal of food energy}$$

17. Personal communication with Steve Windham.

18. Aerial maps photographed January, 1973 (see Table 10), were planimetered for areas. Developed land consisted

of man-made lakes and reservoirs, cleared land and roads, open space and recreation, transportation terminals, commercial, industrial, and residential land uses.

19. Aerial maps photographed January, 1973 (see Table 10), were planimetered for areas. Natural areas consisted of rivers, streams, lakes, fresh and salt water marshes, mangroves, pinelands, cypress, hardwoods, sawgrass marsh, marl prairies, and estuarine water.

20. National average statistic of 1600 lbs/person/yr.

    Total = $1600 \times 1.342 \times 10^6 = 2.15 \times 10^9$ lbs/yr

    $= 1.07 \times 10^6$ tons/yr

21. Based on budget assumed to be 1% of building growth in private sector or 1.53×10^6 ft^2/yr.

22. Value of building permits in 1972 was $1.3 x 10^9. Cost per square foot is approximately $8.50. Thus, the number of square feet built is approximately 1.53×10^8 ft^2/yr.

23. Structure can be measured physically by use of material weight or square feet of floor space. Value of building permits from 1950-72 is approximately $9.25 x 10^9. Estimate that it costs $8.50 to build one square foot. Therefore, total square footage is approximately

    $$\frac{9.25 \times 10^9}{8.5} = 1.09 \times 10^9 \text{ ft}^2$$

    If 5% per year depreciation is assumed from 1950 to 1972, then a value of $.85 \times 10^9$ ft^2 is calculated as the storage in 1972. This is a conservative number since the estimated number of demolitions from 1960 to 1970 was

1300/yr while total construction per year was 15600 (Comprehensive Development Master Plan, 1973). This is a rate of 8.3% per year.

24. Estimated by taking total deposits minus 10% which represents approximate government deposits on a state-wide basis. Therefore, business and personal deposits = $.9 x 3,258,374,000 = $2.93 x 10^9. Assume 50% is personal = $1.46 x 10^9.

25. In 1971 total retail sales were $2.82 x 10^9. Residents accounted for approximately 85% of this which is $2.4 x 10^9. The value in 1972 was taken as this multiplied by the ratio of population in those years (1.039). Retail sales in 1972 were approximately $2.5 x 10^9.

26. Same as in note 24.

27. Based on government budget is approximately 1% of total building permits. This is approximately 1.09 x 10^7 ft^2.

Notes to Table 7

1. From Auer (1974) the estimate of proven fossil fuel reserves in the U.S. is given as 4.5Q where Q = 1.06 x 10^{21} joules. The proportion of this available for Dade County is taken as this number times the ratio of population in Dade County to that of the U.S. This is 4.5Q x 1.35/210 = .03Q. If it is assumed that the efficiency of recovery is 40% (Ballentine), then the Kcal of fossil fuel available to Dade County is approximately:

$$\text{Fossil fuel} = .4 \times .03 \times 1.06 \times 10^{21} \text{ joules} \times \frac{2.389\times10^{-4}\text{ Kcal}}{\text{joule}}$$

$$\text{Fossil fuels} = 3.08 \times 10^{15} \text{ Kcal}$$

2. In 1972 total square footage was approximately 8.5 x 10^8 ft^2 (see note 23, Table 6).

3. Average effective buying income taken as average of value in 1950 and 1971 or

$$\$\left(\frac{.665+4.8}{2}\right) \times 10^9 = \$2.73 \times 10^9$$

4. See note 13, Table 6.

5. Total structure built from 1950-72 is approximately 1261 x 10^6 ft^2 (see note 2). Average square footage built per year is then

$$\frac{1261\times10^6 \text{ ft}^2}{23 \text{ years}} = 55 \times 10^6 \text{ ft}^2/\text{yr}$$

6. Tourist dollars in 1970 were approximately \$3 x 10^9/ 1.267 x 10^6 which is \$2.36 x 10^3/capita. In 1950 an approximate tourist dollar flow would be this times the

population, to give

$$\$(2.36\times10^{3}) \times (.495\times10^{6}) = \$1.17 \times 10^{9}$$

The average tourist dollar flow per year is then

$$\frac{\$(3+1.17)\times10^{9}}{2 \text{ years}} = \$2.09 \times 10^{9}/\text{yr}$$

Money from other income in 1970 is $\$(5.7-3) \times 10^{9} = \$2.7 \times 10^{9}$ where $\$5.7 \times 10^{9}$ is the total income. The approximate value in 1950 is the 1970 value multiplied by the ratio of the populations to give $\$1.4 \times 10^{9}$ in 1950. The average income per year from 1950 to 1970 is $\$(2.7+1.4)/2 \times 10^{9} = \$2.05 \times 10^{9}/\text{yr}$. Total income per year is $\$(2.05+2.09)$ or approximately $\$4 \times 10^{9}/\text{yr}$.

