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URBAN ENVIRONMENTAL QUALITY MANAGEMENT

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Blair T. Bower, 7/90

URBAN ENVIRONMENTAL QUALITY MANAGEMENT

INTRODUCTION

Before a meaningful discussion of environmental quality management in urban areas is possible, some definitions and background are necessary. First, what is environmental quality? To the public health engineer, environmental quality involves, for example, vector control, food sanitation, swimming pool inspection, maintenance of adequate quality of drinking water. To the urban designer, it means the visual quality of the design and arrangement of buildings in space. To the hiker, environmental quality might be the visual aesthetics of the forest through which he/she walks, as that quality is affected by logging operations and by other hikers who have discarded litter along the trails. To the social worker, it might be the quality and condition of housing for workers. In sum, environmental quality probably has as many definitions are there are individuals defining it. This is why it is universally difficult to get politicians, civil servants, environmentalists, academics to agree on what it is, or how to measure it.

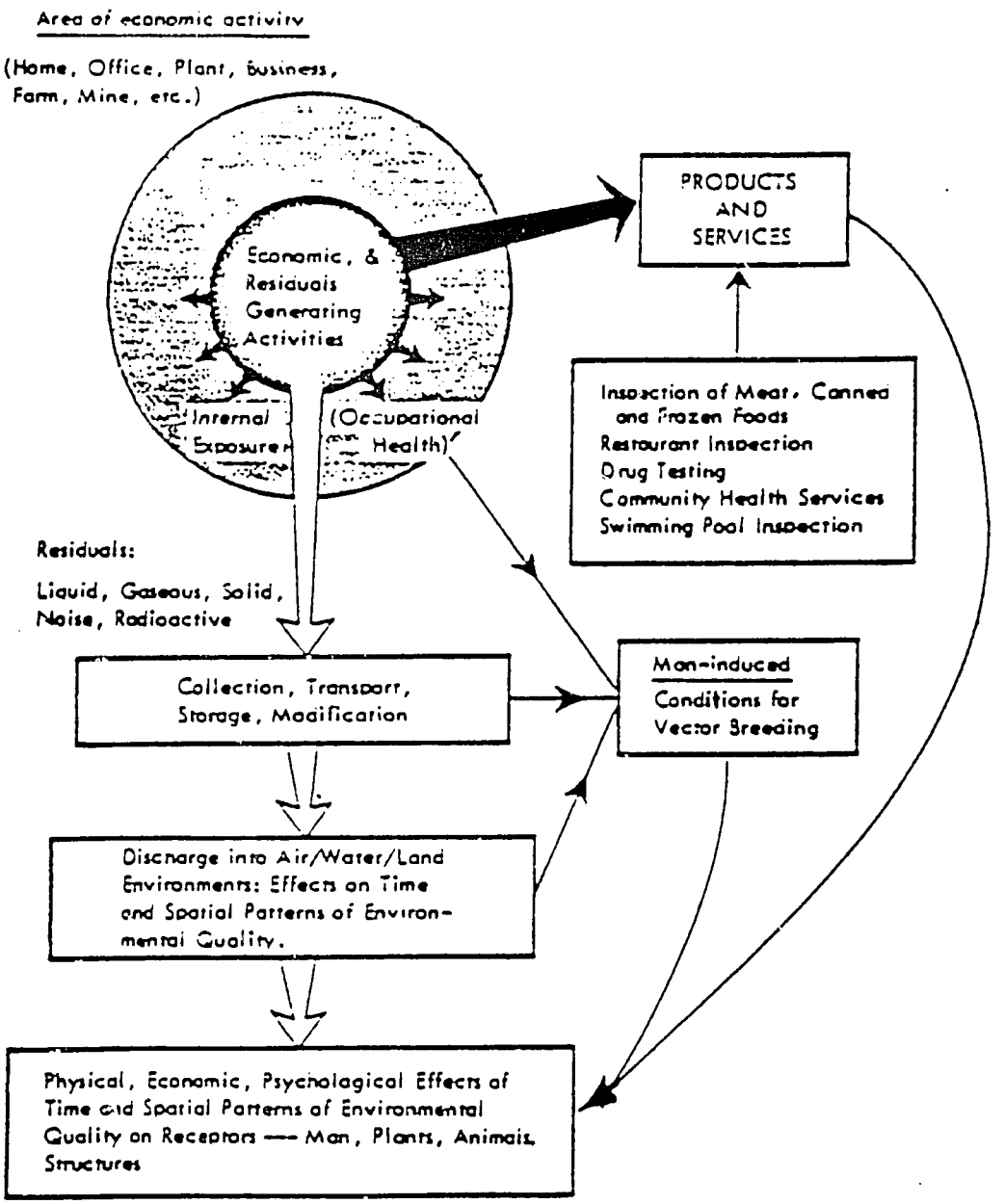
One very important subset of urban environmental quality problems relates to the "discard" of society's leftovers---non-useful outputs or no longer useful outputs---into one or more of the environmental media, i.e., atmosphere, water bodies (surface and ground), land. This sector is termed the residuals-environmental quality sector; it is depicted in Figure 1. It is this sector which is the focus of this report, and it is this sector which is meant when the term "urban environmental quality management" (UEQM) is used.

Some Definitions

Residual

No production or use activity transforms 100% of the material and energy inputs into products, services, utility. There is always something leftover, termed a "nonproduct output" (NPO). No matter how efficient society becomes, there will be leftover liquid, gaseous, solid materials and energy requiring

Figure 1. The Residuals-Environmental Quality Sector of Environmental Quality Management



Source: Bower and Sewell (1971)

disposal.

Traditionally these NPOs have been termed "wastes". However, many of the NPO streams contain materials and/or energy of value. Thus, an NPO becomes a residual only when the cost of collecting, transporting, and processing the NPO to obtain desired material(s) or energy is greater than the value of the material(s) and/or energy obtained. Note that this is an economic definition; hence it is time dependent. That is, the value of the NPO depends on the relative costs of other materials which can be used instead of the NPO, as inputs into other production activities. These costs in turn depend on the level of technology at the point in time, and on various government policies which affect the prices of raw materials. Technology and policies often change over time; hence a residual may become a valuable raw material, or the reverse.

NPOs have also been termed "pollutants", because of the implicit assumption that the discharge of these NPOs into environmental media would have adverse effects on ambient environmental quality (AEQ), and hence on users of the environment. Because not all discharges result in adverse effects---in some cases the effects are actually positive---the neutral term "residual" is used.

The discharge of a residual does not occur until the residual crosses the boundary of the site of an activity, factory or farm, e.g., in or from a pipe or stack, via overland runoff or seepage into groudwater, by truck or rail car. The residual may or may not b modified before discharge into the environment or transport from the activity site.

There are two basic types of residuals, material and energy. There are three forms of material residuals, namely, liquid, gaseous, and solid. Energy residuals are exemplified by heat and noise. Table 1 lists some sources and types of NPOs and residuals. Figure 2 illustrates the basic categories of sources of NPOs and residuals in society.

The driving force in the generation of residuals is final demand, i.e., the

Table 1. Partial List of Residuals Generated in Society, Excluding Spills

Mining: overburden, tailings, leachate, surface runoff, wind entrained particles

Agricultural operations: crop: sediment, pesticides, and nutrients in runoff, nitrogeneous material and pesticides in leachate to ground water, wind-blown sediment, wind transported pesticides, volatilized pesticides, pesticide and fertilizer containers

Silvicultural operations: suspended sediment and pesticides in surface runoff, winds transported pesticides, slash

Transportation: CO, HC, NO_x, particulates, particles from tires deposited on ground surface, oil, liquids discharged from boats, salt/sand from snow "removal", tires, used oil, batteries, obsolete vehicles

Residential: white goods, bulky materials, septage, food wastes, yard wastes, Al (cans, wrap), steel cans, glass, plastic (containers, wrap, trays, utensils), household batteries, UN, UCC, UMOP, junk mail, liquid residuals, CO, NO_x, SO_2, TSP, ash (depending on fuel and heating system)

Energy generation: CO, NO_x, SO_2, TSP, ash (fly, bottom, scrubber sludge), water treatment chemicals, suspended solids, boiler and cooling system blowdown

Manufacturing: "priority pollutants" (liquid), BOD_5, TSS, food wastes, yard wastes, metals, wood, UCC, UN, UMOP, glass, plastic, Al cans, various solid wastes peculiar to manufacturing process/product combinations, e.g., carpet trimmings, cuttings from sheeting in manufacture of mobile homes, gaseous residuals from heating/airconditioning/process steam/electricity generation, water treatment sludge, wastewater treatment sludge, scrubber sludge

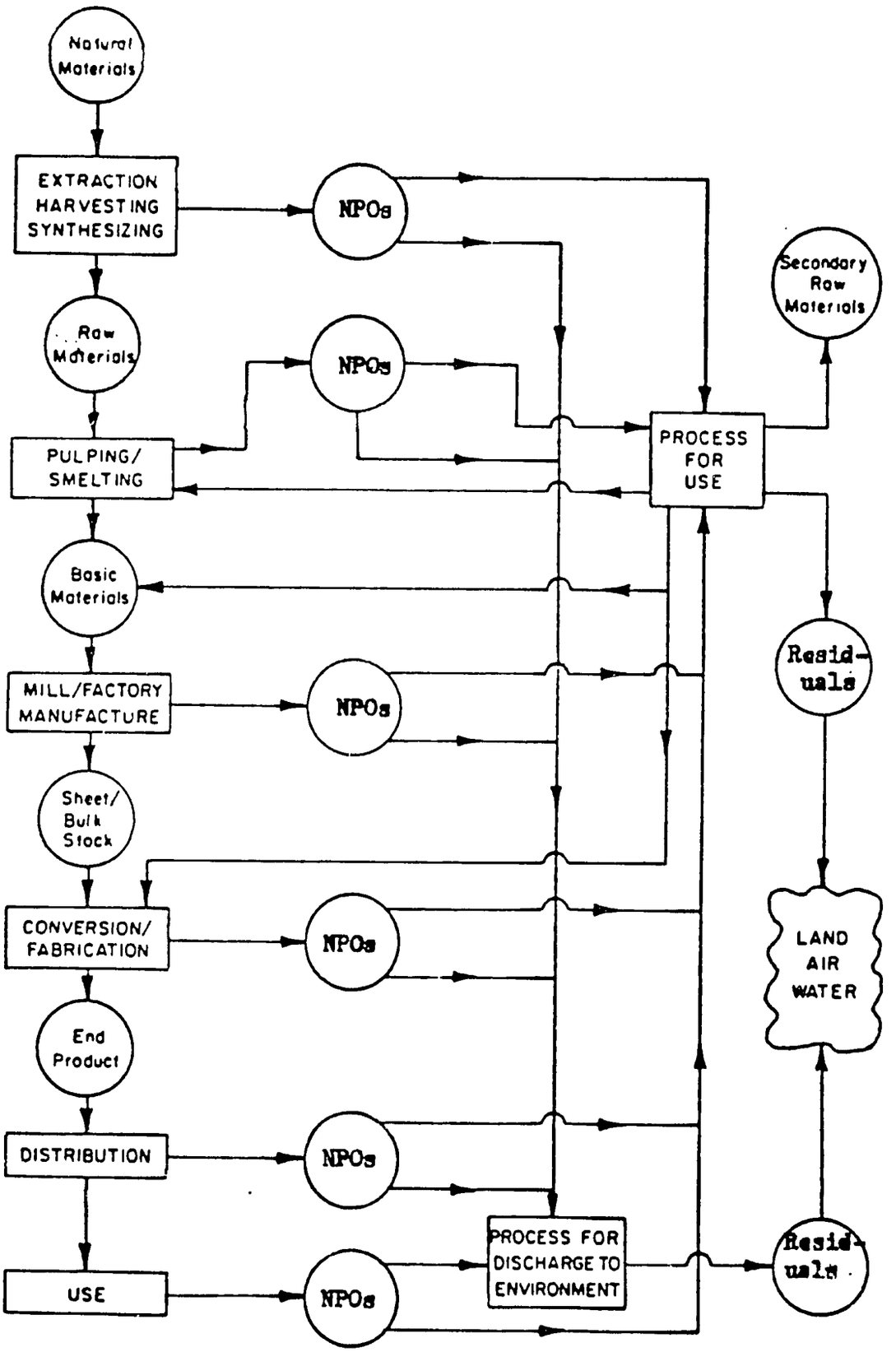
Commercial: food wastes, yard wastes, glass, plastic, Al cans, UCC, UMOP, UN, bulky goods, gaseous residuals from heating/airconditioning, liquid residuals such as BOD_5, TSS

Institutional: same as commercial plus those peculiar to activities, e.g., infectious wastes from hospitals/nursing homes, low level radioactive materials from hospitals/research labs

Municipal: street sweepings, sediment from debris basins, dead animals, grass clippings/brush and tree trimming from public parks/streets/public building areas, water treatment sludge, wastewater treatment sludge, septage

Construction: wood (lumber + tree segments), bricks, dirt, stumps, fixtures, metals, plastic, food wastes and food containers

Figure 2. Sources of NPOs and Residuals in Society



Source: Bewer (1977)

total sum of goods and services demanded by society. These goods and services can be characterized as:

> user goods, e.g., automobiles, transistor radios, food, clothes;
> intermediate goods, e.g., steel, chemicals, lumber;
> producer goods, e.g., buildings, machinery; and
> services, e.g., light, heat, hair cuts, retail stores, legal documents prepared by lawyers and memoranda prepared by government officials.

Note the use of the term "user goods", rather than the traditional "consumer goods". For several hundred years economists lead societies astray with the terms "consumption" and "consumption goods", implying used up/disappear/go away. In reality there is no "away"; goods only provide service or utility or satisfaction for a shorter or longer period of time. Sooner or later a car, suit of clothes, even a building, no longer provides the desired service, and it is "discarded". But its mass does not disappear; the same quantity of material which went into the product essentially is still in existence and must be disposed of in some manner. The law of conservation of mass and energy has not been overthrown, in any society. This fundamental fact indicates the magnitude of the residuals problem in any society, namely: the total weight of residuals to be handled in any year is equal to the total weight of material inputs to production and use activities plus the weight of air withdrawn from the atmosphere for use minus the accumulation of materials in capital goods, such as buildings.

Disposition of NPOs

There are only two basic methods of disposing of NPOs: (1) discharge to the environment, modified or unmodified; and (2) processing to recover material(s) and/or energy for use. Processing requires material and energy inputs and produces residuals as well as desired materials/energy. Various terms are applied to the possible types of processing; no consensus exists with respect to a single set of terms.

Materials and/or energy recovery refers to recovery and use in the same activity. In many, if not most, manufacturing activities, it is economically necessary to recover and use substantial portions of the nonproduct materials and energy formed in producing the given product mix, e.g., recovery of chemicals and fiber in pulp and paper production. Analogous materials and energy recovery is essential in many non-manufacturing activities as well. The extent to which materials and/or energy recovery is practiced at any point in time in an activity is a function of the costs of mater-

ials/energy recovered relative to costs of new (makeup) materials/energy. The latter are usually purchased in the market, or from another segment of the plant or another plant of the firm, at a price which may or may not be close to the open market price. The cost of new and recovered materials and energy is a function of: the technology of basic production; the technology of materials and energy recovery, e.g., technology of heat exchangers for energy recovery; the technology of production of "new" material and energy inputs; prices of other factor inputs, such as water and land; and various government policies such as depletion allowances, severance taxes, freight rates, tariffs. Tradeoffs are possible between the design of production technology to increase the physical efficiency of production, i.e., reduce the formation of nonproduct outputs, and utilization of materials and energy recovery technology. In designing a plant, the objective is to optimize the combination of basic production technology plus materials/energy recovery. [Note: Materials and energy recovery can also take place in service and use activities.]

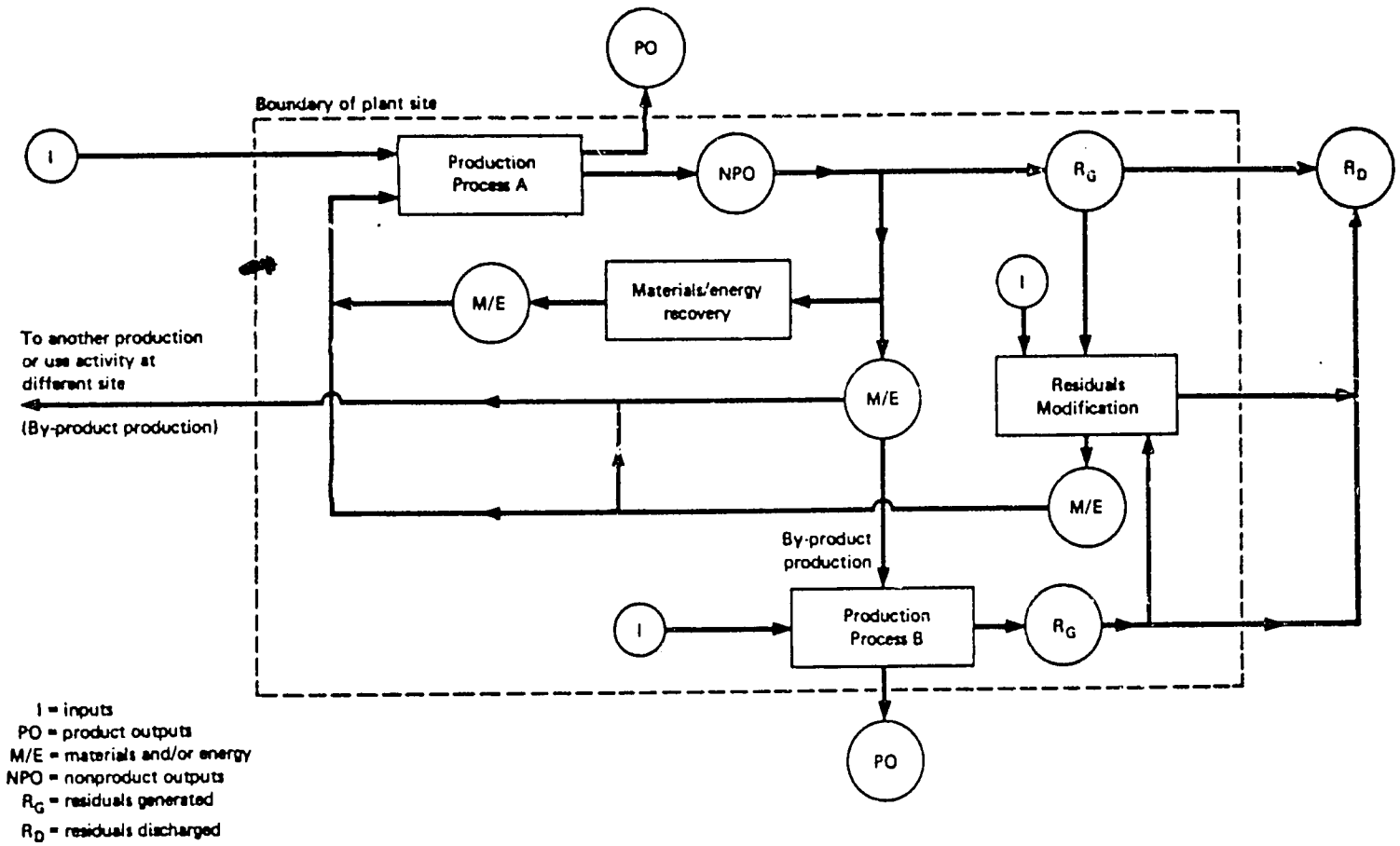
Byproduct production refers to nonproduct materials and energy which are used as inputs into another (different) production activity, at the same location as, or at a different location than, the production activity which generated the original NPOs. Byproduct production is exemplified by the use of tomato pulp from the canning of tomatoes and tomato juice in the production of pet food and the use of peach pits from canning of peaches to make charcoal briquettes.

In terms of profit maximization for an individual plant/activity (assuming profit maximization is the objective), for factor prices faced by, and the product mix/product characteristics of the plant at a point in time, materials/energy recovery and/or byproduct production are undertaken only to the level where the marginal value of the recovered material or energy equals the marginal cost of recovery. Because both the value of the recovered material or energy and the cost of recovery often change over time, the extent of recovery and byproduct production, and therefore the extent of residuals generation, are likely to vary over time.

Reclamation or resource recovery refers to the situation where an NPO is transported from where it was generated to another location in order to be processed to obtain a desired material for use in some production activity. That is, a desired material---such as lead in batteries, steel in obsolete vehicles, copper in used copper wire---is processed to obtain the lead, steel, copper for use as raw materials. Or, an NPO is processed to produce a fuel for use in steam or electric energy generation, e.g., refuse derived fuel (RDF). Or, an NPO is processed to produce compost. Traditionally, the outputs from processing NPOs were termed, "secondary materials" and the activities producing them were referred to as secondary materials operations (firms, plants). This was to distinguish the materials from "virgin" materials, i.e., those extracted directly from nature. By the mid-1980s in the U.S., the term "resource recovery" had become popular, although the processes and principles and objectives were the same as with reclamation.

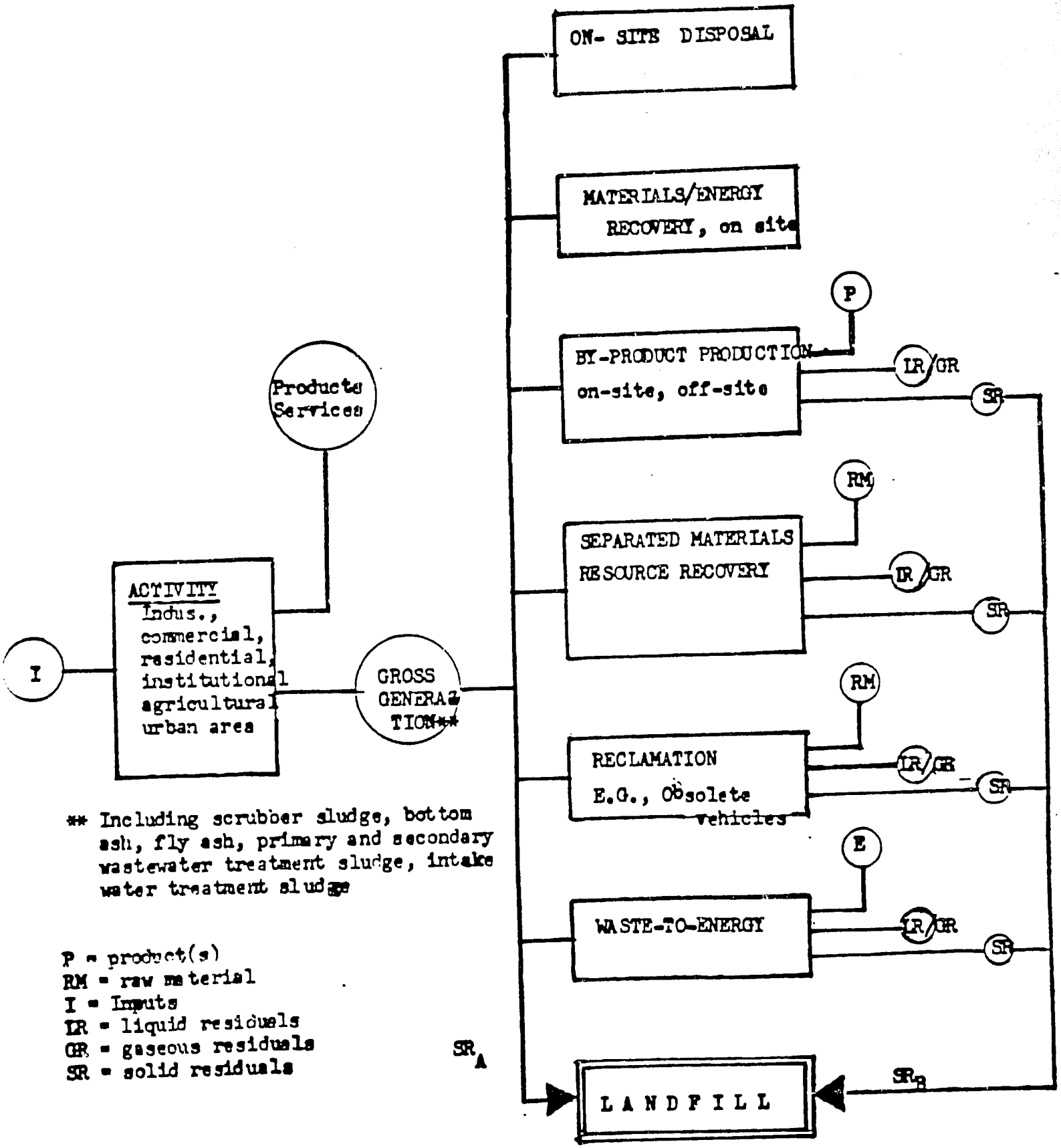
Figure 3 shows the definitions of materials/energy recovery, byproduct production, and residuals generation. Figure 4 illustrates in addition resource recovery/reclamation

Figure 3. Definitions: Materials/Energy Recovery; Byproduct Production; Residuals Generation; Residuals Discharge



Source: Bower (1977)

Figure 4. Disposition of Solid Residuals in Society, Showing Various Processing Alternatives



** Including scrubber sludge, bottom ash, fly ash, primary and secondary wastewater treatment sludge, intake water treatment sludge

P = product(s)
RM = raw material
I = Inputs
LR = liquid residuals
GR = gaseous residuals
SR = solid residuals

Source: Bower (1990)

Two Very Basic Facts

Why Pollution

Traditionally it was considered in all economies that the production of goods and services required some combination of labor (L), raw materials including land (RM), and capital (C). Unfortunately, one essential factor input into production is missing in this formulation, namely, the environmental resources (ES) required, both as inputs---such as air used in combustion processes and water in rivers for production of fish---and as depositories for residuals. Because, as noted above, no production or use process transforms 100% of inputs into desired outputs, the disposal services of the environment media are always required. The same is true for human beings and the residuals they personally generate.

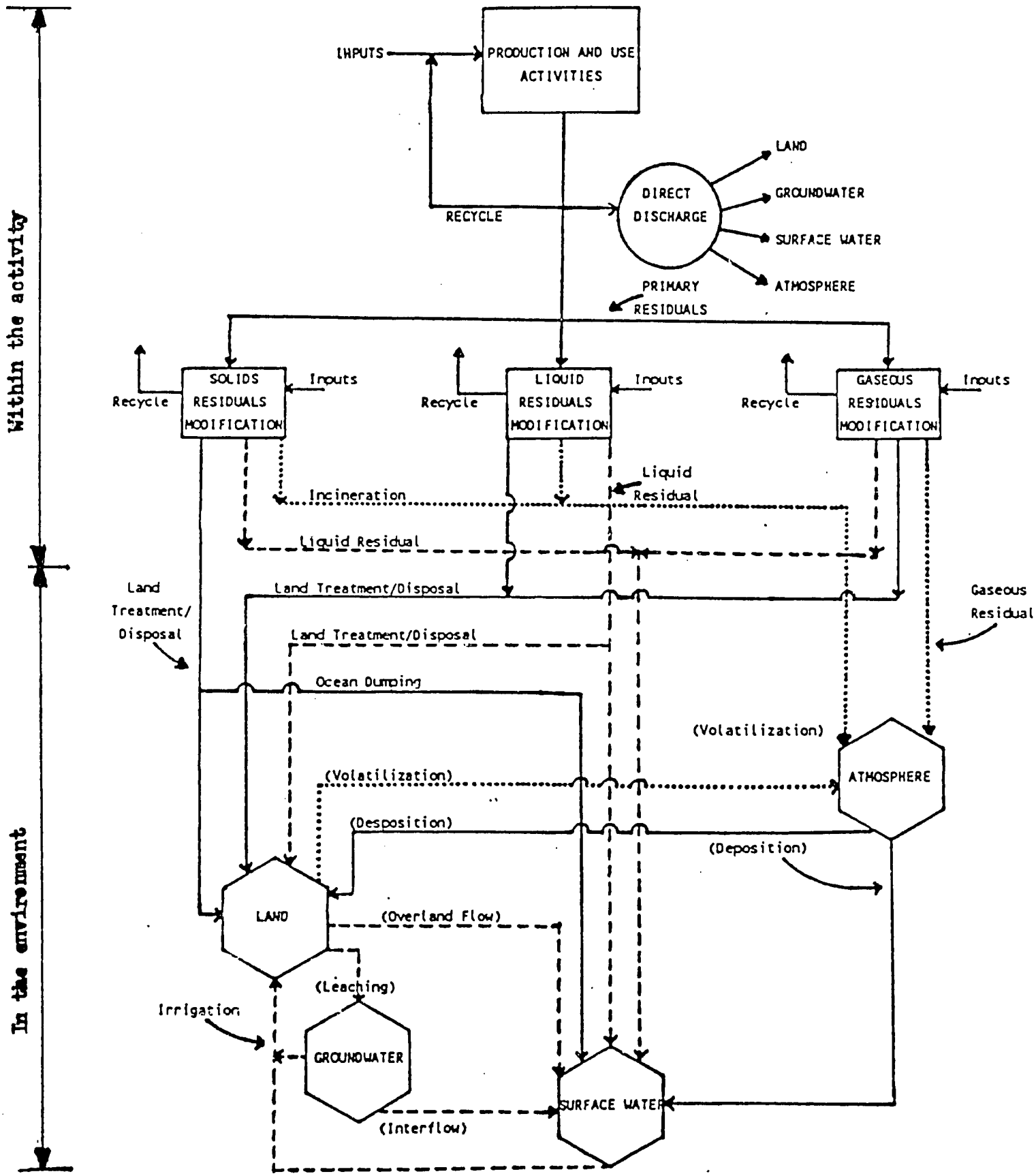
Because no prices were set on the environmental services, whether inputs to activities or repositories for discharges of residuals, the rationale manager/entrepreneur selected that combination of L, RM, C, and ES which maximized the use of the least expensive factor, ES. Consequently, more of ES was used than would have been used if the environmental services had been priced to reflect the social costs of their use, i.e., adverse impacts on other users of the environment, or at least priced to reflect the value of the ES to the activity. This fact is the root of the urban environmental quality problem.

Interrelationships among Residuals

The other basic fact which merits emphasis is one which has often been overlooked. That is, (a) one form of material residual can be transformed into another, either within the generating activity or subsequently after discharge to the environment; and (b) additional material and energy residuals are generated and discharged in the process of modifying an originally generated residuals stream. In addition, material residuals can be "traded off" for energy residuals and the reverse.

Figure 5 illustrates these interrelationships. The mix of residuals generated and discharged to the environmental media is a function of the nature of the production

Figure 5. Interrelationships among Forms of Material Residuals



Source: Bower, et al. (1987)

process and the extent of residuals modification before discharge. Subsequent to discharge, a residual can move from one environmental medium to another, e.g., land to water courses or the atmosphere, atmosphere to land or water, as shown in the figure.

This "transformation" is what occurs in a "treatment plant", e.g., a sewage treatment plant or an electrostatic precipitator. Materials and energy are added in order to remove one or more undesired materials from a waste stream. The rationale is that the removal (transformation) will yield a mix of discharges which will have fewer adverse results than the discharge of the original material(s). But note that the treatment adds to the total material and energy residuals discharged to the environment. Only by reducing the quantity of residuals generated in the first place, will the load on the environment be decreased.

To illustrate the interrelationships, consider a power plant using coal as the fuel for generating electrical energy. The particulates formed in combustion can be discharged to the atmosphere in the gas stream, i.e., as a gaseous residual. If there are constraints on such discharge a wet scrubber could be installed to wash the particulates out of the gas stream, thereby transforming the gaseous residual into a liquid residual, i.e., suspended solids, which then could be discharged to an adjacent river. [To operate the scrubber requires energy, so that the net output of the power plant is reduced.] Increasing suspended sediment discharge may affect fish adversely. To prevent such adverse effects, a settling basin could be installed to remove most of the suspended solids in the scrubber effluent, thereby yielding a semi-solid residual for "ultimate" disposal on land.

Heat is a typical energy residual. Again using the power plant as an example, about two kilowatt hours equivalent heat are generated for every kilowatt hour of desired energy (the "product") produced. This residual heat must be dissipated in some manner. Often this is done by discharge to the environment, i.e., to water course,

as in once-through cooling. When there are adverse effects from such discharge, a typical response is to install a cooling tower, which results in discharge of the heat residual to the atmosphere instead of to the water. Such discharge in turn may have adverse effects, such as increased fog in the area, icing in winter, and increased precipitation in the immediate area. In addition, operation of the cooling tower generally requires energy, again resulting in reduction in net output.

A tradeoff between energy residuals and material residuals is exemplified by restrictions imposed upon aircraft to reduce impacts of noise residuals. One procedure is to prescribe modified takeoff and landing patterns. Such patterns can reduce impacts of aircraft noise, and even reduce the quantity of noise generated. However, the result typically is to increase the quantities of gaseous residuals generated.

A critical implication stemming from the above is that different residuals modification methods and systems may pose significantly different hazards to humans and other species, because of the different pathways of exposure. A small amount of an undesired substance, e.g., lead, discharged to the atmosphere may have greater, lesser, or the same adverse effects as the same amount discharged to surface water or onto the land, from where plant uptake may move it into the food chain. Simply separating an undesirable material, e.g., lead, cadmium, dioxin, from a residuals stream does NOT solve the problem; the separated material still requires disposal. Heavy metals in residuals streams are not destroyed in any processing, recycling, reclamation activity. Depending on the characteristics of the modified residual, e.g., as sludge, ash, compost, and the environmental medium, e.g., soil, water, the heavy metals may become more or less available to various species.

