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AN ECOSYSTEMS FRAMEWORK FOR ENERGY-RELATED ENVIRONMENTAL RESEARCH PLANNING IN PUERTO RICO

by
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1.0 Introduction

1.1 Context

This report summarizes one systems ecology approach to develop a strategic energy-related environmental research planning capability for the Center for Energy and Environment Research, University of Puerto Rico. The Center is one of the principal energy and environment research arms of the Puerto Rico Commonwealth government and conducts research for the federal government. The near term and long term research plans and approaches for the Center are important for an adequately informed government to respond to the serious energy challenges that Puerto Rico addresses. This report describes one conceptual basis for gathering critical information needed to examine energy related environmental problems of the near future. It is a document that describes the challenges to the Puerto Rico Island System, and outlines a framework for developing a general strategy for addressing societies environment-related information needs.

1.2 Organization and Objectives

This report first briefly provides an overview of selected characteristics of the man-nature island system. It then describes one basis for developing research priorities, and an approach for predicting large scale system changes. The last two sections summarize potential Puerto Rico environmental consequences. In the conclusion, the paper describes how shifts in potential pollutants provide an example to inform planning and research priorities.

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1.3 Approach and Limitations

Systems ecology emphasizes the behavior of indicators of total system function and stresses the interrelationships among component parts. This paper places emphasis on energy flows and materials cycles in the linked natural and man-dominated Puerto Rico ecosystem. In part it assumes that understanding or predicting changes in the hierarchical structure of systems components provides a basis for energy and environmental research planning. By including both technological or hardware components and institutional or social components, research plans can provide the basis for gathering information that affects the future behavior of the Commonwealth and its natural environment.

A systems approach has the capability to include a full range of natural and social components and processes. This paper only summarizes several types of interrelationships as examples. While a systems approach can suffer from substituting an understandable model for the complexity of a poorly understood and unpredictable reality, it offers a rational framework to predict, plan, and evaluate policy. This paper is also brief; it describes selected major assumptions and a general framework for developing a research plan. Its purpose is limited, however, to tying research planning and management to the future tangible problems that Puerto Rico will face.

2.0 The Coupled Man-Nature Island System

2.1 Hierarchical Structure

Systems have a hierarchical arrangement of parts that structure the flow of energy and channel the cycle of materials. This sturcture is maintained and developed by renewable and/or exhaustable sources of energy. The temporal "program" of these energy sources control the size, distribution and flows among component parts. For example, solar energy provided for the dispersed, pre-Columbian economy. The use of horses, oxen and human labor energized Puerto Rico's dispersed agricultural economy, prior to the 20th Century. Wood, water power and coal provided a more industrial society during the early part of the 20th Century contributing to fixed transportation paths and strong central cities. Liquid and gaseous fuels account for the mobile and energy intensive Puerto Rican society of today, more dispersed along the coastal zone.

Table 1 HISTORICAL ENERGY PERIODS IN PUERTO RICO

Period	Predominate Energy forms (imports)	Dominant Transportation	Urbanization	Environmental Changes
1500	Solar	Pedestrian, Boats	Rural	Limited
1500 - 1900	Domestic animals Human labor Wind	Boats, Horses, Pedestrian	Dispersed	Localized modification
1900 - 1950	(Coal) (Petroleum) Bagasse Hydroelectric Human labor Wood (Natural gas)	Rail, automobiles Airplane	Centralization	Widespread urbanization; Species composition changes
1950 - 1980	(Petroleum) (Electification) (Natural gas) Water Human labor Domestic animals	Automobiles, Airplane	Central cities and coastal sub-urbanization	Widespread urbanization; Air-Water Quality; Flood plain development; Species composition changes

These major periods of energy use are summarized in Table 1. Four general periods are indicated along with summary reference to transportation, urbanization and environmental change. These data provide a broad picture and are intended only to indicate the major transitions that occurred at the termination of the pre-Columbian era, about the dawn of the 20th Century and during the post world war II periods when Puerto Rico experienced dramatic changes in the form and intensity of energy use. Figure 1 shows some of the patterns of human settlement during these periods of energy use. (Department of Natural Resources, 1977).

