In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institute shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or, in his absence, by the Dean of the Graduate Division when such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.

3/17/65
b

SYSTEMS DYNAMICS OF SOLID WASTE MANAGEMENT

A THESIS

Presented to

The Faculty of the Graduate Division

by

Robert Dale Waldrop

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

March, 1968

SYSTEMS DYNAMICS OF SOLID WASTE MANAGEMENT

Approved:

____

Chairman

____

____

Date approved by Chairman: 4/15/68

ACKNOWLEDGMENTS

I wish to thank each member of the thesis reading committee for their assistance and interest in my research. Dr. Bobby Spradlin, who guided and directed the research as thesis advisor, deserves a special note of appreciation. Dr. Fred Pohland made many worthwhile contributions to the thesis development. To Dr. W. W. Hines goes my thanks for serving on the reading committee. Without the assistance and guidance of these men, the development of the research topic would have been much more difficult.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

The lack of knowledge of the dynamic nature of solid waste systems and their behavior creating mechanisms obstructs efforts to improve such systems.

In this study, a simulation model based on information-feedback control theory is used to analyze a solid waste system. An information-feedback model of a solid waste management system for a city of approximately 2,000,000 people was constructed using Dynamo computer language for the simulation. Manipulation of the model on an IBM-7094 digital computer provides insights into the dynamics of system behavior under different managerial policies and decision rules.

The model of the solid waste management system contains two major sectors. One of the sectors deals with the generation and disposal of solid wastes. Social, economic, and technological factors interact within the model to change the amount of solid wastes being generated and disposed. The other sector concerns itself with the recognition of solid waste pollution by the community. Community recognition of the seriousness of solid waste pollution leads to action which affects the generation and disposal sector of the system.

Manipulation of the model of the solid waste management system on a computer suggests that the most effective way to combat solid waste pollution is to reduce the volume of wastes being produced. Current solid waste systems seem to generate little pressure to initiate such reductions. However, it was found that solid waste management can

stimulate the growth of pressures that lead to reduced production of solid wastes by establishing a regional planning group to create community awareness of solid waste pollution.

CHAPTER I

INTRODUCTION

The mounting solid waste load in the United States creates a major environmental problem. The huge amounts of solid waste generated daily in the United States contain demolition and construction debris, abandoned vehicles, stoves, refrigerators, food wastes, furniture, trees, grease, scum, fly ash, chemicals, plastics, paper, glass, metal cans, and a seemingly endless variety of other objects and substances. As technology advances and the population becomes more affluent, the amount and the variety of discarded objects and substances increases.

The seriousness of the solid waste problem increases in the United States because of the rising per capita production of refuse coupled with growth and concentration of the population in urban areas. What to do with the mounting volume of solid wastes generated becomes an increasingly complex problem.

Magnitude of the Solid Waste Problem

A frequently quoted estimate places the unit output of municipal solid waste in the United States at 4.5 pounds per capita per day. For the present population of the United States, this estimate means 250 billion pounds of municipal solid waste is generated each year. Collection and disposal costs amount to between 1.5 to 2.5 billion dollars.

Forecasts predict the per capita output to be 5.5 pounds per day by 1980.[1]

Orientation to convenience in packaging creates an increasing potential for litter in the United States. In 1962 more than 18 million tons of paper went into the manufacture of various types of containers. The statistics of 48 billion metal cans a year, 26 billion bottles and jars, and 65 billion metal and plastic caps and crowns indicate the vast quantity of materials likely to be discarded.

Solid wastes of industrial origin further complicate the solid waste disposal problem. Although significant amounts of industrial wastes are salvaged and recycled, salvage cost precludes reuse of the major portion of industrial wastes.

Mining of solid fuels, metals, and nonmetallic minerals produces large quantities of waste material. During 1963, mines in the United States produced 3.3 billion tons of waste rock and mill tailings. Huge piles of overturned earth resulting from strip mine operations pose as a striking example.

Land Pollution

The tremendous amounts of solid waste generated annually in the United States create problems of land pollution. Land pollution problems differ from air or water pollution problems in that the polluting material remains in place for long periods of time unless removed or

---

[1] "Restoring the Quality of Our Environment," Report of the Environmental Pollution Panel, President's Science Advisory Committee, The White House, November 1965, p. 139.

destroyed. However, solid waste disposal has received the least scientific consideration of any of the areas of pollution control. The classic approach consists of disposal by incineration, sanitary landfill or dumping, although disposal by any one of these methods frequently intensifies either water or air pollution.

Within recent years, aesthetic considerations have become important in land pollution. Concern over pollution of landscapes by automobile junkyards and other visible refuse heaps is growing.

Accumulations of refuse and scrap increase fire and accident hazards. Insect and rodent control relate closely to the problem of scrap heaps. Estimates indicate that every cubic foot of garbage can produce approximately 75,000 flies.[2] Garbage continues to be the most important source of food for rats and other rodents. Thus, accumulations of solid wastes can create health and disease problems.

Growing concern has been widely expressed throughout the United States over the preservation of as much of the natural landscape as possible. Since sanitary landfill practices can completely destroy portions of the landscape, solid waste disposal by sanitary landfill receives criticism. Unfortunately, the kind of land that harbors the best remaining ecological niches for wildlife and plants usually

---

[2] *Solid Waste Management and Control*, Publication 1400, National Academy of Sciences--National Research Council, Washington, D.C., 1966, p. 84.

possesses the least economic value and hence is selected for sanitary landfill. Conservationists strongly criticize the destruction of wildlife habitats by sanitary landfills even if the sanitary landfills are badly needed.

Nature of the Solid Waste Problem

Custom permits classification of waste products and attendant disposal problems into gaseous, liquid, and solid categories. Although this division implies that each of the categories can be considered separately, separation of solid waste disposal from consideration of air and water pollution is impossible. Incineration of solid wastes may aggravate air pollution. Disposal of solid wastes in landfills may create ground water pollution. Conversely, abatement of air pollution or water pollution may produce an additional solid waste burden.

Because solid wastes include not only the output of households and municipalities, but also the discards of business, industry, and agriculture, handling procedures vary widely. Handling may be divided into three parts: collection, processing, and disposal. Collection includes storage and transfer as well as pickup. Processing may take on a variety of forms including the salvage of usable and useful portions. Disposal includes any treatment for making the disposition more effective. When the disposal point is reached, the waste should have been reduced to a minimum both in volume and in usable material. Handling of household wastes involves all three parts in a coordinated way. Agricultural wastes, however, are often disposed of near the point of origin without processing. Since industrial solid wastes may be homogenous and high in salvage value, their disposal can be a smaller problem than their collection.

Methods of ultimate disposal usually consist of incineration of combustibles, and use of sanitary landfills. Less frequently used disposal methods are composting, animal feedings, and disposal at sea of material that will not float. Incineration sterilizes and reduces the volume of material that must ultimately be buried or carried off to sea. The residue is approximately 20 per cent of the original volume. Composting transforms solid wastes into a residue which may be used as a land enrichment source. Feeding garbage to hogs recycles waste to a productive industry. Sanitary landfills and the ocean comprise the two basic burying methods for unwanted things.

Estimates indicate that less than half of the cities in the United States have satisfactory refuse disposal systems.[3] Most larger cities, however, have operations that combine disposal methods, the most common being joint use of incinerators and sanitary landfills.

The task of handling solid wastes falls to both public and private services. Private incinerators and private sanitary landfills operate in the same communities with public incinerators and public landfills. Private and public collection services operate in the same communities, but both now face rapid change due to technological and social factors. In processing solid wastes, private firms conduct most of the salvage operations. However, these firms also face crises

---

[3] "Restoring the Quality of Our Environment," p. 143.

because of the rising cost of labor. Unless waste is separated at the source, the chance for salvage is low.

The large population centers dramatically emphasize the problems of dealing with collection, storage, and disposal of solid wastes. Local government jurisdictions compound the problem of effective waste management. Complexities resulting from a variety of waste materials, a variety of sources, salvage aspects, ties with water and air pollution, and logistics of transfer and disposal create waste management problems of enormous magnitude.

Motivation for control of solid wastes can arise from factors relating to public health and safety. Other motivations for waste control arise from the economics of salvage or recovery of usable materials. Emerging motivations are long-range conservation needs and esthetic values.

The solid waste problem is growing rapidly. Although this problem is directly related to population growth, population concentration also plays an important role. The amount of solid wastes generated also depends upon the standard of living and the state of technological development. As the use of any commodity rises, a point occurs at which the commodity becomes a discard of sufficient quantity to contribute to the solid waste problem.

In perspective, an organized materials input system, highly motivated by consumer demand and enterprise economics, forms the basis for industrialized society in the United States. Society collects widely scattered resources, processes them, and distributes useful goods to the public. The waste output side of this picture reflects the same steps in reverse. The steps of collecting from the consumer (reverse distribution), salvage, and waste processing (reverse resource acquisition) are disorganized when compared to the complex organization for resource acquisition. Since consumer demand and enterprise economics are largely missing from disposal practices, the entire activity is thought of as a public service.

In the overall picture, some feedback exists, particularly with respect to scarce materials. Economics of materials consumption dictates the feedback. A key problem arises in how to effect a greater tie between the waste output and materials consumption so that consideration of ultimate disposal may be a factor in the design or marketing of new materials. Closing of the loop can be based on a number of devices, such as taxes on newly used materials, subsidies for reclaimed materials, or conditions imposed upon design criteria.

The overall nature of the solid waste problem is such that attention should be given to

(1) the improvement of organization and systemization of the waste material outflow portion of our consuming society,

(2) the improvement of technology dealing with this outflow and with the separate steps of collecting, processing, and disposing, and

(3) the adoption of practices and policies that will close the loop between the materials consumption and the waste production parts of our society so that decisions relative

to consumption will consider the waste product problem.[4]

Definition of Research Problem

The nature of the solid waste problem in the United States requires a thorough investigation of the behaviorial characteristics of solid waste management systems. Before adopting policies that attempt to improve system behavior, managers in solid waste systems must know the nature of the system and the mechanisms that create its behavior. The current lack of knowledge of the nature of solid waste systems and their behavior creating mechanisms obstructs efforts to improve such systems.

Research Objectives

In attacking the lack of knowledge of the nature and behavior of solid waste management systems, three main objectives are sought; construction of an information feedback model of a solid waste management system, manipulation of the model to determine the nature of solid waste management systems and the mechanisms which regulate their behavior, and determination of which areas can exert the most influence toward improving system behavior.

Scope of Research Problem

The investigation of the nature and behavior of a solid waste management system focuses attention on a city in the United States of

---

[4] "Restoring the Quality of Our Environment," p. 145.

approximately 2,000,000 people. Selection of a city of this size permits inclusion in the system model of those factors which can be identified as having an effect on solid waste management systems. Although some factors in the model have national implications, these factors exert influence on the system model only to the extent that they exert influence on the real system.

Information Feedback

Solid waste management systems depend upon information feedback to provide a basis for making policy and operational decisions. An information feedback system exists when an environment leads to a decision which results in action that affects the environment and hence influences future decisions.[5] Interaction between solid wastes, air pollution, and water pollution provides an example of how information feedback operates in solid waste management systems. If in a particular city the sanitation department decides to construct an incinerator and operate sanitary landfills to replace open dumps, air pollution can result from an improperly designed incinerator and pollution of the town's water supply can result from seepage from poorly operated landfills. When the air and water pollution becomes noticeable to the populace of the town, complaints plague the sanitation department. The information feedback in the form of complaints certainly exerts influence on future sanitation department decisions regarding landfills and incinerators.

---

[5] Forrester, Jay W., *Industrial Dynamics*, Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 1964, p. 14.

Solid waste management systems contain the basic relationships usually found in nonlinear, dynamic, information feedback systems. The three basic relationships are that the unit of analysis of a feedback system is the feedback loop, that the system behavior for intervals of time is dominated by a few feedback loops, and that there are mechanisms which transfer dominance of the system among the feedback loops.[6] An information feedback model of a solid waste management system should demonstrate the validity of these basic relationships.

Sources of Information for Model Construction[7]

Many people assume that adequate data on which to base an information feedback model does not exist. These people believe that extensive collecting of statistical data must come before construction of such a model. The exact reverse may be true.

Usually enough descriptive information already exists on which a highly useful information feedback model can be based. One of the first uses of the model is to determine what formal data needs to be collected. Routine, clerical collection of numerical data usually does not expose new concepts or previously unknown but significant variables. Some of the most important information for a realistic dynamic model does not and cannot exist as tabulated statistical data.

In actuality, managers use verbal models of corporate systems continuously with only the data they have at hand. A verbal model is

[6] Swanson, Carl, "Some Properties of Feedback Systems as a Guide to The Analysis of Complex Simulation Models," Massachusetts Institute of Technology, 1965.

[7] Forrester, p. 53-59.

closely related to a mathematical model because both are abstract descriptions of the real system. Because the mathematical model tends to dispel hazy inconsistencies that can exist in a verbal description, the mathematical model is more orderly and precise. The mathematical model, however, does not necessarily possess more accuracy than the verbal model. Accuracy here means the degree of correspondence with the real world. Mathematical models can precisely represent verbal descriptions and yet to be totally inaccurate. Much of the value of mathematical models arises from their precision and not from their accuracy since the act of constructing a mathematical model requires a specific statement of what is believed to be true about the real system.

Some persons believe that a mathematical model cannot be useful unless every constant and functional relationship is known to high accuracy. Quite often, however, intangible factors of a system cannot be measured in any statistical sense, but can only be estimated using intuitive judgment. Purists who insist on directly measuring a factor before placing it in a mathematical model often omit unmeasured or immeasurable factors by stating the assumption that the factor plays no part in the model. Omission of such variables actually says that the variables have zero effect, which is probably the only value that is known to be entirely wrong.

Different goals and objectives of mathematical models generate different attitudes toward data and their accuracy. If the desired model must fully explain the real system, the model must possess a high degree of accuracy as well as precision. If the model's objective is to enhance understanding of the system, a model of what is believed to be the nature of the system proves very useful. Construction of a mathematical model of what is believed to be the system uncovers inconsistencies in basic conceptualizations about the system. A verbal model when translated into mathematical form may be inconsistent with the qualitative nature of the real world, thus requiring revision of the verbal description.

An information feedback model must start with a structure, meaning the general nature of the interrelationships within it. Before collecting data from the real system, assumptions must be made about structure. After a reasonable structure of existing knowledge is made, plausible numerical coefficients must be assigned which represent identifiable characteristics of the real system. To eliminate disagreement and improve performance, the information-feedback model and the real system can be altered.

The mathematical model that is constructed can be used to study the significance of assumptions that go into its construction. For every numerical value that goes into a model, a range exists in which the model is relatively insensitive to changes of value within the range. Refinement of an estimate within this range is thus unjustified. However, the entire qualitative behavior of a model may depend upon an assumed numerical value. When a model demonstrates vulnerability to an error in a particular numerical value, the systems analyst may measure the value with adequate accuracy, control the value to a desired range, or redesign the real system and the model to make the value less important.

Mathematical models should be based on the best information available, but design of an information feedback model should not be postponed until all pertinent parameters have been accurately measured. Although values should be estimated where necessary, sufficient information usually exists to serve the model builder in his initial efforts. Indeed, more danger lies in being insensitive to and unperceiving of important variables than from lack of information about variables that have been isolated.

Judging Model Validity[8]

The ultimate purpose of information feedback models is to aid in the design of improved systems. The real test of whether a model is suitable for this purpose lies in whether or not a better system results from investigations based on model experimentation. Evaluation of systems improvement almost certainly rests on subjective judgment rendered by the managers of the system. Objective, non-controversial proof of the effectiveness of an experimental system design usually cannot be obtained.

If the purpose of the information feedback model is to aid in the design of improved systems, the particular undertaking must be addressed to important questions and problems. Since the worth of a model can be no greater than the worth of its objectives, the value of the objectives transcends all other considerations in determining model utility. An elaborate and accurate model can do little to assist in

[8]Forrester, pp. 115-129.

systems improvement if it relates to questions and behavior that are of little or no consequence to the success of the system.

Information feedback models in operational use predict the results of changes in system behavior that result from altering a structural relationship or policy. The second area of interest lies in the extent of the systems improvement resulting from a given change. However, if a model is to indicate the effects of real system changes, a reasonably close correspondence must exist between the parameters and structure in the model and the actual parameters and structure of the real system.

The presumption that an information feedback model accurately portrays the real system rests on two foundations. Primarily, confidence depends on how well the model represents organization and decision-making details of the actual system. Secondarily, confidence in the model can be confirmed by correspondence of total model behavior to that of the actual system. System models should predict and reproduce only the behavior character of a system, not specific events or particular, unique sections of actual past history or specific future events. Economic and social systems cannot, even to a crude approximation, be independent of a process that would predict the state of the system far into the future. Since predictions act as a guide to actions taking place within the system, the actions taken as a result of a prediction directly affect the stream of events whose prediction is being attempted.

CHAPTER II

MODEL OF A SOLID WASTE MANAGEMENT SYSTEM

The construction of an information feedback model of a solid waste management system involves four main stages. In stage one, a basic conceptualization of the real system must be formulated. Solid waste management systems contain intangible factors and highly non-linear variables which make basic system conceptualization most difficult. After identifying the basic system, a detailed flow diagram incorporating refinements of the basic system conceptualization must be made in stage two. In this stage, changes such as addition of delays and variables which make the system definition more precise and accurate may be made. In stage three, abstraction of the flow diagram into dynamo computer language presents an information feedback model of the real system in mathematical form. The data required for the computer program is added to the model in stage four.

Basic System Conceptualization

Conceptualization of a basic solid waste management system for a city of approximately 2,000,000 people requires consideration of many variables and many feedback loops. Some loops deal primarily with establishing community recognition of solid waste problems. Other loops deal mainly with the generation and disposal of solid wastes. The feedback nature of the loops results in interaction between all the different loops in the information feedback model. Hence, changes occurring in the recognition loops may dramatically influence the generation and disposal loops and vice versa.

The portion of the flow diagram to the right of the solid line in Figure 1 shows the structure of the main factors relating to recognition of the solid waste pollution problem. Recognition of the solid waste pollution problem relies on two major stimuli. Regional planning activity through its efforts to establish pollution standards and to enhance community perception of solid waste pollution provides one stimulus. Technological advances in the measurement of solid waste pollution provides the second stimulus to recognition of the problem. Figure I indicates that technological advances in measurement of solid waste pollution do not affect the community's perception of the level of pollution until after a considerable delay. Regional planning effort also experiences a delay before exerting an impact on recognition of the solid waste pollution problem. Regional planning can channel its efforts into increasing the community's perception of solid waste pollution and into the establishment of pollution standards and laws regarding solid waste. A perspicacious planning group should gage its own impact and after contributing toward recognition of the problem, should channel its efforts into the feedback loops affecting funding of research and technology. When regional planning reaches the point where additional growth is ineffective, it shuts its growth down to prevent useless additions of personnel. The difference between the perceived and acceptable level of pollution which arises partially as a result of regional planning effort leads to community awareness of the solid waste pollution problem. After comparison of current

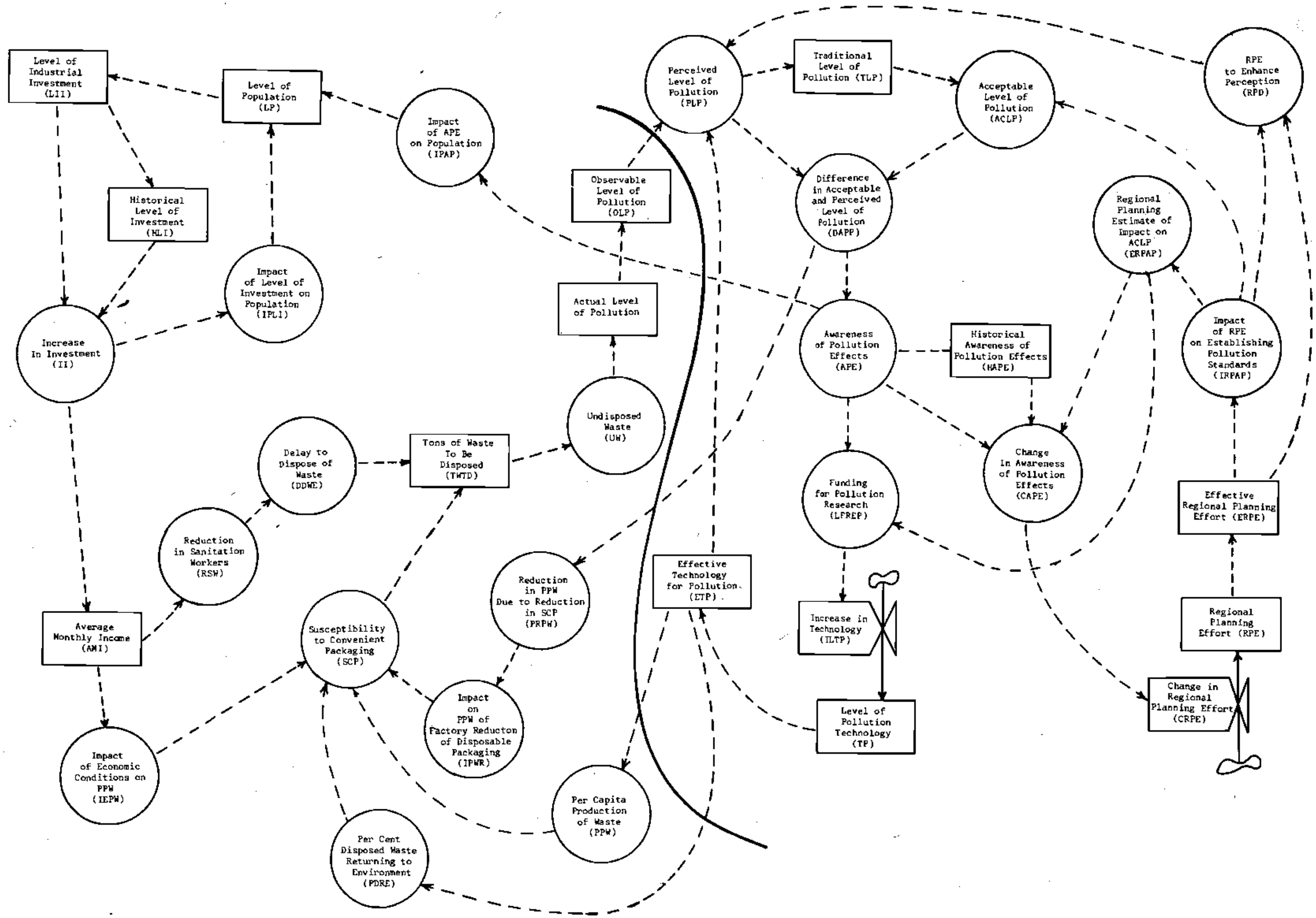


Figure 1. General Flow Diagram

awareness with historical awareness of pollution effects, the resulting change in awareness can lead to changes in regional planning effort. Awareness of pollution effects also leads to funding of pollution research in an effort to increase the associated technology.[9]

The portion of the flow diagram to the left of the solid line in Figure 1 shows the structure of the variables and loops which deal mainly with the generation and disposal of solid wastes. The difference in the perceived and the acceptable level of pollution in Figure 1 leads to a change in the individual's susceptability to purchasing goods in disposable packages. Changes in consumer susceptibility to disposable packaging affects the per capita production of waste and the tons of waste to be disposed. A portion of the waste to be disposed originates from certain disposal techniques. The residue remaining after incineration poses as an example. Technology of pollution may exert an impact on the waste to be disposed by changing the percentage of disposed waste that returns to the environment. Industry too can exert an impact on the per capita production of waste. Through advances in technology, industry can change the amount of goods offered for sale in disposable packages. Average yearly income may affect the waste to be disposed in two ways. First, as the community becomes more affluent, the amount of solid waste generated tends to increase. Secondly, as the average yearly income rises, the number of people willing to work in sanitation areas decreases, thereby increasing the delay in disposing of waste. The tons of waste to be disposed

[9]Spradlin, B. C., "Recognition of Community Hazard Problems: The Systems Dynamics," Georgia Institute of Technology, June, 1967.

when above the capacity of the sanitation department leaves some undisposed waste. This undisposed waste in turn affects the perceived level of pollution by acting through the observable level of pollution. The left portion of the flow diagram also demonstrates the interaction between population and the solid waste management system. Awareness of pollution exerts an impact upon the city's level of population. As the population changes, the level of industrial investment tends to change. Changes in industrial investment in turn affect the level of the city's population and the average yearly income.

To illustrate the cause and effect considerations given each loop in Figure 1, consider Loop A in Figure 2. If the observable level of solid waste pollution increases for some reason, the community perceives a portion of this increase. If the community standards of acceptance exist and the adjustment to the new level is not too rapid, a difference between the perceived and the acceptable level of pollution arises and leads to an awareness of pollution effects. As the awareness in the community grows, governmental bodies support general funding of pollution research. Increasing funds for research leads to increasing technology for pollution. The increasing technology for pollution, however, does not exert an immediate influence on the solid waste problem. A sizeable delay expires before the improvements in technology for solid wastes become effective in operational practice. When the increase in technology does become effective, the perceived level of pollution may again increase due to improved measurement techniques and an increase in general knowledge regarding pollution. Loop A is a positive feedback loop where a high perceived level of

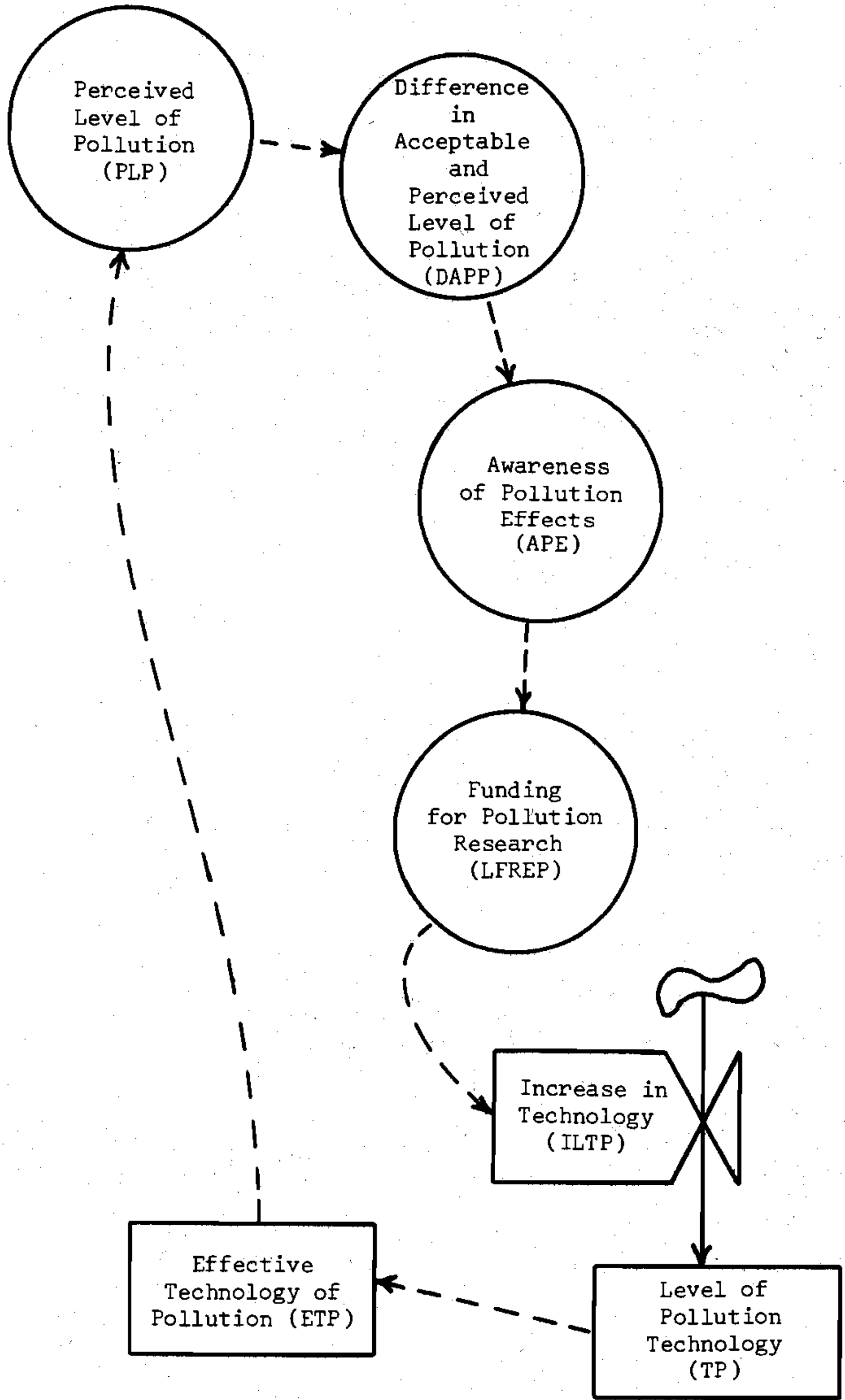


Figure 2. Loop A

pollution sets up a difference between the perceived and acceptable levels of pollution which, through the effects of feedback, further increases the perceived level.

The difference between the perceived and the acceptable levels of pollution can also be affected by regional planning's effort to define the acceptability of pollution. Regional planning's role in alerting the community to solid waste pollution appears in Loop B in Figure 3. When regional planning expends some effort in the area of solid waste pollution, a delay expires before the expended effort can become completely effective in accomplishing its intended purpose. The regional planning group may attempt to secure passage of pollution laws and formulation of pollution standards. A lower acceptable level of pollution results from the establishment of pollution laws and standards. The lower acceptable level of pollution can lead to greater awareness of pollution effects due to the existence of a greater difference between the perceived and the acceptable levels of pollution. Changes in the awareness of pollution effects are noted by comparing the current awareness of pollution with the historical awareness. The changes in awareness of pollution influence future expenditures of effort on the solid waste pollution problem by regional planning. Loop B is a highly positive feedback loop in which regional planning can increase the awareness of pollution and thereby set up pressures to initiate further expenditure of regional planning effort on pollution problems. To provide control of the amount of planning effort allocated to pollution problems, regional planning management adopts the policy in Loop C shown in Figure 4.

