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WATER QUALITY MANAGEMENT IN INDUSTRIAL AREAS*

INTRODUCTION

This paper is based on two assumptions. First, an industrial area is defined as a geographic area in which industrial activities comprise the predominant source of water demands, in terms of water withdrawals, liquid residuals discharges, or both withdrawals and discharges. Such an area could be: an industrial park; an industrial section of a metropolitan area; an heavily industrialized section of an estuary, such as the upper Delaware estuary in the United States (U.S.). Although industrial activities may predominate with respect to water withdrawals, they may not predominate with respect to discharges of all liquid residuals of interest having adverse effects on ambient water quality. Other sources -- in addition to urban activities other than industrial -- which may be more important than industrial activities in an industrial area for a particular residual are: channel erosion with respect to suspended solids (SS) and phosphorus (P); urban storm runoff with respect to SS, biochemical or chemical oxygen demand (BOD_5/COD), metals, oil, grease; and deposition from the atmosphere with respect to SS, P, metals, acid. For example, in the Great Lakes Basin (U.S. and Canada), from 20% to 50% of phosphorus loads into lakes Superior, Michigan, and Huron were estimated to be a result of deposition from the atmosphere.(1)** In developing a water quality management strategy for an industrialized area,

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* Paper prepared for presentation at the International Symposium on Water Resources Management in Industrial Areas, 7-11 September 1981, Lisboa, Portugal.

** Footnotes are at the end of the paper.

it is critical that the relative importance of the various sources of the liquid residuals of concern be determined.

Second, an industrial area is defined by boundaries which represent the boundaries of some existing governmental agency -- or set of governmental agencies -- which has jurisdiction and authority to perform the tasks of water resources management in the industrial area. The governmental agency may be: a department of a government of general jurisdiction, such as in a province in The Netherlands and Canada; a regional water authority such as in U.K. and Hungary; a multi-gemeinde or multi-county agency such as some Waterschappens in The Netherlands and multi-county irrigation districts in the U.S. What is essential is that, if the task of water resources management is in fact to be performed, the authority for doing so must be clearly specified in relation to political boundaries and geographic areas, and in relation to the authorities of other ministries.

DEFINITIONS

In order to provide a common basis for discussion, some terms must be defined. The definitions presented below may not be acceptable to all. However, they: (a) are operational; (b) have been found to be useful; and (c) enable understanding the subsequent discussion in the paper.

Activity (Enterprise). An activity is a decision unit which consists of a set of one or more unit processes and unit operations. An industrial plant, a farm, a mining operation, a restaurant, an office building, an household -- each is an activity, and each uses water and generates residuals according to some time patterns. Often the activity involves several inter-process transport operations, such as by flume, pipeline, conveyor belt, as in manufacturing activities. ("Enterprise" is a term in common use in some countries, e.g., Yugoslavia, to refer to the same phenomenon.)

Firm. -- It is important to clarify the use of the term "firm". Traditionally -- particularly in western economic and business literature -- the term "firm" has been used to refer to an activity in the classical sense of Adam Smith and the individual entrepreneur who owned a single plant. This has long since ceased to be the reality, with the multi-plant firm, company, corporation becoming common in both production and service sectors. Thus, there are single-plant firms and multi-plant firms.

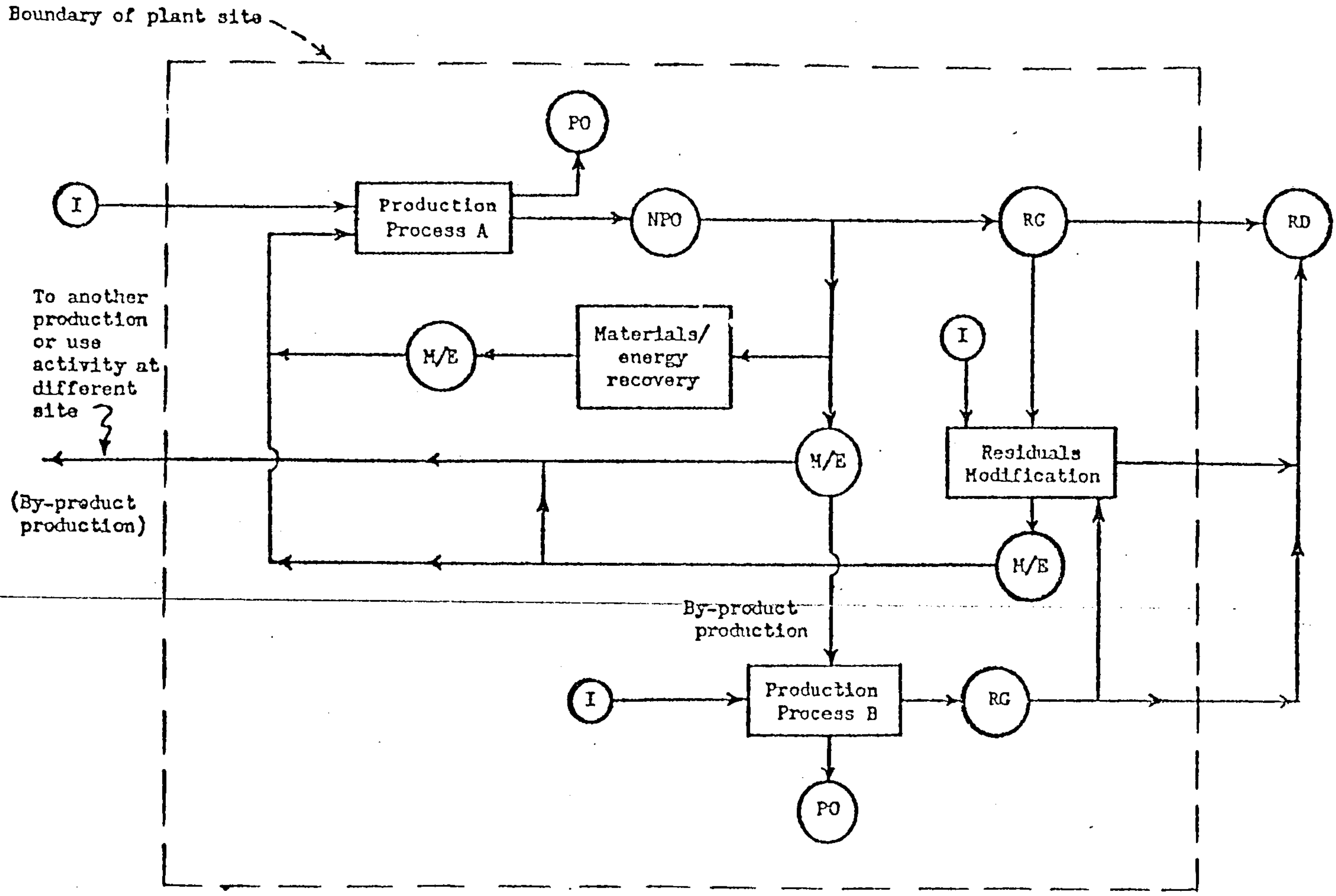
The nature of the activity or enterprise in terms of locus of control of decisions is an important factor in water quality management, particularly in terms of the problems of inducing desired behavior to reduce discharges into surface and ground water bodies. Responses of individual activities (enterprises, plants) differ depending on whether the plant is: 100% privately owned; 100% publicly owned (state corporation, national ministry); mixed private-public (as are some major companies in France); privately held but publicly regulated (as private electric utilities in the U.S.). If an individual activity is one plant of a multi-plant firm/company/ministry, then the decisions on how to respond to incentives imposed on the activity are taken within the context of the entire company/ministry. Responses are also affected by the extent to which the industry of which the activity is a part of a national monopoly or an international cartel.

Residual. -- A residual is a nonutilizable output of material or energy from an activity which has zero value or a value less than the cost of its recovery and transport for use in the same or another activity. Traditionally such residuals have been termed pollutants, with the implicit assumption that their discharge would have adverse effects on ambient environmental quality and hence on users of the environment. Because not all discharges of residuals result in adverse effects -- in some cases the effects are actually positive -- the neutral term "residuals" is used.

Residuals are generated by all activities, because no production or use activity transforms all inputs into outputs of desired products and services. The discharge of a residual does not occur until the residual is discharged into the environment across the boundary of the site of an activity, e.g., in or from a pipe, overland runoff, groundwater seepage, stack, truck, rail car. The residuals may or may not be modified before discharge into the environment or transport from the plant site in a sewer line or by truck. Figure 1 illustrates the definitions of residuals generation, residuals discharge, materials/energy recovery, and byproduct production.

Materials and/or energy recovery refers to recovery and reuse in the same production activity. In many, if not most, manufacturing activities, it is economically necessary to recover and reuse substantial portions of the nonproduct materials and energy formed in producing the given product mix, for example, recovery of chemicals and fiber in pulp and paper production. Analogous materials and energy recovery is essential in many nonmanufacturing 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 cost of recovered materials/energy relative to new (makeup) materials/energy, the latter usually being purchased in the market -- or from another segment of the plant -- at a price which may or may not be close to the open market price. The relative cost of new and recovered materials and energy is a function of: the technology of basic production; the technology of materials and energy recovery, for example the technology of heat exchangers for energy recovery; the technology of production of "new" material and energy inputs; and various governmental policies such as depletion allowances, severance taxes, freight rates, tariffs. Tradeoffs are possible between the

Figure 1. Illustrations of Definitions of Residuals Generation, Residuals Discharge, Materials/Energy Recovery, and Byproduct Production



Abbreviations:

I, inputs; PO, product outputs; NPO, nonproduct outputs; M/E, materials and/or energy; RG, residuals generated; RD, residuals discharged.

design of production technology to increase the physical efficiency of production, i.e., reduce the formation of nonproduct outputs, and utilization of material and energy recovery technology. In designing a plant, the objective is to optimize the *combination* of basic production technology *plus* materials/energy recovery.

Byproduct production refers to nonproduct materials and energy which are used as inputs into *another* production activity, at the same location as, or at a different location than, the production activity which generated the original nonproduct outputs. 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 to make charcoal briquettes.

In terms of profit maximization for an individual plant, 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 -- assuming rational plant managers -- 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 of byproduct production, and therefore the extent of residuals generation, are likely to vary over time.

Water demand. Operationally, water demand can usefully be considered to be comprised of seven interrelated dimensions, two of which might be termed "derivative dimensions". The first six dimensions, shown in figure 2, are: water intake (abstraction, withdrawal); gross water applied; consumptive use of water; wastewater discharge, including the quantities of material and energy in the wastewater (2); intake water treatment sludge; and wastewater treatment sludge. The last two listed are the derivatives of the first four. The seventh dimension is time. That is, there is a time pattern related to each dimension, e.g., the time pattern of water withdrawal by a given activity, the time pattern of wastewater treatment sludge generated.

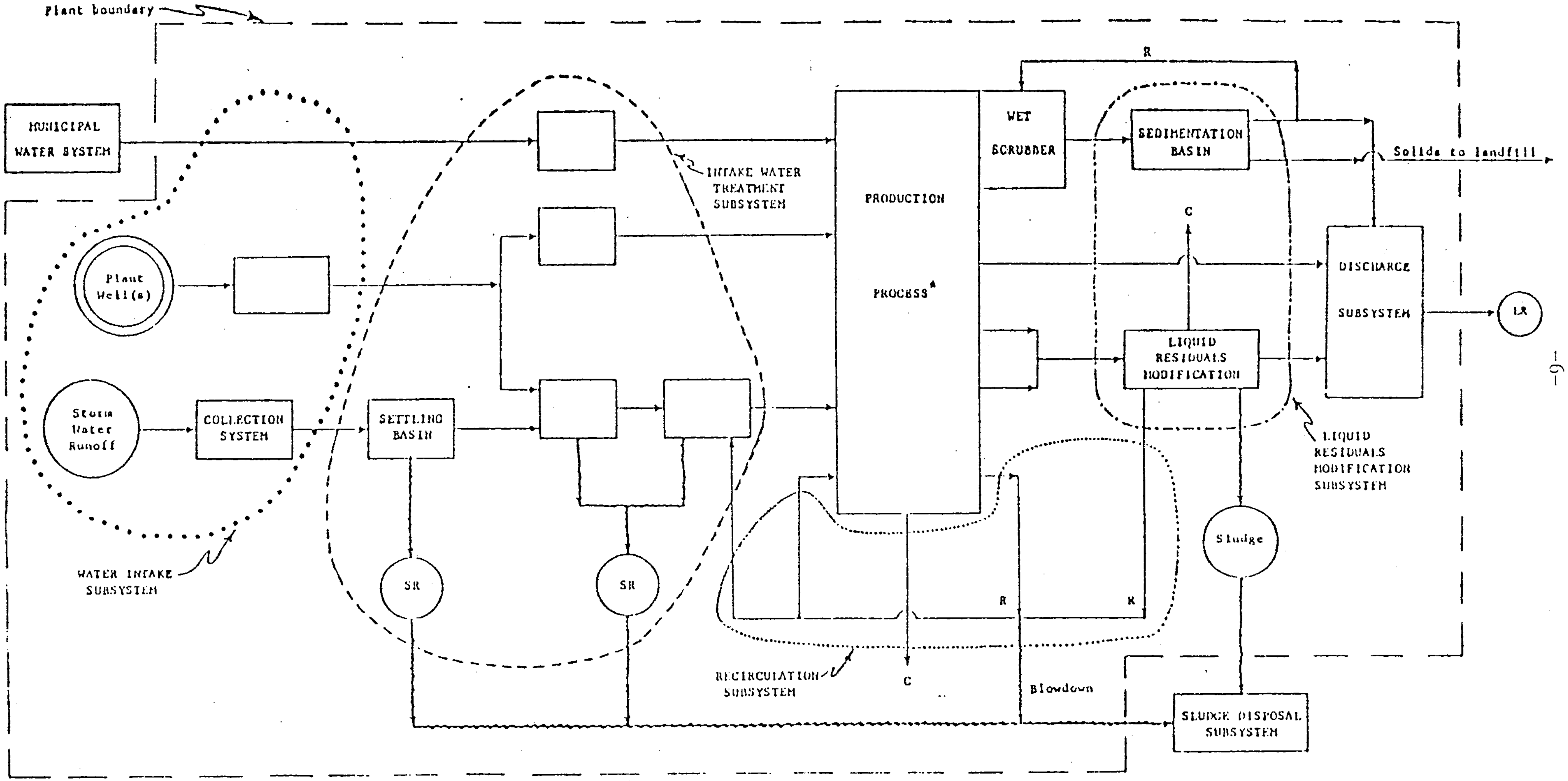
Abstraction (intake, withdrawal). These terms refer to the quantity of water taken in at the intake of the water system of an activity, which intake may be the end of a pipe in a surface water body, a well tapping a ground water aquifer, or the beginning of the pipe connection from a communal water distribution system to the individual activity.

Withdrawal standard (abstraction condition). This is a condition imposed on the quantity, time pattern, and/or location of a water withdrawal.

Emission (discharge, effluent). These terms refer to the quantities of water and contained materials and heat passing beyond the boundary of an activity and entering a surface or ground water body or a communal sewer system.

Discharge standard. This is a condition imposed on the quantity, quality, time pattern, and/or location of a discharge.

Figure 2. The Dimensions of Industrial Water Demand



* Components of water utilization system relating to the unit operations, including cross connections, are not shown.

R = recirculated water
C = consumptive use of water

LR = liquid residuals
SR = solid residuals

Note: Liquid residuals from backwashing intake water treatment facilities are ignored.

License or permit. A license or permit is an authorization given by a governmental agency to withdraw water or discharge wastewater under specified conditions, e.g., quantity, time pattern, location of withdrawal or discharge, special limitations under drought conditions, requirements for self-measuring/monitoring. This is analogous to a business permit, e.g., a condition of doing business.

Fee. A fee is the amount of money which must be paid to obtain a permit or a license, e.g., a license fee. It may be a one-time fee or an annual fee. It is payment for the authorization to withdraw or to discharge, and must be paid regardless of whether or not a withdrawal or discharge is made.

Abstraction (withdrawal) charge. This is the amount of money paid for withdrawing water from a surface or ground water body, based either on each volumetric unit of water withdrawn, e.g., cubic meter, or on each unit of water flow withdrawn, e.g., liters per second.

User charge. A user charge is the amount of money paid for a service rendered, e.g., treating intake water to potable standards, developing a reservoir and piping system to convey water to individual users, treating wastewater. In the United Kingdom the term, "trade effluent charge", is used to refer to charges paid by industrial activities for discharging their industrial wastewaters to municipal sewerage systems for subsequent treatment at sewage treatment works owned and operated by regional water authorities.

Effluent charge. Conceptually an effluent charge is a payment for use of the assimilative capacity of the water environment, and is imposed on each unit of residual (material and energy) discharged to a surface or ground water body. Operationally an effluent charge is conceived of as an economic incentive to induce reduction in discharge. However, only if the charge is high enough will it act as an incentive to reduce discharges. If the charge is less than the marginal cost of reducing discharge for most dischargers, there will be little incentive effect and the charge simply becomes a means of raising revenue. (The same is true for user charges. If such charges are high enough, they will be incentives for dischargers to reduce their discharges.)

Pollution charge. As commonly used, the term includes both user charges and effluent charges. It is applied to each unit of a residual discharged.

Tax. A tax is a payment exacted by a governmental body in order to raise revenue, e.g., personal and corporate income taxes, value added tax, sales tax, real estate tax. In the U.S. there is a critical legal distinction between charges and taxes; the terms are not synonomous.

Implementation incentive. -- An implementation incentive is that which induces an activity to reduce discharges of residuals or to reduce or modify water withdrawals. It may be economic, regulatory, administrative, informational, judicial, or combinations of these.

Implementation incentive system. -- An implementation incentive system consists of one or more implementation incentives plus the related monitoring, sampling, inspection, reporting, sanctions, sanction-imposing procedures. (3)

Strategy. -- A water quality management strategy for an industrial area -- or for any area -- is comprised of: (1) the physical measures for improving ambient water quality; (2) the implementation incentive systems to induce activities generating residuals to install and operate the physical measures; and (3) the institutional arrangement by which the responsibilities for executing implementation incentive systems and for executing other tasks of water quality management are allocated among governmental agencies. Implicit in a strategy is the set of rules for operating the physical measures on a day-to-day basis under varying hydrologic, meteorologic, and demand conditions.