With any large scale energy flow moving in one direction, a counter flow of energy in the opposite direction exists that exerts a feedback control (Odum and Odum, 1976). Consumers control the flow of energy to their homes with overt decisions supplying in the opposite direction to energy, a controlling flow of money. The Commonwealth and federal government control energy flow with purchases, taxation, regulation and other policies. The form, distribution, and activity of flows upwards through the hierarchy of Puerto Rico and the counter-current control flows are diagramed in Figure 2. As indicated in the figure, all energy flow is ultimately dispersed as heat, although energy may be stored for varying periods of time.

Most energy incorporated in ecosystems, moves along paths of materials flows, and all materials flows contain some energy. The paths of energy movement in a complex ecosystem intersect at structures where changes in form of quality occur. As energy moves upwards, the power to control increases along with its quality or ability to influence other flows. Materials in turn are frequently concentrated in these process steps. For example, on the social level some wealth in most societies tends to concentrate among the few people in the controlling sectors of the economy. Recognizing this problem, the government of Puerto Rico institutes some economic redistribution policies to achieve its socially desirable goals of enhanced equity among citizens. In an analogous process as cities become larger, pollutants also tend to concentrate in centers of activity, such as, San Juan, Ponce and Peñuelas. With high rates of energy input secondary industries develop in close conjunction with primary industry contributing to socially desirable economic development,