7. See note 14, Table 6.

8. Based on mean building life of 20 years.

9. Money spent in running system internally is taken as total income minus money spent for goods (vehicles) and fuels. This is 4-(2.099+.592) billion dollars = $\$1.31 \times 10^{9}$. Money drain needed for goods and services is then taken as money for goods (mostly vehicles) plus the above number calculated for services. Thus, $\$(1.31+2.099) \times 10^{9} = \$3.4 \times 10^{9}$.

10. See note 15, Table 6.

Notes to Table 8

1. See Table 7, note 1.
2. See Table 7, note 2.
3. See Tables 11 and 12.
4. See Table 4.
5. See Table 7, note 3.
6. See Table 6, note 13.
7. See Table 7, note 5.
8. See Table 9. Money for food, fuel, and goods amounts to \$5.44 billion while that from manufacturing and property income amounts to \$2.79 billion. The difference is \$2.65 billion.
9. See Table 7, note 8.
10. See Table 9.
11. See Table 9.
12. See Table 9.
13. See Tables 11 and 12.
14. For a steady-state situation, assumed to be the same as production over a year.
15. See Table 12. Natural system energies in 1950 were 14.86×10^{12} Kcal (FFWE) while in 1972 they were 13.88×10^{12} Kcal (FFWE). To obtain the rate of destruction per year, subtract these two values and divide by 22 years to get

$$\frac{(14.86-13.88)\text{x}10^{12}\ \text{Kcal}}{22\ \text{years}} = .05 \times 10^{12}\ \text{Kcal(FFWE)/yr}$$

Notes for Table 11

1. Areas of systems obtained from Table 10 which was constructed by planimetering an aerial photograph.
2. Natural ecosystems metabolic work is gross primary production and is estimated directly from the literature for most calculations.
3. The energy concentration factor is the ratio of the output energy flow for a particular energy conversion process to the sum of the input energies. If the output is expressed in fossil fuel equivalents (work equivalent to coal), then the energy concentration factor is the number of Kcal of a particular type of energy flow which can do the same work as one Kcal of coal. This factor allows conversion of natural energy flows to the same units as man's energy flows. See Methods and Table 1 for references and further details. Some factors are uncertain and are marked with a question mark.
4. Column D is obtained by multiplying the work per unit area (column B) by the area of land (column A) and dividing by the energy concentration factor (column C). The result is Fossil Fuel Work Equivalents, FFWE (column D).
5. To gain perspective of various works done, annual energy contributions in column D are divided by the approximate ratio of work to money spent in the U.S. economy, 25000 Kcal/dollar.

6. Fresh water marsh productivity estimated as 20 $gC/m^2/day$ (Bayley and Odum, 1973; Young *et al.* 1974). Thus, productivity in $Kcal/m^2/yr$ is

$$20.5\ gC/m^2/day \times 9\ Kcal/gC \times 365\ days/yr$$
$$= 67.3 \times 10^3\ Kcal/m^2/yr$$

7. Salt water marsh productivity estimated as 10.6 $gC/m^2/day$ (Teal, 1962; Bayley and Odum, 1973). Productivity in $Kcal/m^2/yr$ is

$$10.6\ gC/m^2/day \times 9\ Kcal/gC \times 365\ days/yr$$
$$= 34.8 \times 10^3\ Kcal/m^2/yr$$

8. Estimated productivity as 2.8 $gO_2/m^2/day$ (Bayley and Odum, 1973). Productivity in $Kcal/m^2/yr$ is

$$2.8\ gO_2/m^2/day \times 4.5\ Kcal/gO_2 \times 365\ days/yr$$
$$= 4.6 \times 10^3\ Kcal/m^2/yr$$

9. Pineland productivity estimated as 3.5 $gC/m^2/day$ (Bayley and Odum, 1973, pg. 42) so that productivity in $Kcal/m^2/day$ is approximately

$$3.5\ gC/m^2/day \times 9\ Kcal/gC \times 365\ days/yr$$
$$= 11.5 \times 10^3\ Kcal/m^2/yr$$

10. Cypress productivity estimated as 20000 $Kcal/m^2/yr$ (Odum, E. P., 1971).

11. Bottomland hardwood gross production was estimated from values of a tropical rain forest (Odum, 1970) which was approximately 140 $Kcal/m^2/day$. For a 9-month deciduous period yearly productivity is approximately

$$140\ Kcal/m^2/day \times 365\ days \times .75$$
$$= 38.3 \times 10^3\ Kcal/m^2/yr$$

12. Estuarine productivity estimated as 20000 $Kcal/m^2/yr$.

13. Mangrove productivity estimated as 9 $gC/m^2/day$ (Snedaker and Lugo, 1973). Personal communication with Larry Burns (Center for Wetlands, University of Florida) which is

$$9\ gC/m^2/day \times 9\ Kcal/gC \times 365\ days/yr$$
$$= 29.5 \times 10^3\ Kcal/m^2/yr$$