URBAN ENVIRONMENTAL QUALITY MANAGEMENT (UEQM)

Introduction

At the outset, four points should be stressed. One, the context of UEQM is regional (and national) economic development. EQM is a derivative sector, as are water, energy, and sanitation sectors. [Occasionally the energy sector will be

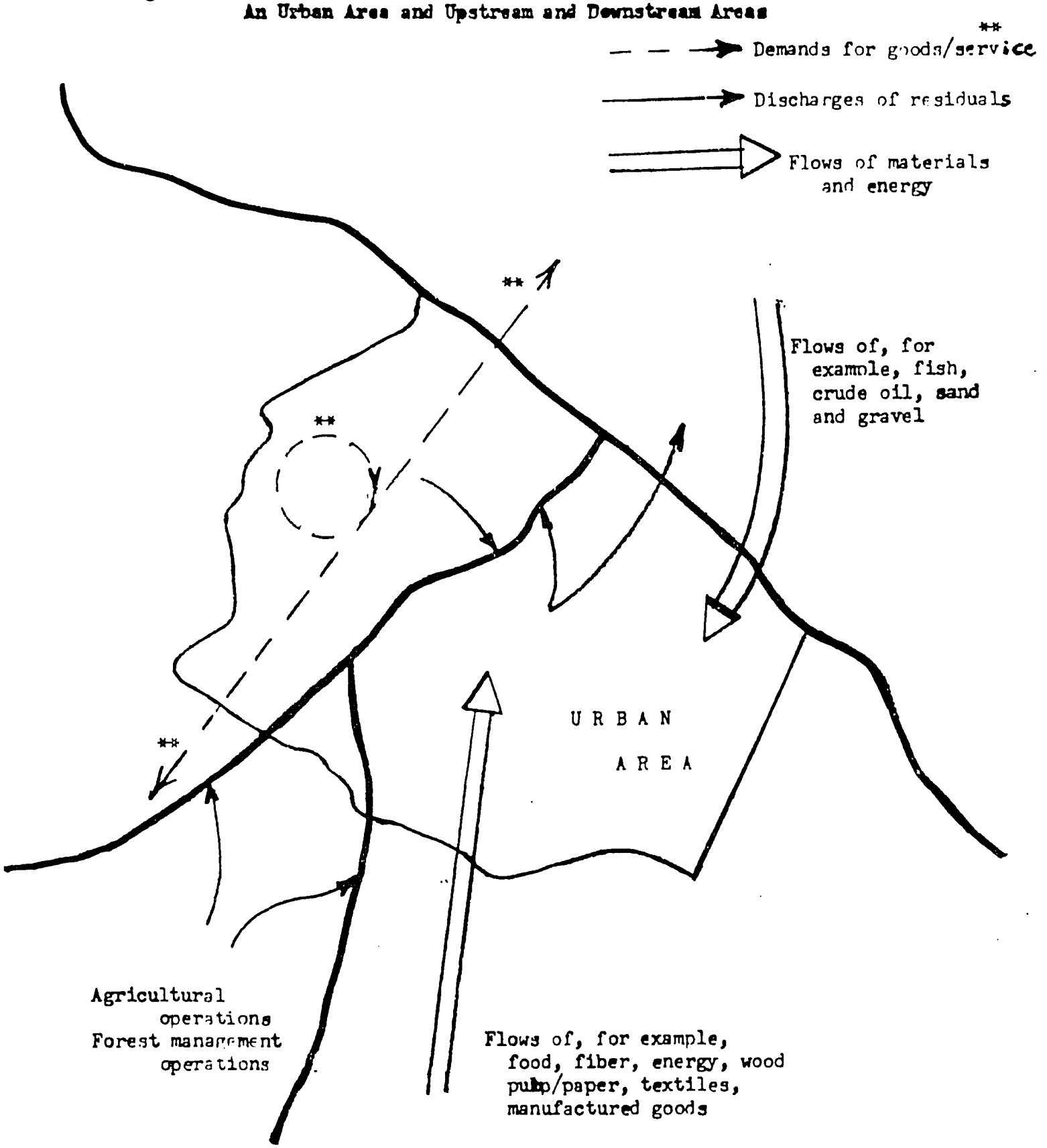
a development sector, e.g., where there is a large hydroelectric potential the development of which could attract energy-intensive industrial operations.] That is, EQM is driven by demands from population and economic activities in: (a) major urban areas; (b) in market towns; and (c) in rural areas with many small villages. The basic problem is how to incorporate EQM in economic development decisions, as discussed in detail in Hufschmidt, et al. (1983), and explicitly in the management of urban areas.

Two, the orientation of this report is GIFRAD: generating information for resource allocation decisions. That is, the operational concern is how to produce relevant information for urban decision-makers in terms of alternative combinations of levels of AEQ and strategies to achieve these levels in the "real world".

Three, the focus of this report is on urban/metropolitan areas, which typically are defined in terms of management jurisdiction/authority by boundaries of governments of general jurisdiction. These boundaries rarely coincide with the boudaries of resource management areas, such as watersheds and airsheds. Nor do they coincide with either demand areas or effects areas. Demands in relation to UEQM are derived from areas peripheral to the defined urban area, and from areas far beyond in terms of products and services produced by the urban area which are demanded by "outsiders", e.g., tourists. Similarly, areas affected by activities in the urban area extend far beyond its boundaries, both downstream/downwind, and upstream. Long-range transport in the atmosphere carries residuals hundreds and thousands of miles away from an urban area. Demands of the urban area for fuel can have substantial effects on forest lands upstream. These relationships are very simply depicted in Figure 6.

Four, the nature, extent, severity of environmental quality problems in urban areas are a function of: spatial pattern of activities; mix and levels of activities; geographic location, e.g., coastal, valley, upland; meteorological conditions; hydrologic conditions; demands for goods and services; and governmental actions/nonactions. These factors are incorporated in the conceptual framework and computational framework described in the next two sections.

Figure 6. Simplified Representation of Interrelationships between An Urban Area and Upstream and Downstream Areas



**Includes demands for disposal of residuals, e.g., liquid to streams, coastal waters; solid to land; gaseous to atmosphere, some of which move inland via on-shore winds for deposition on land

MAGNITUDE OF MATERIAL AND ENERGY FLOWS INTO URBAN AREA = f["life style", e.g., type of transport system, product characteristics]

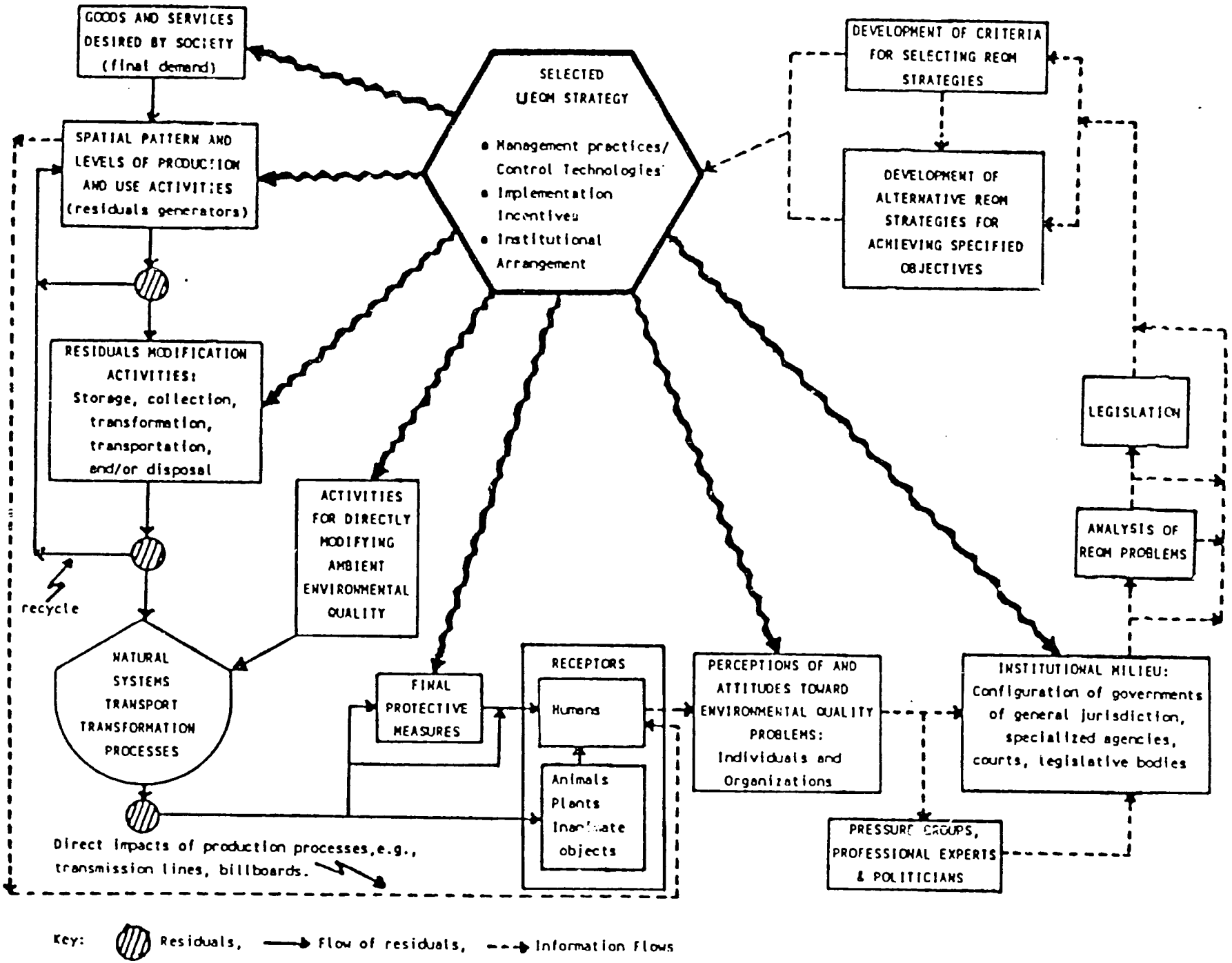
Conceptual Framework

Figure 7 shows a conceptual framework of an urban environmental quality management system. The system is "driven" by final demand of society, i.e., the goods and services desired. This in turn drives the spatial pattern and levels of production and use, e.g., household, activities. These activities---mining, farming, steel manufacturing, retail operations, universities, households---are the residuals generators and hence the demanders for and users of environmental services. [These activities are often major demanders of improved AEQ, given the often adverse effects on these activities of degraded AEQ. They are both "polluters" and the "polluted".]

The activities may discharge their residuals unmodified into the environment. Or they undertake various types of modification measures, individually or collectively, before discharging. The time and spatial patterns of discharges enter the environmental media, in which they are transported, often transformed, deposited, the result being changes in the time and spatial pattern of AEQ, as measured by various AEQ indicators, e.g., chemical, physical, biological. The short-run and long-run changes in AEQ affect various recepters, including humans, plants, animals, materials. The effects on recepters are a function of exposure, which in turn is a function of mobility, and of any protective measures, e.g., intake water treatment, imposed between the environment and the recepters.

The other components of the system represent the institutional response mechanisms of a society. If the environmental quality problems are considered to be sufficiently adverse, various parties at interest are likely to try to stimulate action to improve AEQ. Through the interaction of formal and informal power structures of a society, decisions will be made and an urban environmental quality management strategy will be selected. That strategy may in fact be to do nothing to affect the present patterns of, and trends of, ambient environmental quality. Or it may be to appoint a commission to do some studies and undertake research. Or, the strategy selected may involve physical measures, implementation incentives, institutional arrangements which induce actions to improve the situation at various points in the system.

Figure 7. Conceptual Framework of an Urban Environmental Quality Management System



Computational Framework

In order to generate information for decisions, a conceptual framework must be translated into a computational framework, one which will enable analyzing the components of the system and the system for different values of the parameters and the decision variables. A computational framework then is a set of linked models/analyses, either formally linked by some algorithm, or linked in the sense that the output of one analysis or the outputs of several analyses become inputs into another analysis. A computational framework is analogous to a CPM or PERT diagram, either representing a set of connected analyses or activities to produce an output in some specified time.

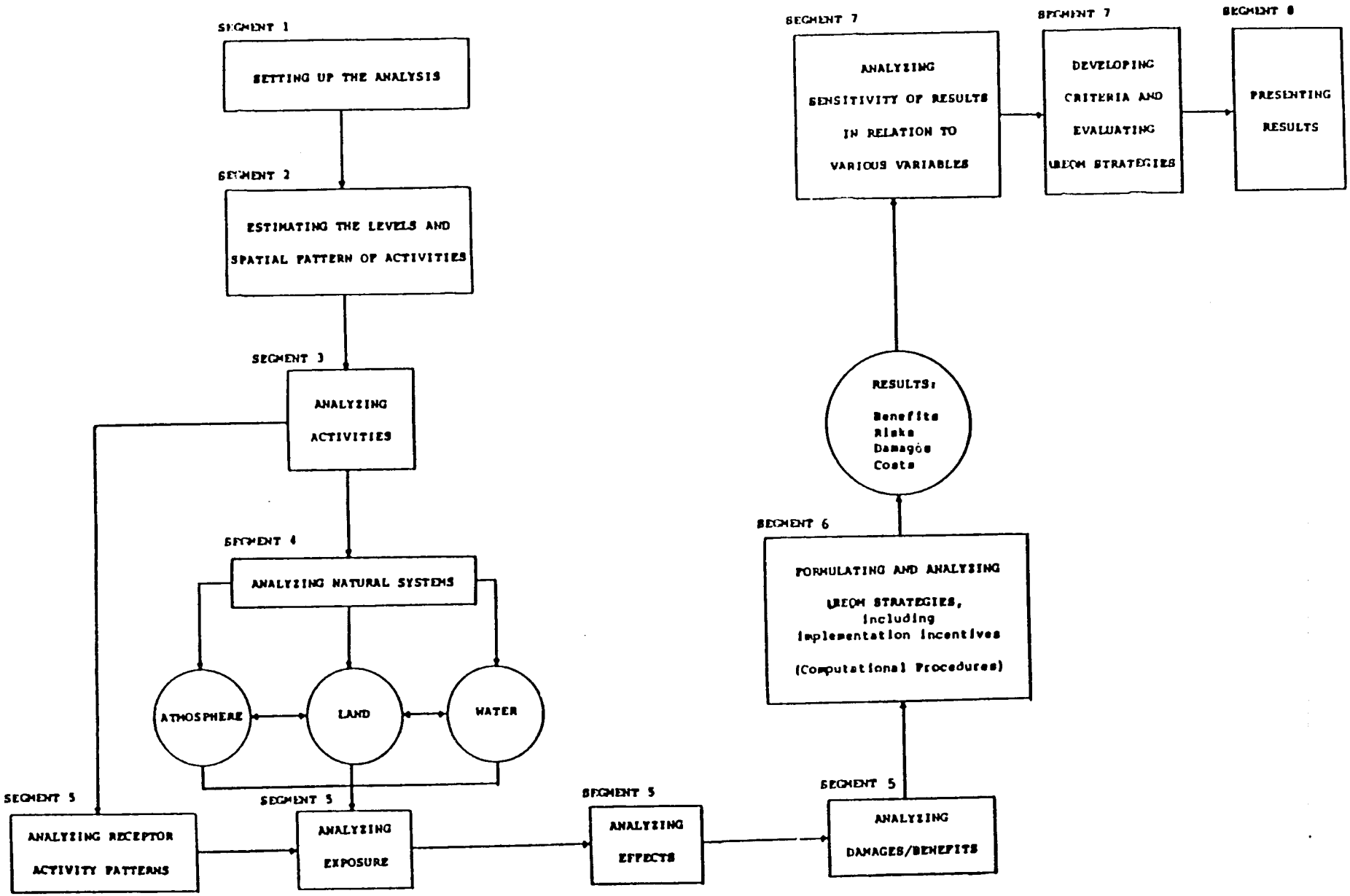
Figure 8 shows the computational framework for analysis for urban environmental quality management, in terms of a set of steps or segments of the analysis. Carrying out the various segments requires analytical techniques from economics, engineering (technology), ecology, and institutions (including public administration, sociology/anthropology, and political science). The major problem in analysis for UEQM is finding staff capability to integrate the various disciplines. For example, segment 2 involves economics in the analysis of demands, demography in the analysis of population/households, engineering/technology in relation to factors affecting location decisions. Segment 3 involves particularly economics and technology. Segment 4 involves ecology, hydrology, geomorphology, hydraulics, meteorology.

Subsequent sections contain discussions of some of the segments of analysis, with major emphases on; segment 3, analyzing activities; segment 4, analyzing natural systems; and segment 6, formulating and analyzing strategies.

SETTING UP THE ANALYSIS (SUTA)

In all situations involving UEQM, there will be a finite period of time in which, and a finite amount of resources with which, to develop the relevant information for the resource allocation decisions. [Resource allocation decisions include not only capital investment, but also operation, maintenance, replacement, and administrative cost

Figure 8. Computational Framework for Analysis for Urban Environmental Quality Management



Source: Bower, et al. (1987)

Therefore, setting up the analysis is a very critical part of the analysis task.

The fundamental premises herein with respect to the analysis are: (1) that the analysis will be quantitative; and (2) that the analysis will result in alternative UEQM strategies, from which the decision-makers can choose, where each strategy shows the costs and consequences of the components of the strategy. SUTA is comprised of two basic parts. The first is the selection of "analysis conditions" The second is the selection of the analytical approaches/techniques to be used for each of the segments of the analysis. The three basic outputs of SUTA are these two, plus the allocation of available analytical resources to the various segments including preparation of the final report, over the time period available.

Analysis conditions include, at least, the following:

- Specific questions to be answered, e.g., what segments of the population are most severely affected by adverse AEQ conditions, which sources of discharges of which materials are more important;
- The priorities among the questions;
- Base year and future time horizons to be analyzed;
- Regional and subregional boundaries for demand areas and effects areas;
- Identification of X-boundary flows of residuals, in and out, on a preliminary basis;
- Discount rate or rates to be used in the analyses;
- Criteria for evaluating strategies;
- Formats for presentation of the results of the analyses;
- Scenarios to be analyzed and how these are to be defined; and
- Meteorologic and hydrologic conditions to be analyzed.

These analysis conditions drive the selection of analytical approaches to be used, along with the available analytical resources. That is, even if it is desired to answer some questions at a level of detail which would require a specific type of analysis, this may be impossible because there are insufficient resources to do the analysis at that level. For example, there may be a single major source of discharges in the region, for which one would like to do a detailed, unitprocess/unit operations analysis, as described in a subsequent section. However, the resources available enable only doing a "black box", i.e., aggregate, analysis. The criteria for evaluation affect the choice of analytical approaches. For example, if the decision makers are interested in the effects on different socioeconomic groups in the region, then the analytical approach selected must be able to generate information by group.

A detailed discussion of setting up the analysis is in Bower, et al. (1987). Figure 9 is a flow chart of SUTA.

ESTIMATING LEVELS AND SPATIAL PATTERN OF ACTIVITIES

For the present, or base year or base period, and for each time horizon selected, estimates must be made of population by household type, levels of activities in terms of employment or physical units of output, and the locations of both. This must be done, no matter how crude the estimates and inaccurate the results. An host of factors affects trends in population and economic activities. As one U.S. Bureau of Census demographer said, in connection with the Bureau's 1989 projections of U.S. future population, "We will be wrong, I guarantee you" (Berke, 1989).

Nevertheless, the only basis for estimating effects of urban activities on AEQ is a characterization of the levels and spatial location of those activities. The analysis can start with a national 5-year plan, accompanied by some estimate of the regional disaggregation of the activities in the 5-year plan. Sophisticated formal models exist, beginning with national econometric models and linking these to regional disaggregation models, as indicated in Figure 10. However, in most developing countries that level of sophistication may well not produce any more accurate estimates than extrapolation of trends modified by judgment of knowledgeable individuals. Probably the key factors in making estimates of future conditions are estimates of changing---often deteriorating---productivity in agriculture and forestry and estimates of trends in a few key industrial, mining, tourist sectors.

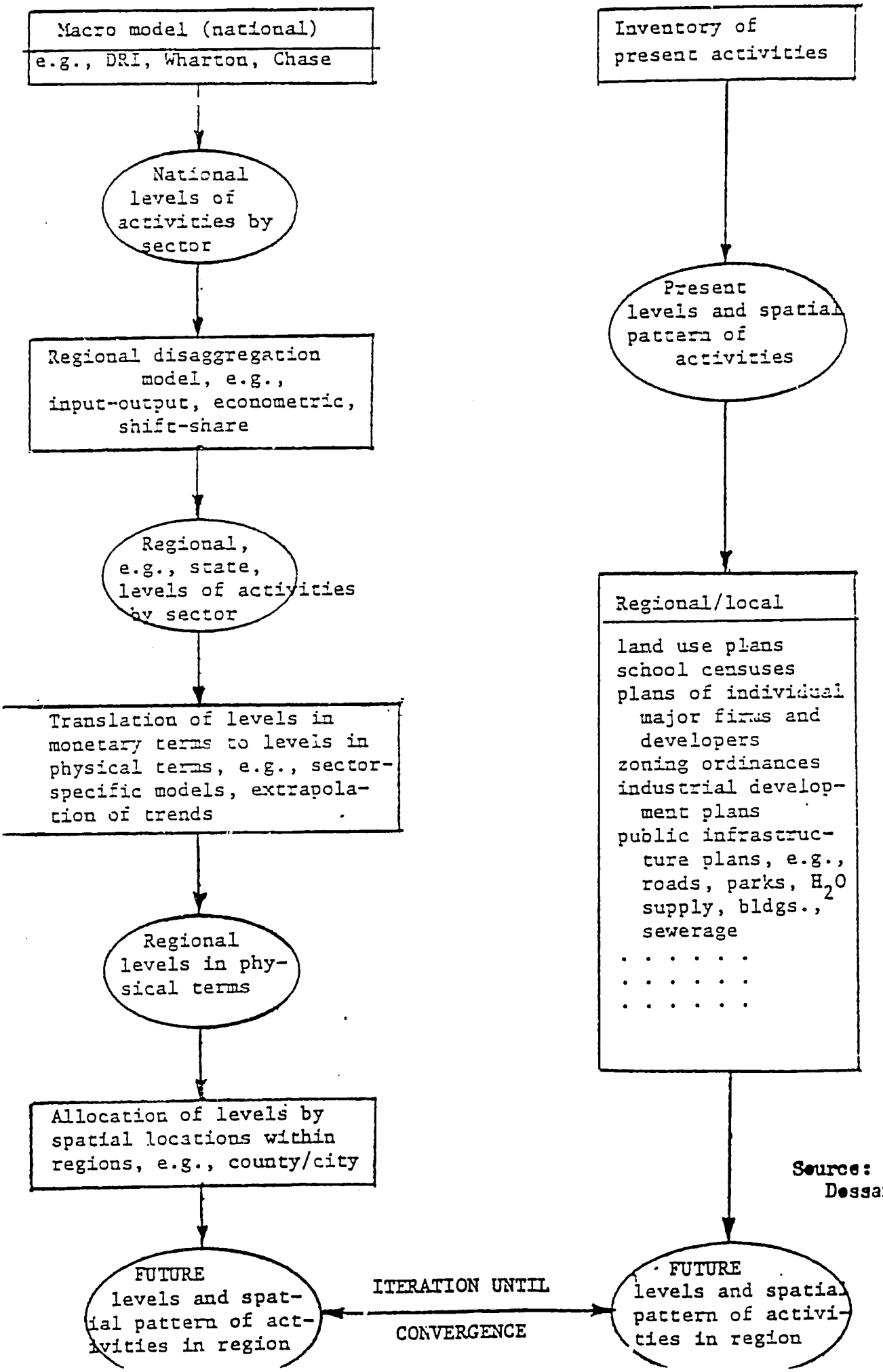
A detailed discussion of various methods for proecting/estimating levels of activities in the future is provided by Dossani (1987).

ANALYZING ACTIVITIES

Analyzing activities is critical for the development and for the implementation of strategies for urban environmental quality management. (1) One needs to understand the factors which affect residuals generation and discharge, so that incentive systems can be developed to induce reductions in discharge. (2) One needs to understand

Figure 9. Flow Chart of Setting Up the Analysis (SUTA)

Figure 10. Linking the Macro, Regional, and Local Estimates



Source: Dessani (1987)

the factors in order to be able to estimate the costs of reduction under various sets of conditions, and hence to be able to check the claims of very high costs made by many activities. (3) One needs to be able to analyze the various activities in order to determine what the relative importance of sources is with respect to different residuals, e.g., industrial vs. residential with respect to discharges from fuel combustion, industrial vs. storm runoff in urban area with respect to suspended sediment discharges. Relative importance of sources combined with segments of population and other receptors most adversely affected are major determinants of an UEQM strategy. The purpose of this section is to convey some ideas about, provide some perspective on, analyzing activities.

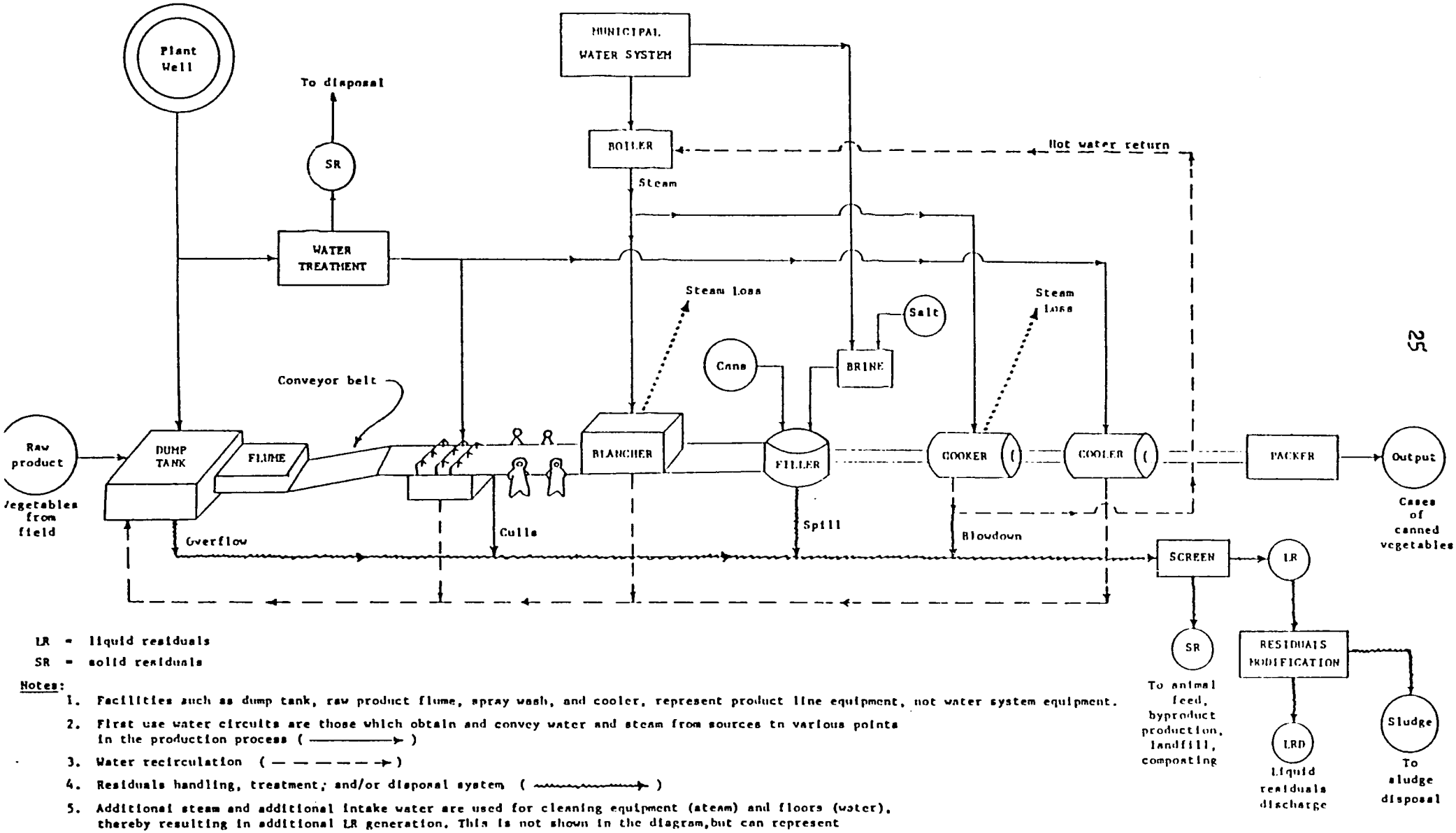
Some Characteristics of Activities

An activity is defined as a decision unit which consists of a set of one or more unit processes and operations, as illustrated for a vegetable cannery in Figure 11 and an iron and steel mill in Figure 12. A farm, a mining operation, a restaurant, an office building, a management unit of a national forest, a motor vehicle, each is an activity, and each generates some mix of residuals according to some time pattern.

Often the activity involves several inter-process and inter-operation transport operations, such as by flume, pipeline, conveyor belt in manufacturing activities. These in turn may involve valves, junctions, flow dividers. Residuals generation and/or residuals discharge may occur in relation to the unit process or unit operation, or in relation to the transport operation. Leaks of gases from valves and solid material blown from a conveyor belt are examples of the latter.

It also should be pointed out that the term "point source" -- often termed concentrated and/or stationary source -- is misleading. An integrated steel mill, an integrated pulp and paper mill, a petroleum refinery, an open pit mine, a metallurgical plant, each represents a set of unit processes and unit operations occupying a given site, which site often is several hundred hectares in size. The steel mill, the pulp and paper mill, the refinery, the metallurgical plant always will have multiple stacks for discharging gaseous residuals. Further, although an open pit mine is usually considered a stationary source, probably the primary activity generating residuals in an open pit mine is the transport activity, e.g., trucks hauling ore out of the mine to the processing plant.

Figure 11. Simplified Flow Diagram of Vegetable Canning



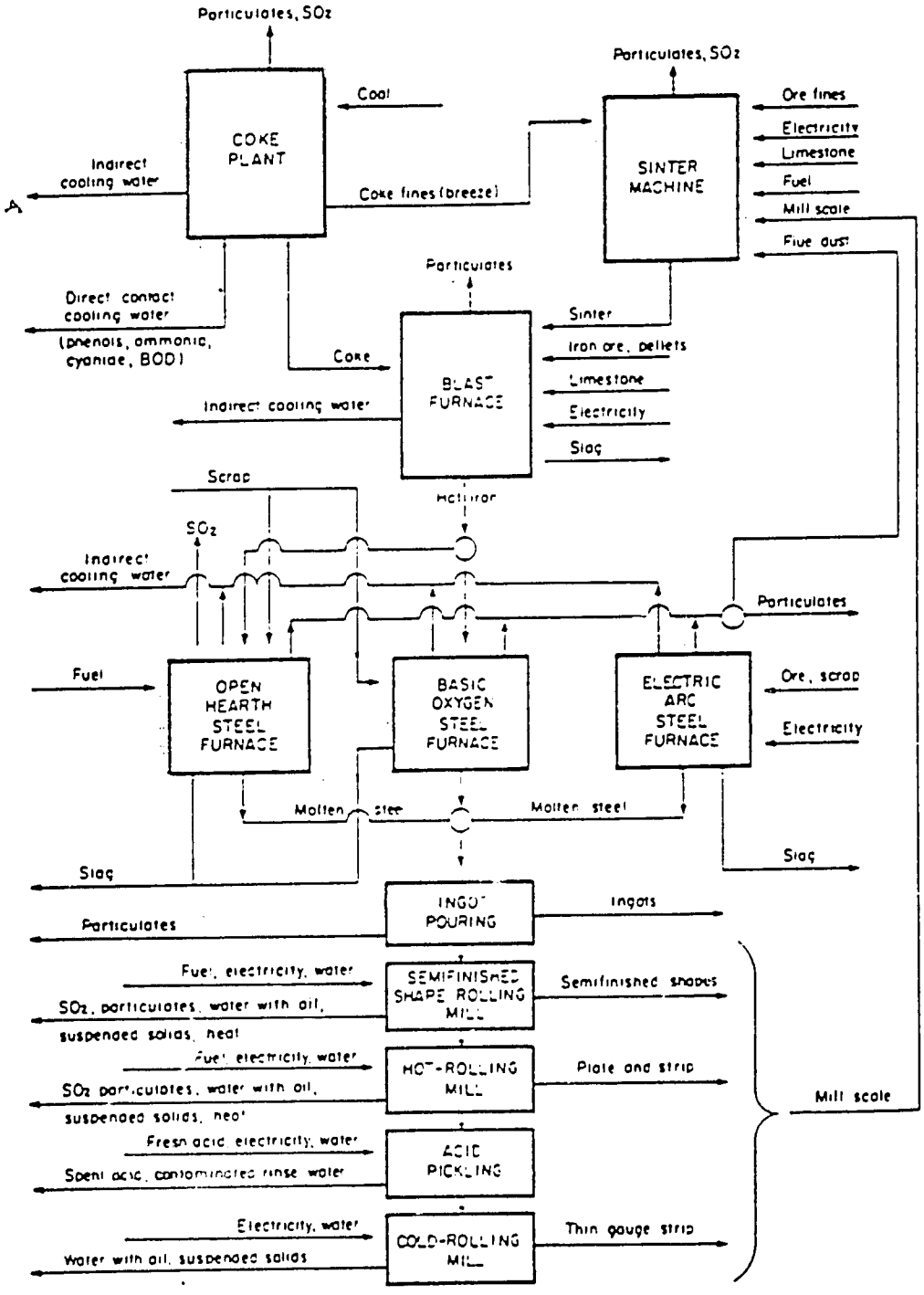
LR = liquid residuals

SR = solid residuals

Notes:

1. Facilities such as dump tank, raw product flume, spray wash, and cooler, represent product line equipment, not water system equipment.
2. First use water circuits are those which obtain and convey water and steam from sources to various points in the production process (——————→)
3. Water recirculation (— — — — — →)
4. Residuals handling, treatment, and/or disposal system (~~~~~~~~~~→)
5. Additional steam and additional intake water are used for cleaning equipment (steam) and floors (water), thereby resulting in additional LR generation. This is not shown in the diagram, but can represent a significant portion of total water intake (demand).

Figure 12. Simplified Chart of Iron and Steel Production



Source: Russell and Caughan (1976)

Thus, the term "SOURCE" applied to "point" or "stationary" sources is used ambigously, to refer to different phenomena. A petroleum refinery as a whole is referred to as a "source" of residuals discharges; "devices" within the refinery -- such as valves -- are also referred to as "sources"; and each discharge stack in the refinery is referred to as a "source". In sum, there often are multiple "origins" of residuals generation in an activity and multiple "locations" of residuals discharges from an activity. Some of the origins and locations may be identical. Figure 13 illustrates the multiplicity of origins and locations for an actual metallurgical plant. For example, gaseous residuals are generated: in the electrolytic processes; at the stock piles of raw materials; from conveyor belts; in byproduct sulphuric acid production.

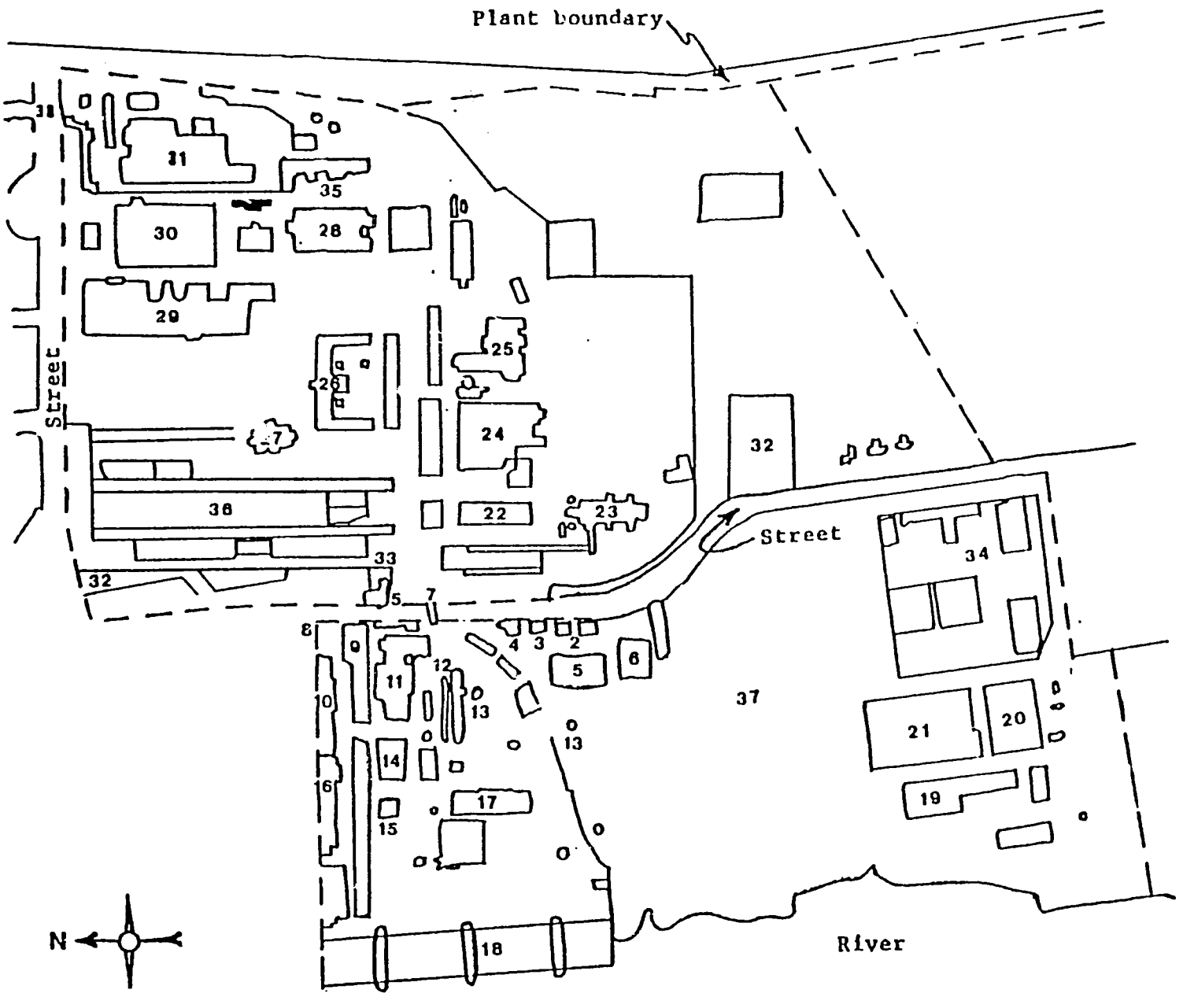
It is particularly important to understand the multiple sources of especially gaseous discharges in an industrial facility. Table 2 shows the source of hydrocarbon discharges in a very small petroleum refinery, 46,000 barrels per day crude throughput. The sources above the wavy line represent either stacks or tanks for which it is possible to measure directly or to estimate discharges. The sources below the wavy line, which total about 32,000, represent non-stack sources for which direct measurement is not possible. These sources represent about one-quarter of th total estimated discharges. Thus, even if one could reduce discharges from the stac and tank sources to a very low level, the refinery would still be discharging substantial amounts of hydrocarbons.

