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As the final chapter of "Industrial Pollution Control, Technological Strategies," a publication which points to the effects, controls, and environmental impact of industrial pollutants, chapter 6 describes different decision-making techniques related to establishing effective government or private procedures to control pollution. Understanding that the advantages of a clean environment are weighed against the economic, social, political, and technological feasibility of alternative pollution control methods and standards, this chapter bases its techniques on the general concepts of: 1) goal definition, 2) identification of alternative solutions, 3) methods of evaluating alternatives, and 4) selection of the best alternative. The section on evaluation of alternatives includes a cost-benefit analysis approach, the decision tree probable value method and an environmental constraint model.

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INDUSTRIAL POLLUTION CONTROL

TECHNOLOGICAL STRATEGIES:

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BY

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PREFACE

A two-volume study was prepared to provide information relating to the impact and control of environmental pollution from industrial sources. It is intended for the use of government leaders, industrialists, and other concerned individuals who may have widely differing technical and national backgrounds.

Volume I provides background information and reference sources to facilitate general policy decisions relating to the control of industrial pollutants.* Volume II is concerned with the technical application and comparative costs of pollution abatement in manufacturing operations.

Although the purpose of the report is to describe the effects of industrial discharges and their control, it is recognized that other sources of pollution contribute to environmental problems. The problems of pollution abatement, however, are similar wherever they originate. The general principles and control methods discussed in the report will therefore usually be applicable to pollutants from both industrial and non-industrial sources.

* See inside back cover for information on ordering Volume I.

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CHAPTER 1

INTRODUCTION

The primary purpose of this volume is to provide information on commonly used technologies for reducing the environmental impact of industrial air and water pollutants, and to indicate their relative costs for removing different quantities of pollutants from industrial waste streams.

The topics discussed include:

- Pollution abatement approaches which may supplement, facilitate, or replace end-of-pipe treatment processes.
- The potential adverse effects of major air and water pollutants generated by industrial sources.
- Available techniques, processes, and equipment which may be used separately or as parts of a system for removing or reducing pollutants in industrial discharges to the air and water environment.
- Pollutants generated by selected basic industries, and examples of suitable treatment systems for their control.
- Actual pollution abatement practices used by specific industrial plants in three case study industries.
- Related economic data and cost curves.

MINIMIZING POLLUTION CONTROL COSTS

A major objective of industry is to maximize profits. Industrial firms will therefore usually seek the most cost-efficient method of achieving desired or required levels of pollution control. Two related factors should be considered: the need to comply with both present and anticipated future control requirements, and the alternative means by which pollution abatement may be achieved.

The first factor is important because retrofitting can be excessively difficult and costly. Industrial planners should therefore consider the advisability of installing at least the basic fittings for future control devices during initial construction of new plants or additions to existing plants. The actual control devices can then be attached later at minimum cost whenever stricter pollution control programs require their installation.

The second factor is important because consideration of alternative options for pollution control will help in the selection of the most suitable and least costly system of control for an individual industrial plant or operation. Approaches which can advantageously supplement, and sometimes replace, end-of-pipe treatment include: substituting

alternative non-polluting manufacturing processes, modifying existing processes to reduce their polluting effects, substituting less-polluting raw materials, preventing pollution through the recycling and by-product recovery of waste discharges, and appropriate land use and plant siting--especially industrial parks which permit comprehensive, multi-plant pollution control treatment and waste reuse methods.

NATURAL PURIFICATION--PROS AND CONS

Natural cycles involve a combination of physical, chemical, and biological processes which maintain a dynamic equilibrium among organic and inorganic matter, living organisms, and inanimate objects. Major natural self-purification processes include the mixing and dilution of wastes, absorption of particulates and gases by rainfall, adsorption of gases by plants, settling of particulates discharged into the air onto the ground and surface water, precipitation of suspended solids discharged into water bodies onto the bottoms, biological decomposition of organic matter, and chemical conversion of organic and inorganic matter.

Industrial and other pollutants enter natural cycles when discharged into the environment. In most developed regions, however, self-purification processes cannot eliminate all the potential harmful effects of untreated industrial discharges. Some pollutants are generated and released into the environment more quickly than the natural processes can reduce their harmful effects; others interfere with desirable ecological relationships, or have toxic effects which resist or interfere with self-purification processes.

The full impact of some toxic substances may be delayed for years. Certain pollutants, for example, may be concentrated in the food chain by plants and animals, and in their higher forms become highly toxic; or the effects may become evident later or in succeeding generations as a cause of cancer, failure to reproduce, or genetic damage. Other pollutants, such as nutrients (organic carbon or carbon dioxide, nitrogen and phosphorus compounds), may cause an over-development of particular links in natural food chains, with secondary effects which cause environmental degradation. Even small nutrient discharges into a water body may stimulate excessive algal growth and, as a consequence, contribute to eutrophication and resulting damage to fish and other desirable aquatic life. In addition, since even effective self-purification processes generally require considerable time to restore environmental quality, they are of little value in reducing the immediate local harmful impacts of industrial pollutants on nearby human, animal, and plant life.

There has been an optomistic tendency to overestimate the capacity of environmental self-purification mechanisms, and to perceive actual or potential damage as insignificant when compared with the benefits of industrial development. The subsequent damage to important natural systems, however, has pointed up the limitations of natural purification processes, the costs of environmental pollution, and the need to weigh these costs against the costs and benefits of controlling pollution from industrial sources. In general,

therefore, natural self-purification processes cannot be relied upon to control the potential adverse effects of industrial pollutants. Photographs 1-3, 1-4 , and 1-5 show three examples where natural purification failed to make polluted lake water safe for drinking, fishing or recreation.

TYPES OF INDUSTRIAL POLLUTION CONTROL OPTIONS

Figure 1-1 summarizes the basic types of industrial pollution control measures which can be used to protect the environment. A pollution control program may combine all or several. For each basic type of strategy, the report will describe commonly used methods with broad industrial applications. Technological process changes which are very specific to individual industries are multitudinous and beyond the scope of this book.

MEETING POLLUTION ABATEMENT OBJECTIVES

In most countries, protecting the natural environment is either a current objective or is being reviewed as a future national objective. The information provided in this volume can assist industrial planners to develop pollution abatement programs which meet present or anticipated discharge standards. Further helpful information can be secured from appropriate government, industry, and institutional agencies in countries and regions where programs to control industrial discharges are already in effect. Direct observation, personal contacts, and a search of available literature may all be useful. The last chapter of Volume I offers further suggestions on possible sources of information. *

Although the scope of this guidebook is limited to industrial pollutants, most of the discussion and control methods will apply equally well to polluting discharges from other commercial and municipal sources.

* See inside back cover for information on ordering Volume I.