14. Tides in Biscayne Bay. Mean tidal range in Biscayne Bay is approximately 2 feet (Tide Tables). Potential energy due to tides estimated from

$$\text{Work} = 1/2\ \rho g A h^2$$
$$\rho = \text{density of water} = 1\ gm/cm^3$$
$$g = \text{gravitational constant} = 980\ cm/sec^2$$
$$A = \text{area of water column} = 1\ cm^2$$
$$h = \text{mean tidal height} = 2\ ft = 61\ cm$$

$$\text{Work} = \frac{1}{2} \times 1 \times 980 \times (61)^2 = 182 \times 10^4\ ergs/cm^2 \text{ per rise or fall of tide.}$$

$$\text{Work} = 182 \times 10^4\ ergs/cm^2 \times 2\ \frac{cycles}{day} \times \frac{365\ days}{year} \times \frac{10^4\ cm^2}{m^2} \times 2.39 \times 10^{-11}\ Kcal/erg$$

$$\text{Work} = 318\ Kcal/m^2/yr.$$

15. The length of eastward-facing shores including the mainland, the Miami Beach shoreline, Virginia Key, Crandon Park, Key Biscayne, and Elliott Key was measured as approximately 178 miles from aerial photographs (see note 1). Assume the wave energy is dissipated over a 20-foot-wide strip running along the coast. The area is then

$$\text{Area} = 178 \text{ miles} \times \frac{5280 \text{ ft}}{\text{mile}} \times 20 \text{ ft} \times \frac{1 \text{ km}^2}{10.76\text{x}10^6 \text{ ft}^2}$$

$$\text{Area} = 1.75 \text{ km}^2$$

16. Beach wave energy was calculated by assuming 1-foot-high waves in South Dade County and 1.6-foot-high waves in North Dade County (Shore Protection Manual). The kinetic energy per cm of coastline is given by

$$\text{Kinetic energy} = \frac{1}{8}\,\rho g^{1.5} \times H^{2.5}$$

$$\text{K.E.} = \frac{1}{2} \times \left(\frac{1}{8} \times 1 \times 980^{1.5} \times 30.5^{2.5} + \frac{1}{8} \times 1 \times 980^{1.5} \times (1.6{\cdot}30.5)^{2.5}\right)$$

$$\text{K.E.} = 4.18 \times 10^7 \text{ ergs/cm/sec}$$

If it is assumed that the wave energy is dissipated over a 20-foot = 610 cm side strip along the coast with 1-foot-high waves along half the coast and 1.6-foot-high waves along the other half, then the average kinetic energy per unit area is

$$\text{Kinetic energy/unit area/time} = \frac{4.18\text{x}10^7 \text{ ergs/cm/sec}}{610 \text{ cm}}$$

$$= .685 \times 10^5 \text{ ergs/cm}^2\text{/sec}$$

$$= 1.64 \times 10^{-2} \text{ Kcal/m}^2\text{/sec}$$

$$\text{Kinetic energy/m}^2\text{/yr} = 516 \text{ Kcal/m}^2\text{/yr}$$

17. The wind energy dissipated to the ground through turbulent mixing was calculated for the urbanized part of the county and the natural part. Height of buildings was assumed to be 30 feet, whereas average height of vegetation was taken as 5 feet. Velocity at 100 feet elevation was approximated as 12 miles per hour. The air flow over Dade County was assumed to be that of turbulent flow over a rough plate with a logarithmic velocity

distribution (Schlichting, 1960). The energy dissipated to the ground is given by

$$P = \frac{1}{2} \rho \times U^3 \times C_f$$

P = rate of energy dissipation/unit area

ρ = density of air

U = velocity high above the ground

$C_f = (1.89+1.62 \times \log(1/4xh))^{-2.5}$

L = length of rough plate of square dimension

h = average height of vegetation or buildings

For the urban region of 565 km^2 with average building height of 30 feet

$$P = 300 \text{ Kcal/m}^2\text{/yr}$$

For the natural area in the county with average vegetation height of 5 feet

$$P = 200 \text{ Kcal/m}^2\text{/yr}$$

$$\text{Average power density} = \frac{300 \times 565 + 200 \times 4917}{5482}$$

$$\text{Average power density} = 210 \text{ Kcal/m}^2\text{/yr}$$

18. The average height above sea level of Dade County is approximately 10 feet (Buchanan, 1973). The potential energy of water flowing to the sea would be approximately

$$\rho g \times \Delta h = 1 \text{ gm/cm}^3 \times 980 \text{ cm/sec}^2 \times 10 \text{ ft} \times 30.48 \text{ cm/ft}$$

$$= 298.7 \times 10^3 \text{ ergs/cm}^3$$

$$\rho g \times \Delta h = 713.6 \times 10^{-8} \text{ Kcal/cm}^3$$

The overland flow per year is 10 inches per year (Wang, 1974; Heaney and Huber, 1974). This figure multiplied by the area of the county gives the total volumetric flow which is

$$\text{Flow} = 10 \text{ in/yr} \times .0254 \text{ meters/in} \times 4983 \times 10^6 \text{ meters}^2$$

$$\text{Flow} = 1.2657 \times 10^{15} \text{ cm}^3\text{/yr}$$

Therefore, the energy flow is given by

$$\text{Energy/yr} = 713.6 \times 10^{-8} \text{ Kcal/cm}^3 \times 1.2657 \times 10^{15} \text{ cm}^3\text{/yr}$$

$$\text{Energy/yr} = .009 \times 10^{12} \text{ Kcal/yr}$$

The energy density is this divided by the land area of the county or

$$\frac{.009\text{x}10^{12} \text{ Kcal/yr}}{4.983\text{x}10^{9} \text{ meter}^2} = .0018 \times 10^{3} \text{ Kcal/m}^2\text{/yr}$$

This represents the work done by flowing water in the entire county.