Variability in Residuals Generation
and Discharge

Short-run variability.

Rarely, if ever, is there an activity in which residuals generation--per unit generation and total generation--is constant over time, in the short-run. In residences there are diurnal, weekly, seasonal fluctuations in residuals generation representing different activities at different times of day, week, and season. Similar short-run fluctuations in residuals generation occur in commercial, institutional, transportation, and agricultural activities. In manufacturing activities at least six types of short-run variations occur.

Figure 13. Physical Arrangement of Facilities at a Metallurgical Plant



1 Workers' entrance
2 Personnel Department
3 Infirmary
4 Training
5 Refectory-Changing-room-bath-Safety
6 Cycle-racks
7 Foot-Bridge
8 Employees' entrance
9 Central Management
10 Assay Laboratory
11 Generation Station
12 Cottrell
13 Stacks
14 Workshops 3 and 5
15 Copper Hall
16 Warehouse
17 Blast Furnaces
18 Loading Platform
19 Sampling
20 Arsenic
21 Warehouses
22 Milling and Roasting
23 Sintering
24 Sulphuric Acid
25 Tin
26 Research Laboratory
27 Castle
28 Harris I
29 Harris II
30 Precious Metals
31 Workshop 1
32 Car Park
33 Transport Service
34 Reframet
35 Antimony furnaces
36 Ore Park
37 New stocking area
38 Entrance workshops

Scale: 1/2800

Table 2. Sources of Hydrocarbon Discharges in a Petroleum Refinery with 46,000 barrels per day Crude Throughput

Type of Source	Number in Refinery		Estimated Annual Discharges tons per year		Percent of Estimated Refinery Hydrocarbon Discharges
Process heaters and boilers		22		53.0	12.1
Cooling towers		6		61.0	13.9
Storage tanks (total)		85		164.0	37.4
150-foot diameter	2				
110- to 120 foot diameter	7				
86- to 90-foot diameter	8				
60-foot diameter	14				
30- to 48-foot diameter	24				
10- to 22-foot diameter	30				
Water/oil separators		3		14.0	3.2
Gasoline Loading Terminal		1		20.0	4.6
Valves (total)		8,000		30.2	6.9
Gas	500		5.3		1.2
Heavy liquids	6,000		17.1		3.9
Light liquids	1,500		7.8		1.8
Flanges		24,000		2.8	0.6
Pumps (total)		450		76.1	17.3
Light liquids	50		2.7		0.6
Heavy liquids	400		73.4		16.7
Process drains		50		14.3	3.3
Flares/incinerators		3		3.2	0.7
		32,620		438.6	100 0

Source: Ginberg and Schaumburg (1979)

1. Start-up/Shut-down: Start-up occurs at the beginning of a production cycle, with shut-down occurring at the end, just prior to clean-up. Typically, residuals generation per unit increases above that of normal production operations during these stages.

2. Clean-up: Clean-up occurs at the end of a production cycle and results in a marked increase in flow and residuals generation during this period of increased "house-keeping" activities.

3. Upsets During Production With No Halt in Operations: An upset may occur at any time in the production cycle. It is essentially a production system imbalance resulting from any number of causes, e.g., a contaminated batch of product, valve left open. In the interval, raw materials and/or product may be lost and excess residuals generated and discharged.

4. Breakdowns (Production Ceases): A breakdown is an upset with a cessation of production and/or an unscheduled clean-up. Residuals generation continues or increases because pipes, tanks, stacks must be drained or vented before production can resume.

5. Accidental Spills: Accidental spills can occur at any time, both during production and during down-time, from a myriad of causes. Substantial quantities of residuals are often generated, and discharged, over a short time interval.

6. Normal Production Operations: Variations during "normal" production operations can be subdivided into:

   a. less than daily and daily operations;
   b. less than seasonal production cycle variations, reflecting changing product mix;
   c. seasonal variations.

Some of the factors which result in less than daily and daily variations in residuals generation and discharge are:

a. variation in quantity and quality of raw material input, e.g., inflow of raw vegetables from different sources in canning operations, the quality of wood chips in paper manufacture;

b. variation in operating conditions, e.g., basic conductivity in steel-making changes throughout the cycle of a basic oxygen furnace, changing residuals generation during the cycle which in turn, for any given installation of particulate removal equipment, varies residuals discharge throughout the cycle, since removal efficiency = f(conductivity); "pushing" a production unit (power plant, paper mill) beyond design capacity for short periods (30 minutes, 2-3 hours) also results in significant variation in residuals generation;

c. variation in conditions of operating equipment, e.g., the efficiency of saws and chippers in wood chip production for paper manufacture changes with use, so that residuals generation gradually increases over time, until the saws and chippers are resharpened; the effectiveness of the felts on a paper machine gradually decreases over time, thereby increasing residuals generation; failure properly to maintain automobile engines results in increased residuals generation;

d. variation in product mix, e.g., product mix in a cannery (canned tomatoes, tomato paste, tomato juice) can vary from hour to hour; similarly, a large paper mill with several paper machines can show substantial variations in product mix within a single day, as well as variations of grades of a single product, both resulting in significant variations in residuals generation and discharge.

Definite seasonal patterns exist for some production operations, e.g., in a large cannery packing various fruits, vegetables, soups, fish, where residuals generation depends on which raw product is in season; a petroleum refinery producing both gasoline and fuel oil, where the proportion of the two varies with the season (winter versus summer); the skewed production cycle of automobile assembly plants. Many activities

other than manufacturing exhibit major variations by season, such as agricultural operations, logging operations, resort operations. Household activities also exhibit substantial variation by season with respect to residuals generation and discharge.

Variation in residuals generation and discharge as described above stems from the nature of the activity and internal factors. But variation is also a result of meteorological conditions. For any activity involving space heating and cooling, such as an household, an office building, a manufacturing plant, residuals generation and residuals discharge will vary with temperature, humidity, wind. Similarly, where an activity involves condensing or cooling processes, as in energy generation and chemical manufacturing, residuals generation and discharge will vary with meteorological conditions. Residuals generation and discharge from nonpoint sources, such as agricultural operations and urban storm runoff, are a direct function of meteorological conditions.

Variation is illustrated in tables 3 and 4, and in figures 14 and 15. Table 3A and Table 3B show the variations in production rates for an automobile assembly plant and an industrial dry cleaning plant, respectively. Table 4 shows the typical patterns of water intake for three major types of canneries, reflecting the variation in operating rate throughout a year. Figure 14 shows the daily variation in suspended solids discharge from a well-operated integrated pulp and paper mill. The wide variation shown is a result of the combination of various factors cited above. Figure 15 shows frequencies distributions of hydrocarbon discharges from two similar industrial operations.

Two important implications stem from the "fact of life" of varability in residuals generation and discharge. One, such variability makes it difficult to achieve some <u>minimum</u> level of desired AEQ 100%, or close to 100%, or even 95% or 90%, of the time. Two, such variability makes monitoring the performance of activities very difficult.

Table 3. Examples of Variation in Daily Rate of Production

3A. One Automobile Assembly Plant[a]

Output Rate, Cars per Hour	Hours of Production per Day		
	8	9	10
40	10	0	0
52	10	30	10
55	0	20	20

Note:
a. Values in the table represent the percent of days on which the indicated combination of hours of production and rate of output occurred.

Source: Ginberg and Schaumburg (1979)

3B. One Industrial Dry Cleaning Plant

Percent of Days	Production Rate, pounds per day	Percent of Hours	Production Rate, pounds per hour
10	1170	10	174
20	990	20	139
40	900	40	116
20	810	20	93
10	630	10	58

Note: The average production rate is 900 pounds per day and 116 pounds per hour.

Source: Ginberg and Schaumburg (1979)

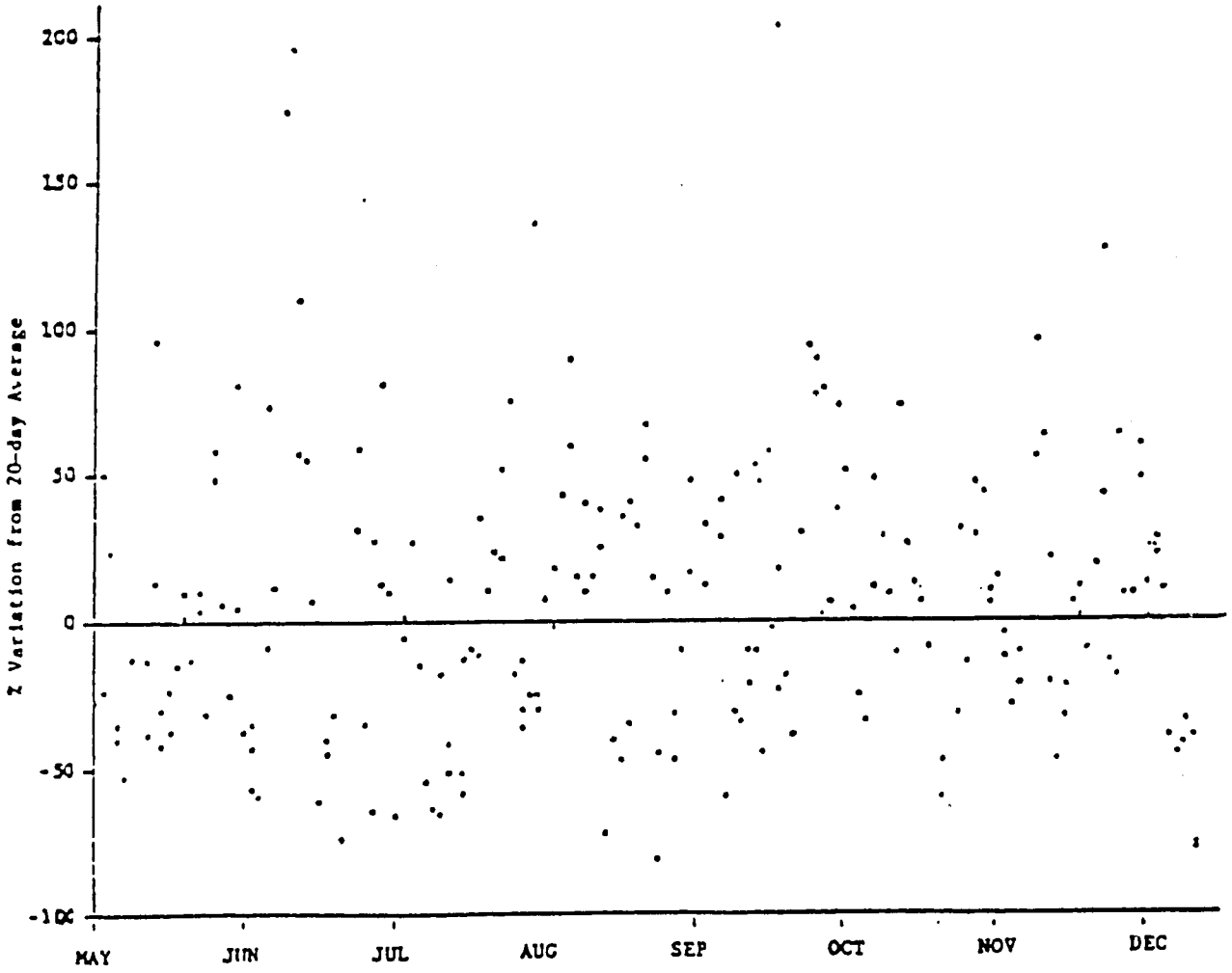
Table 4. Monthly Distribution of Intake Water Demand, with no In-plant Recirculation, by Type of Cannery

Month	% of Annual Water Intake Demand		
	Type I	Type II	Type III
January	0.5	1	4
February	0.5	1	4
March	0.5	1	4
April	0.5	1	8
May	0.5	1	7
June	0.5	5	7
July	6	10	6
August	35	20	15
September	40	25	20
October	10	20	13
November	4	10	7
December	2	5	5

Cannery Types: I -- very seasonal;
II -- seasonal;
III -- mixed (both seasonal and non-seasonal products)

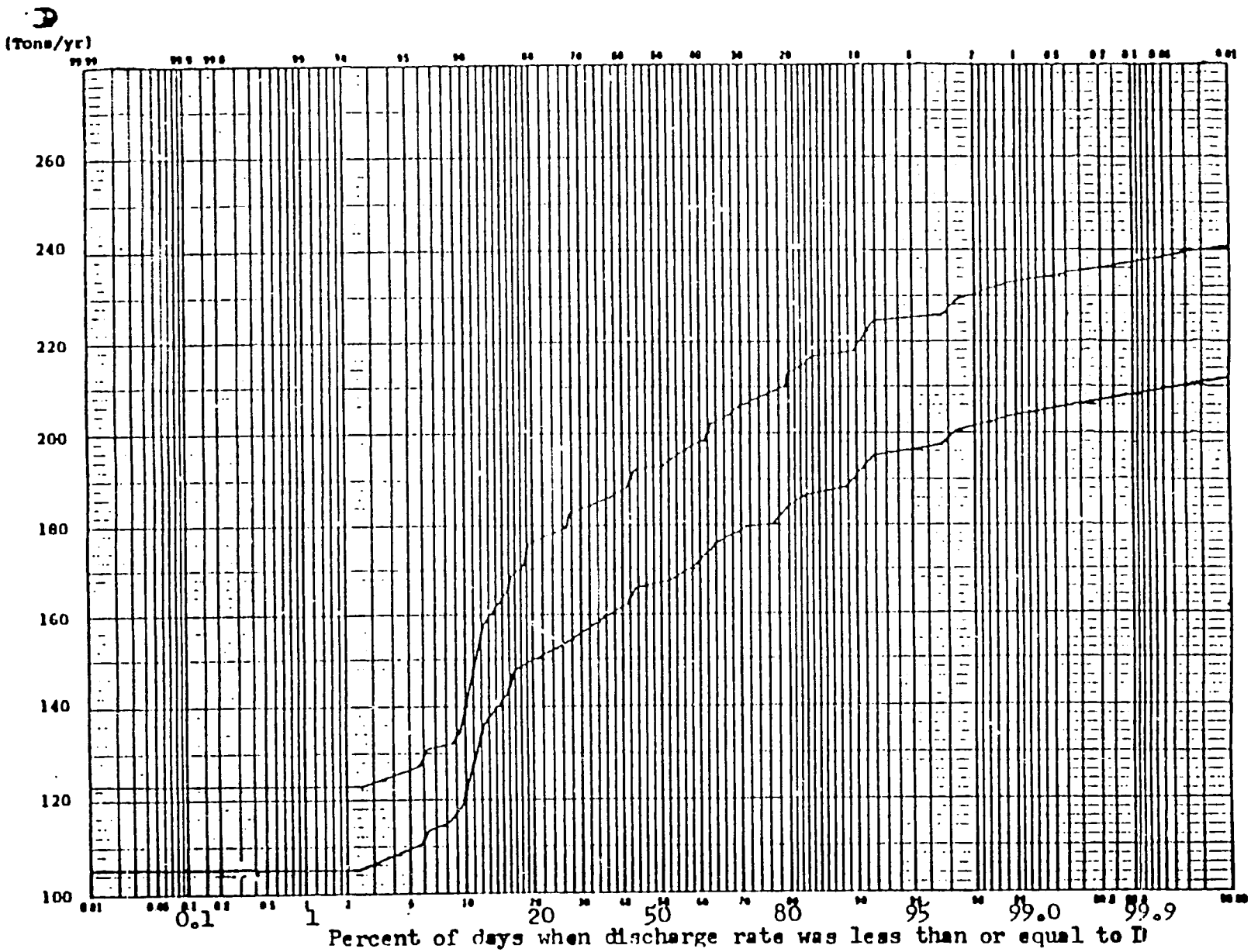
Source: Bewer (1966)

Figure 14. Daily Variation in Suspended Solids Discharge from Secondary Clarifier of Integrated Pulp and Paper Mill[a], Percent Deviation from 20-day Average



[a]Mill had bleached ground wood and bleached kraft pulping. It is located in north central U.S.

Figure 15. Cumulative Distributions of Daily Hydrocarbon Discharge Rates for Two Industrial Activities



Factors Affecting Residuals
Generation and Discharge

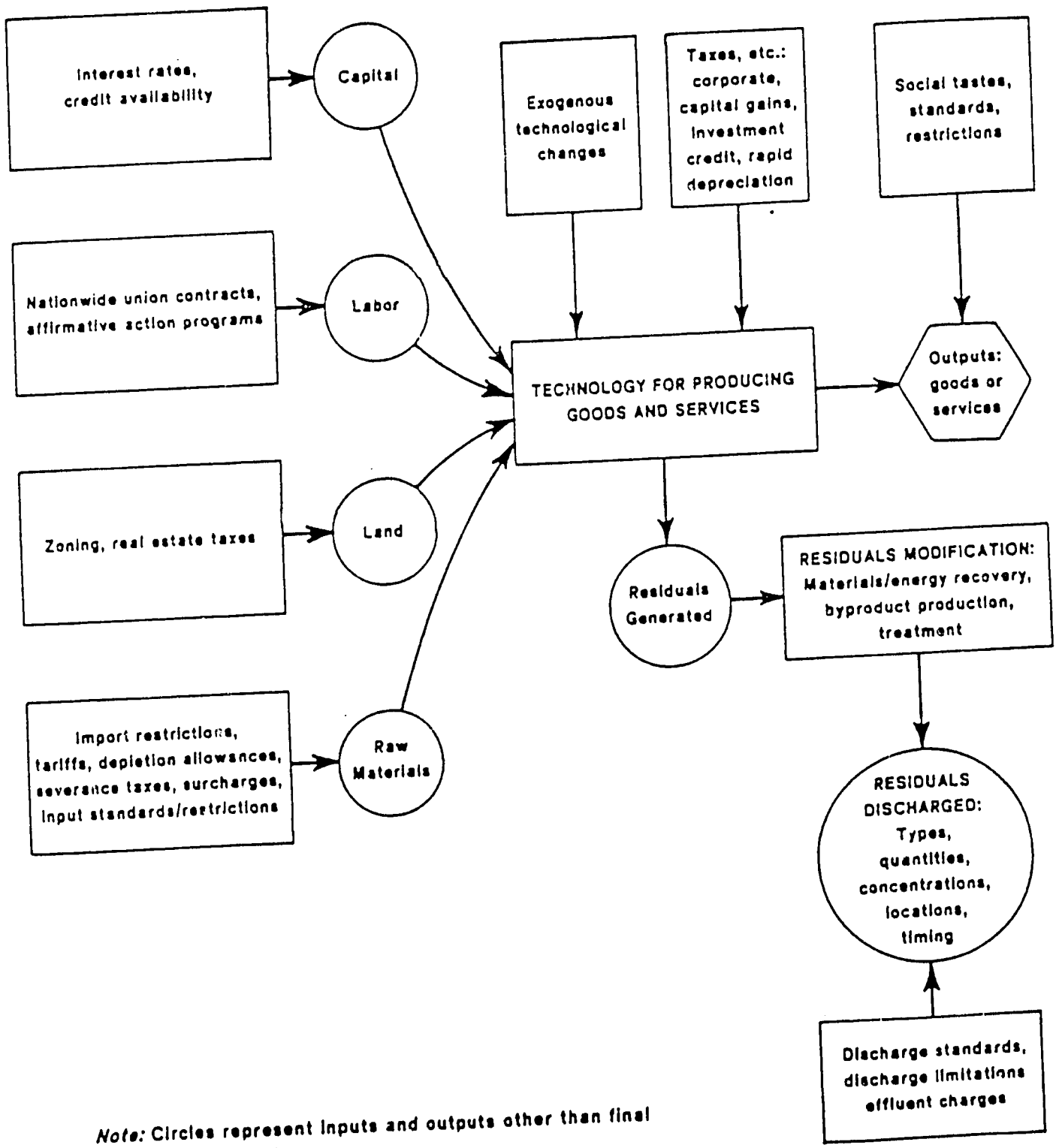
The following formulation to characterize the factors affecting residuals generation and discharge by an activity is illustrated in terms of manufacturing activities. However, the approach is, and many of the variables are, equally applicable to other types of activities, e.g., mining operations, households, institutional operations, agricultural operations.

The quantities and types of residuals generated, the quantity of intake water withdrawn from all sources, the quantity of energy use are a function of: technology of production; raw materials used; product output mix; product characteristics; operating rate; size of plant; physical layout of plant; costs of materials recovery; costs of energy recovery; possibilities of byproduct production; factor input prices; constraints on discharges; costs of solid residuals disposal. Different combinations of raw materials and production processes can yield the same product mix and same product characteristics. The choice of combination by any given activity is a function of, or is affected by, both endogenous and exogenous variables. Some or many, depending on the situation of the factors enumerated are not under the control of the manager of the activity, such as market-established factor input prices, technological developments in the same industry but outside the manager's company.

Many of the factors have values which change over time, with changing technology, depletion of nonrenewable resources, governmental policies/programs/activities. As a result, residuals generation, water intake, energy use for a given plant, can vary substantially over time, even if the product mix and product characteristics do not change. The factors are summarized in Figure 16. Figure 17 illustrates the simultaneous determination of water intake, energy intake, and residuals generation

[Given the considerable confusion in relation to terminology with respect to water utilization, clarification would be helpful, even if a given set of terms were not universally accepted. Figure 18 provides one set, applicable to all activities, not merely to industrial activities. Note that when the term "water use" is used, it could refer to I, to G, or to total consumptive use.]

Figure 16. Factors Affecting Water Use, Energy Use, Residuals Generation by an Activity



Note: Circles represent inputs and outputs other than final goods and services.

Figure 17. Residuals Discharge, Water Withdrawal, Energy Demand

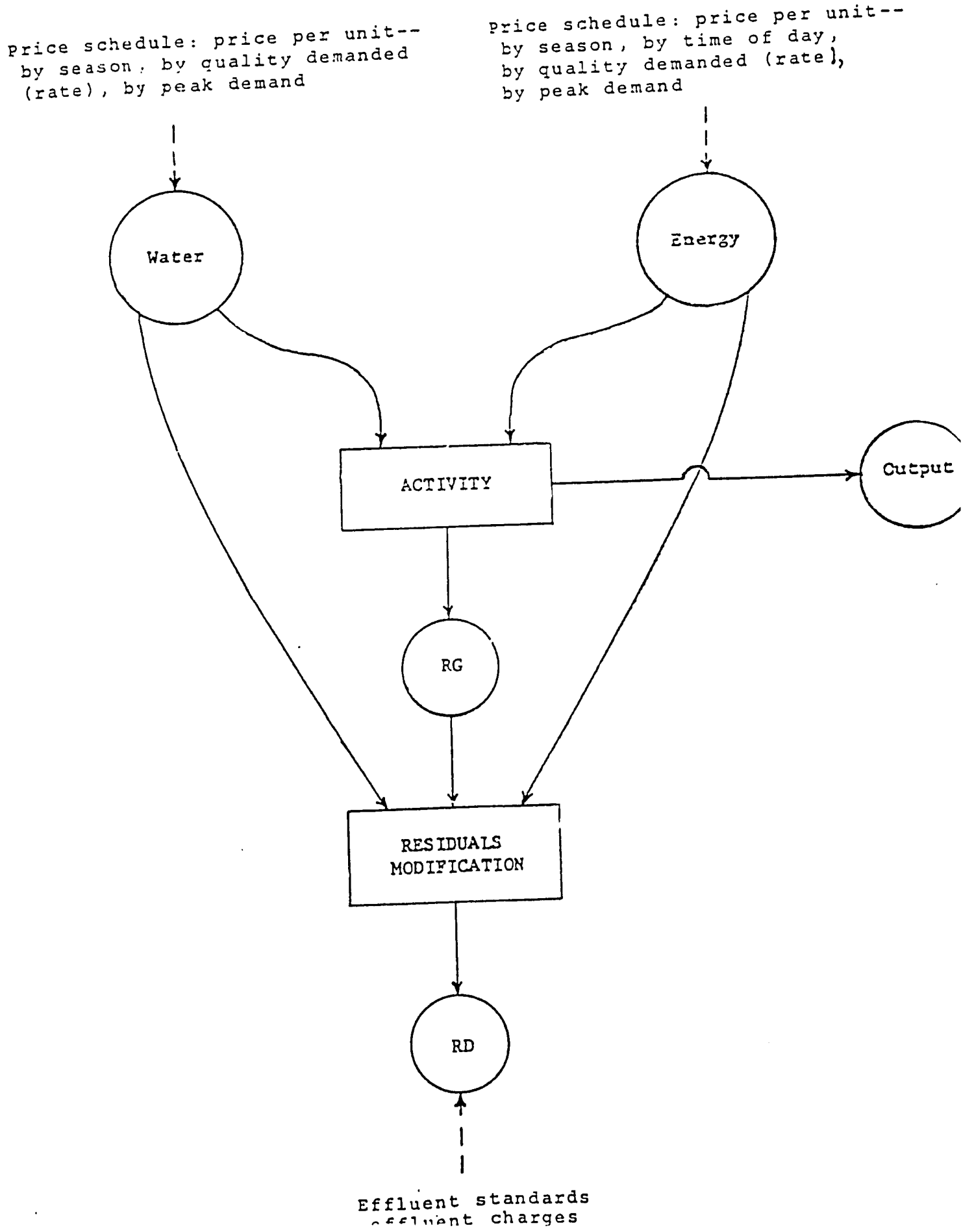
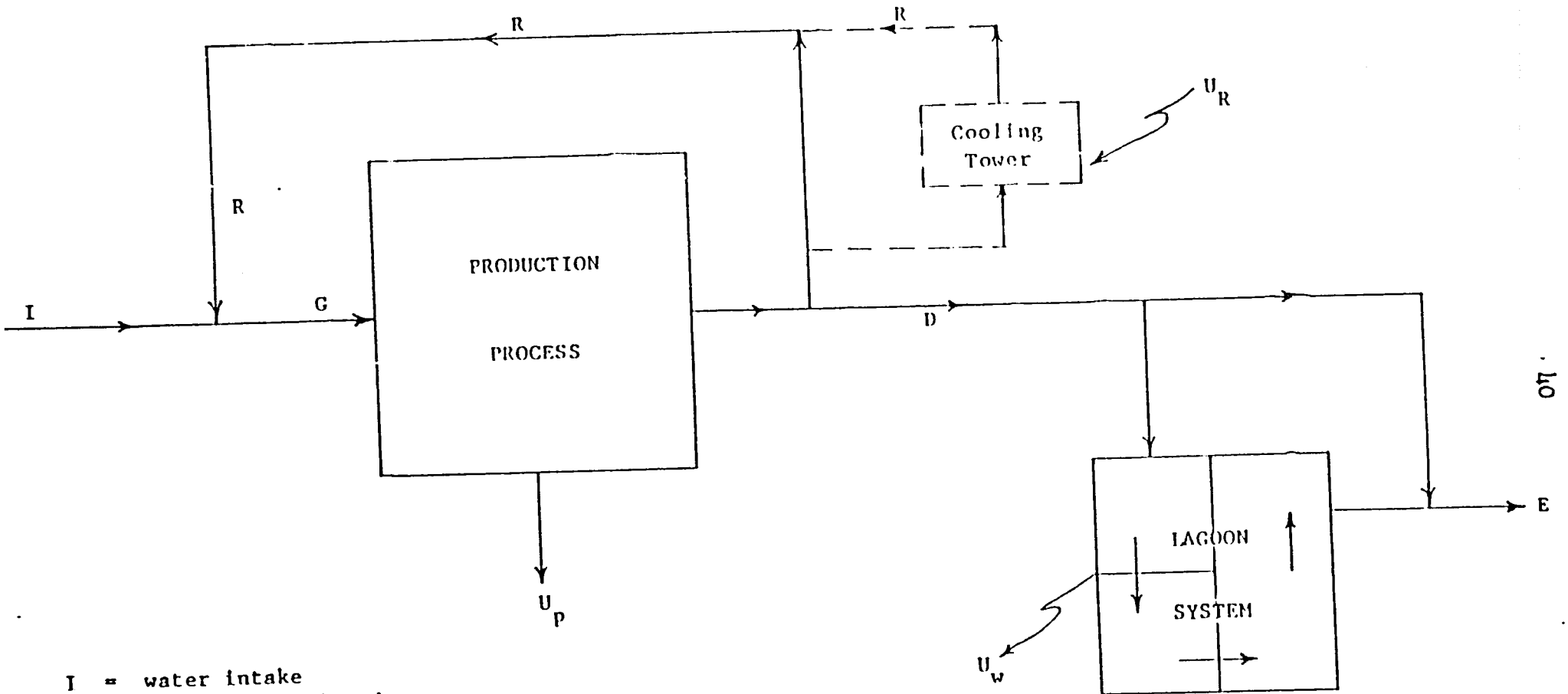


Figure 18. Terminology Relating to Water Utilization



I = water intake
R = water recirculated
G = gross water applied
D = waste water (liquid residuals) generated in production process
E = final effluent
U_p = consumptive use (net depletion) of water in the production process
U_w = consumptive use in waste treatment
U_R = consumptive use in the cooling water circuit

Note: water circuits in relation to unit processes and unit operations within the production process (activity) are not shown

Analytical Approaches: Some Examples

Given the foregoing background, what are operational approaches for analyzing activities?? Basically, the analysis of any activity involves estimating materials and energy balances for the activity, under at least one set of "conditions", e.g., factor input prices, product mix, product characteristics, discharge limits. The level of detail and degree of sophistication can vary from a "simple" black box analysis to a complicated linear or mixed integer programming analysis. The level of detail should be function of the relative importance of the activity with respect to the residuals it generates and and the relative importance of the impacts of its discharges compared to discharges of other activities, plus available resources.

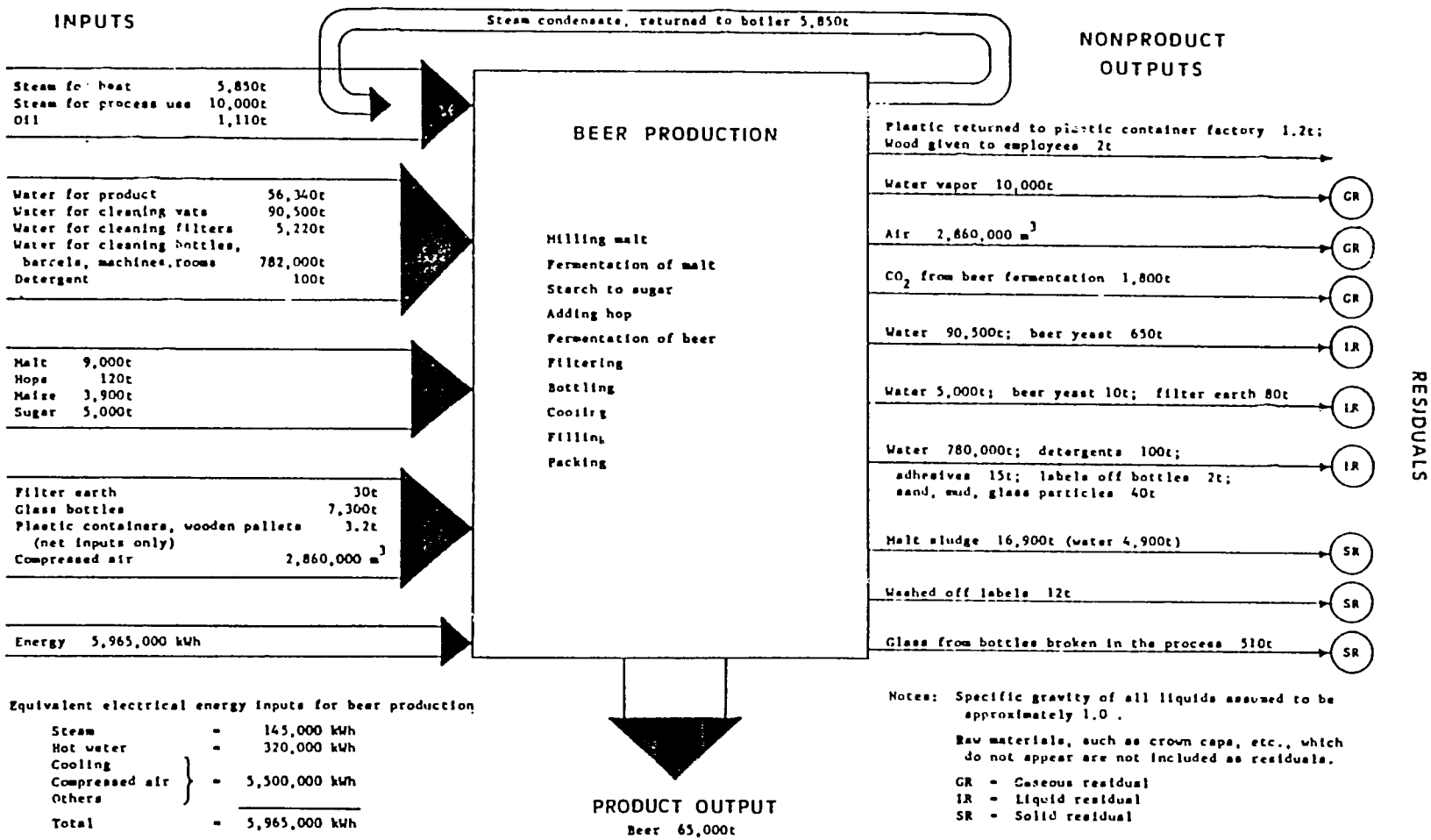
Figure 19 is an example of a "black box" analysis, i.e., one that considers the total plant as an aggregated activity. This is in contrast to analyses which develop the materials and energy balances for each unit process and unit operation. The analysis for the Union Brewery was produced by some sampling, some careful use of various plant records, and iteration until the balances were consistent. It was done with individuals who had never done a materials balance analysis previously.