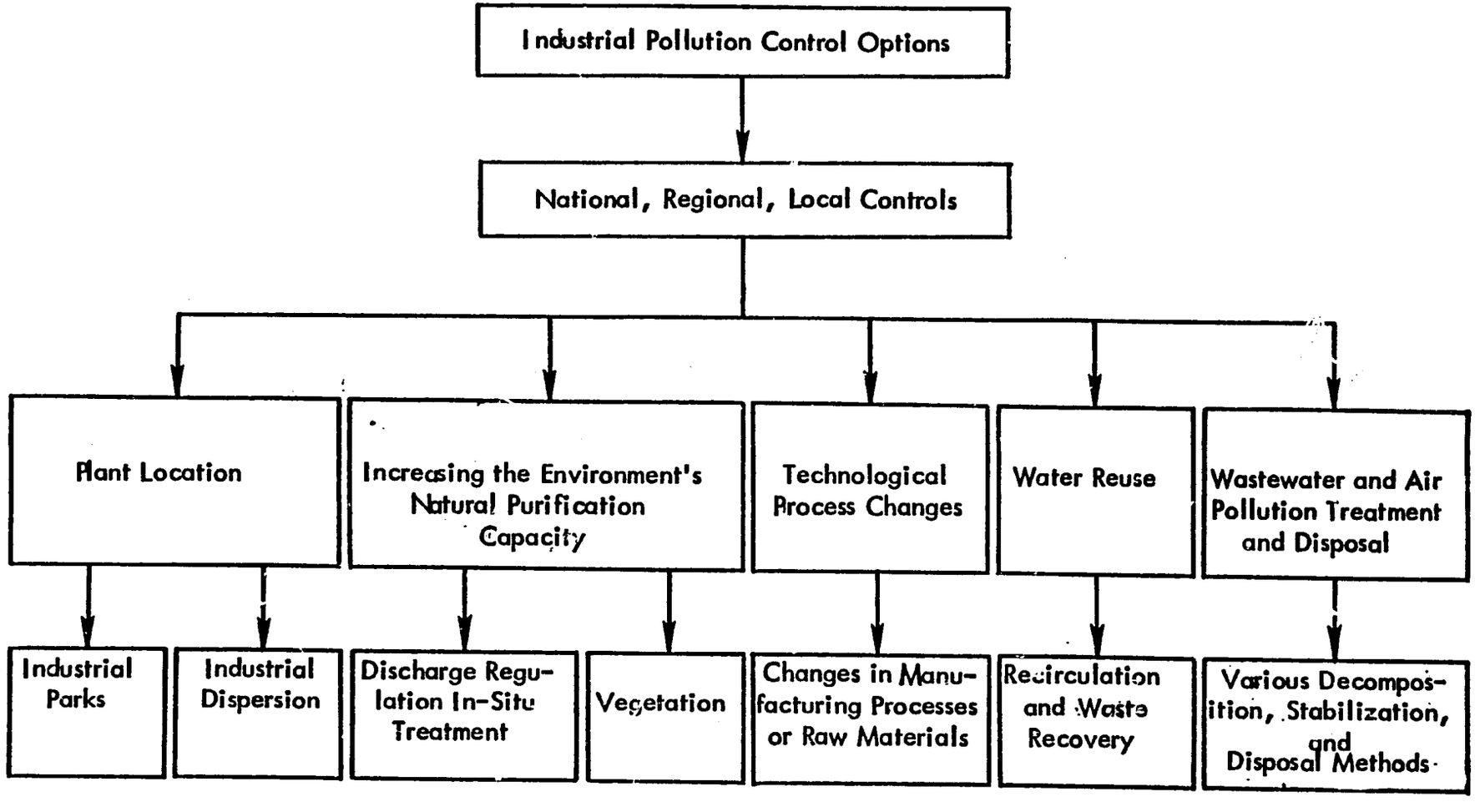

FIGURE 1-1
INDUSTRIAL POLLUTION CONTROL OPTIONS

DECISION-MAKING METHODS FOR POLLUTION CONTROL

April 1977

(Chapt. 6 of Industrial Pollution Control, Technological Strategies)

by

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CHAPTER 6

DECISION-MAKING METHODS FOR POLLUTION CONTROL

In making decisions related to establishing effective government or private procedures to control industrial pollution, the advantages of a clean environment are weighed against the economic, social, political and technological feasibility of alternative pollutution control methods and standards. While decision-making aids vary in technical complexity, the purpose of any approach is to choose a course of action that will achieve the established goals. This chapter describes different decision-making techniques based on the general concepts of: (1) goal definition, (2) identification of alternative solutions, (3) evaluation of alternatives, and (4) selection of the best alternative.

STEPS IN DECISION MAKING

Definition of Goals

Formulation of a comprehensive goal set is the first step in decision-making. Policy goals do not exist in isolation. The goal of reducing undesirable industrial pollution implies a subset of social, economic, and environmental costs and benefits. Expressed in another way, the primary and subsidiary policy goals are the criteria against which the government's regulatory pollution control options will be judged.

To be most effective, the methods of selecting and defining goals must:

- Produce specific statements of goals and objectives that are of direct use in system planning and evaluation.
- Identify relative priorities associated with the attainment of each goal to facilitate trade-off decisions.
- Provide for multiple inputs representing a variety of viewpoints.
- Assist in identifying conflicts over goals and priorities.

Group judgment is one way to increase the effectiveness of goal definition.

Identification of Alternative Solutions

Since effective pollution control decisions involve a trade-off between the costs and benefits at different levels or methods of control, many intermediate solutions are possible once goals have been defined. Government decision-makers should therefore identify both potential regulatory options (e.g., ambient/discharge standards, zoning/land use restrictions, warrants, subsidies) and possible industrial techniques to satisfy those regulations (e.g., process modification, recovery/reuse/reclamation, waste treatment). Industrial decision-makers will be concerned with the latter alternatives, which are discussed in greater detail in earlier chapters of this volume.

Evaluation of Alternative Solutions

Evaluation of the economic, environmental, and social effects of alternative solutions is the third step in the decision-making process. At a governmental level, difficulties arise when comparing the profit goals of industrial firms with diffuse, complicated, and often intangible socio-environmental goals. Where important values cannot be quantified easily, the less technical approaches may be more appropriate. For the industrial firm with a clearly defined and quantifiable goal (such as achievement of a regulatory discharge standard at the least cost), the various engineering quantitative cost analysis methods can be employed.

NON-QUANTITATIVE APPROACHES

Decision Tree Method

A "decision tree" helps to identify the effects branching from any one goal, decision, or other factor (see Figures 6-1 and 6-2). The method is quite flexible. Figure 6-1 shows how the question "Should industrial discharges be regulated?" leads to successive questions and decisions. Additional information could easily be included. The item "Low Standards, Mandatory Compliance," for example, might generate four branches: good industrial cooperation, minimum economic dislocation, low abatement value, and high health hazard. This method is effective in identifying criteria which might otherwise be overlooked, and in clarifying the logical relationships among goals, criteria, options, and decisions.

The level of detail in decision tree construction depends on two factors: the amount of available information, and whether the method is used for decisions requiring high levels of precision or those of a more general nature. A later section of the chapter, "Decision Tree Probability Analysis," discusses the use of numbers to determine probable end values of alternative decisions.

Identification and Ranking

With this method, basic objectives such as economic welfare, resource conservation, and public health can be listed, and the related criteria identified. Table 6-1 shows a sample list. To establish priorities, the criteria can be ranked in order of estimated importance. For example, one possible ranking might be: (1) level of abatement, (2) cost of control, and (3) aesthetics.

Another useful procedure is to make a systematic inventory of the available options and their potential advantages and disadvantages. The policy maker can develop such lists to help compare the effects of alternatives.

QUANTIFYING INTANGIBLES

Score Card Option-Rating Method

The score card option-rating method is one means of numerical evaluation of intangibles, that is, factors difficult to quantify. For example, assume that the goal is to eliminate a specific industrial waste discharge; the options being considered are high, moderate,