19. Energy values and quality for fresh/salt water concentration gradients were obtained from Costanza (1975), who constructed maps of this energy potential for South Florida. Energy quality factors were calculated by consideration of osmotic pressure across a semi-permeable membrane resulting in a hydrostatic head.

20. Improved pasture productivity was estimated as 10.4 $gC/m^2/day$ during the wet season (Bayley and Odum, 1973). If it is assumed that productivity is proportional to solar energy, then the average productivity over the year is

$$\frac{2}{\pi} \times 10.4 \text{ gC/m}^2\text{/day} \times 365 \text{ days} \times 9 \text{ Kcal/gC}$$

or 21.8×10^3 $Kcal/m^2/yr$

21. Truck crops estimated as 35 $Kcal/m^2/day$ (Odum, E. P., 1971; Odum, H. T., 1971).

22. Productivity of citrus crop taken as 4.3 $gC/m^2/day$ (Bayley and Odum, 1973, pg. 45) for an apple tree and adjusted for solar energy input. On a yearly basis this is

$$4.3\ gC/m^2/day \times 9\ Kcal/gC \times 365\ days$$
$$= 14.1 \times 10^3\ Kcal/m^2/yr$$

23. See note 13, Table 6.

Notes to Table 13

1. Average mean daily insolation for each month in Miami was obtained from Bennett (1965). Average incident sunlight was calculated as 4500 Kcal/m^2/day. This is equivalent to

$$4500 \text{ Kcal/m}^2\text{/day} \times 365 \text{ days} \times 4.46 \text{ m}^2 \text{ of collector}$$
$$= 7.33 \times 10^6 \text{ Kcal/yr of sunlight}$$

2. For a four-person family water use is approximately 20 gallons/person/day (Dr. Farber, Dept. of Mechanical Engineering, University of Florida). Total use is

$$4 \times 20 \ \frac{\text{gallons}}{\text{person-day}} \times 365 \ \frac{\text{days}}{\text{year}} \times 10 \text{ years}$$
$$= 2.92 \times 10^4 \text{ gallons/yr}$$

3. Efficiency of Solar Thermal Process is approximately 65% (Aimone, 1974). Heat losses are

$$7.33 \times 10^6 \text{ Kcal/yr} \times .35 = 2.56 \times 10^6 \text{ Kcal/yr}$$

4. Assume 10-year life of the system (Aimone, 1965; Solar Water Heater Co., Miami, Fla.). Initial cost in a new house for an 80-gallon tank and 48 ft^2 Collector is \$650. Cost of an immersion heater back-up system is \$7. In Kcal this was

$$\$657 \times \frac{25000 \text{ Kcal}}{\text{dollar}} = 16.4 \times 10^6 \text{ Kcal}$$

Initial plus installation costs in an old house were \$657 + \$144 = \$801 which is

$$\$801 \times \frac{25000 \text{ Kcal}}{\text{dollar}} = 20 \times 10^6 \text{ Kcal}$$

Depreciation was

New house: $.1 \times 16.4 \times 10^6 = 1.64 \times 10^6$ Kcal/yr

Old house: $.1 \times 20 \times 10^6 = 2 \times 10^6$ Kcal/yr

5. See note 2. Assume 10% heat loss from water tank and water heated by 39°C temperature increase

$$29.2 \times 10^3 \frac{\text{gal}}{\text{year}} \times \frac{3.785 \text{ Kg}}{\text{gal}} \times \frac{1 \text{ Kcal}}{\text{Kg-}^\circ\text{C}} \times 39^\circ\text{C}$$

$$= 4.3 \times 10^6 \text{ Kcal/yr}$$

6. Additional electrical energy is needed during the months of January, February, October, November, and December. Using the data from Bennett (1965), this amounts to 476.3 Kwh/yr. In FFWE this is

$$476.3 \text{ Kwh/yr} \times \frac{860 \text{ Kcal}}{\text{Kwh}} \times 4 = 1.64 \times 10^6 \text{ Kcal/yr}$$

7. Amount of electrical energy can be obtained from note 6 and is

$$476.3 \text{ Kwh/yr} \times 860 \text{ Kcal/Kwh} = .41 \times 10^6 \text{ Kcal/yr}$$

