

MARC REPORT NUMBER 42

An EIA Guidance Document

ENVIRONMENTAL IMPACT ASSESSMENT

OPERATIONAL COST BENEFIT ANALYSIS



MONITORING AND ASSESSMENT RESEARCH CENTRE

WORLD HEALTH ORGANIZATION

The Monitoring and Assessment Research Centre (MARC) is an independent international institute undertaking research on major environmental pollution problems. It is located in King's College London in the University of London and has been in operation since July 1975.

The objective of the MARC core research programme is to develop and apply techniques for the assessment of pollution problems of global, regional or local significance. The programme is mainly carried out by means of reviews which synthesize existing relevant knowledge from a wide range of disciplines.

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Environmental impact assessment

Operational Cost Benefit Analysis

by Frank C. Go

An EIA Guidance Document (1988)

Prepared jointly by



Monitoring and Assessment Research Centre
King's College London, University of London



World Health Organization

With the support of
Global Environment Monitoring System
United Nations Environment Programme

ISBN 0 905918 38 X

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Foreword

There is a growing awareness worldwide of the need to assess the implications for human health of many major development projects and policies. The belief that 'prevention is better than cure' was never more applicable than in the assessment of potential damage which can occur when implementing these projects, particularly in developing countries. Sound development planning and the application of acceptable guidelines are essential at the outset to avoid damaging health effects.

A series of major guidance documents has been developed at MARC in co-operation with the World Health Organization for the assessment of broad human health and welfare effects in the context of the Environmental Impact Assessment process. These documents highlight substantive issues relating to decision-making and the evaluation of impacts. The aim is to provide a compact source of references that gives a quick perspective of the important issues for different types of projects and information that helps to guide the evaluation of impacts and alternatives. Case studies will be outlined where possible to provide a practical perspective to the conceptual framework.

One set of guidance documents addresses the methodological issues and substantive problems of decision-making and provides background information. The second series of documents, also in the MARC series, will provide specific guidance relating to design proposals that focus on classes of projects that affect human health and welfare.

The documents are designed to assist health agency officials and decision-makers in developing countries in dealing with human health and welfare issues related to development projects. Graduate students gaining experience in effective impact management will also find the documents of use either in their training course or when they assume wider responsibilities for community development projects.

P. J. Peterson
Director

Introduction

Although cost benefit analysis (CBA) has been well accepted in certain public planning activities such as water resources development, its application to environmental impact assessment has not been widespread. Part of the problem is the inherent difficulty of quantifying environmental and health impacts, but it can also be ascribed to the fact that the role of CBA is frequently misunderstood. CBA does not eliminate the need for the political resolution of conflicting objectives, but it can assist the process of objective formulation and choice.

When the technique is used to address environmental impact, there are special problems. But even with all the limitations, CBA still provides a framework for ordering information. It provides a basis for an unambiguous trade-off between quantifiable benefits and unquantifiable values. Public health and environmental officials can promote the interest of human health and welfare more effectively when they can have a dialogue with development planners and engineers on common ground. This is provided by CBA. Where resources are limited, as in developing countries, it is even more important for these officials to analyse benefits and costs and have a mutual understanding of how trade-offs are made. Further, the framework can be an effective technique for health and environmental authorities to utilize when assessing the relative merit of different regulatory policies.

This guideline report concentrates on the operational aspects of applying CBA to evaluate projects when there are significant environmental impacts. It is addressed to the need for officials and planners in developing countries to have an overview of the subject and, perhaps even more important, to have a quick review of the operational problems of applying the technique to environmental and health impact assessment. Essential economic concepts relating to the application of CBA to human health and environmental problems are discussed. Examples and case studies are included to illustrate how CBA has been used for a range of problems. (For those who need or are interested in more detailed discussions on the theories and assumptions underlying CBA, standard textbooks and references listed in the Bibliography should be consulted. The literature on CBA is extensive, but is usually highly specialized.)

Even though CBA is typically inexact when many of the benefits are social and intangible (that is to say, cannot be measured) or are diffused

and are difficult to quantify and value, the process of systematic accounting of costs and benefits can contribute to informed decision-making.

It is believed that an appreciation by planners and engineers of the utility of CBA in the evaluation of environmental impact is one of the effective ways to bring about an overt consideration of human health and welfare impacts in development planning. Health authorities also need to be familiar with this operational tool if they are to play their advocacy and advisory role since they need to understand the project proponent's viewpoint.