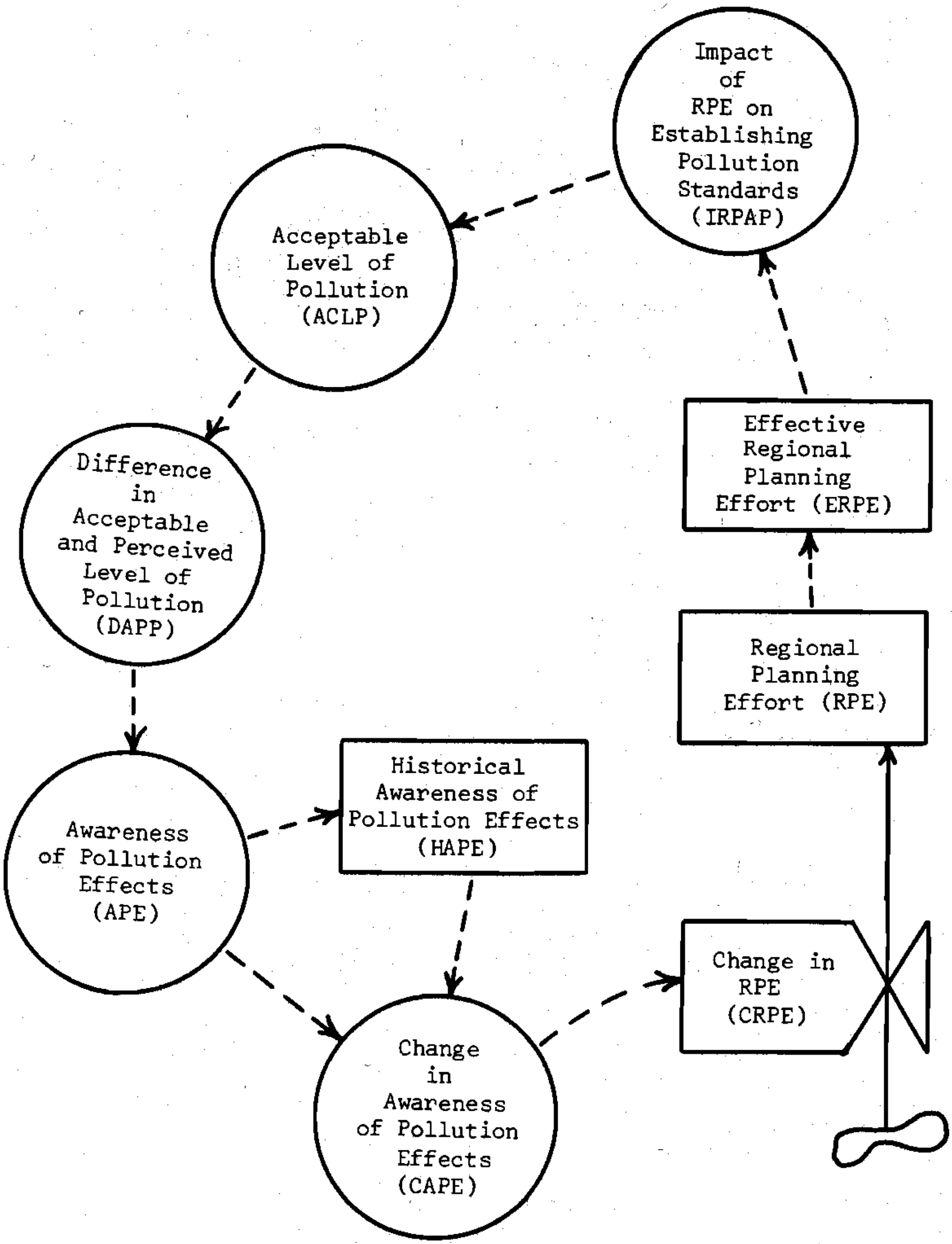


Figure 3. Loop B

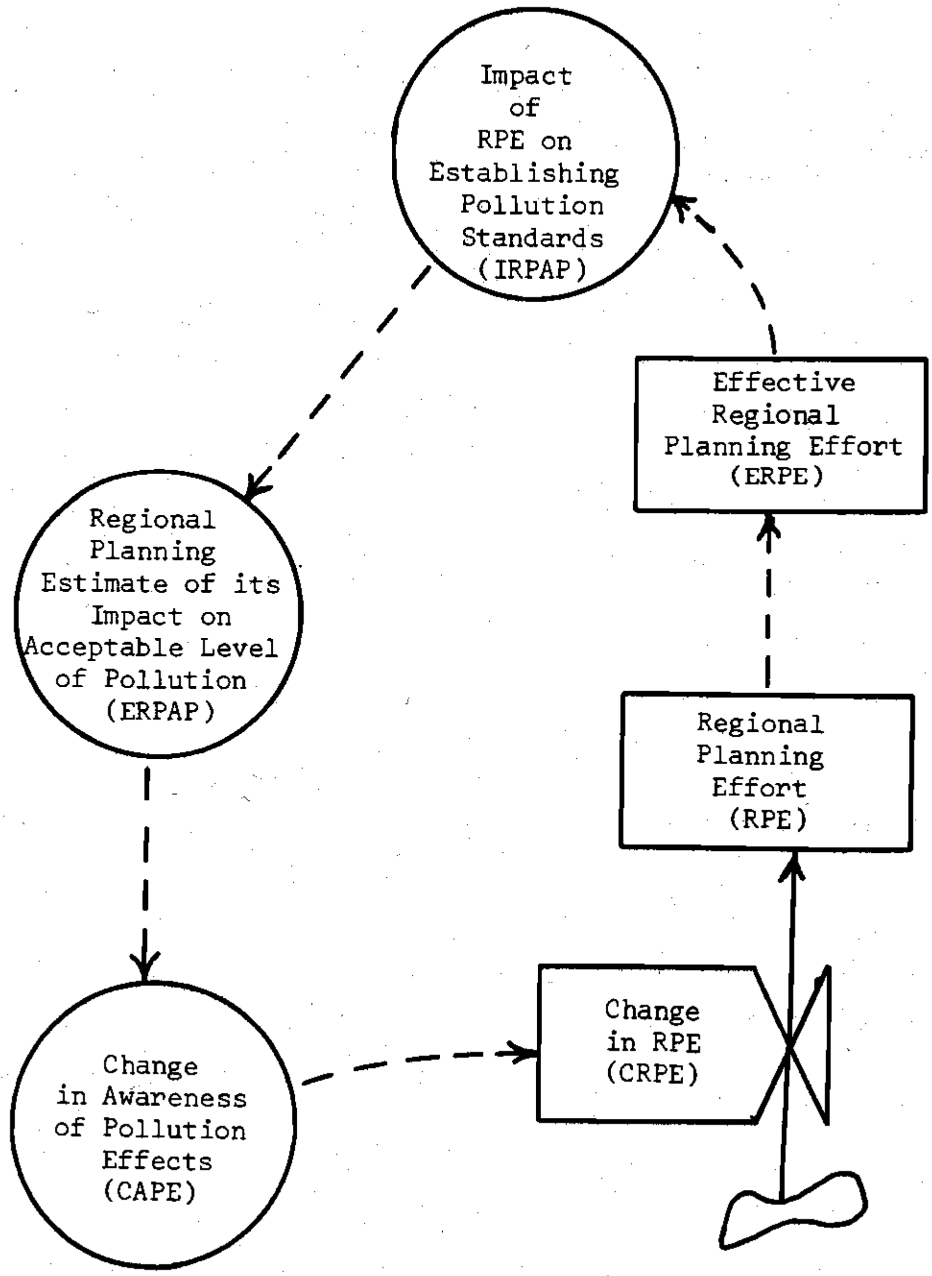


Figure 4. Loop C

In Loop C, regional planning management monitors the amount of effort allocated to defining the acceptability of solid waste pollution. When management estimates that increases in expenditure of effort would result in no further reduction in the acceptability of pollution, no increase in effort is made. Loop C acts to restrain the growth of the regional planning effort by counteracting the pressure set up in Loop B to increase regional planning effort. By monitoring its expenditure of effort, regional planning contributes to abatement of the pollution level in the most economical manner.

One way of effectively combatting solid waste pollution is to reduce the amount of disposable packaging used by industry. Loop D in Figure 5 considers how such a reduction might be accomplished. First, a reduction in the amount of disposable packaging used can arise only if technology advances enough to find suitable packaging substitutes. If the use of disposable packaging is reduced, the amount of waste to be disposed decreases. Hence, less waste remains in the environment and the level of pollution abates. With the abatement of the level of pollution, the community's perception of the problem declines and awareness of pollution decreases. Reductions in the level of funding for pollution research and education result from the decline in awareness of pollution, thereby limiting future technological growth. Without technological growth, further reduction of the disposable packaging used by industry does not arise. Loop D demonstrates a negative feedback loop in which decreases in the amount of waste produced reduces pressures that cause technological growth, thereby adversely affecting future reductions in the production of waste.

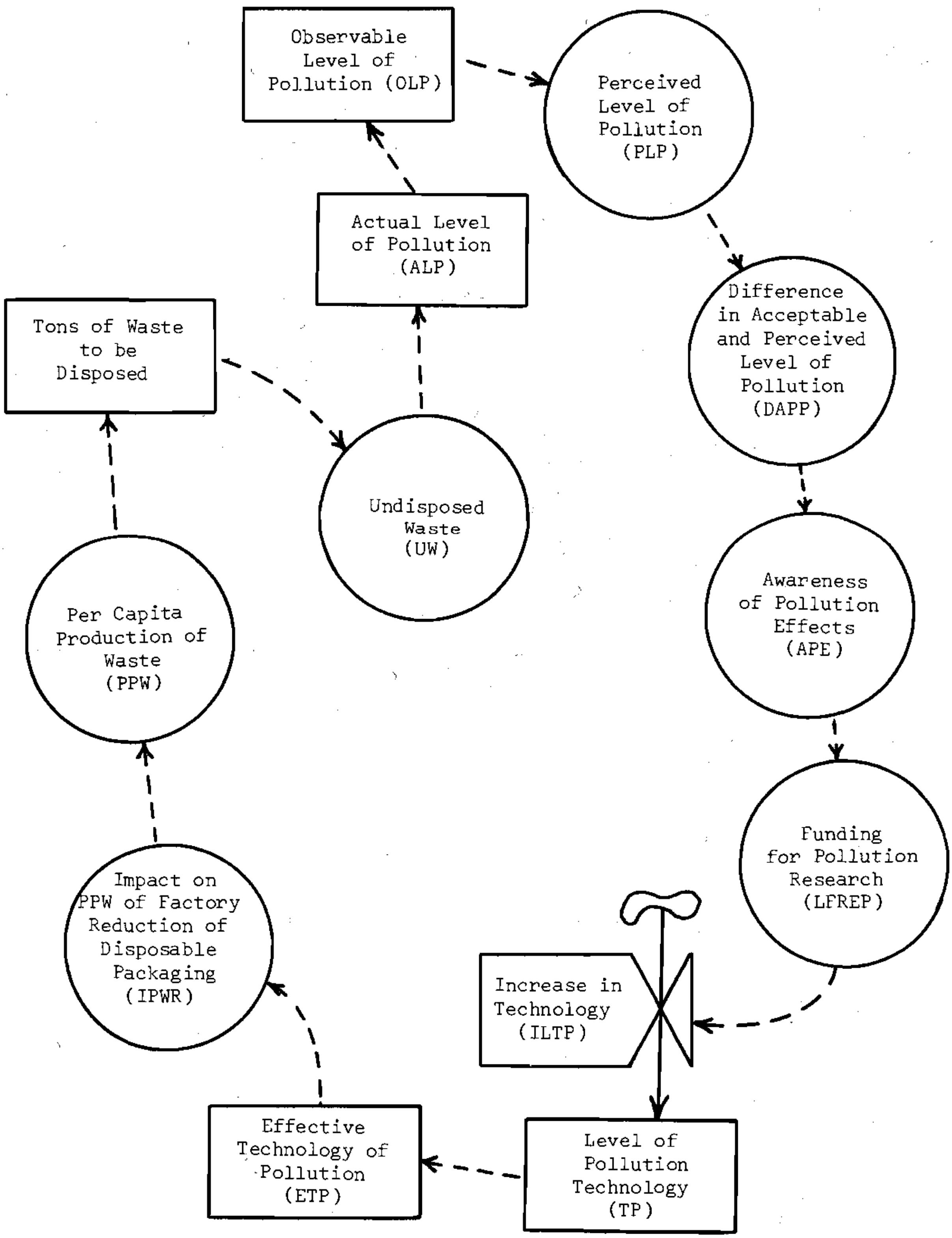


Figure 5. Loop D

A reduction in the use of disposable packaging can arise from consumers as well as from industry. Loop E in Figure 6 shows how such reductions can arise. Differences in the perceived and the acceptable levels of pollution lead to changes in the susceptibility of the consumer to disposable packaging. If the consumer perceives a much higher level of pollution than is acceptable, he becomes less inclined to purchase goods in disposable packages. For example, the consumer might purchase soft drinks in returnable bottles rather than in disposable cans or disposable bottles. As a result of a decrease in consumer susceptibility to disposable packaging, the per capita production of waste declines and the tons of waste to be disposed decreases. The resulting decline in the undisposed waste remaining in the environment leads to abatement of the pollution problem and a decline in community perception of pollution. Changes in the difference between the perceived and acceptable level of pollution results from the changes in the perceived level of pollution. Loop E may be either positive or negative depending upon the difference between the perceived and the acceptable level of pollution.

Model Formulation

From the general flow diagram in Figure 1, a detailed flow diagram can be constructed to assist in the development of a mathematical model of a solid waste management system. This section discusses the development of the equations and numerical data used in each segment of the detailed flow diagram appearing at the end of this chapter.

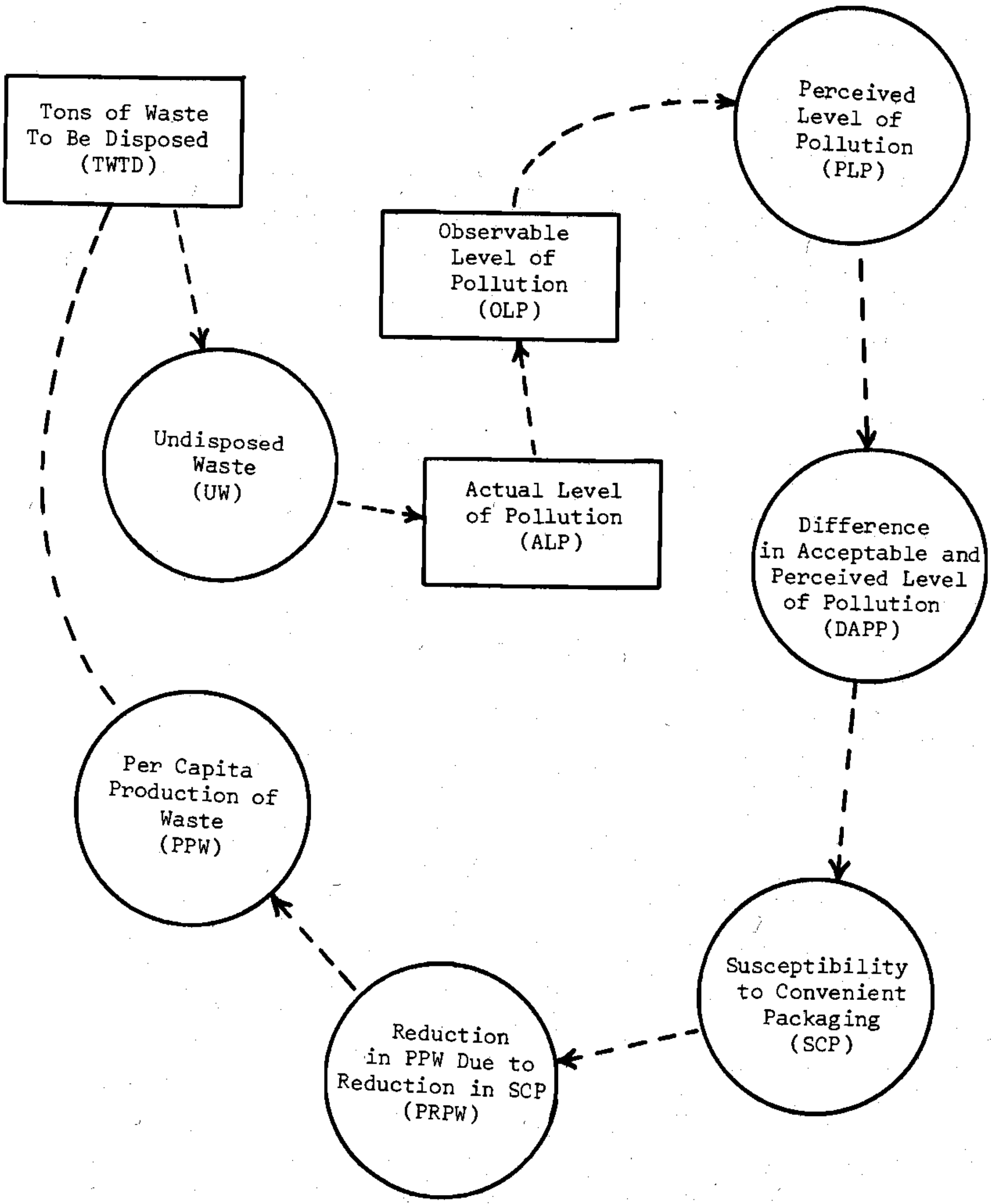


Figure 6. Loop E

The availability of data only in qualitative form poses as one of the major problems in the study of this system. But since the emphasis of the study is to promote understanding of the mechanisms that control dynamic behavior patterns, the lack of specific data does not prohibit accomplishment of the desired objectives. Even when differences between real system data and model data do exist, the conclusions drawn from the study can aid in understanding the behavioral mechanisms of the real system. For example, knowledge of how to accomplish systems amplification of a certain variable and what the implications of the amplification are can be more important than knowing the exact value of the variable.

Segment I--Per Capita Waste Production

The per capita production of solid waste appearing in the equations below changes due to the influence of economic, technological, and social factors. Changes in these factors, however, experience a delay before they exert an impact on the per capita production of waste.

```
3L    PPW.K=PPW.J+(DT)(1/DETS)(PETS.J-PPW.J)
6N    PPW=139.5
C     DETS=40
```

PPW = Per Capita Production of solid Waste (pounds/person/month)

PETS = Per Capita Production of waste effected by Economic, Technological, and Social factors (pounds/person/month)

DETS = Delay for Economic, Technological, and Social factors to affect per capita production of solid waste (month).

The initial value for the per capita production of solid waste is 139.5 pounds per month, the current production rate in the United States. Changes in social, economic, and technological factors are believed to require at least 40 months to exert their full impact on the per capita production of waste.

The factors which influence the per capita waste production operate in many diverse ways. Psychological effects of solid waste pollution can make the community less susceptible to purchasing goods in disposable packaging. Factories can seek packaging techniques that do not contribute to solid waste pollution. Increases in per capita production of solid waste usually accompany economic growth. Due to the interaction of past social, economic, and technological factors, the present normal per capita production of solid waste amounts to 4.5 pounds per day or about 145 pounds per month.

```
13A    PETS.K=(IEPW.K)(PRODT.K)(FNPPW)
18A    PRODT.K=(CIPWR)(1-PRPW.K)
7A     CIPWR=1-IPWR.K
C      FNPPW=145
```

PETS = per capita Production of waste effected by Economic, Technological and Social factors (pounds/person)/(month)

IEPW = Impact of Economic conditions on per capita Production of waste (percentage)

FNPPW = Factor for normalizing Per capita Production of Waste (pounds/person)/(month)

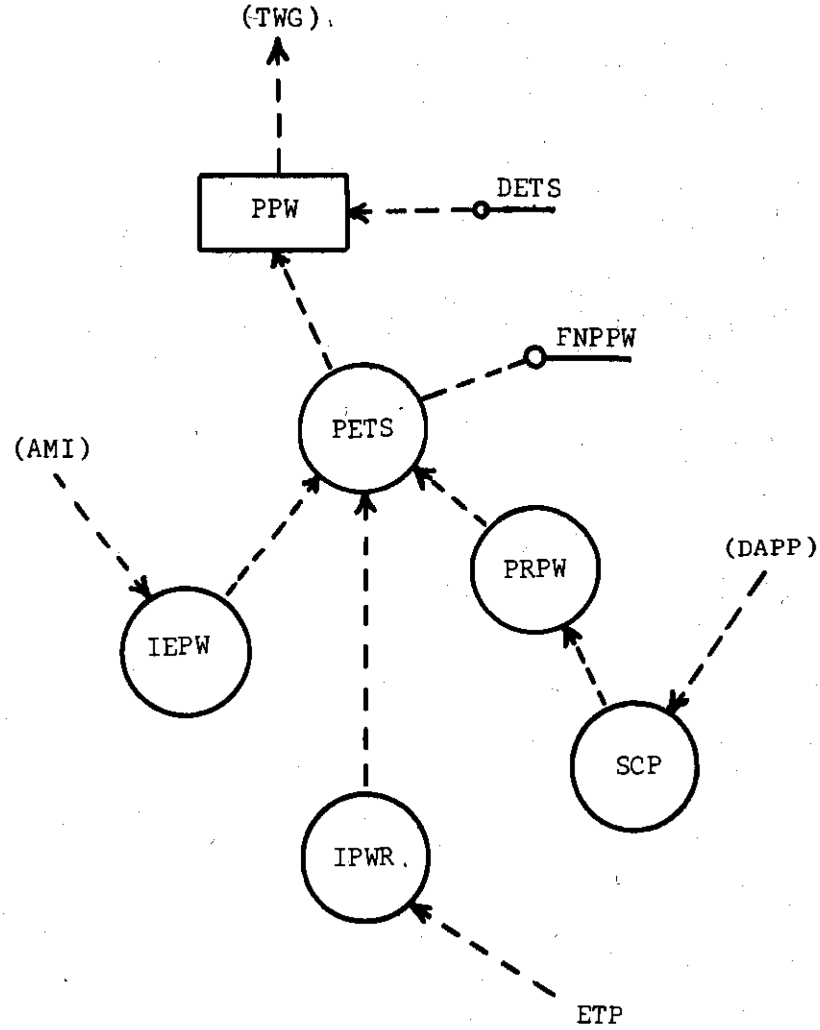


Figure 7. Segment I. Per Capita Waste Production

Table 1. Legend for Segment I

PETS	=	per capita Production of waste effected by Economic, Technological and Social factors
IEPW	=	Impact of Economic conditions on per capita Production of waste
FNPPW	=	Factor for normalizing Per capita Production of Waste
IPWR	=	Impact on per capita Production of Waste due to factory Reduction in disposable packaging
PRPW	=	Per cent Reduction in Per capita Waste production resulting from reduction in susceptibility to disposable packaging
SCP	=	Susceptibility to Convenient Packaging
DAPP	=	Difference between Acceptable and Perceived level of solid waste pollution in the community
AMI	=	Average Monthly Income
PPW	=	Per capita Production of solid Waste
DETS	=	Delay for Economic, Technological, and Social factors to affect per capita production of solid waste
ETP	=	Effective Technology in use to combat solid waste Pollution
TWG	=	Tons of Waste Generated

IPWR = Impact on per capita Production of Waste due to factory Reduction in disposable packaging (percentage)

CIPWR = auxiliary variable to assist in defining PETS

PRPW = Percentage Reduction in Per capita Waste production resulting from reduction in susceptibility to disposable packaging (percentage)

PRODT = auxiliary variable to assist in defining PETS.

As the perceived level of solid waste pollution becomes greater than the acceptable level, the difference between the acceptable and the perceived level becomes more negative. When the community perception of solid waste pollution increases, consumers may tend to become less willing to purchase goods in disposable packaging. Figure 8 shows the susceptibility to convenient packaging as a function of the difference between the acceptable and the perceived level of pollution.

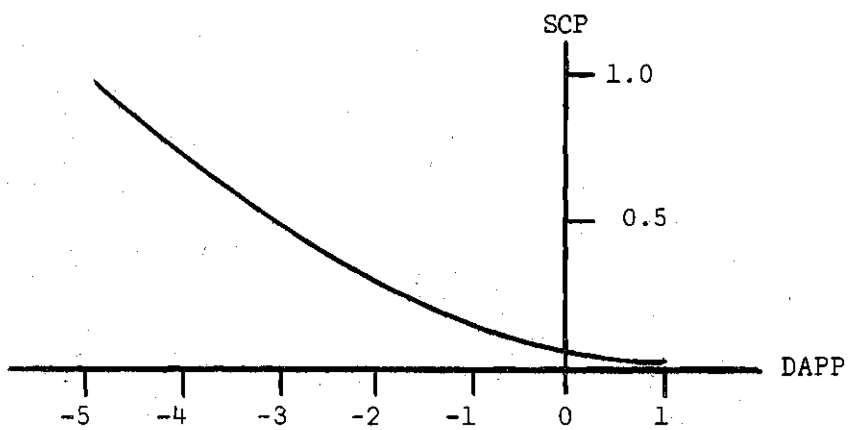


Figure 8. SCP vs. DAPP

Before any decrease in the community's susceptibility to convenient packaging can be realized, the perceived level of pollution must exceed the acceptable level. Large differences between the perceived and the acceptable level tend to exert a large influence on the susceptibility to convenient packaging. A value of 1 for SCP indicates a consumer highly susceptible to disposable packaging.

```
58A     SCP.K=TABHL(TSCP,DAPP.K,-5,1,.5)
C       TSCP*=.07/.1/.15/.20/.27/.36/.47/.56/.65/.65/.80/1/1
```

SCP = Susceptibility to Convenient Packaging (percentage)

TSCP = Table for SCP

DAPP = Difference between Acceptable and Perceived level of solid waste Pollution in the community (percentage)

The following equations allow reduction in the per capita production of solid waste due to factors affecting the consumer and industry. As consumers become less susceptible to purchasing goods in disposable packages, the percentage reduction in per capita waste production rises. In a similar manner, as the technology of pollution increases, the impact is toward factory reduction of the amount of disposable packaging.

```
58A     PRPW.K=TABHL(TPRPW,SCP,0,1,0.1)
C       TPRPW*=4/.39/.36/.29/.22/.125/.006/.0025/.001/0/0
58A     IPWR.K=TABHL(TIPWR,TP.K,0,5,.5)
```

C TIPWR*=.025/.05/.075/.1/.125/.6/.195/.235/.275/.35/.5

SCP = Susceptibility to Convenient Packaging (percentage)

PRPW = Per cent Reduction in per capita waste Production resulting from consumer's reduced susceptibility to convenient packaging (percentage)

TPRPW = Table for PRPW

ETP = Effective Technology in use in solid waste management systems (percentage)

IPWR = Impact on per capita Production of Waste due to factory Reduction in disposable packaging used (percentage)

TIPWR = Table for IPWR

Changes in the average monthly income influence the per capita production of waste. As the average monthly income increases from its present level of $280 per capita per month, waste production increases. When a population becomes more affluent, the tendency to discard goods and purchase new things increases. Conversely, when the average monthly income shrinks, people tend to make items last longer, thereby reducing the per capita disposal rate.

58A IEPW.K=TABHL(TIEPW,AMI.K,200,404,34)

C TIEPW*=.9/.95/.98/1.1/1.2/1.3/1.3

AMI = Average Monthly Income (dollars)

IEPW = Impact of Economic conditions on per capita Production of Waste (percentage)

TIEPW = Table for IEPW

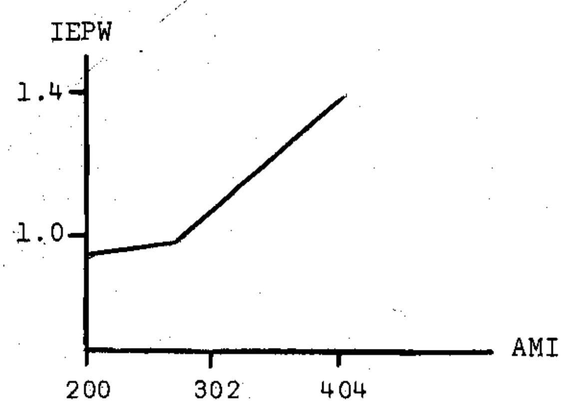


Figure 9. IEPW vs. AMI

Segment II--Generation and Disposal of Solid Wastes

The tons of waste generated per month equals the per capita production of solid waste in tons multiplied by the level of the population.