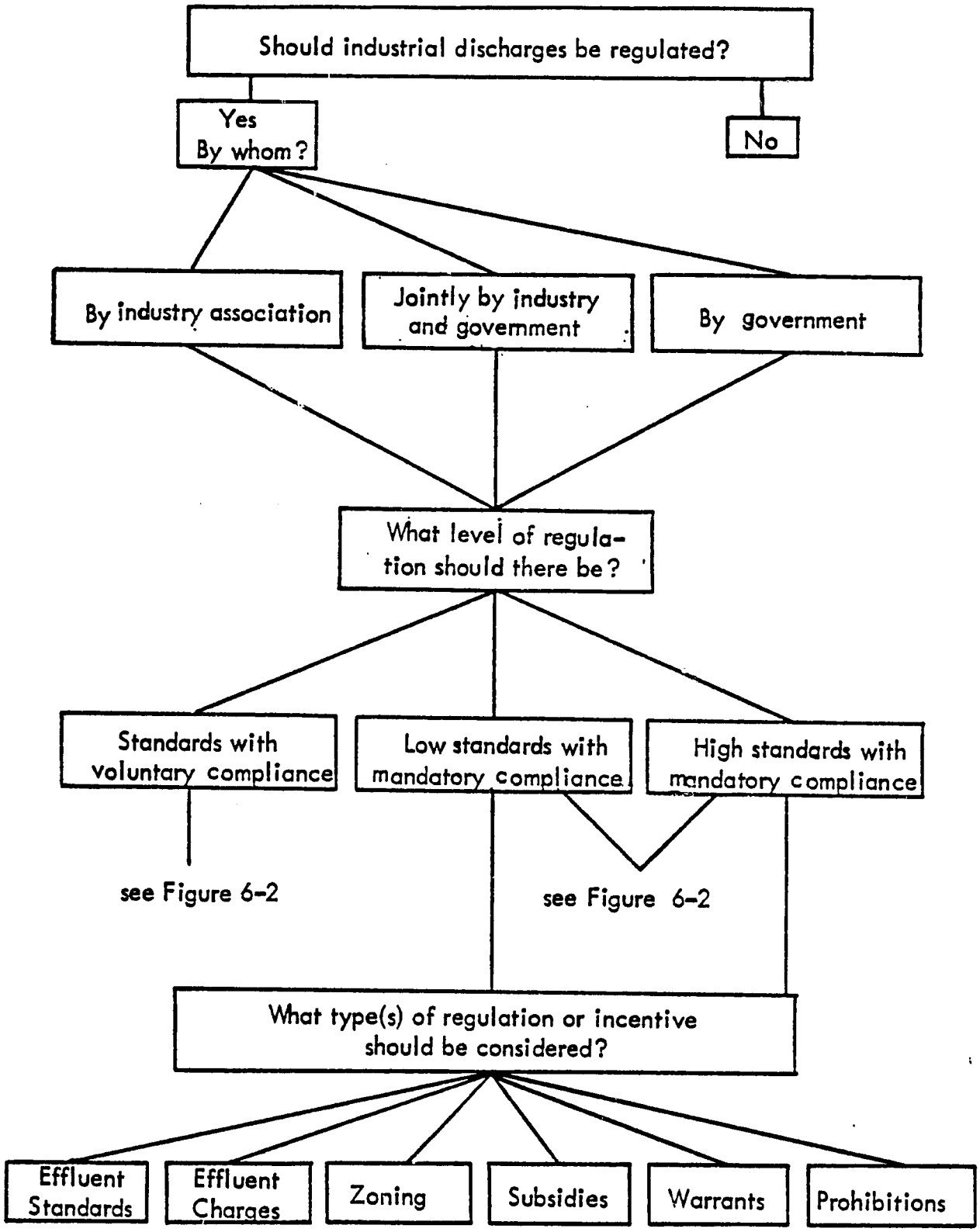


FIGURE 6-1
GOVERNMENT POLLUTION
CONTROL DECISION TREE

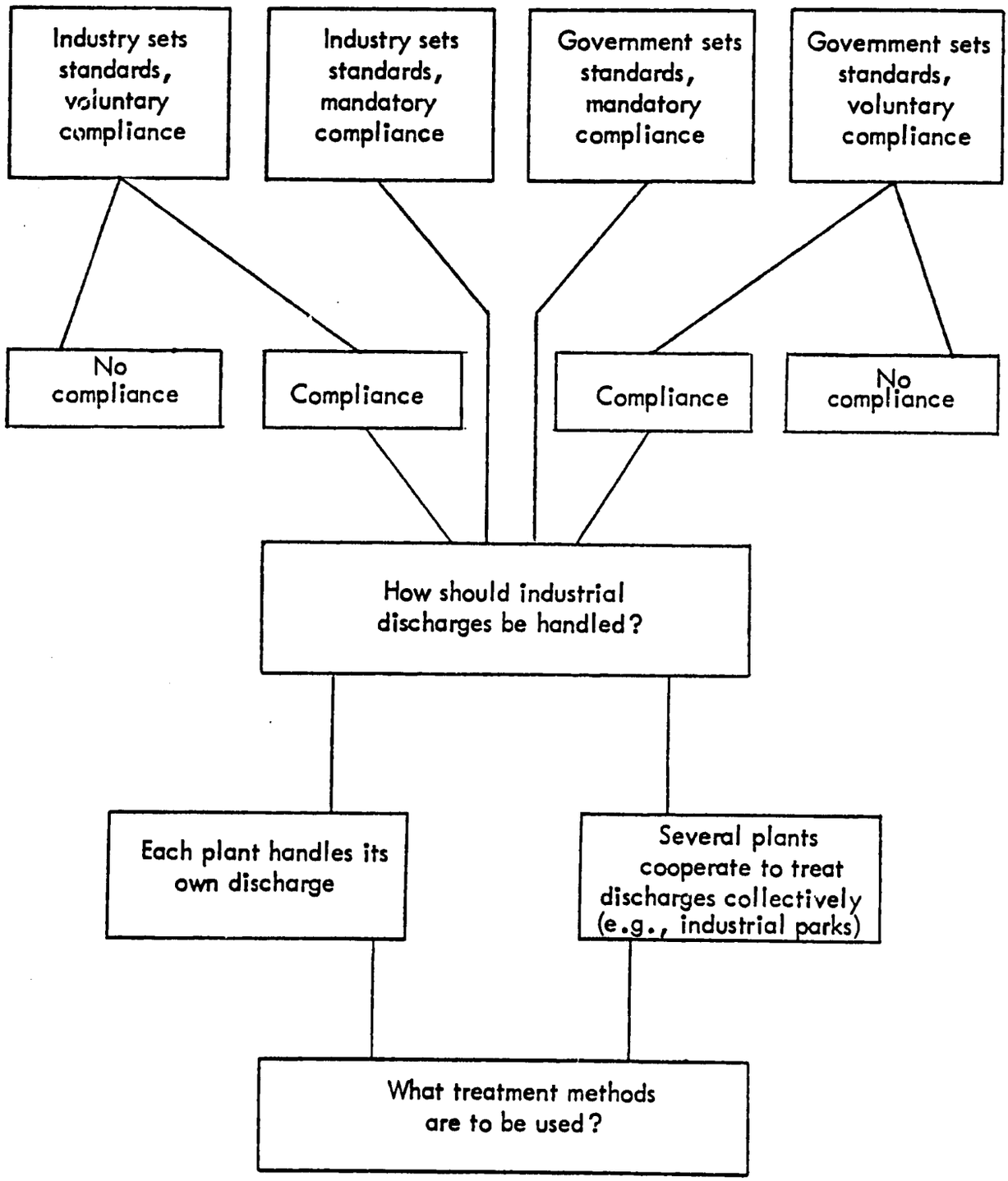


FIGURE 6-2
INDUSTRY POLLUTION CONTROL
DECISION TREE

TABLE 6-1

SAMPLE LIST OF
DECISION-MAKING CRITERIA

Economic welfare	Costs of control (including monitoring and enforcement), savings from recycled resources, revenue losses from pollution damage (tourism, recreation, agriculture, land values, fishing), development of new pollution control industries, cost of adverse health effects, growth and development effects.
Resource conservation	Energy consumption, land use, raw resource consumption, recycling, repair of damage to resources, irreversible damage to land and water.
Socio-political welfare	Public support, political feasibility, legislative constraints, administrative simplicity, quality of life (standard of living), public health, national image.
Environmental quality	Air, water, and land pollution, ecological disruption, aesthetics of clean air, water, and land.

and low emission standards; and the chosen option will be the one which best satisfies stated criteria. The criteria are first identified and then rated, perhaps on a scale of 0 to 10, with 0 indicating no importance and 10 maximum importance. Two factors will reduce subjective bias and increase the reliability of the results: (1) listing all related criteria including those considered to be of marginal importance, and (2) having a group of concerned, informed individuals rate the criteria. The average of the group's rating for each criterion is used to indicate its relative importance, or "weight." A simplified hypothetical example will illustrate:

Criterion	Individual Ratings				Average Rating
No adverse effect on economy	9	8	10	9	9
High level of abatement	10	8	10	8	9
Conservation of natural resources	5	7	4	3	5
Administrative simplicity	2	3	5	1	3
Maximum public support	7	10	6	4	7

The options are then rated as to their estimated ability to satisfy the criteria. Again using a scale of 0 to 10, with 0 indicating total inability to satisfy a specific criterion and 10 indicating maximum ability, a score card can be developed to evaluate the relative advantages of the three options. Again, an average of individual ratings is preferred. Table 6-2 demonstrates the method and final calculations for one score card.

The option with the highest total score is presumed to be the most satisfactory alternative. But because the method is subjective and imprecise, if results for the two highest scores are close (perhaps within 10 percentage points), further evaluation would be advisable. The method is designed to indicate relative superiority. If all the options receive low ratings (say 4 or less), additional options or confirmation from other decision-making approaches should be sought.