Manufacture of Tissue Paper

To illustrate both how the analysis can be done and what can be learned from the analysis relevant to UEQM, an example of an integrated kraft paper mill producing tissue paper will be used. Figure 20 is a simplified flow chart of production in such a mill.

The residuals generated in producing tissue paper are a function of: the species of wood used; the method of wood preparation, i.e., debarking and chipping; the type of pulping process; the characteristics desired in the final product, in this case wet strength, softness, absorbency, and color; the type of paper machine; the efficiency of the paper machine and the speed of operation; and the efficiency of the converting operation. The degree of whiteness desired is of particular importance, because this determines the amount of bleaching required. Bleaching is a major source

Figure 19. Materials Balance for Beer Production in Union Brewery, Ljubljana, Yugoslavia, 1972



Equivalent electrical energy inputs for beer production

Steam	=	145,000 kWh
Hot water	=	320,000 kWh
Cooling, Compressed air, Others	=	5,500,000 kWh
Total	=	5,965,000 kWh

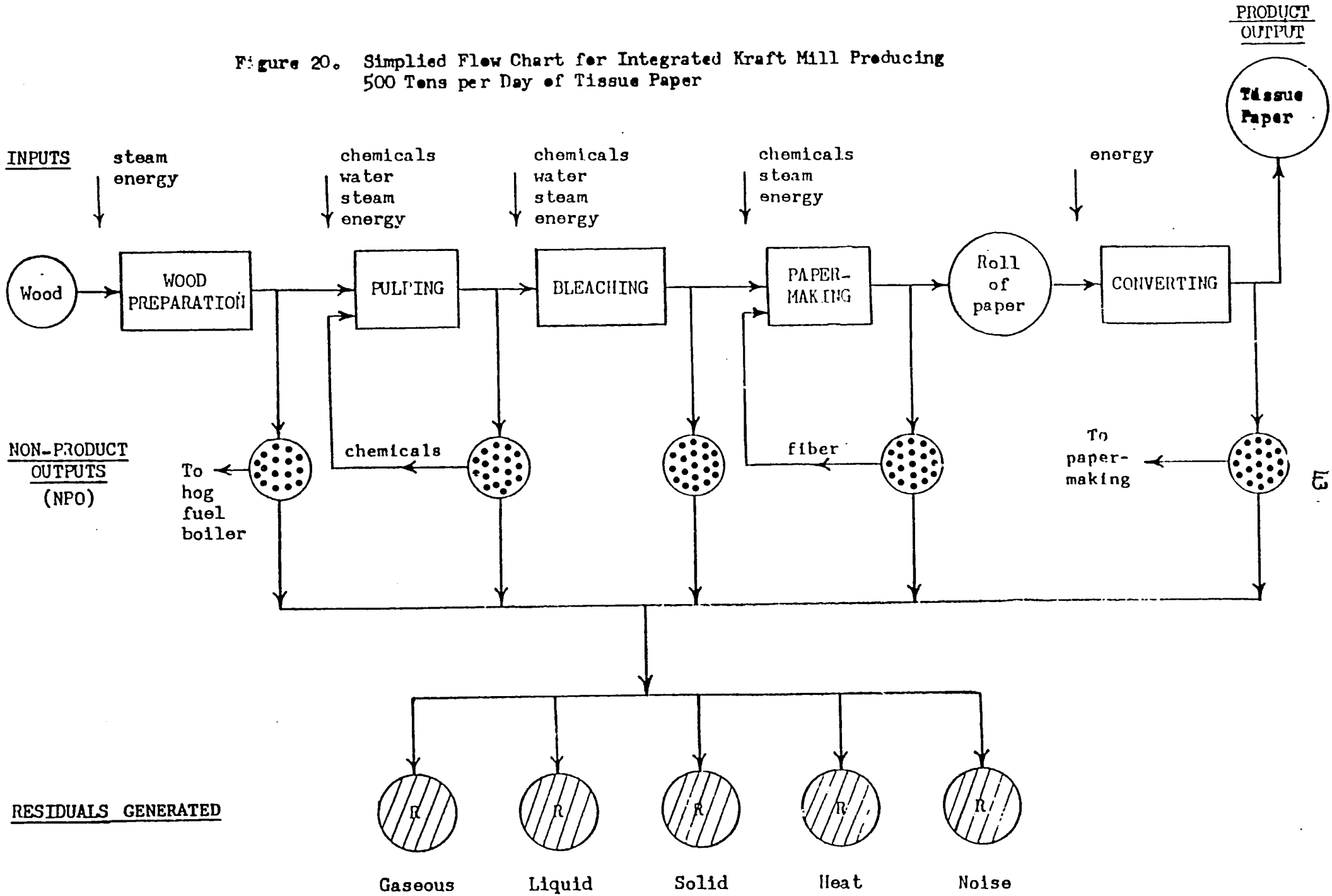
Notes: Specific gravity of all liquids assumed to be approximately 1.0 .

Raw materials, such as crown caps, etc., which do not appear are not included as residuals.

GR = Gaseous residual
LR = Liquid residual
SR = Solid residual

Source: Modified from Bower and Basta (1973)

Figure 20. Simplied Flow Chart for Integrated Kraft Mill Producing 500 Tons per Day of Tissue Paper



of residuals generation in the production of paper products, partly because it is an energy intensive process.

The objective of the mill manager is to maximize profits, or to minimize costs to produce a specified output, within whatever external and internal constraints exist. Various combinations of raw materials-pulping technology-bleaching sequence could be used to produce a given product or product mix. In this case raw material consists of softwood logs, with hydraulic debarking and kraft (sulphate) pulping. Major residuals generated include particulates, SO_2, reduced sulphur compounds, suspended solids (organic and inorganic), some complex organochloride compounds, and various solids. Reduction in particulate discharge is used to illustrate the analytical approach.

Table 5 shows the main sources of particulate generation in the integrated kraft mill producing 500 tons per day of tissue paper. [The output level is significant because there are significant economies of scale.] For each of these NPO streams of particulates, the objective is to find the least cost set of measures to achieve increasingly larger reductions in discharge of particulates, remembering that the removal of a material from one waste stream results in another residual requiring disposal. Thus, each measure which results in modifying a "primary" residual results in one or more secondary residuals, which in turn require disposal and perhaps modification, thereby generating tertiary residuals.

Figure 21 shows the net annual costs for reducing discharges of NPO particulates from four of the major sources identified in Table 5. "0" indicates zero net annual cost; any point above that line is a net cost; any point below the line is a net profit. Positive net annual costs, i.e., profits, occur because---for two of the four sources---the particulate material represents valuable raw material, which---if recovered---can be returned directly into the production process. [This is the materials recovery identified in the Introduction.] Note that for the recovery furnace, materials recovery would be carried out to about 95% recovery. Beyond that lev the incremental cost of recovery would be larger than the value of the recovered material

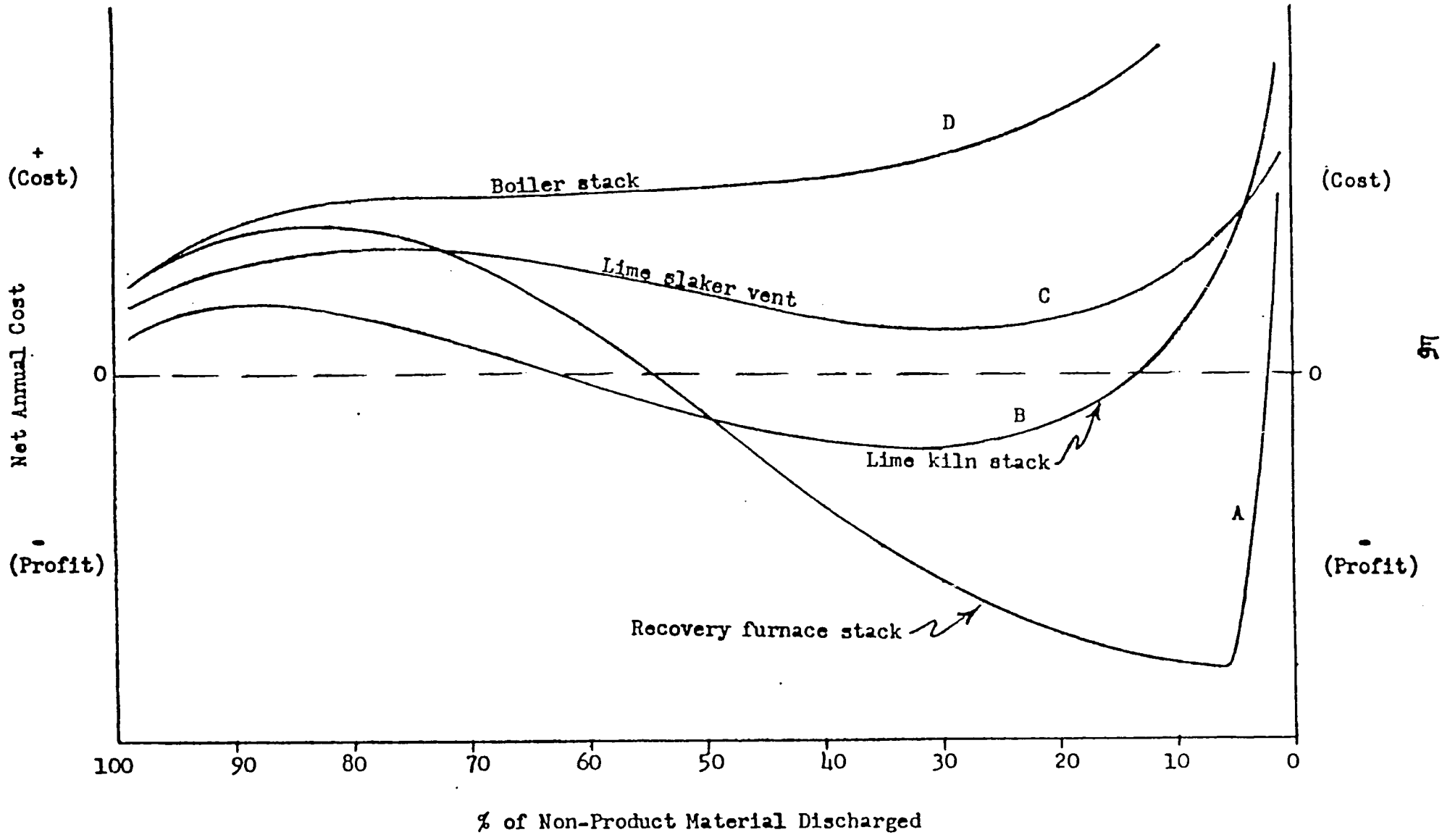
Table 5. Main Sources of Particulate Generation in an Integrated Kraft Paper Mill Producing 500 Tons per Day of Tissue Paper

Source	Pounds of Particulates Generated Per Ton of Paper
Recovery furnace stack	5.0
Lime kiln stack	11.7
Combination bark-fuel boiler stack	27.6
Slaker vent	0.7*
Smelt dissolving tank vent	1.2
Fuel-fired boiler stack	1.0
Total	47.2

*Estimated

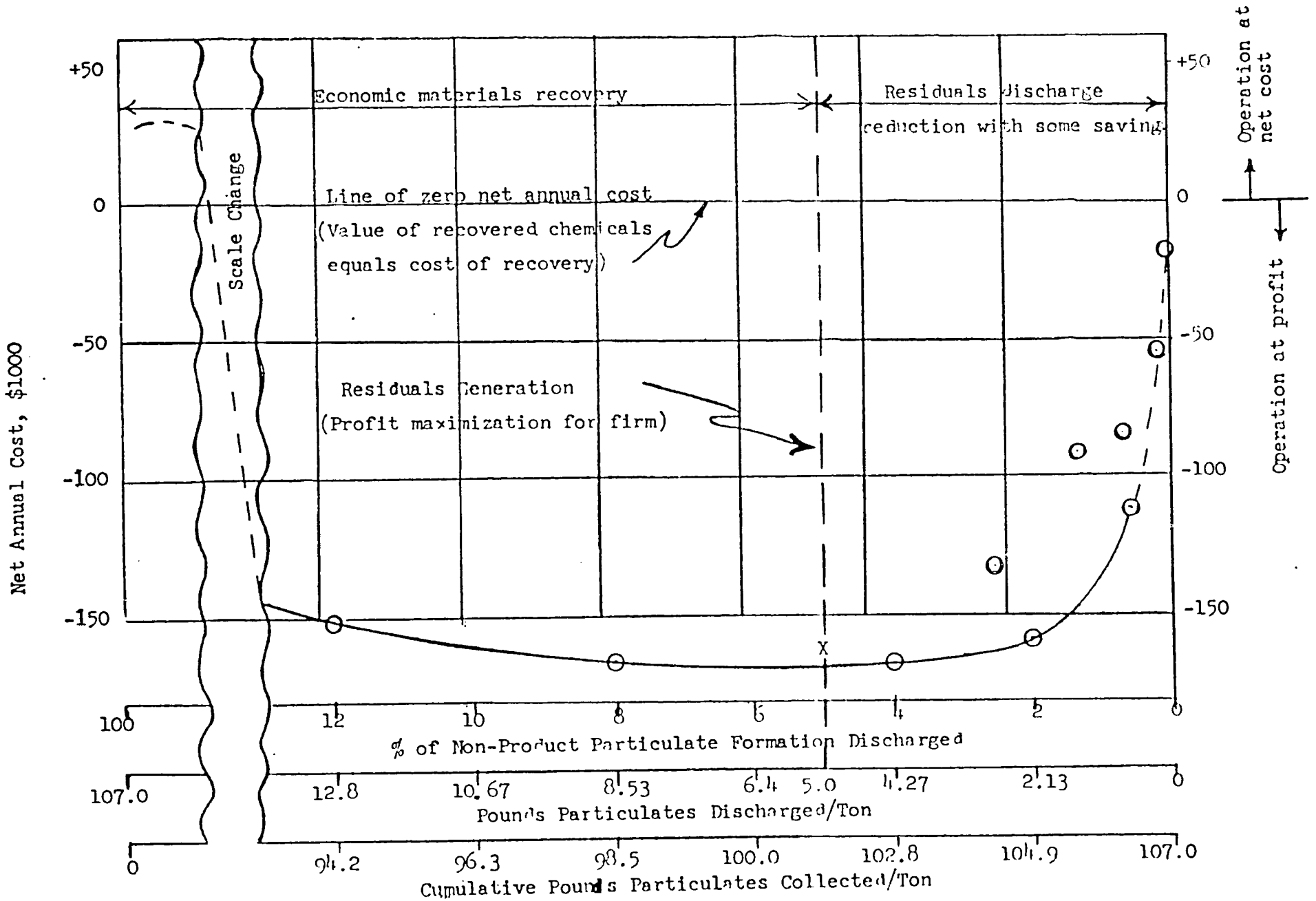
Source: Löf, Hearon, and Bower (1973).

Figure 21. Net Annual Cost Functions for Reduction in Discharge of NPO Particulates Formed in Four Operations in a 500 Tons per Day Integrated Kraft Mill Producing Tissue Paper



Source: Løf, Hearon, and Bewer (1973)

Figure 22. Net Annual Cost of Reduction in Discharge of NPO Particulates Formed in Recovery Furnace of 500 Tons per Day Integrated Kraft Mill Producing Tissue Paper



Source: Taf, Hearon, and Bower (1973)

For the lime kiln stack, about 70% of the NPO particulates would be recovered. For the boiler stack and the lime slakdr vent, there is no level of recovery which is economic, i.e., the value of the recovered materials is greater than the cost of recovery. Therefore, no reduction in discharge would occur unless constraints are placed on such discharge, e.g., discharge standards/limits. It should be emphasized that the degree of recovery at a point in time is a function of relative prices of factor inputs and of costs of recovery, and the costs of disposal.

These net annual discharge reduction cost functions are developed by specifying increasingly stringent discharge standards, as shown in Table 6, and then determining the least cost set of measures, including interrelationships among residuals and residuals modification measures, to meet the standards.

Table 6. Specification of Increasingly Stringent Residuals Discharge Standards: Integrated Kraft Mill Producing 500 Tons Per Day of Tissue Paper

Residual	Level 0	I	II	III	IV
		All values in pounds per ton			
SO_2	No Control*	50	35	20	10
Particulates	No Control	30	8	4	2
Reduced sulfur compounds	No Control	10	2	0.5	0.2
Suspended solids	No Control	50	20	10	5
BOD_5	No Control	60	35	20	10

Note: Standards apply to total mill operation (i.e., from all sources).

*No restrictions on discharges; reflects basic production costs.

Source: Löf, Hearon, and Bower (1973).

The analyses reported above were for a "production combination" involving 100% kraft pulping, a CEHD bleaching sequence (Table 7), and output of tissue paper with brightness of 80-82 (General Electric Brightness, GEB), and specific specifications for absorbency, wet strength, and softness. The analyses yielded estimated costs, net, for residuals management for the production combination Ti 4, shown in Table 7. Costs increase as the limits on discharges are increased, from Set I to Set III.

The effect of the degree of whiteness of the product desired is shown also in Table 7, by comparing production combination Ti 31 with P.C. Ti 4. The former reflects the same raw material, pulping process, and product specifications except for brightness, which---for Ti 31---is about 25, the "color" of unbleached kraft pulp. Note that net residuals management costs for Ti 31 are about 20% of those for Ti 4, for Level III. This difference reflects not only less use of environmental services but less use of input resources.

Table 7. Net Residuals Management Costs Per Ton of Output, Integrated Kraft Mill Producing 500 Tons Per Day of Tissue Paper

Costs	Level of Discharge Standards		
	I	II	III
P.C. Ti 4: Bleached Tissue Paper			
Gaseous residuals modification, $/ton	0.16	0.59	1.66
Liquid residuals modification, $/ton	3.07	4.09	6.76
Solid residuals disposal, $/ton	0.38	0.38	0.38
Total, $/ton	3.61	5.06	8.80
P.C. Ti 31: Unbleached Tissue Paper			
Gaseous residuals modification, $/ton	0.12	0.46	0.83
Liquid residuals modification, $/ton	0.10	0.40	0.72
Solid residuals disposal, $/ton	0.33	0.33	0.33
Total, $/ton	0.55	1.19	1.88

Note: Costs are in 1970 dollars and are based on estimates of operating labor, maintenance labor and supplies, power and material requirements, 12.5 percent annual charge on estimated capital investment, and are credited with chemical recoveries at typical market prices. Operation 350 days per year was assumed.

The costs of any secondary solid residuals generated in liquid and gaseous residuals modification (sludge) are included in the liquid and gaseous residuals modification costs.

Source: Löf, Hearon, and Bower (1973)

Linked Activities

In some cases it is not sufficient to analyze an individual activity in the process of trying to devise a strategy for improving urban environmental quality. This is because certain types of activities are inextricably linked, even though they are spatially separated. This type of situation is exemplified by the use of coal to generate electrical energy for an urban area.

Figure 23 shows the "coal-electric energy system", with alternatives of surface and underground coal mining, and generation at a mine-mouth plant or a load center plant. The liquid, gaseous, and solid residuals generated at various points in the system are indicated. Figure 24 shows the effects on various elements of the system of various strategies devised to improve some aspect of AEQ. For example, if physical measures are installed to reduce SO_2 and particulate discharges from the power plant, Strategy 8, all of the impacts on the system are <u>negative</u> (plus signs in figure). This is because measures to reduce discharges themselves require energy. Therefore, to maintain the same energy output, more coal has to be mined, prepared, transported. For the same reason, all of the residuals streams are increased, except for the reduced SO_2 and particulates from the power plant.

Agricultural/Forest Operations

The approach to analyzing activities illustrated in the foregoing with the pulp and paper mill is equally applicable to agricultural operations and to forest management operations. That is, different combinations of factor inputs can be applied to the agricultural land or to the forest land to produce different combinations of outputs. The decision for the manager of the agricultural operation or forest operation or game farm involves choosing that mix of inputs which, combined with the characteristics of the land and inputs from "nature" (sunlight, precipitation), will result in maximum sustained outputs. This is reflected in Figure 25 for agricultural production and Figure 26 for forest operations.

Figure 23. Linkages among Spatially Separated Activities in the Use of Coal to Generate Electrical Energy: Alternative Residuals Generation/Modification Systems

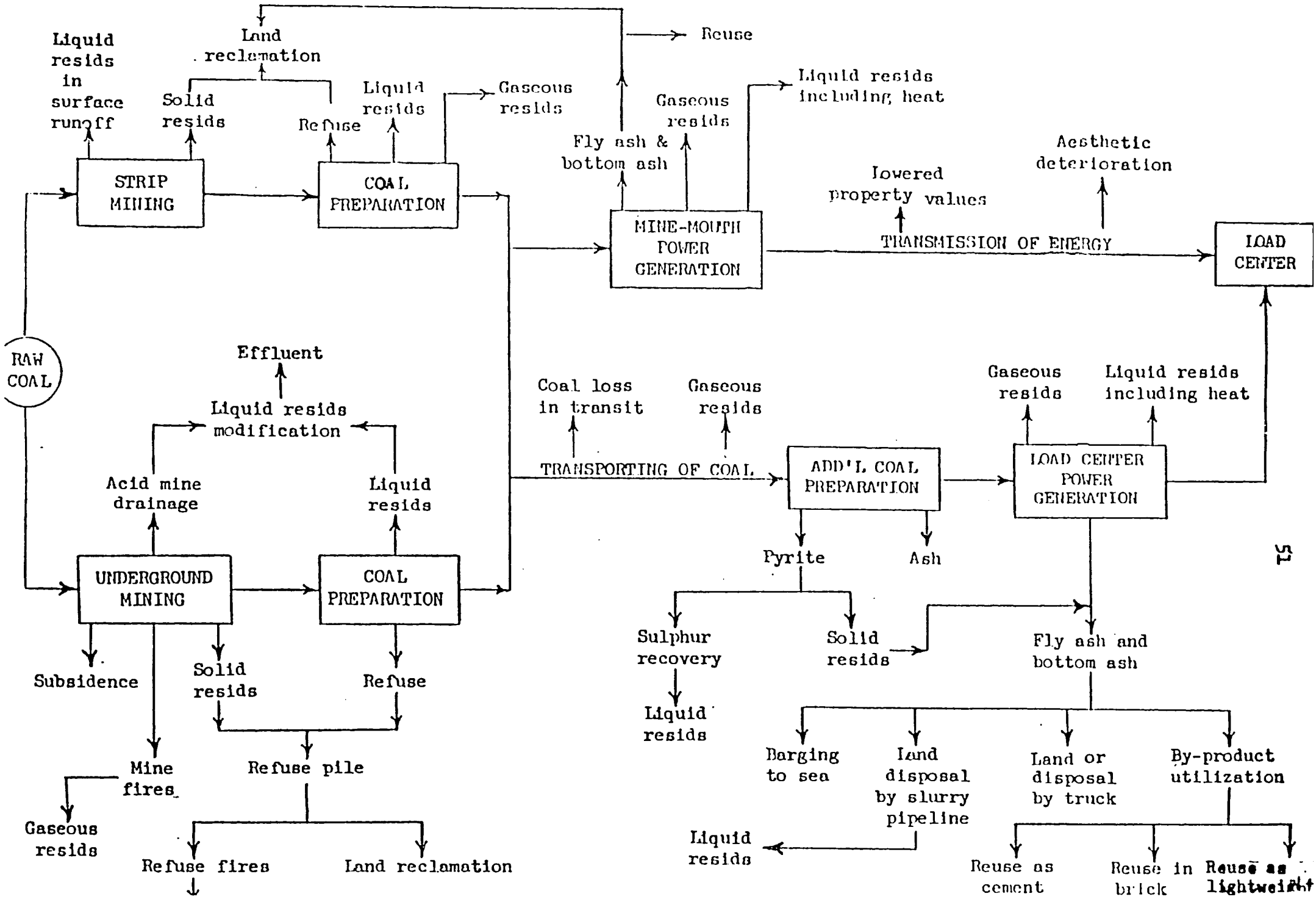


Figure 24. Effects of Various Strategies on Other Elements of the Coal-Electrical Energy System

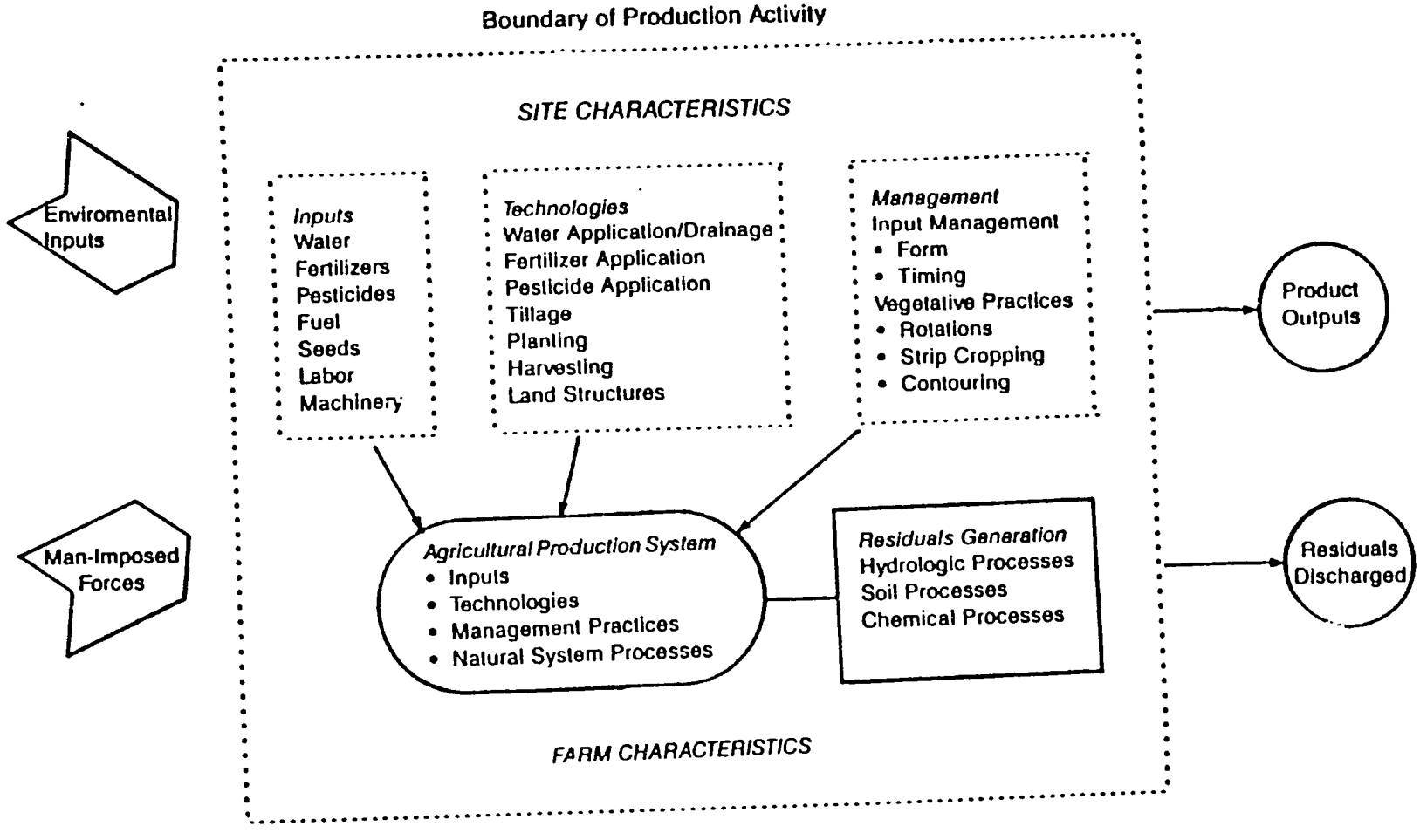
STRATEGY	1	2	3	4	5	6	7	8	9	10
IMPACTS ON SYSTEM										
Quantity of coal mined	0 1/	0	0	0	- 1/	+ 1/	-	+	0	+
Quantity of raw mine drainage	-	0	0	0	-	+	-	+	0	+
Quantity of refuse at mine	0	+	+	+	-	+	-	+	0	+
Quantity of coal transported	0	0	0	0	-	-	-	+	0	+
Qty. of solid resids at power plant	0	0	0	0	-	-	-	+	0	+
IMPACTS ON RESIDUALS										
Useful land	+	0	0	0	+	-	+	-	0	-
Acid and iron effluent	0	-	0	0	-	+	-	+	0	+
Suspended solids discharged from prep. plant	0	0	-	0	-	+	-	+	0	+
Part. discharged from prep. plant	0	0	0	-	-	+	-	+	0	+
Part. and sulfur oxides discharged from power plant	0	0	0	0	-	-	-	-	0	+
Heat dis. from power plant to water courses	0	0	0	0	-	0	0	+	0	-
Susp. solids dis. from power plant to water courses	0	0	0	0	-	-	-	+	-	.
Solid resids. from power plant	0	0	0	0	-	-	-	+	+	.

1/ 0 = no change; - = less; + = more; all + changes represent negative impacts except for

STRATEGIES:

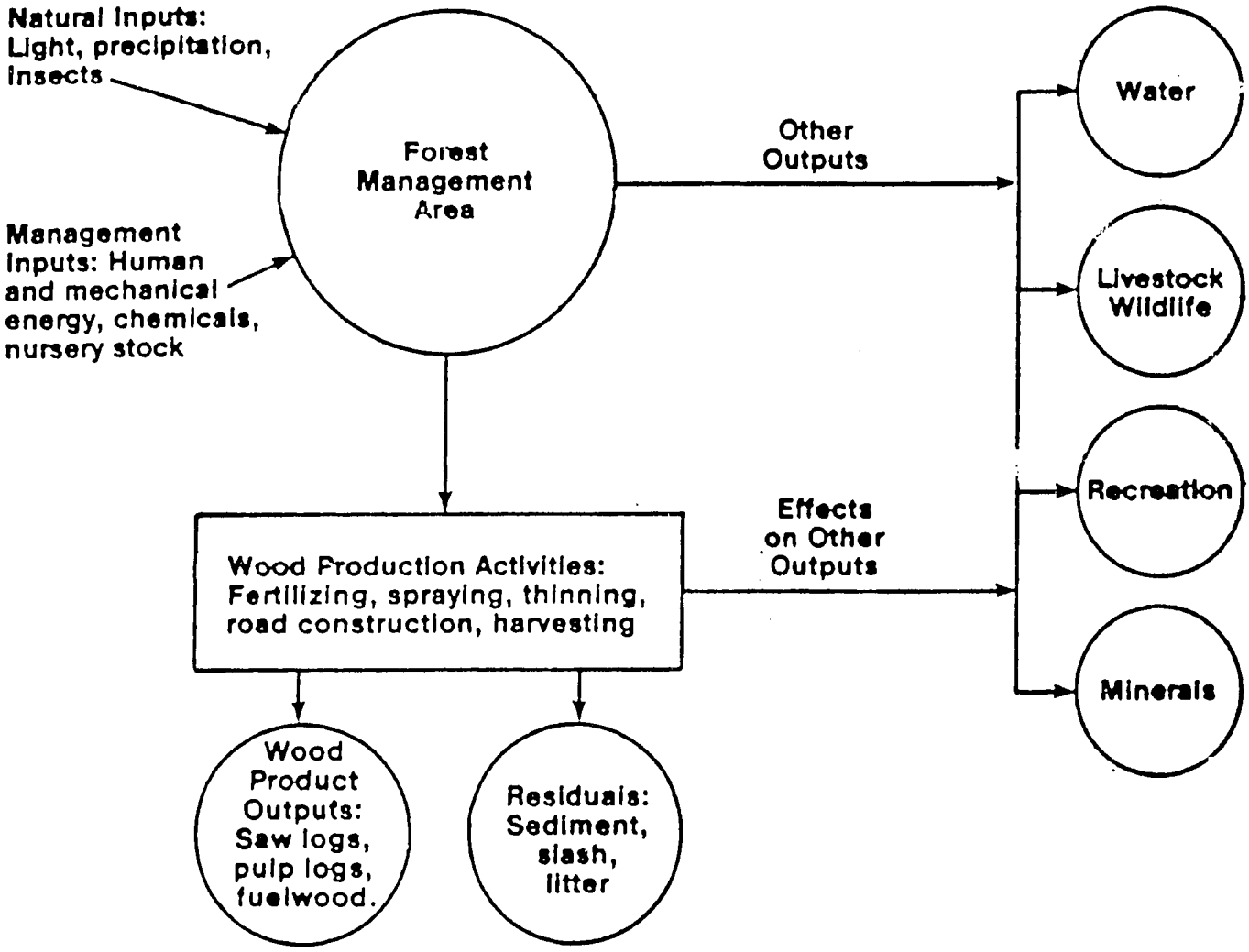
1. Grade and replant land
2. Treat acid mine drainage
3. Treat waste water from preparation plant
4. Collect particulates from preparation plant
5. Increase generator efficiency
6. Use more coal preparation
7. Use higher quality raw coal
8. Treat power plant flue gas
9. Treat suspended solids from power plant
10. Use cooling towers

Figure 25. Elements of an Agricultural Production System



Source: Waddell and Bower (1988)

Figure 26. Product Mix and Residuals Generation in Forest Operations



Source: Hufschmidt, et al. (1983)

Just as with power plants, petroleum refineries, pulp and paper mills, agricultural and forest activities generate and discharges residuals which can, and often do, have adverse impacts on AEQ beyond the boundaries of the activity, downstream and downwind. In addition, generation and discharge of residuals often affects the productivity of the agricultural or forestry site itself, e.g., as detailed by Bull and Kugler (1990).

Urban Storm Runoff

Storm runoff in urban areas is a major, and often the predominant---in certain seasons---source of discharges having adverse effects on AEQ. This is particularly true in areas where high intensity storms are typical throughout the "wet" season. The quantity of runoff is a function of:the amount of precipitation; the proportion of impermeable area, in the form of building tops, parking lots, streets; and the topography. The quality of the runoff, or the quantities of residuals carried in the runoff and discharged to water courses, is/are a function of: vehicular traffic and the exhaust discharges therefrom and the particles from tires; litter; residuals of animals; residuals from street markets/open markets, cooking operations; materials dumped from residences, commercial operations; used and leaking oil; the amount of bare soil exposed; materials piled in industrial and commercial sites from which residuals are leached. [This listing is meant to be suggestive, not exhaustive.]

An important factor contributing to the increase in the importance of urban storm runoff is the encroachment onto steep lands in the periphery of urban areas. The elimination of vegetation substantially increases runoff. Further, in many of these areas not only are there no sewerage systems, but the standard on-site systems, e.g., septic tanks, cannot function properly, thereby adding more load for transport in the runoff.

A wide range of "undesirables" is found in urban storm runoff, from heavy metals such as cadmium, grease, oil, through pathogenic organisms and viruses. For example, urban areas are estimated to be one of the major sources of hydrocarbon inputs into coastal waters (Fam, et.al., 1988). The range of materials, the many factors affecting both runoff quantity and quality---as noted above---make estimating discharges from urban storm runoff difficult. However, because of its importance in virtually all urban areas, ranges in estimates---no matter how crude---should be made, as a basis for comparison with discharges from other sources. Huber (1986) reviewed the status of estimating urban runoff quality; little has changed since that review.