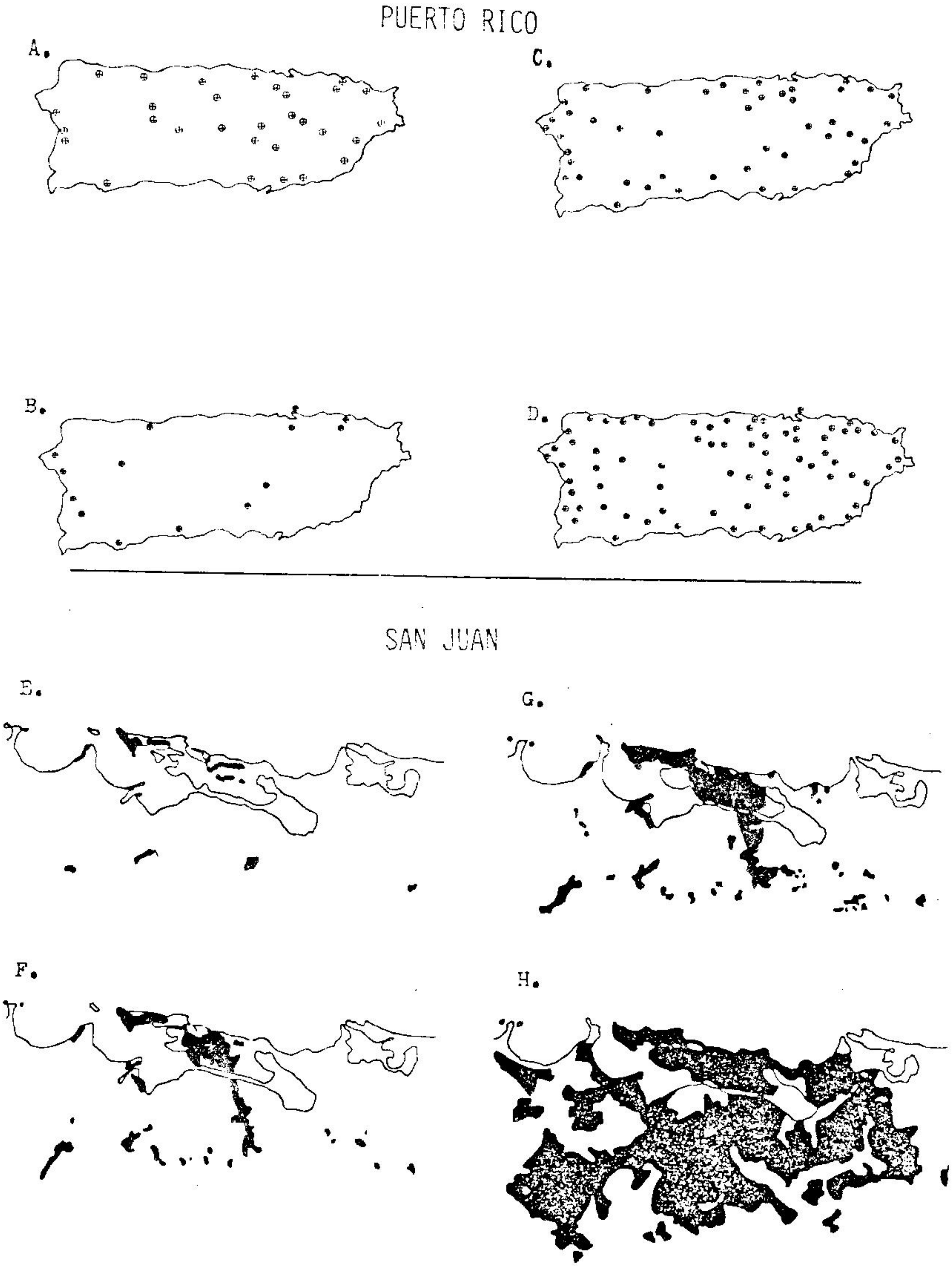

Figure 1: Puerto Rico and San Juan urbanization distribution. A. pre-Columbian; B. 1700; C. 1800; D. 1900; E. 1900; F. 1920; G; 1940; H. 1970.

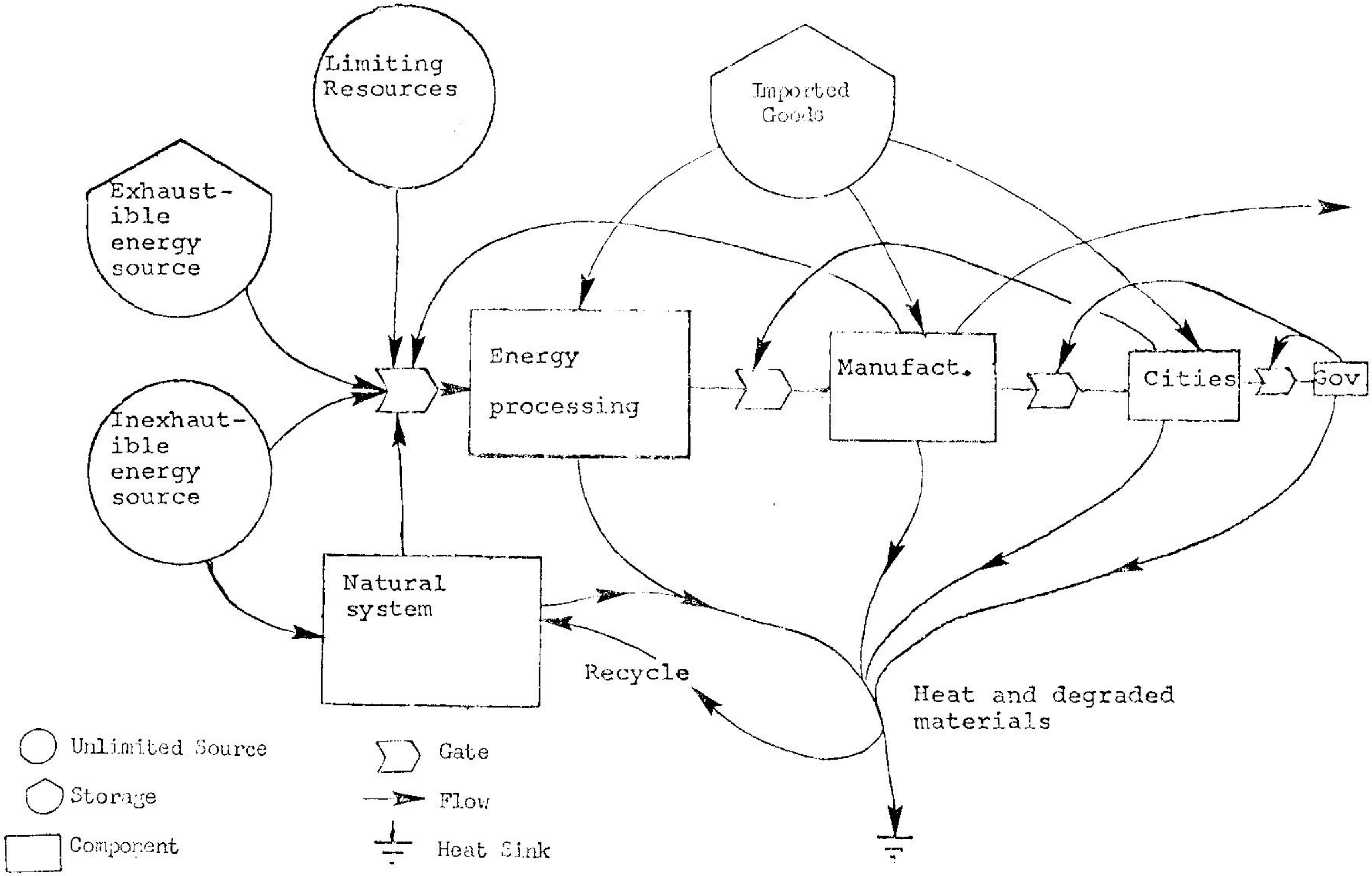

Figure 2: Generalized components of the Puerto Rico Island System.