THE NATURE OF WATER DEMAND

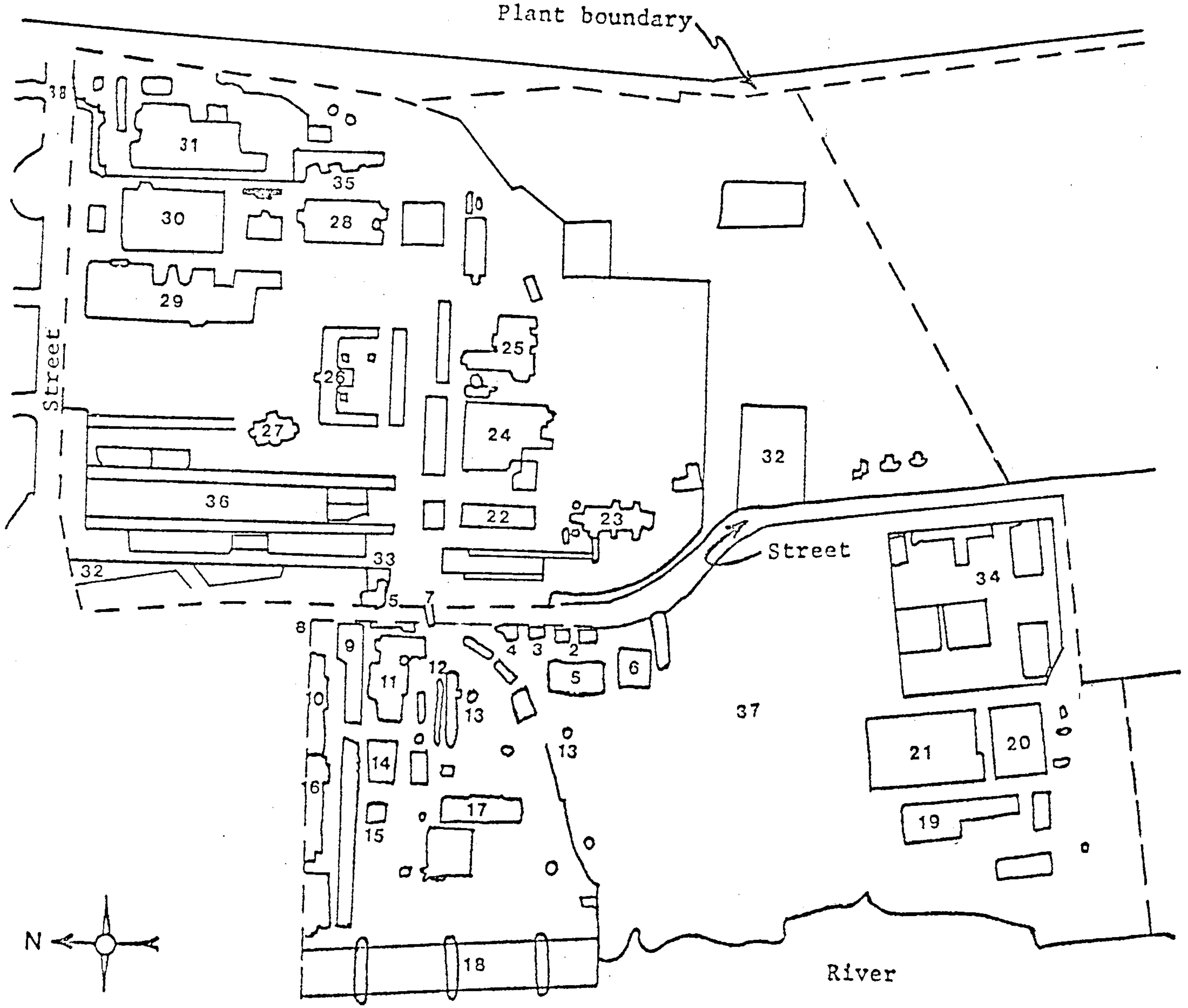
Because understanding industrial water demands is essential to achieving efficient and effective water quality management in industrial areas, some discussion of the nature of those demands is merited. Water and the services directly derived from the use of water -- such as intake water and the assimilative capacity of water resources needed for the disposal of liquid residuals -- are commodities or factor inputs analogous to other factor inputs to an activity, e.g., chemicals, energy, iron ore used in the production of steel. Hence, water and water-related services have values, and the demands for them should represent what users would be willing to pay to obtain them if in fact they had to be purchased.

Demand then is a function of the price of the factor input -- water or water-related service -- faced by the activity, e.g., as the activity "sees it". Two points merit emphasis. First, a water user faces not one price for water, but several prices simultaneously. For example, if the user purchases water from a municipal water authority and discharges wastewater to a municipal sewage system, he is likely to face a price on each unit (volume) of intake water purchased, a price on each unit (volume) of wastewater discharged, a price on each unit (kilogram) of biochemical oxygen demanding material and/or suspended solids material discharged, plus prohibitions on the discharge of certain materials, e.g., grease and oil, and constraints relating to other indicators of the quality of his discharge, e.g., pH must be between 5.5 and 9.5. He may also face a charge on the amount of water actually consumed, and either a charge or a constraint on peak flow.

Second, in many cases a water user has additional options in terms of his own: possible sources of supply, such as wells; possible facilities for treating intake water and modifying wastewater before discharge; and possible facilities for recirculating water within his activity. Given the *externally* established prices and the *internally* established costs for different levels of water supply, intake water treatment, water recirculation, wastewater modification, and sludge disposal, the rational water user compares the total costs of different combinations of these options and selects that combination which best satisfies his choice criteria. Thus, a water user is responding to a *set* of prices and costs -- either direct or in the form of constraints -- not to a single price.

A water-using activity consists of one, a few, or many unit processes and unit operations, in each of which water may be applied, consumed, recirculated, discharged. For each unit process/operation there is a time pattern of water intake demand and associated water quality "requirements". Depending on the process/operation, the water quality requirements may be stringent, as for feedwater for high pressure boilers, or lenient, as for water to wash incoming sugar beets. Because there often are many processes and operations in a given industrial activity, as illustrated in figure 3, there are multiple opportunities for direct and sequential uses of water. For example, in the integrated steel mill in Fontana, California, each cubic meter of water is used an average of 42 times. (4)

Figure 3: Facilities at a Metallurgical Plant



Scale: 1/2800

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

It is not always easy to distinguish the water utilization system in an industrial activity from the production process. The production of electrical energy requires water for cooling and for boiler feedwater. Water is used for cooling various types of production machinery, such as the rollers in rolling mills in the iron and steel industry, and canned products in the canning industry. Water bodies are used for the disposal of nonproduct outputs from industrial activities. Water can serve as a feedstock and become incorporated in the product itself. The beverage industry is an obvious example, but water or steam is also used as feedstock or processing agent in numerous chemical and pharmaceutical processes. Water is sometimes used to convey product from one stage of the production process to another. For example, cellulose fiber is transported in slurry from the pulping operation to the bleaching and papermaking processes. In the canning industry fruits and vegetables are often transported through the production process in a water stream.

Water is used for washing and cleaning throughout industrial facilities. In the canning industry fruits and vegetables are washed with water at the beginning of the production process. Hydraulic debarking in the pulp and paper industry is a standard method to remove the bark and to clean the dirt from incoming logs. Water is also used: to wash final products, equipment, floors, trucks and other vehicles; in sanitary systems; for drinking water; to water vegetation; and for fire protection. Steam may be used for space heating. Moreover, an examination of the water utilization system of an industrial plant may show that water is actually a net output of some stages of the production activity. Liquid residuals result from the production of some dry foods.

An increasingly significant use of water in industrial operations is in residuals modification. For example, water is used in the wet scrubbing of stack gases and in the pumping of manure, fly ash, and tailings to evaporation ponds or other disposal areas. Solid residuals from industrial operations -- such as nonproduct wood fiber, fruit skins and seeds from canning operations, and "red mud" from alumina production -- are often transported by water streams from the area of generation to the place of disposal.

Finally, increasingly it has become recognized that the demand on the assimilative capacity of water courses for disposal of storm runoff from plant sites is often a significant factor in terms of effects on ambient water quality in an industrial area. Thus, both process wastewater and storm water runoff are parts of wastewater discharge demand. Precipitation falling on the site of the activity must be explicitly considered, either because effluent standards and/or effluent charges are imposed on the discharges of the activity, or because the high cost of intake water induces the activity to use storm water internally, or both.

FACTORS AFFECTING INDUSTRIAL WATER DEMANDS

Many factors affect industrial water demands. Some perspective on the range and variety of these factors, and hence on the complexity of analyzing water demands and developing water quality management strategies for industrial areas, is provided simply by listing factors without discussing them. The following listing is meant to be suggestive, not exhaustive; the order of listing does not imply order of importance. Among the factors affecting water demand by individual industrial activities are:

price of water at the intake;
costs of different levels of intake water development;
price on consumptive use of water;
quality of water at intake, surface or ground;
costs of different degrees of intake water treatment;
stsndards and/or charges applied to wastewater discharges to water bodies;
costs of handling water within the activity;
costs of different amounts of water recirculation within the activity;
physical layout of the plant, structure of the building, topography of plant site;
technologies -- of unit processes and unit operations -- for producing the products and/or services (5)
product/service mix and characteristics of each product and/or service;
level of production;
operating rate, e.g., units processed or produced per hour;
qualities and prices of raw materials other than water, e.g., energy, chemicals, round wood;
unit values of outputs of products and services;
unit values of recoverable nonproduct outputs of materials and energy;
costs of different levels of materials and energy recovery;
unit values of byproducts which can be produced;
costs of different levels of solid residuals disposal, including sludge;
continuity of operations, e.g., continuous versus batch;
capital availability, which is a function of the nature of the financial structure of the individual activity, e.g., single-plant firm, multi-plant firm, nationalized firm, regulated firm, conglomerate;
costs of different degrees of in-plant liquid residuals modification;
subsidies available for in-plant liquid residuals modification, e.g., investment tax credit, low interest rate loans and rapid depreciation in tax computations for residuals modification equipment;
limits/standards imposed on discharges of gaseous residuals, e.g., requiring installation of wet scrubbers, cooling towers;
restrictions on qualities of raw material inputs, e.g., upper limit on % sulphur in fuel;
water user knowledge of alternative possible technological options for in-plant water utilization;
water user attitudes, e.g., "resource conserving", water conserving, attitude toward "housekeeping", e.g., how important efficient water use is conceived to be by the plant manager and how he implements that concern; empirical evidence shows that there is substantial difference in the behavior patterns of plant managers even among plants under the same ownership;

drought experience;
linkage with spatially separated activities;
existence of metering and frequency of billing;
physical limit on available intake water, e.g., overdrawn ground water basins;
occupational health and safety regulations, food safety regulations, food grading specifications;
heating demand, e.g., water demand for steam for space heat f (insulation, building design, thermostat setting, ...);
energy conservation practices, e.g., conserving hot water to reduce electrical energy use to heat water not only reduces water intake by the activity but also reduces cooling water demand for electrical energy generations;

deterioration of equipment, as a function of age and level of maintenance, e.g., even with the highest level of maintenance the heat rate of a power plant increases with time, so that more water is required per net unit of kwh output;
plumbing codes which specify types of lower water-using equipment to be installed in various types of buildings, e.g., automatic turn off valves, faucet flow reducers;
water pressure at the tap(s) of the individual activity, i.e., higher pressure, higher water demand;
household income, particularly in rural areas;
extent of on-site energy generation, in the forms of both electrical energy and steam;
product yield, i.e., the amount of product output produced per unit of raw material input;
weather, e.g., frequency distribution of meterological conditions.

The above factors can be classified in several ways. One way is shown in table 1.

Three types of observations with respect to the above factors are relevant. First, the fourth category in table 1, behavioral variables, merits special mention, because it is often overlooked. Water-using "behavior" of plant managers is conditioned by their attitudes, i.e., personal predilections and social values. Some plant managers have reputations for "good housekeeping", e.g., programs to encourage careful use of water by employees, a regular maintenance program to find and stop leaks and maintain pumps, installation of automatic equipment to control in-plant water flows. The importance of the behavioral variables varies from one industrial

Table 1. Classification of Variables Affecting Industrial Water Demands

VARIABLES DETERMINED EXOGENOUSLY TO THE ACTIVITY

1) Economic variables -- those whose values are determined in the national economy, either by markets or by governmental water authorities, e.g., prices of various production input factors such as electrical energy, fuel, water, other raw materials, interest rates

2) Political variables -- those whose values are established by legislative bodies, e.g., tariffs, import or export restrictions, limits on residuals discharges, ambient environmental quality standards, deglomeration regulations

VARIABLES DETERMINED ENDOGENOUSLY TO THE ACTIVITY

3) Technological[a] and micro-economic variables, e.g., production technology, costs of recirculation, materials recovery, by-product production technology, capital availability, product mix, product specifications

4) Behavioral variables, e.g., attitudes toward "housekeeping", such as temperature of rooms, temperature of hot water, toilet flushing, regular surveys for and repair of leaks

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[a] The decisions with respect to the technological options to be used within an activity are internal to the activity, or to the firm if the plant is one plant of a multi-plant or ministry. The technological options reflect technological developments/evolution in the activity category as a whole, and -- occasionally -- across categories.

activity to another, and over time. Where an activity is one unit of a multi-plant firm (ministry) the level of this factor is likely to reflect firm (ministry)-wide programs.

Second, several general comments on the above factors are in order. One, although all dimensions of water demand of an activity are interrelated and are simultaneously determined as a function of multiple factors, rarely has this simultaneity been recognized explicitly in the analysis, by agency water quality managers, of water demands of individual activities. Two, rarely have many of the interactions among the various factors cited above been recognized. Three, the physical (technological) options for responses to the set of factors by an activity are usually more limited for an existing plant/facility/activity than for a plant being planned. Four, the values of many of the factors affecting water demand are location -- region/municipality -- and site specific. Five, some factors, such as energy costs, affect all dimensions of water demand. Six, increases in prices of factor inputs other than water intake and liquid residuals discharges often have resulted in larger reductions in water intake and/or liquid residuals discharges than have increases in water prices. For example, the substantial increase in energy prices in the United States since 1974 has had, in many cases, greater effects on industrial water demands than effluent or user charges, effluent standards, intake water prices. In general, increases in the prices of raw materials other than water, e.g., wood fiber, chemicals, electric energy, fuel, have stimulated increased materials and energy recovery, thereby decreasing the discharges of liquid residuals and also often decreasing water intake. (5)

The sixth point is illustrated by the white water system in a paper mill. Such a system is designed and installed when the plant is constructed to recover a certain amount of fiber from the white water, e.g., 70%. The degree of recovery chosen at the time is that at which the cost to the plant of the last increment of recovery equals the value of the last increment of recovered material, expressed in terms of original raw material input to the plant, i.e., round wood, chips, waste paper, some combination of inputs, or in terms of the input to the paper machine itself. As the price of round wood/chips/waste paper increases, even with the same prices of intake water and of wastewater discharge, at some price level it will become economic to install facilities for additional fiber recovery. This in turn will result in decreased water intake demand, a decreased demand for wastewater disposal, and a decreased content of suspended solids in the wastewater discharge.

Third, the factors -- product output characteristics and technology -- merit special mention.

Product Output Characteristics

The characteristics of the products produced by an industrial activity, along with product mix, comprise one of the most important factors affecting all dimensions of industrial water demand. For example, wet strength, basis weight, brightness, are characteristics specified for so-called consumer paper products, e.g., towels, tissues, napkins. The more stringent and exacting the product specifications, the larger the water demand per unit of product. A simple example is displayed in table 2, which shows the quantities of residuals generated in the production of one ton of white tissue paper (GE brightness of 80-82) and the quantities generated in producing one ton of unbleached tissue paper (GE brightness 25), using the same raw material and pulping process, and having all other product characteristics the same. Because an high level of bleaching is required to achieve the higher brightness , and because bleaching is an highly water and energy intensive process,

Table 2. Residuals Generated in Producing One Ton[a] of Tissue Paper[b]

	Standard Brightness (GEB 80-82)[c]	Unbleached (GEB 25)
	All values in pounds per ton	
Gaseous		
Chlorine	1.2	0
Chlorine dioxide	0.6	0
Sulfur dioxide[d]	5.6/20.0[e]	5.1/7.0[e]
Hydrogen sulfide and organic sulfide	25.5	23.2
Particulates[d]	57.5/1.0[e]	52.4/0.3[e]
Liquid		
Dissolved inorganic solids	263	22
Dissolved organic solids	244	41
Suspended organic solids	113	107
Suspended inorganic solids	4.5	4.1
Five-day biochemical oxygen demand	147	31
Solid		
Inorganic solids	82.0	73.7
Organic solids	0	0

[a] Output is as air-dry paper (6% moisture), equivalent to 1880 pounds on a bone-dry basis.

[b] From softwood, using kraft (sulphate) pulping process, with no constraints on discharges.

[c] Using CEHD bleaching sequence.

[d] 1% sulfur fuel oil assumed for use to generate heating steam and electrical energy for plant use.

[e] First figure relates to production process, second to fuel combustion.

Source: Kneese, A.V. and Bower, B.T., 1979, Environmental quality and residuals management, Johns Hopkins Press, Baltimore, Table 2, pp. 65-67.

the higher product specification -- solely for appearance -- results in a substantially increased demand for water, both directly and indirectly, the latter with respect to energy generation. Even paper industry experts think that some, perhaps many, of the brightness specifications with respect to consumer products, publication papers, packaging, and many specialties are excessive, in some cases even counterproductive. (6) Some performance specifications for some paper products may also be excessive in relation to uses for which the products are intended. (7)

Technology

It should be emphasized that the three elements of a production activity are integrally interrelated: (a) raw material; (b) production technology (the set of unit processes and/or unit operations); and (c) product outputs with specific characteristics. To produce a product with certain characteristics limits the types of raw materials and production technology which can be used to produce it. Or, the objectives of producing multiple products and of recovering nonproduct materials will limit the possible production technologies which can be used.

Two points with respect to technology in the context of analysis for water quality management in industrial areas merit emphasis. One, because most activities involve sets of unit processes and unit operations, all of the unit processes/operations in any given industrial plant need not be -- in fact, are seldom likely to be -- at the same "level" of technology, e.g., old/new, conventional/advanced. Often one unit process or unit operation can be replaced or modified without significant changes in the other unit processes and operations. All units of an industrial activity are likely to be in "synchronization" with respect to level of technology only at the very beginning of operation after construction is completed. Much technological change is incremental; one process in a production line is changed, or one line of multiple lines is changed at one time.

Two, there is a continuum with respect to the time required for technological changes to be installed, abstracting from any capital availability problems of the individual plant (enterprise, firm) and from any problems of availability of equipment and of installation capability. There are those technological changes which can be made in a few months -- in some cases in even less time -- such as changing the catalyst used in the production of a chemical, or the installation of a recirculation pump and pipe on a fluming operation in a cannery. At the other end of the continuum are those technological changes involving large capital investment and relatively long installation time, such as a shift from open hearth furnace to a basic oxygen furnace in steelmaking, or from ingot casting to continuous casting.

Analysis of industrial water demand can be aided by subdividing technology into classes relating to the elements of production. Table 3 represents one attempt to develop a classification of technology. (8) It is included solely to help in suggesting that estimating the effects of technological change on water demands can best be done by first identifying where any given technological change fits in the total production system. Some technological changes or combinations of technological changes will result in increased demands for water and related natural resources, others in decreased demands.

SOME FACTS OF LIFE

Integral to developing an efficient and effective water quality management strategy for an industrial area is a recognition of some basic facts of life. Several of these are identified and discussed.

Table 3. Classification of Technology

Technology of "raw" materials development/processing	
Examples:	genetic development of "giant" trees, genetic development of fruits with desired properties, e.g., suitable for canning; pelletizing ores; car shredders; intake water treatment processes
Technology of "basic" production	
Examples:	steel making--open hearth, basic oxygen furnace, electric furnace, ingot casting, continuous casting pulp manufacture--sulphate, magnefite (magnesium sulphite), refiner groundwood; oxygen bleaching logging--drag by tractor, high-line, ballon agricultural production--monoculture, multiple cropping; dry, irrigated; artificial fertilizer, natural fertilizers; synthetic pesticides, biological pest controls; conventional tillage, minimum tillage energy generation--solar, wind, geothermal, fossil fuel steam, ~~nuclear steam~~ fish production--natural water bodies, hatcharies, aquaculture
Technology of materials recovery	
Internal processes and/or operations	
Examples:	chemical recovery in sulphate pulping; recirculation of flume water for conveying peaches in canning peaches; heat exchangers
Processes/operations at "end-of-pipe"	
Examples:	lime particulate recovery by venturi scrubber from lime kiln of sulphate pulp mill; fiber recovery in white water system associated with paper machine
Technology of byproduct production	
Examples:	industrial yeast from sulphite pulping waste liquor; pet food from tomato pulp; animal feed from cheese whey; candy from citrus peels; glue from pulp mill primary sludge
Technology of residuals handling before processing or modification (other than of volume)	
Examples:	facilities for separation of solid residuals at the point of generation, i.e., paper residuals in an office building; compactor units for solid residuals for use in apartment buildings; solid residuals collection equipment; baler

continued...