Analyzing Activities: Concluding Comments

Methods for Improving AEQ in Urban Areas

There are two basic classes or categories of methods for improving ambient environmental quality: (1) reducing discharge of residuals to the environment; and (2) making better use of, or increasing, the assimilative capacity of the environment. With respect to the first there are two major subclasses: (a) reducing generation of residuals; and (b) modifying residuals after generation. Reduction in generation can be accomplished by changing final demand, i.e., the characteristics of goods and services desired, changing production processes, and changing raw materials. (In some situations these three are interrelated, i.e., a change in product specifications will enable changes in both production process and raw material

Modification of residuals after generation can be accomplished by materials recovery (direct reuse in the same production process), by-product production (indirect reuse, i.e., use of a residual as an input to a different production process, at the same or a different location), some times by recirculation of water or air, and finally by what is traditionally termed "waste treatment", i.e., a sewage treatment facility or an incinerator.

The second basic class of methods for improving environmental quality can also be subdivided into two subclasses: (a) making better use of existing assimilative capacity; and (b) increasing assimilative capacity. Examples of the former are building stacks for discharging gaseous residuals at levels to achieve greater dispersion; relocating outfalls to where there is greater assimilative capacity in streams; temporary withholding of liquid residuals, during periods of low streamflow, for subsequent discharge when streamflow, and hence assimilative capacity, is higher; rescheduling of activities in time, such as changing the time pattern of traffic flow; and relocating activities in space, i.e., changing the land use pattern, to be more in accord

with the natural assimilative capacity in an area, such as locating industrial activities downwind from residential areas. Increasing the assimilative capacity can be accomplished by such measures as the addition of water to streams during low flow periods; artificially adding oxygen to streams, lakes, and estuaries; and building topography with solid residuals, i.e., making artificial hills. Note that all of these methods do not change the quantity or type of residual discharged. They are based on the fact that the natural environment has some finite capacity to assimilative residuals, although that capacity is stochastic, i.e., varies randomly with time.

Three points merit emphasis. One, it is technologically and economically possible to make changes in existing plants, often at relatively small costs, or even at a profit (cost savings). It must be remembered that most activities involve a set of unit processes and operations. Changes can be made in one unit process without changing all other unit processes. (Input quantities will change.) For example a peach cannery might have three canning lines. As a start in reducing discharges, a dry peeling operation could be installed on one line in place of the wet peeling operation; the other lines would not need to be changed while the "pilot project" was operated to determine its utility. Or, the batch cooker on one line might be changed to a continuous cooker.

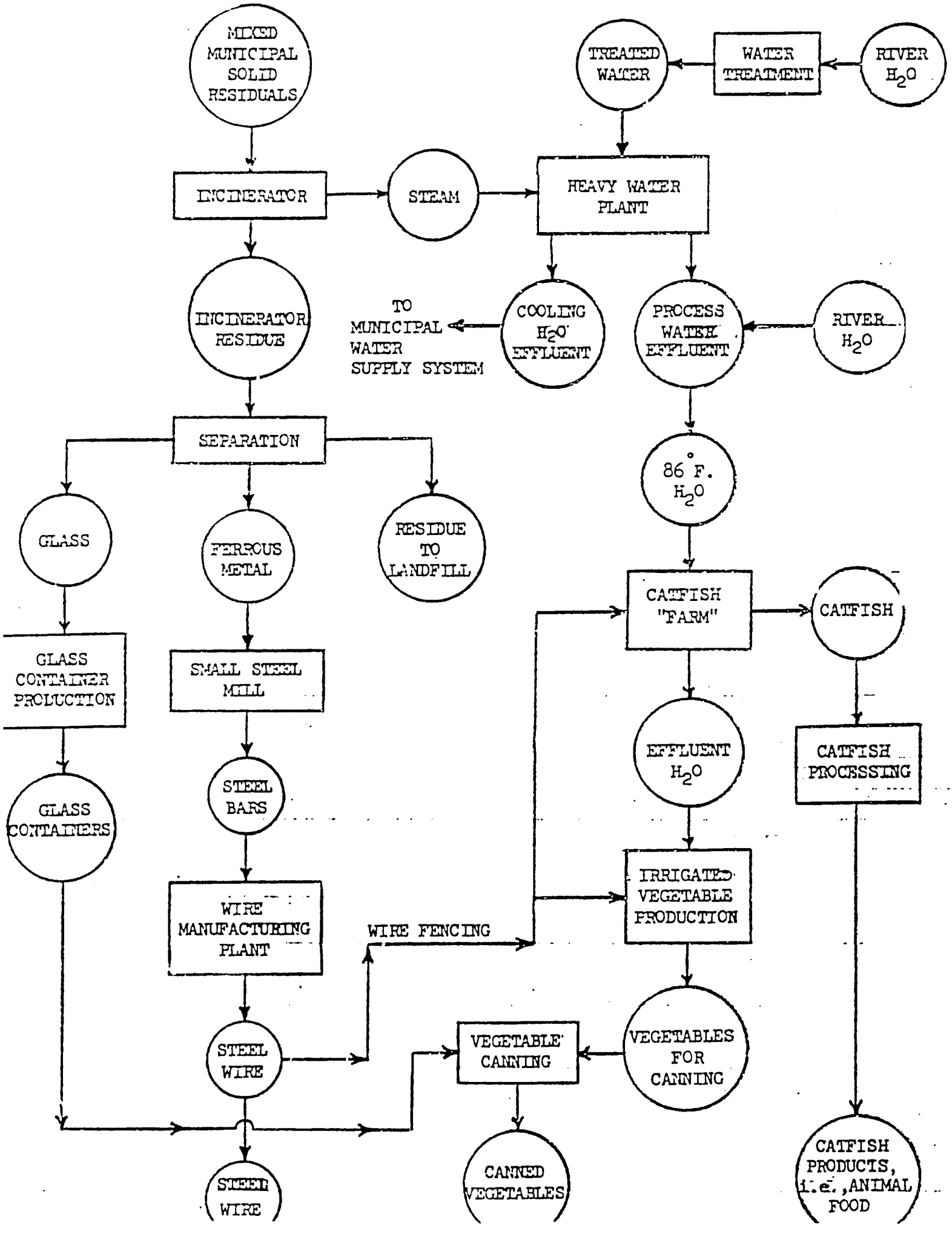
What has been learned from responses to changes in factor input prices, e.g., energy price increase in 1974, initiation of sewer charges, is that many options are available. One does not have to buy a "new" plant. This incremental, "rethinking" approach is the basis of the various Pollution Prevention Pays programs, now (1990) probably the major thrust in EQM, although pioneered by the 3M Company (The 3M Company, no date) 10-15 years ago, and pushed by Resources for the Future about 20 years ago (Kneese and Bower, 1968). Although the approach has been applied most commonly to manufacturing activities, it is just as relevant to hospitals, supermarkets, universities.

Two, in estimating the costs of improving AEQ by reducing discharges, it must be recognized that there are TWO points of view from which cost estimates are made. One is society's point of view, from which one is analyzing costs in terms of actual resource costs to society. The other is the activity's point of view, which considers its actual outlays of money, i.e., its cash flow requirements. These two points of view rarely coincide. This is because of the various subsidies which typically are available to many activities, whether these are privately or publicly owned. These subsidies include low interest rate loans, tax breaks, depletion allowances, direct grants for part of capital and/or operating costs. Thus, the costs to the activity are less than the real resource costs to society, the other portion of the costs being borne by the rest of society (and by the activity, to the extent of its taxes).

The result of this difference is that the activity may well choose an option to meet a discharge limit, which involves higher resource costs than necessary. For example, the least cost option to society may be a change in one unit process or an increase in materials recovery. An alternative is to install a "waste treatment" facility, at the "end-of-the-pipe". Such a facility, in the U.S. and many countries, is likely to be subsidized, by one or more of the means noted in the previous paragraph, because the rules/regulations are written in terms of "pollution control", which is interpreted to mean end-of-pipe. With the subsidy, the cash flow costs to the activity turn out to be less than the cash flow costs of materials recovery, for which there is no subsidy.

Three, the major problem is to try to develop the capacity in EQM agencies and in the management of different activities, to consider the entire range of options for reducing discharges. How can innovation and imagination be stimulated?? What conflation of factors resulted in the idea, subsequently implemented, for using cooling towers as trickling filters, thereby reducing both heat discharges to the water environment and those of oxygen demanding materials?? What stimulated the imaginative system shown in Figure 27, a system which interrelates a number of activities in a given region?

Figure 27. Schematic of a Regional Residuals Management Complex



Developing efficient and effective UEQM strategies requires much more attention to these types of micro and regional measures.

ANALYZING NATURAL SYSTEMS

Introduction

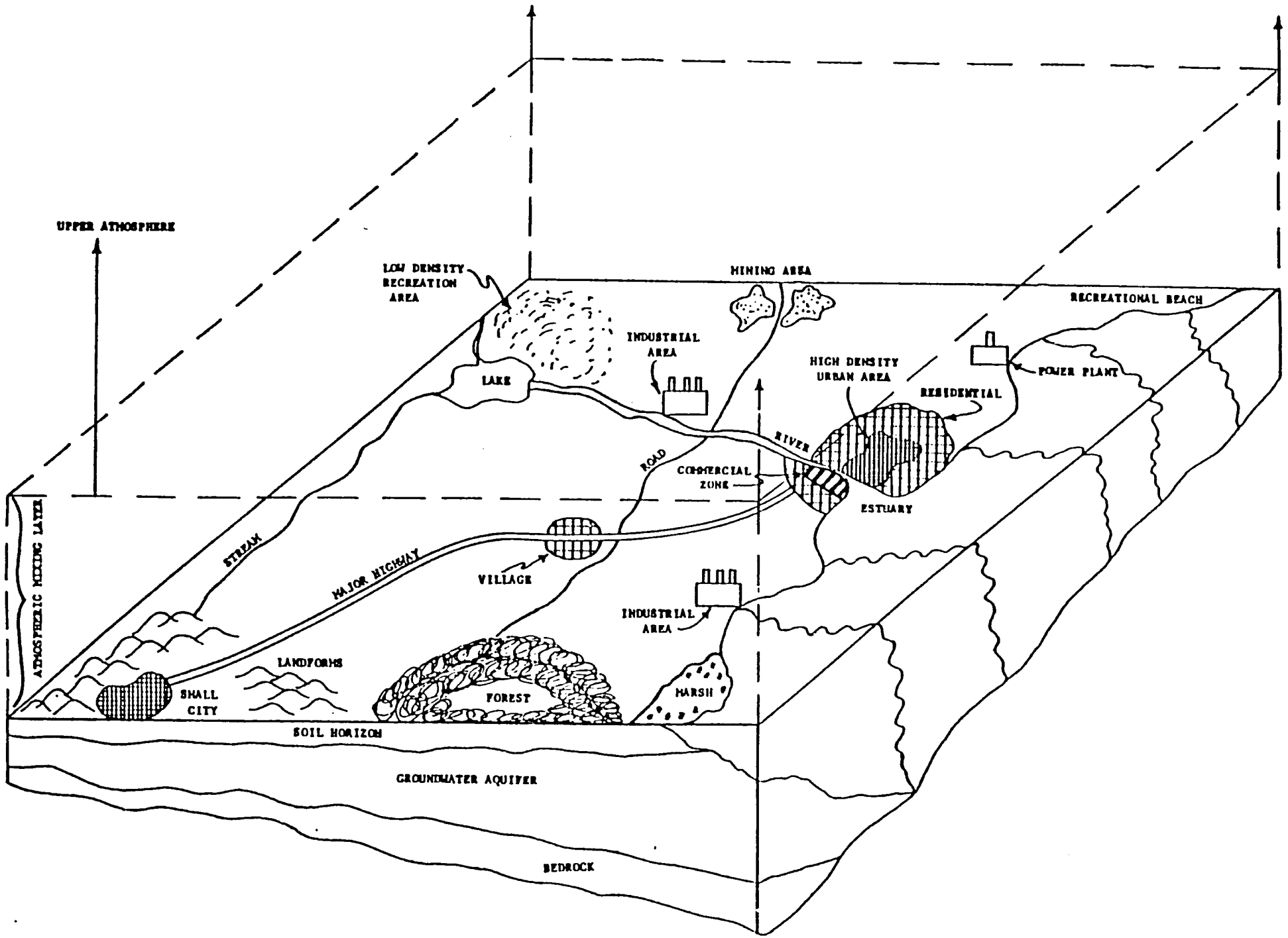
Man's activities in an urban region act upon, and are acted upon, by the natural systems of which the "biosphere" is comprised, in terms of the three environmental media: atmosphere; water bodies; land. These interactions are reflected in Figure 28. The function of natural systems models (NSMs) is to translate the time and spatial pattern of residuals discharges from man's activities into the resulting time and spatial pattern of ambient environmental quality (AEQ). However, it must also be remembered that many constituents discharged as residuals from man's activities are also discharged to natural systems as a result of natural processes.

AEQ is defined by such indicators as: concentration of dissolved oxygen in a stream; the biomass of fish per cubic meter of water in an estuary; the concentration os sulphur dioxide or carbon monocide in the atmosphere over an urban area; the concentration of nitrates in groundwater. The indicators used to characterize AEQ in any given context are a function of: the relevant management problem(s); the available data; and the desired levels of AEQ.

In natural systems, five basic processes are at work: chemical; biochemical; physical; physicochemical; and ecological. These processes affect the movement, and transformation into other related forms, of material and energy in natural systems, thereby alterning AEQ in both space and time.

"Chemical processes involve the reaction of two or more compounds with each other to form one or more different compounds. An example of a chemical process in a natural system is the transformation of SO_2 into SO_3 and eventually into H_2SO_4 (sulfuric acid), in the atmosphere. Biochemical processes differ from purely chemical processes in

Figure 28. Schematic of Regional Setting of Man-Environment Interactions



that the transformation is the result of chemical-biological interaction. An example is bacterial decomposition of organic material in a water body where the reaction takes place within a biological organism. Examples of a purely physical process are the movement of particulate matter in the atmosphere by wind currents and the downstream transport of suspended material not subject to decomposition. Physicochemical processes involve the chemistry and physics of molecules as they interact with their surroundings, for example, the adsorption of organic molecules onto solid sediment particles in a stream. Ecological processes involve interactions between or among different species of organisms in the food chain and--for any given organisms or group of organisms--processes such as consumption by prey organisms, growth, mortality, and respiration." (Basta and Bower, 1982, p. 31) Any given NSM involves one process or several of these processes.

Categories of Natural Systems Models

Typically, NSMs have been developed by specialists, e.g., hydrologists, biologists, meteorologists, engineers, ecologists, limnologists, in a wide range of settings and for a variety of purposes. Consequently, there is no consensus with respect to a scheme for classifying or categorizing NSMs. However, some classification scheme is essential for describing NSMs relevant to UEQM, because analysis for UEQM is likely to require several different NSMs, each providing information about a different part of the biosphere and related AEQ, in order to answer the questions of concern. The following is an operational categorization of NSMs.

(1) Models of residuals generation and discharge from land surfaces, urban and nonurban;

(2) Models of surface receiving waters;

(3) Models of subsurface waters;

(4) Models of atmospheric systems;

(5) Models of geomorphological processes;

(6) Models of terrestrial ecosystems; and

(7) Models of movement of materials in food chains.

Models in the first category produce estimates of residuals generation and discharge from land surface as a result of the combination of man's activities affecting the characteristics of the land surface and natural agents of wind and precipitation. Examples are the discharge of particulate material from cropland to the atmosphere as a result of wind action, and the generation and discharge into surface waters of organic material, heavy metals such as cadmium, and suspended solids resulting from precipitation on, and the flow of water over, land surfaces. Models in the second category produce estimates of the time and spatial pattern of water quality in rivers, streams, lakes, estuaries, bays, reservoirs, as a result of the discharge of residuals into these water bodies, including input via the atmosphere. [That is, one of the more recently recognized significant sources of discharges into major water bodies is deposition from the atmosphere.]

Models in the third category produce estimates of the time and spatial pattern of quality in a ground water body as a result of discharges into the body, e.g., leaching of nitrates from irrigation water application, leaching of chemicals from landfills. Models in the fourth category product estimates of the time and spatial pattern of ambient air quality as a result of discharges into the atmosphere, including volatilization of certain compounds from wastewater treatment lagoons. Particularly important in this category is spatial scale. Most of the current operational models for estimating air quality apply to local or regional, e.g., urban area, contexts. Models for estimating long-range transport, e.g., over hundreds to a thousand or so miles, are relatively new and relatively crude. However, this is an "arena" which has become of major importance, with the recognition of so-called "acid precipitation" problems.

Models in the fifth category produce estimates of changes in geomorphological processes as a result of man's activities, e.g., aggradation/degradation in stream channels as a result of reservoir construction, change in sand deposition on coastal beaches as a result of construction of groins and breakwaters, changes in erosion

along coasts as a result of removal of mangroves. Models in the sixth category produce estimates of the state of a given natural system as a result of the combination of endogenous processes at work within the system and external forces imposed on the system. Examples include: effects on soil structure and soil constituents of the combination of pests, application of pesticides, cultivation practices, crop rotation practices; effects of different forest harvesting methods, e.g., clear cutting, patch cutting, strip cutting, selective cutting, on wildlife. This is illustrated in Figure 29.

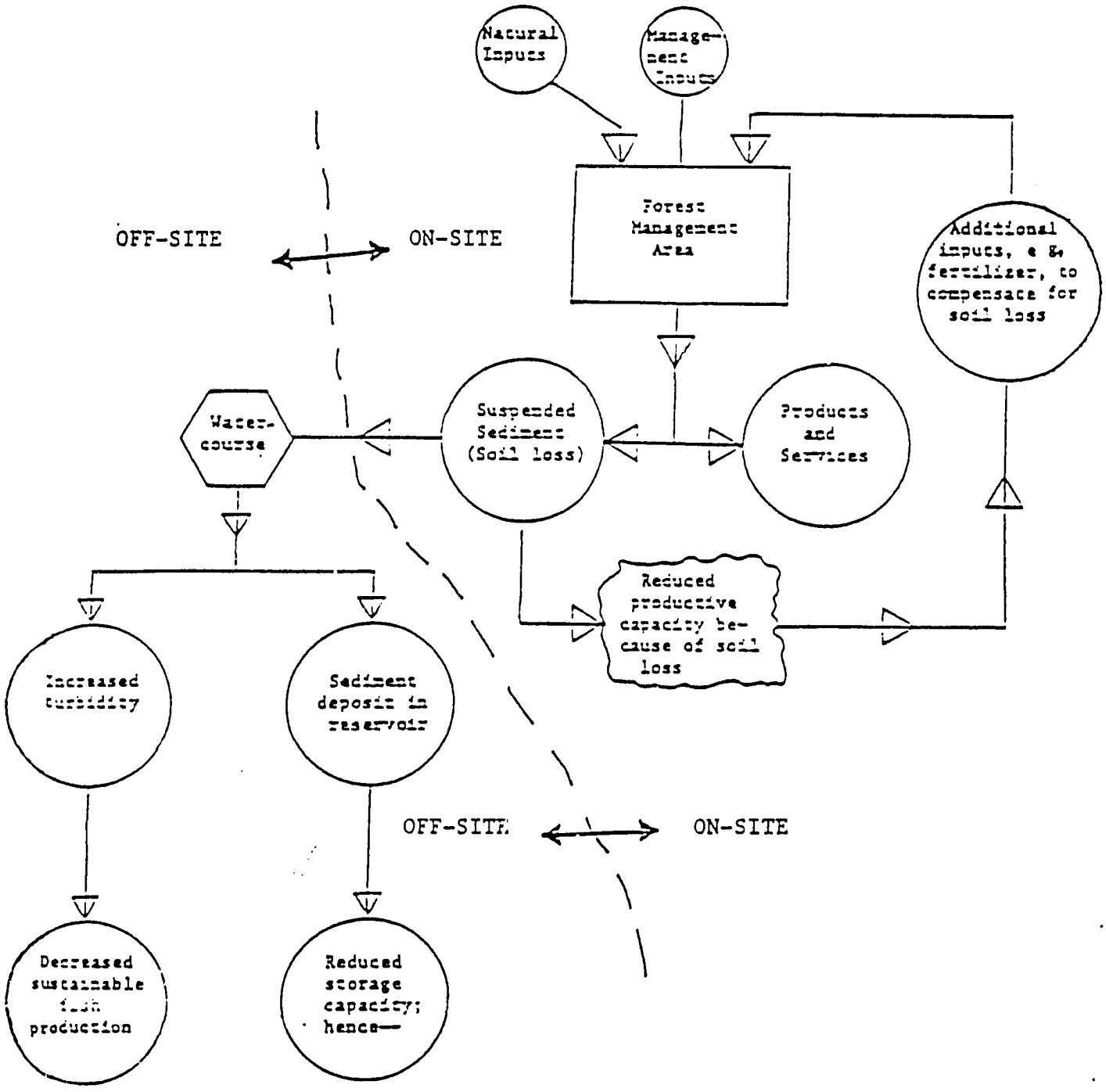
Models in the seventh category have elements of models in (1), (2), (4), (5), and (6). These models attempt to trace the "fate" of compounds in the environment as they move through the food chain, from lower to higher trophic levels, as depicted in Figure 30. Particularly important in these models is the phenomenon of "biomagnification", in which the concentration in the organisms increases with the trophic level.

In each of the foregoing categories there is a wide range in the complexity of models available. In addition, development and use of models is occurring all the time, so that the "population" of possible models for use in analysis for UEQM is continually changing.

Approaches to Analyzing Natural Systems

At least three approaches to analyzing natural systems can be identified. These are: (1) what might be termed "simple averaging models"; (2) statistical models: and (3) conservation of mass and energy models. The first approach is exemplified by: (a) estimating a rate of change based on empirical observation over some period of time; and (b) "bathtub" models. Figure 31 shows the changes in channel cross-section of a stream in an urbanized area, in which the degree of urbanization---measured for example by proportion of watershed or drainage area above the cross-section consisting of impermeable surface---began to increase rapidly in the late 1960s. A bathtub model is one in which the volume of a reach of a river, a portion of an estuary, or a lake, is estimated and the total quantity of a residual discharged from various sources into the volume

Figure 29. On-Site and Off-Site Effects on Natural Systems of a Forest Management Activity



reduced outputs of electric energy, flood damage reduction and irrigation water

Source: Hufschmidt, et al. (1983)

Figure 30. Schematic of a Food Chain Model

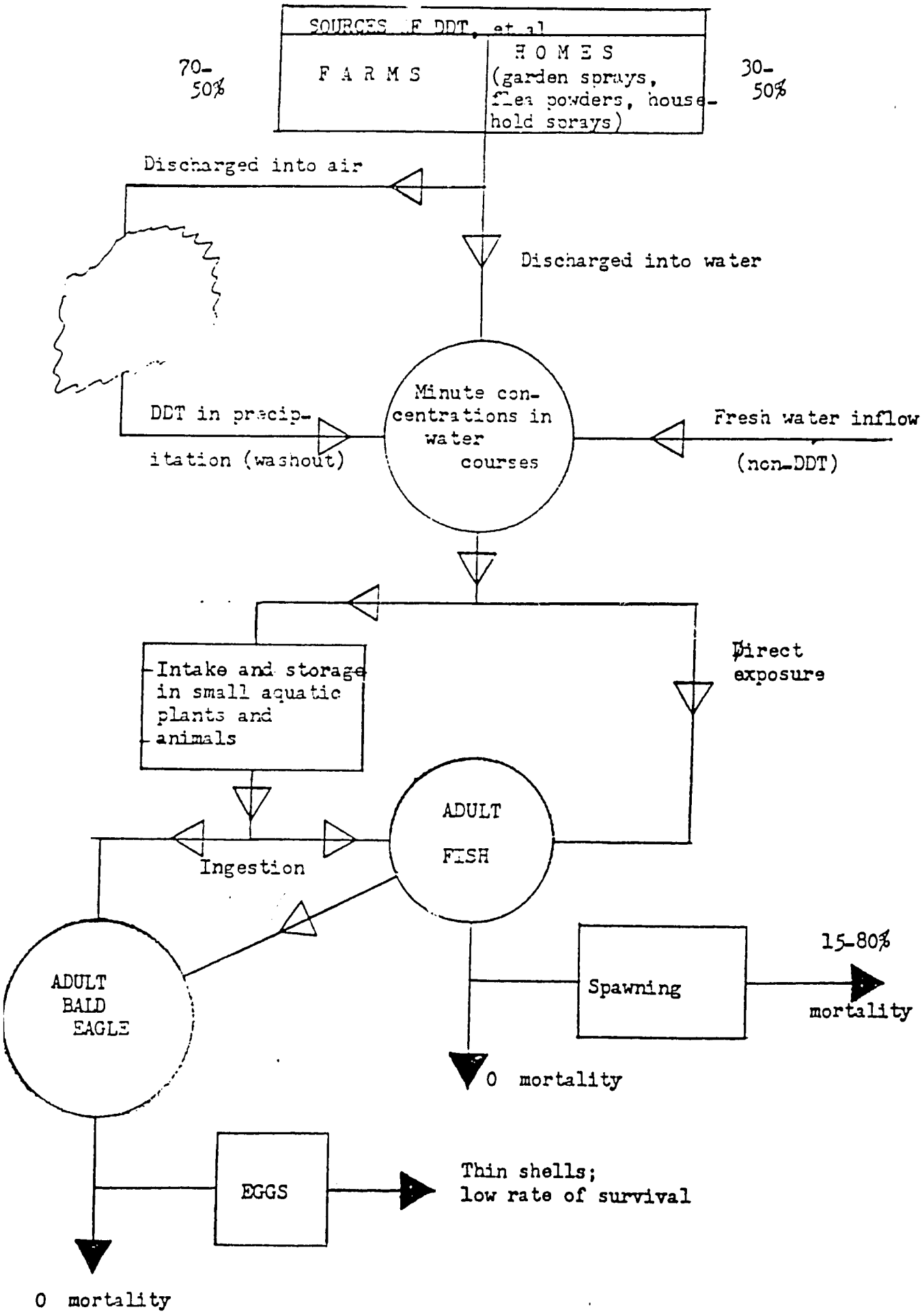
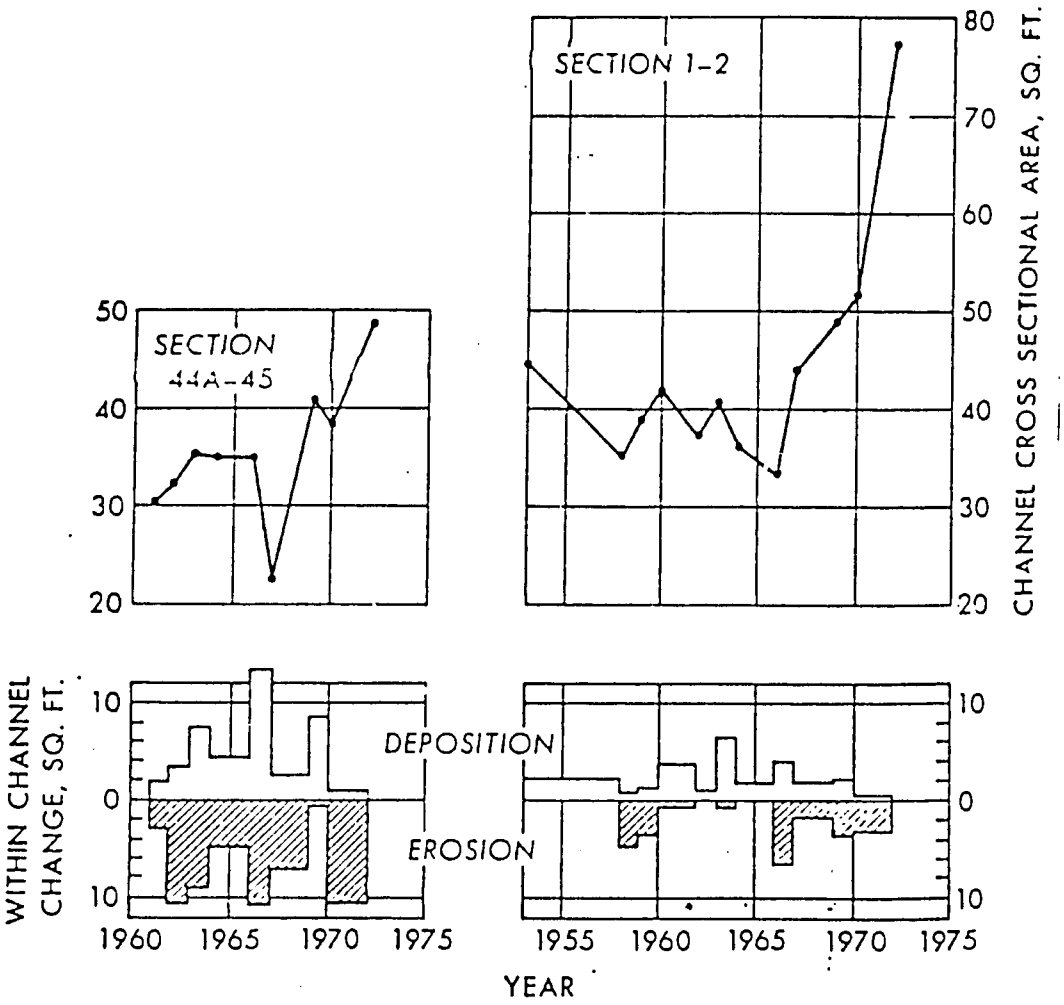


Figure 31. Change in Cross-Sectional Area of Stream Channel in Urban Area over Time



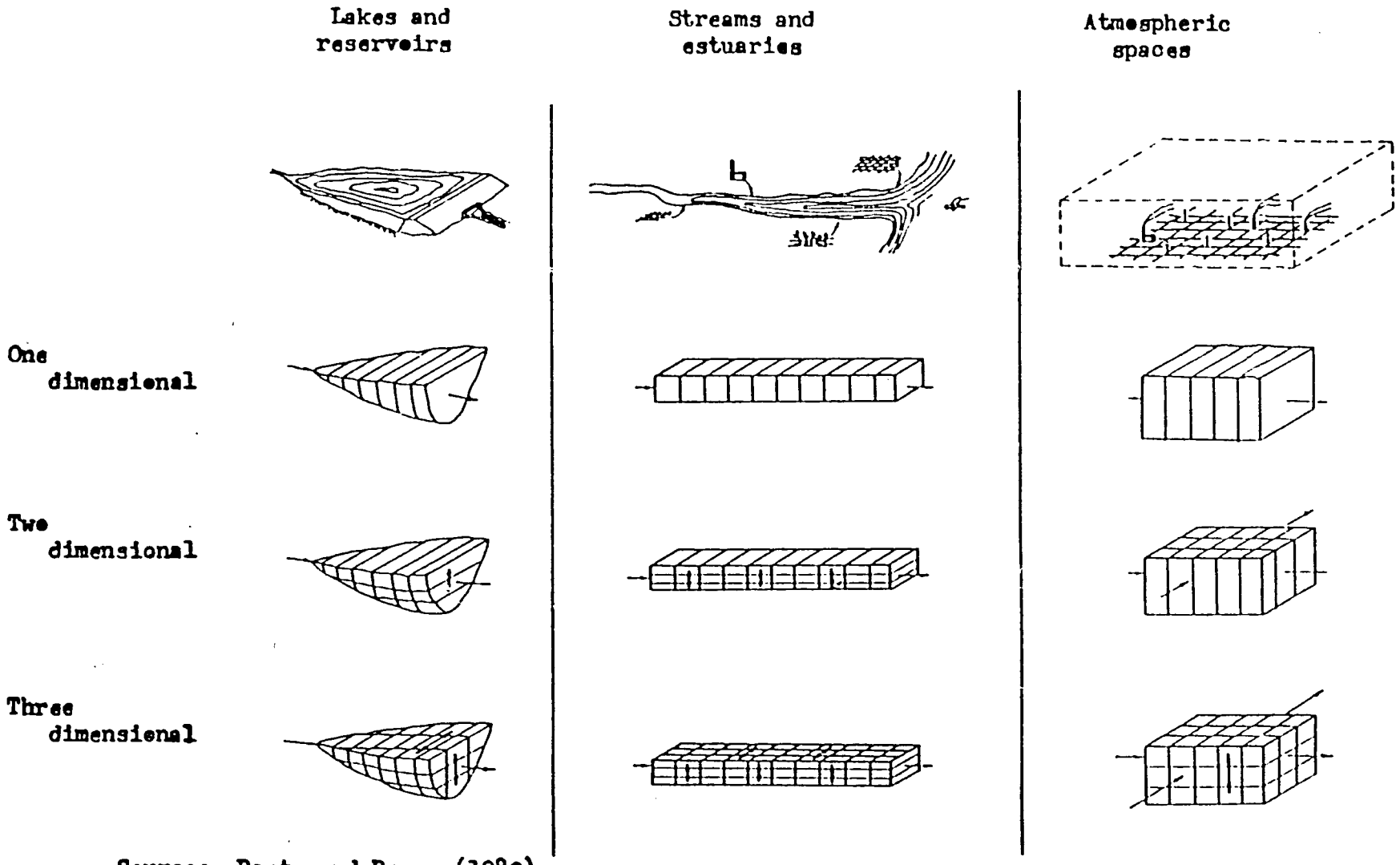
Source: Leopold (1973)

is assumed to be completely mixed in the volume. Hence, a mean concentration for the volume can be estimated, admittedly a crude figure, but at least a starting point. Depending on the characteristics of the water body in terms of mixing process, the estimate may be relatively accurate with respect to conservative materials. Another example is represented by the calculation of the volume of air over and urban area, based on the area and the height to the inversion layer. Under inversion conditions, all of the gaseous residuals discharged into the volume are assumed to remain in the volume and become completely mixed. A rough estimate of concentration at the end of the inversion period can then be made.

In statistical models two types of input variables are identified: residuals discharge variables and environmental conditions variables. Statistical models do <u>not</u> attempt to simulate <u>explicitly</u> the actual processes occurring in natural systems, e.g., those which transport and transform material and energy. Rather, the models provide estimates of the value of an output variable given values of the residuals discharge and environmental conditions variables. The procedure is, first, some AEQ variable of concern is selected as the "dependent" variable, e.g., suspended sediment concentration in a stream, SO_2 concentration (mean) in an urban area. Second, variables are indentified which are considered to affect the value of the dependent variable, and for which data over some period of time are available. Third, given a number of observations of values of all the variables, some statistical technique is applied to determine if a statistically significant relationship exists. An example of the development and application of a statistical model to estimate SO_2 mean concentrations, is described in detail in Basta, et al. (1978).

Models based on the conservation of mass and energy attempt to simulate explicitly the processes which occur in natural systems. Usually such a model divides the system being analyzed into a number of segments or three-dimensional cells, as is illustrated in Figure 32. The model, in fact a series of equations, then simulates (or attempts to simulate): (a) material and energy flows into each cell; (b) the

Figure 32. Sectioning Natural Systems for Application of Conservation of Mass and Energy Approach



Source: Basta and Bewer (1982)

transformations, if any, which take place within the cell; and (c) the resultant outflows from the given cell into adjacent cells. The conservation of mass and energy approach is reflected in figures 33 and 34. Figure 33 is a flow diagram of the eight-compartment, aquatic ecosystem model of the Delaware estuary; Figure 34 shows the differential equation sets for the model.

In any UEQM situation, the selection of NSMs to use, if any, is a critical task. Table 8 summarizes the steps for setting up the analysis of natural systems. Table 9 describes the various characteristics of NSMs which one must identify to provide a basis for comparison, both among models and with respect to resources required to use the models.