but adverse environmental consequences, such as congestion, air, water and land pollution. Technological advances also concentrate pollutants: Factories concentrate wastes compared to cottage industry; large modern power plants have sharp temperature gradients and are hot spots of thermal addition. As society grows more dense it has called on industry to concentrate pollutants still further in sludges, holding ponds or land fills.

As the complex Puerto Rican system develops and the linear hierarchies of flow become more elaborate, the materials are more concentrated or move faster. Although the flows are most easily represented in a linear fashion, the increasing complexity results in web-like flows. The diversity of chemicals in these web-like systems of emergent developed countries is directly linked to their industrial and natural complexity.

2.2 Human Domination and Technology

As humans develop value systems and manipulate natural systems they become a significant if not dominant component of the environment. An industrial ecosystem is one obviously dominated by man (Tilley 1979). Materials tend to move faster through human sectors than through non-human pathways. Materials (pollutants) accumulate in various compartments of the biogeochemical cycles. Although the values of humans have a significant affect on technologies used and the materials cycled, the sheer numbers of humans (4.0 million in Puerto Rico) now makes them the dominant force irrespective of technology. Taken as a whole humans affect a behavior pattern in the island ecosystem as do other component parts: they tend to maximize energy flow through their subsector and do so by extending controls.

Technologies generally elongate and make more complex the energy paths as do social controls such as industry, government or consumer behavior. Technologies are generally designed to increase the power (energy flow/unit time) and stability of the system or subsystem. For example, widespread use of automobile transportation in Puerto Rico generally increases the effectiveness and power of those riding in them and the corporations selling them. (This mutualistic situation is homologus in ecosystem development to expotential increases in domestic animals following the pre-Columbian era). The U.S. Environmental Protection Agency (EPA) has controlled automobile emissions so that people can continue riding autos or ever purchase two or more while still sustaining or even improving physiological and natural energy flows. Both subsystems (automobile transportation and EPA regulation) result in an exponential growth of systems components through suppliers, auditors, and new parts and institutions. The patterns generally continue unless fundamental systems shifts occur such as changes in the underlying driving energy sources.

2.3 Pollution and Stress

The web of energy and materials flows persists by the sources or exhaustable and inexhaustable energy (Odum, 1971), and by the continuation of recycle pathways. Accumulation of materials in any one or more compartments can result in system death from two interrelated causes: (1) accumulation of materials to toxic concentrations that poisons components (2) starvation of components. Accumulation as a hazard may take many forms such as, altering properties of the atmosphere or hydrosphere that can subsequently trigger changes at lower geographic scales such as mesoclimatological shifts or physiological and genetic responses. However, overall systems characteristics may retain unchanged or dramatically shift. Thermal pollution may eliminate some species, but total system respiration and production may increase, creating a more powerful developmental step (Odum, 1974), for example.[1]

2.4 Values and Systems Function

Scientists, managers, and lay persons establish values as a part of their activities to make operational judgement or to evaluate the quality of the environment and system function. These values can take several general forms. Deviation or change from a steady state can be established as one value. Others may not agree that a steady state exists and believe that the composition of cities, forests, lakes, streams and coastal wetlands has been continually changing. Some believe that a steady state exists, but that it represents some average around which a pattern or random fluctuation occurs. In part this apparent probabilistic behavior is due to the complexity at all levels of systems structure (Kowal, 1971).

[1] The relative advantage of this developmental step is dependent on a range of criteria such as stability and value of species.

However, the basis of environmental policy and information needs frequently rests on the approach or values used to measure the state of the man-nature system, rather than its variable of stochastic nature.

The significance of the accumulation of materials in environmental components or pools can be critical information in a systems context in several ways. First, criteria of components and flows can be established and used as effective measures of form and function: concentration, size, diversity, rate of flow, and constancy through time, as examples. Second, and perhaps more important, the values that are developed and applied by government and industry change through time, and these shifts can be assessed in a systems context. As liquid and gaseous fuels became widespread, what followed was a shift in values and lifestyle. For example, expanded transportation with its interdepency among geographic areas is major aspect of the Puerto Rico economy and in other areas using these fuels. When disparities between the intensity of energy use and the assimilative capacity (recycle pathways) occured, changing values brought about new Federal policy. An emerging reorientation of values is also likely for the near as well as more distant future, and the range of reorientation is accessible by tracing the effects of new energy sources.