8. For interest rate of 10%/yr and lifetime of 10 years the amortization factor was .163. The costs per year were

New house: \$657 x .163 = \$107/yr

Old house: \$801 x .163 = \$130/yr

9. Assume 10% loss of heat from hot water tank. Multiply value in note 5 by .1 to get $.43 \times 10^6$ Kcal/yr.

10. See note 8.

New house: \$107/yr x 25000 Kcal/dollar

$= 2.7 \times 10^6$ Kcal/yr

Old house: \$130/yr x 25000 Kcal/dollar

$= 3.3 \times 10^6$ Kcal/yr

11. See note 5. Assume 10% loss so that total heat required is

$$(4.3+.43) \times 10^6 \text{ Kcal/yr} = 4.73 \times 10^6 \text{ Kcal/yr}$$

12. See note 6. Additional energy is 476 Kwh/yr. Average cost per Kwh was approximately $.023/Kwh for an average monthly consumption of 1000 Kwh (Fla. Power and Light Corp.). The fuel adjustment was

    476 Kwh/yr x $.009/Kwh = $4.29

    Total price

    $10.95 + $4.29 = $15.24/yr

13. Costs quoted by the Solar Water Heater Co., Miami, Fla., Mr. Morrow, President. See note 4 for detailed costs.

Notes to Table 14

1. See Table 13, note 2.
2. 5% of 4.73×10^6 Kcal/yr = $.24 \times 10^6$ Kcal/yr.
3. Assume 10%/yr depreciation:

   $$.1 \times 3.3 \times 10^6 \text{ Kcal} = .33 \times 10^6 \text{ Kcal/yr}$$
4. See Table 13, note 9.
5. See Table 13, note 5.
6. Amount of heat required for hot water is 4.73×10^6 Kcal/yr. If the electrical system is 95% efficient, 4.98×10^6 Kcal/yr is required or 5.79×10^3 Kwh/yr.
7. Average cost of electricity is \$.023/Kwh (see Table 13, note 12) with a fuel adjustment of \$.009/Kwh.

   $$\text{Cost} = 5.79 \times 10^3 \text{ Kwh/yr} \times (\$.023/\text{Kwh}+\$.009/\text{Kwh})$$
   $$\text{Cost} = \$185/\text{yr}$$
8. From note 6 annual consumption of electricity is 4.98 $\times 10^6$ Kcal/yr. This is equal to

   $$4 \times 4.98 \times 10^6 \text{ FFWE/yr} = 19.9 \times 10^6 \text{ FFWE/yr}$$
9. See note 12 for cost of equipment. Assuming an equipment lifetime of 10 years and an interest rate of 10%/yr, the amortization factor is .163. The annual cost is then $.163 \times \$132 = \$21.5$/yr.
10. See note 9. The energy cost for the equipment would be

    $$\$21.5/\text{yr} \times 25000 \text{ Kcal/dollar} = .54 \times 10^6 \text{ Kcal/yr}$$
11. See Table 13, note 11.
12. Sears Roebuck costs listed as

Cost of heater =	\$75.00
Cost of installation =	57.00
	\$132.00

$$\$132 \times 25000 \text{ Kcal/dollar} = 3.3 \times 10^6 \text{ Kcal}$$

13. The total natural gas needed to provide hot water is 5.91×10^6 Kcal/yr (see note 14). Gas burns 80% efficiently so that $.2 \times 5.91 \times 10^6$ Kcal/yr = 1.18×10^6 Kcal/yr is lost.

14. The amount of heat energy required to heat the water is 4.3×10^6 Kcal/yr (see note 5). If 10% loss from tank is assumed, then $4.3/.9 \times 10^6$ Kcal/yr = 4.73×10^6 Kcal/yr is needed to heat water entering tank. Natural gas burns 80% efficiently so that $4.73/.8 \times 10^6$ Kcal/yr = 5.9×10^6 Kcal/yr of natural gas is needed.

15. Cost of natural gas is natural gas use times price or

$$5.91 \times 10^6 \text{ Kcal/yr} \times (\$1\text{x}10^{-5}/\text{Kcal}) = \$59.1/\text{yr}$$

16. Sears Roebuck gives costs of a natural gas water heater as follows:

Initial cost =	\$115
Installation =	57
	\$172

Amortize cost over ten years for interest rate of 10% gives a total cost of 172 x (.163) = \$280 or \$28/yr which is

$$\$28/\text{yr} \times 25000 \text{ Kcal/dollar} = .7 \times 10^6 \text{ Kcal/yr}$$

17. Initial cost of equipment is \$172 or

$$\$172 \times 25000 \text{ Kcal/dollar} = 4.3 \times 10^6 \text{ Kcal}$$

Notes to Table 18

Figures are approximately 1965-66 values.

Assume that the natural energies balance the losses to maintain a steady-state in the natural system. Thus, $S = K_1Q_1$ where it is assumed that $K_1Q_1 = 0.02\ Q_1 = 2\%$ of Q_1/yr.