Concluding Comments

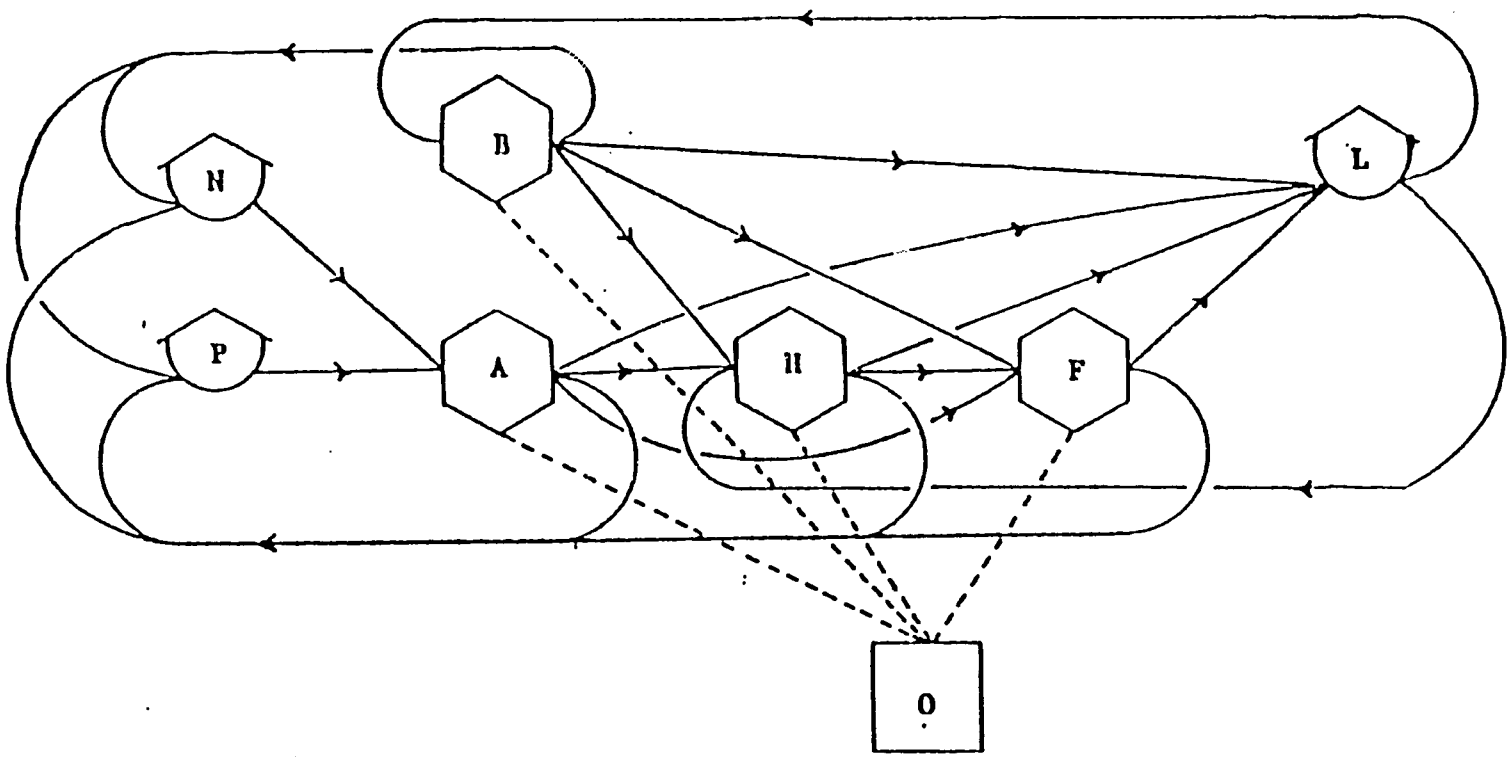
Three generic points with respect to analyzing natural systems merit emphasis. One, ideally, a model should have been calibrated and verified before it is used. This pertains only to the structure of models based on conservation of mass and energy. That is, if a particular formulation of this type of model has been verified in at least two applications, then there is some confidence that the structure of the model, that is, the specification of interrelationships, is reasonably valid. However, for any model applied to another area, there are various coefficients and constants which must be developed for the "new" area. Verification of statistical and bathtub models is relevant only for the particular location for which they are being applied. Even so, a statistical model relating certain residuals discharge variables and certain environmental conditions variables to ambient concentration of SO_2 would at least be suggestive for another area.

Two, one of the major problems in analyzing natural systems is that of estimating cumulative effects. Most of the models in use are steady-state models; only a few are dynamic, and then only for relatively short periods up to about one month. Yet discharges continue to occur, and materials---such as heavy metals---which do not degrade, remain intact in the environment, accumulating in certain sinks or continuing

Figure 33. Diagram of Materials Flows among Compartments within a Single Reach of the Delaware Estuary Aquatic Ecosystem Model

Notation: N = nitrogen
P = phosphorus
A = algae
B = bacteria
H = zooplankton
F = fish
L = organic matter (as BOD)
O = dissolved oxygen

Note: The three remaining endogenous variables--heat (temperature), toxics, and suspended solids--are assumed to affect the rates of material transfers among the ecosystem components, or "compartments".



Source: Spofford, et al. (1975)

Figure 34. Equation Set for Eight Compartment Aquatic Ecosystem Model

Differential equations for each compartment, for each unit volume:

Algae, (A) mg/l $\quad \frac{dA}{dt} = f_A - r_A - d_A - e_A - p_A + T_A$

Zooplankton, (Z) mg/l $\quad \frac{dZ}{dt} = f_Z - r_Z - d_Z - e_Z - p_Z + T_Z$

Bacteria, (B) mg/l $\quad \frac{dB}{dt} = f_B - r_B - d_B - e_B - p_B + T_B$

Fish, (F) mg/l $\quad \frac{dF}{dt} = f_F - r_F - d_F - e_F$

Oxygen, (O) mg/l $\quad \frac{dO}{dt} = 2.319(f_A - r_A - r_A - r_A - r_A) + \alpha T_O + i_O$

BOD, (L) mg/l $\quad \frac{dL}{dt} = d_A + e_A + d_Z + e_Z + d_B + e_B + d_F - e_F - f_B + T_L + i_L$

Nitrogen, (N) mg/l $\quad \frac{dN}{dt} = 0.1087(r_A + r_Z + r_B + r_F - f_A) - \delta + T_N + i_N$

Phosphorus, (P) mg/l $\quad \frac{dP}{dt} = 0.02174(r_A + r_Z + r_B + r_F - f_A) - \gamma + T_P + i_P$

Differential equations for endogenous variables:

(1) Suspended Solids, σ, mg/l $\quad \frac{d\sigma}{dt} = -\delta + T_\sigma - i_\sigma$

(2) Toxics, ϕ, mg/l $\quad \frac{d\phi}{dt} = -\varepsilon - T_\phi + i_\phi$

(3) Temperature, θ, °C $\quad \frac{d\theta}{dt} = -\zeta + T_\theta + i_\theta$

where: f = feeding, e = excretion, γ = precipitation,
p = predation, T = transport, δ = sedimentation,
r = respiration, α = reaeration, ε = toxics decay, and
d = death, β = nitrification, ζ = heat exchange.
i = input from industrial, municipal, or tributary sources,

Inputs of residuals: lbs/day: BOD, N, P, Toxics, Suspended Solids
Btu: Heat

Source: Kelly (1975)

Table 8. Summary of Sequence of Steps for Setting up the Natural Systems Analysis

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Given: The "questions" to be addressed by the study have been identified and translated into specific information requirements to be generated on AEQ, distributions of AEQ, and AEQM costs. The residuals of concern, relevant time periods, and boundaries of the study area for which information is required have been specified.

Step 1: Make a preliminary identification of the environmental media and relevant characteristics thereof that are affected by the residuals of concern, e.g., by considering known transport pathways, impacts of residuals on relevant species, accumulation and/or degradation of residuals in environmental media, and a determination of the categories of natural systems analyses--residuals generation/discharge, surface receiving water, terrestrial flow routing, subsurface flow, terrestrial ecologic, and atmospheric ambient quality--that are necessary to undertake in relation to the questions to be answered.

Step 2: Based on the foregoing and on available data on environmental conditions variables, residuals discharge variables, and AEQ variables, make a preliminary analysis in order to determine: (1) if the right questions have been asked; (2) if the important residuals have been identified; (3) the relative importance of various point and aerial sources of residuals; (4) the potential importance of intermedia and interregional transfers; and (5) any additional characteristics of the problem which will help to determine the NSM(s) to use.

Step 3: Based on the results of step 2, specify the level of complexity desired for the natural systems analysis in terms of: (1) time intervals of analysis, i.e., hourly, daily, monthly, seasonal, mean annual; (2) spatial aggregations, i.e., number of grid areas, stream reaches, lake layers; (3) constituent/species aggregations to be considered, i.e., forms of nitrogen, number of fish species; and (4) specific physical, chemical, and biological processes to be incorporated.

Step 4: Determine the feasibility of carrying out the natural systems analysis specified in step 3, in relation to the available analytical resources.

Step 5: Select the NSM or NSMs to be used based on the relevant evaluation criteria.

Step 6: Develop a work plan for the natural systems analysis which is compatible with other segments of the AEQM analysis.

Table 9. Identification and Description of Characteristics for Describing NSMs[a]

Characteristic	Summary Description
Time Properties	Description of how temporal variations in flow and/or transport of residuals are represented in a model, both conceptually and computationally. Information includes: (1) time variability: steady state, quasi-nonsteady state, and nonsteady state; and (2) time units of application: input and output values and computational time step.
Space Properties	Identification of capability of model to represent spatial variations of residuals concentrations. Information includes: (1) model dimensionality: one-dimensional, horizontal or vertical plane; or multi-dimensional, longitudinal, latitudinal, and/or vertical plane; (2) spatial aggregation: size and number of segments, layers, and volumes possible; and (3) typical areal units of application.
Physical Properties	Identification of the physical processes considered in a model which account for the transport of residuals. Information includes: (1) the principal hydraulic and meteorologic driving forces, i.e., tidal action, wind currents, and stream currents; and (2) the individual physical processes involved: advection, diffusion, dilution, convection, heat budget-temperature, wind, Coriolis acceleration forces.
Chemical Processes	Description of the chemical transformations/interactions considered in a model which result in changes in concentration over time. Information includes: (1) basic chemical processes: thermo-chemical equilibrium and coupled or noncoupled chemical reactions; and (2) ambient quality indicators represented: conservative substances and nonconservative substances.
Ecological Processes	Identification of basic biological processes that affect interactions between AEQ indicators, constituents, and among the various organisms represented in a model. Included are: (1) biochemical processes, i.e., photosynthesis, respiration-biological decay; and (2) cropnic dynamics, i.e., trophic levels, population growth dynamics, mortality, predator-prey interactions.
Mathematical Properties	Description of the theoretical basis for the mathematic representation in, and the solution methodology applied to, a model. Information includes: (1) theoretical aspects: deterministic, stochastic, and combinations; and (2) types of solution methodology: statistical, i.e., regression methods, and other mathematical techniques, i.e., analytically integrated or numerically integrated.
Computational Status	Identification of status of model in relation to manipulation on digital computers. Information includes: (1) whether model is coded or uncoded; (2) computer language used, e.g., FORTRAN; and (3) the various computer/accessory equipment required (hand calculator, analogue computer, digital computer, including needed storage capacity, compilers, magnetic tapes or disks for storage).
Input Data Requirements	Description of the various data required to set up, run, calibrate, and verify a model. Generalized historical data bases and/or site-specific data may be required, depending upon the extent of prior applications.
Ease of Application	Description of expected difficulties in obtaining, modifying, and applying a model. Information includes: (1) the availability of model and supporting documentation from various sources; and (2) identification of anticipated areas of difficulty in model application.
Output and Output Format	Identification of model output with respect to the types of information produced, spatial and temporal distributions possible, and the format in which the output is presented.
Linkages to Other Models	Description of linkages between a model and other types of models used in REQM analysis and the forms of such linkages. Information provided includes linkages to other natural systems models, damage/benefit models, and models of activities and the ways in which the linkages are structured.
Manpower Needs	Identification of types, number, and desired levels of experience of personnel required to apply a model. Requirements for additional model development and/or major internal modification may differ significantly from those for model application. Information includes: (1) position descriptions (engineer, programmer, systems analyst, ecologist, others); (2) need for specialized training or capabilities; and (3) the related experience of interdisciplinary team members.
Costs	Specification of all costs involved in applying a model, from initial acquisition of the model through analysis of model output. Model costs are a combination of: (1) man-hour expense required to complete certain tasks (including data collection); (2) expense of obtaining a model itself and/or available user's manuals/documentation reports; and (3) direct computation costs for the application. Where possible, cost information is provided under the categories of model acquisition, data preparation, actual computation expense, computer accessory costs, and output analysis. Complete cost information is not available for most NSMs.
Model Accuracy and Sensitivity	Description of the overall capability of a model to represent accurately a natural system and its essential processes. Information includes: (1) the representativeness in relation to the "real" system, especially the extent of the description and simplifying assumptions; (2) numerical accuracy--stability and dispersion (in numerically integrated models); and (3) sensitivity to input errors or rate coefficients, both known and estimated values.
Other Comments	Description of miscellaneous facts concerning a model, its history of development and modification, and informative observations as to its utility in REQM analysis. Information includes: (1) model limitations and restrictions; (2) special features and options; and (3) model originators or producer of current derivation (if modification of existing model).

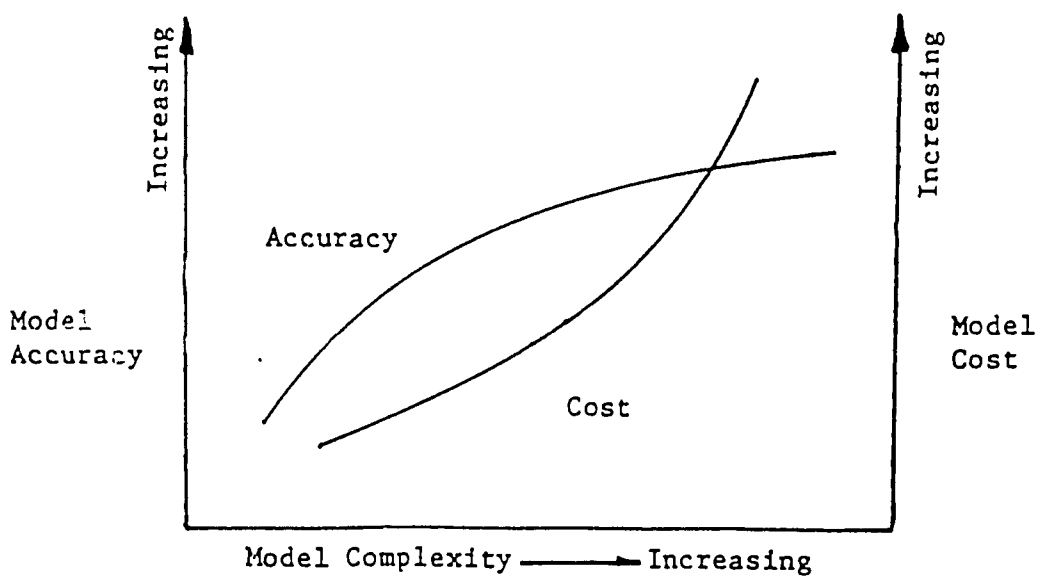
[a]Only those characteristics which are relevant for more than one category of NSMs are included.

Source: Basta and Bower (1982)

to move in one or another of the environmental media.

Three, an important consideration in selecting natural systems models for use in analysis for UEQM, is the relationship among model complexity, model accuracy, and model cost. The degree of complexity selected depends on: the questions one is trying to answer; the costs of developing and applying the model, or of applying a model already developed; and the accuracy of an NSM relative to the accuracy of the residuals discharge data or the environmental conditions data. There is no point in having a very sophisticated NSM if the estimates of residuals inputs to the NSM are no better than an order of magnitude. It is also important to recognize that increasing accuracy, i.e., measured by validity of outputs, is done usually by increasing the number of variables explicitly considered/incorporated in the model. Incremental costs increase rapidly as complexity increases, as shown in Figure 35. Also, additional "units" of complexity generally result in smaller and smaller increments in accuracy.

Figure 35. Relationships Among Model Complexity, Model Accuracy, and Model Cost



ANALYZING IMPACTS ON RECEPTORS

The ultimate rationale for developing and implementing UEQM strategies is to reduce adverse impacts on receptors. Given the changes in AEQ resulting from application of various NSMs in a given urban region, the next step is to translate these changes into physical and biological effects on receptors, and subsequently translating these effects into monetary effects, i.e., damages under various situations, benefits from improving AEQ.

Table 10 provides a typology of receptors. An important characteristic of receptors is mobility, because exposure to AEQ conditions is a function of activity patterns, i.e., degree of mobility. Humans typically in their daily (weekly, seasonal) activities move from one place to another, and back, e.g., home to work to home, home to recreational area and back. Thus, individuals are exposed to different AEQ conditions for different time periods. The suburban commuter has a very different exposure pattern from the center city dweller who may spend a large portion of his/her time in the core of the urban area, including sidewalks and/parking lots during non-work periods. Further, humans are stressed through various pathways, as shown in Figure 36.

Figure 36. Pathways of Human Exposure to Residuals

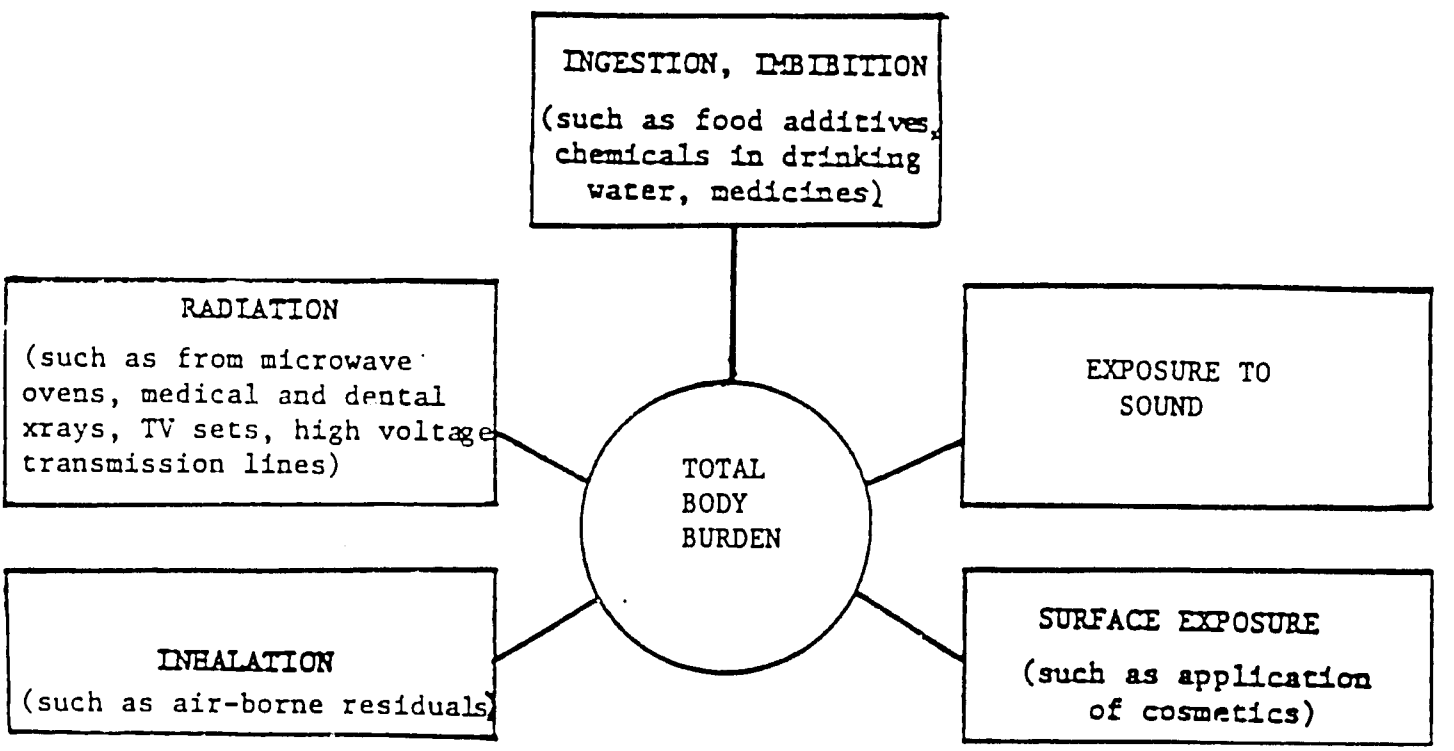
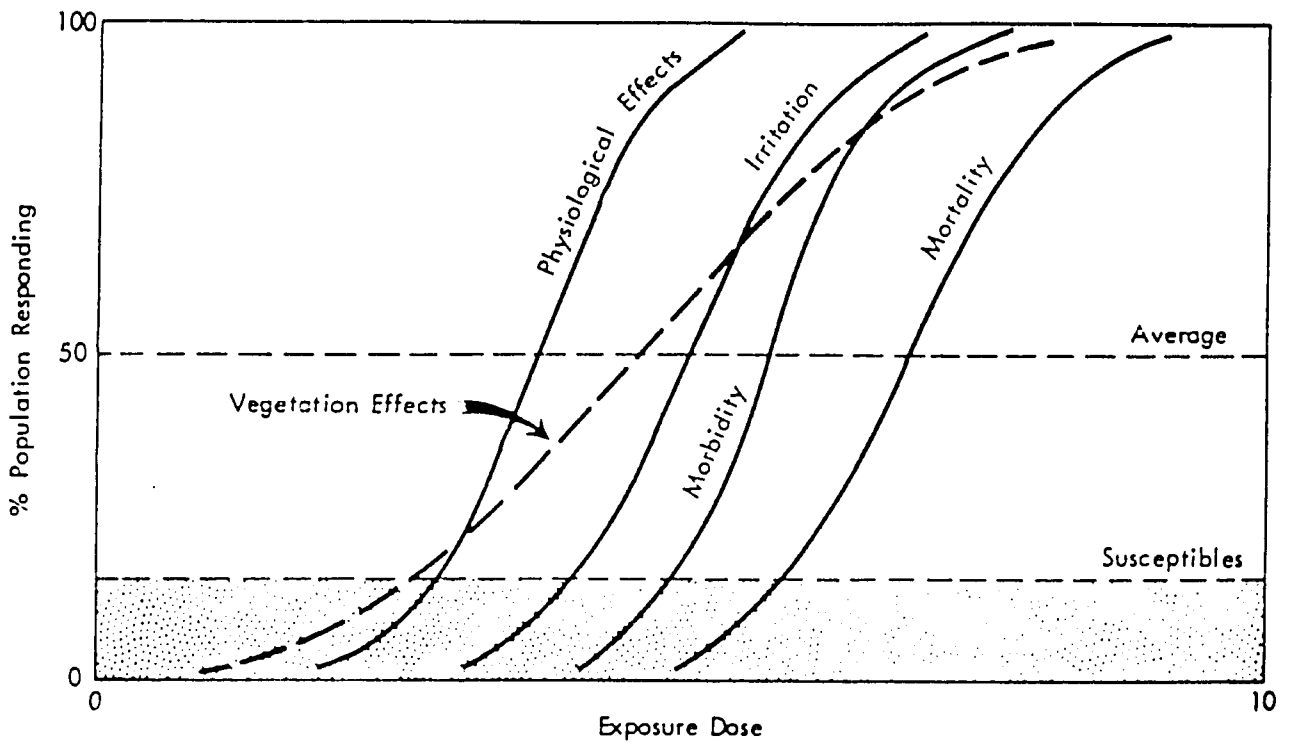


Table 10. Typology of Receptors

Receptors	Stationary	Mobile within fixed habitat	Mobile
Resident fish species		X	
Migratory fish species			X
Resident animal species		X	
Migratory animal species			X
Natural vegetation	X		
Materials in structures	X		
Materials in vehicles			X
Agricultural and forestry activities	X		
Industrial and commercial activities	X		
All other activities	X		
Residences	X		
Humans			X

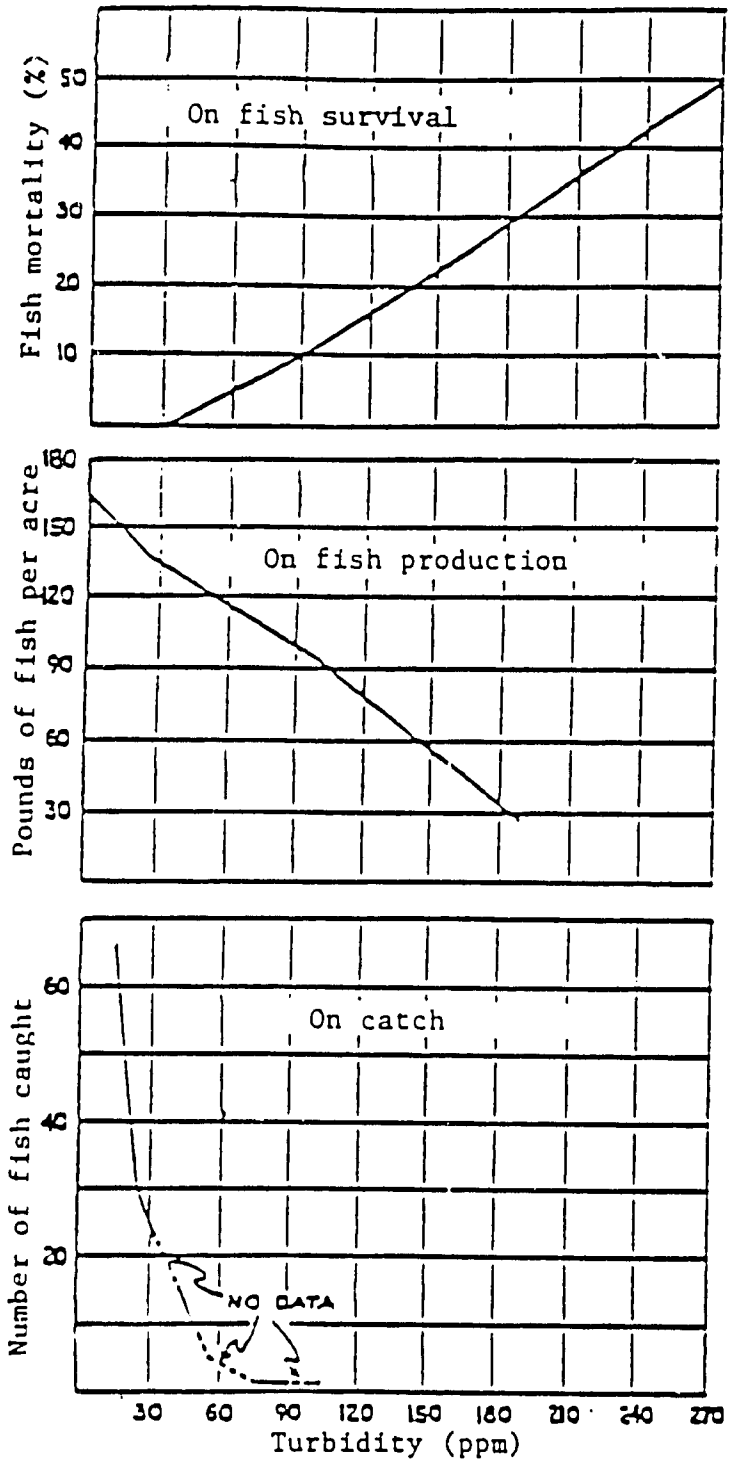
Individuals of various species---human, flora, fauna---respond differently to the same exposure. Response is a function of physical condition, age, nutritional level (relevant for plants and animals as well as for humans), and such behavior patterns for humans as smoking. Figure 37 illustrates this differential response pattern. [Dose is a combination of concentration and time, e.g., aggregation of concentration-hours.]

Figure 37. Distribution of Responses of Various Segments of the Population to Different Doses



Effects on humans include irritation, sickness, and---in some circumstances or after lengthy exposure---mortality. In turn these are reflected in lower productivity, absenteeism, medical costs, all of which represent resource costs to society. For crops exposure typically results in lower yields and/or lesser quality of products for birds and animals, lower reproductive capacity, lesions, malformations. Yields of various finfish and shellfish species are reduced by lowered water quality and by the covering up or filling in of habitat, e.g., by dumping solid residuals. Figure 38 illustrates the type of effect of water quality, measured by turbidity concentration, on fish.

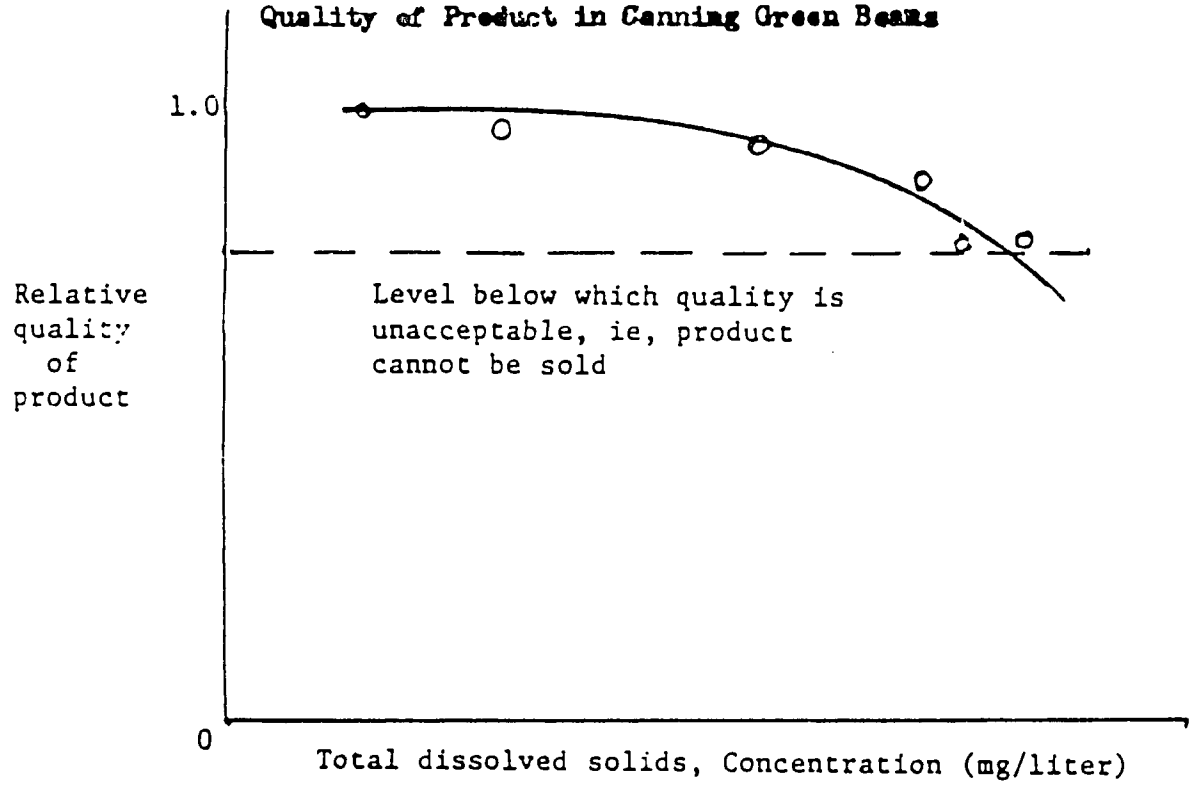
Figure 38. Effects of Turbidity on the Survival, Production, and Catch of Fish



Source: Hufschmidt, et al. (1983)

Many types of municipal, commercial, industrial activities incur losses because of reduced AEQ. Increased concentration of suspended sediment in water sources increases water intake treatment costs for municipal water systems, industrial plants, hotels. Water quality can deteriorate so far, that product output is no longer saleable, as illustrated by Figure 39.

Figure 39. Relationship between Quality of Intake Water and Quality of Product in Canning Green Beans



In the context of developing UEQM strategies, it is useful to consider three types of losses stemming from impacts: (1) increased costs imposed on activities, e.g., increased water intake treatment, increased air intake treatment, moving of water intake, shifting of source of raw material; (2) decreased yields, as of finfish and shellfish species, crops, tree growth, or decreased quality of crops or fish; and (3) human health losses. The first two are reasonably amenable to quantification in monetary terms. For the last, evaluation is difficult because of the many variables involved.

Distribution of Impacts

Who is, what groups are, affected adversely at present by poor AEQ is, or should be, a major concern in developing UEQM strategies. Therefore, at a minimum, the analysis should identify various subgroups of the population by socioeconomic class and residential location, and attempt to estimate the AEQ conditions to which they are exposed through various media and pathways. Identification by location of residence of course does not account for mobility, but it does represent at least a "first cut" at identifying the distribution of exposure, as was done by Freeman (1972) and Zupan (1973).

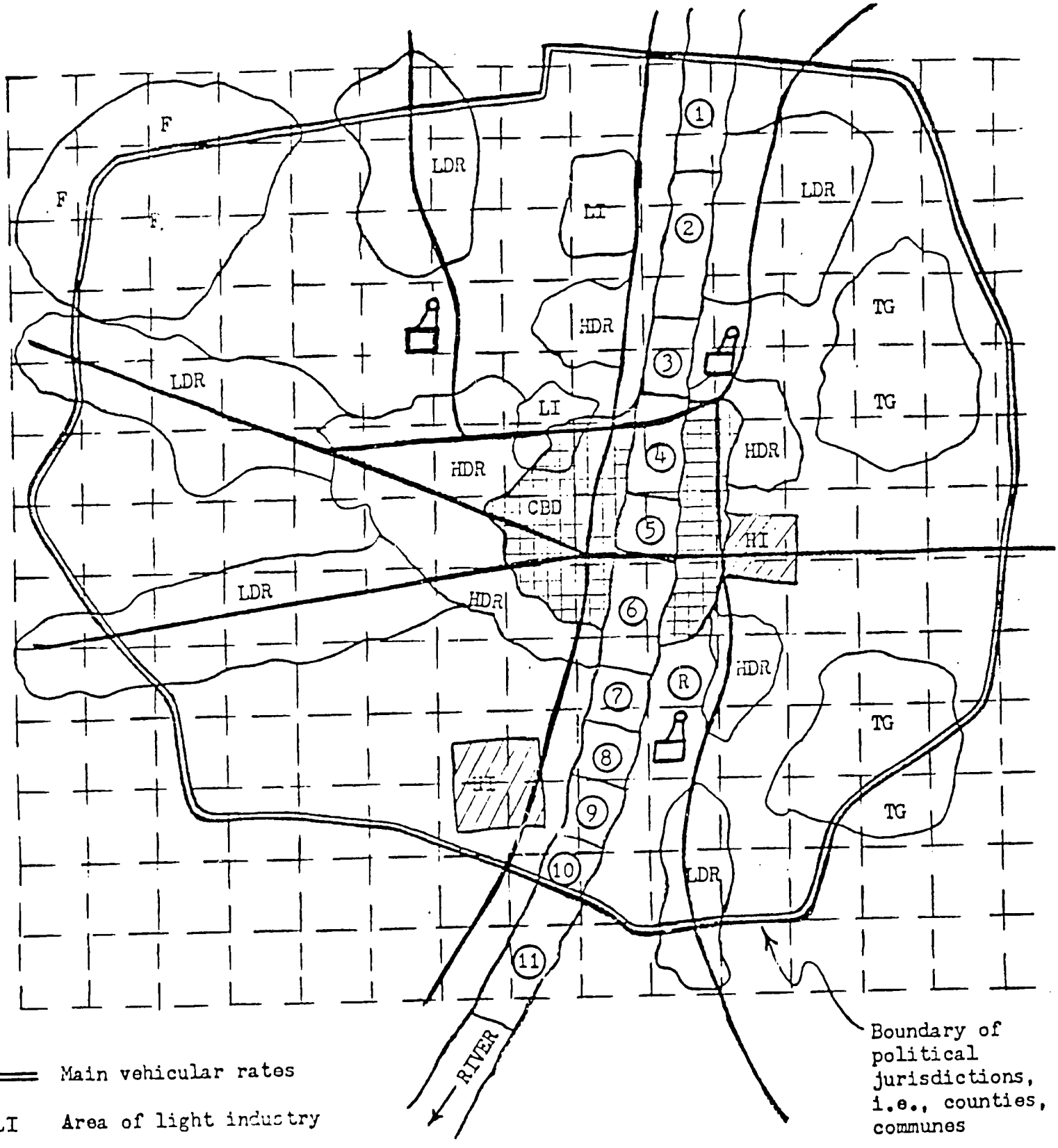
APPLICATION TO URBAN REGIONS: ILLUSTRATIONS

Given the foregoing explication of some of the segments of analysis for UEQM, what remains is to illustrate the application. Figure 40 shows a prototype urban region, "set up" for an UEQM analysis. That is, the region has been subdivided into various subareas by type of activity. The river has been divided into reaches for the analysis of water quality. A grid has been imposed on the region for the analysis of air quality. However, rather than proceeding to illustrate the application of the framework for analysis by applying it to the prototype region, short descriptions of studies of two real regions, New York City region and Ljubljana, Yugoslavia, are presented.