3.0 Criteria for Developing Research Priorities

Future energy-related research activities will be largely influenced by the industrial character and technological opportunities available to Puerto Rico, the values and norms that influence the direction of policy, and the scientific basis for accurate and effective decisions. Each of these criteria is likely to change. Several approaches are possible in attempting to develop an effective research strategy to anticipate these changes: (1) develop a responsive process oriented research framework that is flexible; (2) develop a system that identifies alternative likely futures; and (3) identify critical existing problems and issues and associated uncertainties and areas where new information would have an effective payoff.

Some combination of the above or related approaches can be useful. The development of an effective anticipatory or predictive system for Puerto Rico can provide one rational approach. This approach would examine critical alternative ecosystem limiting factors or forcing functions and trace their consequences on system structure. Alternative patterns of change in this structure can affect a reorientation of human values so that potential ranges of new social problems might be described and integrated with natural and engineering sciences. In addition, changes in the distribution of residuals and their accumulation or concentration in specific systems components can be identified. This approach facilitates a linkage among analytical levels from cellular and organismic responses through population and total systems behavior. It also provides a mechanism to link the natural and social sciences and engineering disciplines. By examining alternative futures, the research agenda is not locked on a technical fix, but can provide information about a range of choices or outcomes.

3.1 Alternative Futures

If an effective research plan can be developed based on a single likely future, only limited research and development would need to be undertaken. The cornerstone of research and development rests on presumption that we now know little and that the future is highly uncertain. The uncertainty of even historic accounts provides support for this. A systems approach informs us, however, that indeed parts do collapse and perish, but that magnitude and complexity results in a persistence of systems behavior patterns.

Because the future is also highly uncertain, an effective research plan must be informed on the basis of alternative futures and their implications on human health and environmental quality. A research planning <u>strategy</u> is used here to mean the effective deployment of limited research resources in a manner that provides an understanding of the major risks or threats to the quality of the human environment from technological change and identifies courses of mitigating action. This strategy must take into account the magnitude of risks within alternative futures, and prepares a contemporaneous research infrastructure to meet the challenges of the coming decades.

While alternative futures are affected by a wide range of policies both within the Commonwealth, the nation and in other countries, this paper rests primarily on the concept that the form of society and natural systems is largely affected by energy policy and other resource limiting

A.

B.

C.

D.