1. Ecosystem lands - Upland forests ≈ 18.5×10^6 acres

   Mangrove ≈ 0.691×10^6 acres

   19.19×10^6 acres

2. Disordered parts - Bombed

Agriculture:	31000 acres
Forest:	9030 acres in craters
City:	890 acres
	4.092×10^4 acres

   Herbicided

Forest:	150000 acres
Agriculture:	5.94×10^4 acres
	21×10^4 acres

   TOTAL: $Q_2 \approx 25 \times 10^4$ acres

3. Agricultural land ≈ 7.31×10^6 acres.
4. Urban land ≈ 2.47×10^4 acres.
5. Capital in city ≈ $281 million
6. Herbicide use - Agricultural land: 198×10^3 gallons

   Upland forest: 455×10^3 gallons

   Mangroves: 11×10^3 gallons

   644×10^3 gallons

7. Communist energies - 140000 men or $555 million.

8. Rate of growth of urban land: $K_{11}Q_1Q_2M \simeq 1235$ acres/yr

9. Bare forest land returning to agriculture:

   $K_7Q_1Q_2M \simeq 5600$ acres/yr

10. Assume 50% of agricultural land replanted. Thus,

    $K_8Q_3CW = 0.5[3.1\text{x}10^4+5.94\text{x}10^4] \simeq 4.5 \times 10^4$ acres/yr

11. Ecosystem lands destroyed:

    $K_3Q_1CW = 0.05[(9.03+150)\text{x}10^3] = 7.95 \times 10^3$ acres/yr

12. War appropriations from U.S.:

    $W \simeq \$200$ million

13. U.S. aid:

    $A \simeq \$250$ million

14. Purchased input amounts to

    $K_4M \simeq \$50.3$ million

15. Amount of structure destroyed:

    $K_5CW[Q_1+Q_3+Q_4] \simeq 40 \times 10^3$ acres/yr

16. Amount of money flowing in due to sales:

    $K_{14}Q_3 \simeq \$40.5$ million

17. The amount of money flowing out to purchase goods and fuel:

    Goods $= (K_{15}+K_{16})M \simeq \$130.5$ million

    Fuel $= K_{16}M \simeq \$80.5$ million

18. Bare land returning to agriculture:

    $K_6Q_1Q_2M \simeq 14000$ acres/yr

19. Amount of natural land changing into urban land:

    $K_{11}Q_1Q_2M \simeq 1235$ acres/yr

20. Amount of natural land converted into agricultural land:

    $K_7Q_1Q_2M \simeq 5600$ acres/yr

21. Rural destruction:

$$K_8Q_3CW \simeq 4.5 \times 10^4 \text{ acres/yr}$$

22. Rate of return of disordered land to natural land:

$$K_0Q_2 \simeq 1.25 \times 10^4 \text{ acres/yr}$$

23. Ecosystem destruction due to herbicide:

$$K_{31}Q_1H \simeq 1.5 \times 10^5 \text{ acres/yr}$$

24. Agricultural land destroyed by herbicide:

$$K_{30}Q_3H \simeq 5.94 \times 10^4 \text{ acres/yr}$$

25. Total herbicide destruction:

$$K_{21}H(Q_1+Q_2+Q_4) \simeq 21 \times 10^4 \text{ acres/yr}$$

26. Urban bomb destruction:

$$K_{13}Q_4CW \simeq 890 \text{ acres/yr}$$

27. Total ecosystem transformation into rural and urban:

$$K_2Q_1Q_2M \simeq 1235 + 5600 = 6835 \text{ acres/yr}$$

28. Assume approximately 2% recycle into Q_2 from Q_1, Q_3, and Q_4; $K_1 \simeq K_9 \simeq K_{12} \simeq 0.02$.

Notes to Tables 19-22

1. Numbers compiled in Table 19 were obtained from Minerals Yearbook (1950-1970) and from several Mineral Industry Surveys. Fuels used by the Electric Utilities Industry have not been included since kilowatt-hour data have been compiled for Dade County. The Minerals Yearbook did not include figures for distillate, residual, kerosene and liquid petroleum fuels in 1967 and 1968. It also did not list electric utility consumption of distillate, residual and kerosene fuels from 1950-53 and from 1961-68. Percentage used by electric utilities for the years 1954-56 was approximately 44% so it was assumed this was true for 1950-53. For 1961 this percentage was 39%, whereas for 1969 it was 57%. It was assumed that this percentage increased linearly from 1961-69 in order to obtain the figures in Table 1.
2. Most data in Table 20 were obtained from various county and state publications listed in the references.
3. Square footage was approximated by dividing value of building permits by average building cost of $\$850/ft^2$.
4. Consumption of distillate, residual, kerosene and liquid petroleum fuels was obtained by multiplying the Florida consumption by the population ratio to arrive at the Dade County estimate. It was felt that this was a good estimate since, aside from the electric utilities, most of this fuel is residentially and commercially consumed.