COST ANALYSIS

Cost-benefit analysis defines the objective and identifies the alternative which yields the greatest net benefit with respect to an objective. Cost-effectiveness analysis defines the objective, identifies alternate ways of achieving the objective, and then determines which alternative is most effective for a given cost, or which alternative will achieve a given level of effectiveness at the least cost. Cost-efficiency analysis is a form of cost-effectiveness analysis. It defines the objective and the amount of money available to achieve that objective, then identifies the alternative that best meets the objective at the indicated monetary limit.

Cost-Benefit Analysis

This approach has a well-defined economic basis. Unfortunately, practical environmental applications are not well-developed for several reasons:

TABLE 6-2

SCORE CARD METHOD: HYPOTHETICAL EXAMPLE

Criterion	Weight	Ability to Satisfy Criterion (average ratings)			Score (rating x weight)		
		Option[a] One	Option Two	Option Three	Option One	Option Two	Option Three
No adverse effect on economy	9	5	6	7	45	54	63
High level of abatement	9	10	6	2	90	54	18
Protection of natural resources	5	8	7	3	40	35	15
Simple administration	3	5	6	7	15	18	21
Maximum public approval	7	7	3	2	49	21	14
					Total: 239[b]	182	131

[a] Options One, Two, and Three refer respectively to high, medium, and low emission standards.

[b] Preferred option.

(1) Government decisions relating to industrial pollution control involve a broad range of possible social and economic objectives. The monetary costs of control can generally be estimated by engineering methods with reasonable accuracy. The related social costs and benefits, however, can never be completely identified, quantified, and expressed as monetary values.

(2) A further difficulty is that the incidence of costs and benefits will differ for the general public and for various interest groups. If the major costs of industrial pollution are externalities (shifted to the outside community), the major benefits of pollution control will also be externalities. The costs of control, however, are usually internalized (shifted back to the responsible industrial firm). As a result, the relative cost-benefit impacts of pollution control may be very different for the controlled industry and the nation or affected region. The interests of the pollution-abatement industry, however, might either coincide with those of the community, or lie in the direction of unnecessarily stringent or costly methods.

(3) Where the estimated economic benefits exceed the estimated economic costs, the nonmonetary or less tangible benefits could be considered a bonus. But even here, cost-benefit analysis would not always identify the best of available government options since the unquantified costs and (especially) benefits might be more significant than the known costs and benefits.

In industrial decision-making, cost-benefit analysis is probably most appropriate when mandatory standards can be met through abatement strategies which also result in greater manufacturing efficiency, lower operating cost, or reclamation of valuable materials. In government decision-making, it can be used to supplement other types of analysis when there are positive net economic benefits. This approach allows for consideration of nonmonetary costs and benefits which may influence the relative ranking of alternatives.

In order of preference, the data for cost-benefit analysis is based on:

- Quantification in actual monetary values.
- Quantification in physical units (for example, kg of pollutant removal, reduction in number of hospital admissions, hectares of cropland restored).
- Subjective evaluation (assigning weight, rank, or monetary value based on individual or group judgment).

Where monetary values cannot be determined, physical units or subjective judgment must be used to measure costs and benefits. Questionnaires asking people how much they would be willing to pay for a clean environment, reviewing past experience, and group estimates by informed, unbiased individuals may be helpful in subjective evaluation.

Simple cost-benefit analysis attempts to identify the alternative which maximizes the difference between total benefits and total costs ($B - C > 0$), and may consider the total benefit to cost ratio ($B/C > 1$). The benefit to cost ratio indicates the efficiency of money expenditures and is rarely used alone, since a small investment with a high B/C ratio may provide less total profit than a large investment with a low ratio. For example, a firm can use either of two alternatives to provide the required pollution control, with the respective cost-benefits of:

$$\frac{B}{C} = \frac{\$1,000,000}{\$\ 500,000} = 2;\ B - C = \$500,000$$

and

$$\frac{B}{C} = \frac{\$50,000}{\$10,000} = 5;\ B - C = \$40,000.$$

Assuming that capital is available for which there are no more profitable uses, the first alternative with a smaller B/C ratio would be preferred since it maximizes profits. Where more profitable uses of capital are available, the preferred alternative would have the highest B/C at the lower cost, in order to maximize the benefits received per dollar spent.

Marginal cost-benefit analysis attempts to define an optimal level of pollution control by equating the marginal cost and the marginal benefits of a pollution control program. Two sets of factors are measured:

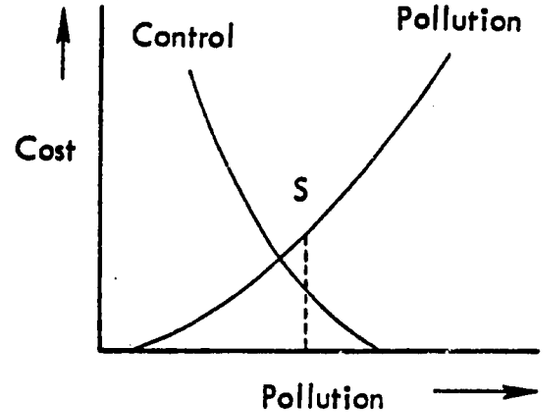
- The costs of alternative levels of pollution control: lower emission rates will involve higher control costs.

- The benefits of pollution control: benefits result from the reduction in pollution levels and, hence, the adverse impacts of pollution. In other words, the benefits are reductions in the costs of pollution impacts.

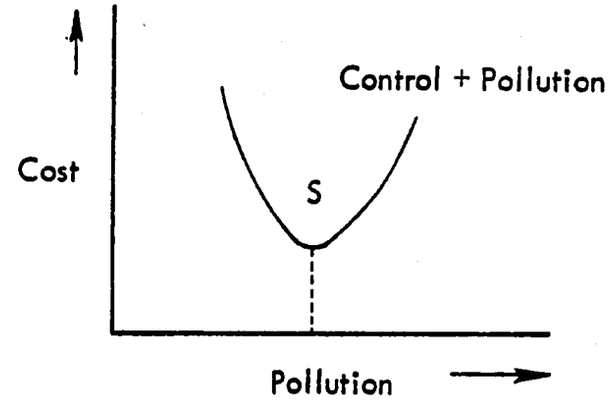
Figure 6-3 illustrates the rationale of the marginal cost-benefit approach. As the level of pollution rises, the costs of pollution (or benefits foregone from lack of control) can be expected to rise and to continue rising at a rapid rate. The cost of control, which is minimal at high levels of pollution, increases rapidly as pollution control programs are applied. The marginal cost curves of Figure 6-3c are derived from the total cost curves of Figure 6-3 a. The marginal cost of pollution (MCP) curve shows the incremental cost of permitting an additional unit of pollution and the marginal cost of control (MCC) curve represents the incremental cost of reducing pollution by one unit.

The optimal level of pollution control occurs at "S," the intersection between the marginal cost and marginal benefit curves. At this point, net benefits (total benefits minus total cost of the pollution control program) are maximized. Increasing the level of control to any degree would increase costs more than benefits, while reducing the level would decrease benefits more than costs.

6-3a Total Costs



6-3b Sum of Costs



6-3c Marginal Costs

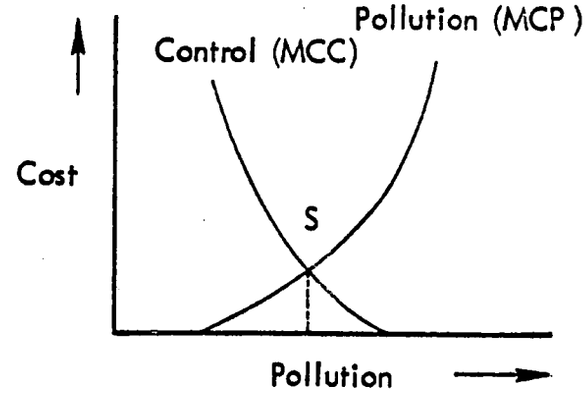


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FIGURE 6-3
MARGINAL COST-BENEFIT APPROACH

Environmental improvement projects usually extend over a long period of time: predicted benefits and costs will initially be expressed as time flows. To compare these flows it is necessary to convert them to a single point in time. This is usually done by calculating the present value of the net benefits (total benefits minus total cost) of the project. The present value of a project is expressed by:

$$PV = \frac{B_1}{(1+r)} + \frac{B_2}{(1+r)^2} + \ldots + \frac{B_n}{(1+r)^n}$$

Where

PV = present value

B = net benefits (subscripts indicate time period)

r = social discount rate.