New York Region

The New York Region, as defined by the Regional Plan Association of New York, covers 31 counties in the states of New York, New Jersey, and Connecticut. The region, and the rings into which it divided, are shown in Figure 41. In connection with the development of the Second Regional Plan for New York Region, a study was done to try to show specifically the relationship between the spatial pattern of activities in a

Figure 40. Prototype Urban Region



Main vehicular rates

LI Area of light industry

HI Area of heavy industry

TG Truck garden area

R Petroleum refinery

F Forest: wood producing operations

Power plant

HDR High density residential

LDR Low density residential

CBD (primarily office and commercial)

5 River reach

Note: Not all land uses are shown.

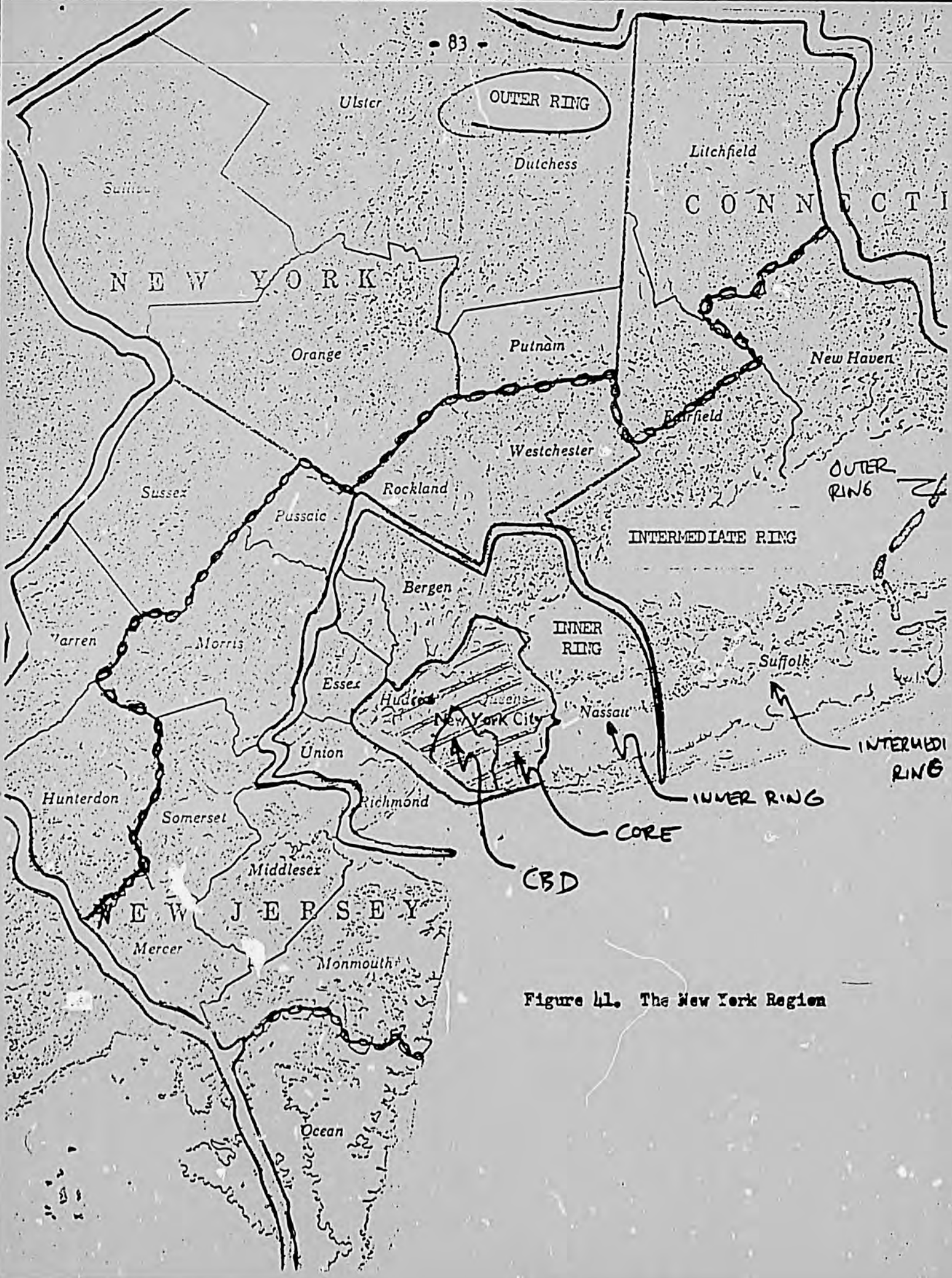


Figure 41. The New York Region

region, and AEQ/EQM strategies.

After having specified employment by category in each of the rings for each of the growth variants, sets of wastes generation conditions were specified, as shown in Table 12. These reflected estimates of technological changes, factor input price changes, behavior patterns, governmental actions. Then, sets of wastes management conditions were specified, as shown in Table 13. The objective was to show how combinations of factors affecting generation and alternative management strategies would affect AEQ. Given the wastes generation conditions and the wastes management conditions, various combinations of the two were specified, and the results in terms of AEQ were estimated, along with wastes management costs. [Note that the option of "recycling" paper was explicitly investigated.]

As hypothesized, all three of the variables---spatial pattern, wastes generation conditions, wastes management conditions---affected AEQ and UEQM costs.

Ljubljana, Yugoslavia**

The study of the Ljubljana area of Yugoslavia, in terms of urban environmental quality management, presented substantially different conditions than the study of the New York region. For some types of needed data, the Yugoslavian situation was much better than the U.S. situation, e.g., data on size of and fuel use in residences, types of boilers in various facilities. On the other hand, there were essentially no data on residuals generation. The area of the study is shown in Figure 42.

The first step was to select a base year for the analysis. 1972 was chosen, primarily based on the fact that that year was the latest for which basic data were available. [The study was initiated in late 1973.] The next step was to identify the various activities in the region, and the levels of these activities in 1972. These are shown in Table 14 and Table 15, respectively.

**All figures and tables in this section are from Basta, et al. (1978).

Table 11. Growth Variants for the New York Region: Population and Employment by Ring for "2000"

All values in millions

VARIANT	RING	Population	Office Employment	Total Employment
I	MANHATTAN CBD	0.5	1.30	2.40
	REST OF CORE	8.6	0.56	2.88
	INNER RING	7.3	0.45	2.65
	INTERMEDIATE RING	9.4	0.52	3.83
	OUTER RING	4.4	0.17	1.41
	TOTAL	30.2	3.00	13.17
II	MANHATTAN CBD	0.5	1.10	2.11
	REST OF CORE	7.0	0.52	2.56
	INNER RING	6.0	0.38	2.25
	INTERMEDIATE RING	11.5	0.75	4.53
	OUTER RING	5.2	0.25	1.72
	TOTAL	30.2	3.00	13.17
III	MANHATTAN CBD	0.7	1.50	2.72
	REST OF CORE	10.0	0.70	3.50
	INNER RING	11.0	0.50	3.54
	INTERMEDIATE RING	6.5	0.20	2.53
	OUTER RING	2.0	0.10	0.88
	TOTAL	30.2	3.00	13.17

Note: In terms of population distribution within the region, the Variants are characterized as follows:

Variant I - moderately centralized
Variant II - dispersed
Variant III - centralized

Source: Bewer, et al. (1968)

Table 12. Wastes Generation Conditions, New York Region, "2000"

TYPE OF WASTE AND SOURCE	GENERATION CONDITION X	GENERATION CONDITION Y
ENERGY GENERATION (E)	Estimated generation "mix" with related fuel use, present wastes generation per unit of fuel	Same as for X
SPACE HEATING, RESIDENTIAL (H_r)	Decrease in oil use by 1/3 by shift to gas and electric heating, accompanied by increase in efficiency of heating	Same as for X
SPACE HEATING, COMMERCIAL AND INDUSTRIAL (H_i)	No change in use of oil	Same as for X
INTERNAL COMBUSTION VEHICLES (T)	Present pattern of vehicle utilization, types of vehicles, average vehicle-miles per gallon of gasoline, wastes generation per gallon	Same as for X
MIXED SOLID WASTES (S)	100% increase in per capita generation	Present per capita generation
LIQUID WASTES, HEAVY INDUSTRY (L_i)	Per unit generation without external stimuli, i.e., in response to changing production technology and product mix	Per unit generation reflecting best practices under external stimuli; positive changes in production technology compensate for adverse changes in product mix
LIQUID WASTES, RESIDENTIAL (L_r)	Small increase in per capita BOD generation reflecting increased affluence; larger increase in volume generated reflecting present practices relating to water intake (See Liquid Wastes -- Residential, Management Condition 1)	Small increase in per capita BOD generation reflecting increased affluence; no increase in volume generated reflecting changes in practices relating to water intake (See Liquid Wastes -- Residential, Management Condition 2)
GASEOUS WASTES, HEAVY INDUSTRY (EXCEPT FROM SPACE HEATING) (G_i)	Present per unit quantities in absence of more stringent external stimuli than exist at present, i.e., considering changes in production technology and product mix which are likely to occur	Per unit quantities reflecting best practices, changes in product mix, positive changes in production technology, and imposition of external stimuli

Source: Bower, et al. (1968)

Table 13. Wastes Management Conditions, New York Region, "2000"

ENERGY GENERATION (E)	1	Mean annual efficiency of particulate removal devices, 95%; mean annual reduction of SO_2 (fuel and/or emission control) 50%
SPACE HEATING (H)	1	None, except as reflected in fuel shift for residences
TRANSPORTATION (T)	1	1968 federal standards re vehicle exhaust, i.e., 50% reduction; no change in governmental policies concerning modal split
	2	90% reduction in vehicle exhaust; no change in governmental policies concerning modal split
SOLID WASTES (S)	1	Continuation of present distribution of disposal practices except no hog feeding, no open burning, and all incinerator emissions to meet N.Y.C. P.L. 14 dust limitations; 50% of solid wastes consists of paper and paper products a 0% of paper recycled b 20% of paper recycled c 80% of paper recycled
	2	All solid wastes incinerated in central or municipal incinerators, with recommended federal emission rates, i.e., 0.2#/1000# of air at 50% excess air (approximately 4# of particulates per ton of refuse incinerated); 0% of paper recycled; residue to landfill in region
	3	All solid wastes incinerated in central or municipal incinerators, with recommended federal emission rates; 0% of paper recycled a Residue by rail to landfill out of region b Residue by barge to sea
	4	All incineration prohibited; 0% of paper recycled a Disposal of all wastes by rail to landfill out of region b Disposal of all wastes by barging to sea
GASEOUS WASTES, HEAVY INDUSTRY (except heating) (G_i)	1	Levels of emission control as currently proposed
	2	90% reduction of wastes generated
LIQUID WASTES, HEAVY INDUSTRY (L_i)	1	35% average reduction of wastes generated, in on-site facilities
	2	85% average reduction of wastes generated, in on-site facilities
LIQUID WASTES, RESIDENTIAL, COMMERCIAL, LIGHT INDUSTRY (L_r)	1	Continuation of present pattern of jurisdictions for water supply and liquid waste disposal; continuation of present practices in NYC system i.e., no additional metering, flat rate charges when assessed, no use of reclaimed waste water except on Long Island, no tightening up of distribution system; 35% BOD reduction in collective facilities
	2	Efficient subregional systems for waste water handling: 100% metering, charges by volume, tightening of system, maximum utilization of ground water and reclaimed waste water; 35% BOD reduction in collective facilities
	3	Same as 2, except with 85% BOD reduction in collective facilities

Figure 42. The Five-Commune Area of Ljubljana, Yugoslavia

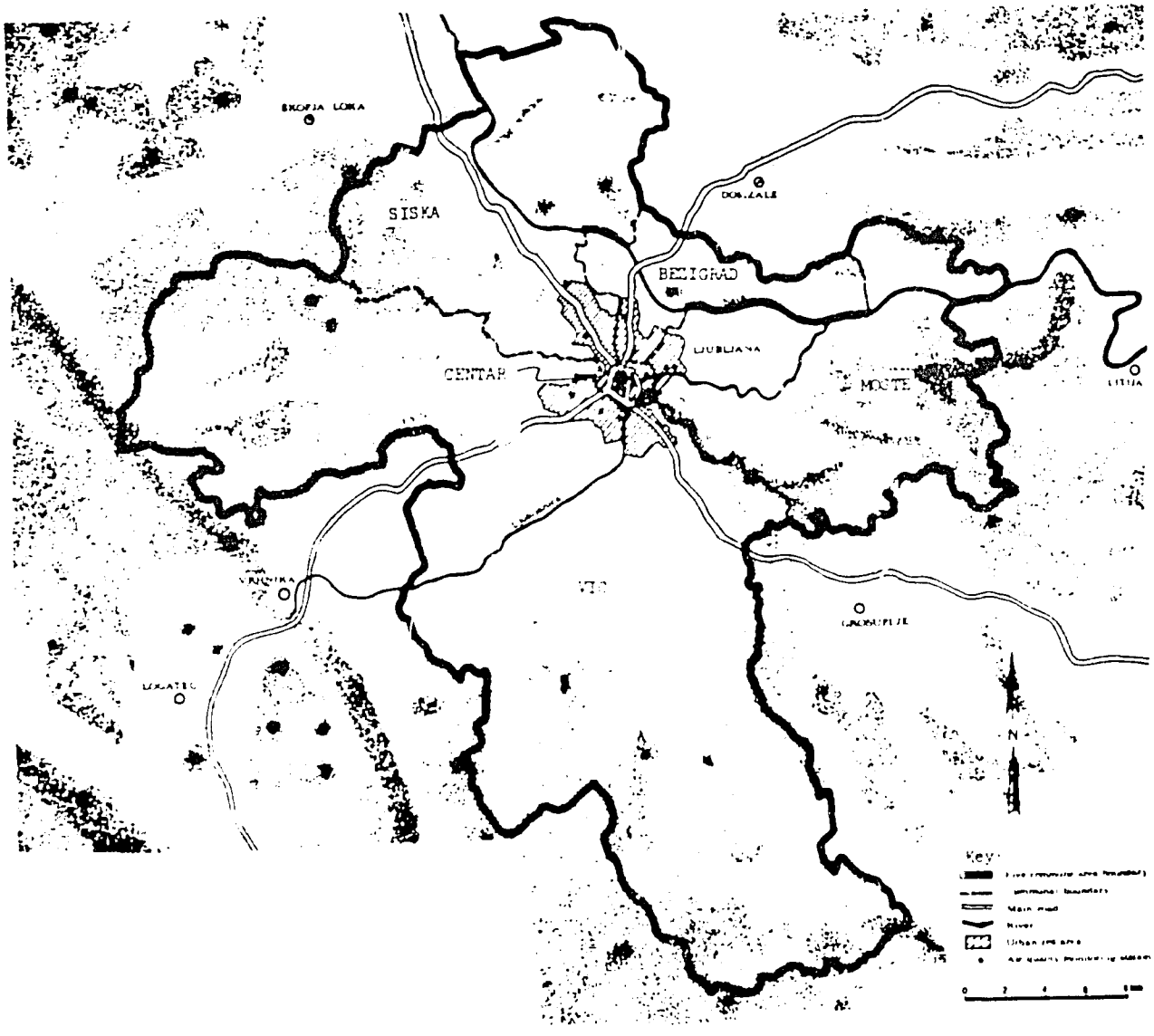


Table 14. Activity Categories and Subcategories Used in Analysis for Environmental Quality Management in Ljubljana Area of Yugoslavia

INDUSTRIAL ACTIVITIES	INSTITUTIONAL ACTIVITIES
Metal processing	Government
Electrical products	Research
Chemical	Hospitals
Building materials	Cultural institutions[a]
Pulp and paper	University facilities
Paper products	Schools other than university
Textile	
Food Products	TRANSPORTATION ACTIVITIES
Graphics	
All other	Vehicular travel[b]
	Services[c]
RESIDENTIAL ACTIVITIES	
	POWER PLANT ACTIVITIES
Multi-flat	
Single-flat	Moste plant
	Siska plant
COMMERCIAL ACTIVITIES	
	COLLECTIVE RESIDUALS HANDLING AND MODIFICATION ACTIVITIES
Restaurants	
Hotels and motels	Municipal solid residuals collection agency
Retail stores	Municipal sewerage agency
Offices	Salvaging operations
Wholesale stores and warehouses	

[a] Refers to cinemas, playhouses, art galleries, museums, etc.

[b] Vehicular travel is further subdivided into seven road types in urban and nonurban areas.

[c] Refers to service stations, garages, repair shops.

Table 15. Activity Categories and Subcategories and 1972 Levels of Activity, Five-Commune Area of Ljubljana, Yugoslavia

Activity Category and Subcategory	Level of Activity, 1972	Unit
INDUSTRIAL ACTIVITIES		
Metal processing	94,382	Ton of P.O.
Electrical products	19,583	"
Chemical	99,940	"
Building materials	891,703	"
Pulp and paper	59,312	"
Paper products	27,171	"
Textile	11,541	"
Food products	173,049	"
Graphics	26,579	"
All other	58,743	"
RESIDENTIAL ACTIVITIES		
Multi-flat	165,756	Inhabitants
Single-flat	84,230	"
COMMERCIAL ACTIVITIES		
Restaurants	2,577	Employees
Hotels and motels	910	"
Retail stores	6,759	"
Offices	8,995	"
Wholesale stores and warehouses	12,356	"
INSTITUTIONAL ACTIVITIES		
Government	3,754	Employees
Research	3,125	"
Hospitals	4,804	"
	74,563	Patients[a]
Cultural institutions[b]	1,076	Employees
University facilities	2,264	"
Schools other than university	45,315	Students
TRANSPORTATION ACTIVITIES		
Vehicular travel[c]	995 x 10^9	Vkt: Gas
	110 x 10^9	Vkt: Diesel
Services[d]	9,595	Employees
POWER PLANT ACTIVITIES		
Waste plant	1.427 x 10^{12}	Calories
Sisak plant	0.057 x 10^{12}	"
COLLECTIVE RESIDUAL HANDLING AND MODIFICATION ACTIVITIES		
Municipal solid residuals collection agency	300	Employees
Municipal sewerage agency	370	"
Salvaging operations	265	"

Abbreviations: P.O., product output; Vkt, vehicle kilometers traveled.

a Average stay in hospitals, 17.2 days.
b Refers to cinemas, playhouses, art galleries, museums, etc.
c Vehicular travel is further subdivided into seven road types in urban and nonurban areas.
d Refers to service stations, garages, repair shops.

The next step was to develop residuals generation coefficients for all of the subcategories. The results for solids and liquids are shown in Table 16. Various means were used to develop the coefficients, as would be done in any setting. For example, boiler technology was essentially the same as that in the U.S. Therefore, the coefficients developed in the U.S. by boiler and fuel type were applied, given the detailed information on boilers and their fuels available. For the pulp and paper industry, technology again was essentially the same, so that U.S. coefficients could be easily adjusted for somewhat different raw materials and product mix. To obtain coefficients for solid wastes generation, actual data were collected by measuring weights collected and sorting by material type, and by interviewing various industrial operations to obtain data on materials sent to byproduct production or resource recovery. For liquid residuals, a small program of measuring discharges at a sample of activities was done. For generation by vehicles, FRG data were used, because the vehicle and fuel mixes were very much the same in FRG and Slovenia.

The generation coefficients thus developed were applied to the levels of the activities in 1972 to yield estimated residuals generation in 1972, which was essentially the same as discharge, their being no discharge reduction measures. The next step was to develop cost-discharge reduction functions or tables for the residuals of concern. Two of these are shown, for reduction of SO_2 discharges in the area in Figure 43, and for reduction of BOD_5 and TSS in Figure 44. Each of the points on the functions represents the least cost measure or combination of measures, to achieve the indicated AEQ or degree of reduction in discharge. In Figure 43 for example, the symbols 3A, 6B, etc. represent the least cost increment added. Thus, 3A represents a shift from coal to light liquid fuel in the pulp and paper industry.

Given the discharge reduction cost functions, it was then possible to develop combinations of measures to produce different combinations of environmental quality. Table 17 shows five of these combinations, which reflect different total costs and different degrees of improvement in air quality and water quality. That is, one could "have" more water quality and less air quality or the reverse, for a given

Table 16. Estimated Mean Residuals Generation Coefficients for Activity Subcategories, Five-Commune Area, 1972

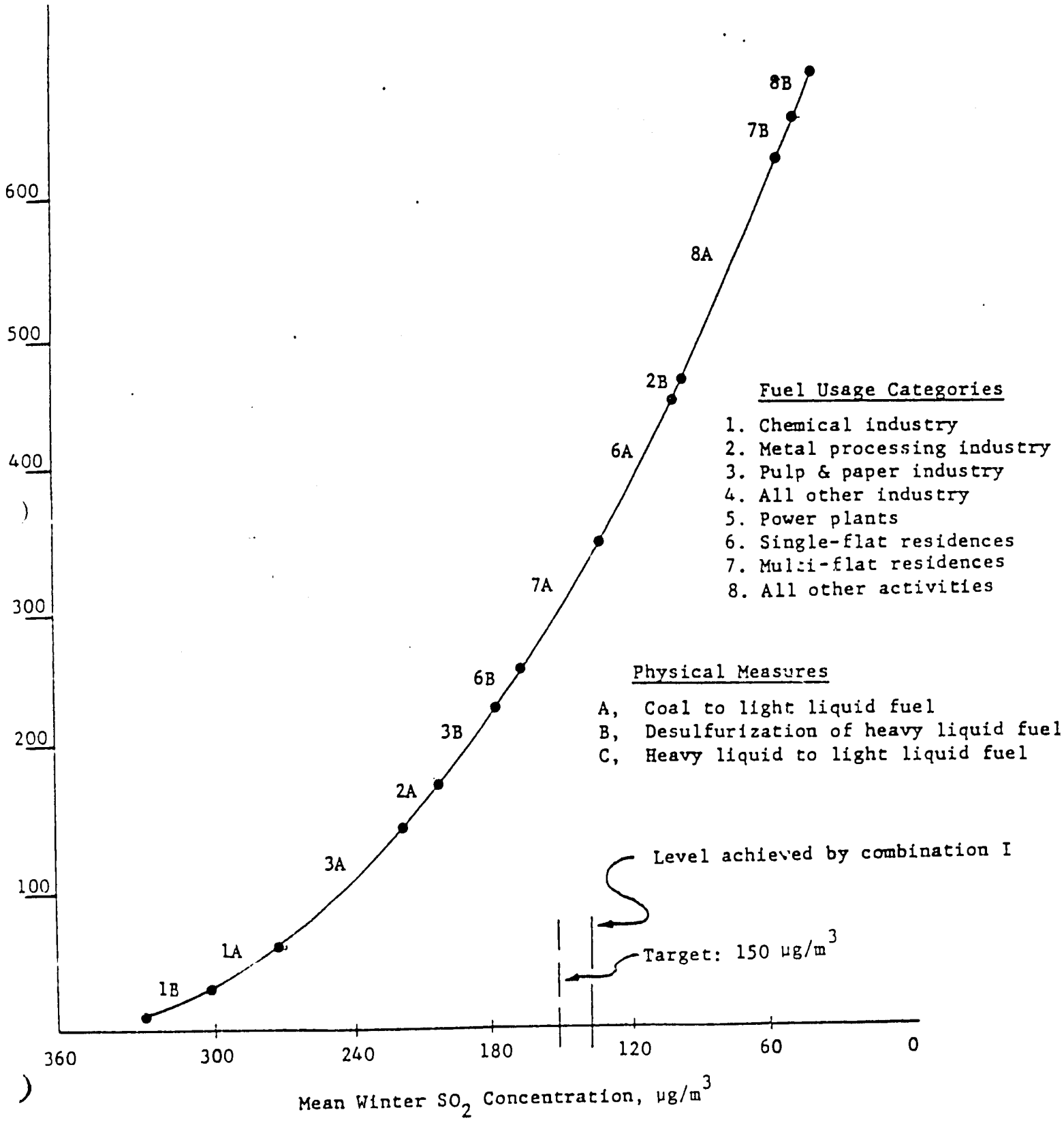
Activity Category and Subcategory	Mixed Solid Residuals: Quantity generated per unit		Liquid Residuals: Wastewater Discharge: Quantity generated per unit		BOD: Quantity generated per unit		TSS: Quantity generated per unit	
	kg	Unit	m^3	Unit	kg	Unit	kg	Unit
INDUSTRIAL								
Metal processing	91	Ton of P.O.	15	Ton of P.O.	0.2	Ton of P.O.	23.9	Ton of P.O.
Electrical products	195	"	25	"	7.1	"	6.5	"
Chemical	[illegible]	"	21	"	2.4	"	3.7	"
Building materials	5	"	0.5	"	Included in All other		Included in All other	
Pulp and paper	155	"	150	"	74.2	Ton of P.O.	13.5	Ton of P.O.
Paper products	14	"	1	"	N	"	N	"
Textile	115	"	53	"	7.0	"	5.4	"
Food products	62	"	21	"	19.0	"	8.1	"
Graphics	51	"	16	"	0.2	"	0.5	"
All other	149	"	4	"	3.0	"	2.6	"
RESIDENTIAL								
Multi-flat	[illegible]	Inhab/day	0.14	Inhab/day	0.07	Inhab/day	0.06	Inhab/day
Single-flat	[illegible]	"	0.15	"	0.07	"	0.06	"
COMMERCIAL								
Restaurants	[illegible]	Emp/yr	0.54	Emp/day	0.07	Emp/day	0.06	Emp/day
Hotels and motels	[illegible]	"	0.61	"	0.07	"	0.06	"
Retail stores	[illegible]	"	0.20	"	0.07	"	0.06	"
Offices	[illegible]	"	[illegible]	"	0.07	"	0.06	"
Wholesale stores and warehouses	[illegible]	"	0.09	"	0.07	"	0.06	"
INSTITUTIONAL								
Government	[illegible]	Emp/yr	0.11	Emp/yr	0.07	Emp/day	0.06	Emp/day
Research	[illegible]	"	[illegible]	"	0.07	"	0.06	"
Hospitals	[illegible]	"	[illegible]	Patient/day	0.07	Patient/day	0.06	Patient/day
Cultural institutions	[illegible]	"	[illegible]	Emp/day	0.07	Emp/day	0.06	Emp/day
University facilities	[illegible]	"	[illegible]	"	0.07	"	0.06	"
Schools other than university	[illegible]	Student/yr	[illegible]	Student/day	0.07	Student/day	0.06	Student/day
TRANSPORTATION								
Vehicular travel								
Urban	N	$10^{[illegible]}$/yr	N	$10^{[illegible]}$/yr	N	$10^{[illegible]}$/yr	N	$10^{[illegible]}$/yr
Nonurban	N	"	N	"	N	"	N	"
Services								
Maintenance	[illegible]	Emp/yr	[illegible]	Emp/day	N	Emp/day	N	Emp/day
Gasoline sales	[illegible]	"	[illegible]	"	N	"	N	"
Offices	[illegible]	"	0.11	"	[illegible]	"	0.06	"
POWER PLANTS								
Waste plant (Solid fuel)	[illegible]	$10^{[illegible]}$ cal	41	$10^{[illegible]}$ cal	N	$10^{[illegible]}$ cal	N	$10^{[illegible]}$ cal
Biska plant (Liquid fuel)	N	"	Included with Waste plant		N	"	N	"
COLLECTIVE RESIDUALS HANDLING AND MODIFICATION[a]								
Municipal solid residuals collection system	[illegible]	Emp/yr	[illegible]	Emp/day	0.07	Emp/day	0.06	Emp/day
Municipal sewerage system	[illegible]	"	[illegible]	"	[illegible]	"	0.06	"
Incinerator operations			[illegible]	"	[illegible]	"	0.06	"

Abbreviations: cal, calorie; Emp, employee; Inhab, inhabitant; kg, kilogram; m^3, cubic meter; N, negligible; P.O., product output; Veh, vehicle kilometers traveled.

a. Coefficients relate to office activities.

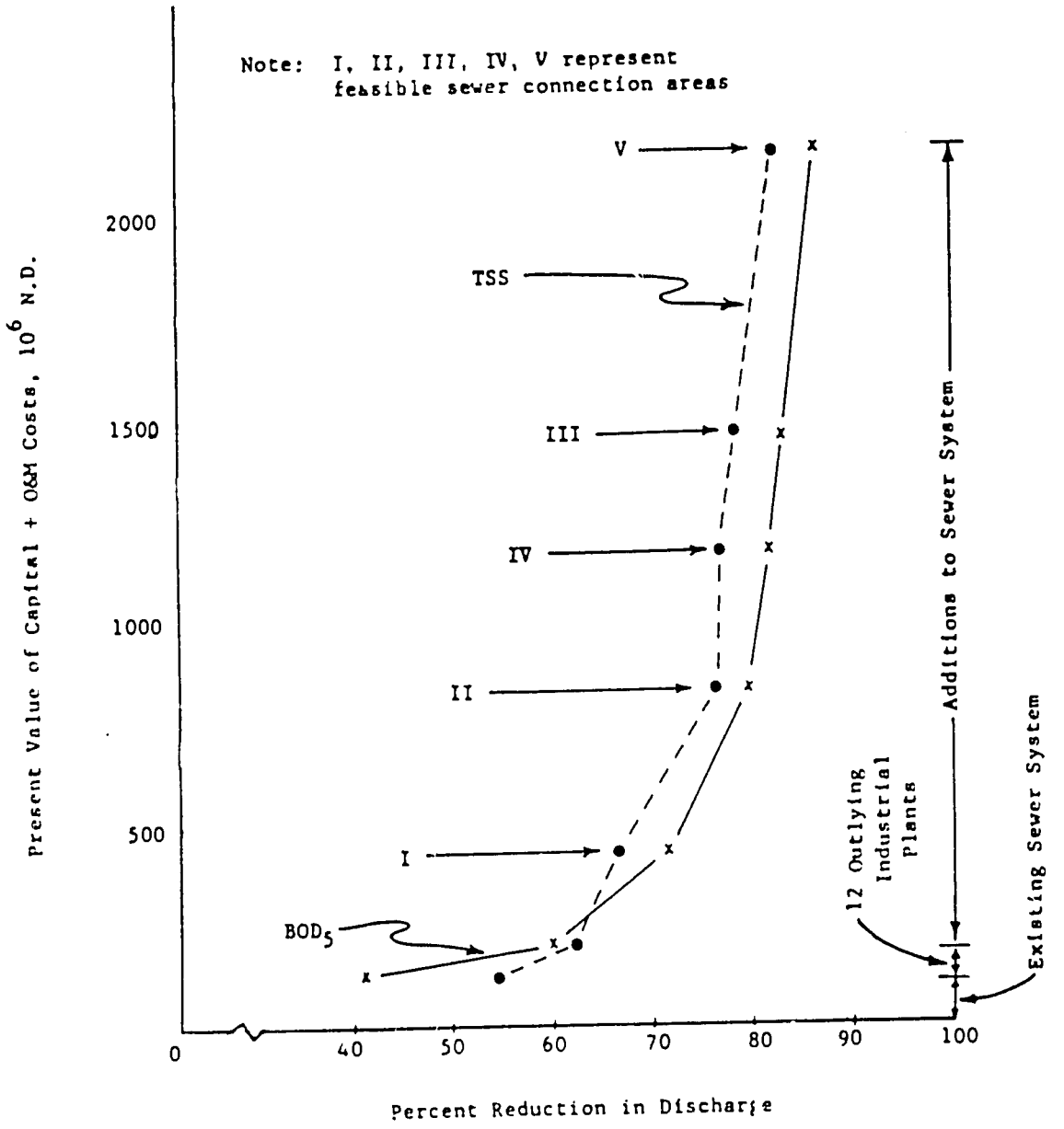
b. [illegible] day of wet [illegible] sewage generated in sewage treatment.

Figure 4B. Relationship between Mean Winter Concentration of SO_2 and Discharge Reduction Costs, 1972 Conditions, Five-Commune Area[a]



a Costs are net and in 1974 N.D.; 40-year time period of analysis; 11% discount rate.

Figure 44. Discharge Reduction-Cost Functions for BOD_5 and TSS, 1972 Conditions, Five-Commune Area, Ljubljana, Yugoslavia



a Costs are net and 1974 N D.; 40-year time period of analysis; 11% discount rate.

Table 17. Environmental Quality Levels Achieved and Corresponding Present Values of Costs for Various Combinations of Physical Measures, 1972 Conditions, Five-Commune Area, Ljubljana, Yugoslavia

E.Q. Indicator	Combination I		Combination II		Combination III		Combination IV		Combination V	
	Mean E.Q. level achieved	P.V. of costs, 10^6 N.D.	Mean E.Q. level achieved	P.V. of costs, 10^6 N.D.	Mean E.Q. level achieved	P.V. of costs, 10^6 N.D.	Mean E.Q. level achieved	P.V. of costs, 10^6 N.D.	Mean E.Q. level achieved	P.V. of costs, 10^6 N.D.
SO_2 TSP	135 $\mu g/m^3$ 74 $\mu g/m^3$	360	135 $\mu g/m^3$ 74 $\mu g/m^3$	360	170 $\mu g/m^3$ 80 $\mu g/m^3$	250	200 $\mu g/m^3$ 80 $\mu g/m^3$	180	110 $\mu g/m^3$	470
CO HC NO_x	35% DR 25% DR 6% DR	890	35% DR 25% DR 6% DR	890	35% DR 25% DR 6% DR	890	35% DR 25% DR 6% DR	890	35% DR 25% DR 6% DR	890
TSS BOD_5	80% DR 76% DR	2170	76% DR 71% DR	1180	74% DR 69% DR	840	63% DR 61% DR	420	76% DR 71% DR	1180
MSR	All MSR into good quality sanitary landfill	30	All MSR into good quality sanitary landfill	30	All MSR into good quality sanitary landfill	30	All MSR into good quality sanitary landfill	30	All MSR into good quality sanitary landfill	30
Total Costs		3450		2460		2010		1520		2570

Abbreviation: DR, discharge reduction

a All values are rounded. Costs are net and in 1974 N.D.; 40-year period of analysis; 11% discount rate.

level of expenditure of resources.