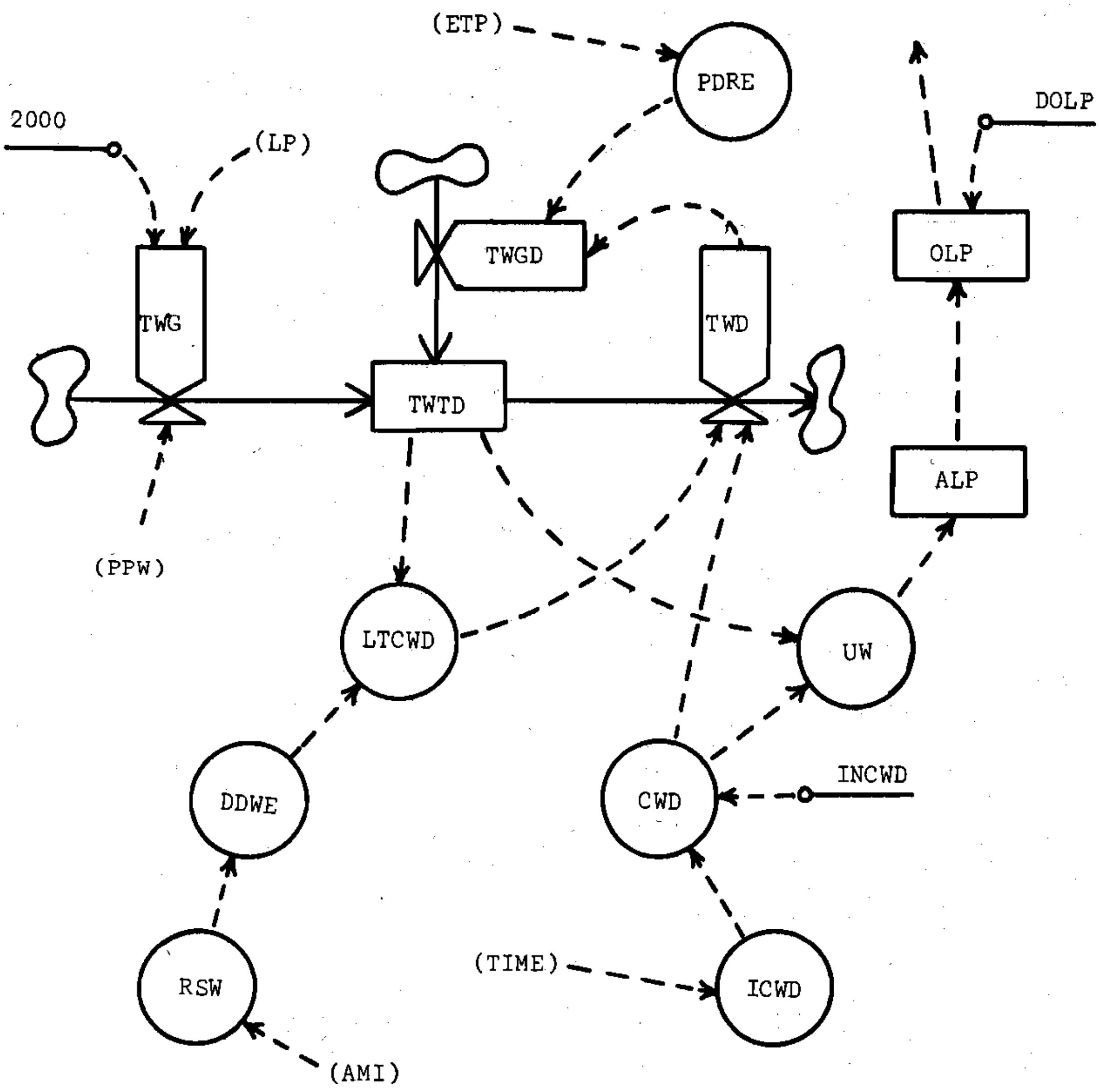
44R TWG.KL=(PPW.K)(LP.K)/2000

TWG = Tons of solid Waste Generated (tons/month)

PPW = Per capita Production of solid Waste (pounds/person)/(month)

LP = Level of Population (people)

The tons of waste to be disposed at a given time depend upon the amount of waste to be disposed from the previous time period and the



SEGMENT II

Figure 10. Generation and Disposal of Solid Wastes

Table 2. Legend for Segment II

CWD	= Capacity of Waste Disposal System
LTCWD	= disposal rate when Less Than Capacity of Waste Disposal system
DDWE	= Delay in Disposing of Waste from Environment
TWTD	= Tons of Waste To be Disposed
TWG	= Tons of Waste Generated
TWGD	= Tons of Waste Generated by Disposal Techniques
TWD	= Tons of Waste Disposed
PDRE	= Per cent of Disposed waste Returning to the Environment
AMI	= Average Monthly Income
RSW	= Reduction in number of Sanitation Workers
ETP	= Effective Technology in use to combat solid waste Pollution
LP	= Level of Population
PPW	= Per capita Production of solid Waste
ICWD	= Increase in Capacity of Waste Disposal system
UW	= Undisposed Waste
ALP	= Actual Level of solid waste Pollution
OLP	= Observable Level of solid waste Pollution in the Community
DOLP	= Delay for an actual level of pollution to become Observable
PLP	= Perceived Level of solid waste Pollution

change in waste to be disposed during the intervening time. The change in tons of waste to be disposed results from the difference between the tons of waste generated by the population and by disposal techniques and the tons of waste disposed. Certain disposal techniques, such as incineration, return a portion of the waste disposed to the environment, thereby becoming a source of waste that must be disposed of by other techniques. Figure 11 shows how the percentage of disposed waste returning to the environment decreases with advances in the technology of solid waste pollution.

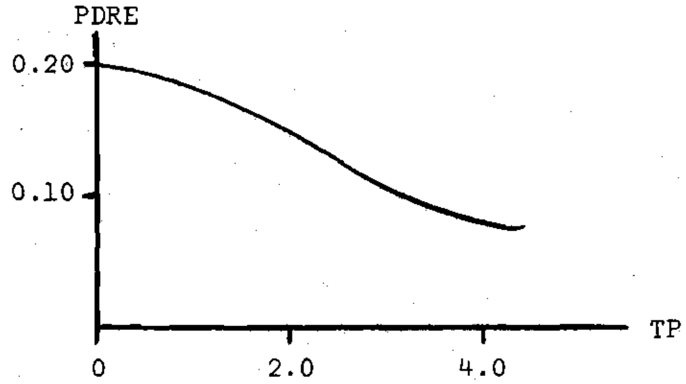


Figure 11. PDRE vs. TP

With advances in technology, disposal techniques can be improved so that a smaller percentage of the waste disposed returns to the environment.

```
2L      TWTD.K=TWTD.J+(DT)(TWG.JK+TWGD.JK-TWD.JK)
6N      TWTD=140000
12R     TWGD.KL=(PDRE.K)(TWD.JK)
58A     PDRE.K=TABHL(TPDRE,TP.K,0,4,.4)
C       TPDRE*=0.20/0.19/0.18/0.17/0.15/0.12/0.10/0.08/0.07/
        0.07/0.07
```

TWTD = Tons of Waste To be Disposed (tons)

TWG = Tons of Waste Generated (tons/month)

TWGD = Tons of Waste Generated by Disposal Techniques (tons/month)

TWD = Tons of Waste Disposed (tons)

PDRE = Per cent of Disposed waste Returning to the Environment (percentage)

TPDRE = Table for PDRE

TP = Technology of Pollution widely known among educators, researchers, and management in solid waste areas (percentage)

The solid waste disposal rate is the smaller of the capacity of the disposal system or the tons of waste to be disposed multiplied by a delay for waste disposal and divided by the solution interval DT. The delay for waste disposal results from a reduction in the number of available sanitation workers due to increases in economic prosperity. The table values for the disposal delay allow social and economic implications that produce changes in the number of sanitation workers to influence the delay in disposing of waste.

```
51R   TWD.KL=CLIP(CWD.K,LTCWD.K,LTCWD.K,CWD.K)
44A   LTCWD.K=(TWTD.K)(DDWE.K)/DT
58A   DDWE.K=TABHL(TDDWE,RSW.K,0,.4,.04)
C     TDDWE*=1/.96/.92/.88/.84/.8/.74/.68/.62/.58/.52
```

TWD = Tons of Waste Disposed (tons/month)

CWD = Capacity of Waste Disposal system (tons/month)

LTCWD = disposal rate when Less Than Capacity of Waste Disposal system (tons/month)

TWTD = Tons of Waste To be Disposed (tons)

DDWE = Delay in Disposing of Waste from Environment (percentage)

TDDWE = Table for DDWE

RSW = Reduction in the number of Sanitation Workers

The capacity of a waste disposal system may change according to the expansion policies adopted by the management of the system. Figure 12 defines a management policy such that growth in the capacity of the disposal system rises to twice the initial capacity over a period of 15 years. The capacity of the disposal system is initially 190,000 tons per month.

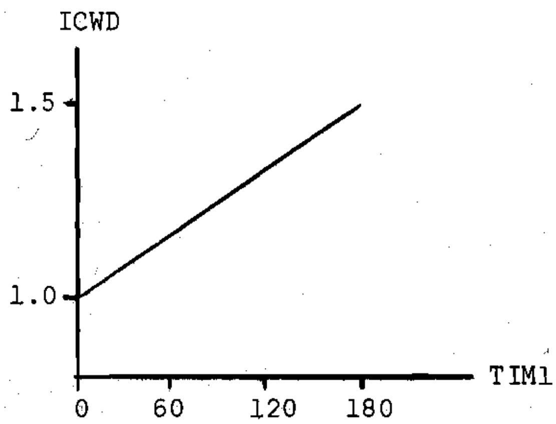


Figure 12. ICWD vs. TIM1

C	INCWD=190000
12A	CWD.K=(INCWD)(ICWD.K)
58A	ICWD.K=TABHL(TICWD,TIM1.K,0,180,60)
C	TICWD*=1/1.3/1.6/2.0
1L	TIM1.K=TIM1.J+(DT)(1+0)
6N	TIM1=0

CWD = Capacity of Waste Disposal system (tons/month)

ICWD = Increase in Capacity of Waste Disposal system (percentage)

TIM1 = counter for passage of time (months)

The undisposed waste may be expressed as the ratio of the tons of waste to be disposed to the capacity of the waste disposal system. The unit for undisposed waste is the number of months required to dispose of the volume of waste in existence when the disposal system operates at peak capacity.

20A UW.K=TWTD.K/CWD.K

UW = Undisposed Waste (months)

TWTD = Tons of Waste To Be Disposed (tons)

CWD = Capacity of Waste Disposal system (tons/month)

Figure 13 shows the actual level of pollution as a function of the undisposed waste. When the undisposed waste, expressed in the number of months required for disposal when the system operates at capacity, increases, the actual level of pollution rises sharply.

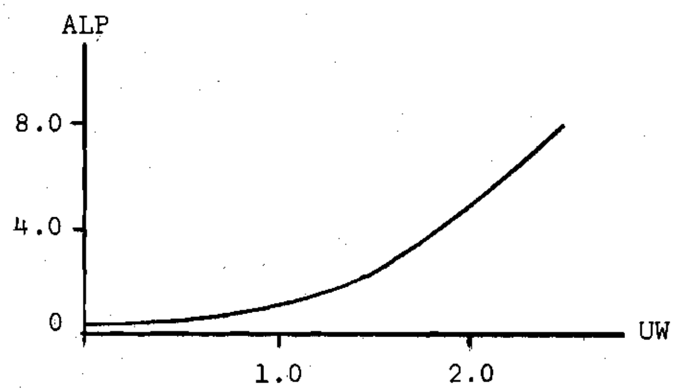


Figure 13. ALP vs. UW

58A ALP.K=TABHL(TALP,UW.K,0,2.5,.5)

C TALP*=0/.5/1/2/5/8

ALP = Actual Level of solid waste Pollution (percentage--an index value)

TALP* = Table for ALP

UW = Undisposed Waste (months)

Changes in the observable level of solid waste pollution arise, after a delay, from differences between the actual level and the past observable level of pollution.

```
3L      OLP.K=OLP.J+(DT)(1/DOLP)(ALP.J-OLP.J)
6N      OLP=.40
C       DOLP=6
```

OLP = Observable Level of solid waste Pollution in the community (percentage)

DOLP = Delay for an actual level of solid waste pollution to become an Observable level of Pollution (months)

ALP = Actual Level of solid waste Pollution in the community (percentage--an index affected by undisposed waste)

Rises in the average monthly income act to reduce the number of workers available for work in sanitation areas. Because salaries for workers who collect and handle solid wastes are low in relation to others job, workers can be lured away to jobs which pay higher salaries. As the average monthly income increases, the salaries in sanitation areas tend to become less competitive and thus allow workers to be drawn away as shown in Figure 14. Also, in an increasingly affluent society, handling solid waste becomes less acceptable socially.

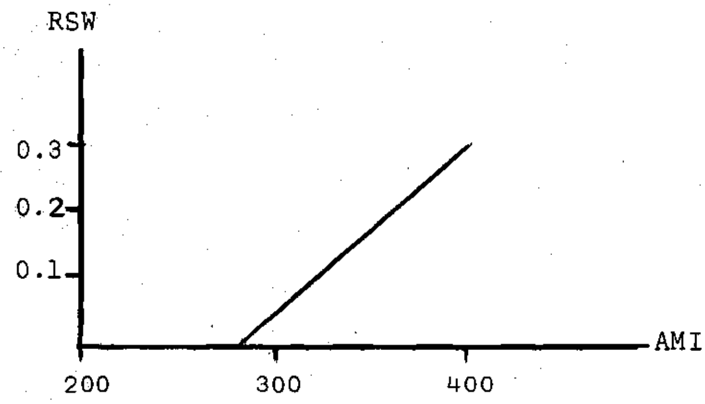


Figure 14. RSW vs. AMI

```
58A     RSW.K=TABHL(TRSW,AMI.K,200,400,20)
C       TRSW=0/0/0/0/0/.05/.1/.15/.20/.25/.3
```

AMI = Average Monthly Income (dollars)

RSW = Reduction in number of Sanitation Workers (percentage)

TRSW = Table for RSW

Segment III--Perception and Acceptability of Solid Wastes

Increases in the technical knowledge of solid waste pollution do not lead to immediate applications of this new knowledge. A delay occurs before new technical knowledge can be applied in the practical operation of a solid waste system. Because of this delay, a difference

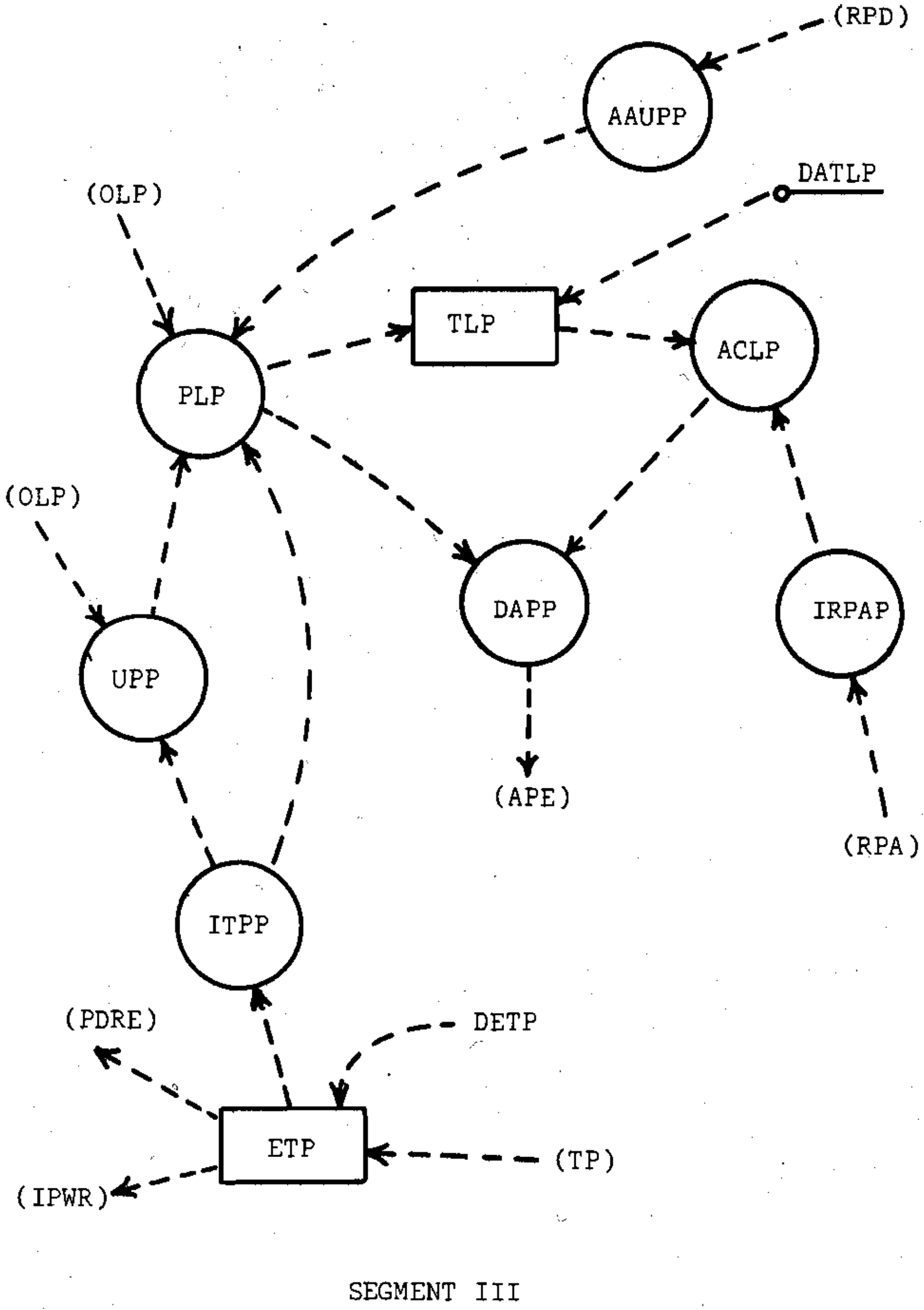


Figure 15. Perception and Acceptability of Solid Wastes

Table 3. Legend for Segment III

ITPP	= Impact of effective Technology on community Perception of solid waste Pollution through measurement
UPP	= Unmeasured or immeasurable solid waste Pollution Problem in the community
AAUPP	= Ability to Awake community about Unmeasured or immeasurable solid waste Pollution Problem
RPD	= Regional Planning effort to Discover unmeasured or immeasurable levels of solid waste pollution
ACLP	= Acceptable Level of solid waste Pollution in the community
TLP	= Traditional Level of solid waste Pollution in the community
DATLP	= Delay in Accepting as Traditional a perceived Level of Pollution
IRPAP	= Impact of Regional Planning on the Acceptance of a traditional level of solid waste Pollution
IPWR	= Impact on per capita Production of Waste due to factory Reductions in the use of disposable packaging
PDRE	= Per cent of Disposed waste Returning to the Environment
DAPP	= Difference between Acceptable and Perceived level of solid waste Pollution in the community
PLP	= Perceived Level of solid waste Pollution in the community
RPA	= allocation of Regional Planning effort to define the Acceptability of solid waste pollution
OLP	= Observable Level of solid waste Pollution in the community
TP	= Technology of Pollution
ETP	= Effective level of Technology in use in solid waste management systems
DETP	= Delay for Technology of solid waste Pollution to become Effective through actual use

exists between the aggregate technology of solid waste pollution widely known and that technology which is in actual use by management in solid waste systems.

```
3L    ETP.K=ETP.J+(DT)(1/DETP)(TP.J-ETP.J)
6N    ETP=TP
6N    DETP=60
```

ETP = Effective level of Technology in use in solid waste management systems (percentage of technology in existence at time 0)

TP = Technology of Pollution widely known among educators, researchers, and management in solid waste areas (percentage)

DETP = Delay for Technology of solid waste Pollution to become Effective through actual use (months)

For initial steady-state conditions, the effective technology of solid waste pollution equals the technology widely known to solid waste management. The delay for a level of technology to become effective is set at 60 months. It is felt that this period represents a reasonable amount of time required to secure support and funds for application of new techniques.

Certain portions of solid waste technology in use by managers of solid waste systems deal with the measurement of solid waste pollution. The impact of the effective aggregate solid waste technology on community perception of solid waste pollution depends upon the use of these available measurement techniques.

```
58A     ITPP.K=TABHL(TITPP,ETP.K,0,1,.1)
C       TITPP*=.09/.27/.38/.47/.53/.60/.68/.73/.82/.90/1
```

ITPP = Impact of effective Technology on community Perception of solid waste Pollution through measurement (percentage)

TITPP = Table for ITPP (percentage)

ETP = Effective level of Technology in use to combat solid waste pollution (percentage of technology in existence at time 0)

The perceived level of solid waste pollution in the community depends upon several factors. The community possesses an observable level of pollution of which portions may be measured as a result of effective use of solid waste technology. Thus, the effective level of measurement technology has an impact on the perception of a portion of the observable level of pollution. Regional planning can awaken the community to the remainder of the observable level of solid waste pollution by extensive educational campaigns and programs.

```
15A     PLP.K=(ITPP.K)(OLP.K)+(AAUPP.K)(UPP.K)
18A     UPP.K=(OLP.K)(1-ITPP.K)
58A     AAUPP.K=TABHL(TAAUP,RPD.K,0,16,2)
C       TAAUP*=0/0/.1/.2/.25/.32/.48/.55/.6
```

PLP = Perceived Level of solid waste Pollution in the community (percentage of the observable level of pollution)

OLP = Observable Level of solid waste Pollution in the community (percentage)

ITPP = Impact of effective Technology on community Perception of solid waste Pollution through measurement (percentage of the observable level)

UPP = Unmeasured or immeasurable solid waste Pollution Problem in the community (percentage of the observable level)

AAUPP = Ability to Awake community about Unmeasured or immeasurable solid waste Pollution Problem

TAAUPP = Table for AAUPP

RPD = Regional Planning effort to Discover unmeasured or immeasurable levels of solid waste pollution (man months/month)

Regional planning's initial efforts have no effect on its ability to alert the public to the undetected pollution problem because the initial efforts are directed at developing techniques to estimate this undetected pollution problem. After estimation techniques are developed, further effort raises regional planning's ability to alert the community.

A traditional level of pollution exists in the community due to a certain amount of solid waste remaining in the environment continuously. If a difference between the perceived level of solid waste pollution and the traditional level of solid waste pollution exists, the difference leads to a change in the traditional level of pollution after a delay.

```
3L      TLP.K=TLP.J+(DT)(1/DATLP)(PLP.J-TLP.J)
6N      TLP=0.152
C       DATLP=24
```

TLP = Traditional Level of solid waste Pollution (percentage)

PLP = Perceived Level of solid waste Pollution in the community (percentage)

DATLP = Delay in Accepting as Traditional a perceived Level of Pollution (months)

The initial steady-state value for the traditional level of pollution is believed to be 0.152. The delay in accepting as traditional a level of pollution will be varied to determine the effect of the delay upon system behavior.

The acceptability of a level of solid waste pollution in the community may be affected by regional planning as it checks the drift of tradition. As regional planning secures passage of laws and standards for regulating solid waste practices, the effect is to decrease the community's acceptable level of pollution. Differences which arise between the acceptable level of solid waste pollution and the perceived level may be expressed as a ratio to the acceptable level.

```
12A    ACLP.K=(TLP.K)(IRPAP.K)
58A    IRPAP.K=TABHL(TIRP,RPA.K,0,16,2)
C      TIRP*=1/.96/.88/.75/.55/.44/.37/.31/.25
21A    DAPP.K=(1/ACLP)(ACLP.K-PLP.K)
```

ACLP = Acceptable Level of solid waste Pollution in the community (percentage)

TLP = Traditional Level of solid waste Pollution in the community (percentage)

IRPAP = Impact of Regional Planning on the Acceptance of a traditional level of solid waste Pollution (percentage)

TIRP* = Table for TIRPAP

DAPP = Difference between Acceptable and Perceived level of solid waste Pollution in the community (percentage)

PLP = Perceived Level of solid waste Pollution in the community (percentage)

RPA = allocation of Regional Planning effort to define the Acceptability of solid waste pollution (man-months/month)

Figure 16 shows regional planning's impact on the traditional level of pollution as a function of the effort allocated to enact legislation and set standards related to solid waste pollution. As regional planning allocates more effort to defining acceptability, the impact tends to decrease the acceptable level of solid waste pollution.

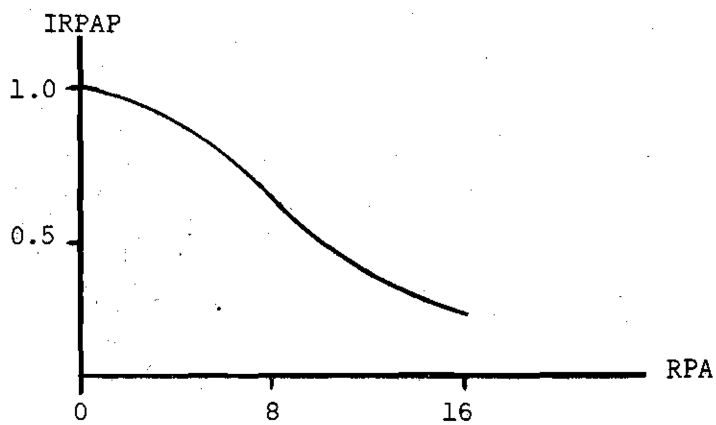


Figure 16. IRPAP vs. RPA

Segment IV--Regional Planning Effort for Solid Waste Pollution

The level of community regional planning effort on the solid waste problem depends upon the past efforts and the changes occurring in effort.

```
IL      RPE.K=RPE.J+(DT)(CRPE.JK+0)
6N      RPE=2
```

RPE = community Regional Planning Effort (man-months/month)

CRPE = Change in community Regional Planning Effort (man-months/month)

Initially RPE was chosen to be two full-time men. This may represent the full-time managerial activity of a city sanitation department.

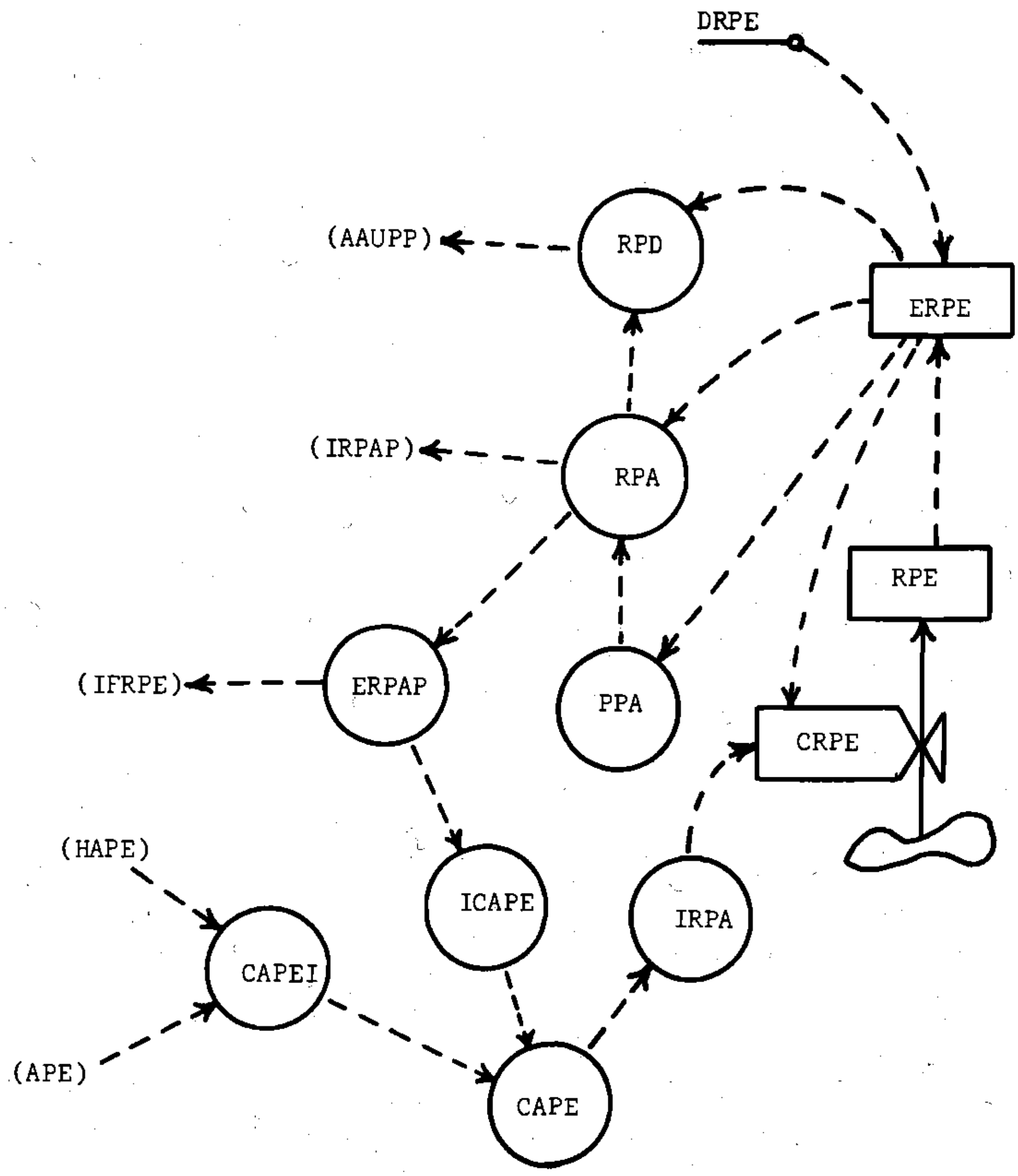
Changes in regional planning effort that are effective in alerting the community about solid waste pollution result, after a delay, from differences in past effectiveness of effort and the planning effort exerted.

```
3L      ERPE.K=ERPE.J+(DT)(1/DRPE)(RPE.J-ERPE.J)
6N      ERPE=RPE
C       DRPE=24
```

ERPE = Effective Regional Planning Effort (man-months/month)

DRPE = Delay in Effectiveness of Regional Planning Effort (months)

RPE = Regional Planning Effort (man-months/month)



SEGMENT IV

Figure 17. Regional Planning Effort for Solid Waste Pollution

Table 4. Legend for Segment IV

CAPEI	=	difference between the present awareness of pollution effects and the historical awareness
APE	=	Awareness of solid waste Pollution Effects
HAPE	=	Historical Awareness of solid waste Pollution Effects
ICAPE	=	Influence on Change in Awareness of solid waste Pollution Effects due to regional planning effort
CAPE	=	effective Change in Awareness of solid waste Pollution Effects
ERPAP	=	Estimate by Regional Planning of its impact on Acceptability of solid waste Pollution
IRPA	=	Impact of Awareness of solid waste pollution on Regional Planning effort
ERPE	=	Effective Regional Planning Effort
CRPE	=	Change in Regional Planning Effort
RPA	=	allocation of Regional Planning effort to define an Acceptable level of solid waste pollution
PPA	=	Policy of regional Planning for Allocation of effort (percentage of effort)
RPD	=	Regional Planning effort to Discover unmeasured levels of solid waste pollution
RPE	=	Regional Planning Effort
DRPE	=	Delay in effectiveness of Regional Planning Effort
IFRPE	=	Impact on Funding of Regional Planning Effort
AAUPP	=	Ability to Awake community about Unmeasured or Immeasurable solid waste Pollution Problem
IRPAP	=	Impact of Regional Planning on the Acceptance of a traditional level of solid waste Pollution

The delay for regional planning effort to become effective was set at 24 months. Initially, the effective regional planning effort equals the regional planning effort.

A forward-looking regional planning group monitors its impact and after making its contribution toward recognizing the solid waste pollution problem, channels its efforts into the feedback loop affecting technology. Planning effort also shuts down its own growth when it reaches the point where additional growth is ineffective.

```
12A     RPA.K=(PPA.K)(ERPE.K)
7A      RPD.K=ERPE.K-RPA.K
58A     PPA.K=TABHL(TRPAP,RPA.K,0,20,2)
C       TPPA*=1/1/1/1/1/1/1/1/1/1/1
```

RPA = allocation of Regional Planning effort to define an Acceptable level of solid waste pollution (man-months/month)

PPA = Policy of regional Planning for Allocation of effort (percentage of effort)

TPPA* = Table for PPA

RPD = Regional Planning effort to Discover unmeasured levels of solid waste pollution (man-months/month)

ERPE = Effective Regional Planning Effort (man-months/month)

The table values defining PPA appear in Figure 18. Values of RPA were allowed to range from 0 to 20. PPA with a constant value of one means that all regional planning effort is directed toward setting standards of acceptability for solid waste pollution.