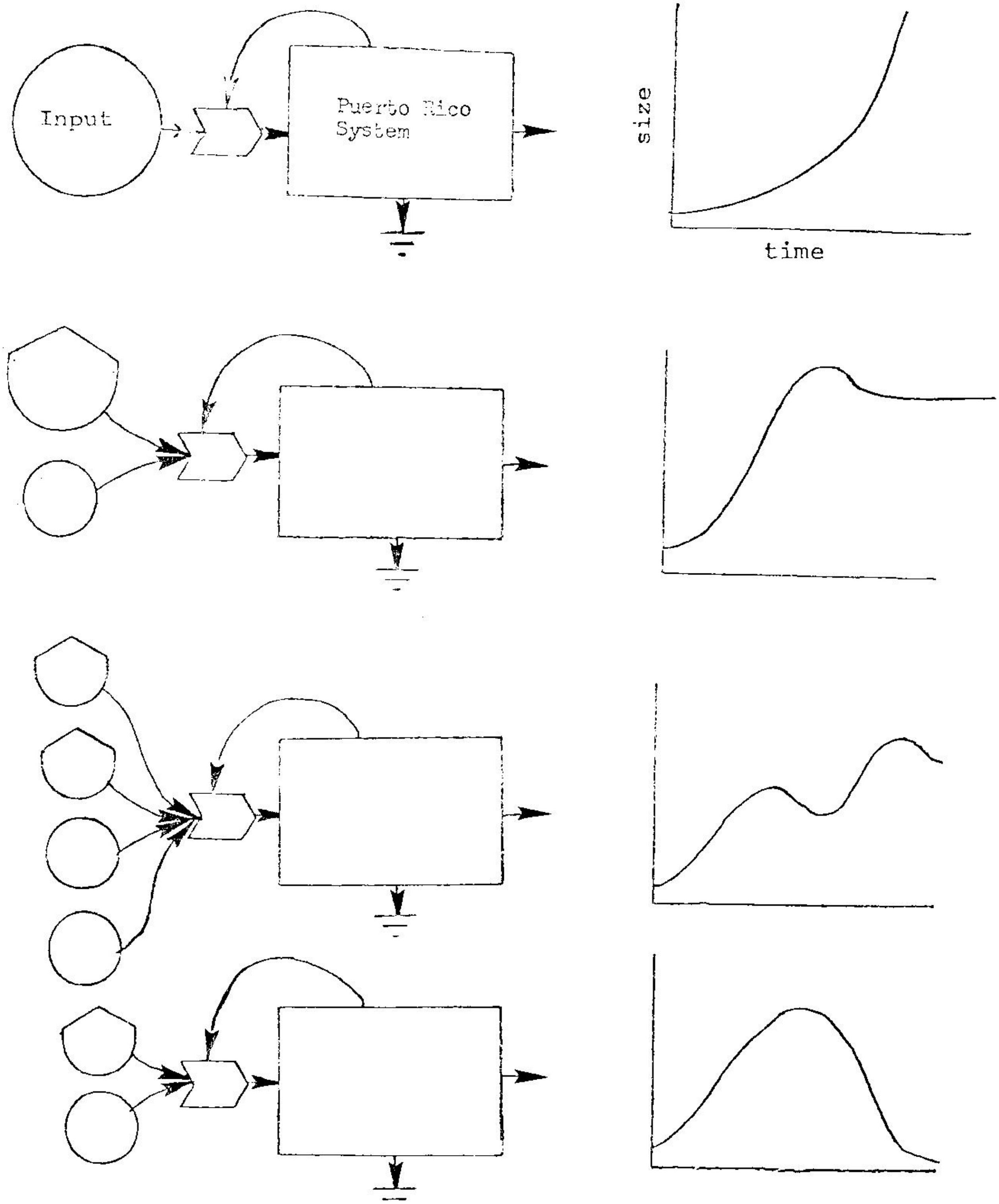

Figure 3: Alternative forcing function configurations and a graph of the resultant island system size as a function of time (scales not quantified). A = unlimited energy supply; B = limited fossil fuel but significant renewable resources; C = Shifts and time lags in alternative fuel sources; D = limited fossil fuels and low renewable resources.

factors. However, for Puerto Rico, the linkage between trade, growth, energy and environment are critical because of its insular yet interdependent nature.

3.2 Predicting Systems Changes

Several critical factors influence and maintain the organization of natural systems. The most critical are inputs or driving forces. The Commonwealth of Puerto Rico, like many geographic, political or natural entities is such an open system it hardly makes sense to define it as an isolated system (the boundaries of a system are defined for convenience of analysis and for effective policy development) except that social and technical controls primarily are implemented as bounded by Commonwealth borders. Prinicipal forcing functions in Puerto Rico are the available energy sources and the equipment and raw materials which act as a gate to use those energy sources. So many sources are now imported, that environmental control policies must begin to recognize the relative position of the Puerto Rican subsystem within the world. An obvious example, petroleum is almost entirely imported, and as petroleum supplies are diminished, they will act as a forcing function requiring policy and technological change in power generation. By systematically examining the future availability of energy sources and limiting factors, a general understanding of alternative futures can unfold.

3.3 Potential Fluctuations

A range of possible alternative futures exists, based on potential future "driving forces". As diagramed in Figure 2, these future patterns basically include continued exponential growth, sigmoid growth, fluctuating growth, and growth and decay. However, as indicated in section 2.4, it is difficult to distinguish small scale patterns of fluctuations to larger patterns of steady-state, growth or decay. In fact, frequently steady states are maintained through "pulses". (Odum, 1971). These pulses apply short term bursts of power, and may be required for systems function. Thus a system may not be able to apply continuing high rates of energy use to maintain complexity without periods of decay as wastes accumulate, parts wear out or congestion occurs. Subsequent periods of reduced power output functionally represent times in which the "batteries" are recharged (capital accumulates) or wastes are disposed, so to speak. For Puerto Rico occurences of congestion, subsequent urban renewal and new transportation corridors, provide examples of local pulses. Despite these natural fluctuations, policy is frequently deployed or evaluated on the basis of whether or not rates change: i.e. if pollution is "increasing" or "decreasing". Thus research and control strategies are confronted with continuing dilemas in pulsed systems, despite the possibility that the quality of the system is only maintained through pulses. Most public policy systems have limited tolerance for pulses, and policies are often implemented to suppress them.[1]