Table 17 represents the "achievement" of GIFRAD. The information in the table is part of the input to the decision process. Other supplementary analyses are usually necessary in order to generate information on other relevant criteria, some of which are shown in Table 18.

IMPLEMENTATION

Determining the least cost set of physical measures to achieve desired levels of AEQ does not, in and of itself, result in any change in AEQ. The generating activities must be induced to act, to adopt measures, to change behavior patterns. Figure 45 characterizes this incentive problem, and makes the point that both positive and negative incentives, carrots and sticks, exist. Figure 46 indicates the role of implementation incentives as a basic element of urban environmental quality management.

Implementation Incentives and
Implementation Incentive Systems

A variety of implementation incentives (IIs for convenience) is available. Table 19 shows them divided operationally into Regulatory, economic, administrative, judicial, and educational/informational. Other classifications are possible. The important point to be emphasized is that many options exist, not just the few very often considered.

Given the various possible IIs, where might they be imposed in the urban setting?? Figure 47 indicates some of the possible loci of imposition. What and where are two elements, but a third is required, the "who". Some entity must be responsible for imposing the II or IIs, or several entities must be, on the activity. Table 20 shows some examples of the types of relationships necessary among activity, physical measure, implementation incentive, and responsible entity.

The foregoing are necessary, but not sufficient, to achieve the desired actions on the parts of the activities. What is required is an "implementation incentive system".

Table 18. Some Criteria for Evaluating Strategies

1. PHYSICAL, CHEMICAL, BIOLOGICAL EFFECTS OVER TIME

   a. Changes in ambient environmental quality in the various subregions and subsections of the region
   b. Effects of changes in ambient environmental quality on receptors, users of the region
   c. Extra-regional ecosystem effects
   d. Net energy used or produced

2. ECONOMIC EFFECTS AND THEIR DISTRIBUTIONS OVER TIME

   a. Direct benefits, e.g., values of products and services produced
   b. Direct costs of products and services produced
   c. Administrative costs
   d. Indirect benefits associated with products and services produced
   e. Indirect costs associated with products and services produced

3. ADMINISTRATIVE CONSIDERATIONS

   a. Simplicity
   b. Effects on staffs of existing agencies
   c. Retention of effectiveness under changing conditions
   d. Ease of modification under changing conditions

4. TIMING CONSIDERATIONS

   a. Years before production of products/services begins
   b. Years before adverse impacts on ambient environmental quality begin to be measured
   c. Time required to establish implementation incentive/institutional arrangement systems

5. POLITICAL CONSIDERATIONS

   a. Priority in relation to execution of strategies in other resources management regions
   b. Degree to which strategy can be executed by a single agency rather than by multiple agencies
   c. Impact on intergovernmental relations, i.e., relations between and among various governmental levels
   d. Acceptability to public
   e. Legal difficulties

6. ACCURACY OF ESTIMATES

   a. Physical, chemical, biological effects
   b. Benefits, direct and indirect
   c. Costs, direct and indirect

7. FEASIBILITY OF FINANCING

   a. cash flow requirements for implementation
   b. ability to pay
   c. sources of cash flow, e.g., user charges, grants, subsidies
   d. bond sale feasibility

Figure 45. The Nature of the Incentive Problem

The following definitions are according to Webster:

IMPLEMENT: to fulfill; perform; carry out; to put into effect according to or by means of a definite plan or procedure.

INCENTIVE: something that incites to action.

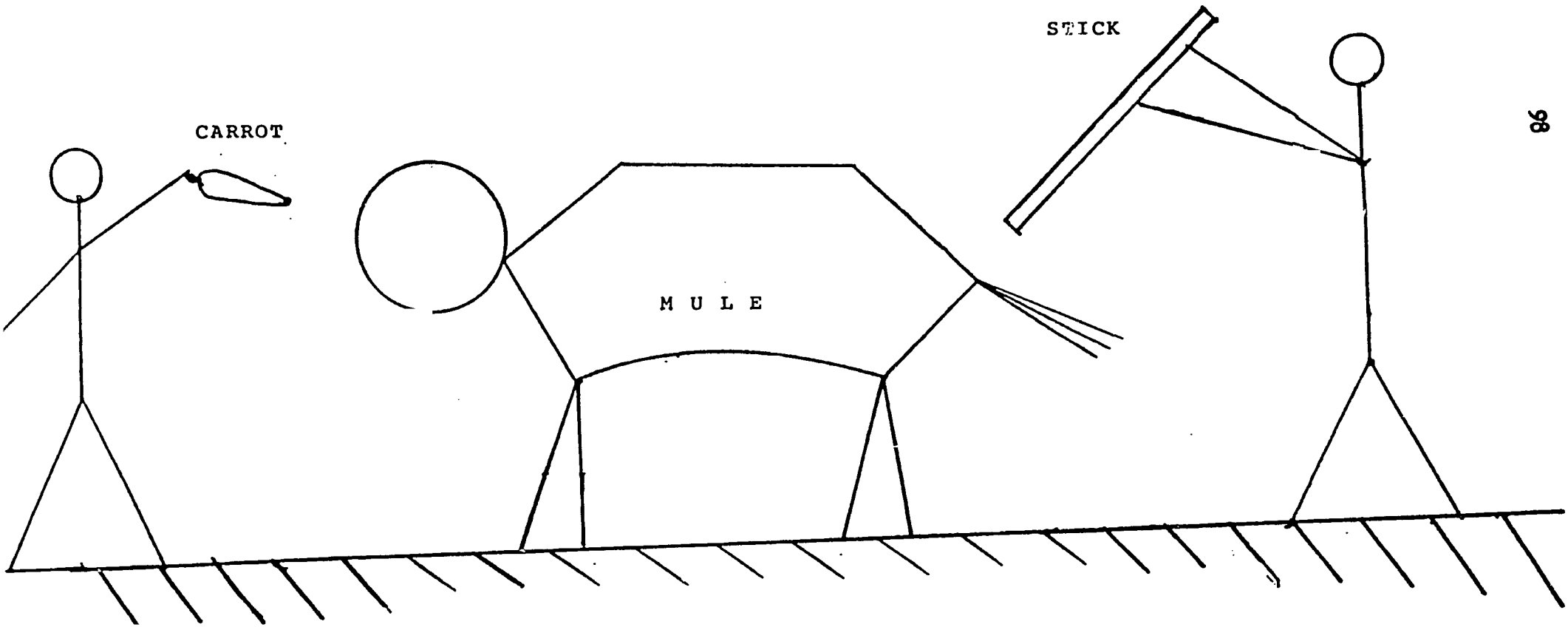
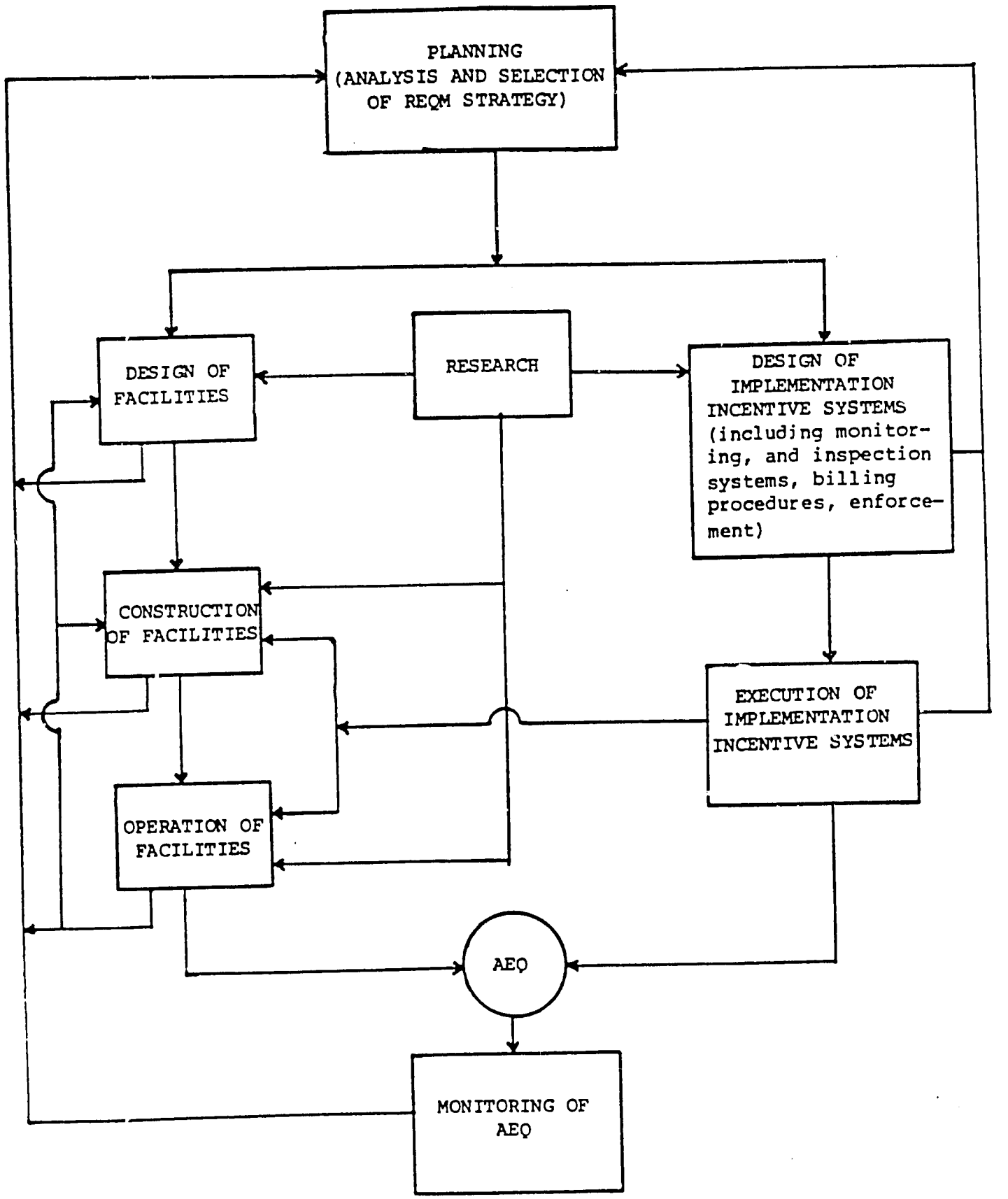


Figure 46. Interrelations Among Planning, Implementation Incentives, Physical Measures, and AEQ



Source: Bower, et al. (1987)

Table 19. Classification of Implementation Incentives with Examples

Incentive Category	Operational Specification	Description of Specification	Example
Regulatory (law ordinance, permit)	Management practice/ control technologies	Characteristic(s) of raw material inputs	- no more than 1% sulfur fuel - target-specific degradable pesticides
		Production process	- amount of thermal insulation in buildings - conservation tillage in agricultural crop production
		Residuals modification and/or handling	- activated sludge sewage treatment plant - debris basins on construction sites - pretreatment technology - landfill liners
		Product output	- amount of lead in gasoline - amount of phosphate in detergents - standard number/sizes/designs of glass containers
	Result of performance	Total quantity of residual per unit ≤ a specified amount	- ≤ X kilograms of suspended solids per ton of steel - ≤ y grams of hydrocarbons per vehicle-kilometer traveled
		Total quantity of residual discharged per unit time ≤ a specified amount	- kilograms of suspended solids per day - kilograms of particulates per day
		Concentration of residuals in discharge ≤ a specified amount	- 30 mg/1 of suspended solids in waste water
		AEQ level to be achieved	- maximum quarterly average of lead-1.5 ug/m^3; - maximum concentration of 0.01 of cadmium in drinking water
		Performance	- 85% BOD_5 removal (from specified base) in sewage treatment plant - 98% particulates removal (from specified base) in power plant stack - efficiency of energy use by appliance must be ≥ specified level - automobile must achieve at least 40 kilometers per liter of fuel in city driving
	Locations or limitations on locations of activities		- designate hazardous landfill sites - limit density of construction where infiltration capacity for septic tanks is less than a specified rate - prohibit surface mining on slopes > 25%

(Continued)

Table 19 (continued)

Incentive Category	Operational Specification	Description of Specification	Example
	Extent, timing type of activity		- allow only carpools to use particular routes during particular time periods - prohibit all-terrain vehicles in environmentally fragile areas - prohibit aerial spraying of pesticides when wind > 8 kilometers per hour
	Procedure		- require environmental impact statement be prepared on each project according to specified guidelines - semi-annual testing and inspection by public agency of discharge controls on motor vehicles - require public hearings before REDM strategy is adopted
Economic	Applied directly to residuals		- charge on each unit of residual discharged - X $ per kg. of BOD_5 - Y $ per kg. of SO_2 emitted
	Applied to inputs		- surcharge on each unit of energy intake - charge on each ton of nitrate fertilizer applied
	Applied to product outputs		- charge on each kilogram of packaging - annual surcharge on horsepower of automobile
	Applied to activities		- severance taxes on virgin materials extracted - reduced parking fees for car pools - parking surcharges - payment to farmers to set aside cropland into conservation reserve
	Applied to residuals modification		- sewer and landfill user charges - reduced taxes for installation of residuals discharge reduction measures - grants to municipalities to finance installation and operation of residuals handling and modification facilities
Administrative (By order within a governmental agency or an enterprise)	Applied directly to residuals		- require separation of various types of residuals - collect all used lubricating oil and used tires for reprocessing

(Continued)

Table 19 (continued)

Incentive Category	Operational Specification	Description of Specification	Example
	Applied to products used		- specify that only unbleached consumer paper products can be used - specify that only raw materials in reusable containers can be purchased
	Applied to activities		- specify limits on thermostat settings for heating and air conditioning
Judicial	Court or Administrative Law Review Civil or criminal suits		
Educational/ Informational	Educational programs		- adverse impacts of activities on AEQ - technical assistance for soil/water conservation planning
	Informational programs		- appliance labeling with respect to energy efficiency - fuel economy rating - pesticide labeling

Source: Bower, et al. (1987

Figure 47. Possible Loci for Imposition of Implementation Incentives

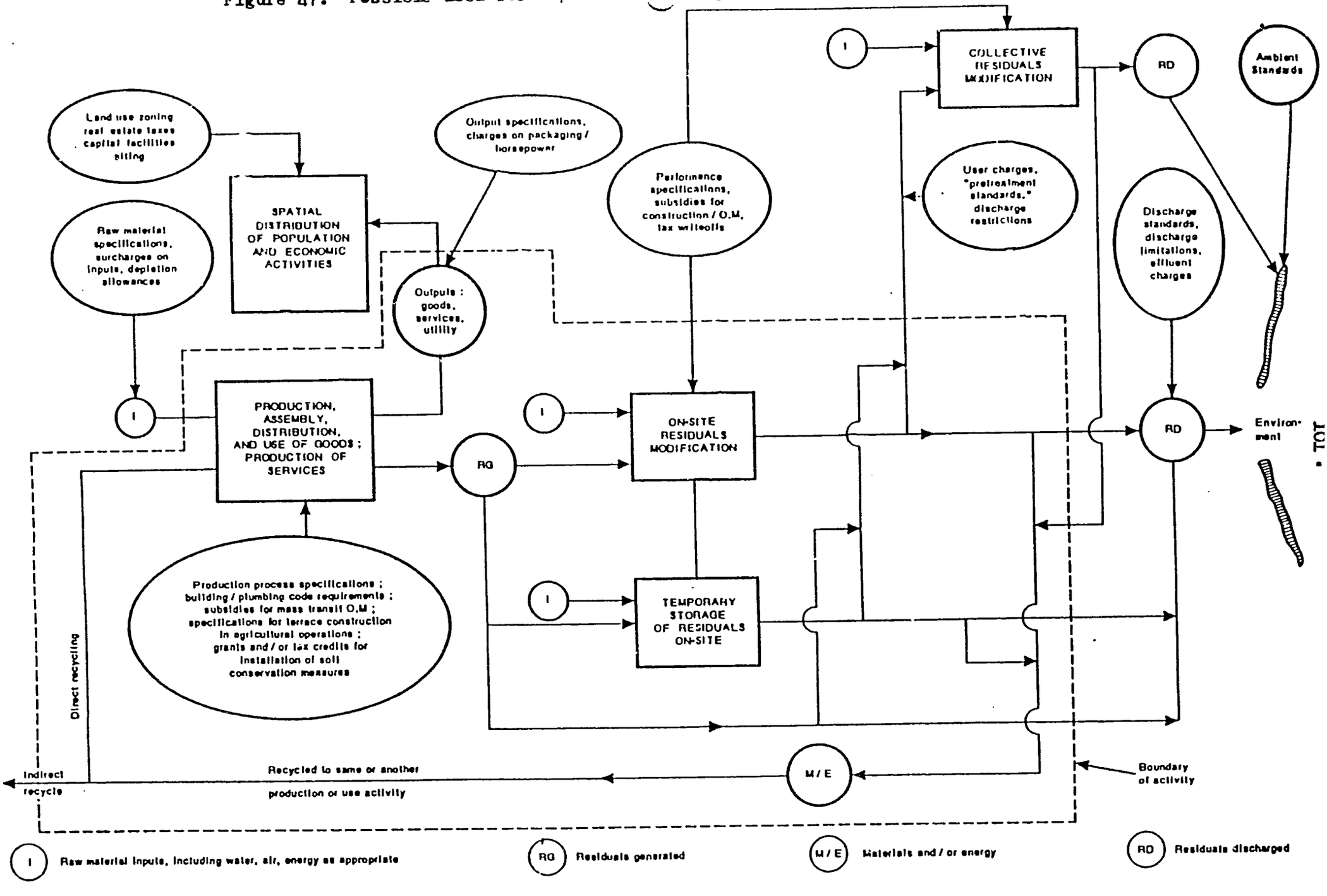


Table 20. Illustrations of Combinations of Activities, Physical Measures, Implementation Incentives, and Institutional Arrangements

Residual(s) Affected	Management Practice	Applicable Activity	Implementation Incentive	Institutional Arrangement
Windblown particulates	Plant/maintain windbreak/trees	Agricultural operation	Provision of free tree stock, Technical Assistance	USDA/SCS, State Department of Environmental Quality, State Department of Agriculture
Discharges from municipal sewage treatment plant	Better operation of sewage treatment plants	Municipal sewage treatment plant	Training of operators (cost borne by state)	U.S. Environmental Protection Agency, State Department of Environmental Quality
			Salary increment for licensed operators	Municipality
			Require operators to have licenses (after training and certification exam)	State Department of Environmental Quality
Chromium	Recovery System	Manufacturing operation	Provide detailed information	U.S. Environmental Protection Agency
Phosphates	Limit phosphate content in detergents	Detergent production	Ordinance	State, municipality, and federal government
Suspended solids and phosphates	Conservation tillage	Agricultural operation	Require conservation plan to receive USDA program benefits, Technical Assistance	USDA, SCS, State Department of Agriculture
Hazardous Wastes	Landfill liners	Landfills	Require permit and groundwater monitoring, Restrict certain wastes	U.S. Environmental Protection Agency, State Department of Environmental Quality
Particulates	Precipitators, etc.	Incinerator	Control technology requirement, Effluent charge - X cents per kg discharged above standard	U.S. Environmental Protection Agency, State Department of Environmental Quality

An implementation incentive systems consists of:

(1) a set of implementation incentives; e.g., rules or procedures that an activity must follow, a set of discharge limitations which must not be exceeded by some amount some portion of the time, and/or a set of charges related to inputs to the activity, to residuals discharges from the activity, or to some measure of performance;

(2) a system of measuring performance; e.g., the quantities of materials discharged, the qualities and/or quantities of material and/or energy inputs, the quantity of residuals removed from the discharge streams, quality of product output;

(3) a system of on-site inspection to determine if, for example, specified equipment is in place and operating, the system for measuring performance is in place and operating, the analysis of the samples taken is accurate; and

(4) a set of sanctions -- fines, fees, withdrawal of operating permit, exclusion from government contracts, imprisonment-- for failure to comply with the rules/procedures/standards, or failing to pay charges.

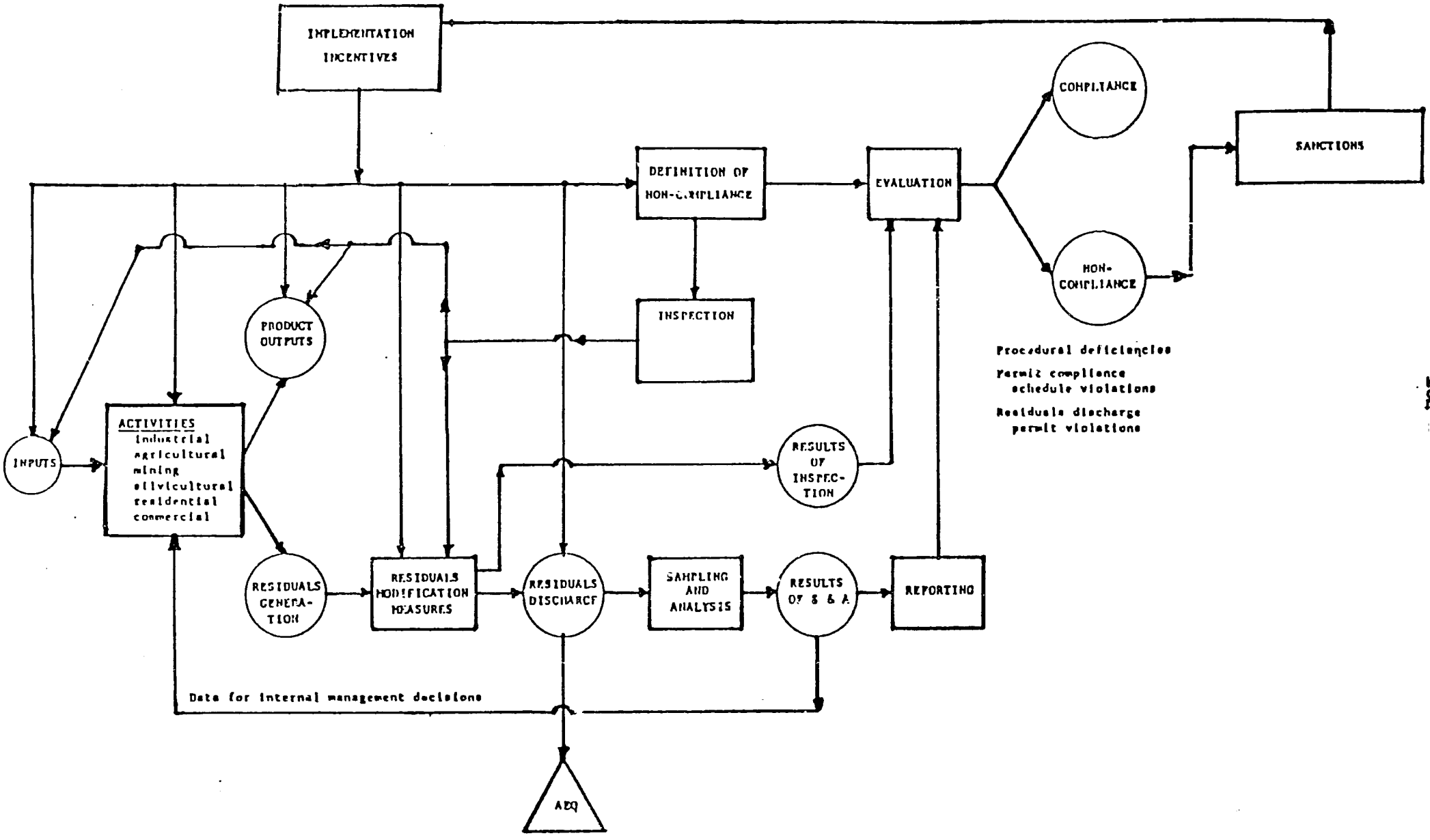
Whatever comprises the first element of an implementation incentive system, i.e., what combinations of IIs, the other three elements are essential if the desired behavior is to be achieved. For example, both effluent standards and effluent charges require all four elements to be effective.

Some "Facts of Life" with respect to Implementation

No presumption is made that the following points represent the totality of problems/issues/facts of life with respect to implementation. They do represent aspects often unrecognized or overlooked.

(1) The substantial variation in residuals generation,and often therefore in residuals discharge, by many activities creates difficulties for monitoring performance, and for inspection of facilities. What type of sampling and analysis program, both by the activity and by the EQM agency is required to obtain a representative sample of performance?? Vaugham and Russell (1983) and Watson and Downing (1976) discuss some of the inherent problems. With respect to inspection, experience shows clearly that if inspections are limited only to weekdays between 0800 and 1700, that substantial

Figure 48. Flow Diagram Showing Elements of an Implementation Incentive System



deviations from required performance will occur. "Midnight dumping" is a phenomenon common to many, if not all, societies. Experience shows that unless inspections are unannounced, accurate appraisal of performance is not achieved. Figure 49 suggests what is likely to be the relationship among frequency of unannounced inspections, inspection costs, and discharger performance.

Even if representative sampling of an activity could be achieved, the problem remains, how good are the numbers produced by the lab analysts?? How good (or bad) is quality control of lab analyses?? Tables 21 and 22 reflect this problem. The constituents in Table 21 all are conservative, common, and relatively simple to analyze. The ones shown in Table 22 are common, and almost as simple to analyze. Yet, in both cases, there is a wide range in what the different labs reported as being in a sample with known concentrations. Although it is hoped that the situation has improved since the 1960s and 1970s, some evidence suggests not much improvement has occurred, This is particularly a problem because of the recent concern with trace elements, synthetic organic compounds, organochloride compounds, for many of which concentrations are in the parts per billion and parts per trillion range. Lab analyses have become much more difficult.

(2) The behavior of different types of activities in terms of responding to incentives of various types is neither well studied nor well documented. The assumption has often been made, particularly by economists, that activities---in general, no caveats---will respond to economic incentives. However, it is clear from experience that some types of activities, such as public agencies, do not---in fact---respond to economic incentives from society's point of view. Some of the worst "polluters" in developed and developing countries alike are government entities. The effect of incentives in an urban setting is, to an important degree, a function of the type of organization to which the activity belongs, e.g.; one plant of a multi-plant firm; public agencies, such as schools, park departments; single plant firm; nation-wide franchise organization; member of a national trade association.

Figure 49. Hypothesize Relationship among Frequency of Unannounced Inspections, Inspection Costs, and Discharger Performance

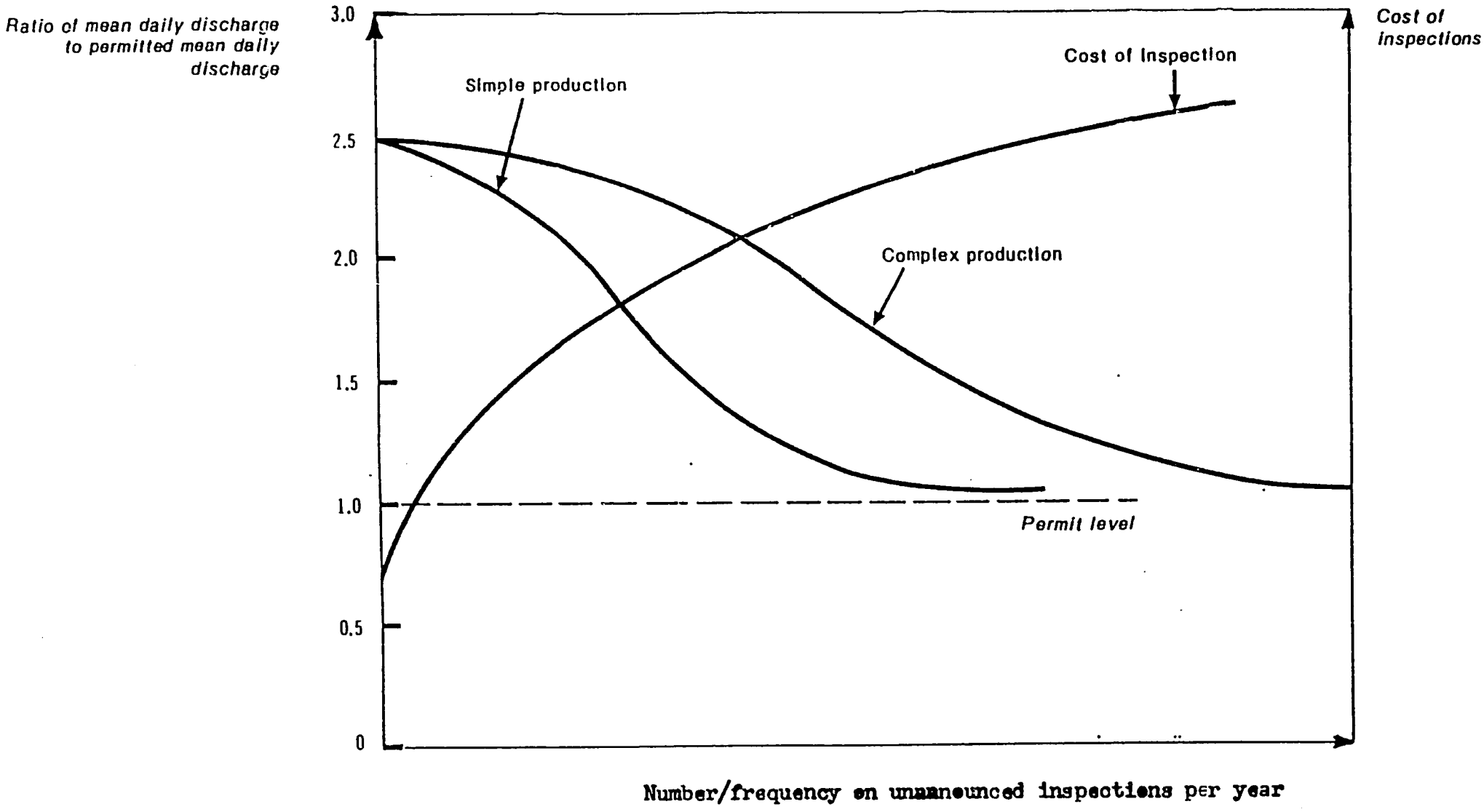


Table 21. Results of Analyses of Samples of Known Concentrations by Operating Laboratories

Constituent	Known Concentration, ppm	Number of Laboratories Reporting	Reported Concentrations	
			Minimum, ppm	Maximum, ppm
Sulfate	259	65	9.6	332
Chloride	241	63	210	392
Fluoride	0.57	53	0.0	1.09
Nitrate	1.1	53	0.2	28

Constituent	Ratio: Maximum Reported to Minimum Reported	Ratio of Minimum Reported Concentration to Known Concentration	Ratio of Maximum Reported Concentration to Known Concentration
Sulfate	35:1	0.037	1.28
Chloride	1.9:1	0.87	1.63
Fluoride	109:1 [a]	0	1.91
Nitrate	140:1	0.18	25.0

[a]Arbitrarily assuming minimum reported of 0.0 to be 0.01.

Source: Kinney (1968)

Table 22. Results from Analysis of Nutrient Sample 3001, Phase Six Lab Quality Control Program, the Miami Conservancy District Water Conservation District

	Nutrients - mg/l				
Lab No.	NO_3-N	NH_3-N	TKN	Ortho P	Total P
1	0.17	2.28	42.00	2.94	4.50
2	--	--	--	0.91	4.49
3	8.4	1.2	--	1.0	1.5
4	--	1.1	--	0.35	--
5	2.1	--	--	--	--
6	1.32	1.32	1.99	1.05	1.03
7	1.8	1.4	10.0	--	2.9
8	1.59	1.33	--	--	0.84
Value	1.27	1.18	1.18	0.96	0.96

Note: Both manual and automated methods were used.
-- means not reported, i.e., not found by laboratory

Source: Miami Conservancy District (1976)

(3) Most, if not all, implementation systems in various countries are mixed systems, i.e., comprised of various combinations of the different types of incentives: economic; regulatory; technical aid; judicial sanctions. "Pure" systems do not exist. This is not surprising, given the wide range in combinations of activities, governmental structure, culture.

(4) Effective implementation requires that the EQM agency or set of agencies have the following capabilities:

- technical capability to review applications to discharge and to aid activities in selecting economic measures to reduce discharges;
- technical capability to monitor and inspect sources, and to measure performance of sources;
- authority and capbility to apply sanctions; and
- capability to finance its operations.

CONCLUDING COMMENTS

- Two widely existing perceptions are myths. One is that "pollution control" is always very expensive. The analyses of activities, along the lines described in the section on analyzing activities, and much experience, indicate that this is not so. Two, the assumption that private industrial activities are always the worst polluters in urban areas is not always, and may seldom be correct. The typical approach has been to ignore public industrial activities, urban storm runoff, and commercial activities such as hotels, tourist resorts, and office buildings.

- Many uncertainties exist in relation to analysis for UEQM. These include: hydrologic and meteorologic; ecologic, in terms of inadequate understanding of how ecosystems behave; economic; technologic; behaviorial, e.g., will the activities respond to the incentives as assumed; and political. As a result, it is essential that alternative scenarios be analyzed and sensitivity analysis be performed.

- Analysis for, and implementation of, UEQM requires the integration of

economics, technology, ecology, and institutions (legal, social, political). It is not easy to develop the capability of integrating, in any country.

- UEQM is a CONTINUOUS activity. To achieve and maintain desired EQM levels requires:

institutional capability to carry out the integration cited above;

an understanding that the costs of improving AEQ are often small, and may even be positive, especially in the industrial sector;

a recognition that "life style" is the driving force in making demands on environmental services, both as inputs and as repositories for leftovers, and therefore explicit consideration should be given to possible modifications of "life style" in developing UEQM strategies; and

political will.

Recommendations to A.I.D.

(1) Urban environmental quality management considerations can be incorporated in AID "environmental" coursesby utilizing the framework presented herein, with more detailed discussion of the various elements of the framework. But it should also be noted that the framework is just as applicable, and has been applied, to nonurban areas as well.

(2) The framework can be applied to any of the AID urban programs/projects in order to assess the environmental effects thereof.

Reprise

The emphasis herein has been on analysis for UEQM. It is a truism that analysis by itself does nothing, i.e., generation of information without the means for execution is futile. But it is also a truism that execution with analysis is very likely to be dangerous. Shakespeare stated the situation well four hundred years ago, to wit:

"When we mean to build,
We first survey the plot, then draw the model;
And when we see the figure of the house,
Then we must rate the cost of the erection;
Which if we find outweighs ability,
What do we then but draw anew the model
In fewer offices, or at last desist
To build at all? Much more, in this great work,
Which is almost to pluck a kingdom down
And set another up, should we survey
The plot of situation and the model,
Consent upon a sure foundation,
Question surveyors, know our own estate,
How able such a work to undergo,
To weigh against his opposite; or else
We fortify in paper and in figures,
Using the names of men instead of men:
Like one that draws the model of a house
Beyond his power to build it; who, half through,
Gives o'er and leaves his part-created cost
A naked subject to the weeping clouds
And waste for churlish winter' tyranny."

William Shakespeare
Henry IV, Part II, Act I, Scene III

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