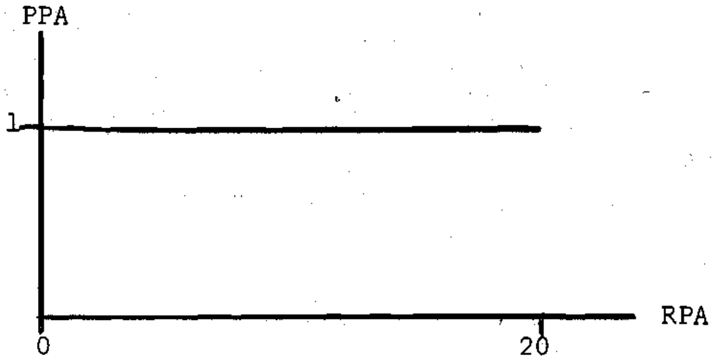


Figure 18. PPA vs. RPA

Regional planning estimates its impact on the community pollution standards. This estimate varies with changes in regional planning effort allocated to determining these standards.

```
58A    ERPAP.K=TABHL(TRPAP,RPA.K,0,20,2)
C      TRPAP*=1/.96/.88/.75/.50/.44/.38/.32/.25/.22/.20
```

ERPAP = Estimate of Regional Planning of its impact on Acceptability of solid waste Pollution (percentage)

TRPAP = Table for ERPAP

RPA = allocation of Regional Planning effort to define the Acceptability of solid waste pollution (man-months/month)

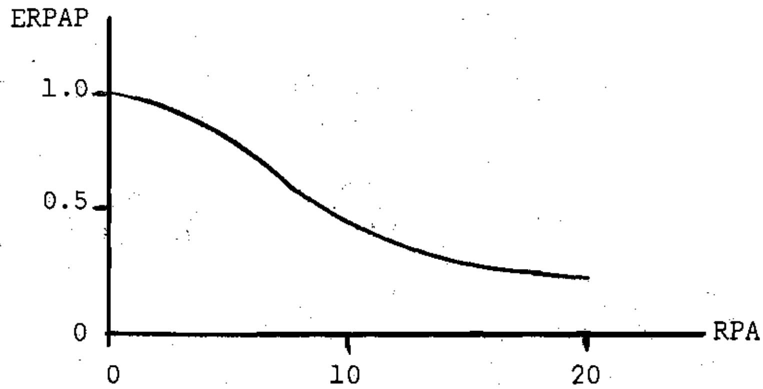


Figure 19. ERPAP vs. RPA

Figure 19 shows that as regional planning allocates more and more effort to setting pollution standards, the estimate of its impact increases. Hence, the more effort regional planning allocates to definition of solid waste pollution, the less acceptable solid waste pollution becomes, thereby causing an increase in regional planning's estimate of its impact on acceptability. An ERPAP value of 1 represents no impact.

The following group of equations describes regional planning's policy for regulating its own growth.

```
7A     CAPEI.K=APE.K-HAPE.K
58A    ICAPE.K=TABHL(TICAP,ERPAP.K,0,1,0.1)
C      TICAP*=0/0/0/.08/.28/.5/.67/.84/1/1/1
12A    CAPE.K=(CAPEI.K)(ICAPE.K)
58A    IRPA.K=TABHL(TIRPA,CAPE.K,-0.5,0.5,0.1)
C      TIRPA*=-.075/-.07/-.06/-.04/0/0/.05/.08/.0925/.1/.105
```

12R CRPE.KL=(IRPA.K)(ERPE.K)

CAPEI = difference between the present awareness of pollution effects and the historical awareness

APE = Awareness of solid waste Pollution Effects (percentage)

HAPE = Historical Awareness of solid waste Pollution Effects (percentage)

ICAPE = Influence on Change in Awareness of solid waste Pollution Effects due to regional planning effort (percentage)

TICAP = Table for ICAPE

CAPE = effective Change in Awareness of solid waste Pollution Effects

ERPAP = Estimate by Regional Planning of its impact on Acceptability of solid waste Pollution (percentage)

IRPA = Impact of Awareness of solid waste pollution on Regional Planning effort (percentage)

ERPE = Effective Regional Planning Effort (man-months/month)

CRPE = Change in Regional Planning Effort (man-months/month)

The change in awareness of solid waste pollution results from the influence that regional planning exerts upon differences between the awareness. Figure 20 shows regional planning's influence on the change in awareness as a function of regional planning's estimate of its impact on determining acceptable levels of solid waste pollution. Figure 20 in conjunction with Figure 21 describes how regional planning monitors its growth. In Figure 20, regional planning does not want to deter its growth when it first begins to exert an impact on the

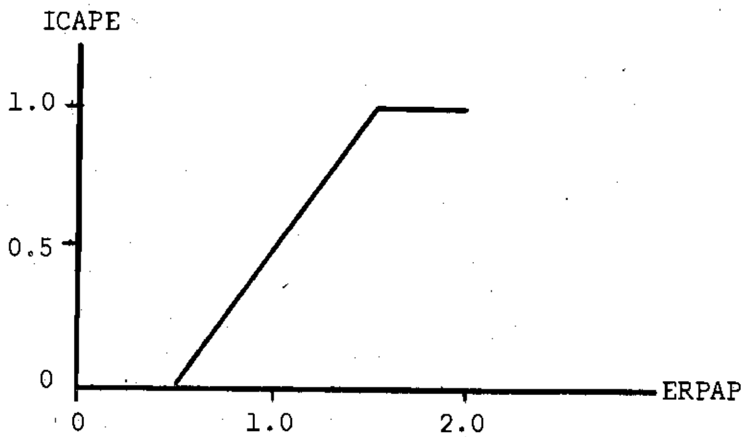


Figure 20. ICAPE vs. ERPAP

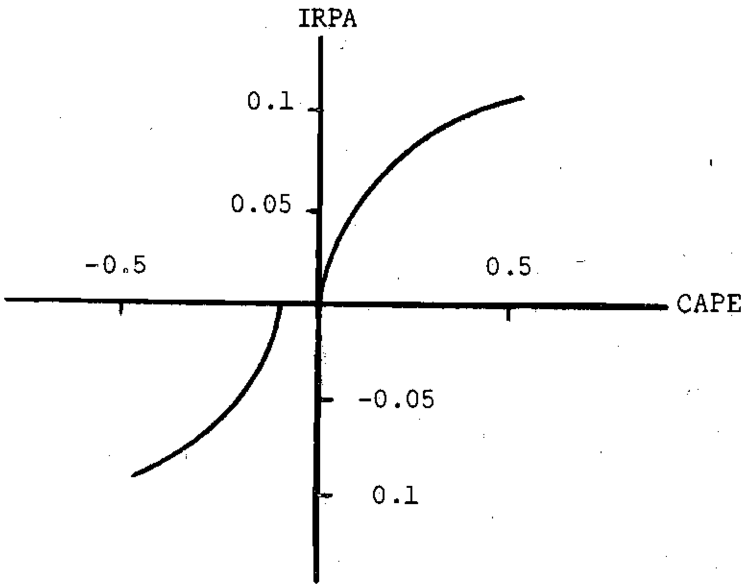
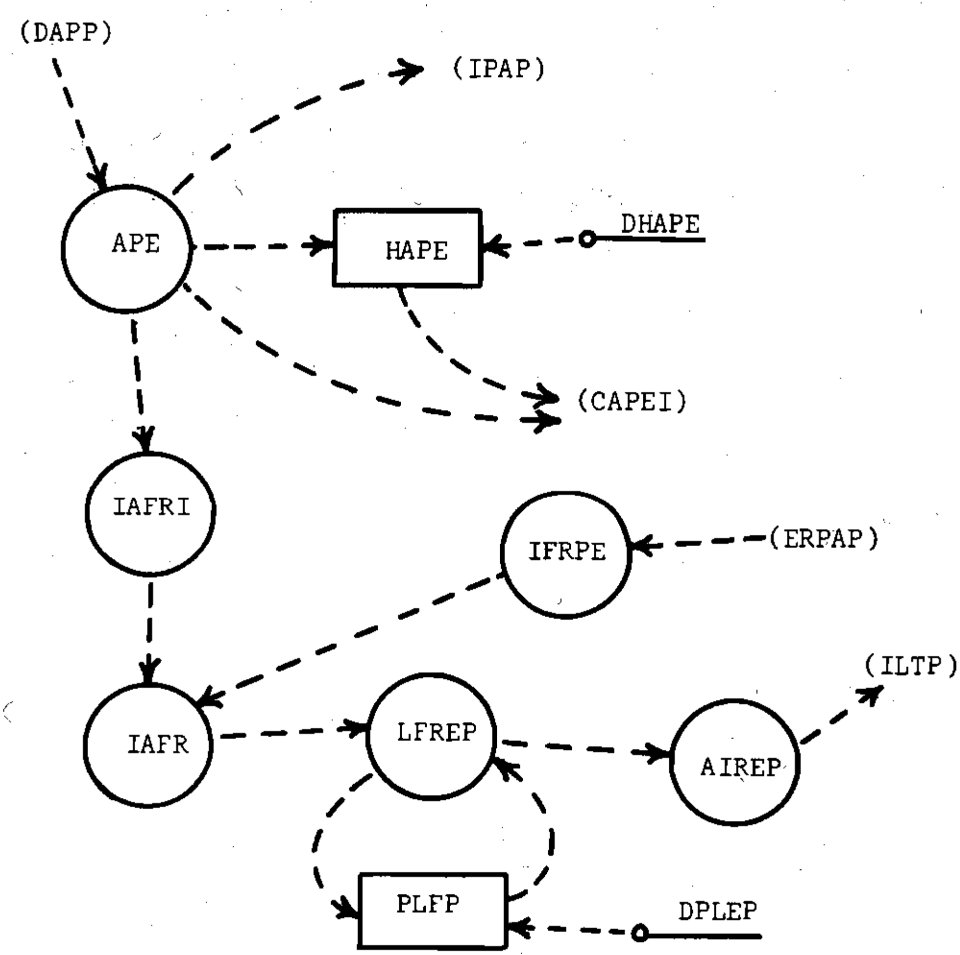


Figure 21. IRPA vs. CAPE

acceptability of solid waste pollution. Hence for regional planning's estimate of its impact from 1.0 to 0.7, regional planning does not influence the change in awareness in order to reduce further growth. In the estimate range of 0.7 to 0, however, regional planning begins to rapidly exert considerable impact toward a reduction of the acceptable level of solid waste pollution. In this range regional planning takes its most aggressive action toward reducing further growth so as to prevent expansion beyond the point of usefulness. The delay that exists before a level of regional planning effort can become effective is the reason regional planning starts to cut back its growth rate when it begins to exert its largest impact on acceptability. After regional planning begins to affect the acceptability of pollution, the effort that has already been expended but has not become effective reinforces the impact on acceptability to a greater extent as time passes without the initiation of new regional planning effort. Figure 21 shows the relationship between changes in awareness of solid waste pollution and their impact on regional planning. Changes in awareness of solid waste pollution can initiate reduction in the regional planning effort as well as growth, for regional planning may overexpand and find it necessary to reduce its level of effort.

Segment V--Awareness of Pollution and Funding for Research

A non-linear relationship exists between the community's awareness of pollution effects and the difference in the perceived and the acceptable levels of pollution.



SEGMENT V

Figure 22. Awareness of Pollution and Funding for Research

Table 5. Legend for Segment V

APE	= community Awareness of solid waste Pollution Effects
IFRPE	= Impact on Funding of research and education by Regional Planning Effort
IAFR	= total Impact of community Awareness of solid waste pollution and regional planning effort on Funding for Research and education in solid waste pollution
ERPAP	= Estimate by Regional Planning of its impact on the Acceptability of solid waste Pollution
DAPP	= Difference between Acceptable and Perceived level of solid waste Pollution
IAFRI	= Impact of community Awareness of solid waste pollution on Funding Research and education
HAPE	= Historical Awareness of solid waste Pollution Effects
DHAPE	= Delay for an Awareness of solid waste Pollution Effects becoming historical
CAPEI	= difference between the present awareness of pollution effects and the historical awareness
IPAP	= Impact on Population of Awareness of solid waste Pollution effects
LFREP	= Level of Funding for Research and Education in solid waste Pollution
PLFP	= Previous Level of Funding for research and education in solid waste Pollution
DPLP	= Delay for Previous Level of funding to realize changes in the level of funding for research and education in Pollution
AIREP	= Actual Increase expected in aggregate technology through funding for Research and Education in Pollution
ILTP	= Increase in aggregate Level of Technology related to solid waste Pollution

```
58A    APE.K=TABHL(TAPE,DAPP.K,-5,1,0.5)
C      TAPE*=.95/.90/.84/.74/.68/.52/.40/.32/.22/.12/.09/.07/.05
```

APE = Awareness of solid waste Pollution Effects (percentage)

TAPE = Table for APE

DAPP = Difference between Acceptable and Perceived level of solid waste Pollution

Figure 23 depicts the curve defined by the relationships between DAPP and APE.

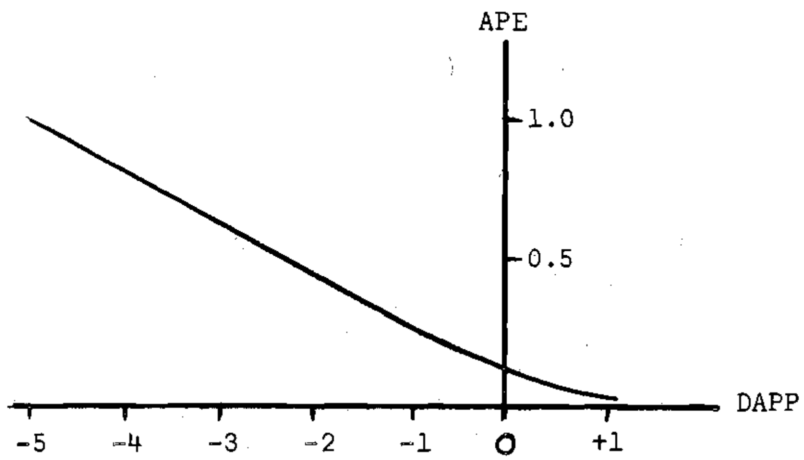


Figure 23. APE vs. DAPP

When the difference between the acceptable level of solid waste pollution and the perceived level becomes negative, the community perceives a larger level of solid waste pollution than is acceptable. As the difference becomes more negative, the community becomes more aware of the solid waste problem. When the difference between the acceptable level and the perceived level becomes positive, the community has a greater acceptable level of solid waste pollution than the level it perceives. Hence, as the difference becomes more positive, the community's awareness of pollution effects decreases.

When the awareness of pollution effects increases, the impact upon funding of research and education also increases. The impact from increased awareness combines with the impact from regional planning to create the total impact on funding of research and education in solid waste pollution.

```
58A     IAFRI.K=TABHL(TIAFR,APE.K,0,1,.1)
C       TIAFR*=.50/.70/.80/1/1.08/1.20/1.29/1.33/
12A     IAFR.K=(IFRPE.K)(IAFRI.K)
```

IAFRI = Impact of community Awareness of solid waste pollution on Funding Research and education (percentage)

RIAFR = Table for IAFRI

APE = community Awareness of solid waste Pollution Effects (percentage)

IFRPE = Impact on Funding of research and education by Regional Planning Effort (percentage)

IAFR = total Impact of community Awareness of solid waste pollution and regional planning effort on Funding for Research and education in solid waste pollution (percentage)

As the estimate of regional planning's impact on the acceptability of solid waste pollution decreases, thereby making pollution less acceptable, the impact is to increase funding of solid waste research and education. When the estimate of regional planning's impact decreases to less than 0.3, the rate of funding increases dramatically.

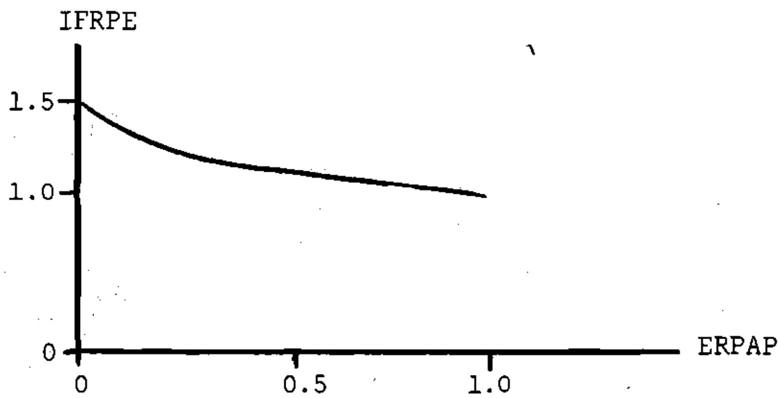


Figure 24. IFRPE vs. ERPAP

58A IFRPE.K=TABHL(TFRPE,ERPAP.K,0,1,0.1)

C TFPE*=1.5/1.4/1.3/1.27/1.24/1.21/1.18/1.15/1.13/1.05/1

IFRPE = Impact on Funding Research of regional Planning Effort (percentage)

TFPE = Table for IFRPE

ERPAP = Estimate by Regional Planning of its impact on the Acceptability of solid waste Pollution (percentage)

The level of funding for research and education depends upon the previous level of funding and the impact on this level exerted by community awareness of pollution and regional planning effort. Currently in the United States, the level of funding for research and education is approximately $25,000,000 per year.

A delay of approximately 24 months is arbitrarily chosen to represent the time taken before differences between the present level of funding and the past level begin to gain acceptance as part of the normal research and education expenditure.

```
12A    LFREP.K=(PLFP.K)(IAFR.K)
3L     PLFP.K=PLFP.J+(DT)(1/DPLEP)(LFREP.J-PLFP.J)
6N     PLFP=25000000
C      DPLEP=24
```

IAFR = total Impact of community Awareness of solid waste pollution and regional planning effort on Funding for Research and education in solid waste pollution (percentage)

LFREP = Level of Funding for Research and Education in solid waste Pollution (dollars)

PLFP = Previous Level of Funding for research and education in solid waste Pollution (dollars)

DPLEP = Delay for Previous Level of funding to realize changes in the level of funding for research and Education in Pollution (months)

As the amount of money spent on research and education in solid waste pollution changes, the actual expected increase in aggregate technology also changes. Figure 25 shows the relationship between the expected increase in solid waste technology and the level of funding for research and education.

```
58A    AIREP.K=TABHL(TAIRE,LFREP.K,0,200000000,25000000)
C      TAIRE*=0/.05/.12/.25/.42/.63/.75/.83/.90
```

AIREP = Actual Increase in aggregate technology through funding for Research and Education in Pollution (percentage)

TAIRE = Table for AIREP

LFREP = Level of Funding for Research and Education in solid waste Pollution (dollars)

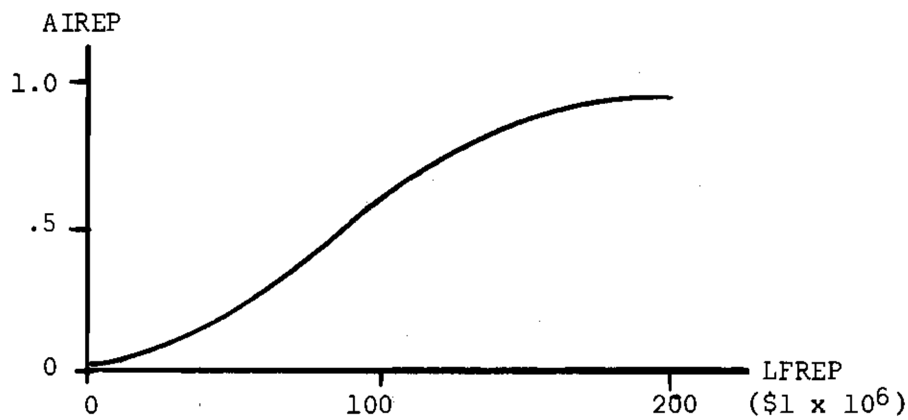


Figure 25. AIREP vs. LFREP

The historical awareness of solid waste pollution changes as a result of differences between the awareness of solid waste pollution effects and the historical level itself.

3L HAPE.K=HAPE.J+(DT)(1/DHAPE)(APE.J-HAPE.J)

6N HAPE=0.06

C DHAPE=36

HAPE = Historical Awareness of solid waste Pollution Effects (percentage)

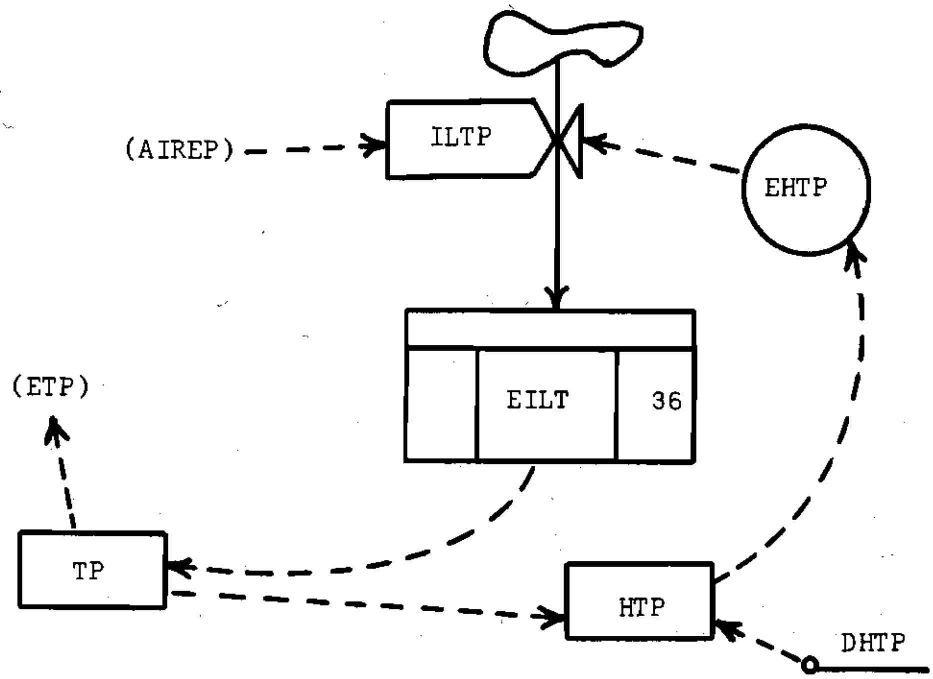
APE = Awareness of solid waste Pollution Effects (percentage)

DHAPE = Delay for an Awareness of solid waste Pollution Effects to become historical (months)

The initial value for the historical awareness is believed to be low and was arbitrarily initialized at 0.06. A delay of 36 months was chosen to depict the time required for an awareness of pollution effects to become viewed as historical.

Segment VI--Growth of Pollution Technology

The next set of equations to be developed involves the level of technology related to solid waste pollution. An increase in the aggregate level of technology related to solid waste pollution depends upon the maximum increase that is possible and the effect that historical levels of technology exert upon the realization of this possible increase. When research by individuals or research teams does increase the level of solid waste technology related to pollution, a delay



SEGMENT VI

Figure 26. Growth of Pollution Technology

Table 6. Legend for Segment VI

ILTP	=	Increase in aggregate Level of Technology related to solid waste Pollution
AIREP	=	Actual Increase possible in aggregate technology for current level of funding for Research and Education in solid waste Pollution
EHTP	=	Effect of Historical level of aggregate Technology on advancement of solid waste technology
EILT	=	rate at which solid waste educators, researchers, and managers acquire Increases in the aggregate Level of solid waste Technology
DIT	=	Delay Increases in solid waste Technology experience before becoming widely known among solid waste educators, researchers, and managers
TP	=	Technology of Pollution widely known among educators, researchers, and management in solid waste
ETP	=	Effective Technology in use to combat solid waste Pollution
DT	=	Delta Time, the solution interval for the system of equations
HTP	=	Historical level of aggregate Technology for solid waste Pollution
DHTP	=	Delay for a level of widely known technology to become a Historical level of Technology for solid waste Pollution

transpires before the new technical knowledge becomes widely known among researchers, educators, and management in solid waste areas.

```
12R    ILTP.KL=(AIREP.K)(EHTP.K)
39R    EILT.KL=DELAY3(ILTP.JK,DIT)
C      DIT=36
IL     TP.K=TP.J+(DT)(EILT.JK+0)
6N     TP=0.20
```

ILTP = Increase in aggregate Level of Technology related to solid waste Pollution (percentage/month)

AIREP = Actual Increase possible in aggregate technology for current level of funding for Research and Education in solid waste Pollution (percentage)

EHTP = Effect of Historical level of aggregate Technology on advancement of solid waste technology (percentage)

EILT = rate at which solid waste educators, researchers, and managers acquire Increases in the aggregate Level of solid waste Technology (percentage/month)

DIT = Delay Increases in solid waste Technology experience before becoming widely known among solid waste educators, researchers, and managers (months)

TP = Technology of Pollution widely known among educators, researchers, and management in solid waste (percentage of the technology in existence at time 0)

DT = Delta Time, the solution interval for the system of equations (months)

All levels require initial conditions. The initial value of the level of technology of solid waste pollution that is widely known is taken to be 0.20 of the knowledge in existence.

A period of 36 months appears appropriate for the delay increases in technology experience before coming widely known. A delay of this magnitude allows ample time for new technical knowledge to be presented in articles, technical papers, seminars, and books.

The technology of solid waste pollution that is widely known provides a base knowledge which affects the direction and magnitude of future research. Research tends to develop in those areas which have received attention in the past and seem to offer high returns for research work done. Hence, the historical level of aggregate technology of solid waste pollution exerts an effect on further increases in the technology of solid waste pollution by encouraging more research.

```
3L      HTP.K=HTP.J+(DT)(1/DHTP)(TP.J-HTP.J)
6N      HTP=TP
C       DHTP=30
58A     EHTP.K=TABHL(TEHTP,HTP.K,0,10,1)
C       TEHTP*=.1/.2/.25/.5/.75/.9/1/1/1/1/1
```

HTP = Historical level of aggregate Technology for solid waste Pollution (percentage of technology in existence at time 0)

TP = Technology of Pollution widely known among educators, researchers, and management in solid waste (percentage of the technology in existence at time 0)

DHTP = Delay for a level of widely known technology to become a Historical level of Technology for solid waste Pollution (months)

EHTP = Effect of Historical level of aggregate Technology on advancement of solid waste technology (percentage/month)

TEHTP= Table for EHTP

The historical level of aggregate solid waste technology equals the technology for solid waste pollution in the steady-state initial value. A delay of 30 months is felt to expire before a level of technology comes to be viewed as the historical level.

Figure 27 shows the relationship between the historical level of solid waste pollution technology and the effect it exerts on future technological advances. As can be seen from Figure 27, the larger the base knowledge in solid waste pollution becomes, the greater the effect the base exerts on future increases in the technology of solid waste pollution.

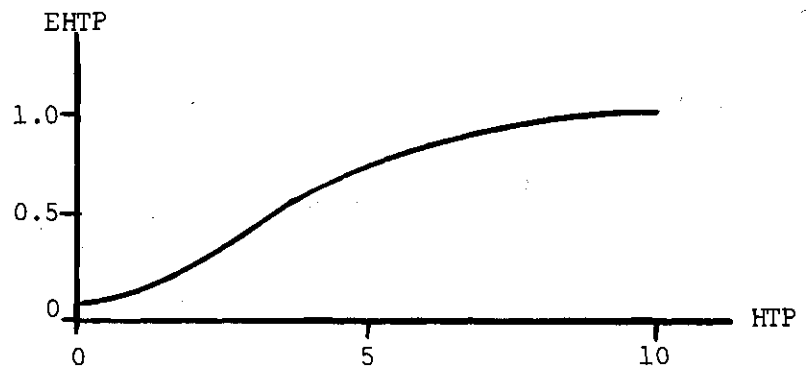


Figure 27. EHTP vs. HTP

Segment VII--Changes in Population

Changes in population may occur due to the awareness of pollution effects. As the awareness of pollution effects increases, the impact tends to decrease the population because of people moving from the polluted areas.