4.0 Consequences for the Environment

An inventory of several combinations of future energy sources for Puerto Rico and the resultant system attributes are described in Table 2. These selected characteristics are size, power, human values, and control. Others parameters could be included. These parameters were chosen to emphasize the underlying relationships between forcing functions and important characteristics that may affect environmental research and decision making. The actual timing as to when some of these characteristics may predominate in part is dependent on the use and flow of information about the system. Environmental research thus can anticipate these problems, and the widespread anticipation of these characteristics can result in earlier policy adjustments or environmental controls. Environmental attitudes and values are likely to come into adjustment with the forcing functions at some time, however.

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[1] The suppression of pulses is partly due to use of near term information rather than data relating to long term stability or growth of the total system. This points to the limitations of any comprehensively rational strategy or plan. Because the system structure is continually changing, either over the short or long term in response to forcing functions or long term internal change, a totally comprehensive understanding of research strategies is not possible. It is difficult to evaluate merits of policies within a system, since the system structure is modified when policies are in place. It should be noted, however, that often tendencies to stabalize a fluctuating system are one part of the controls that enhance long term growth and output.

Table 2: Characteristics of systems inputs and selected potential shifts in size, values and controls

Characteristics of System Inputs	System Size	Values	Social and Technological Controls
Unlimited renewable energy supplies	Constrained by space, pollutants and non-energy resources	Expansionist	Social controls grow
Fossil fuels limited and limited renewable	Potential growth but decline to steady state	Conservative significant environment awareness	Social controls restructured and decentralized
Shifts among alternative energy sources with continued long term increase in supplies	Growth continues but quality heterogeneous among time frames geographic areas and economic classes	Heterogeneous and divisive	Policy fluctuates but attempts to increase controls intensity
Fossil fuels runout without development of significant renewable sources	Reduction in structure and maintenance	Awareness of increased dependence on natural systems	Controls decentralize and are reduced over long term Short term instability

4.1 Tendencies Toward Equilibria

The basic driving forces (e.g. energy and other factors) are useful as tools for prediction because the behavior of the system comes into adjustment to the underlying resources. Exceptions to this occur, primarily over the short term. For example, without environmental control technology, pollutants accumulate to make areas undesirable. Environmental control then acts as a feedback to reduce pollutants and permit more growth. Without environmental controls the natural behavior of the system would be to achieve redistribution. Energy can be the ultimate determinate for geographic, technological and political equilibria, but frequently it is not. In the arid states of the south U.S. Mainland, for example, populations are limited by water availability, not the availability of fuels. Limited water forces the fuel rich area to ship fuels out of state. However, water limits the availability of natural energies to allow for the development of large populations and urban growth. Thus, Puerto Rico and eastern parts of the U.S. assimilate high population densities through vegetation and high rainfall that buffers both people and the terrestrial and aquatic habitats from intensive urban and industrial growth.

4.2 Pollution Distribution

The effect of tendencies towards equilibria is to distribute growth uniformly. This can be used as a predictive tool. Because energy is frequently a key factor, growth tends to distribute uniformly in relation to the availability of energy (Odum and Odum, 1976). The pattern of pollution distribution comes close to that of energy availability, as modified by transportation technology and overt policy decisions. The combination of Federal and Commonwealth policies for growth have developed incentives to relocate industry and people in Puerto Rico. An underlying factor is also the assimilative capacity of the natural environment, and the changes in values of those deciding relocation policies. Information about density patterns that relate to the distribution of resources and assimilative capacity of the environment can provide a policy basis that recognizes the natural capacity of the environment to disperse pollutants at low resource cost or limited change in the hierarchy of system structure.

4.3 Pollution Sources

The criteria for evaluating environmental policies rests on a range of values as described in Section 2.4. Existing research is directed to the evaluation of separate pollution sources, with little concern to overall system power or function. In Puerto Rico, as on the mainland U.S., performance standards have been developed for separate plants for individual industries with limited regard for the heat losses generated or the value contributed to system stability or conservation of resources. As the emission of one plant, or an industry are reduced at a cost of net output, each related system component receives less, and ironically more material is cycled yet less is produced. Research plans to study a system are different than plans for its parts and the outcome to inform technological development can be different. Ultimately, if Puerto Rico maximizes controls, stability and power, it is more likely to persist over competing systems than those that shunt energy to dissipative heat sinks, introducing more "residuals" into the environment.