5. Total gasoline sales were obtained from the Dade County Department of Transportation.
6. If the total consumption of natural gas in Florida for 1971 is multiplied by the ratio of the populations of Dade County to the population of Florida for 1971 (1.3154/7.041 = .1868), a total consumption of 25500 x 10^6 ft^3 is obtained for the county. This would be a good approximation if the mix of commercial, residential and industrial sectors was homogeneous throughout the state. A correction for this ratio was calculated by finding out the actual natural gas sales for Miami from the Annual Report of Florida Gas Co., 1971, calculating a per capita consumption for Miami, and then multiplying this by the total population of Dade County to obtain a more accurate consumption figure for the county. This turned out to be 11337.5 x 10^6 ft^3. The ratio of this figure to that calculated from Florida data is .444 (11357.5/25500). With the aid of this correction the consumption in Dade County was calculated for each year by multiplying the Florida consumption by the population ratio times .444.
7. Kilocalorie energy values of the various fuels were obtained by using the following conversion factors (Federal Power Commission, 1970):

Natural gas: 1075 BTU/ft^3 x .253 Kcal/BTU

= 271.975 Kcal/ft^3

Residual, distillate and kerosene fuel:

6.4 x 10^6 BTU/barrel x .253 Kcal/BTU

= 1.6192 x 10^6 Kcal/barrel

Liquid petroleum: 4.011×10^6 BTU/barrel

$\times .253$ Kcal/BTU = 1.014783×10^6 Kcal/barrel

Gasoline: 3.6×10^4 Kcal/gal

Electricity: 1 kilowatt-hour = 859.85 Kcal

Electrical energy is considered to be a high quality energy which is easy and clean to distribute. In order to achieve this high quality approximately 4 units of lower quality coal or oil must be consumed (this ratio includes maintenance costs; see Table 1). In order to put the kilowatt-hour consumption on the same energy reference level as natural gas and liquid fuels, the electrical energy use should be multiplied by four. The total energy was calculated by the following formula:

Total energy = natural gas + (distillate, residual and kerosene fuel) + liquid petroleum fuel + gasoline + 4 x (electrical energy)

8. Per capita data were obtained by dividing total figures for county by total population.
9. First differences give an indication of the rates of change from year to year.

APPENDIX III

SCALED EQUATIONS FOR MODELS SIMULATED

Model in Fig. 20

$$\frac{\dot{Q}_1}{2x10^9} = .3 \text{ x } \frac{F}{7.7x10^{15}} \text{ x } \frac{Q_1}{2x10^9} \text{ x } \frac{M}{10^{10}} - .05 \text{ x } \frac{Q_1}{2x10^9}$$

$$\frac{\dot{F}}{7.7x10^{15}} = -.11 \text{ x } \frac{F}{7.7x10^{15}} \text{ x } \frac{Q_1}{2x10^9} \text{ x } \frac{M}{10^{10}}$$

$$\frac{\dot{M}}{10^{10}} = .468 \text{ x } \frac{I_2}{10^{10}} - .681 \text{ x } (10) \text{ x } \frac{F}{7.7x10^{15}} \text{ x } \frac{Q_1}{2x10^9}$$

$$\text{x } \frac{M}{10^{10}} \text{ x } \frac{P_1}{.804x10^{-4}} - .15 \text{ x } (100) \text{ x } \frac{M}{10^{10}} \text{ x } \frac{P_1}{.804x10^{-4}}$$

$$\frac{\dot{P}}{.804x10^{-4}} = 0 \text{ before } 1973$$

$$\frac{\dot{P}}{.804x10^{-4}} = \text{constant after 1973 depending on inflation rate}$$

Model in Fig. 24

$$\frac{\dot{Q}_1}{2x10^9} = .129 \text{ x } (10) \text{ x } \frac{E}{300x10^{12}} \text{ x } \frac{Q_1}{2x10^9} \text{ x } \frac{M}{10^{10}}$$

$$- .48 \; \frac{Q_1}{2x10^9} \text{ x } \frac{Q_1}{2x10^9}$$

$$\frac{\dot{M}}{10^{10}} = .015 \; \frac{I_2}{10^{10}} - .855 \text{ x } (10) \text{ x } \frac{E}{100x10^{12}} \text{ x } \frac{Q_1}{2x10^9} \text{ x } \frac{M}{10^{10}}$$

$$\text{x } \frac{P_1}{.804x10^{-4}} - .15 \text{ x } (100) \text{ x } \frac{M}{10^{10}} \text{ x } \frac{P_1}{.804x10^{-4}}$$