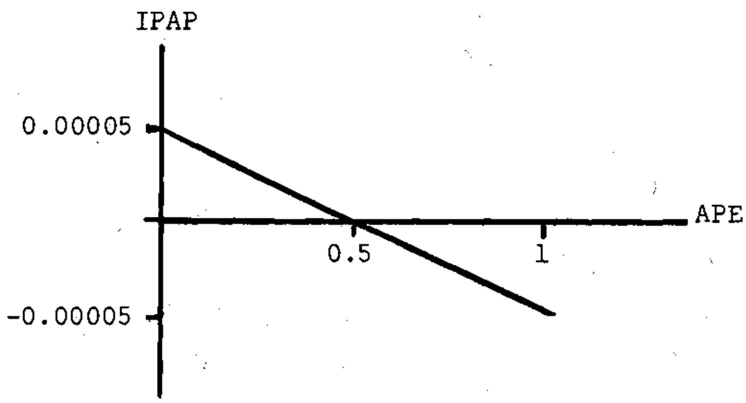


Figure 28. IPAP vs. APE

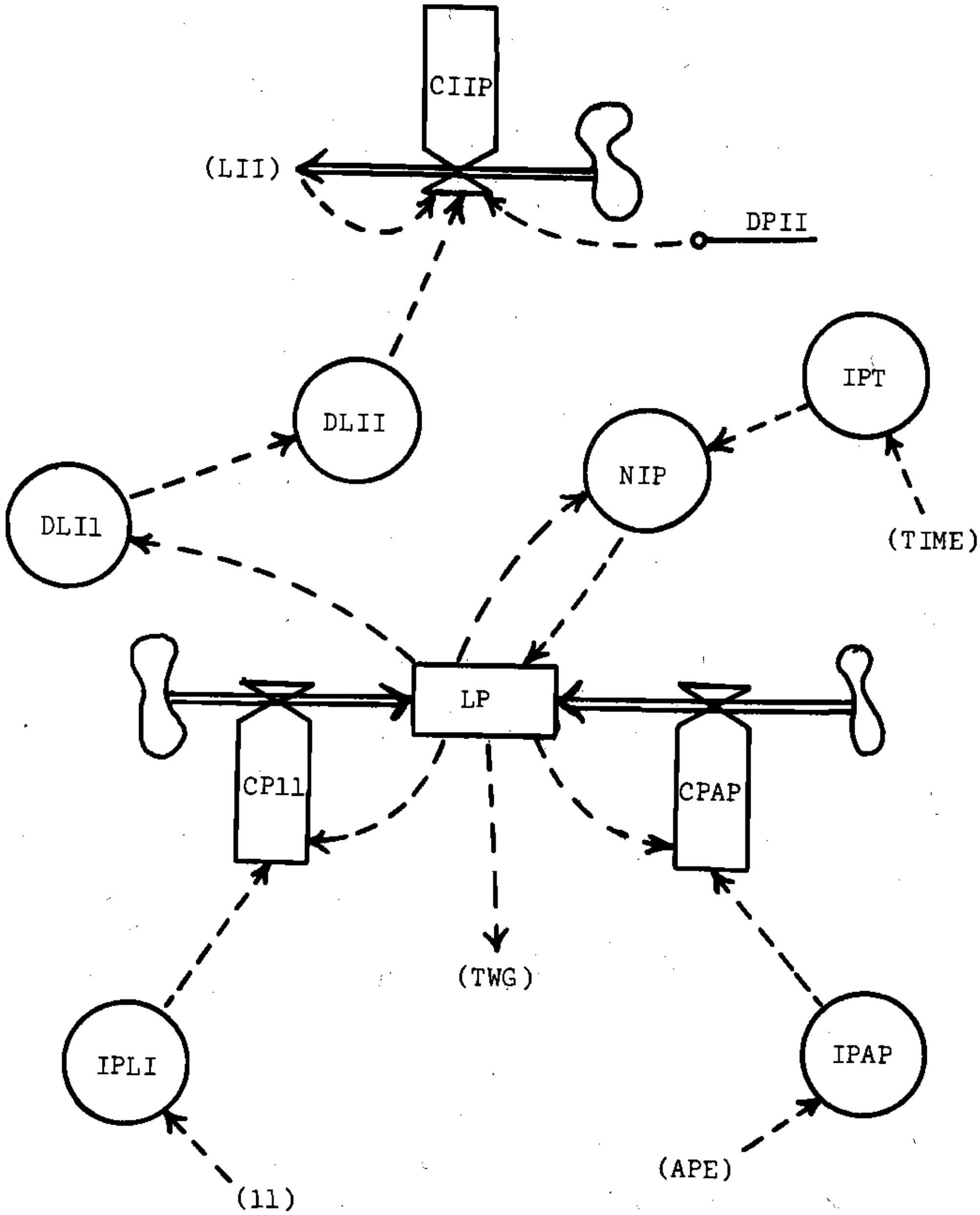
12R CPAP.KL=(IPAP.K)(LP.K)

58A IPAP.K=TABHL(TIPAP,APE.K,0,1,0.1)

C TIPAP*=.00005/.00005/.00004/.00003/.00002/0/-.00001/-.00002/-.00004/-.00007/-.0001

CPAP = Change in Population due to Awareness of solid waste Pollution effects (people/month)

IPAP = Impact on Population of Awareness of solid waste Pollution effects (percentage)



SEGMENT VII

Figure 29. Changes in Population

Table 7. Legend for Segment VII

CIIP	=	Change in Industrial Investment due to Population pressure
DPII	=	Delay for Population to Influence Investment
DLII	=	Desired Level of Industrial Investment
LII	=	Level of Industrial Investment
LP	=	Level of Population
DLII	=	Desired Level of Investment per capita
CPII	=	Change in Population due to Industrial Investment
IPLI	=	Impact on level of Population of Increases in Investment
II	=	Increases in Investment
CPAP	=	Change in Population due to Awareness of solid waste Pollution effects
IPAP	=	Impact on Population of Awareness of solid waste Pollution effects
IPT	=	Increase in Population over Time
APE	=	Awareness of solid waste Pollution Effects
LP	=	Level of Population
CPII	=	Change in Population due to aggregate Industrial Investment
CPAP	=	Change in Population Due to Awareness of solid waste Pollution effects
NIP	=	Normal Increase in Population
TWG	=	Tons of Waste Generated

TIPAP = Table for IPAP

LP = Level of Population (people)

APE = Awareness of solid waste Pollution Effects (percentage)

The level of population from the previous time period and the changes in the intervening time determine the current level of the population. Since attention is being focused on a city of approximately 2,000,000 people, this value is used for the initial level of population.

```
2L    LP.K=LP.J+(DT)(CPII.JK+CPAP.JK+NIP.JK+0+0+0)
6N    LP=2000000
```

LP = Level of Population (people)

CPII = Change in Population due to aggregate Industrial Investment (people/month)

CPAP = Change in Population Due to Awareness of solid waste Pollution effects (people/month)

NIP = Normal Increase in Population (people/month)

The normal increase in population can be stated as a percentage of the population over time. Without economic and environmental influences, the percentage increase is about 0.08 per cent per month.

```
12R   NIP.KL=(IPT.K)(LP.K)
58A   IPT.K=TABHL(TIPT,TIM1.K,0,180,20)
```

C TIPT*=.0008/.0008/.0008/.0008/.0008/.0008/.0008/.0008/
.0008/.0008

NIP = Normal Increase in Population (people/month)

IPT = Increase in Population over Time (percentage)

TIPT = Table for TIPT

TIM 1 = counter for time

Changes in industrial investment also exert an impact upon changes in population. Increases in industrial investment attract people to live in the areas near new sources of employment. Decreases in industrial investment mean the closing of plants and businesses and are thus accompanied by losses of people who must seek employment elsewhere.

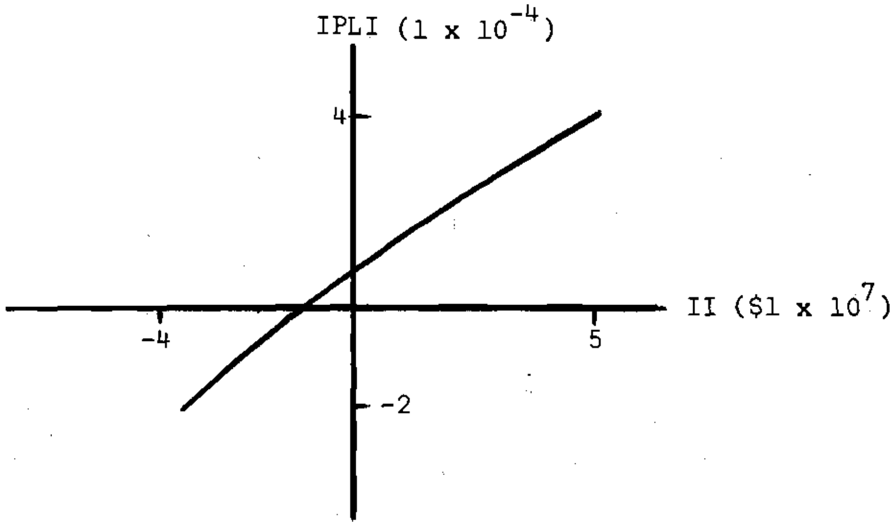


Figure 30. IPLI vs. II

```
12R   CPII.KL=(IPLI.K)(LP.K)

58A   IPLI.K=TABHL(TIPLI,II.K,-4E+7,5E+7,IE-7)

C     TIPLI*=-.00002/-.00001/-.000005/0/.000005/.000015/
      .00002/.000025/.00003/.00004
```

CPII = Change in Population due to Industrial Investment (people/month)

LP = Level of Population (people)

IPLI = Impact on level of Population of Increases in Investment (people/month)

II = Increases in Investment (dollars)

The rate of change in industrial investment results from differences between the desired level and the actual level of investment. The delay for these differences to affect the change is taken to be about 60 months due to the time consumed in planning and in securing funds for investment. The total desired level of investment depends upon the level of population and the desired level of investment per person. As the population increases, the desired level of investment per person increases because of the increased cost of expansion in a highly populated area.

```
21R CIIP.KL=(1/DPII)(DLII.K-LII.K)

12A   DLII.K=(DLI1.k)(LP.K)

58A   DLI1.K=TABHL(TIIP,LP.k,0,4000000,500000)

C     TIIP*=0/1250/2500/3750/5000/6750/8500/10250/1200

C     DPII=60
```

CIIP = Change in Industrial Investment due to Population pressures (dollars/month)

DPII = Delay for Population to Influence Investment (months)

DLII = Desired Level of Industrial Investment (dollars)

LII = Level of Industrial Investment (dollars)

LP = Level of Population (people)

DLII = Desired Level of Investment per capita (dollars/person)

TIIP = Table for DLII

Segment VIII--Industrial Investment

The average monthly income, which is currently $280 per month in the United States, depends upon the monthly income in the previous time period and the change in average monthly income in the intervening time period. The rate of change in average monthly income is a function of the increase or decrease in capital investment as shown in Figure 31. The change in monthly income is more sensitive to very large changes in investment than to small changes.

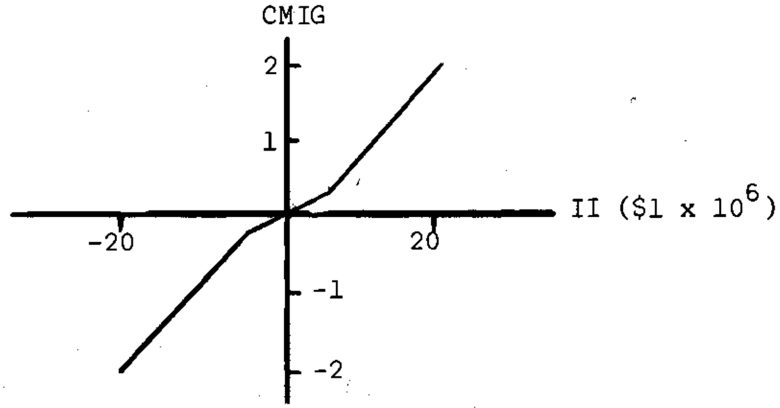
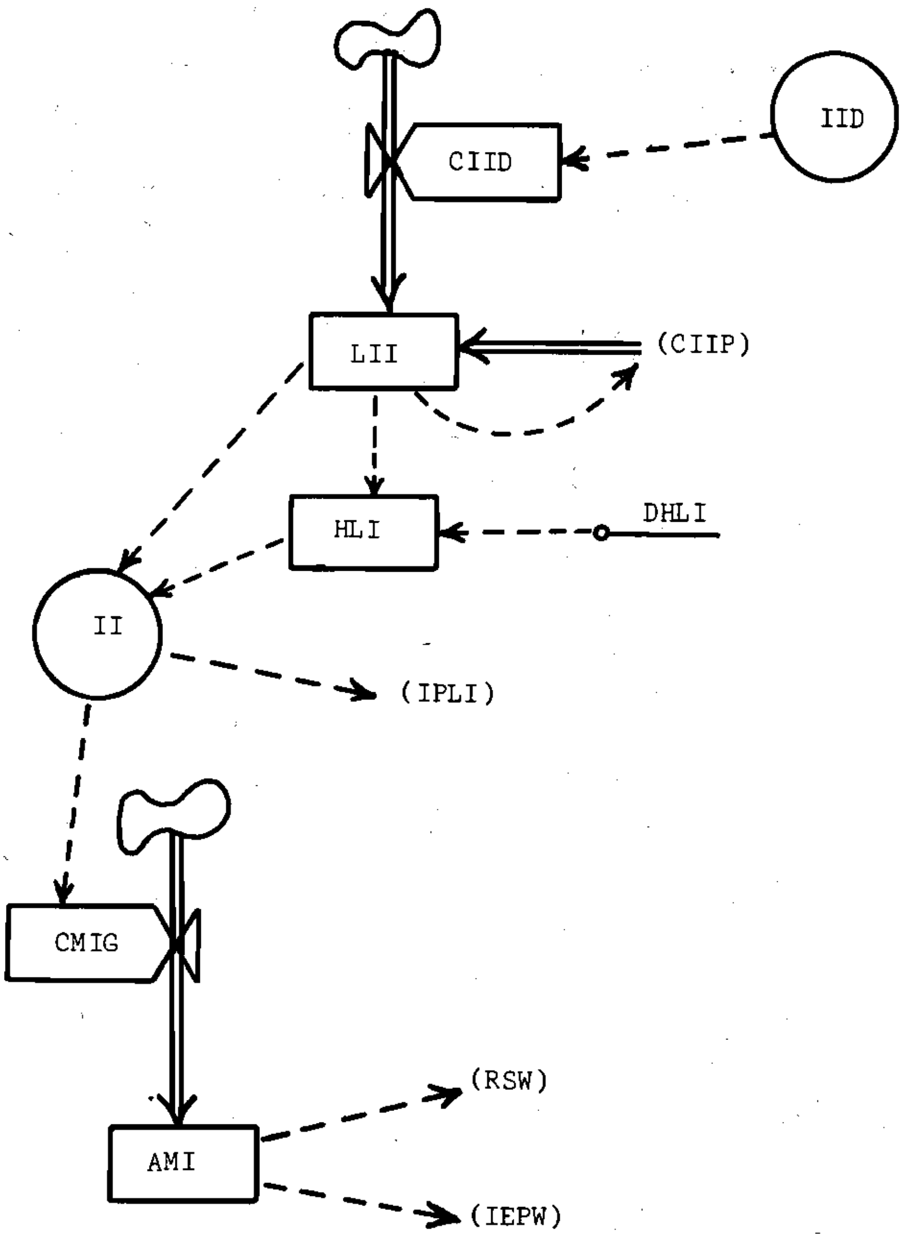


Figure 31. CMIG vs. II



SEGMENT VIII

Figure 32. Industrial Investment

Table 8. Legend for Segment VIII

LII	= Level of Industrial Investment
CIIP	= Change in Industrial Investment due to Population pressures
CIID	= Change in Industrial Investment due to solid waste Disposal problems
IID	= Influence on industrial Investment of waste Disposal problems
HLI	= Historical Level of Investment
LII	= Level of Industrial Investment
DHLI	= Delay for changes in investment to become Historical
II	= Increase or decrease in industrial Investment
IPLI	= Impact on level of Population of increases in Investment
AMI	= Average Monthly Income
CMIG	= rate of Change in Monthly Income resulting from industrial Growth
RSW	= Reduction in number of Sanitation Workers
IEPW	= Impact of Economic conditions on per capita Production of Waste

```
IL     AMI.K=AMI.J+(DT)(CMIG.JK+0)
6N     AMI=280
58R    CMIG.KL-TABHL(TCMIG,II.K,-20000000,20000000,5000000)
C      TCMIG*=2/-1.25/-.5/-.125/0/.125/.5/1.25/2
```

AMI = Average Monthly Income (dollars)

CMIG = rate of Change in Monthly Income resulting from industrial Growth (dollars/month)

TCMIG = Table for CMIG

II = Change in Industrial Investment (dollars)

Changes in the level of industrial investment result from population pressures to increase investment and, to a much smaller extent, solid waste disposal problems. The level of investment is initially taken to be 10 billion dollars. Changes in industrial investment due to solid waste disposal problems is expected to be about 0.0000001 of the level of industrial investment.

```
IL     LII.K=LII.J+(DT)(CIIP.JK+CIID.JK)
6N     LII=1E+10
12R    CIID.KL=(IID.K)(LII.K)
C      IID=0.0000001
```

LII = Level of Industrial Investment (dollars)

CIIP = Change in Industrial Investment due to Population pressures (dollars/month)

CIID = Change in Industrial Investment due to solid waste Disposal problems (dollars/month)

IID = Influence on industrial Investment of waste Disposal problems (percentage)

The delay for a level of industrial investment to be viewed as historical was taken to be 60 months. Initially, the historical level of investment equals the actual level of investment. In later time periods, increases or decreases in industrial investment are represented by the difference between the current level and the historical level of investment.

```
3L    HLI.K=HLI.J+(DT)(1/DHLI)(LII.J-HLI.J)
6N    HLI=1E+10
C     DHLI=60
7A    II.K=LII.K-HLI.K
```

HLI = Historical Level of Investment (dollars)

LII = Level of Industrial Investment (dollars)

DHLI = Delay for changes in investment to become Historical (months)

II = Increase or decrease in industrial Investment (dollars).

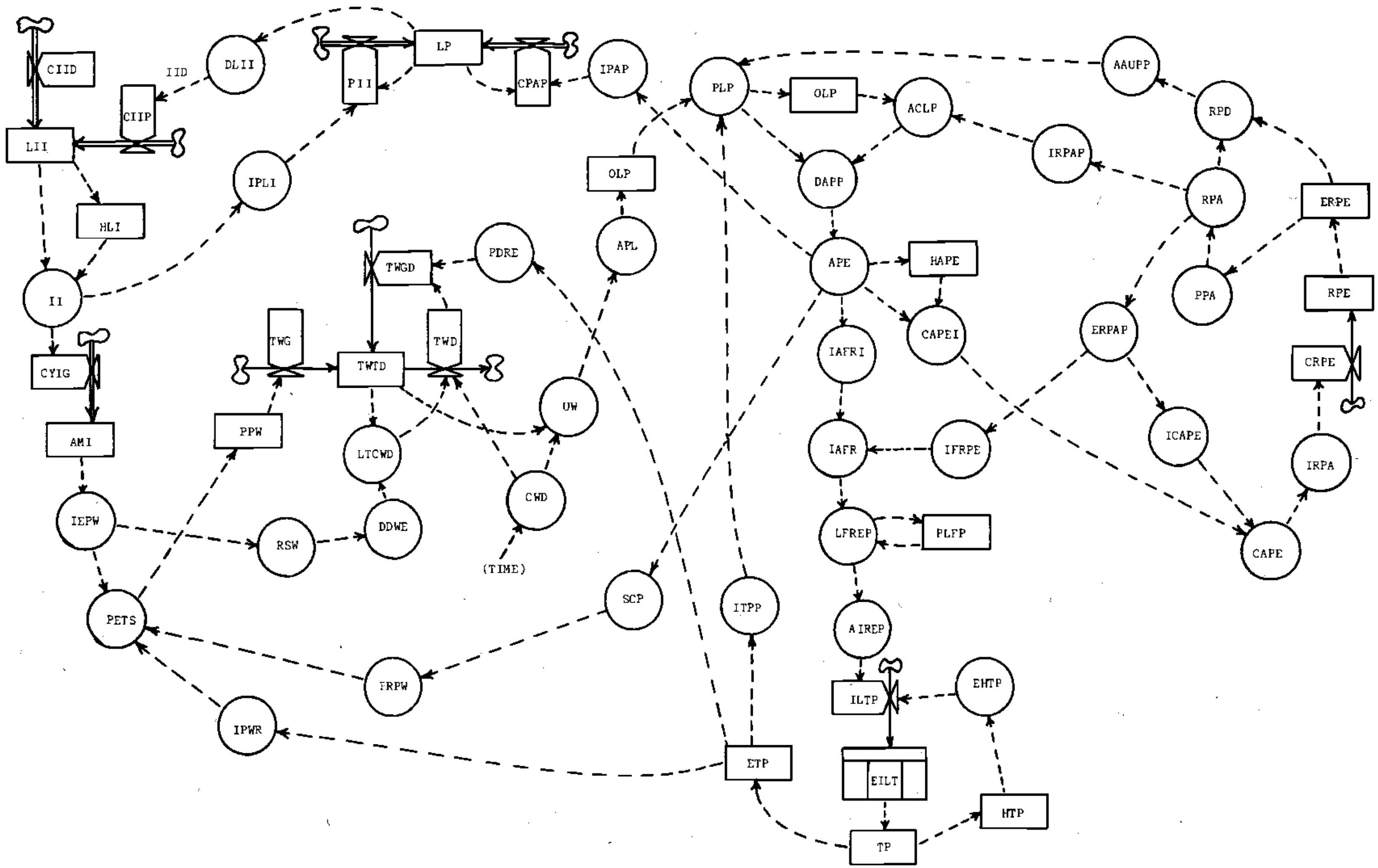


Figure 33. Detailed Flow Diagram

CHAPTER III

BEHAVIOR OF BASIC MODEL

The information feedback model developed in Chapter II can be used to study the dynamic behavior of a solid waste management system. The runs discussed in this chapter exhibit system behavior under different environmental conditions and different managerial policies.

Since the model represents a hypothetical system, the results do not specifically apply to any particular solid waste management system. However, the results do indicate the kind of system behavior which can follow from the conditions and policies studied.

In order to make the analysis of system behavior less difficult, noise does not appear in any of the runs. The exclusion of noise facilitates efforts to gain understanding of the basic system dynamics without distortion by random events.

Run I--Vigorous Growth Policy

Run I differs from the basic model developed in Chapter II in two main areas. First, the per capita production of waste cannot be reduced either by the consumer or industry. The second major change lies in the disposal system growth policy adopted by management. In Run I, disposal system capacity grows to four times the initial capacity in 15 years. These two changes in the basic model were accomplished by the following equations:

```
C       TPRPW*=0/0/0/0/0/0/0/0/0/0/0
C       TIPWR*=0/0/0/0/0/0/0/0/0/0/0
C       TICWD*=1/2/3/4.
```

The changes in Run I reflect the real world situation in many cities in the United States. Most governments and most industries expend no effort to reduce the amount of waste being produced. Instead of dealing with the solid waste problem at its source, municipalities expand their solid waste disposal systems at a rate fast enough to avert an obvious solid waste pollution problem. Hence, consumers never become less susceptible to disposable packaging because they do not perceive a menacing level of solid waste pollution.

Figure 34 shows the results of Run I. The actual level of pollution initially rises in the face of increased per capita waste production. By month 4, however, disposal system capacity becomes able to handle the solid waste generated and the level of pollution declines until month 40. From month 40 to month 52 the level of pollution rises due to the delay in disposing of waste that results from the reduction in the number of sanitation workers. The vigorous growth policy adopted by management enables the disposal system to abate the level of pollution after month 52 even though labor problems exist. Since the disposal system effectively handles the waste generated, pressures to increase funding for pollution research do not arise and thus the level of funding for research declines. As a result of the reduction in funding for research, the effective technology of pollution experiences little growth.

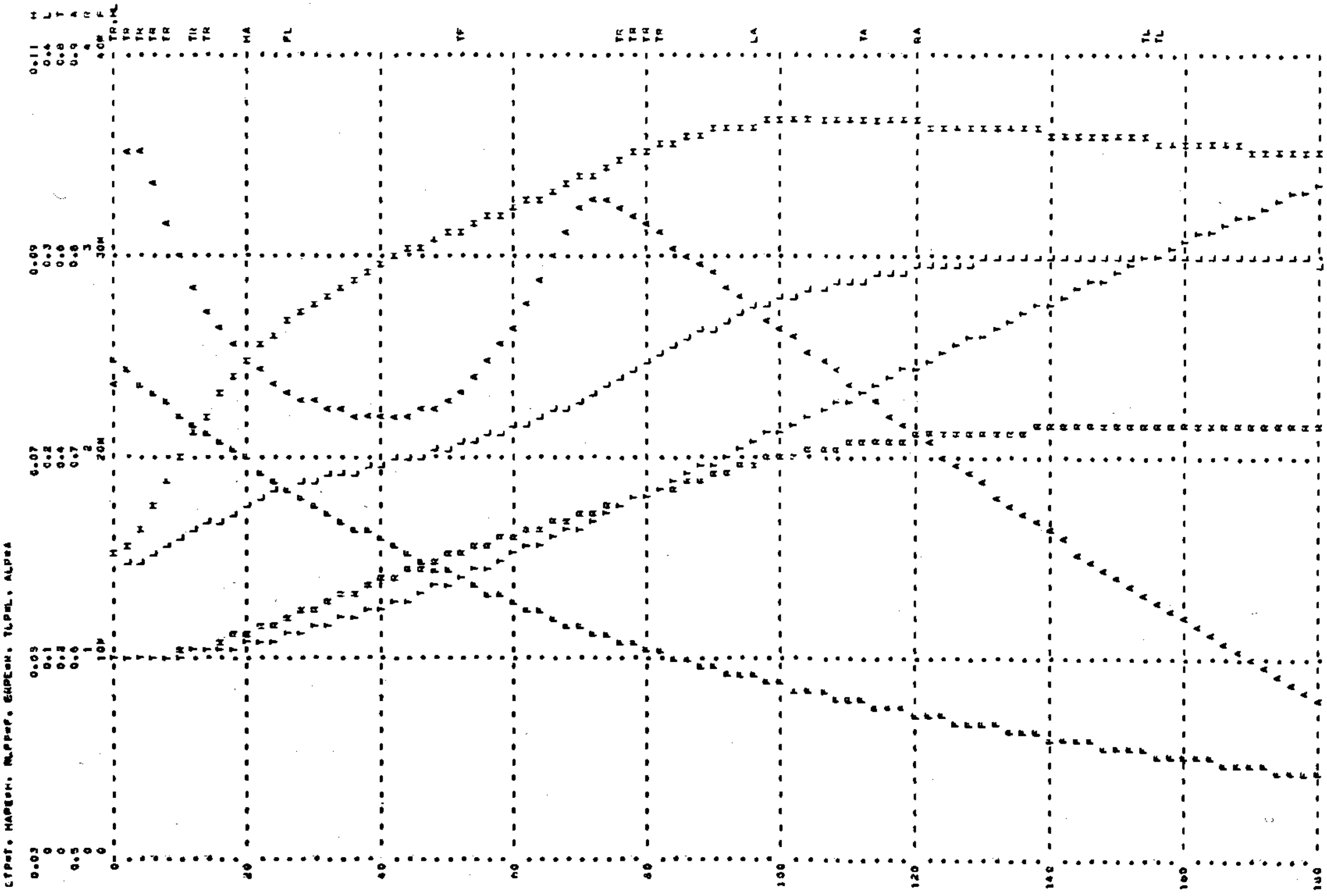


Figure 34. Run 1--Vigorous Growth Policy

Table 9. Key to Printouts of Basic Model

T =	Effective level of Technology use to combat solid waste Pollution
H =	Historical Awareness of solid waste Pollution Effects
F =	Previous level of Funding for research and education in solid waste Pollution
R =	Effective Regional Planning Effort
L =	Traditional Level of solid waste Pollution in the community
A =	Actual Level of solid waste Pollution

The effective regional planning effort expended on solid waste problems increases from one full-time man to above two full-time men. This amount of planning effort does not appreciably increase the community awareness of solid waste problems. In fact, the regional planning effort expended cannot check the downward drift of the historical awareness of pollution effects when the actual level of pollution declines. The traditional level of pollution in Run I continually increases because the actual level of pollution is greater than the traditional level for the duration of the run.

The results of Run I indicate that a vigorous capacity growth rate for a solid waste disposal system can prevent significant reductions in the amount of waste generated. Even if reductions in the solid waste production rate had been possible in Run I, the pressures that implement the reductions do not arise. Awareness of solid waste pollution is too low to result in any appreciable reduction in consumer susceptibility to disposable packaging. Likewise, industry cannot reduce its use of disposable packaging because pollution technology fails to grow enough to provide suitable packaging substitutes. Both the low level of awareness of pollution and the lack of significant technological growth result from the disposal system's ability to avert a serious pollution problem.

Run 2--Primary and Secondary Source Reduction

The results of Run 2 appear in Figure 35. This run contains the policies and environmental conditions that were developed in Chapter II. Run 2 differs from Run I in that the disposal system capacity increases to 1.5 times the initial capacity in Run 2 as compared to 4 times the initial capacity in Run 1. In addition, Run 2 permits both primary and secondary source reduction in the generation of wastes. Primary source reduction arises when industry develops substitutes for disposable packaging through growth in solid waste pollution technology. Secondary source reduction of wastes results from consumers becoming less susceptible to purchasing goods in disposable packaging because of solid waste pollution.

In Run 2, the actual level of pollution rises to 2.5 times as high as the level in Run 1 due, in part, to the more moderate growth in disposal system capacity. The actual level of pollution in Run 2 increases gradually until about month 72 and then remains relatively stable until month 120. After month 120, a decline in the actual level of pollution occurs because of reductions in the use of disposable packaging by consumers.