Table 3. (continued)

Technology of residuals modification
To produce raw materials and/or energy
Examples: stripping used wire; removal of impurities from obsolete steel products; power plants to use mixed solid residuals as component of fuel; generating methane gas from manure; air classification for sorting mixed solid residuals
No materials or energy recovery
Examples: polymers for conventional sewage treatment; irrigation with sewage effluent;[a] oxidation ditches
Technology of instrumentation
Examples: digital computer control of manufacturing processes/operations; continuous monitoring of quantity and quality of fluid flows
Technology of sludge disposal
Examples: composting; application in liquid form to land

[a] Nutrient recovery can be considered to occur where crops are grown or livestock grazed on land irrigated with the effluent.

INTERRELATIONSHIPS AMONG RESIDUALS

No activity -- manufacturing process, residential activity, agricultural operation -- transforms 100% of inputs into desired products and services. There is always something "leftover", i.e., residuals which must be disposed of in some manner. Most often disposal is to one or more of the environmental media: water, air, land.

Material and energy are the two classes of residuals. The three forms of material residuals are liquid, gaseous, and solid; energy residuals include heat, noise, light, vibrations, and certain forms of radioactivity. One form of material residual can be transformed into one or more other forms, or different types of the same form. Thus, a liquid residual may be converted into another type of liquid residual plus a gaseous residual plus a separated "solid" residual to be disposed of in a water body, in the atmosphere, and on land, respectively. A solid residual may be transformed into liquid, gaseous, and other solid residuals. The modification of a residual into other forms requires material and energy inputs which themselves become residuals. Modification is undertaken under the assumption that the discharge of the set of residuals resulting from modification will have fewer adverse effects on ambient environmental quality than the discharge of the original residual.

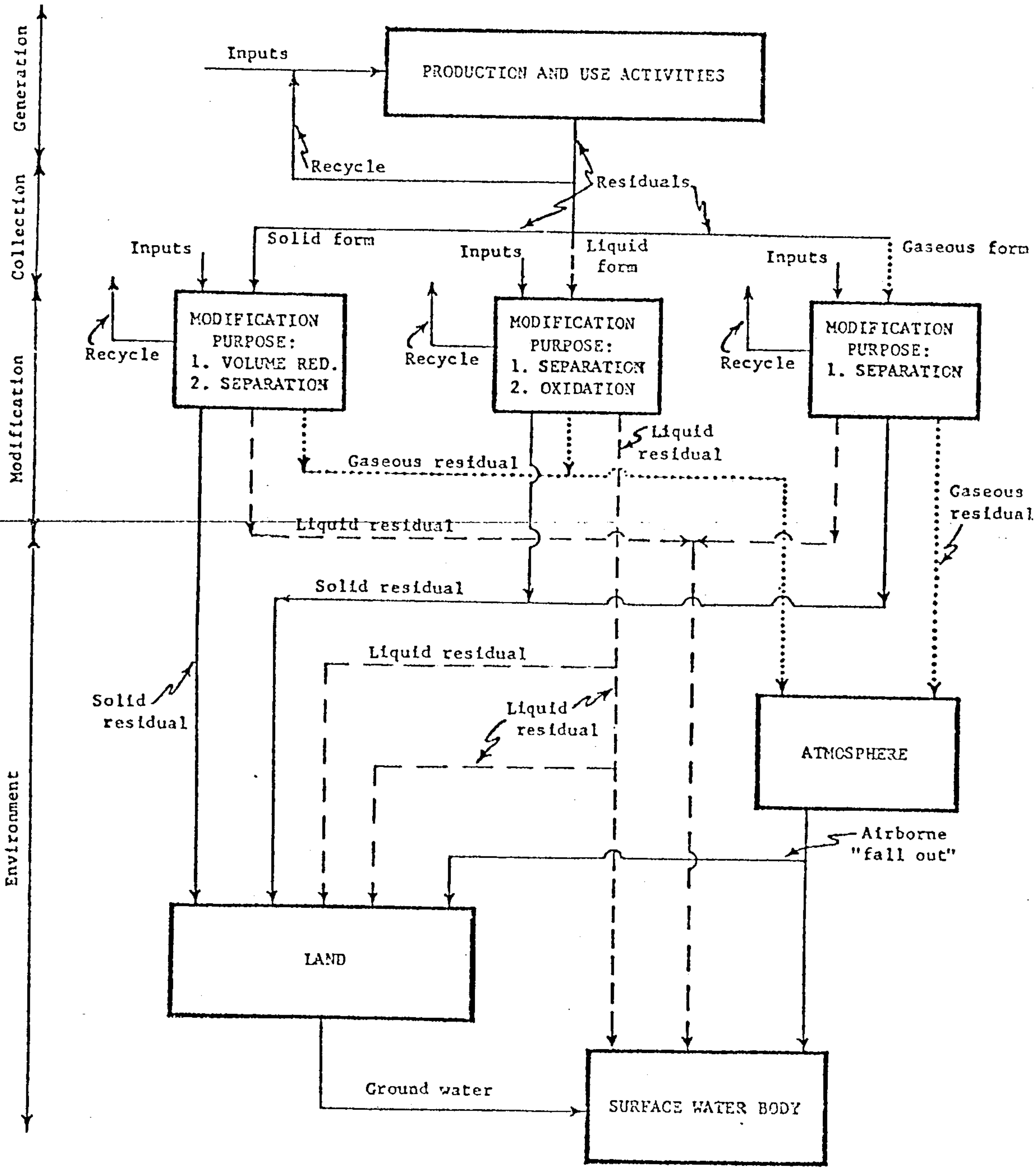
Thus, modification of sewage in a sewage treatment plant results in the generation of a semi-solid residual, sludge, plus various types of liquid and gaseous residuals. If the sludge is incinerated, gaseous residuals such as particulates are generated. If the sludge is placed in a landfill, there may be seepage of residuals into ground or surface water bodies. Finally, because virtually all residuals modification requires energy inputs, additional gaseous, liquid, and solid residuals are generated in fuel combustion to produce energy for residuals modification. Thus, conventional waste treatment increases the total quantity of residuals discharged into the environment. Figure 4 illustrates interrelationships among the three forms of material residuals.

The residuals originally generated by an activity are termed primary residuals, i.e., they result from a set of one or more unit processes and/or operations to produce a good, a service, or utility. Secondary residuals are generated in the handling and/or modification of primary residuals. Tertiary residuals are generated in the handling and/or modification of secondary residuals, and so on.

VARIABILITY OF DEMAND

There is large variability from day to day, and even from hour to hour, in water intake and in the generation and discharge of liquid (and gaseous,solid) residuals from individual industrial activities, even under normal operating conditions. Rarely -- if ever -- is there an activity in which water intake and/or residuals generation and discharge -- per unit and total -- is constant over time, in the short-run and in the long-run. For example, in residences there are diurnal, weekend, and seasonal fluctuations in water intake and residuals discharges representing different activities that occur at different times of day, week, and season. These are reflected in the time pattern of discharges from municipal sewage treatment plants. Similar short-run fluctuations in residuals generation and discharge occur in industrial, commercial, institutional, and transportation activities. Figures 5, 6, and 7 illustrate this variability for industrial activities. Figure 5 shows the daily variation in water intake for a fruit and vegetable cannery in California. Figure 6 shows the

Figure 4. Interrelationships Among Forms of Residuals



Abbreviation: Red. , reduction.

Figure 5. Daily Variation in Water Intake for a Fruit and Vegetable Cannery in California

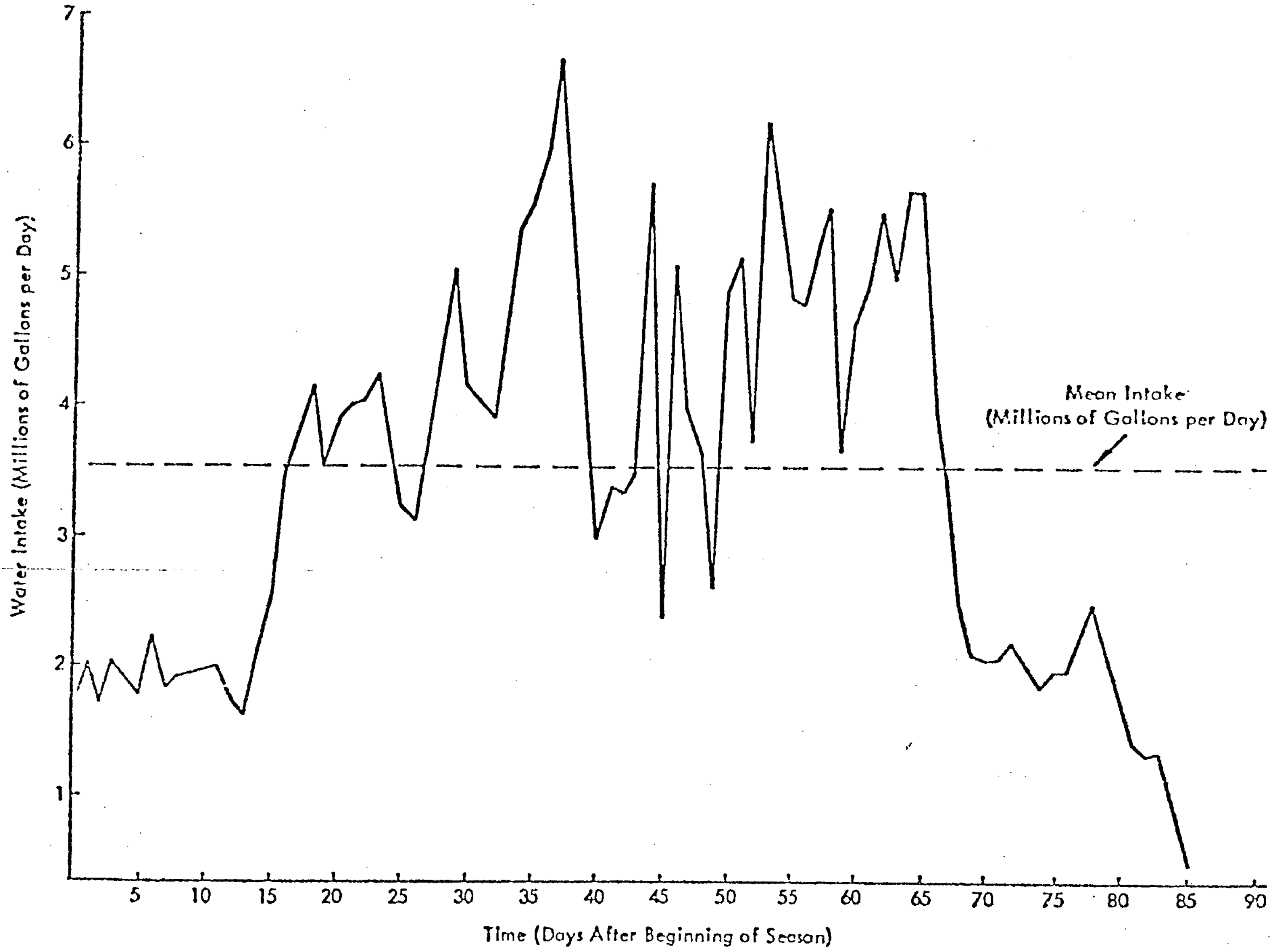
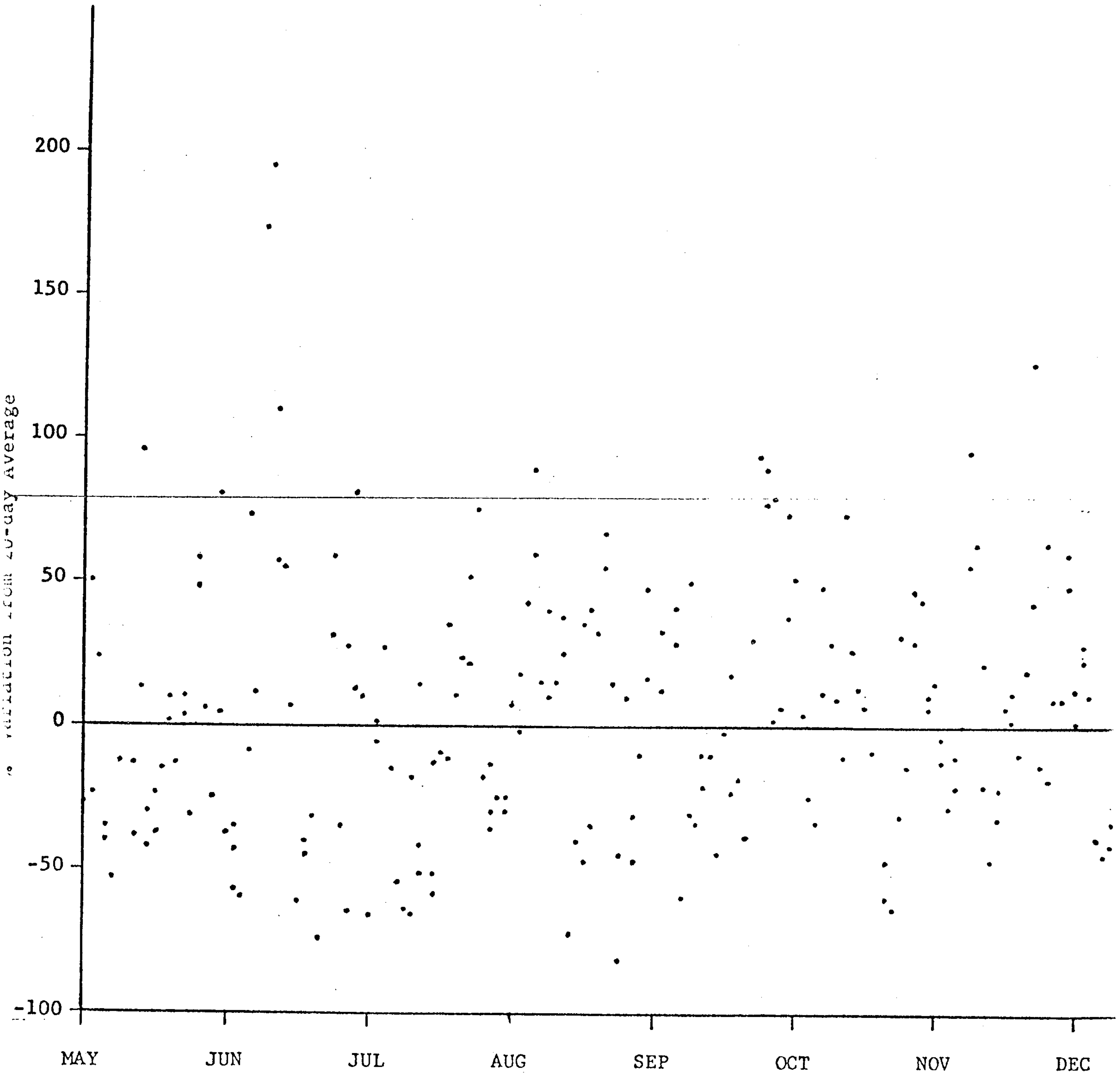


Figure 6. Variation in Suspended Solids Discharge from Secondary Clarifier of Integrated Pulp and Paper Mill*, Percent Variation from 20-day Average



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* Bleached ground wood and bleached kraft pulping; mill located in north central U.S.

variation in suspended solids discharge from a modern integrated pulp and paper mill. Figure 7 shows cumulative distributions of residuals discharges from two industrial activities.

In manufacturing activities at least six types of conditions occur which result in short-run variations in water intake and/or in residuals generation and discharge: (1) start-up/shut-down of production processes; (2) cleanup operations; (3) upsets during production with no halt in production; (4) breakdowns such that production ceases; (5) accidental spills; and (6) variations during "normal" production operations. The reasons for the first five types of short-run variations are obvious.

Variations during "normal" production operations can be subdivided into: less than daily and day-to-day variations; less than seasonal production cycle variations reflecting changing demand and product mix; and seasonal variations. Some of the factors that result in variations within the day and from day-to-day during normal production operations include:

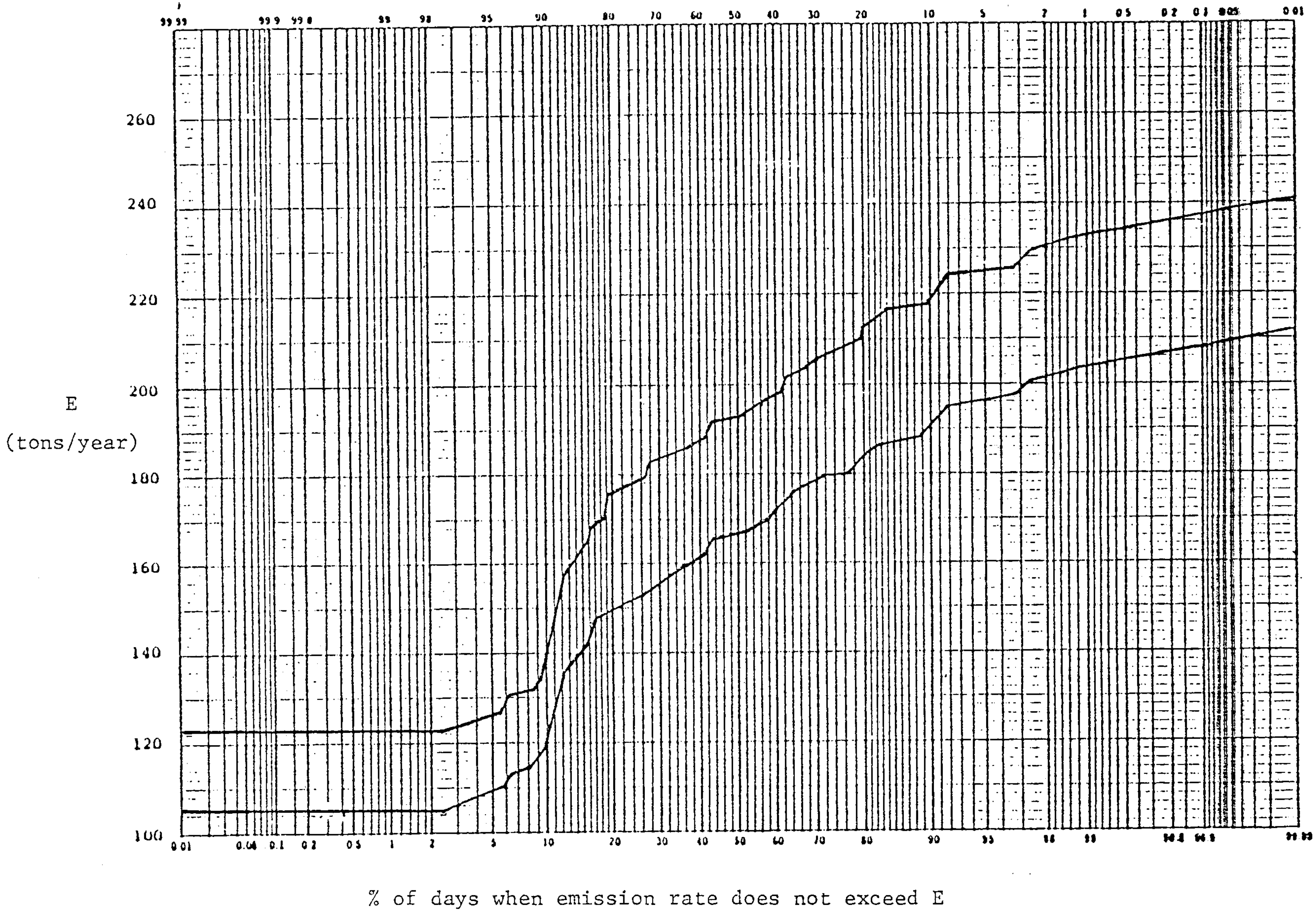
a. variation in quantity and quality of raw material inputs, e.g., inflow of raw vegetables from different sources in canning operations, the quality of wood chips in paper manufacture;

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, "pushing" a production unit (power plant, paper mill) beyond design capacity for short periods;

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 and water withdrawal per unit gradually increase 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 per unit; and

d. variation in production level and product mix, e.g., product mix in a tomato cannery (canned tomatoes, tomato paste, tomato juice) can vary from hour to hour; similarly, a

Figure 7. Cumulative Distributions of Residuals Discharges from Two Industrial Activities



> 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 water withdrawals, residuals generation, and residuals discharge.