Model in Fig. 27

$$\frac{\dot{P}}{.804x10^{-4}} = 0 \text{ before } 1973$$

$$\frac{\dot{P}}{.804\text{x}10^{-4}} = \text{constant after 1973 depending on inflation rate}$$

$$\frac{\dot{Q}_1}{2\text{x}10^9} = .31 \text{ x } \frac{F}{7.7\text{x}10^{15}} \text{ x } \frac{M}{10^{10}} \text{ x } \frac{Q_1}{2\text{x}10^9} - .05 \text{ x } \frac{Q_1}{2\text{x}10^9}$$

$$\frac{\dot{Q}_2}{20\text{x}10^{12}} = .144 \text{ x } (10) \text{ x } \frac{Q_2}{20\text{x}10^{12}} \text{ x } \frac{J_R}{2\text{x}10^{15}}$$

$$- .008 \text{ x } \frac{Q_1}{2\text{x}10^9} - \frac{Q_2}{20\text{x}10^{12}}$$

$$\frac{\dot{Q}_3}{10^7} = .159 \text{ x } \frac{F}{7.7\text{x}10^{15}} \text{ x } \frac{M}{10^{10}} \text{ x } \frac{Q_1}{2\text{x}10^9} - .014 \text{ x } \frac{Q_3}{10^7}$$

$$\frac{\dot{M}}{10^{10}} = .145 \text{ x } \frac{\frac{F}{7.7\text{x}10^{15}} \text{ x } \frac{Q_1}{2\text{x}10^9} \text{ x } \frac{Q_2}{20\text{x}10^{12}}}{\frac{P_2}{.804\text{x}10^{-4}}} + .535 \frac{Q_3}{10^7}$$

$$- .18 \text{ x } (10) \text{ x } \frac{Q_3}{10^7} \text{ x } \frac{M}{10^{10}} - .3 \text{ x } (100) \text{ x } \frac{M}{10^{10}}$$

$$\text{x } \frac{Q_1}{2\text{x}10^9} \text{ x } \frac{F}{7.7\text{x}10^{15}} \text{ x } \frac{P_1}{.804\text{x}10^{-4}}$$

$$\frac{\dot{F}}{7.7\text{x}10^{15}} = -.102 \text{ x } (10) \text{ x } \frac{F}{7.7\text{x}10^{15}} \text{ x } \frac{M}{10^{10}} \text{ x } \frac{Q_1}{2\text{x}10^9}$$

$$\frac{J_R}{2\text{x}10^{15}} = .7 - .144 \text{ x } (10) \text{ x } \frac{J_R}{2\text{x}10^{15}} \text{ x } \frac{Q_2}{20\text{x}10^{12}}$$

$$\frac{\dot{P}_1}{.804\text{x}10^{-4}} = 0 \text{ before 1973} \qquad \frac{\dot{P}_1}{.804\text{x}10^{-4}} = .02 \text{ after 1973}$$

$$\frac{P_2}{.804\text{x}10^{-4}} = .007 \text{ before 1973} \qquad \frac{P_2}{.804\text{x}10^{-4}} = .011 \text{ after 1973}$$

Model in Fig. 38

$$\frac{\dot{Q}_1}{10^6} = .384[S] + .5[Q_2] - .134(10)[Q_1][C][W] - .6[Q_1]$$
$$- .234[Q_1][H] - .15(100)[Q_1][Q_2][M]$$

$$\frac{\dot{Q}_2}{.33\text{x}10^6} = .14[M] + .5[C][W](.3[Q_1]+.0098[Q_3]+.0098[Q_4])$$
$$+ .5(.142(100)[Q_1]+.475[Q_3][H]$$
$$- .938(100)[M][Q_2][Q_1] + .18(10)[Q_1]$$
$$+ .06(10)[Q_3] + .06[Q_4]$$

$$\frac{\dot{Q}_3}{.33\text{x}10^6} = .365(100)[M][Q_1][Q_2] - .2(100)[Q_3][C][W]$$
$$- .6[Q_3] - .244[Q_3][H]$$

$$\frac{\dot{Q}_4}{.33\text{x}10^5} = .11(1000)[Q_1][Q_2][M] - .6[Q_4] - .117(1000)$$
$$\cdot [Q_4][C][W]$$

$$\frac{\dot{M}}{.33\text{x}10^3} = .166[Q_3] + .15(10)[A] - .86(10)[M]$$
$$- .86(10)[M] + .18(100)[W]$$

Maximum Values:

$Q_{1m} = 30\text{x}10^6$	$Q_{3m} = 10^7$	$C_m = 2\text{x}10^3$	$A_m = 500$
$Q_{2m} = 10^7$	$M_m = 10^4$	$W_m = 6\text{x}10^3$	$H_m = 1$

Brackets represent scaled variables. For example, [Q] = Q/Q_{max}. See Methods section.

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BIOGRAPHICAL SKETCH

James John Zucchetto was born March 11, 1946, in Brooklyn, New York. He was graduated in June, 1962, from James Madison High School in Brooklyn. In June, 1966, he was graduated from the Polytechnic Institute of Brooklyn with a Bachelor of Science in Mechanical Engineering and was elected to "Who's Who in American Colleges and Universities." He completed graduate work at New York University with a National Science Foundation Traineeship and was graduated with a Master of Science in Mechanical Engineering in June, 1969. From 1969 to 1971 he was employed at Bell Telephone Laboratories as a member of the Technical Staff. From September, 1971, until the present time he has been enrolled in the Graduate School of the University of Florida. Financial support has been provided by the Environmental Protection Agency and the Atomic Energy Commission, under which work toward the degree of Doctor of Philosophy was pursued.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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