The social discount rate is an estimate of society's time preference: its preference for benefits now rather than one period hence. For example, a social discount rate of 10 percent implies that society would take $1 now in exchange for $1.10 one year hence. The higher the discount rate, the lower the present value of any given program. This is significant when the ranking of alternative programs may be dependent on the rate chosen: for example, program A might be preferred to B at a 6 percent rate, but B preferred to A at 9 percent. This means that the intersection point of the MCP and MCC curves will depend on the social discount rate selected.

There is no commonly accepted method of determining the social discount rate. Various suggestions have been made, including (1) the rate on long-term government debt (neglects risk factor), (2) private borrowing rate (includes risk, but some argue it should be excluded), and (3) rate of return in similar projects (not appropriate to most pollution control programs). Sensitivity analysis is frequently used to reduce the conflict inherent in selection of a discount rate. In this approach, alternative projects are evaluated to determine over what range of discount rates each alternative is preferred. If one alternative is preferred for any rate or over a range of rates considered "reasonable," it is selected as the best alternative. This approach is most practical where relatively few alternative programs are being considered. Whatever the method of selecting a social discount rate, the choice is really a value judgment.

Figure 6-4 summarizes the decision-making process using a cost-benefit approach. The left side of the model shows a method for finding the least-cost means for achieving a given level of pollutant reduction at the single plant level.

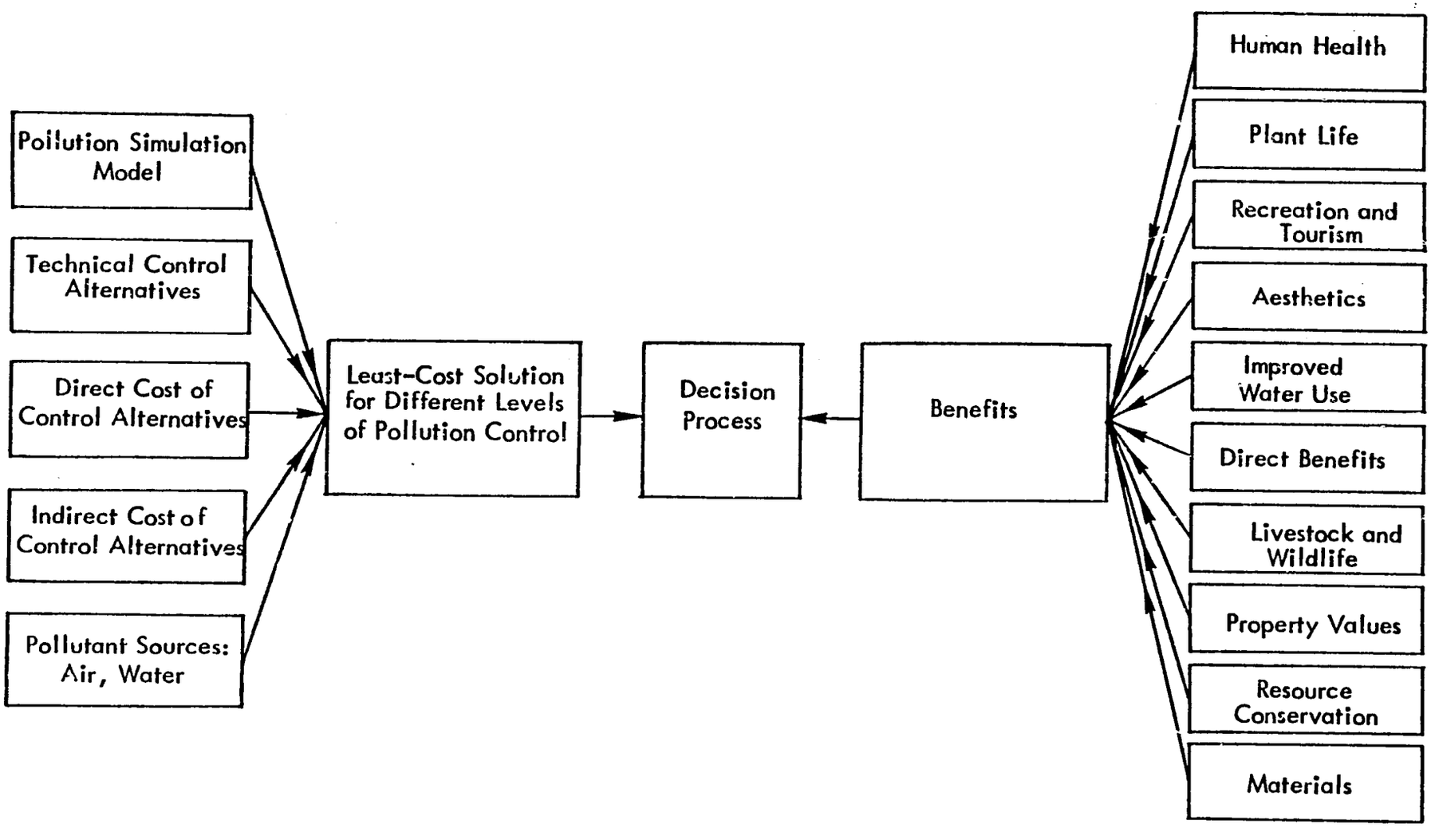


FIGURE 6-4
COST-BENEFIT TRADE-OFF ANALYSIS
OF INDUSTRIAL POLLUTION CONTROL

A pollution simulation model is used to estimate improvements in ambient air and water quality following from various control options. The model will be limited by the data available and the reliability of projection methods. Technical control alternatives should include major process shifts and add-on devices. Direct costs would cover equipment purchase, operation, and maintenance.

Once the costs of various levels of pollution control have been obtained, the associated benefits are determined, such as those on the right side of Figure 6-4. The benefits can be described for this purpose as damages averted, that is the estimated reduction in damages resulting from anticipated reductions in current levels of pollution. If damages should increase for some benefit category, this would be viewed as a negative benefit rather than as a cost.

Cost Effectiveness and Goal Achievement Analysis

Cost-effectiveness methods estimate the costs and the efficiency of the allocation of funds, thereby avoiding the problem of assigning monetary values to social costs and benefits.

Two procedures that can be used in a cost-effectiveness analysis are:

- Maximize pollution abatement subject to a cost constraint (efficiency approach).
- Minimize cost subject to pollution discharge constraint (economy/goal achievement approach).

Figure 6-5 shows that the two approaches lie on the same total cost curve. The second method is applicable in pollution control planning where a given level of control is the immediate goal, and minimizing cost is the next consideration.

An expanded cost-effectiveness approach includes a comprehensive assessment of goal achievement. A ratio between the cost and the effectiveness (degree of goal achievement) is determined and used as a basis for selecting an optimal level of pollution control. The steps in this method as shown in Figure 6-6 are:

- Formulate goals.
- Formulate criteria for measuring progress toward the goals.
- Weight the criteria and goals for importance on a scale of 0-10.
- Predict the impacts of a particular level of pollution control on the criteria.
- Normalize the impacts on a scale of 0-1.
- Multiply the normalized impacts by their respective weighting factors.
- Sum the weighted scores.
- Estimate total costs of implementing the controls on an industry-wide basis.
- Calculate a goal achievement/cost ratio by dividing the summary score of the impacts by the total cost.