With respect to the fourth, table 4 illustrates the variation in rate of production in one industrial plant. This degree of variation is more normal than abnormal. Various combinations of conditions resulting in variation in liquid residuals discharges from an industrial activity are shown in table 5.

It is important to emphasize that tradeoffs are slmost always possible between increasing production in an industrial activity and water demand. For example, on a modern Fourdrinier paper machine, the standard procedure increasingly is to make grade changes without stopping the machine. This means that for some period of time all of the output is wasted to the broke system -- to be returned subsequently to the paper machine -- and all water used provides no product output. In total, change of grade probably is responsible for more water use in this context than dry end breaks. For example, for a product output of 480 tons per day, or 20 tons per hour, a 15-minute grade change would involve on the order of 5 tons of broke. At 6% moisture off the machine, the amount of water to dilute the paper to one quarter of one percent consistency is about 500,000 gallons. This represents a significant increase in total daily water demand over a production procedure which would shut down between grade changes. But shutting down is more expensive than the additional water used.

In addition to the within day and day-to-day variations in water demand, definite seasonal patterns exist for some industrial operations, as illustrated in table 6 for three types of canneries. These seasonal variations often exhibit some regularity, in that certain activities take place

Table 4. Variation in Rate of Production in One Industrial Plant

Percent of Days	Production Rate pounds per day
10	1170
20	990
40	900
20	810
10	630

Percent of Hours	Production Rate pounds per hour
10	174
20	139
40	116
20	93
10	58

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

Source: Ginberg, P. and Schaumburg, G.W., Jr., 1979, Economic incentive systems for the control of hydrocarbon emissions from stationary sources, Report to Council on Environmental Quality, Meta Systems Inc., Cambridge, Table 25, p. 104.

Table 5. Combinations of Conditions Resulting in Larger Than Normal Discharges of Liquid Residuals from an Industrial Activity

Production Process Event	Condition of Physical Measure for Emission Reduction	Remarks Regarding Frequenty and Magnitude of Excess Emission(s)
Upset (not planned)	Normal operation	Design load on physical measure exceeded because upset results in much larger than normal residuals generation.
	Breakdown	Probability of breakdown occurring simultaneously with upset is probably low, unless excess load results in breakdown or clogging of physical measure.
	Scheduled maintenance	Probability of occurence depends on extent to which production is continued during scheduled maintenance of physical measure for discharge reduction.
Overloading (planned)	Normal operation	Design load on physical measure exceeded.
	Breakdown	Depending on nature of production activity and type of technology, overloading may occur with considerably higher frequency than upset. Result is similar, except that excess loading is usually much smaller than with upset.
	Scheduled maintenance	Probability of occurrence depends on extent to which production is continued during scheduled maintenance of physical measure.
Normal Variability	Normal Operation	Frequency of occurrence depends on complexity of production process, variability in raw material quality, frequency of change in product mix.
	Breakdown	Frequency of occurrence is greater than for overloading. Result is similar; excess loading is usually much smaller than with upset.
	Scheduled maintenance	Probability of occurrence depends on extent to which production is continued during scheduled maintenance of physical measure.

Table 6. 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)

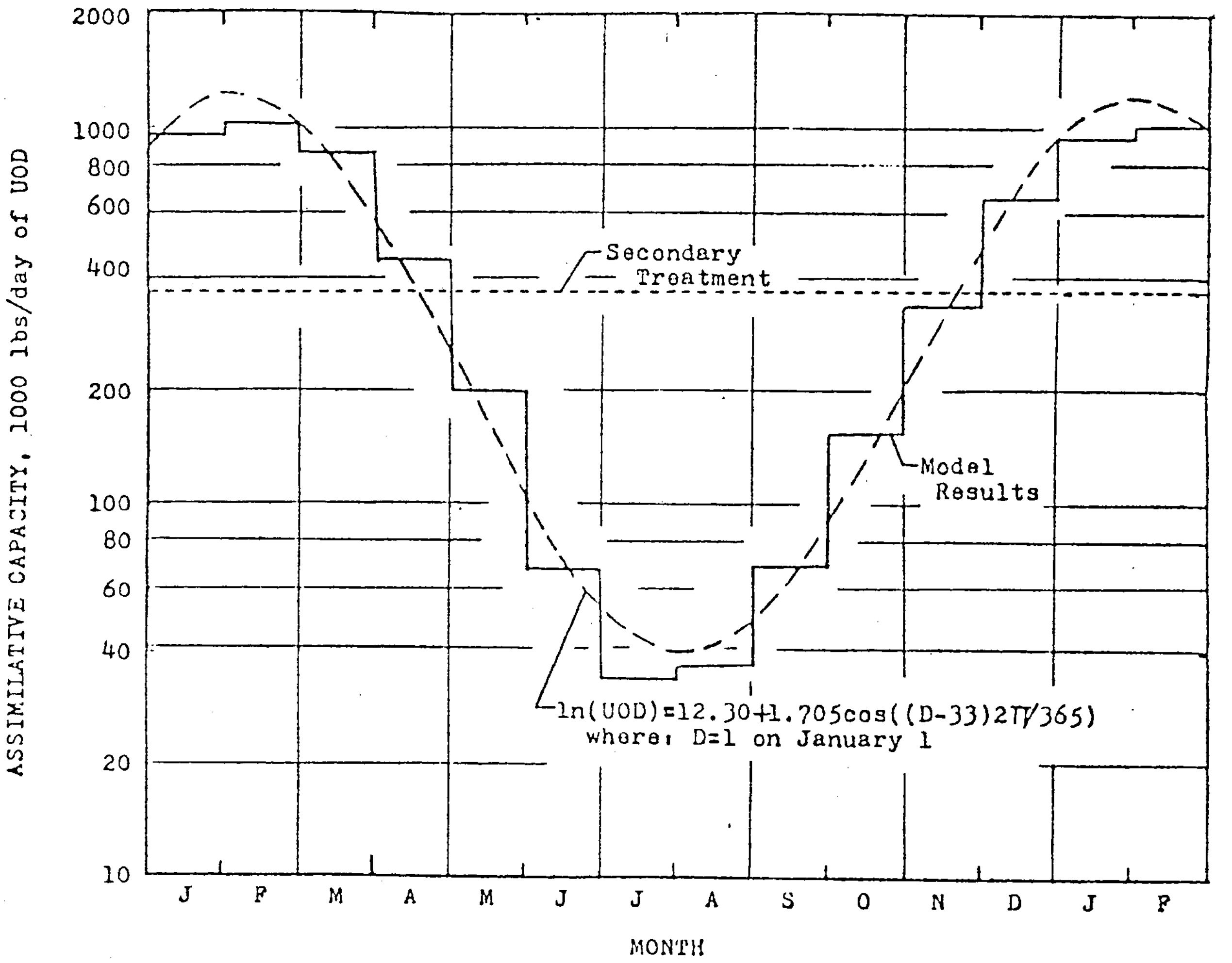
Source: Bower, B. T., 1966, Water utilization in canning, Paper Presented at 59th Annual Convention of The National Canners Association, Harbour, Florida each year during a certain season, although the specific beginning and ending dates and levels of activity can vary from year to year. One example consists of the times when the product mix in a petroleum refinery shifts from more fuel oil to more gasoline in the spring and back in the fall, depending on the weather. Where steam is used for space heating in an industrial activity, whenever space heating ceases for the year, the withdrawal of water for steam for space heating ceases. Water demand for cooling obviously varies by season, as a function of ambient temperature.

Of course, in addition to the variability in water intake and residuals generation and discharge, the assimilative capacity of water courses varies by season, as illustrated in figure 8. The two types of variability compound the problem of achieving desired ambient water quality targets in industrial areas.

EXOGENOUS FACTORS

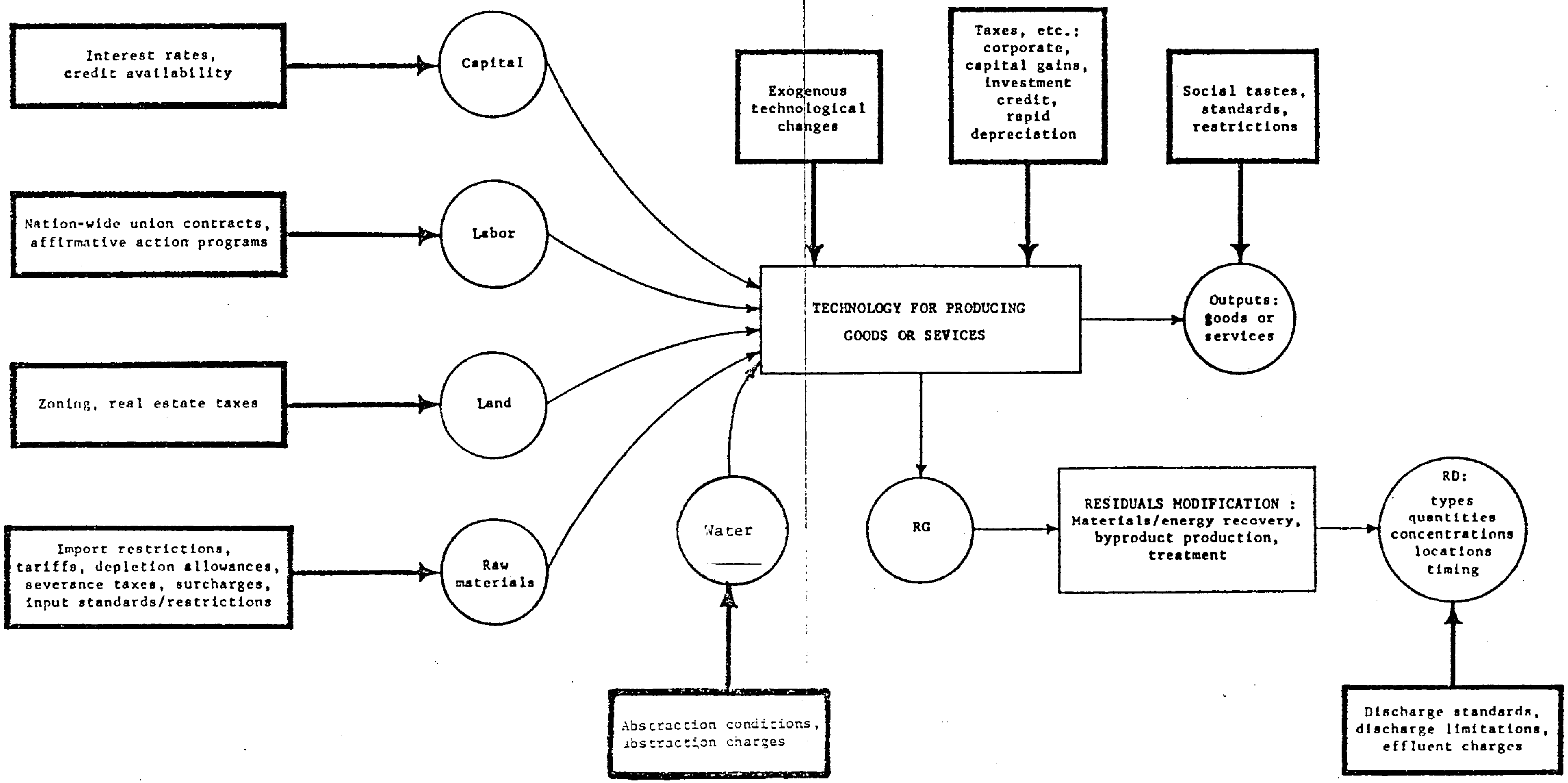
Decisions with respect to water resources management at the level of the individual activity -- the water user -- are affected by many decisions and factors exogenous to the activity, over which the activity has no control and which are often not related directly to water. That is, the decision with respect to the value, price, magnitude of this type of factor is essentially outside the control of the decision makers of the activity. Examples include: prices of energy, water, fuel, and of other raw material inputs, i.e., chemicals, ores, secondary materials; tax policies; freight rates; tariffs; import, export restrictions. These factors influence decisions on the degree of internal water recirculation and the levels of materials and energy recovery and byproduct production which would take place in the absence of any constraints on water withdrawals and/or residuals discharges to the environment. Some of these factors are illustrated in figure 9.

Figure 8. Seasonal Variation in Assimilative Capacity of the Potomac Estuary



Source: Flaherty, T., 1980, The Environmental Defense Fund's Potomac Estuary Project, Paper presented at Annual Meeting of the Interstate Commission on the Potomac River Basin.

Figure 9. Examples of Exogenous Factors Affecting Water Demand and Residuals Generation and Discharge by Individual Activities



Note: Rectangles with darkened borders represent exogenous factors.
Rectangles without darkened borders represent sets of unit processes and operations within the activity.
Circles represent represent inputs and outputs.

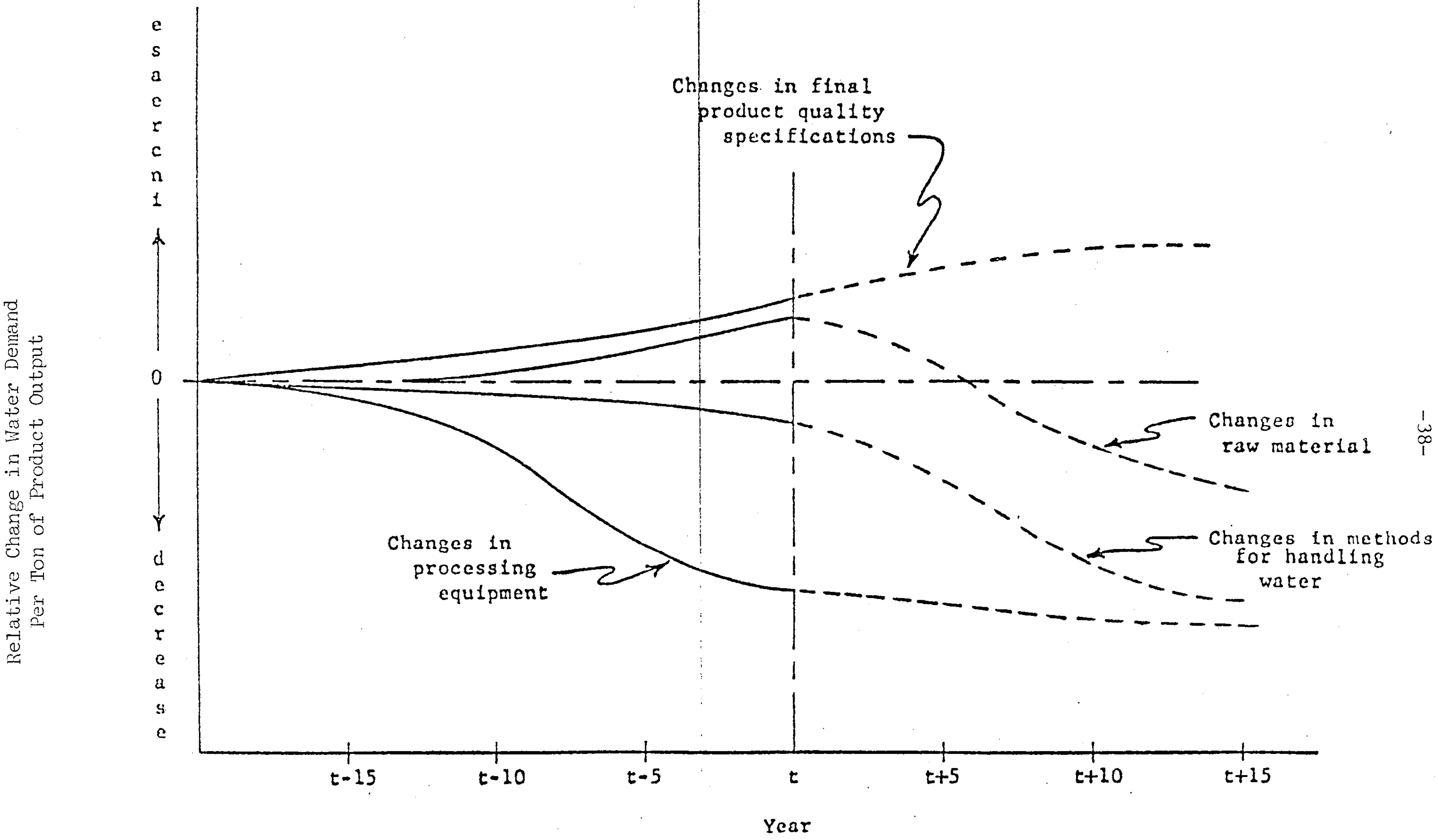
Abbreviations: RG, residuals generated; RD, residuals discharged.

It should be emphasized that many of these factors are not under the jurisdiction of water resources management agencies, as well as not being directly related to water. Tax provisions represent one prime example. The objectives of the finance ministry in establishing taxes, tax procedures, tax incentives are to raise revenues, to stimulate investment, and/or to redistribute income. They are not directed toward water resources management. (9) Further, there may be several links in the "chain" of effects before arriving at water demand. For example, increases in postal rates for magazines stimulated a demand for lower weight publication grade paper. This resulted in changed product output characteristics and hence changes in raw material-production technology combinations and hence in water demand.

DYNAMIC CONTEXT

Water resources management takes place in a dynamic context. There are continual changes in societies in: technology; factor prices; product mix; product characteristics; governmental regulations; social tastes. Failure to understand -- or at least to recognize the existence of -- the impacts of these changing factors can lead to unanticipated impacts on water resources management. For example, technological change is stimulated by: (1) changes in factor prices, e.g., raw materials, labor, capital; (2) research and development (R&D) on technological processes/operations; (3) R&D on new products, which can induce changes in production technology and raw materials; (4) R&D on new raw materials; (5) suggestions from sales departments; and (6) exogenously imposed restrictions, regulations, charges on raw materials, product specifications. Thus, technological change takes place as a result of the interaction of multiple factors, including various types of governmental actions. Figure 10 illustrates, qualitatively, the

Figure 10. Estimated Impacts of Various Technological Developments on Water Demand in Fruit and Vegetable Canning in the United States.



Note: t = present (1980) ——— = actual - - - - - = projected estimated impacts of technological developments on water demand in fruit and vegetable canning in the U.S.

Even where technology in a given industrial plant remains "the same", water demand in terms of water intake and/or wastewater discharge is likely to change over time as a result of deterioration of equipment, even with good maintenance. For example, the heat rate of a power plant increases over time, thereby requiring more water for cooling for the same net energy output. The chippers in a pulp/paper mill become dull, increasing water demand and residuals generation per unit of output.