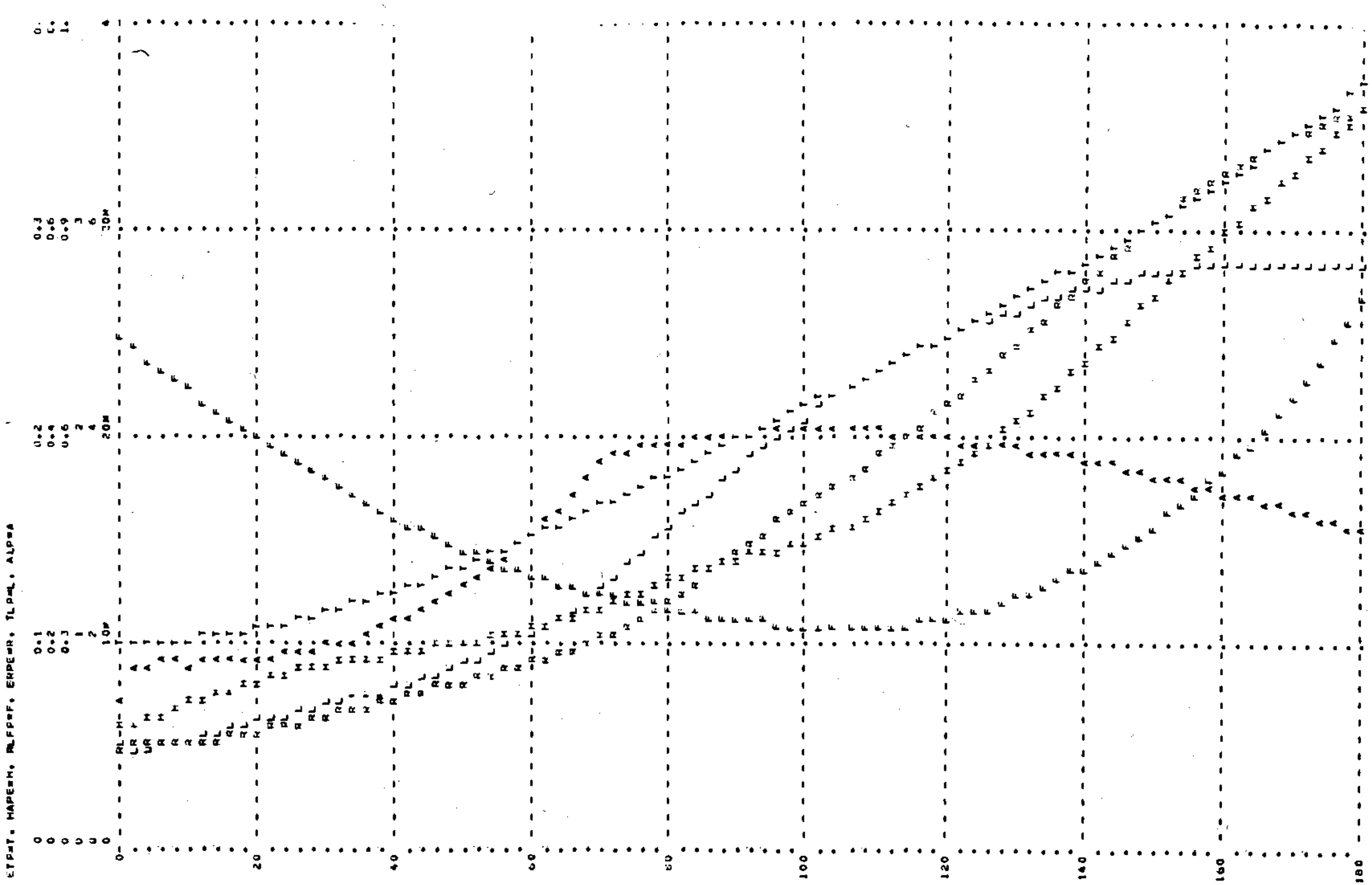


Figure 35. Run 2--Primary and Secondary Source Reduction

Such reductions allow the disposal system with its increased capacity to remove some undisposed waste from the environment. As in Run 1, technology in Run 2 does not grow enough to implement any significant reduction in the amount of disposable packaging used by industry. Funding for pollution research, however, does increase after month 114 primarily because of the awareness of pollution effects generated by the regional planning effort to define acceptability of pollution. The effective regional planning effort in Run 2 rises to over seven full-time men as compared with two full-time men in Run 1. The additional planning effort in Run 2 aids in creating a higher level of historical awareness of pollution than exists in Run 1. In Run 2 the historical awareness of pollution is over three times as great as the level in Run 1 due to the greater regional planning effort to define acceptability and to the existence of a higher level of pollution. The higher level of pollution in Run 2 also results in the community accepting as traditional a level of pollution almost three times as great as the traditional level in Run 1.

Run 2 depicts system behavior when management depends upon the solid waste pollution problem to create pressures that lead to pollution abatement. Even though the actual level of pollution is relatively high in Run 2, pressure on industry to implement primary source reduction of waste through technological growth does not arise. Although secondary source reduction of waste by consumers does occur, no lasting solution to the solid waste pollution problem can come from consumers alone. Substitutes for disposable packaging used by industry and better solid waste disposal techniques are also essential. The results of Run

2 indicate that pressures from solid waste pollution alone do not initiate the technological growth necessary for developing packaging substitutes and improving disposal techniques.

CHAPTER IV

RESTRUCTURE OF BASIC MODEL

The solid waste management system as formulated in Chapter II does not effectively attack solid waste pollution at its source because of limitations in technological growth. To overcome the stagnation of pollution technology, management might delegate to regional planning the task of stimulating funding for solid waste pollution research. Regional planning's policies for allocating and controlling the expenditure of effort to affect funding are discussed in this chapter. Other system changes also discussed are management's policy for disposal system growth and the impact of technology on regional planning's ability to define the acceptability of pollution. The complete flow diagram including restructure changes appears at the end of the chapter in Figure 44.

Regional Planning Policies to Affect Funding for Pollution Research

The results of the runs in Chapter III indicate that existence of excess disposal system capacity tends to prevent increases in the amount of funding for solid waste pollution research. When the amount of solid waste being produced dramatically increases, excess disposal system capacity acts to delay the emergence of a solid waste pollution problem and to soften its severity. Hence, the community's lack of awareness of the seriousness of the level of pollution prevents growth in the level of funding for research. To counteract the lack of community pressure to increase pollution research funding, regional planning might allocate effort to directly influence funding. When the volume of waste to be disposed increases, regional planning can estimate the amount of excess disposal system capacity as shown in Figure 36. As the estimate of the amount of excess capacity changes, regional planning regulates the amount of effort expended to affect research funding. Figure 37 shows the policy for allocating planning effort and the impact which planning can have on research funding. After technology experiences enough growth to dramatically reduce the volume of waste being produced, regional planning need not exert more effort to support research funding. The policy for restricting regional planning's impact on funding appears in Figure 41.

Estimate of Excess Disposal System Capacity

This section discusses the manner in which regional planning estimates the amount of excess disposal system capacity. The estimation procedure is shown in Figure 36.

Regional planning can monitor the tons of waste to be disposed to determine the average amount of waste that must be processed. A delay of about six months expires before changes in the tons of waste to be disposed are fully perceived in the average.

```
3L    ATWTD.K=ATWTK.J+(DT)(1/DOT)(TWTD.J-ATWTD.J)
6N    ATWTD=140000
C     DOT=6
```

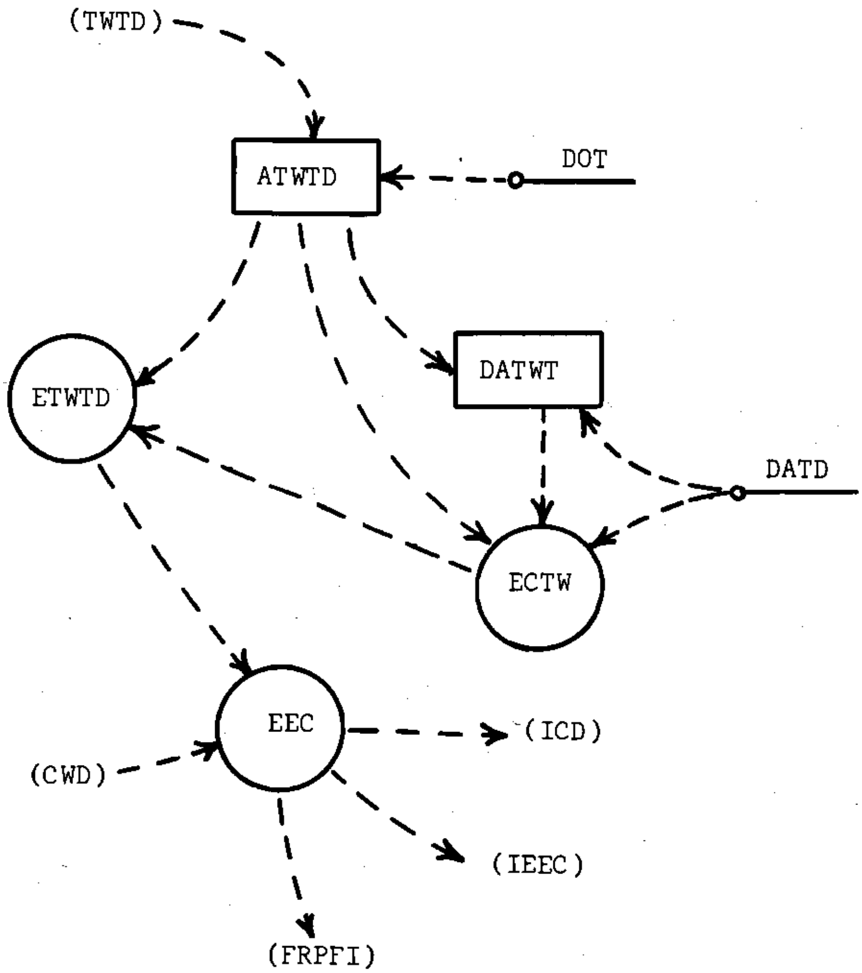


Figure 36. Estimate of Excess Disposal System Capacity

Table 10. Legend for Figure 36

DATWT	=	Delayed value of Average Tons of Waste to be disposed
ETWTD	=	Expected Tons of Waste to be Disposed
EEC	=	Expected Excess disposal system capacity
CWD	=	Capacity of solid Waste Disposal system
DATD	=	Delay to Average Tons of waste to be disposed
ATWTD	=	Average Tons of Waste To Be Disposed
DOT	=	Delay to Observe Tons of waste to be disposed
ECTW	=	Expected Change in Tons of Waste to be disposed
TWTD	=	Tons of Waste To be Disposed
ICD	=	Impact of excess Capacity on growth of Capacity of Disposal system
IEEC	=	Impact of Estimated Excess Capacity
FRPFI	=	Fraction of Regional Planning effort directed toward Funding as Indicated by excess capacity

TWTD = Tons of Waste to Be Disposed (tons)

ATWTD = Average Tons of Waste To Be Disposed (tons)

DOT = Delay to Observe Tons of waste to be disposed (months)

An additional delay of six months is required before regional planning detects shifts in the average tons of waste to be disposed.

```
3L    DATWT.K=DATWT.J+(DT)(1/DATD)(ATWTD.J-DATWT.J)
6N    DATWT=140000
C     DATD=6
```

DATWT = Delayed value of Average Tons of Waste To Be Disposed (tons)

DATD = Delay to Average Tons of waste to be disposed (months)

ATWTD = Average Tons of Waste To Be Disposed (tons)

By comparing the average tons of waste to be disposed with the delayed average, regional planning can observe significant changes in the amount of waste to be disposed. The expected change in the amount of waste generated may then be used to predict the volume of waste to be disposed in the future. Regional planning estimates the amount of excess disposal system capacity in existence by comparing the capacity of the disposal system with the expected tons of waste to be disposed.

```
7A    ECTW.K=ATWTD.K-DATWT.K
7A    ETWTD.K=ATWTD.K+ECTW.K
21A   EEC.K=(1/CWD.K)(CWD.K-ETWTD.K)
```

ECTW = Expected Change in Tons of Waste to be disposed (tons)

ATWTD = Average Tons of Waste to be Disposed (tons)

DATWT = Delayed value of Average Tons of Waste to be disposed (tons)

ETWTD = Expected Tons of Waste to be Disposed (tons)

EEC = Expected Excess disposal system Capacity (percentage)

CWD = Capacity of solid Waste Disposal system (tons)

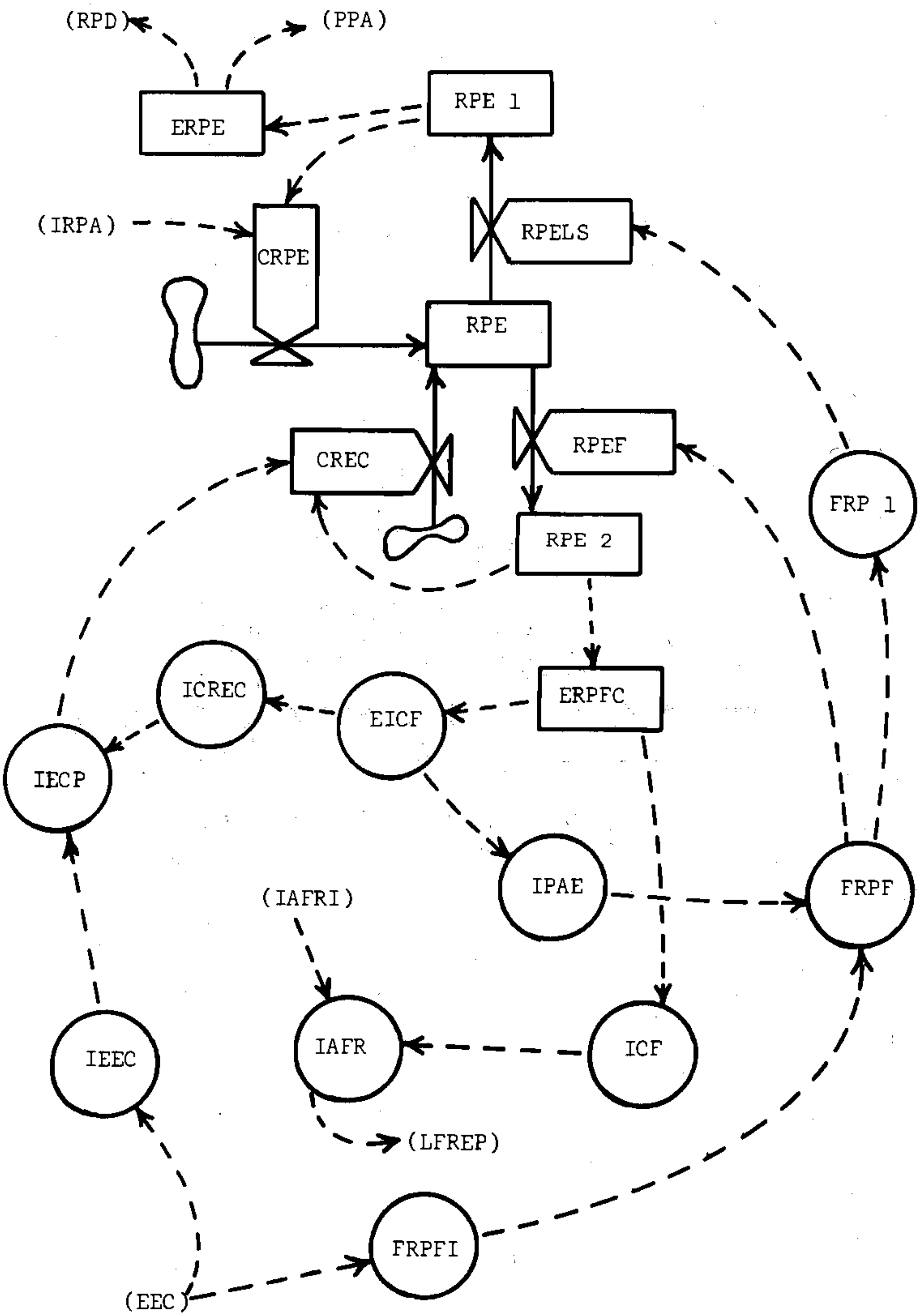


Figure 37. Allocation and Impact of Planning Effort

Table 11. Legend for Figure 37

FRPFI	= Fraction of Regional Planning effort directed toward Funding as Indicated by excess capacity
EEC	= Expected Excess disposal system Capacity
FRPF	= Fraction of Regional Planning effort directed toward stimulation of research Funding
IPAE	= Impact on Planning Effort Allocation of Estimate of past effects of planning effort on funding
RPEF	= Rate of allocation of Regional Planning Effort to encourage Funding for pollution research
RPE	= Regional Planning Effort awaiting allocation to a specific function
RPE2	= Regional Planning Effort allocated to stimulate funding for solid waste pollution research
ERPFC	= Effective Regional Planning effort toward Funding due to Capacity considerations
DPF	= Delay for Planning to affect Funding
RPELS	= Regional Planning Effort Allocated for Legislative and Social tasks
CRPE	= Change in Regional Planning Effort
CREC	= Change in Regional Planning Effort due to Capacity Considerations
IRPA	= Impact of Awareness of Solid waste Pollution on Regional Planning Effort
RPE1	= Regional Planning Effort allocated to enhance community awareness of solid waste pollution
IEEC	= Impact of Estimated Excess Capacity
EICF	= Estimated Impact of regional planning on Funding
ICREC	= Impact on Change in Regional planning Effort due to Capacity considerations
IECP	= Impact of Excess Capacity on Planning effort
FRP1	= Fraction of Regional Planning Effort allocated for legislative and social tasks
ERPE	= Effective Regional Planning Effort for legislative and social taks
RPD	= Regional Planning effort to Discover unmeasured levels of solid waste pollution
PPA	= Policy of regional Planning for Allocation of effort
ICF	= regional planning Impact on Funding for pollution research due to excess Capacity
IAFR	= total impact of community awareness of solid waste pollution and regional planning effort on Funding for Research and education in solid waste pollution
IAFRI	= Impact of community Awareness of solid waste pollution on Funding Research and education
LFREP	= Level of Funding for Research and Education in solid waste Pollution

Allocation and Impact of Planning Effort

Regional Planning's policy for allocating expenditure of effort appears in Figure 37. Changes in the regional planning effort arise from two sources. The changes in planning effort to affect community awareness of solid waste pollution results from the past effort allocated to enhance awareness and the impact of this effort. The second source of change in regional planning effort lies in the change in planning effort in order to affect funding for pollution research. Regional planning effort as defined in the equation below represents the amount of planning effort added in each solution interval before allocation to a specific function.

12R CRPE.KL=(IRPA.K)(RPE1.K)

12R CREC.KL=(IECP.K)(RPE2.k)

52L RPE.K=RPE.J+(DT)(CRPE.JK+CREC.JK-RPELS.JK-RPEF.JK)

CRPE = Change in Regional Planning Effort (man-months/month)

CREC = Change in Regional Planning Effort due to Capacity Considerations (man-months/month)

IRPA = Impact of awareness of solid waste pollution on Regional Planning Effort (percentage)

RPE1 = Regional Planning Effort allocated to enhance community awareness of solid waste pollution (man-months/month)

IECP = Impact of Excess disposal system Capacity on Planning effort (man-months/month)

RPE2 = Regional Planning Effort allocated to stimulate funding for solid waste pollution research (man-months/month)

RPE = Regional Planning Effort awaiting allocation to a specific function (man-months/month)

RPELS = Regional Planning Effort Allocated for Legislative and Social tasks (man-months/month)

RPEF = Regional Planning Effort to encourage Funding for pollution research (man-months/month)

The regional planning effort allocated to affect funding for pollution research changes as a result of estimates of excess disposal system capacity. Management of the solid waste system increases the planning effort to stimulate research funding when excess disposal capacity exists. The decision to increase the planning effort for funding is colored by estimates of the impact of past expenditures of effort. When planners are allocated to affect funding for pollution research, they do not immediately become effective. A delay of approximately 12 months expires before an expenditure of effort becomes fully effective.

```
58A    FRPFI.K=TABHL(TFRP,EEC.K,0,1,.1)
C      TFRP*=0/.07/.14/.21/.28/.35/.42/.44/.5/.5/.5
12A    FRPF.K=(FRPFI.K)(IPAE.K)
12R    RPEF.KL=(RPE.K)(FRPF.K)
IL     RPE2.K=RPE2.J+(DT)(RPEF.JK+0)
6N     RPE2=0.5
```

```
3L    ERPFC.K=ERPFC.J+(DT)(1/DPF)(RPE2.J-ERPFC.J)
6N    ERPFC=0
C     DPF=12
```

FRPFI = Fraction of Regional Planning effort directed toward Funding as Indicated by excess capacity (percentage)

TFRP = Table for FRPFI

EEC = Expected Excess disposal system Capacity (percentage)

FRPF = Fraction of Regional Planning effort directed toward stimulation of research Funding (percentage)

IPAE = Impact on Planning Effort Allocation of Estimate of past effects of planning effort on funding (percentage)

RPEF = Rate of allocation of Regional Planning Effort to encourage Funding for pollution research (man-months/month)

RPE = Regional Planning Effort awaiting allocation to a specific function (man-months/month)

RPE2 = Regional Planning Effort allocated to stimulate funding for solid waste pollution research (man-months/month)

ERPFC = Effective Regional Planning effort toward Funding due to Capacity considerations (man-months/month)

DPF = Delay for Planning to affect Funding

The amount of regional planning effort allocated for legislative and social tasks is that portion of the effort awaiting allocation after making assignments for funding. The level of effort for legislative and social tasks experiences a delay of about 24 months before becoming fully effective.

```
7A    FRP1.K=1-FRPF.K
12R   RPELS.KL=(RPE.K)(FRP1.K)
1L    RPE1.K=RPE1.J+(DT)(RPELS.JK+0)
6N    RPE1=0.5
3L    ERPE.K=ERPE.J+(DT)(1/DRPE)(RPE1.J-ERPE.J)
6N    ERPE=0
C     DRPE=24
```

RPELS = Regional Planning Effort for Legislative and Social tasks (man-months/month)

FRP1 = Fraction of Regional Planning effort allocated for legislative and social tasks (percentage)

FRPF = Fraction of Regional Planning effort directed toward stimulation of research Funding (percentage)

RPE = Regional Planning Effort awaiting allocation to a specific function (man-months/month)

RPE1 = Regional Planning Effort allocated to legislative and social tasks (man-months/month)

ERPE = Effective Regional Planning Effort for legislative and social tasks (man-months/month)

DRPE = Delay for Regional Planning Effort allocated to legislative and social tasks to become effective

When the effective regional planning effort to stimulate funding increases, a rise occurs in the level of funding for solid waste pollution research. The rise in funding results from regional planning's impact on community awareness of pollution as shown in Figure 38.

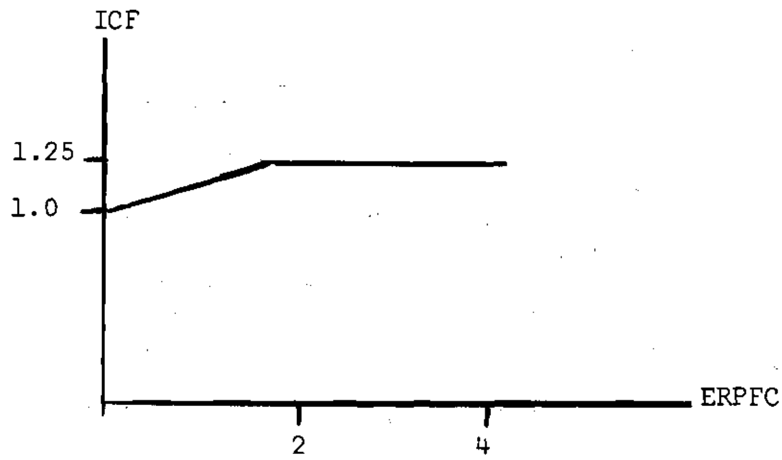


Figure 38. ICF vs. ERPFC

58A ICF.K=TABHL(TICF,ERPFC.K,0,4,.4)

C TICF*=1.05/1.1/1.15/1.2/1.25/1.25/1.25/1.25/1.25/1.25/1.25

12A IAFR.K=(IAFRI.K)(ICF.K)

ICF = regional planning Impact on Funding for pollution research due to excess Capacity (percentage)

ERPFC = Effective Regional Planning effort to stimulate research Funding due to Capacity estimates (percentage)

IAFR = total Impact of community Awareness of solid waste pollution and regional planning effort on Funding for Research and education in solid waste pollution (percentage)

IAFRI = Impact of community Awareness of solid waste pollution on Funding Research and education (percentage)

Regional planning estimates the impact of its efforts to affect research funding and uses this estimate to restrain the pressures which tend to unnecessarily increase the number of regional planners available for allocation. When management of a solid waste system foresees a large increase in the amount of waste to be disposed, the amount of regional planning effort is increased. By increasing the number of planners available, management can allocate more effort to stimulate funding research.

Figure 39 shows management's policy for increasing regional planning effort as a function of excess disposal system capacity. When no excess disposal capacity exists, management does not add planners to affect research funding. Instead, management depends upon the level of solid waste pollution in the environment to set up pressures to increase funding for research. If excess disposal capacity exists, management adds planners to affect funding without waiting for stimulation of funding by a polluted environment.

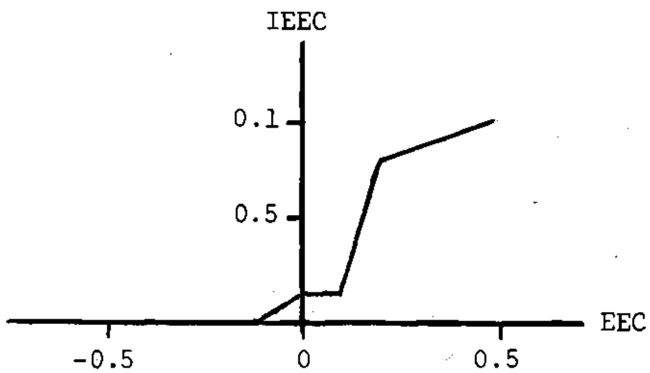


Figure 39. IEEC vs. EEC

The total change in regional planning effort due to capacity considerations results from the managerial increase in planning effort as colored by the estimate of planning's impact on research funding.

```
58A    IEEC.K=TABHL(TIE,EEC.K,-.5,.5,.1)
C      TIE*=0/0/0/0/0/.05/.05/.08/.0925/.1/.105
58A    EICF.K=TABHL(TEIC,ERPFC.K,0,4,.4)
C      TEIC*=1.05/1.1/1.15/1.2/1.25/1.25/1.25/1.25/1.25/1.25/1.25
58A    ICREC.K=TABHL(TICR,EICF.K,0,1.25,.5)
C      TICR*=1/1/1/1/.5/0
12A    IECP.K=(IEEC.K)(ICREC.K)
12R    CREC.KL=(IECP.K)(RPE2.K)
```

IEEC = Impact of Estimated Excess Capacity (percentage)

EEC = Expected Excess disposal system Capacity (percentage)

TIE = Table for EEC

EICF = Estimated Impact of regional planning on Funding (percentage)

TEIC = Table for EICF

ERPFC = Effective Regional Planning effort toward Funding due to Capacity considerations (man-months/month)

ICREC = Impact on Change in Regional planning Effort due to Capacity considerations (man-months/month)

TICR = Table for ICREC

IECP = Impact of Excess Capacity on Planning effort (percentage)

CREC = Change in Regional planning Effort due to Capacity considerations (man-months/month)

RPE2 = Regional Planning Effort allocated to stimulate funding for solid waste pollution research (man-months/month)

Regional planning also uses the estimate of its impact on research funding to regulate further allocation of effort. When regional planning exerts its maximum impact on research funding, no further effort is allocated to stimulate funding.

```
58A    IPAE.K=TABHL(TIP,EICF.K,1.1.25,0.041)
C      TIP*=1/1/.75/.375/0
```

IPAE = Impact on Planning effort Allocation of Estimate of the planning effort impact on funding (percentage)

TIP = Table for IPAE

EICF = Estimated Impact of regional planning effort on Funding (percentage)

Impact of Source Reduction of Waste on Research Funding

As the per capita production of waste declines due to technological advances, sustained support for solid waste pollution research becomes unnecessary. When technology experiences enough growth to significantly reduce the volume of solid waste produced, funding for pollution research should be decreased. To accomplish this, a national planning commission for solid waste pollution estimates the amount of per capita reduction and reduces the budget for solid waste research funding accordingly. Figure 40 shows the national planning commission's policy for reducing the research budget as a function of its estimate of the reduction in the per capita production of waste.

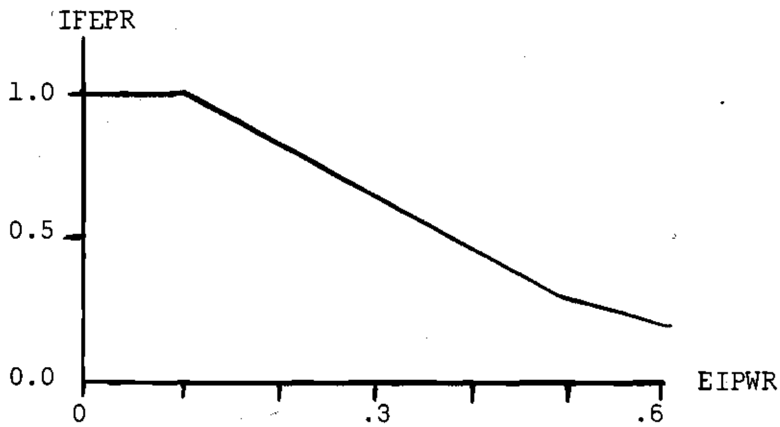


Figure 40. IFEPR vs. EIPWR

```
58A    EIPWR.K=TABHL(TEIPW,ETP.K,0.5,.5)
C      TEIPW*=0/0.25/.05/.1/.18/.25/.35/.5/.6/.6/.6
58A    IFEPR.K=TABHL(TIFE,EIPWR.K,0,.6,.1)
C      TIFE*=1/1/.8/.62/.45/.25/.2
13A    LFREP.K=(PLFP.K)(IAFR.K)(IFEPR.K)
```

EIPWR = Estimate of Impact of technology on Per capita Waste Reduction (percentage)

TEIPW = Table for EIPWR

ETP = Effective Technology of Pollution (percentage)

IFEPR = Impact on Funding of Estimate of Impact of technology on Per capita Reduction of solid waste (percentage)

TIFE = Table for IFEPR

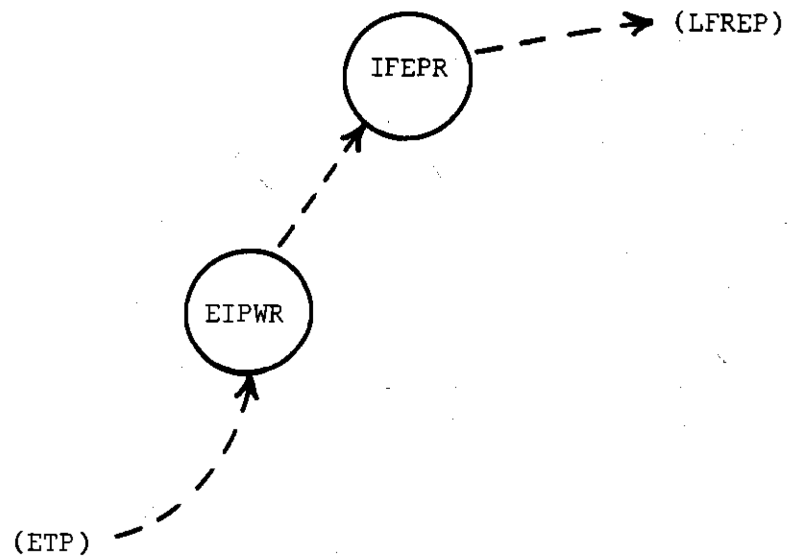


Figure 41. Impact of Source Reduction of Waste on Research Funding

Table 12. Legend for Figure 41

EIPWR	= Estimate of Impact of technology on Per capita Waste Reduction
ETP	= Effective Technology of Pollution
IFEPR	= Impact on Funding of Estimate of Impact of technology on Per capita Reduction of solid waste
LFREP	= Level of Funding for Research and Education in solid waste Pollution

LFREP = Level of Funding for Research and Education in solid waste Pollution (percentage)

IAFR = Impact of community Awareness of solid waste pollution on Funding for Research and education in solid waste pollution (percentage)

PLFP = Previous Level of Funding for research and education in solid waste Pollution (dollars)

Growth in Disposal System Capacity

Solid waste management initiates growth in disposal system capacity in the manner shown in Figure 42. Changes in the estimate of excess capacity can initiate changes in the rate at which additional capacity is added. A long delay of about 60 months expires before capacity on order becomes available for use.