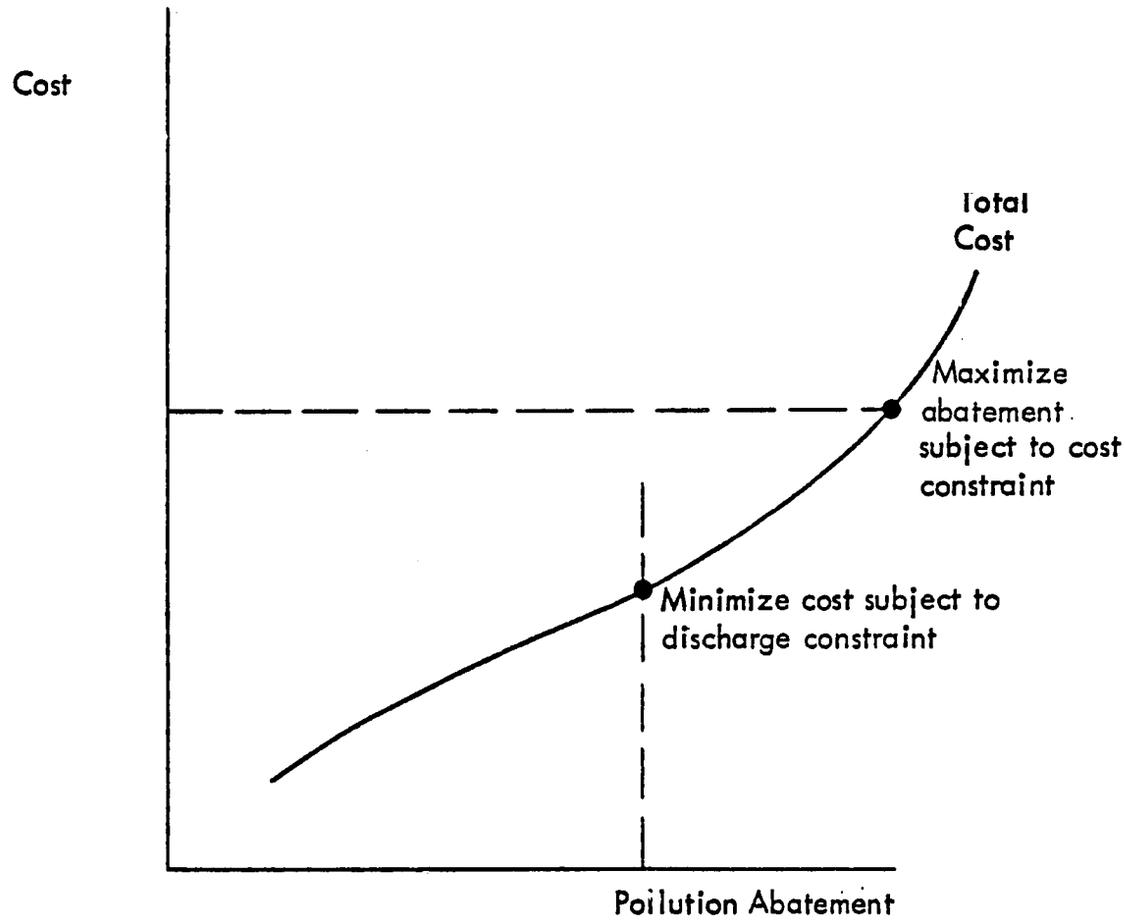


FIGURE 6-5
TWO APPROACHES TO COST-EFFECTIVENESS

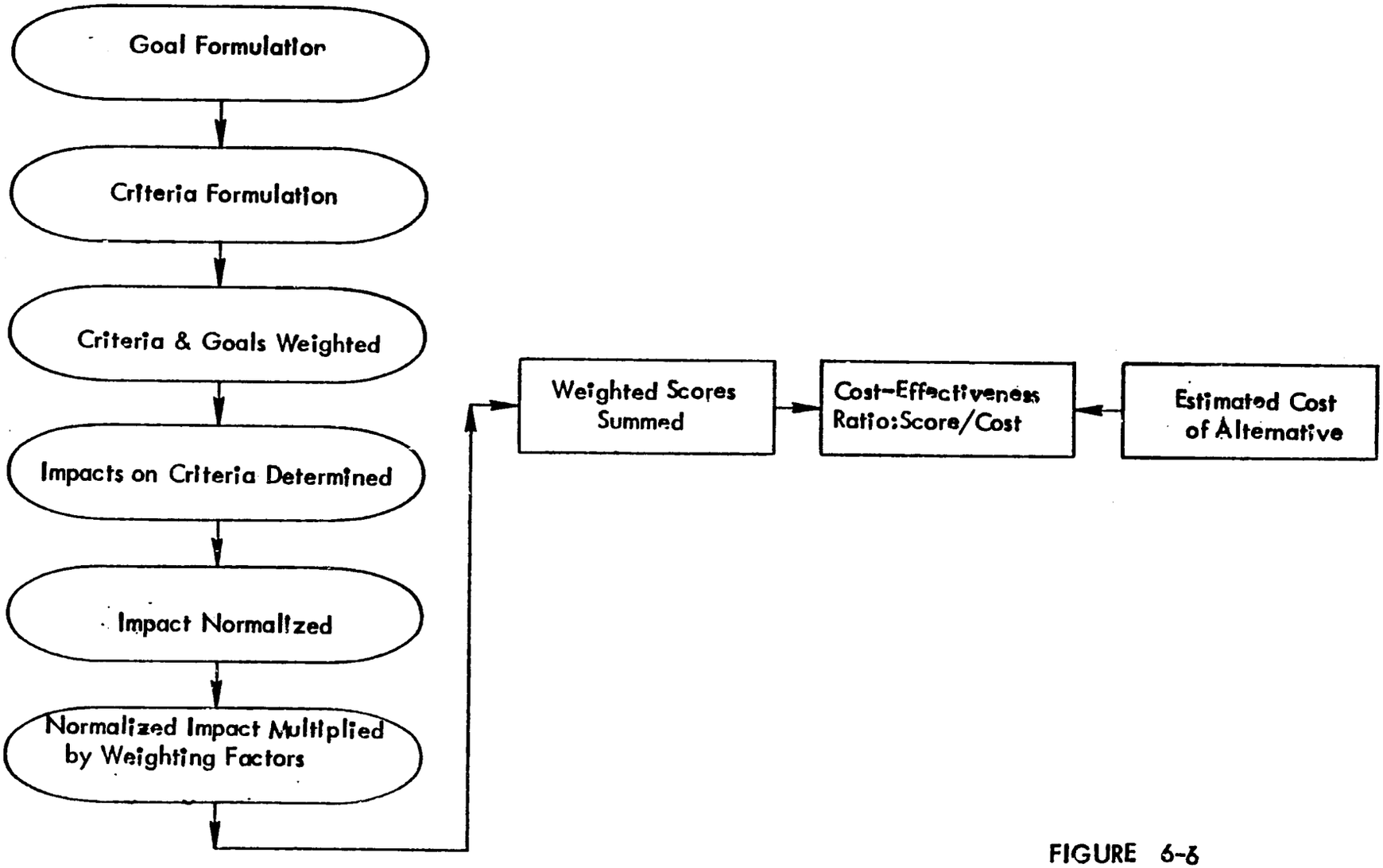


FIGURE 6-8

APPLICATION OF COST-EFFECTIVENESS GOAL ACHIEVMENT METHODS

This model is useful because the normalization of impacts allows evaluation of trade-offs between different goals. The required data can be in three forms: monetary units, physical units, and subjective terms. In comparison to cost-benefit analysis which works most effectively with strictly monetary values, the cost-effectiveness model can readily incorporate non-monetary impacts. Table 6-3 is a worksheet for using the method.

As an example of how to use the worksheet, let G_1 be maintaining economic growth at desirable levels and let G_2 be enhancing the quality of the national environment. Criteria for G_1 might be (a) maintaining an annual 5 percent growth rate in GNP, (b) maintaining unemployment level at 5 percent or less, and (c) allowing total import expenditures to equal export revenues. Criteria for G_2 might be (a) the reduction of quantifiable pollution costs by 50 percent, and (b) the increase of unquantifiable benefits to society (e.g., aesthetics and recreation) by 50 percent. As a next step, the following weightings could be assigned: $G_1 = 0.5$, $G_2 = 0.5$. The criteria within each goal must also be weighted. For example (a) = 0.25, (b) = 0.15, (c) = 0.10 for G_1, and (a) = 0.35, (b) = 0.15 for G_2.

Next, assume a pollutant removal efficiency criterion of 70 percent of uncontrolled suspended solids is selected for a given plant being investigated. Impacts on criteria are estimated, and the values normalized by expressing forecast impact as a percentage of the designated criterion values, and then dividing by 100 to obtain a score on a scale of 0 to 1.0. These normalized impacts are then multiplied by the weightings, and the subsequent steps are undertaken to calculate a cost/goals-achievement ratio. The process is then repeated, for example, for 60, 80, and 90 percent levels of removal of suspended solids.