WATER QUALITY MANAGEMENT IN INDUSTRIAL AREAS

THE NATURE OF WATER QUALITY MANAGEMENT

Water resources management is comprised of the totality of functions/ tasks required to produce water and water-related goods and services. Water resources management can be considered a production function which transforms the quantity, quality, time, and location characteristics of surface and ground water resources into the quantity, quality, time, and location characterists of the desired outputs, e.g., irrigation water, hydroelectric energy, water-based recreation opportunities, flood damage reduction, municipal water, industrial water, navigation possibilities, fish biomass. Water quality management is a component of water resources management. As such it involves a set of tasks the objective of which is to achieve and maintain whatever levels of ambient water quality are desired, within whatever constraints may exist in any given context. For example, there may be constraints on: total costs; the distribution of costs; the timing of physical measures to be installed; meeting production levels for other outputs, e.g., hydroelectric energy, the production of which can adversely affect ambient water quality. The ambient water quality standards may be explicit or implicit. In both cases they usually are established in relation to the uses of the water bodies.

The functions of water quality management include: data collection; research; analysis to generate information for selection of water quality management strategies; planning, i.e., the process of selecting a strategy; design and construction of facilities; operation and maintenance of facilities; forecasting quantity and quality of streamflows; forecasting quality of lakes and ground water bodies; monitoring water withdrawals, wastewater and residuals discharges, and ambient water quality; providing quality control of laboratory analyses; inspecting facilities; setting of regulations, standards, charges, constraints on withdrawals and discharges; imposing implementation incentives on activities; collecting fees/charges; imposing sanctions for non-compliance with standards/regulations/procedures; training operators, laboratory analysts, inspectors; and continual evaluation of performance of facilities and effectiveness of implementation incentives to feedback resulting information into analysis and the process of selecting a strategy. It is the carrying out of this total set of tasks which results in the desired product of ambient water quality.

Because the focus is on management, the geographic context must be for some areal unit for which management activities can be undertaken by duly constituted governmental agencies. Although in most countries all layers of government perform at least one or a few of the activities, the day-to-day activities are performed primarily at the local/regional level. As noted previously, the region can be a county, a soil conservation district, a metropolitan area or a multi-county or multi-gemeinde district, or some combination of local jurisdictions. Often political boundaries will not coincide with water quality problem areas, with river basins, or with economic regions. However, experience indicates that it is less important that the boundaries of the water quality management region include all of the residuals dischargers and all those affected by changes in ambient water quality, than it is that the boundaries represent some area for which there is an institutional arrangement which is directly responsible for water quality management.

The "operating function" is particularly critical in water quality management in industrial areas. That is, at any point in time in a given management area, a system of physical facilities exists, such as surface water reservoirs, well fields, intake structures and raw water treatment facilities, waste treatment plants, in-stream aerators, spray irrigation systems for disposal of wastewater. Associated with this system of facilities and with the ultimate users of water and water-related products and services produced by the system is an "operating procedure". An operating procedure is a set of rules for: withholding water in and releasing water from surface and ground water reservoirs, operating in-stream aerators, closing and opening valves/gates/diversion structures, cleaning debris basins, and prescribing/proscribing behavior of water users during other than normal conditions. Thus, operating procedures must be specified for four types of conditions: (1) "normal" water; (2) excess water (flooding); (3) shortage of water; and (4) spills, e.g., spill of toxic material into a stream as a result of faulty valve, incorrect procedure, accident. To be able to develop efficient and effective operating procedures, the water quality management agency must have detailed understanding of the "water management behavior" of the major individual activities in its area. This is part of the analysis task discussed in the next section.

ANALYSIS FOR WATER QUALITY MANAGEMENT

The analysis task in water quality management is central to the development of water quality management strategies. Operationally, analysis can be divided into the following segments: (1) estimating levels and spatial pattern of activities in the management area; (2) analyzing water demands of activities; (3) analyzing effects of wastewater and residuals discharges on natural systems and subsequently on receptors; (4) formulating and analyzing water quality management strategies; and (5) developing criteria for, and evaluating, water quality management strategies. Discussions of each of the first three, and short descriptions of the last two, follow.

Estimating Levels and Spatial Pattern of Activities

An analysis for regional water quality management must begin with estimates of level of population, related demographic characteristics, and levels of economic activities, distributed in space within the region for each of the time horizons of interest. The spatial pattern of activities refers to the characteristics of the distribution of human activities over the landscape, e.g., dispersed/concentrated, linear/nodal, density, relationship between land capability and land use. The spatial pattern of activities is an important factor affecting water demand. The spatial pattern directly affects losses at both "ends" -- water distribution and wastewater collection -- via exfiltration and infiltration, and the pressure required to serve the periphery of the water distribution system. The lower the density, i.e., the more dispersed the activities, the greater the lengths of water and sewer pipes per capita, the higher the losses per capita, the higher the pressure and hence the higher the water demand per capita in the areas closer to the intake water treatment plants. (10) The spatial pattern also indirectly affects water demands, for example, because of impact on energy demand. An intensive study of energy use in the New York City region -- an area encompassing 31 counties in New York, Connecticut, and New Jersey -- showed that total net energy use per capita was inversely related to gross population density. (11) Lower energy demand means lower water demand for energy generation.

The spatial pattern of activities also directly affects the economics of water quality management. For example, if major water-using industrial activities are concentrated, it is likely to be more possible to develop collective water management facilities than if the industrial activities are dispersed. However, there may be disbenefits to spatial concentration of activities. Although there are economies of scale with respect to both the capital and operation/maintenance costs of water utilization facilities, water supply and wastewater, concentrating discharges in a single area may have larger adverse consequences on the aquatic ecosystem than if the same total load were discharged in a dispersed pattern. The consequences can be substantially aggravated when the large, regional plant malfunctions. Multiple, separate plants of equivalent capacity are not likely to malfunction simultaneously.

For present conditions, locations of various activities are based on information from a variety of existing sources within a region, such as local planning offices, property tax assessment bureaus, recent census reports, reports of state/provincial agencies. For future conditions -- time horizons and associated assumptions -- levels of economic activities for a region are usually derived from either disaggregating a macro (national) economic model or utilizing a regional projection model. Regional totals must then be spatially disaggregated, or allocated, to subareas within the region.

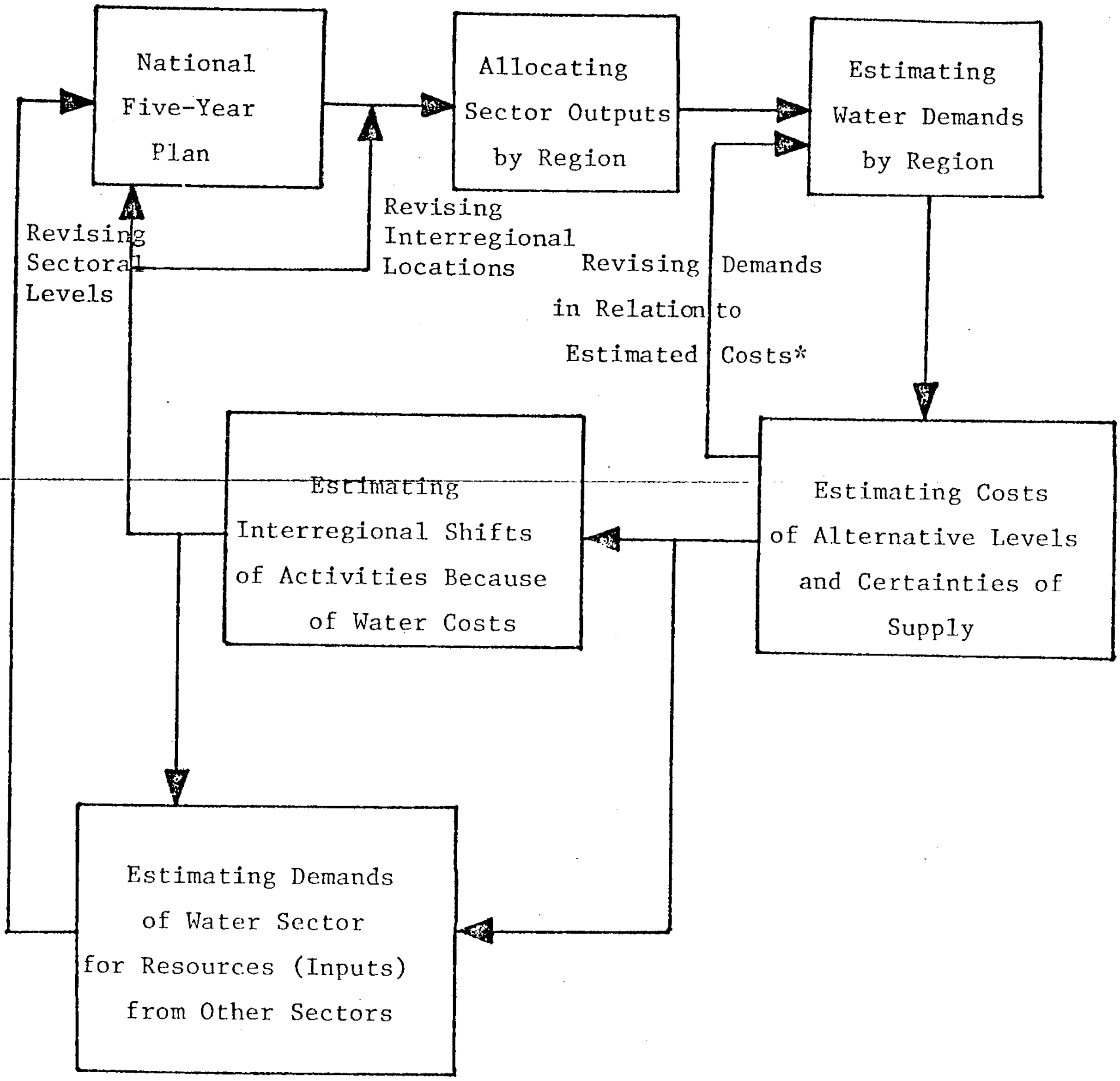
It should be emphasized that the estimation of levels and spatial pattern of activities in an industrial area must be related to Raumplanung at the gemeinde and regional/provincial/state levels, and to national economic planning and economic projections. This is illustrated in figure 11. In the context shown, iteration begins at the local level, in terms of estimating the effects of estimated prices of water -- both supply and wastewater disposal -- on industrial water demands. If the prices are sufficiently high, water demands will be reduced, and lesser water system facilities will be necessary. (12) Iteration is also necessary among regions and between regions and the national level. With respect to the former, the effects of changing costs of water to activities on total production costs of the activities in a given region can result in interregional shifts of activities. (13)

It should also be noted that this segment of the analysis includes estimating levels of factor prices in the region and estimating changes in technology, for the time horizons of interest. The nature of the latter task was shown in figure 10.

Analyzing Activities

A manufacturing activity operates on one or more raw materials via physical, chemical, and biological transformations by use of capital equipment and inputs of human and nonhuman energy to produce one or more desired outputs. For each significant water-using and/or residuals generating activity an analysis of greater or lesser complexity is necessary. Such an analysis should:

Figure 11. Interrelationship Between Multi-Sector National Planning and Planning for Regional Water Resources Management



* Assuming full costs are incorporated in prices to users.

(a) indicate alternative combinations of factor inputs to produce outputs of products and services with specified characteristics;

(b) delineate, for different sets of prices of those factor inputs, the quantities and time patterns of water withdrawn from various sources and the types, quantities, and time patterns of residuals generated per unit of activity, e.g., per ton of steel produced, kilowatt hour of electrical energy generated, ton of corn produced;

(c) identify the various on-site and off-site collective physical measures available for reducing water withdrawals and for reducing the discharge of residuals from the activity into the environment;

(d) estimate the costs of the various physical measures, both in social (resource) cost terms and as the activity "sees" the costs; and

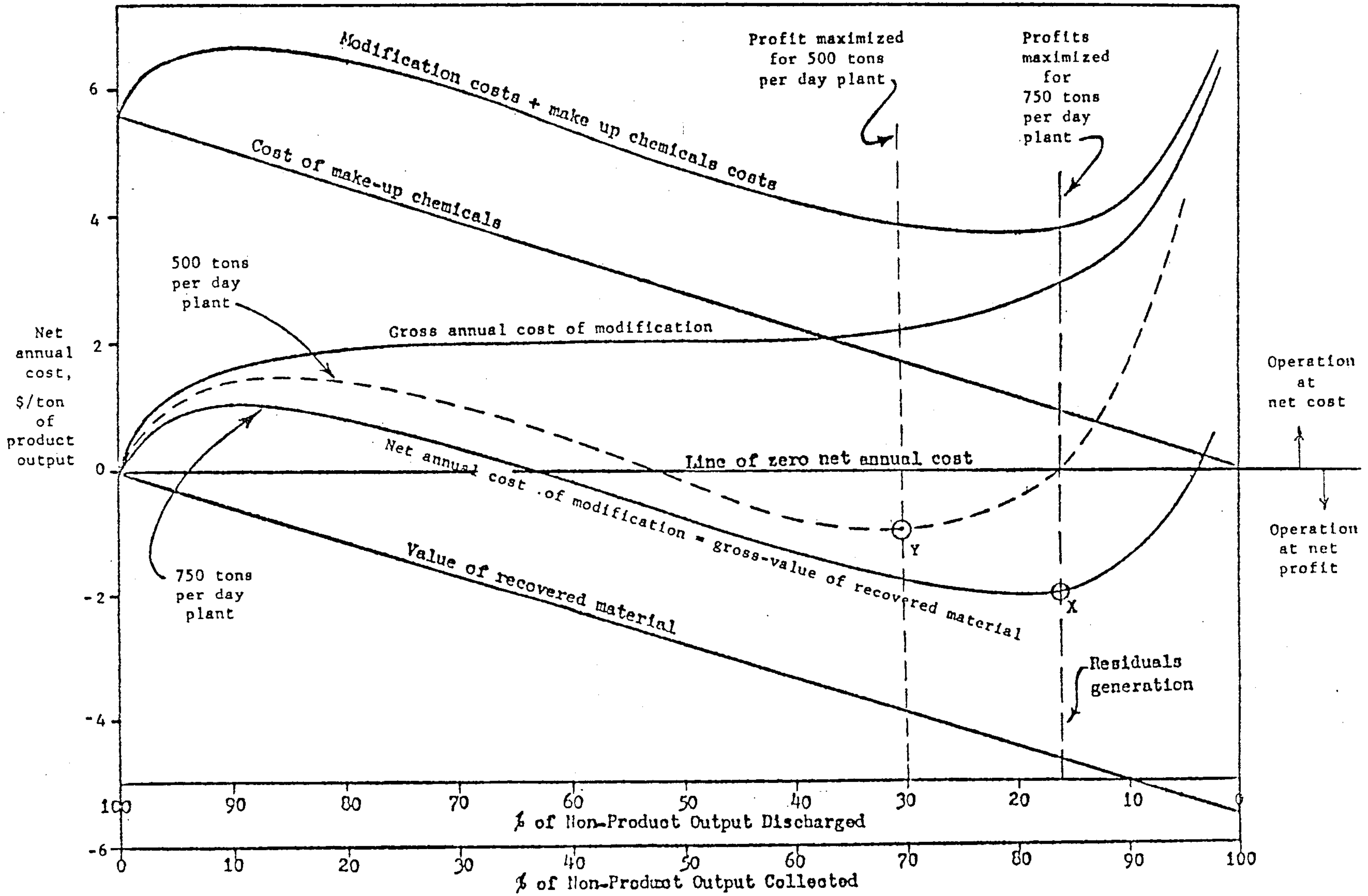
(e) identify possible implementation incentive systems which would induce a given activity to reduce the discharges of specified residuals. It should be emphasized that collective residuals handling, modification, and disposal facilities, e.g., materials recovery plants, sewage treatment plants, sludge disposal operations, are themselves water users and generators and dischargers of residuals, and therefore must be included in the population of possible activities to be analyzed in any given context.

As stated previously, no production activity can be designed for 100 percent conversion of inputs into desired outputs. The "nonproduct outputs" consist of: (1) nonproduct materials formed in production; (2) raw materials not transformed in production such as catalysts; and (3) nonused or nondesired energy outputs from the production activity. It is economically necessary in many, if not most, cases to recover and reuse substantial portions of the nonproduct outputs, both material and energy. The extent to which materials (energy)recovery is practiced at any point in time at a particular plant is a function of the relative costs of recovered materials (energy) versus new (makeup) materials (energy),the latter usually being purchased in the market or from another section of the plant at a price which may or may not be close to the open market price. (14) The costs of recovery are a function of the technology of the production activity and the technology of materials (energy) recovery. Trade-offs are possible between the design of the production activity to reduce the formation of nonproduct materials and energy and the extent of utilization of materials and energy recovery technology. In effect, the plant optimizes the combination of the set of unit production processes and operations plus the materials and energy recovery systems, in the absence of constraints on residuals discharges. When constraints of one type or another are imposed on residuals discharges, the "total system" is optimized -- production process, materials and energy recovery, residuals management measures.

The foregoing principles are illustrated in figure 12. This figure shows relationships between net annual costs and the extent of nonproduct material recovered (not discharged) for use in the same production activity. It reflects the assumption that new or makeup input material is purchased at a constant unit price. However, the cost of recovery varies nonlinearly, as shown.

Several points are suggested by figure 12. One, economies of scale are typical in materials and energy recovery technology and in byproduct production technology, as well as in basic production technology. As shown for the 750 tons per day plant, about 84% of the nonproduct material is recovered, as indicated by point X. This is the point of profit maximization

Figure 12. Relationship Between Net Annual Cost and Extent of Nonproduct Material Recovered for In-Plant Use

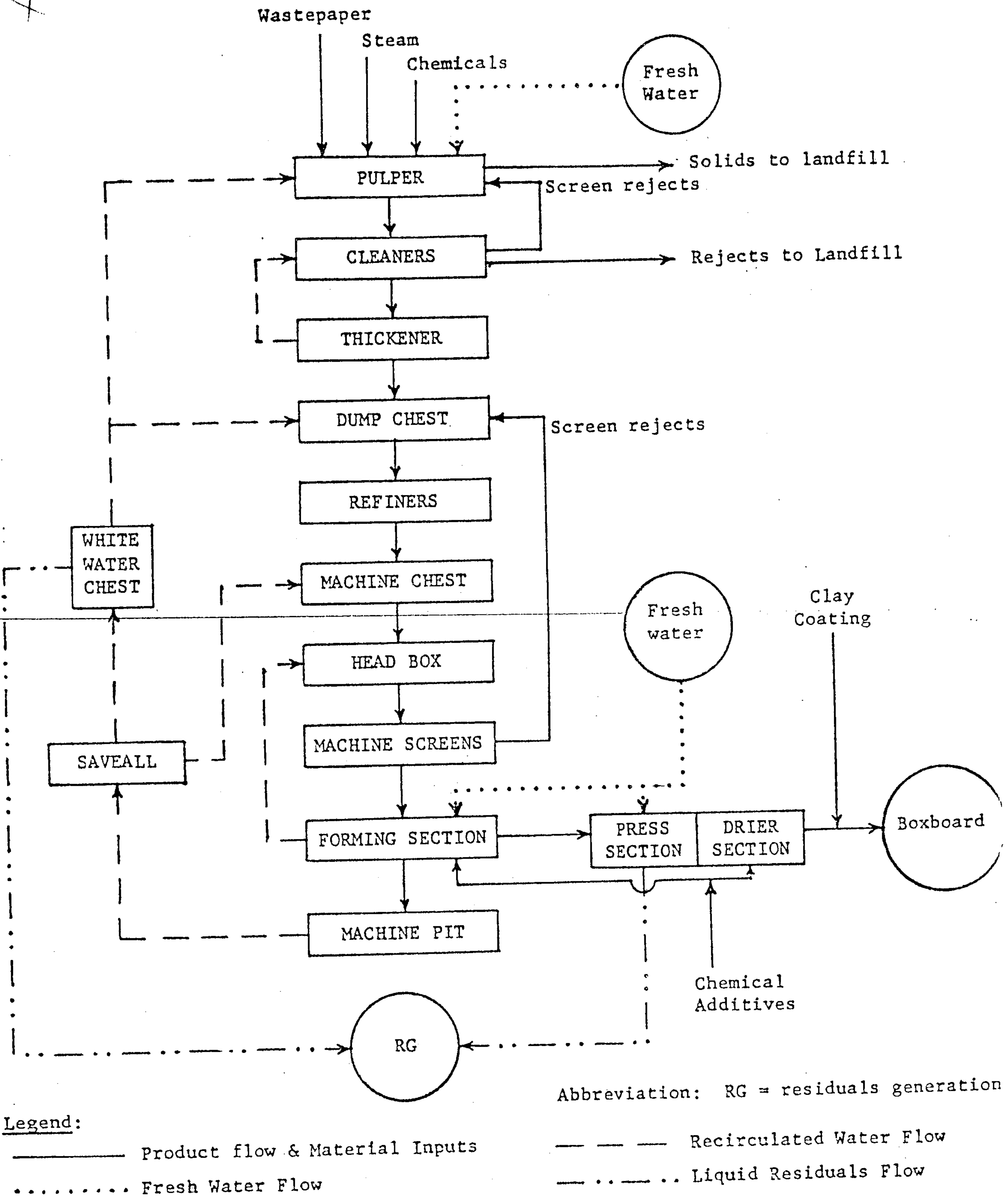


for the plant, and represents residuals generation. For the 500 tons per day plant, profit maximization and residuals generation occur at about 70% recovery. For both plants, if the constraints on residuals discharge required reducing discharge beyond that level, economic materials recovery might be the least expensive means of achieving that reduction. These economies of scale result in different water withdrawal and residuals generation per unit of output among plants of different sizes producing the same product with the same raw material-production system combination.