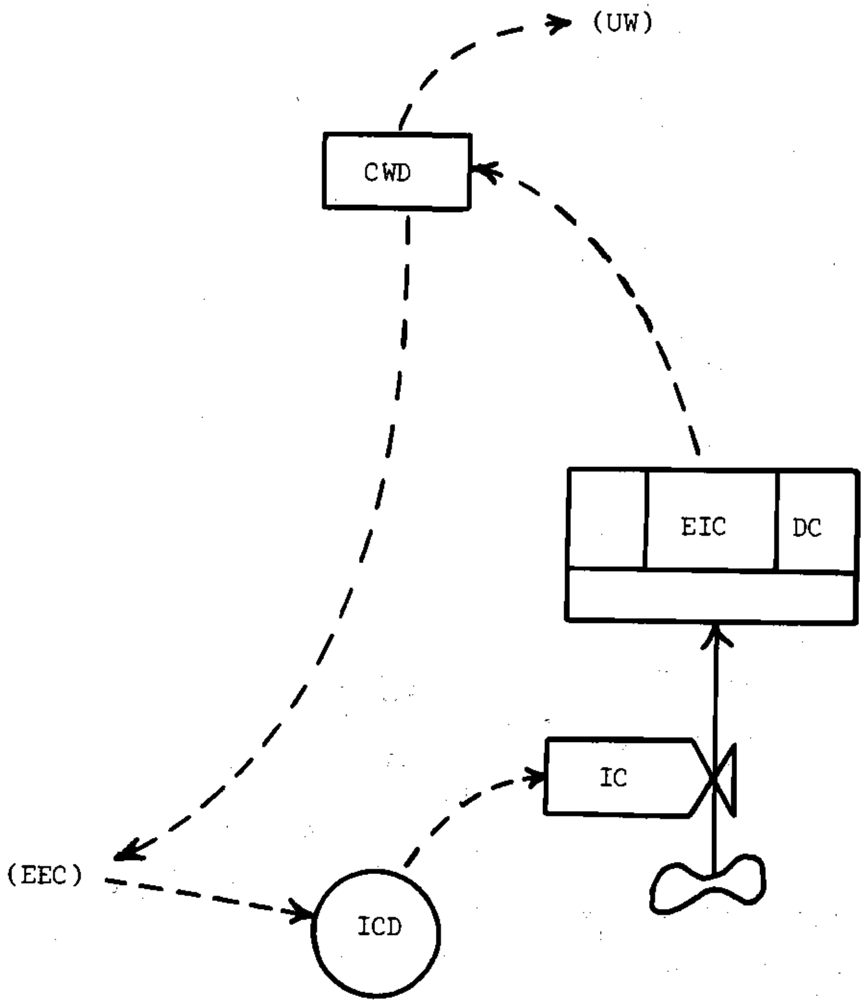


Figure 42. Growth in Disposal System Capacity

Table 13. Legend for Figure 42

EEC	=	Expected Excess disposal system Capacity
IC	=	Increase in rate of Capacity growth
EIC	=	Effective Increase in disposal system Capacity
DC	=	Delay for growth in Capacity
CWD	=	Capacity of Waste Disposal system
ICD	=	Impact of excess capacity on growth of Capacity of Disposal system
UW	=	Undisposed Waste

```
58A   ICD.K=TABHL(TID,EEC.K,-1,.2,.1)
C     TID*=.003/.003/.003/.003/.003/.003/.0024/.0018/.0012/
      .0012/.0012/.0012/0
12R   IC.KL=(ICD.K)(CWD.K)
39R   EIC.KL=DELAY3(IC.JK,DC)
C     DC=60
1L    CWD.K=CWD.J+(DT)(EIC.JK+0)
6N    CWD=190000
```

ICD = Impact of excess capacity on growth of Capacity of Disposal system (percentage/month)

TID = Table for ICD

EEC = Expected Excess disposal system Capacity (percentage)

IC = Increase in rate of Capacity growth (tons/month)

EIC = Effective Increase in disposal system Capacity (tons/month)

DC = Delay for growth in Capacity (months)

CWD = Capacity of Waste Disposal system (tons)

Influence of Technology on Acceptability of Pollution

Technological growth can exert a large impact on the passage of pollution laws and standards. Figure 43 shows the influence of technology on regional planning's ability to define the acceptability of pollution through legislative procedures. As the effective technology of pollution increases, regional planning becomes more effective in determining the acceptability of solid waste pollution per unit of effort expended.

```
58A    ITEP.K=TABHL(TITE,ETP.K,0,5,.5)
C      TITE*=1/.975/.95/.86/.77/.68/.59/.5/.5/.5/.5
58A    IPAPX.K=TABHL(TIRPX,RPA.K,0,8,1)
C      TIRPX*=1/.96/.88/.75/.55/.44/.37/.31/.25
12A    IRPAP.K=(IPAPX.K)(ITEP.K)
```

ITEP = Impact of Technology on Effectiveness of regional Planning in defining acceptability of pollution (percentage)

TITE = Table for ITEP

IPAPX = Impact of regional Planning on Acceptability of Pollution due to planning effort exerted (percentage)

TIRPX = Table for IPAPX

ETP = Effective Technology of Pollution

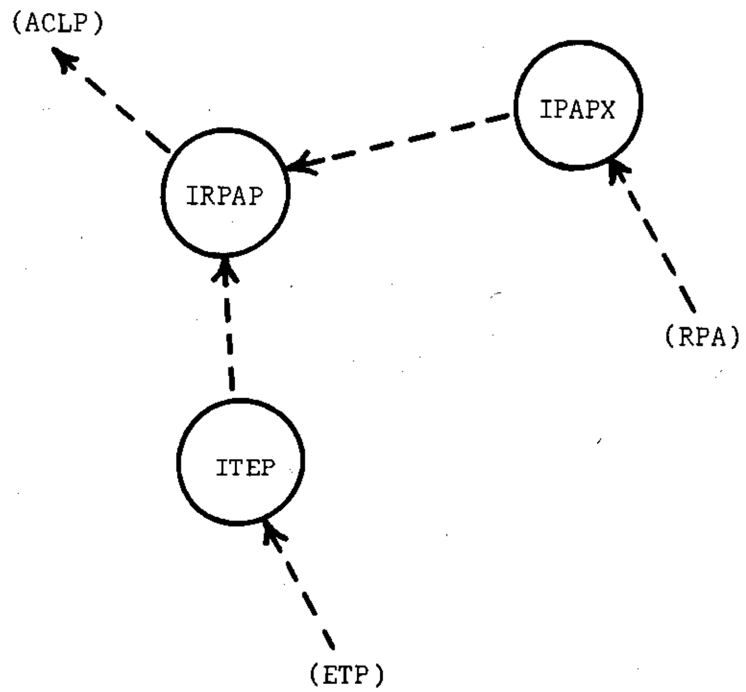


Figure 43. Influence of Technology on Acceptability of Pollution

Table 14. Legend for Figure 43

IPAPX	=	Impact of regional Planning on Acceptability of Pollution due to planning effort exerted
ETP	=	Effective Technology of Pollution
RPA	=	Regional Planning effort to define Acceptability of pollution
IRPAP	=	Impact of Regional Planning on the Acceptance of traditional levels of solid waste pollution
ITEP	=	Impact of Technology on Effectiveness of regional Planning in defining acceptability of pollution
ACLP	=	Acceptable Level of solid waste Pollution in the community

RPA = Regional Planning effort to define Acceptability of pollution (man-months/month)

IRPAP = Impact of Regional Planning on the Acceptance of traditional levels of solid waste pollution (percentage).

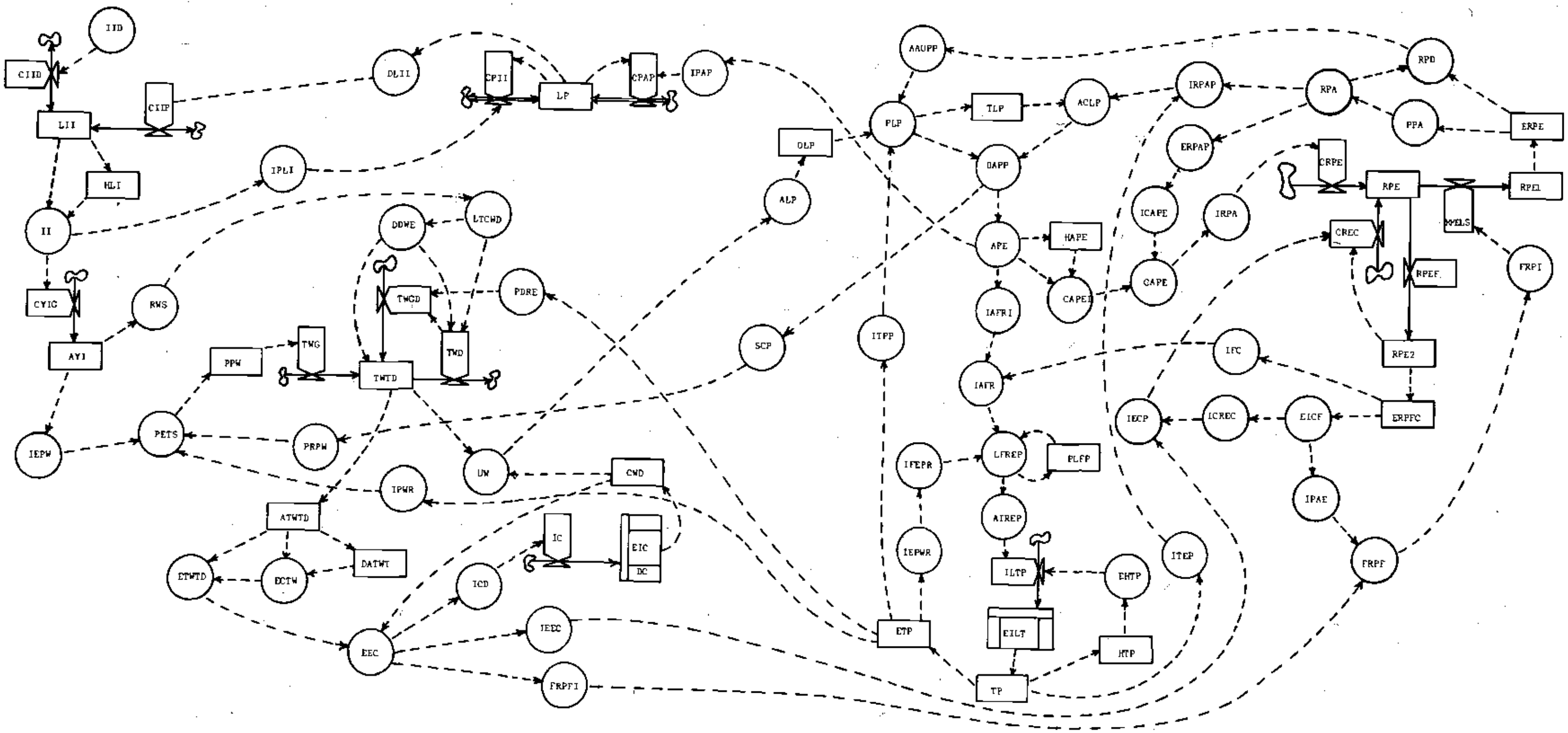


Figure 44. Restructure Flow Diagram

CHAPTER V

ANALYSIS OF RESTRUCTURE RUNS

This chapter discusses the behavior of the model with the restructure changes of Chapter IV. The run analyzed first contains the same policies and environmental conditions for the system that Run 2 displayed. Subsequent runs examine system behavior under different policies and conditions.

Run 3--Restructure of Basic Model

The results of Run 3 appear in Figure 45. Management of the solid waste system in Run 3 attacks pollution by encouraging technological growth which can lead to reductions in the volume of solid waste being produced. The attempt to reduce the rate of production of solid waste represents a departure from the traditional management approach of being concerned only with solid waste disposal techniques.

Some striking differences exist between the results of Run 3 and the results of Run 2. Technology, for example, experiences over 14 times as much growth as in Run 2. An increase in technology of this magnitude makes possible a substantial reduction in the per capita production of solid waste after month 120. The growth in technology results primarily from pressures set up by the actual level of pollution. Although an effective regional planning effort of over 0.7 man-months per month stimulates research funding after month 30, this amount of effort does not halt the decline in the level of research funding that

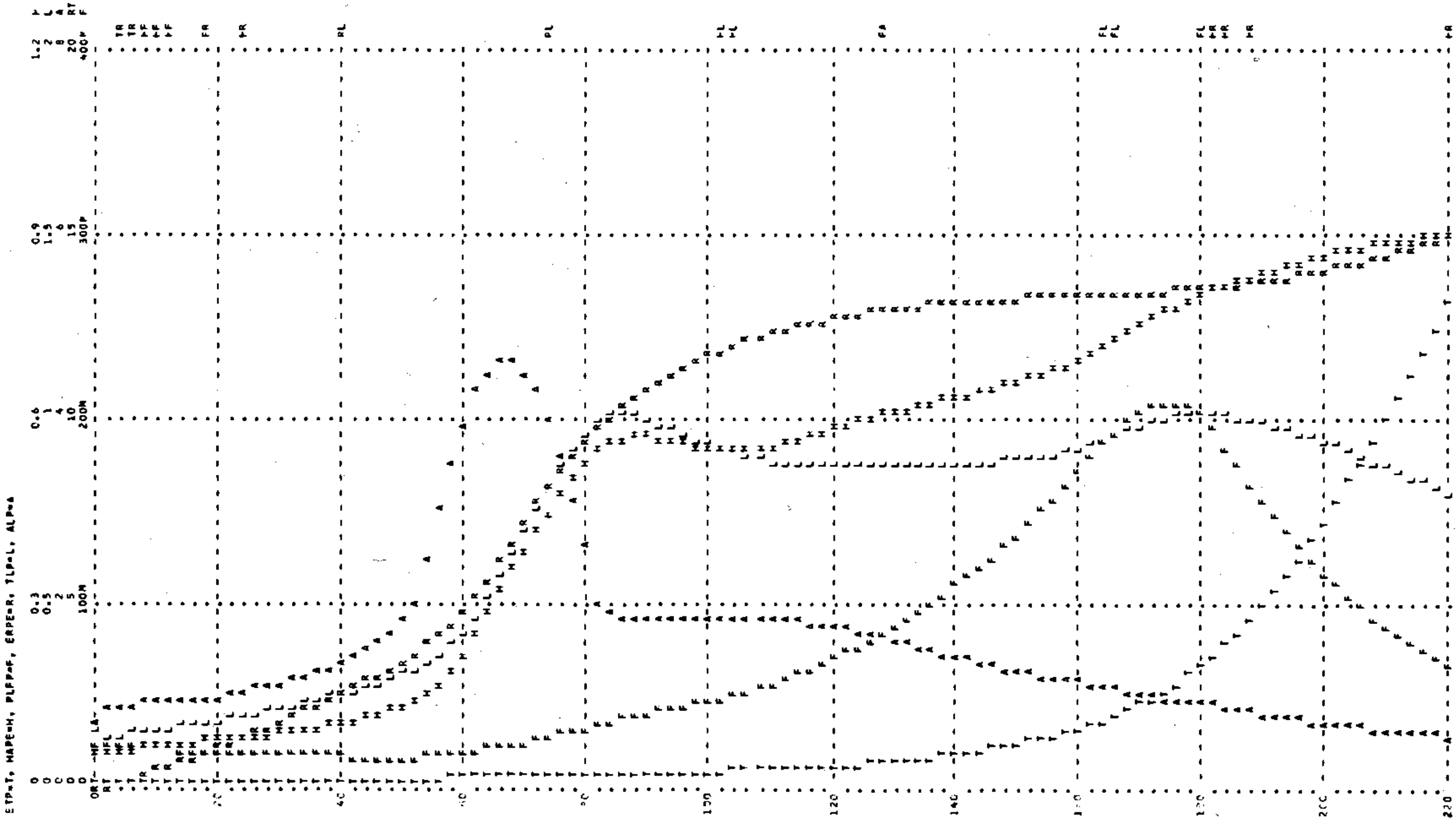


Figure 45. Run 3--Restructure of Basic Model

Table 15. Key to Printouts Restructure of Model

T =	Effective level of Technology in use to combat solid waste Pollution
H =	Historical Awareness of solid waste Pollution Effects
F =	Previous level of Funding for research and education in solid waste Pollution
R =	Regional Planning Effort awaiting allocation to a specific function
L =	Traditional Level of solid waste Pollution in the community
A =	Actual Level of solid waste Pollution

exists until month 48. Prior to month 48 and up to month 68, the actual level of pollution increases and sets up pressures to increase the regional planning effort allocated to enhance community awareness of pollution. The resulting increase in regional planning effort increases community awareness to the extent that funding for pollution research is increased after month 48. Although the actual level of pollution declines after month 68, it remains well above the level of pollution that is acceptable to the community for the remainder of the run. As a result, the regional planning effort to enhance awareness by securing passage of pollution laws and standards continues to increase for the duration of the run to a final value of over 14 man-months per month. Regional planning through its increase in effort is able to continually raise the level of historical awareness of solid waste pollution except for a minor setback from month 90 to month 102. This brief decline in awareness results from the rapid decrease in actual level of pollution from month 68 to month 86. The high level of community awareness of pollution that is sustained by regional planning leads to increases in the level of funding from $17.6 million in month 48 to $209.6 million in month 174. Funding begins to decline after month 174 because of abatement of the pollution problem. Per capita production of waste declines from a high of 156.6 pounds per person in month 54 to a low of 76.3 pounds per person per month in month 220. The decline in per capita production of waste arises due to reductions in the use of disposable packaging by both consumers and industry.

The actual level of pollution in Run 3 experiences a sharp rise from month 52 to month 68 and a sharp decline from month 68 to month 82. The reason for the rapid change in the actual level of pollution is the highly nonlinear nature of solid waste pollution. As the amount of undisposed waste remaining in the environment increases, the actual pollution level increases almost exponentially. From the table for the actual level of pollution, an amount of undisposed waste that would require the disposal system 1.5 months to remove leads to an actual level of pollution of magnitude 2. If the undisposed waste requires 2 months to remove, the actual level of pollution is 5, and for an amount of undisposed waste requiring 2.5 months, the actual level of pollution is 8. Hence, when the amount of undisposed waste in the environment requires more than 1.5 months for disposal, the actual level of pollution can change very rapidly. The rapid decline in the actual level of pollution from month 68 to month 82 results from a decline in the use of disposable packaging by consumers. After month

82, further decreases in the level of pollution become possible due to reductions brought about by a combination of consumer and industrial reductions in the use of disposable packaging.

The results of Run 3 indicate that the system as restructured in Chapter IV can effectively combat solid waste pollution at its source. Since pressures arise that increase the level of funding for pollution research, technology experiences enough growth to implement significant industrial reductions in the amount of waste being produced. As the volume of solid wastes being generated declines, the disposal system becomes able to process the wastes generated, and the level of solid waste pollution abates.

Run 4--Fragmentation of Planning Effort for Enhancing Awareness of Pollution

The entire regional planning effort to enhance community awareness of solid waste pollution was allocated in Run 3 to defining the acceptable level of pollution by securing passage of pollution laws and standards. In Run 4, however, regional planning fragments its effort to affect awareness. Half of the effort goes to define the acceptability of pollution and half goes to enhance community perception of the level of pollution in existence. By comparing the results of Run 4 to those of Run 3, one can observe the changes in system behavior that result from fragmentation of the planning effort to affect awareness of pollution. Fragmentation of the planning effort in the model is accomplished by changing the following table.

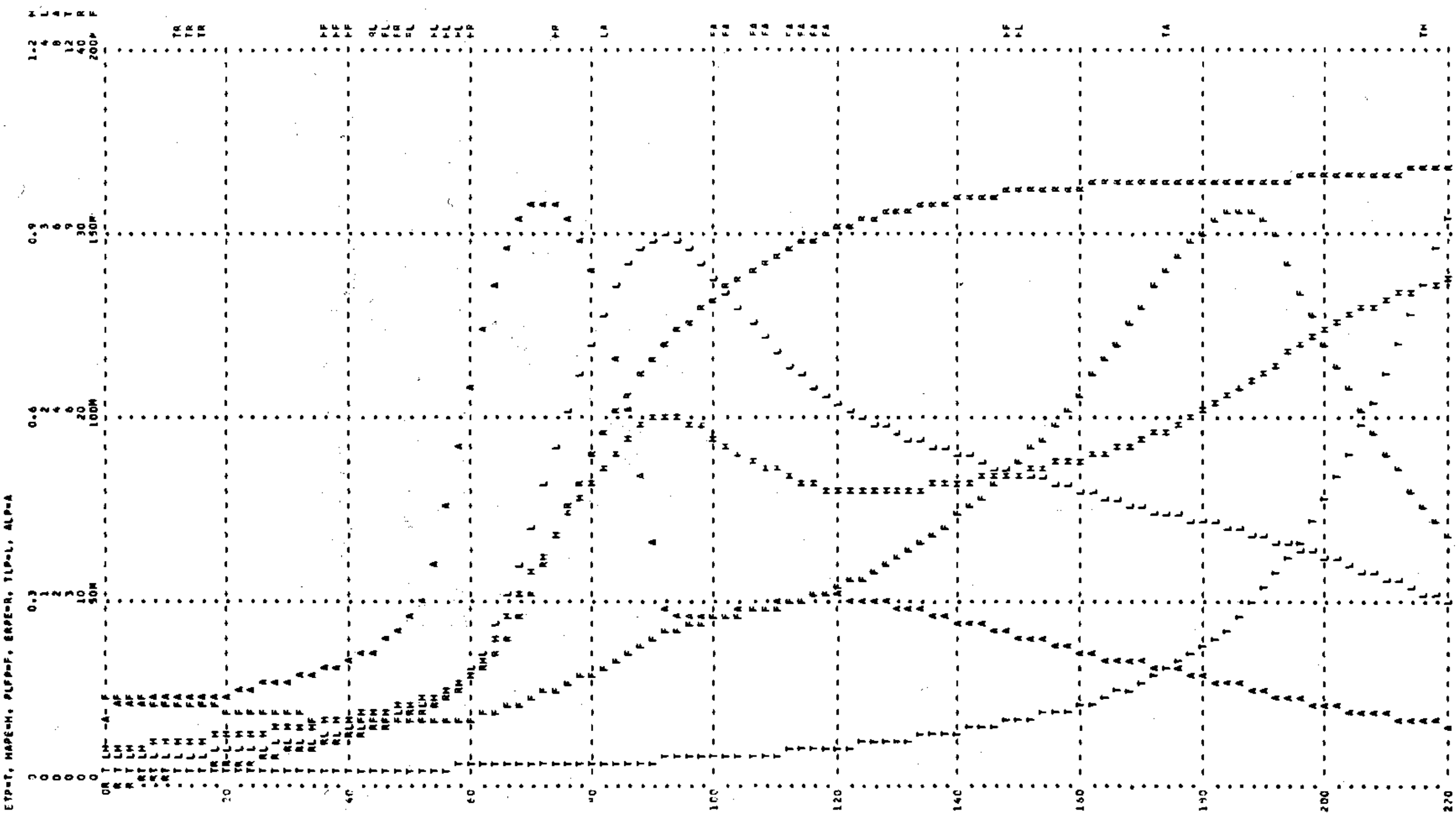


Figure 46. Run 4--Fragmentation of Planning Effort to Enhance Awareness of Pollution

C TPPA*=.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5

The results of Run 4, which appear in Figure 46, closely resemble the behavioral patterns of Run 3. The magnitude of different variables, however, differs considerably between the two runs. The regional planning effort allocated to stimulate awareness of solid waste pollution climbs to over 33 man-months/month in Run 4 as compared with 14.7 man-months/month in Run 3. Since regional planning in Run 4 allocates half of its effort to defining the acceptable level of pollution, more planning effort is spent on defining acceptability in Run 4 than is spent in Run 3. In Run 3, however, the amount of effort allocated to defining acceptability is greater than in Run 4 until month 84. The smaller impact on acceptability that initially exists in Run 4 leads to a lower level of funding for pollution research. In Run 4, the level of funding rises to $156 million in month 186 as compared to $209 million in month 174 in Run 3. The lower level of funding for pollution research in Run 4 restricts technological growth to 69 per cent of the growth of Run 3. Regional planning's initially smaller impact on acceptability of pollution also leads to a higher actual level of pollution in Run 4 than in Run 3. Since planning in Run 4 does not at first reduce the consumer susceptibility to disposal packaging as much as in Run 3, the per capita production of waste is higher in Run 4 for the first half of the run. Hence, the actual level of pollution in Run 4 has an index of 6.3 in month 78 while in Run 3, the index for the level of pollution rises to a high of 4.6 in month 66.

Some interesting observations can be made from the results of Run 4 concerning fragmentation of the regional planning effort to stimulate awareness of pollution. Fragmentation of planning effort allows the actual level of pollution to increase higher than the level which exists without fragmentation. A lower level of funding for pollution research and less technological growth occurs with fragmentation than without, even though much more planning effort is allocated to stimulate awareness of pollution. Comparisons of the results of Run 3 and Run 4 indicate that the greatest reductions in the amount of waste produced can be secured by concentrating planning effort on defining the acceptability of solid waste pollution.

Run 5--Overestimate of Planning Impact on Acceptability of Pollution

Regional planning in Run 5 overestimates its impact on the acceptability of pollution. As in Run 3, regional planning concentrates the entire planning effort allocated to enhancing awareness of pollution on definition of the acceptability of pollution. However, in Run 5 regional planning erroneously estimates its impact on the acceptability of pollution. The error in regional planning's estimate of its impact appears in the following equation which replaces the equation for TRPAP in the restructure model of Chapter IV.

```
C      TRPAP*=1/0.93/0.75/0.45/0.3/0.22/0.18/0.15/0.12/0.09/0.08
```

Figure 47 shows the results of Run 5. The amount of planning effort allocated to define acceptability of pollution is 5.1 man-months

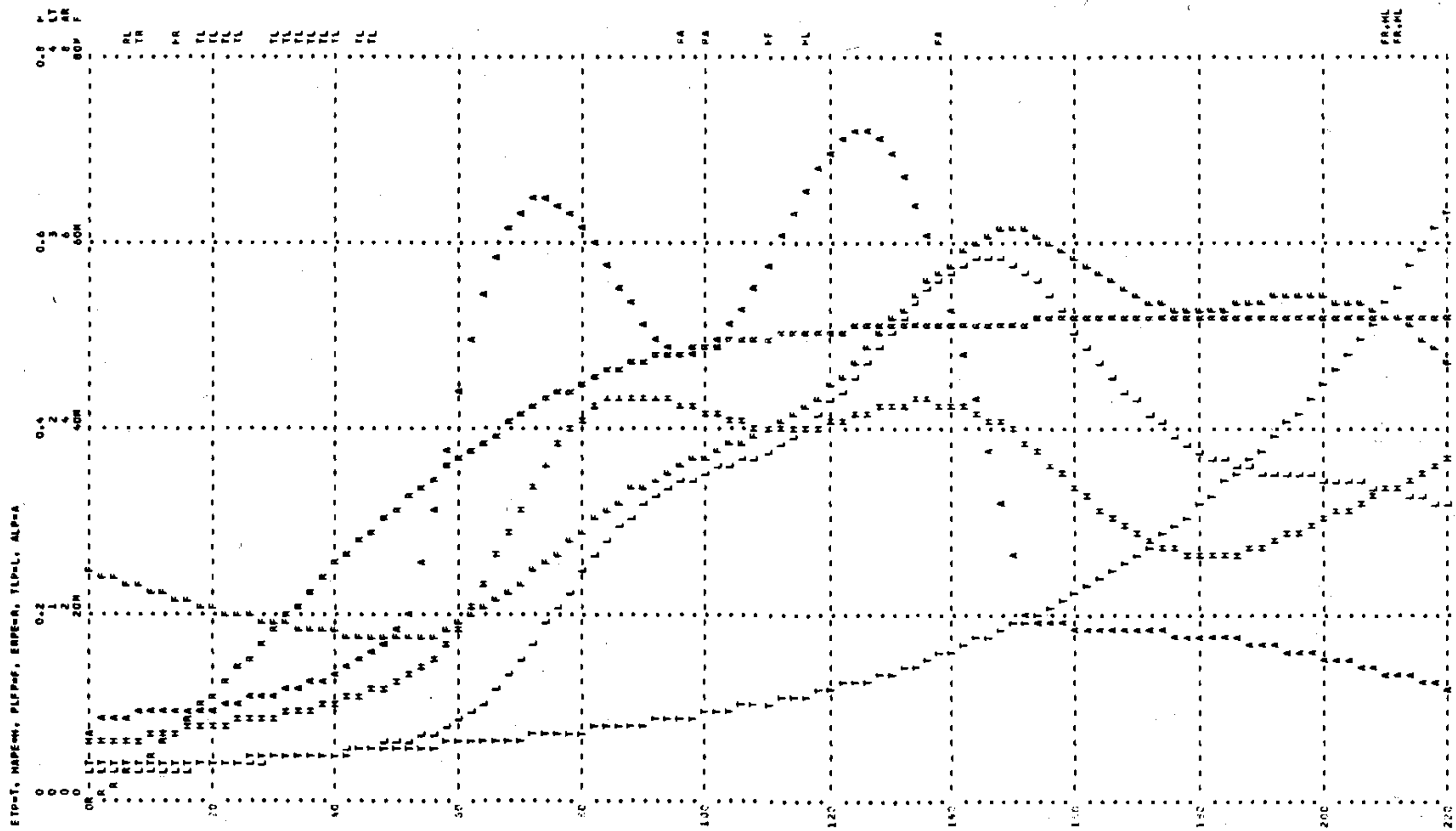


Figure 47. Run 5--Overestimate of Planning Impact on Acceptability of Pollution

per month in Run 5 as compared to 14.7 man-months per month in Run 3. With a smaller amount of planning effort allocated to defining the acceptability of pollution, community acceptability of pollution in Run 5 rises almost ten times as high as in Run 3. The high degree of acceptability allows a high actual level of pollution to arise by month 72. With a rising level of solid waste pollution, community perception of the problem increases until the perceived level of pollution is much greater than the acceptable level. When this happens, consumers begin to purchase merchandise whose packaging does not contribute to the pollution problem and the actual level of pollution abates from month 72 to month 98. However, the lower level of pollution then allows the community perception of the level of pollution to decline and consumers become more susceptible to purchasing goods in disposable packaging. Hence, the actual level of pollution increases from month 98 to month 124. After month 124, declines in the actual level of pollution result from a combination of reductions in the use of disposable packaging by both consumers and industry. The growth in technology made possible some industrial reductions in the use of disposable packaging by finding suitable packaging substitutes. Technology in Run 5, however, experiences only 25 per cent as much growth as in Run 3 due to a much lower level of funding for pollution research. Funding in Run 5 rises to just slightly over $61 million in month 150. In Run 3, funding reaches a high of $209 million in month 174. Since technology experiences much less growth in Run 5 than in Run 3, the per capita reduction in the amount of waste produced is much less in Run 5. In month 216 the per capita production of waste is 149.7 pounds per person per month in Run 5 in contrast to 76.3 pounds per person per month in Run 3.