DECISION AND PROBABILITY

Decisions concerned with pollution control options involve factors with uncertain outcomes. One method for taking this into consideration is to assign probabilities of occurrence to the uncertain factors based on statistical theory, past experience, or subjective estimates. Once probabilities have been decided upon, an expected value can be calculated.

A problem for the decision-maker is that two alternative levels of pollution control might have the same expected value, but one alternative may have a high uncertainty, while the other has an almost certain outcome. In this case, the question is whether the decision-maker should consider the extent of uncertainty, or make a decision based only on the expected value. Also, a low probability of an irreversible impact should probably be given more consideration than a low probability for a reversible one.

Decision Tree Probability Analysis.

An action can usually result in several possible outcomes depending on the occurrence or nonoccurrence of other "chance" or possible events. Decision tree probability analysis can be used to estimate and compare the total probable values of alternative decisions. Figure 6-7 gives an example illustrating the method. There are eight steps.

TABLE 6-3

GOAL ACHIEVEMENT/
COST-EFFECTIVENESS WORKSHEET

Plant: ABC Widget Company

Pollutant: Suspended Solids

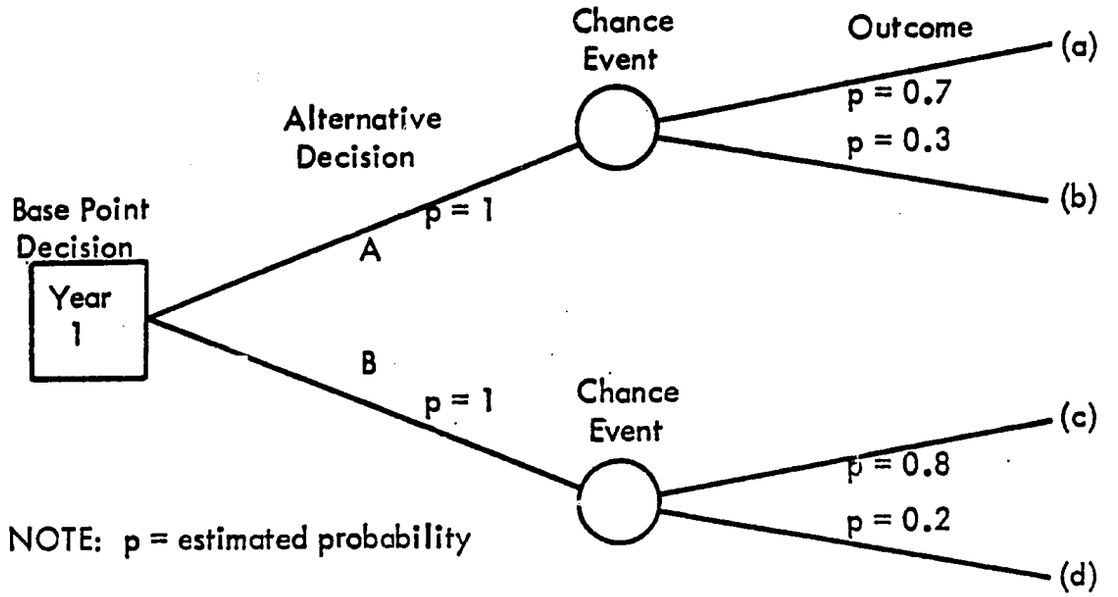
Pollutant Reduction: 70 %

Goals	Weight	Criterion	Weight	Forecast Impact	Normalized Impact	Total Weight[a]	Weighted Score
G_1	0.5	a	0.25	80	0.32	0.125	0.040
		b	0.15	20	0.08	0.075	0.006
		c	0.10	50	0.20	0.05	0.010
G_2	0.5	a	0.35	30	0.12	0.175	0.021
		b	0.15	70	0.28	0.075	0.021
Summary Score		0.098					0.098

Applicable Costs $500,000

Ratio (Cost/Goals-Achievement Effectiveness) $\frac{500,000}{0.098} = 5,102,041$

[a] Goal weight x criterion weight.



Item	Probable Outcomes ($1,000s)			
	Alternative Decision A		Alternative Decision B	
	(a) p = 0.7	(b) p = 0.3	(c) p = 0.8	(d) p = 0.2
Estimated cost	100	1,000	30	50
Probable cost value (est. cost x p)	70	300	24	10
Estimated benefit	50	10	500	10
Probable benefit value (est. benefit x p)	35	3	400	2

NOTE: Payoff equals the difference between total probable costs (including initial cost estimate where p = 1) and total probable benefits. The initial cost estimate for Alternative A is $50,000, and for Alternative B is $100,000.

Alternative A (a + b): $50,000 + $70,000 + 300,000 - $35,000 - $3,000 = $382,000 (probable total net cost value).

Alternative B (c + d): $400,000 + $2,000 - $100,000 - $24,000 - $10,000 = $268,000 (probable total net benefit value).

FIGURE 6-7

DECISION TREE PROBABLE VALUE METHOD

(1) For each decision, establish a single starting point (base decision point). This may represent an existing set of conditions, or a set of conditions at a future point (point of departure) date.

(2) Identify the alternative courses of action as lines branching from the base point.

(3) Identify each chance event that may occur; represent it as a circle (node) on the appropriate branch.

(4) Estimate the probability of the chance event occurring. Express each probability (p) as a decimal; the total of all outcome probabilities branching from any one node must equal one.

(5) Continue to identify subsequent decison alternatives and chance occurrences, assigning probabilities to the chance outcomes until the branches are complete, or carried as far as desired.

(6) Estimate the costs and benefits for each decision and each outcome from chance events on the tree.

(7) Calculate the probable values for alternative decisions and outcomes by multiplying each event probability by its estimated benefits and costs.

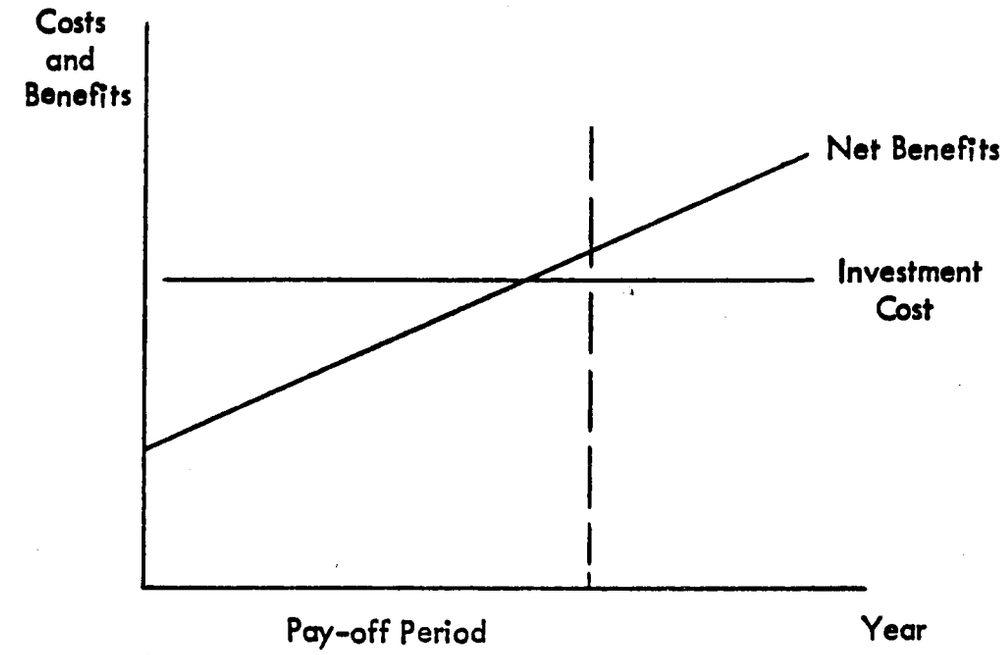
(8) Calculate the anticipated payoff (total probable net value) of each alternative decision: sum the probable values for each decision stage, and subtract as necessary to find the probable net cost or benefit value.

Pay-off Period and Break-even Analysis.