Two, the relationships shown in figure 12 are developed by: (a) starting with a detailed flow diagram of the production activity, as exemplified by figure 13; (b) making a materials and energy balance for each unit process/unit operation, to enable identifying the significant sources of the residual material of interest; and (c) identifying, and then estimating the costs of, alternative physical measures for reducing the discharge of the material from each of the significant sources. Costs must include any additional costs imposed throughout the production activity, such as increased energy costs and changes in capital equipment.

Three, care must be exercised in the analysis of water utilization costs in industrial activities. The available data for an existing plant typically do not differentiate between basic production costs and water utilization and residuals management costs. For example, most existing manufacturing installations have varying amounts of residuals modification facilities, which have been added over the years in response to various pressures for reduction in discharges. Further, neither the production process itself nor the residuals modification measures would likely be identical for the given plant, if a new plant were constructed at the same site with the same constraints and factor input prices.

Figure 13. Flow Diagram of Production of Boxboard from Wastepaper



Source: Modified from, Development Document for Effluent Limitation Guidelines and New Source Performance Standards for the Unbleached Kraft and Semichemical Pulp Segment of the Pulp, Paper, and Paperboard Mills Point Source Category, EPA 440/1-74-025a, US EPA, Washington, D.C., Figure 8, p.34, May 1974.

Four, within the production activity itself other inputs can frequently be substituted for water intake and for primary residuals generation. That is, it is fundamentally incorrect to assume that water intake and residuals generation coefficients, such as cubic meters of water and kilograms of BOD_5 generated per unit of output, are fixed. For any given type of industrial activity, the range is large, because of the multiple variables affecting the coefficients. Each empirically determined coefficient, i.e., measured, reflects a particular set of values of the variables. (15) These site specific factors strongly affect the choice of physical measures for water recirculation and disposal of liquid waste streams, as demonstrated in various case studies. Among many examples which could be cited are: the 80% water recirculation system at the Republic Steel Company mill in Canton, Ohio (16); the use of reclaimed wastewater to provide water of three types of quality for the Petromin petroleum refinery in Saudi Arabia (17); and the use of strongly alkaline spent caustic from scrubbing hydrogen sulphide and mercaptan sulfur generated in catalytic cracking in Gulf Oil Canada's Kamloops refinery as input for pulp production at a nearby Weyerhaeuser pulp mill. (18)

Analyzing Effects on Natural Systems and on Receptors

Outputs of analyzing activities -- the types and quantities of residuals discharged at specific locations in specific time patterns -- comprise the inputs into the analysis of effects on natural systems and receptors, along with the relevant hydrologic, geomorphologic, meteorologic, and pedologic variables, such as temperature, wind velocity, precipitation, soil characteristics, topographic slope, stream channel characteristics, sunlight. Estimating effects on receptors involves three, and sometimes four, steps prior to the monetary evaluation of the effects. The three universal steps are: (1) estimating the time and spatial pattern of changes in ambient water quality; (2) estimating the exposure of receptors to the changes in ambient water quality; and (3) estimating the physical/chemical/biological/psychological effects of the exposure. The fourth step which is sometimes involved, is the perception by humans of changes in ambient water quality and/or of the effects of those changes. The steps are illustrated in figure 14 which shows the sequence of analyses involved in estimating effects on receptors.

Typically the first step involves developing "natural systems models". These models translate the time and spatial pattern of residuals discharges into the resulting time and spatial pattern of ambient water quality. Some models simultaneously estimate both the effects on ambient water quality and the effects on certain aquatic species. Major types of natural systems models relevant to water quality management are: (a) receiving water models; (b) runoff models; (c) terrestrial ecosystem models; and (d) ground water models. (19)

Receptors can be classified in various ways. One operational typology is shown in table 7. Two points about this typology merit emphasis, and reflect its operational orientation. One, it distinguishes between stationary (fixed) and mobile receptors. The greater the mobility of a type of receptor, the more difficult it is to estimate exposure to ambient water quality, and hence to estimate effects. Two, the typology reflects the fact that various activities, e.g., industrial, agricultural, residential, not only generate and discharge residuals which affect ambient water quality but also are affected by changes in ambient water quality.

To illustrate, the time pattern of sediment reaching a stream, as estimated from a runoff model and a sediment delivery ratio, becomes the

Figure 14. Estimating Effects on Receptors

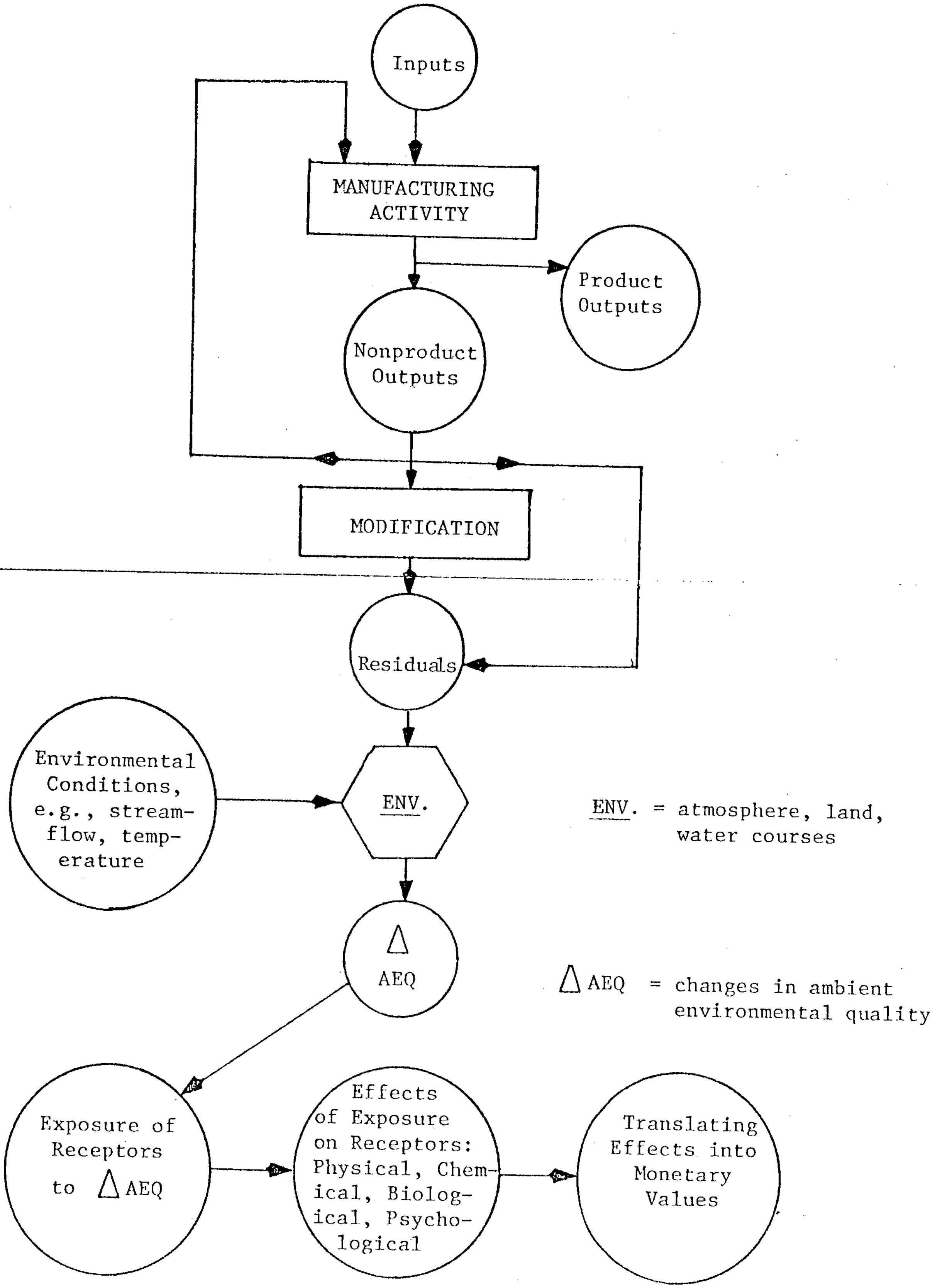


Table 7. Typology of Receptors

Receptors	Stationary (Fixed)	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 silvicultural operations	X		
Industrial and commercial operations	X		
Residences	X		
Humans			X

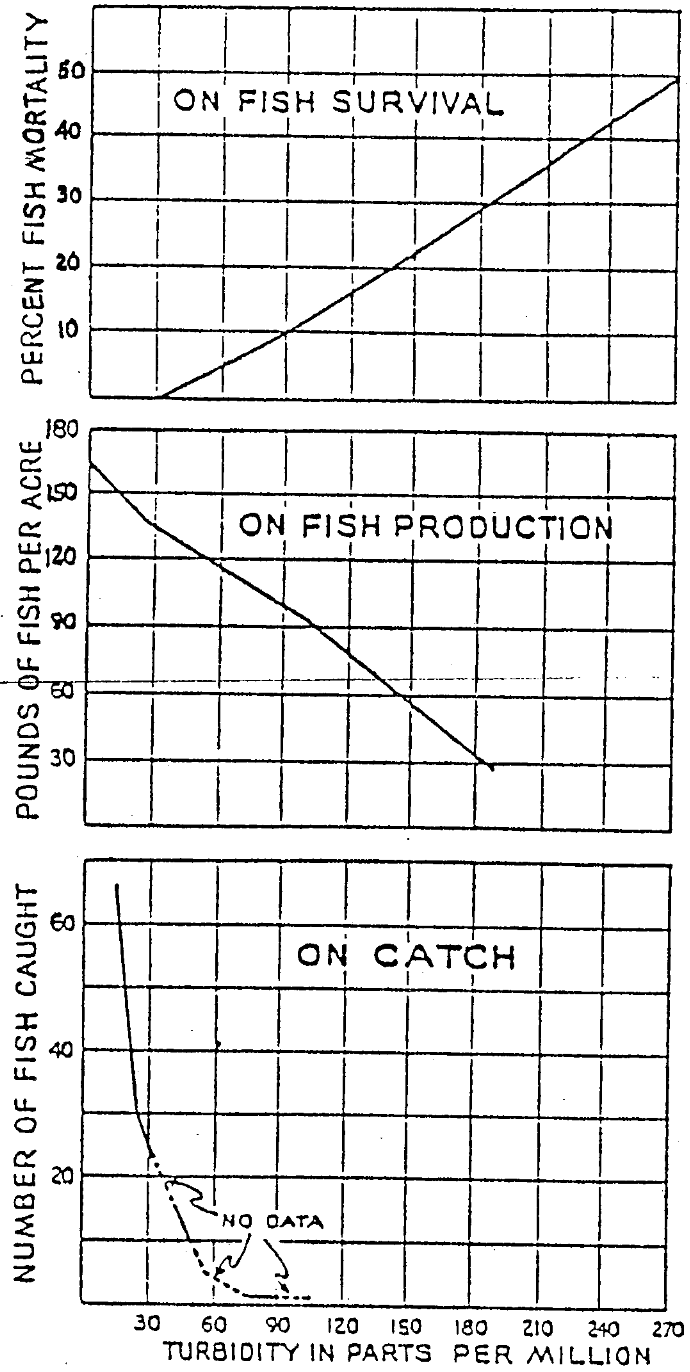
input into one or another receiving water model. For example, a particular receiving water model has been applied which translates the sediment load into stream turbidity. In turn, stream turbidity is translated into physical effects on fish, as illustrated in figure 15. The estimated effects on fish species become the inputs to the evaluation of damages.

Activities such as pulp mills, power plants, vegetable canneries, municipal water plants, require inputs from, as well as make discharges to, the environmental media. The inputs are in the forms of intakes of water and air. To the extent that water quality and air quality are changed by discharges of residuals, so that higher concentrations of certain materials and/or higher temperatures result, adverse effects on activities may occur. Two examples are cited.

A power plant upstream from a paper mill discharges heat to a stream from its cooling operation, thereby increasing the temperature of the stream, particularly in summer and fall. The increase in water temperature decreases the efficiency of water withdrawn from the stream to provide cooling services to the paper mill. The decrease in efficiency can be translated into the necessary equipment which must be installed, or procedures which must be followed -- and the costs thereof -- to compensate for the decrease.

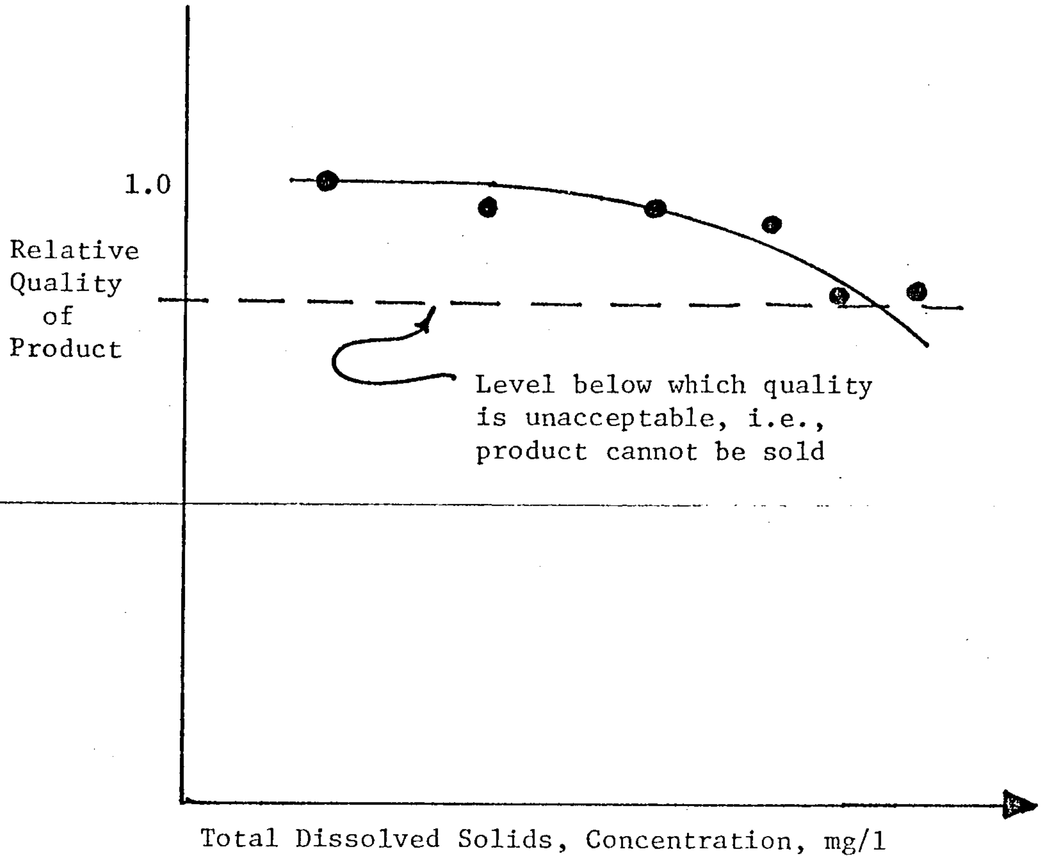
Increased total dissolved solids concentrations in intake water can have adverse effects on industrial activities (as well as on agricultural activities). For example, in canning green beans, at some concentration of total dissolved solids the quality of the product begins to decrease, as illustrated in figure 16. (The circles on the figure represent empirical measurements.) Beyond a certain level, product quality decreases so much that the output is no longer acceptable. The resulting loss in product output can easily be translated into monetary damages.

Figure 15. Effects of Stream Turbidity on the Survival, Production, and Catch of Fish



Source: Anon., 1969, Douglas-fir supply study, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, p. 48.

Figure 16. Relationship Between Quality of Intake Water and Quality of Product in Canning of Green Beans



Level below which quality is unacceptable, i.e., product cannot be sold

A final comment: the linkage between analyzing activities and analyzing effects on natural systems and receptors merits emphasis. The former must result in data inputs in the proper form for whatever natural systems models are chosen for use. Conversely, the natural systems models must be chosen and/or formulated in relation to the outputs which the analyses of activities can provide, the available data, and the desired outputs in terms of ambient water quality indicators.

Formulating and Analyzing Water Quality Management Strategies

Given specified levels of ambient water quality indicators which are to be achieved and/or maintained and given the various activities and groups of activities in the region, combinations of physical measures, implementation incentives, and institutional arrangements, e.g., water quality management strategies, can be posited or developed. The relevant types of physical measures for improving ambient water quality are listed in table 8. The physical measures specified must be consistent with the levels of disaggregation of the sources of residuals and the time horizons of the study. The implementation incentive systems represent the crucial component for inducing responses by water users, as discussed in the next major section of the paper. The cost of each water quality management strategy includes the administrative costs of the implementation incentives, i.e., monitoring, inspection, enforcement.

Analyzing strategies for a region requires a computational procedure to tie together quantitatively the analyses of the various activities and the various natural systems involved. The outputs of the computational procedure, e.g., distribution of costs, distribution of ambient water quality, become the inputs into the evaluation segment.