If regional planning overestimates its impact on the acceptability of pollution, undesirable system behavior results as indicated in Run 5. Too few planners are added to properly define the acceptability of pollution through the passage of pollution laws and standards. The relatively high degree of acceptability of pollution prevents extensive technological growth and hence solid waste pollution persists for a long period of time in the environment.

Run 6--Rapid Growth in Regional Planning

In Run 6 changes in the regional planning effort allocated to solid waste pollution problems are 50 per cent more responsive to changes in the awareness of pollution than in Run 3. If in Run 3 regional planning might add 1 man-month per month for a given change in awareness, planning with its greater response in Run 6 would add 1.5 man-months per month for the same amount of change. The greater response results from changing the following card in the model used for Run 3.

```
C       TIRPA*=-.1125/-.105/-.09/-.06/0/0/.075/.12/.1387/.15/.1575
```

The impact on system behavior of regional planning's greater response to changes in awareness of pollution can be seen in the results of Run 6 in Figure 48. In Run 6 the amount of planning effort allocated for defining the acceptability of pollution increases more rapidly than in Run 3. For example, in month 60 the planning effort to define

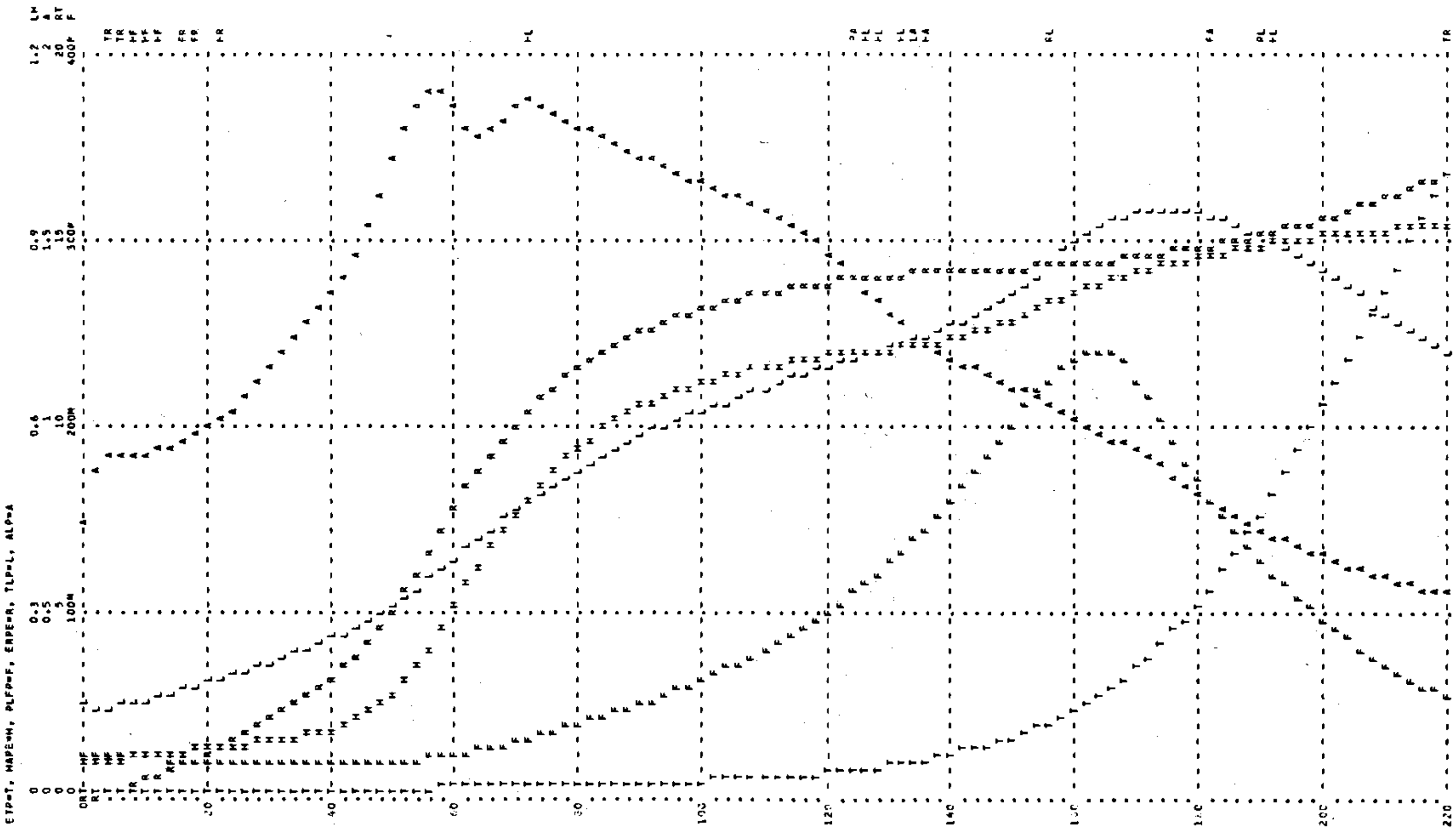


Figure 48. Run 6--Rapid Growth in Regional Planning

acceptability is 4.8 man-months per month in Run 3 and 7.8 man-months per month in Run 6. In month 216, the planning effort for defining acceptability is 14.7 man-months per month in Run 3 and 16.5 man-months per month in Run 6. The more rapid growth in planning effort in Run 6 enables regional planning to create enough community awareness of the pollution problem to lessen the severity of the level of pollution. Because of greater reductions in the use of disposable packaging by consumers, the actual level of pollution in Run 6 rises only 40.6 per cent as high as in Run 3. The earlier planning response also leads to a level of funding for research of $238.7 million in Run 6 as compared to a high of $209.6 million in Run 3. Technology in Run 6 experiences 131 per cent as much growth as Run 3 due to the greater level of research funding.

The results of Run 6 indicate that desirable system behavior results from regional planning being sensitive to system pressures to change its level of effort. The sooner regional planning can expend effort to attack a rising level of pollution, the more the level's growth is restricted. For a given period of time, technology advances more rapidly and to a higher level in a system in which changes in the regional planning effort are more sensitive to changes in the community awareness of pollution. Hence, regional planning can improve system behavior by quickly ascertaining changes in the need for planning effort and making the desired change as rapidly as possible.

Run 7--Consumer Reductions in the Use of Disposable Packaging

In Run 7 consumers never reduce their use of disposable packaging. Regardless of how high the level of solid waste pollution climbs, consumers still purchase as much merchandise as possible in disposable packages. Hence, no decrease occurs in the per capita production of waste due to changes in consumer buying habits. By comparing the results of Run 7 to those of Run 3, the impact on system behavior of consumer reductions in the use of disposable packaging can be noted.

The following card is substituted in the model for Run 3 to reflect the high community susceptibility of disposable packaging in Run 7.

```
C       TPRPW*=0/0/0/0/0/0/0/0/0/0
```

The results of Run 7 appear in Figure 49. In both Run 7 and Run 3, the effective regional planning effort for creating awareness of pollution climbs to just over 14 man months per month. In Run 3, planning can combat the rising level of pollution by affecting consumer buying habits. In Run 7, however, consumers never restrict their use of disposable packaging. Hence, the actual level of pollution in Run 7 rises to its maximum index of 8 by month 64 and remains there until month 204. The actual level of pollution in Run 3 rises to a maximum index of 4.6 in month 64 and rapidly declines to an index of less than 2 by month 84. After month 84, the level declines more slowly to a value of 0.6 in month 216. A sharp decline the actual level of pollution occurs after month 204 in Run 7 due to advances in technology.

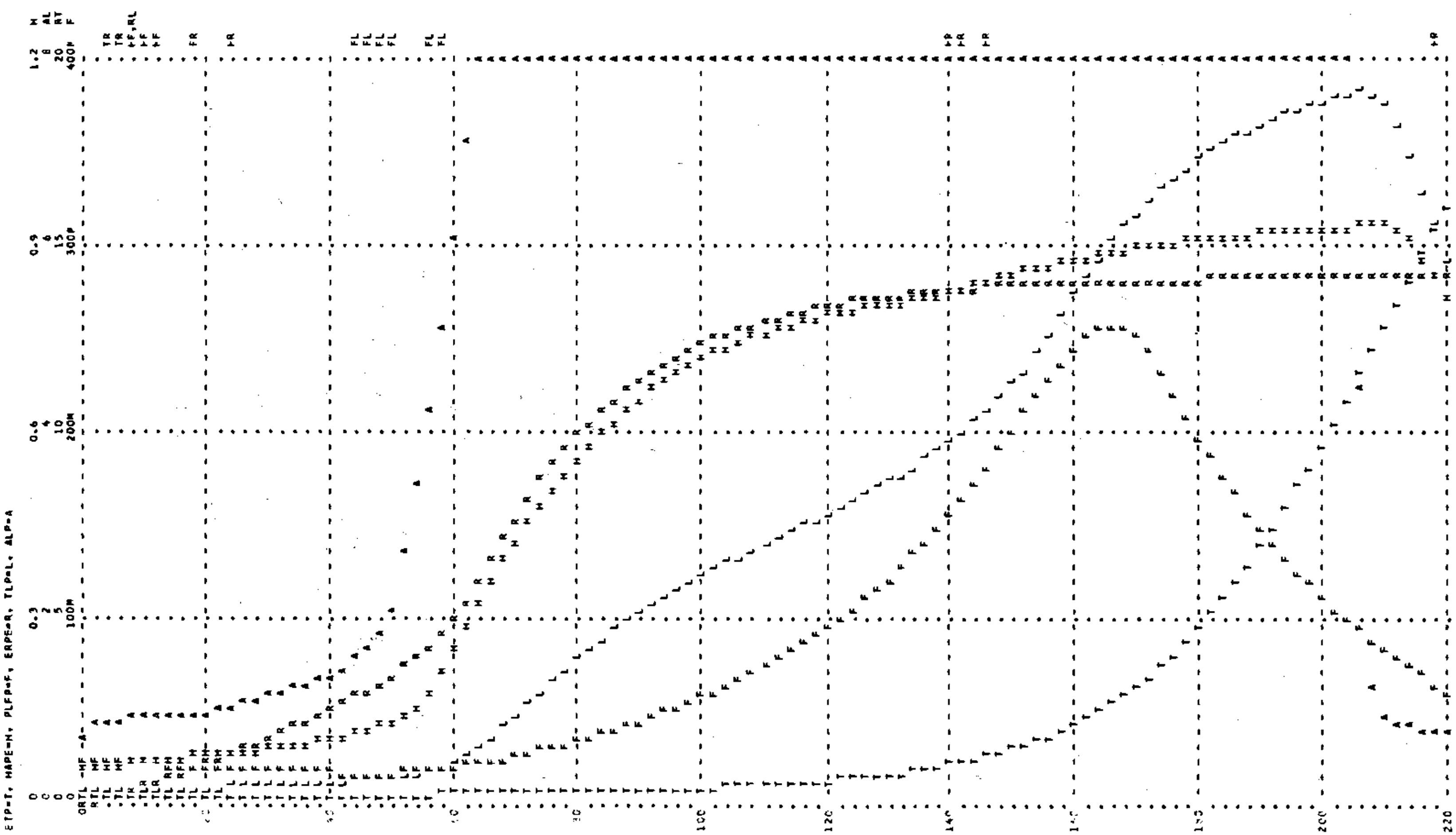


Figure 49. Run 7--Consumer Reductions in the Use of Disposable Packaging

Technology grows 1.25 times as much as in Run 3. A higher level of funding for pollution research in Run 7 made possible the greater technological growth. With a higher level of pollution in the environment, funding for research reaches a high of $256.2 million in Run 7 as compared to $209.6 million in Run 3. The actual level of pollution drops abruptly in Run 7 due to the model's structural relationship between the actual level of pollution and the undisposed waste. The undisposed waste remaining in the environment declines after month 164, but the table for the actual level of pollution does not detect the decline until month 206. At month 206 the undisposed waste in the environment is decreasing rapidly and thus, the actual level of pollution abruptly declines.

The results of Run 7 indicate that a highly polluted environment results when consumers remain insensitive to a rising level of pollution. When personal convenience in the use of disposable packaging outweighs the consumer's concern for solid waste pollution, no consumer reductions in the amount of waste being produced occurs. Without consumer reductions in the production of waste, technology experiences more growth due to the increased pressures built up by the high level of solid waste pollution. The greater advances in technology become necessary to abate high levels of solid waste pollution in environments in which consumers insist on the continued convenience of disposable packaging.

Run 8--Reduced Effectiveness of Regional Planning Effort

The regional planning effort to enhance awareness of pollution in Run 8 is 100 per cent less effective than in Run 3. This means that for a given set of results, regional planning in Run 8 requires twice as many men as in Run 3. The following two cards were substituted in the Run 3 model to make the planning effort less effective.

```
58A    IPAPX.K=TABHL(TIRPX,RPA.K,0,16,2)
58A    ERPAP.K=TABHL(TRPAP,RPA.K,0,16,1.6)
```

Figure 50 shows the results of Run 8. Since the planning effort is 100 per cent less effective in Run 8 than in Run 3, the amount of effort allocated to enhancing awareness of solid waste pollution is approximately twice the amount of Run 3. The high actual level of pollution from month 68 to month 100 stimulates the growth of regional planning in Run 8. The level of pollution continually increases up to its maximum index of eight in month 68 because regional planning in Run 8 is much less effective in alerting the community to the pollution problem. Hence, consumers do not restrict their use of disposable packaging until after month 60. The per capita production of waste decreases from 160 pounds per person per month in month 60 to 137 pounds per person per month in month 108. Hence, enough undisposed waste from the time periods prior to month 60 remains in the environment to overload the disposal system and keep the level of pollution high. After month 86 the amount of undisposed waste in the environment begins to decline, and the actual level of pollution decreases from

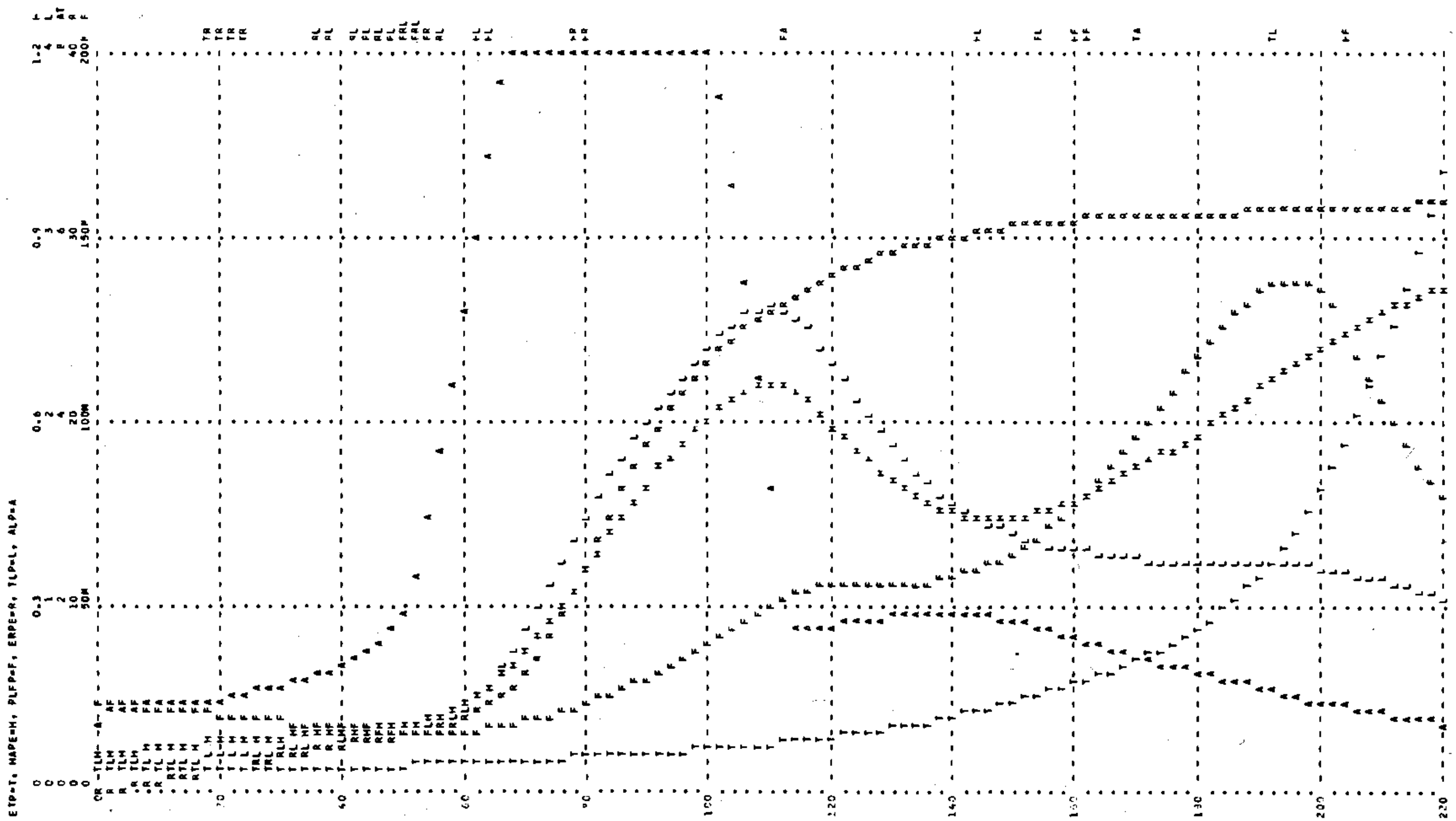


Figure 50. Run 8--Reduced Effectiveness of Regional Planning Effort

month 100 to month 120. With a lower level of pollution, consumers again become susceptible to disposable packaging and the per capita production of waste increases to 161 pounds per person per month in month 144. As a result, the actual level of pollution increases slightly from month 120 to month 146. After month 146, the level of pollution continually declines due to consumer and industrial decreases in the use of disposable packaging. Toward the end of the run, industrial reductions in the use of disposable packaging become more and more important due to technological advances in solid waste research. Technology in Run 8 experiences only 55 per cent as much growth as in Run 3 because of less support in funding for research. Funding in Run 8 increases as in Run 3 until month 120 at which time research funding levels off until month 136. The decline in community awareness of pollution which accompanies the decrease in the actual level of pollution from month 100 to month 120 causes the leveling off of research funding. After month 136 research funding climbs to a high of $138 million in month 198 and declines thereafter due to budget cuts.

When the effectiveness of regional planning effort is low, undesirable system behavior results as indicated in Run 8. Although more planning effort is allocated to enhance the awareness of pollution, the level of pollution rises to serious highs before planning can influence system behavior. Low effectiveness in the planning effort results in lower research budgets and thus, less technological growth. The comparison of the results of Run 8 and Run 3 indicates that steps taken to increase the effectiveness of the regional planning effort should result in improved system behavior.

Run 9--Reductions in Research Budget

In Run 9 the national planning commission for solid wastes erroneously estimates the impact of technological growth on industrial reductions in the use of disposable packaging. The national planning commission in Run 9 estimates that technological advances exert twice as great an impact as they really exert. Hence, the commission reduces the research budget for solid waste pollution a given amount in Run 9 when technology experiences half as much growth as in Run 3. The change in the Run 3 model to include the error appears below.

```
58A   EIPWR.K=TABHL(TEIPW,ETP.K,0,2.5,0.25)
```

The behavior of Run 9 duplicates that of Run 3 until month 152. By month 152, technology has grown enough that the national planning commission begins to reduce the research budget due to its erroneous estimate of technology's impact on the pollution problem. The level of research funding declines from $116 million in month 152 to $23 million in month 220. Due to the earlier budget cuts in Run 9, technology realizes only 63 per cent as much growth as in Run 3. However, this amount of technological growth results in approximately the same reductions in the per capita production of waste as in Run 3. For the immediate pollution problem facing the system, the erroneous estimate of Run 9 seems to have found a solution at a much lower cost than in Run 3. However, the long range benefits which may result from the greater technological growth of Run 3 might overshadow the greater research costs.

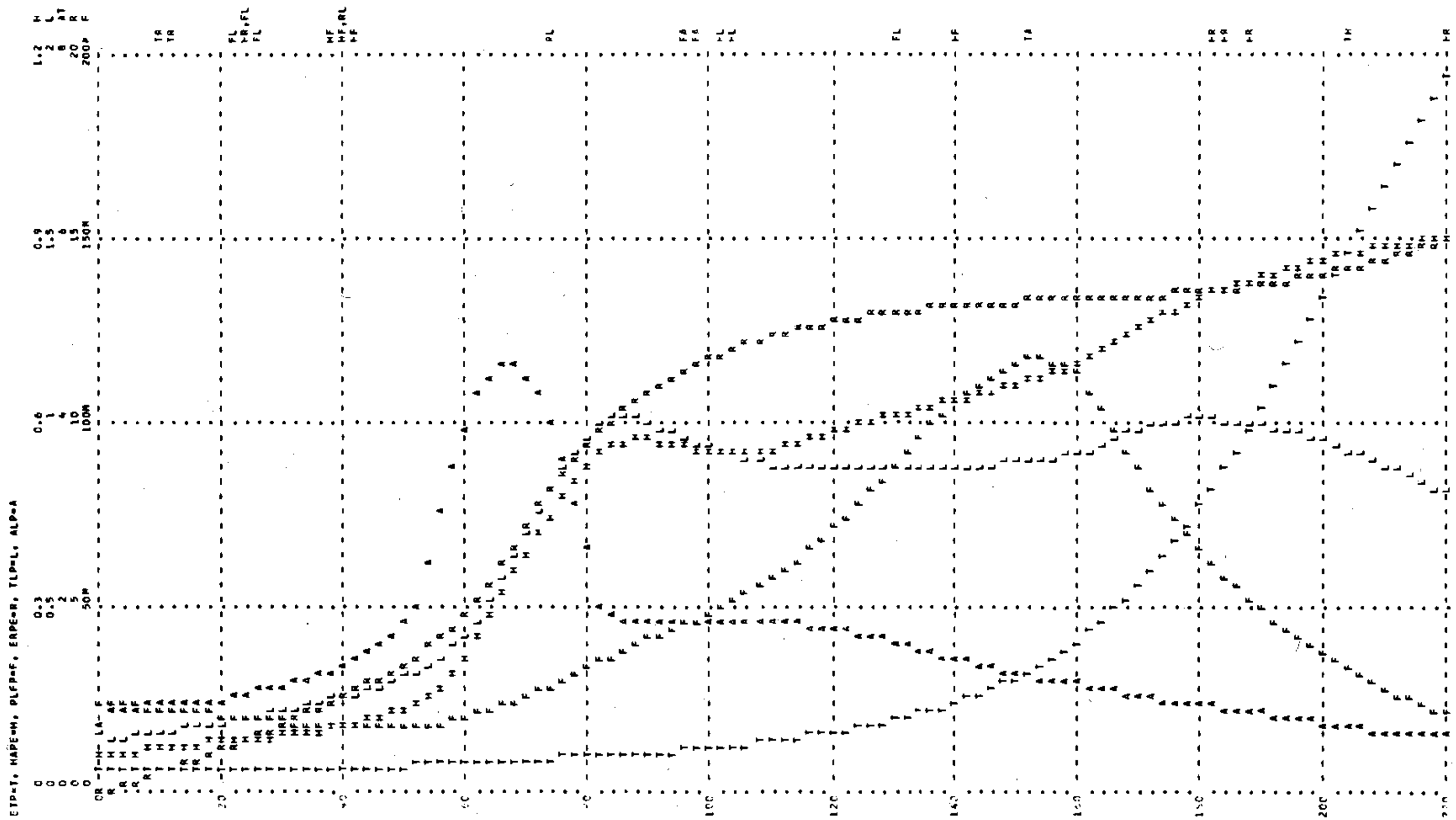


Figure 51. Run 9--Reductions in Research Budget

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

General Conclusions

The analyses of the runs discussed in Chapter III and Chapter V suggest the following general conclusions:

1. Continued emphasis on improvement of solid waste disposal techniques and growth in disposal system capacity may offer temporary solutions to solid waste pollution problems.

2. Solid waste systems at present generate little pressure to reduce the volume of solid waste being generated.

3. Specific allocations of regional planning effort to affect solid waste research funding and to create awareness of solid waste pollution can stimulate the growth of pressures which lead to reductions in the amount of waste produced.

4. The most effective solution to solid waste pollution problems appears to be reductions in the per capita output of solid wastes.

5. When the level of solid waste pollution continually rises, regional planning should concentrate its efforts to create awareness of pollution on the definition of pollution acceptability by securing passage of solid waste pollution laws and standards.

6. Regional planning should attempt to accurately gage its impact on system behavior in order to control its effort expenditure.

7. More desirable system behavior seems to result when regional planning reacts more quickly to system pressures to change its level of effort.

8. A highly polluted environment can result when consumers make no effort to reduce their rate of production of solid wastes even though industrial reductions in the use of disposable packaging do occur.

9. Improvements in the effectiveness of the regional planning effort exerted tend to improve system behavior.

10. Pressures set up in the system can lead to more technological growth than is necessary to reduce the per capita production of waste a given amount.

Recommendations

There are two general areas recommended for additional study. One of the areas pertains to the model as developed in Chapter IV. The other area concerns the construction of a model to study the interaction between different types of pollution.

The present model can be expanded to include salvage considerations in the solid waste management system. Most solid wastes possess some economic value, but the present cost of processing the wastes precludes their salvage. By the addition of salvage aspects to the present model, consideration can be given to the feasibility of recycling solid wastes back into the economy.

Interaction between different types of pollution poses as the other area of possible study. Air pollution, water pollution, and solid waste pollution do not exist independently of each other. Hence, the systems which attempt to control these three types of pollution cannot avoid influencing each other's behavior. To examine the dynamics of the interaction between the systems, a simulation model can be constructed that would lead to a worthwhile analysis of the managerial policies and decisions of pollution control systems.

BIBLIOGRAPHY

BIBLIOGRAPHY

Brennan, Thomas F., "Financing Refuse Collection and Disposal Facilities," Public Works Engineers Yearbook 1954, Chicago: American Public Works Association, pp. 55-100.

Bueche, Dr. Arthur M., "Technology and the Pollution Problem," Testimony before the Subcommittee on Science, Research and Development on "The Adequacy of Technology for Pollution Abatement," U.S. House of Representatives, Washington, D.C., August 9, 1966.

Ehlers, Victor M. and Ernest W. Steel, *Municipal and Rural Sanitation*, Sixth Edition, McGraw-Hill Book Company: New York, 1965, pp. 24-183.

Forrester, Jay W., "Common Foundations Underlying Engineering and Management," *I.E.E.E. Spectrum*, September, 1964, pp. 66-77.

Forrester, Jay W., *Industrial Dynamics*, M.I.T. Press and John Wiley and Sons Inc.: New York, 1961.

Gilbertson, Wesley E., "Scope of the Solid Waste Problem," *Journal of the Sanitary Engineering Division American Society of Civil Engineers*, Vol. 92, No. SA3, June 1966.

Harral, Henry D., "Are Cities Responsible for Disposal of Tree Wastes?," *Compost Science*, Vol. 2, No. 3, Autumn, 1961, pp. 27-29.

Jarmain, W. Edwin, editor, *Problems in Industrial Dynamics*, Cambridge, The M.I.T. Press, 1963.

Lee, Eugene C. and Stanley Scott, "Financing Local Public Works," University of California; Berkeley, 1951.

Olds, Jerome, "Solid Wastes Research and Environmental Health," *Compost Science*, Vol. 3, No. 2, Summer, 1962, pp. 35-37.

Powell, Thomas, "Air Pollution and Incineration," *Compost Science*, Vol. 1, No. 3, Autumn, 1960, pp. 35-37.

Pugh, Alexander L., *Dynomo User's Manual*, Second Edition, The M.I.T. Press, Massachusetts Institute of Technology: Cambridge, Massachusetts, 1963.

"Reclamation of Municipal Refuse by Composting," *University of California Society Engineering Research Project*, Tech Bulletin No. 9, Series 37, June 1953.

"Restoring the Quality of Our Environment," Report of the Environmental Pollution Panel, President's Science Advisory Committee, The White House, November 1965.

McPherson, L. Fillmore, "Organizational Change: An Industrial Dynamics Approach," *Industrial Management Review,* Volume 6, Number 2, Massachusetts Institute of Technology, Spring, 1965, pp. 51-65.

Roberts, Edward B., "Industrial Dynamics and the Design of Management Control Systems," *Management Technology,* December, 1963, pp. 100-118.

"The Solid Waste Disposal Act," Title II of Public Law 89-272, 89th Congress, S. 306-October 20, 1965.

Spradlin, B. C., "Recognition of Community Hazard Problems: The Systems Dynamics," Georgia Institute of Technology, Atlanta, June 1967.

Swanson, Carl. "Some Properties of Feedback Systems as a Guide to the Analysis of Complex Simulation Models," Massachusetts Institute of Technology: Cambridge, 1965.

Waste Management and Control, Publication 1400, National Academy of Sciences--National Research Council, Washington, D.C., 1966.

Wiley, John, "Solid Waste Problems in Metropolitan Areas," *Compost Science,* Vol. 4, No. 2, Summer, 1963, pp. 21-25.