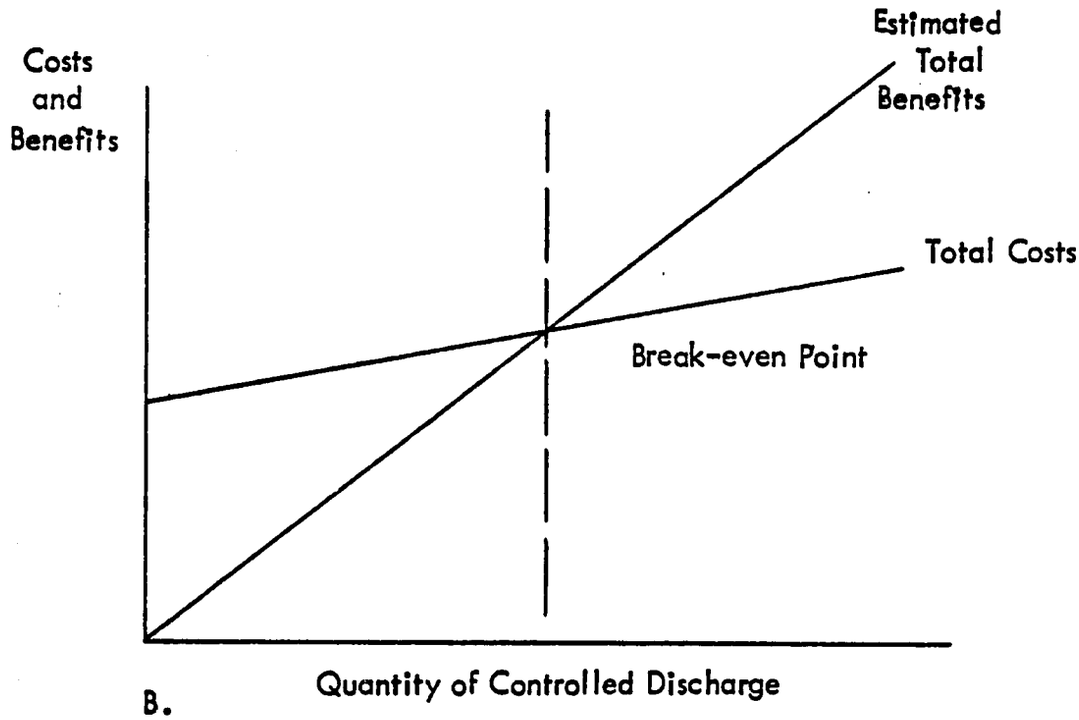
These two methods also allow for uncertainty. In payoff period analysis, pollution control programs are accepted only if the net benefits will equal the investment costs within a specific period of time. Little weight is given to what happens after the pay-off period. Figure 6-8a illustrates a project where the net benefits equal the investment cost within the allotted time. In a break-even analysis for industrial pollution control, the costs for given levels of control are determined. From this basis, a point is determined where the total benefits equal the total costs (see Figure 6-8a). After this point is determined, the total costs predicted must be assessed for their economic realism.

ENVIRONMENTAL CONSTRAINTS

This approach assesses alternative pollution control levels first for environmental suitability, then for economic efficiency (see Figure 6-9). The environmental constraints might be presented in a matrix (see Figure 6-10) which shows the impacts from alternative levels of pollution control. Weights can be assigned to each constraint according to its importance. The impacts of alternative levels of pollution control can then be estimated on either a quantitative or subjective basis and placed on a common scale. Before being multiplied by the weights, the impacts should be evaluated on a scale of -10 to +10, where 0 might be equal to either the constraint value or to baseline conditions. The weighted impacts can then be summed for each level of pollution control.



A.



B.

FIGURE 6-8
PAY-OFF PERIOD AND BREAK-EVEN ANALYSIS

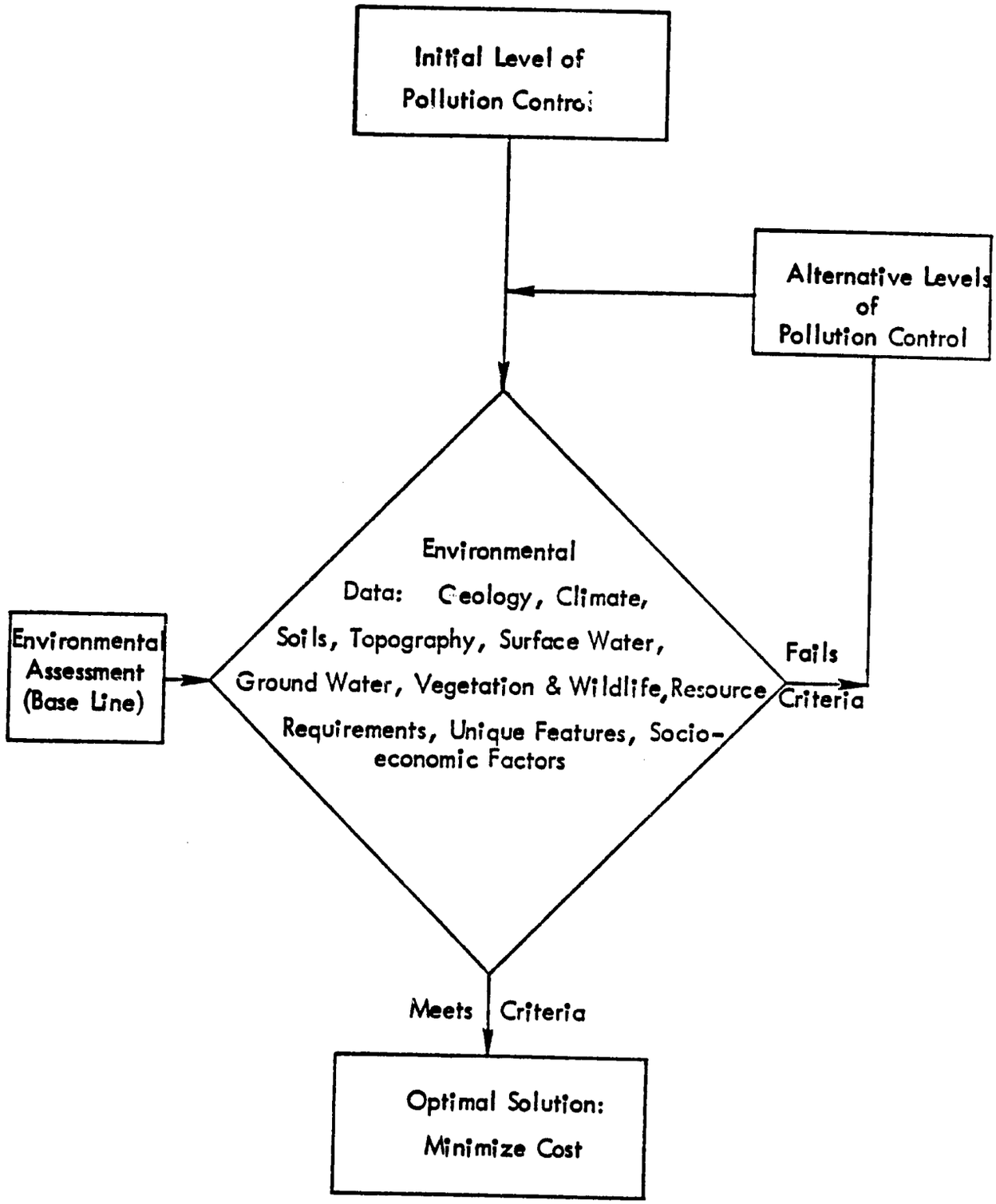


FIGURE 6-9

ENVIRONMENTAL CONSTRAINT MODEL

Environmental Constraints	Alternative Levels of Pollution Control					
	1	2	3	4	5	6
Geology	Impact / Weight					
Climate						
Topography						
Soils						
Surface Water						
Groundwater						
Vegetation & Wildlife						
Resource Requirements						
Unique Features						
Social Conditions						
Summary						

FIGURE 6-10

ENVIRONMENTAL IMPACT ASSESSMENT
FOR REGIONAL/NATIONAL DECISION-MAKING

This method gives an overview of the impacts of the proposed alternative pollution controls and also serves as a guide for more comprehensive evaluation.

SELECTING THE BEST ALTERNATIVE

When the alternatives have been identified and evaluated with one or more of the proposed methods, the final question remains: which alternative should be selected as the best? The ultimate purpose of any decision-making technique is to organize information so that the alternative which best meets desired goals is identified. Since goals and viewpoints will differ among the interested parties, most decisions will involve a fair measure of compromise and a gradual program of stronger pollution control.

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