Table 8. Physical Measures for Improving Ambient Water Quality

Measures for Reducing the Discharge of Residuals

Measures for reducing residuals generation

1. Change raw material inputs
2. Change production processes
3. Change mix of product outputs
4. Change product output specifications
5. In-plant (on-site) recirculation of water[a]

Measures for modifying residuals after generation

1. Materials or energy recovery (direct recycle)
2. Byproduct production (indirect recycle)
3. Residuals modification without recovery for reuse of any material or energy
4. In-plant recirculation of water[b]

Measures Directly Involving Environmental Assimilative Capacity

Measures for making better use of assimilative capacity

1. Redistribute effluent from a given activity over space and/or over time[c]
2. Change the time scheduling of activities[d]
3. Change the spatial location of activities[d]

Measures for increasing assimilative capacity

1. Add dilution water to water bodies
2. Use multiple outlets from reservoirs
3. Artificially mix water in reservoirs and lakes
4. Artificially aerate streams, lakes, estuaries with air or oxygen, by surface or subsurface diffusers
5. Construct artificial falls in streams
6. Planting vegetation to absorb noise; building walls along highways to divert sound upwards

---

[a] Generation of residuals, including wastewater, changes per unit of activity.

[b] No change occurs in residuals generation per unit of activity, except wastewater.

[c] No change in the location, level, timing of the activity itself or in residuals <u>generation</u> by the activity.

[d] Residuals generation per unit of activity may or may not change.

Evaluating Water Quality Management Strategies

As in all decision-making contexts, criteria must be established by which to choose a water quality management strategy. These criteria represent factors which decision makers consider relevant in evaluating strategies. Real resource costs of a strategy represent a major, but not the only, criterion in choosing a strategy for a region. Decision makers use multiple criteria in making decisions, with the criteria and their relative weights being made more or less implicit. Examples of relevant criteria are: (a) physical, chemical, biological, physiological effects and their distributions over time; (b) economic effects and their distributions over time; (c) administrative considerations; (d) timing considerations; (e) political considerations; (f) intermedia, i.e., effects on air and land environments; (g) resource use effects, e.g., energy use; and (h) accuracy of estimates. The criteria may be applied to each residual/activity/physical measure/implementation incentive combination, or to each strategy as a whole.

Some of the criteria relate to direct outputs of the analysis of water quality management strategies. The application of other criteria requires additional analyses. Fewer or more additional analyses will be required, depending on the computational procedure used, that is, how many of the relevant analyses are incorporated in the computational procedure itself.

After rating each strategy according to each of the indicated criteria, the final step is to combine the ratings for the individual criteria. This process involves assigning relative weights to the individual criteria, an activity which is the responsibility of the decision makers, not of the analysts. The application of the ratings and the relative weights yields the evaluation of the given strategy.

INDUCING RESPONSES

To reiterate, an implementation incentive is a behavior modifying factor which induces an activity to modify water withdrawals and/or discharges of residuals. Implementation incentives are imposed to achieve socially established goals. Table 9 lists types of implementation incentives and some examples; figure 17 shows the loci where the implementation incentives can be imposed.

However, regardless of the type of implementation incentive -- effluent charge, input material standard, process specification, effluent standard, marketable permit to discharge -- the associated monitoring and sanction imposing activities are essential. Thus, what is involved is an implementation incentive system. This system consists of:

(1) a set of implementation incentives, e.g., rules or procedures that an activity must follow, a set of abstraction and/or 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 analyses of the samples taken are accurate; and

(4) a set of sanctions for failure to comply with the rules/procedures/standards, or failing to pay charges.

Figure 18 is a flow diagram of the implementation process. Table 10 shows examples of control variables which could be used to monitor performance in relation to various possible economic incentives applied to hydrocarbon

Table 9. Classification of Implementation Incentives for Water Quality Management

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REGULATORY--by law, ordinance, permit

Specification of a physical measure

Specify characteristic(s) of raw material input, e.g., no more than 1% sulfur fuel

Specify "production process", e.g., dry peeling in fruit and vegetable canning

Specify residuals modification and/or handling process, e.g., activated sludge treatment plant

Specify product output characteristics, e.g., limit amount of phosphate in detergents, % by weight

Specification of a result or performance

Specify total quantity of residual discharged per unit of output $\leq$ a specified amount, e.g., $\leq$ X kilograms of suspended solids per ton of steel

Specify total quantity of residual discharged per unit of time $\leq$ a specified amount, e.g., Z kilograms of suspended solids per day

Specify concentration of residuals in discharge $\leq$ a specified amount, e.g., 30 mg/l of suspended solids

Specify ambient water quality level to be achieved, e.g., 6 mg/l dissolved oxygen in spring and fall, 5 mg/l remainder of year

Specify performance, e.g., 85% BOD_5 removal (from specified base) in sewage treatment palnt

Specification of locations or limitations on locations of activities e.g., designate industrial districts

Specification of extent, timing, type of activity, e.g., prohibit discharge during certain months

Specification of procedure, e.g., require sampling of effluent by specified equipment at specified frequency

ECONOMIC

Applied directly to residuals, e.g., charge on each unit of residual discharged, e.g., X cents per kg. of BOD_5

Applied to inputs, e.g., surcharge on each Btu of energy intake

Applied to product outputs, e.g., charge on each kilogram of white packaging

Applied to activities, e.g., grants for research and development

Applied to residuals modification, e.g., sewer user charges, reduced taxes for installation of residuals discharge reduction measures

Table 9. (Continued)

ADMINISTRATIVE--by order within a governmental agency of an enterprise

- Applied directly to residuals, e.g., require collection of all used lubricating oil
- Applied to products used, e.g., specify that only unbleached consumer paper products can be used
- Applied to activities, e.g., specify limits on thermostat settings for water heating

JUDICIAL

- Court or administrative law review and action, or threat thereof, to induce compliance; civil and/or criminal suits

EDUCATIONAL/INFORMATIONAL

- Educational programs to acquaint individuals/groups with the implications of their activities with respect to residuals generation/discharge and adverse impacts on ambient water quality and to acquaint them with alternative behvaior patterns which would reduce such impacts
- Information programs, e.g., appliance labeling with respect to water efficiency, publication in press of "dirty dozen dischargers" each day or week
- Provision of technical information on processes and raw materials which would reduce residuals generation, e.g., technology transfer

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Source: Modified from Bower, B. T., C. N. Ehler, and A. V. Kneese, 1977, "Incentives for Managing the Environment," Environmental Science and Technology vol. 11, no. 3, pp. 250-254.

Figure 17. Loci of Possible Implementation Incentives for Water Quality Management

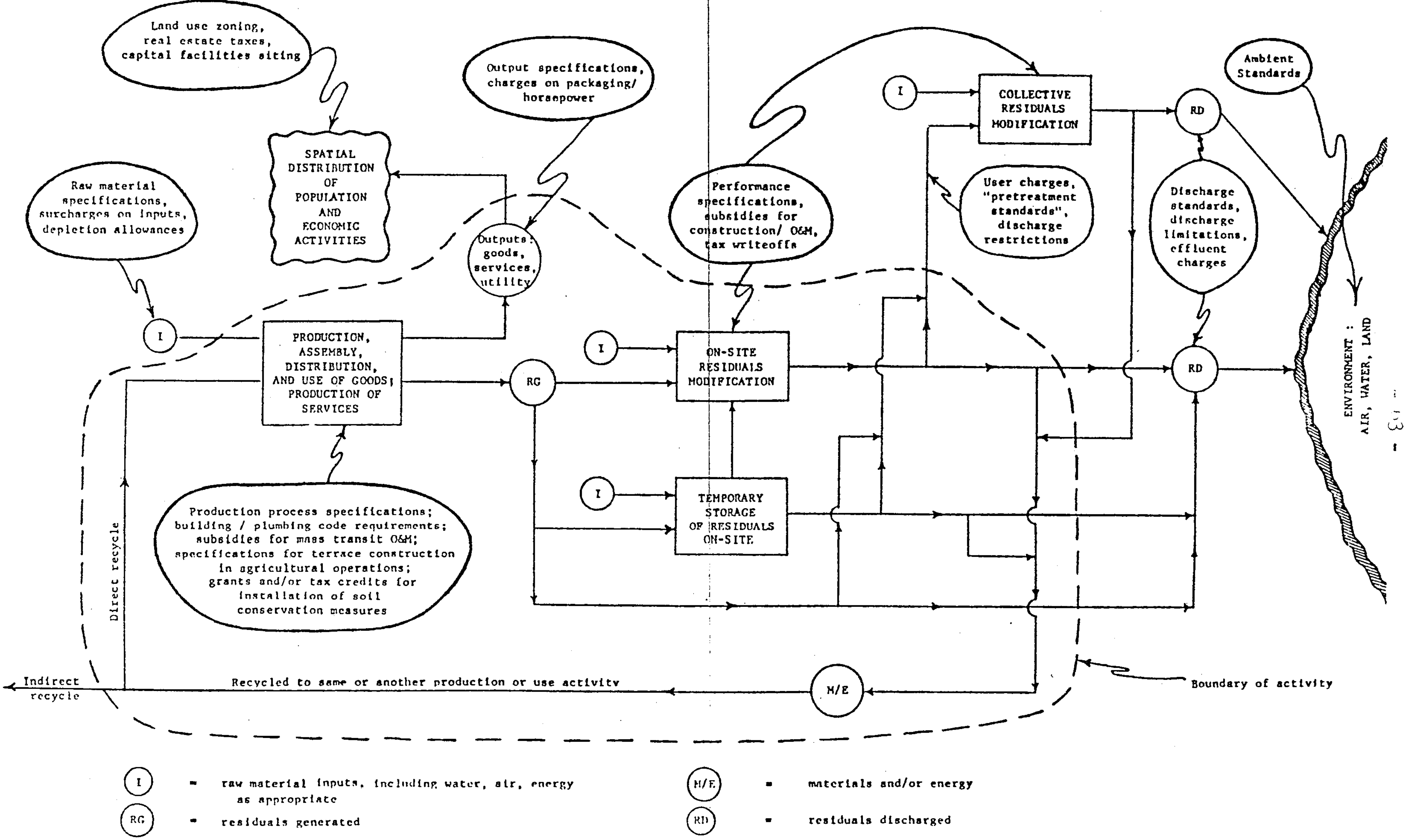

Figure 18. Flow Diagram of Implementation Process

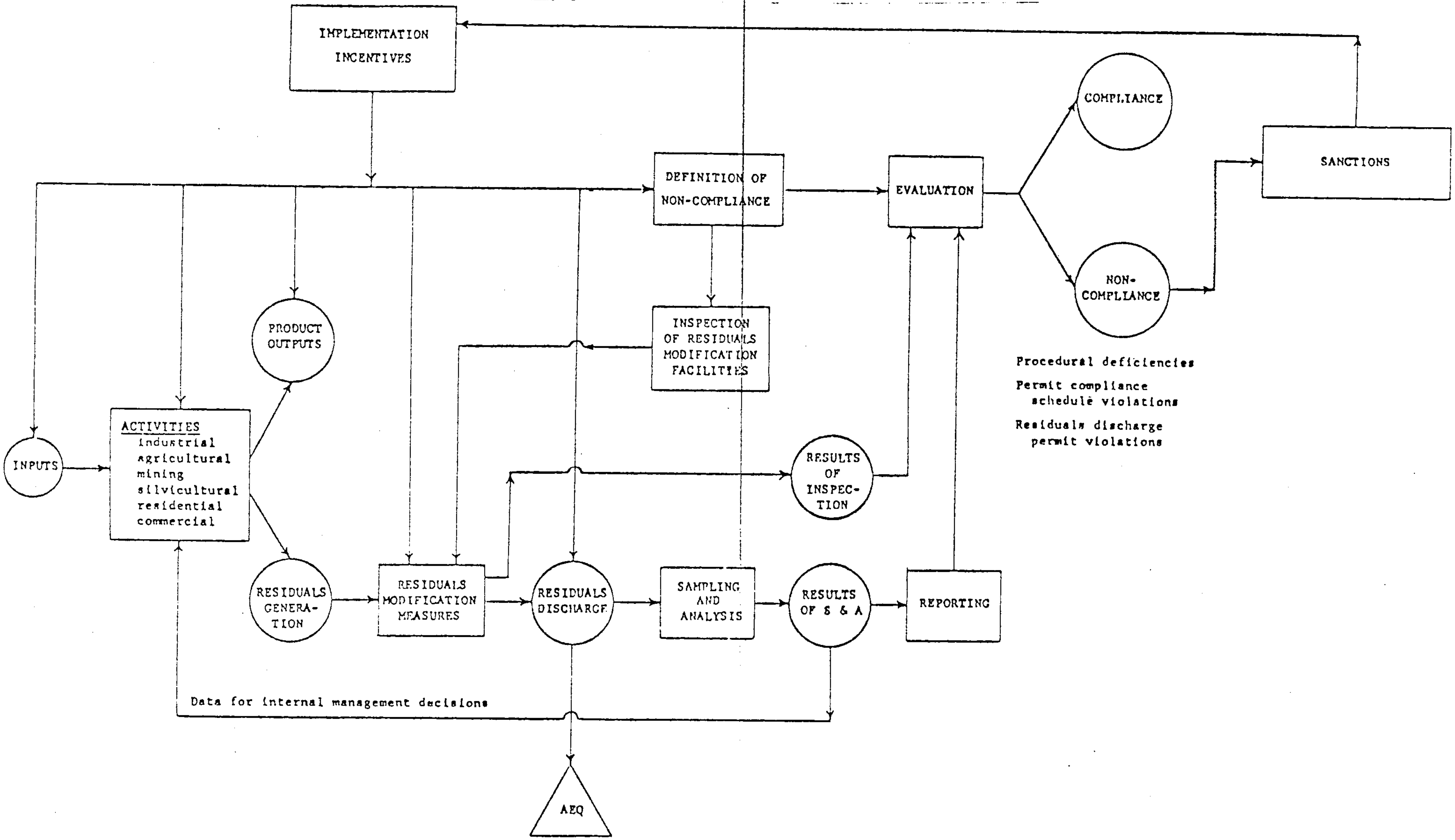

Table 10. Possible Control Variables for Use in Monitoring Performance in Relation to Selected Economic Incentives

Control Variable	Examples of Economic Incentives
Installation of physical measure	
Air pollution control equipment	Daily fine for not installing double seals on floating roof storage tank
Production process	Annual charge for operation of spray booths that use solvent (rather than water) based paints
Production inputs	Fine for use of prohibited cleaning solvents
Production outputs	Per-pound tax on production of solvent based paint
Performance of physical measure	
Amount of emissions	Constant and non-linear charge on emissions; non-linear emission charge schedule with unit charge increasing with emission rate
Emission rate	Charge for emissions greater than specified daily rate; Charge based on daily emission rate with charge higher during summer months
Concentration of emissions	Charge formula with higher charges for higher ppm emission concentrations
Emissions per process weight unit	Charge for any emissions in excess of specified hydrocarbons/ton of laundry limit
Specified operation	Fine for failure to operate degreasers properly
Operation of activity	
Amount of output	Charge for each gallon of gas sold
Amount of process weight	Charge for each ton of solvent used in printing operations

discharges. Table 11 lists the sanctions available in the US which can be applied for non-compliance.

COMMENTS ON IMPLEMENTATION INCENTIVE SYSTEMS

Empirical experiences in various countries provide the basis for the following comments on implementation incentive systems.

One, despite much verbiage -- written and oral -- concerning the relative merits of regulatory versus economic incentive systems, no "pure" implementative incentive system exists for water quality management (or air quality management, or solid residuals management). All existing systems have some mix of regulatory and economic, administrative, judicial, and informational incentives. For example, industrial activities may have imposed on them two or more of: input standards; product standards; discharge standards; specifications with respect to technology of production; specifications of residuals modification equipment by type and /or level of performance; grants for some portion of the construction cost of "pollution control facilities;" grants for some portion of the operation and maintenance costs of "pollution control facilities;" grants to cover some portion of investment in "less polluting" production technology; low (less than market) interest rate loans to cover some portion of investment in "pollution control" facilities and/or "less polluting" production technology; tax credits for investment; rapid depreciation allowances for investment in "pollution control facilities;" withdrawal of operating permits; fines; technical assistance. For example, in water quality management in France, the Ruhr area of the Federal Republic of Germany, and in many U.S. cities, the mix of incentives generally includes: (1) economic subsidies for construction and/or operation

Table 11. Administrative and Judicial Sanctions Available in the United States

ADMINISTRATIVE SANCTIONS (imposed by management agencies)

A. Informal administrative sanctions

- phone calls
- site visits
- warning letters
    - reminder letters
    - directive letters
    - summoning letters

B. Formal administrative sanctions

- administrative orders
- consent orders
- emergency orders
- shut-down orders
- sewer bans
- civil administrative penalties, e.g., delayed compliance fees
- revocation/suspension of permits
- permit modification
- referral to attorney

C. Ancillary sanctions

- blacklisting
- adverse publicity
- withholding of governmental benefits, e.g., contracts

JUDICIAL SANCTIONS (imposed by courts)

A. Civil penalties

- monetary penalties (fines)

B. Injunctive relief

- mandate specific behavior on part of discharger
- prohibit specific behavior on part of discharger

C. Criminal penalties

- fines (usually higher than civil penalties)
- incarceration of corporate or public officials
- fines and incarceration

and maintanance of discharge reduction facilities; (2) discharge standards in the form of permits, which permits specify standards on inputs, production processes, products, and/or quantities of materials/energy in discharges; and (3) effluent charges or sewer charges. It is the mix of incentives to which the activity responds.

Two, an implementation incentive system imposed on a given activity in relation to a given residual usually represents only one of several implementation incentive systems imposed on different liquid residuals, and others on gaseous and solid residuals, to which the activity responds. For some residuals, the same physical measure will reduce the discharge of more than one residual, e.g., BOD_5 and suspended solids, although not to the same extent. Often physical measures designed to reduce the discharge of a given residual may increase the generation of one or more other residuals. It is particularly important to recognize the joint cost and intermedia problems.

Three, some implementation incentives can be imposed at any of the levels of government. Further, the same type of implementation incentive can be imposed simultaneously by more than one level of government, for example, a federal effluent charge on suspended solids discharge into water courses combined with an additional state effluent charge on such discharges. Also, different types of implementation incentives can be imposed on the same residual discharged by different levels of government, for example, a national effluent charge on suspended solids combined with a provincial permit which specifies a limit on kilograms of suspended solids discharged.

Four, implementation incentive systems can be characterized as being either biased or neutral with respect to inducing the adoption of physical measures (technology). For example, implementation incentives which specify waste treatment technology or provide favorable tax treatment only for investment in "end-of-pipe" measures bias the decision of the activity. In contrast, an investment tax credit which is granted for investment in any type of technology allows the water user to choose among the various options including production process changes.

Five, many relevant implementation incentives are not under the jurisdiction of water quality management agencies. Probably the clearest examples are tax provisions such as those relating to depletion allowances, capital gains, severance taxes, accelerated depreciation, and real estate taxes.

Six, implementation incentive systems are imposed in relation both to original compliance and continuing compliance. The former refers to inducing the original installation of physical measures which are presumed to be able to meet or do better than the conditions specified in the discharge permit, whatever the basis for the permit and the means by which it was obtained. Continuing compliance refers to the activity's day-to-day meeting of the conditions specified in the discharge permit. The same implementation incentive or implementation incentive system may not be effective with respect to both original and continuing compliance.

MONITORING

Three types of monitoring are essential in water quality management. These are: (a) compliance monitoring of activities withdrawing water or discharging wastewater; (b) monitoring of ambient water quality to determine the extent to which water quality standards are being met; and (c) biological monitoring of water bodies to determine if achievement of the specified water quality standards does in fact result in the desired aquatic life. Compliance monitoring is undertaken to:

1. determine whether or not a source is in compliance with withdrawal and/or discharge permit conditions;

2. provide the basis, i.e., number of units, on which to assess abstraction and/or effluent charges;

3. monitor a source's progress in correcting violations;

4. provide additional evidence of a violation for enforcement actions; and

5. verify that a source is not constructing a new facility without the required construction or operating permits.