4.4 Environmental Heterogeneity

As technology develops, control loops become more extensive. However, the controls can be implemented using systems performance as a principle criteria. Systems performance criteria recognize heterogeneity in environmental types and the adaptation of technology to meet the assimilative capacity of respective geographic areas: in some locations residuals can be dispersed in air, in others in water, and still others concentrated in landfills. Systems performance also recognize the cyclic nature of environmental processes, and recognizes different time frames (acclimation periods, seasons, geological time and evolutionary time, etc.). The performance of the system can be monitored, and rational social or technical innovations can be undertaken.

5.0 Environmental Research Plans

5.1 Planning for Patterns of Change

Alternative forcing functions and the development of the Commonwealth social and environmental system can be used to predict shifts in major economic sectors and sources of "residuals" (pollutants). Table 3 illustrates some of these shifts. It indicates, for example, that continued system development typically moves toward greater complexity and increased residuals accumulation and movement. Increases in heavy metals

Table 3: Characteristics of systems inputs and selected possible changes in environmental residuals

Characteristics of system inputs	Selected Patterns or changes in energy or materials paths	Potential new residuals
Unlimited renewable energy supplies	Growth in manufacturing consumption and storage technologies	Catalysts, battery technology, new pesticides, potential OTEC surfactants, heavy metals, changing albedo, organics
Fossil fuels limited and limited renewable energy	Agrarian economy reduction in social and industrial mobility	Increased non-point sources
Shifts among alternative energy sources with continued long term supplies	Changing extraction technology; shifts in exotic fuels technologies	Increased residuals with changing control policies; battery technologies, large potential heat losses, organics.
Fossils fuels depleted without significant renewable resources	Agrarian economy reduced manufacturing and consumption	Increased non-point sources reduced point sources

associated with the electronics industry or metals extraction may develop. As petroleum supplies become tighter, alternative sources of energy are likely to be developed. Periods of reduced growth in energy supply would result in a greater consciousness of conservation and energy storage. This may be accompanied by deployment of new battery or storage technologies for example, or shifts in energy sources, with a concomitant shift in residuals. A continued decrease in energy supplies would likely to result in shifts in the ratio of urban and rural populations, (Odum and Odum, 1976) and greater efficiency in technological designs. The potential for letting the environment perform self-cleaning functions rather than rely on energy intensive pollution control technology, may be an area of research importance.

5.2 Developing a Planning Approach

The timing and magnitude of environmental changes can be estimated through quantitative modeling techniques. The accuracy is largely dependent on the certainty of underlying assumptions. Because these assumptions are frequently weak, a selected range of alternative environmental problems that effect alternative energy resource development policy may be a basis for maximizing environmental protection with limited research support.

The examples discussed in this paper are exploratory, and are intended to indicate the qualitative application of this approach to environmental research planning. Further quantitative development of this approach would permit and evaluation of more detailed assumptions, and an elaboration of the research consequences for environmental protection in specific social sectors and natural environments under alternative conditions of energy resources for Puerto Rico.

LITERATURE CITED

Department of Natural Resources., 1977. Puerto Rico Coastal Management Program. Commonwealth of Puerto Rico, DNR. Planning Board.

Kowal, E., 1971. A Rationale for Modeling Dynamic Ecological Systems In: Bernard C. Patten. Systems Analysis and Simulation in Ecology. Academic Press p. 128.

Odum, Eugene D., 1978. The Ecology of the Southeastern U.S., Plenary Address, Annual Meeting of the American Institute of Biological Sciences. August 1978.

Odum, H.T., 1971. Environment, Power and Society. John Wiley and Sons, New York.

Odum, H.T., 1974. "Energy Cost-Benefit Models for Evaluating Thermal Plumes". Thermal Ecology. pp. 628-649.

Odum, H.T. and E.C. Odum, 1976. The Energy Basis of Man and Nature. McGraw Hill, New York.

Tilly, L.J., 1979. Guayanilla Bay. An Industrial Marine Ecosystem. In: J.M. López ed. Proceedings of the symposium on Energy, Industry and the Marine Environment in Guayanilla Bay. pp. 1-9. Center for Energy and Environment Research. Mayaguez, P.R.