Compliance monitoring is essential whether abstraction and discharge are directly from and to a surface or ground water body, or from a communal water purveyor and to a communal sewerage system. If intake charges, effluent charges, and/or standards are varied by time of day or time of year, the monitoring system must be designed to obtain the necessary information on time variations in abstractions and/or discharges.

Two critical aspects of compliance monitoring merit emphasis. Both are related to the efficiency and effectiveness of implementation incentive systems. One is the problem of maintaining quality control over field and laboratory analyses of samples which presumably reflect the contents of the wastewater discharge. The results of these analyses comprise the basis for management decisions and are relevant both to the water quality management agency and to the individual water-using activities. That quality control is not a trivial problem is shown by tables 12 and 13, which contain results of the analyses, by reputable public and private laboratories, of samples with known concentrations. The results speak for themselves.

Table 12. 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 Concention	Ratio of Maximum Reported Concentration to Known Concention
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, J. E. 1968. "The Political Puppet Called Purity," Papers on Industrial Water and Industrial Waste Water, ASTM Special Publication No. 337 (Philadelphia, American Society for Testing Material) p. 5.

Table 13. 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.
-- not reported.

Source: Miami Conservancy District. 1976. Lab Quality Control Program Trace Metal Sample 2001 and Nutrient Sample 3001 (Dayton, Ohio) 10 September.

The other problem is that of determining the "optimal" frequency of monitoring, with respect to both inspections and sampling. Costs to the water quality management agency increase with increasing frequency of inspection; but presumably the degree of compliance by the water user does likewise. These relationships are shown qualitatively in figure 19. However, little is known quantitatively about these relationships.

EFFECTIVENESS OF MIXED IMPLEMENTATION INCENTIVE SYSTEMS (20)

Although factors other than costs do affect decisions of managers of industrial activities, a good start toward estimating likely responses by individual activities can be made by assuming that decision-makers are cost minimizers or profit maximizers. But what are relevant in estimating responses are the costs "as the activity sees them", not as the water quality management agency or the society sees them. The costs to the activity are not likely to be the same as actual resource costs. This fact results from the wide array of direct and indirect subsidies which exist, and from internal company accounting procedures. Table 14 illustrates only the array of tax provisions which affect costs of water utilization systems to an industrial activity. Additional examples include subsidies relating to certain virgin raw materials, certain forms of energy, and the attaining of capital. Thus, unless costs are estimated as the activities in an industrial area see them, the implementation incentive component of water quality management strategies will be ineffective.

Given the above fact with respect to costs, and given the various types of mixed implementation incentive systems in water quality management, what can be said about the responses by individual activities induced by these systems? Ideally, responses are best evaluated by obtaining empirical

Figure 19. Hypothesized Relationship between Frequency of Inspection and Level of Compliance

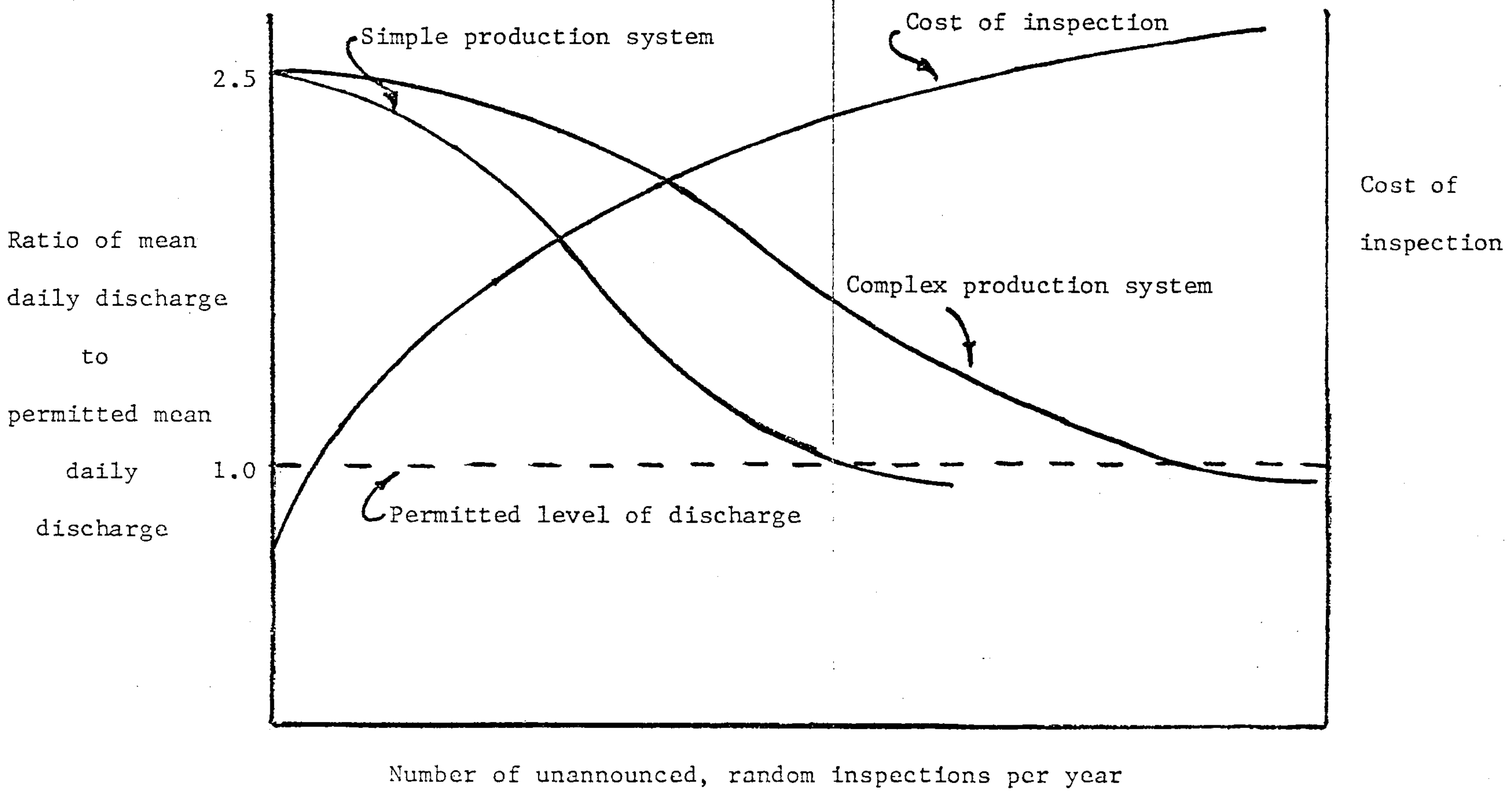

Table 14. Relevant Factors Used in Calculating Discharge Reduction Costs to Activities in California

1. Federal rates of tax on corporate profits are as follows:

Profits	Federal Tax Rate
Less than $25,000/yr	17%
$25,000 - $50,000/yr	20%
$50,000 - $75,000/yr	30%
$75,000 - $100,000/yr	40%
More than $100,000/yr	46%

2. The California state rate of tax on corporate profits is 9%.

3. Federal depreciation writeoffs and investment tax credits for pollution control equipment are as follows:

   a. For equipment with useful life less than 10 years

      10% initial tax credit;
      $2,000 first year "additional" depreciation;
      double-declining-balance method for first year depreciation; and
      sum-of-digits method for remaining years' depreciation.

   b. For equipment with useful life of 10 years or more

      5% initial tax credit;
      $2,000 first year "additional" depreciation;
      five-year accelerated amortization allowable for that portion of pollution control equipment which is eligible; and
      depreciation as above in 3a for the ineligible portion of the equipment.

4. Federal depreciation writeoffs and investment tax credit for physical measures which are not eligible for rules relating to pollution control equipment are the same as in 3a above.

5. State depreciation writeoffs for pollution control equipment are taken on a one-year accelerated basis.

6. State depreciation writeoffs for physical measures which are not eligible for special pollution control writeoffs are the same as in 3a above except that there is no investment tax credit.

[a] Rates and procedures valid as of 1979.

data on the actual behavior of individual plants. Rarely have such data been compiled. However, in a recent study in the U.S. (21) 101 individual plants in five U.S. cities were visited to determine responses to mixed systems including pretreatment (discharge) standards and sewer charges. Types of plants visited included canning, production of chemicals, dairies and other food processing, meat packing, pulp and paper manufacturing, metal finishing, and commercial laundries.

In assessing responses, what must be recognized is that a multiplicity of factors is operating to affect the behavior of an individual activity. Included are: prices of factor inputs other than water, including energy and labor; capital availability; technical information available; regulations on discharges of gaseous and solid residuals; regulations concerning food safety; and regulations concerning worker safety. Attempting to isolate the effects of the implementation incentives relating to liquid residuals within this milieu is difficult. However, based on the 101 individual plant units, the following conclusions seem warranted.

1. Despite the fact that the sewer charges were low in all cases in relation both to total production costs of the activity and to the costs of reducing discharges of liquid residuals by the activity, the charges did induce responses. These included better housekeeping, some changes in production processes, and some changes in byproduct production. In a few cases significant innovation in production systems was induced.

2. The sewer charges induced more continuous adherence to the pretreatment (discharge) standards. The cumbersome nature of the regulatory system in imposing sanctions for each time the pretreatment standards are exceeded results in a relatively ineffective inducement for continuing compliance. Whereas, receiving a bill each month reflecting actual behavior is a readily observable signal to plant managemt.

3. Responses in terms of discharge reduction beyond discharge standards were a function of the level of charges. As charges increase in proportion to total production costs, responses are induced which yield greater reductions in discharges.

4. Physical measures to reduce water intake, wastewater discharge, and energy use often reinforced one another.

5. Stringent regulations imposed on the discharge of toxics generally also resulted in reductions in discharges of BOD_5 and total suspended solids.

6. Regulations directed toward air quality management, solid residuals management, food safety, worker safety, often led to increased water withdrawals and increased discharges of liquid residuals, i.e., they exacerbated the problems of water quality management.

7. The availability of information is an important factor affecting responses. For plants producing the same product or products, some significant differences in responses were found between single-plant firms and multi-plant firms. In general, a plant which was one unit of a multi-plant firm had more relevant information available than did single-plant firms.

Investigations in France in connection with the previously cited report (22) were not able to obtain data comparable to those obtained in the U.S. study. However, the investigations did support the following conclusions with respect to responses by individual activities induced by the existing mixed implementation incentives system for water quality management.

1. The levels of effluent charges are low, relative both to total production costs and to average annual costs -- capital amortization plus operation and maintenance -- of wastewater treatment by the individual activity. However, even with the relatively low levels of the charges, activities where it is cost effective to undertake some discharge reduction have found it profitable to do so.

2. Those industrial sectors where it is more cost-effective to reduce discharges have been pushed, by both regulatory and economic incentives imposed at the national level, to undertake reductions.

3. The river basin agencies, by means of their knowledge of individual dischargers and their criteria for grants, can allocate the available resources to subbasin areas having the more severe ambient water quality problems.

4. The regulatory side of water quality management and the economic incentives side have, in practice, turned out to be complementary. The regulatory side sets the framework in which, on the whole, the basin agencies operate in imposing economic incentives. The regulatory system has kept its importance and continues to be relevant for at least three reasons. One, some kind of licensing procedure is necessary in any case, even if only to check on water withdrawals and/or the discharge of residuals which are

necessarily forbidden by law, e.g., carcinogens. Two, experience has shown that French industrialists are extremely reluctant to modify, even marginally, their production technology, even if the investment is paid back in one year, e.g., 100% return on capital. Such behavior has been observed in many cases in the Seine-Normandie Basin. There are individuals and managers for whom economic incentive has no real meaning. Three, in terms of actual behavior, the inducement for action appears to be a maximum when there is one stick, penalties and sanctions for disregarding standards, from inspectors of the SCE, and one carrot, technical advice, loans, and grants, from a basin agency.

Given the above, how can one assess, finally, the interplay in France of the regulatory incentives and the effluent charge incentives for municipalities and individual private activities? For municipalities, the incentive effect of the regulatory system is fairly low because it is difficult, if not politically infeasible, to impose sanctions, e.g., send a mayor to jail. This means the economic incentive is crucial; clearly, the system of grants of all kinds which reduce the capital costs of treatment plants to the municipalities provides a major economic incentive. Further, the superpremium paid for a given level of efficiency of discharge reduction is also relatively high for municipalities, which increases the economic incentive for reducing discharges. In fact, the system is structured so that relatively little additional regulatory incentive is needed to push municipalities to take actions to reduce discharges.

For private activities, the situation is quite different. For them, the regulatory incentive usually has real weight. Fines are actually levied, court actions are taken in many places, inspections are made. All this reduces noticeably the margin of maneuver for dischargers. Nevertheless, these incentives have been insufficient in the past, as indicated by the fact that ambient water quality of French waters rapidly worsened in the 1960s. What was needed was some economic incentive, but also -- and perhaps even more important than strict economic incentives -- an independent interlocutor (partner) which could give technical advice on what actions the private activity could take and how to take them to achieve the discharge standards. The fact that this interlocutor -- the basin agency -- also makes grants to cover 30% of capital costs is a positive factor. Thus, what can be concluded is that the combined effect of regulatory and economic incentives is to induce private activities to take substantial actions to reduce discharges.

Despite the evidence from France, it is not at all clear the extent to which <u>public</u> entities, such as nationalized industrial activities, respond to implementation incentives, particularly with respect to continuing compliance. In the U.S., even combinations of substantial economic subsidies for installation of discharge reduction facilities and discharge standards have been insufficient to achieve the desired behavior by municipalities. (23) Military installations, some public facilities, and some municipalities have been particularly deficient, even recalcitrant. It seems highly likely that similar difficulties have been encountered with public enterprises in other countries, "eastern" and "western".

Although some evidence is available, and is indicative with respect to the effectiveness of implementation incentive systems, further experimentation is necessary. The fundamental question in water quality management remains, namely, what set of economic incentives, combined with other types of incentives and combined with the other components of implementation incentive systems, i.e., monitoring, inspection, sanctions, will be most effective in inducing private and public entities to adopt preventive rather than curative measures to reduce their demands on the finite capacity of the water environment.

CONCLUDING COMMENT

Until relatively recently, use of the environment for the disposal of residuals was free. Similarly, there was no charge for withdrawing water from water bodies. Consequently, a rational plant manager, individual farmer, householder used as much of those inexpensive factor inputs as possible in producing his goods or services.

However, this condition no longer exists. In essentially all countries there is increasing pressure on the water resource, on both intake and effluent ends. As demands grow in relation to supply -- as appears likely with increasing population and/or production of goods and services and without a major change in life style -- the increased demand will result in increased patterns of interaction among users and in increased incidence of conflicts. Because the assimilative capacity of the environment is essentially fixed, ignoring long-run climatic changes, and hence will only become more scarce in the future relative to the demands on it, the price on the use of that resource will inevitably increase, just as for any increasingly scarce resource. This is true no matter how the price is reflected, e.g., in withdrawal changes, effluent standards, input constraints, product restrictions, effluent charges.

The primary objective of rational water quality management in industrial areas should be to allocate that capacity effectively and efficiently.

FOOTNOTES AND REFERENCES

(1) See International Joint Commission, 1978, Environmental Strategy for the Great Lakes System, Final Report to the International Joint Commission from the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG), IJC, Windsor, Ontario. The estimates were based on materials balances made for each of the lakes.

(2) The more apt term is liquid residuals discharge, which includes both the water and the material and energy residuals transported in and by the water.

(3) Implementation incentives and implementation incentive systems are discussed in the next to last section of the paper.

(4) There was no liquid discharge from the mill until quenching coke with the final liquid residual was prohibited because of air quality problems.

(5) Increased energy costs have stimulated modifications and redesign of wastewater treatment plants. See, for example, Dedyo, J., and R. Doan, Jr., 1981, Reduced energy usage with biological phosphorus removal, Journal Water Pollution Control Federation, 53, 7, 1166-1171, and Middlebrooks, E. J., et al, 1981, Energy requirement for small wastewater treatment systems, Journal Water Pollution Control Federation, 53, 7, 1172-1197.

(6) Day, J. W., 1974, Can we afford to continue cosmetizing paper products during a time of shortages?, Chem 26, Feb., 21-22.

(7) Lowe, K. E., 1973, Too much quality in paper and board?, Pulp and Paper, 47, 12, 162.

(8) One limitation is that the table does not explicitly show such elements of technology as building design. For example, a recently completed office building in Calgary, Alberta (Canada)--a location with very cold winters and hot, dry summers--requires only about one-fourth the energy for heating, cooling, lighting, operation of office equipment that is used in an office building of conventional design, and hence results in a significant decrease in water demand. (See Anon., 1979, Gulf Canada square, Orange Disc, 23, 11, Fall).

(9) For an example of this point, see Part II in Bower, B. T., et al, 1981, Incentives in Water Quality Management: France and the Ruhr Area, Research Paper R-24, Washington, D.C., Resources for the Future.

(10) For an illuminating description of the leakage problem in sewer systems, and its obvious implications, see Gutierrez, A. F., and J. H. Rowell, 1979, Five years of sewer system evaluation, Proceedings American Society of Civil Engineers, 105, EE6, 1149-1163.

(11) Anon., 1974, Regional Energy Consumption, Second Interim Report of a Joint Study by Regional Plan Association and Resources for the Future, Regional Plan Association, New York.

(12) This type of iteration is well described in Hanke, S. H., 1978, A method for integrating engineering and economic planning, Journal American Water Works Association, 70, 9, 487-491.

(13) To estimate such shifts requires at least an interregional programming model for the given economic sector. Few such models exist.

(14) Prices of raw materials listed in trade and market reports are not necessarily the prices actually faced by various activities. Prices quoted to individual activities are affected by discounts for bulk purchases, and probably other factors.

(15) This is ably demonstrated in Russell, C. S., 1973, Residuals Management in Industry: A Case Study of Petroleum Refining, Johns Hopkins Press, Baltimore, and Russell, C. S., and W. J. Vaughan, Steel Production: Processes, Products, and Residuals, Johns Hopkins Press, Baltimore.

(16) Anon., 1980, Republic Steel recycling 80% of steel-mill wastewater, Civil Engineering, 50, 6, 102-103.

(17) Anon., 1979, Reclaimed wastewater will supply Petromin's expanding oil refinery in Saudi Arabia, Camp Dresser McKee Newsletter, 22, 3.

(18) Anon., 1973, One firm's waste is another's wealth, Chemecology, Chemical Manufacturers Association, January.

(19) Discussions of the first three types and of analyzing natural systems in general are contained in Basta, D. J., and B. T. Bower, editors, 1979, Analysis for Regional Residuals-Environmental Quality Management: Analyzing Natural Systems, Resources for the Future, Washington, D.C. Groundwater models are discussed in Bachmat, Y., et al, 1980, Groundwater Management: The Use of Numerical Models, American Geophysical Union Water Resources Monograph 5, AGU, Washington, D.C.

(20) This section draws heavily on Bower, B. T., 1981, Mixed implementation systems for water quality management in France, the Ruhr, and the U.S., in Downing and Hanf, editors, Implementing Pollution Laws: International Comparisons, Policy Science Program, Florida State University, Tallahassee.

(21) Hudson, J. F., et al, 1981, Pollution-Pricing, Industrial Response to Wastewater Charges, Lexington Books, D.C. Heath & Co., Lexington, Mass.

(22) Bower, B. T., op. cit.

(23) Anon., 1980, Costly Wastewater Treatment Plants Fail to Perform as Expected, Report by the Comptroller General of the United States, CED-81-9, USGPO, Washington.