I Rationale for CBA

All public sector decision-making implicitly involves a balancing of costs against benefits. CBA is a quantitative approach to evaluate and rank projects on the basis of economic efficiency. The aim is to show how resources can be channelled into projects which will yield the greatest net benefit to society (Pearce 1971). In principle, the measuring rod is taken to be monetary value. It is assumed that this is at least a first approximation of social welfare. However, because CBA concentrates only on the economic efficiency objective and does not deal with distributional equity or other desirable goals (such as environmental quality) which society may wish to promote, it cannot be used as a sole criterion for decision-making. Thus, broader frameworks for ordering information, such as the Environmental Impact Statement (EIS) have been evolved. CBA in the context of this broader policy analysis provided by the EIS serves as the quantitative element of the evaluation process.

Despite the limitations of the framework and uncertainties in the calculations of benefits and costs, the technique provides a basis for judging whether a project is worth carrying out on the basis of a social objective function (i.e., maximizing net social benefits) and to what scale a project or policy should be carried out.

CBA is generally inappropriate for dealing with strategic issues such as ranking of projects across sectors. For example, it does not address choice-making between public health and transportation spending programmes. The technique is best in dealing with investment decisions at the 'tactical level' where the alternatives to be examined have the same objective.

II Theoretical foundation

The literature on CBA dates from the publication by J. Dupuit in 1844 of his essay *On the measurement of the utility of public works*. Dupuit's contribution to economic thought was the concept of the consumer's surplus or willingness to pay. This idea led directly to the concept of social benefit which is basic to CBA. The application of CBA to public projects was first mandated by the U.S. Flood Control Act of 1936. This Act declared that benefits "to whomsoever they may accrue" of public projects should exceed costs.

The theoretical basis for CBA is based on neoclassical economic theory which emphasizes the philosophy of consumer sovereignty. Social welfare is determined by the sum of individual preferences, in which equal weight must be given to each person's view (Cooper 1981; Pearce and Nash 1981; Hufschmidt *et al.* 1983). The objective of CBA is to assess the relative economic merit of the outcome of different alternatives. The choice criterion used for judging the preferred outcome is the maximization of monetary benefits, without regard to who wins or loses. This is taken to mean there is an increase in welfare provided those who lost can be compensated. This postulate is known as the "Potential Pareto Superiority Criterion". Clearly, value judgements are needed to assume that the monetary equivalents of welfare for different individuals can be aggregated and compared and that any change in income distribution is still acceptable (Eckstein 1976; Hufschmidt *et al.* 1983).

Quantitatively, the technique amounts to choosing the alternative yielding the largest net benefit. Evaluation of a project is based on a comparison of the resulting benefits to the condition without the project.

III Operational elements in CBA

CBA is a structured and systematic approach to estimate gains and costs between alternatives. The framework for analysis is composed of five elements common to all problems. These are summarized by McKean (1966) as follows:

1. objectives, or the benefits to be achieved;
2. alternatives, or the possible systems for achieving the objectives;
3. costs, or the benefits that have to be forgone if one of the alternatives is to be adopted;

4. models, or the sets of relationships that help one trace out the impacts of each alternative on achievements (that is, benefits) and costs;
5. a criterion, involving both costs and benefits to identify the preferred alternative.

The quality of a CBA is dependent on how well the first two operational elements are conceived and elaborated.

IV Decision criteria

A project typically involves streams of costs and benefits over time. To compare money amounts at different times, future values have to be discounted to a reference point in time, usually the *present*. Discounting reduces future benefits and costs to smaller 'present values' in a way that reflects the time preference for money, i.e., future costs and benefits are weighted less than those accruing earlier. CBA is most commonly carried out with present values.

The most popular and commonly used criteria for determining the economic merit of a project and for ranking alternatives are the net present value (NPV), the internal rate of return (IRR) and the benefit cost ratio (B/C). These criteria are reviewed and problems associated with their use examined.

1 Net present value (NPV)

$$NPV = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1+r)^t}$$

given: B_t = benefit stream, C_t = cost stream and r = discount rate.

The NPV is the most appropriate measure for comparing the relative economic efficiency between public investment alternatives. The principal problem associated with using the NPV method is the determination of the appropriate discount rate. The decision rule is simply to choose the project with the largest NPV. When applied as a test of economic feasibility, a project or plan is accepted if its NPV is positive—the benefits of the undertaking outweigh its costs.

2 Internal rate of return (IRR = Ω^+)

The internal rate of return is the discount rate which equalizes the present values of the benefit and cost streams over the life of the project. It is

calculated by setting the NPV equal to zero.

$$NPV = 0 = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1 + \Omega^+)^t}$$

The IRR (Ω^+) has been popularized by some financing institutions but is inferior to NPV as a criterion for choice-making and under certain conditions can lead to different conclusions from the NPV criterion. The decision rule and problems in using this criterion are best illustrated graphically.

(i) *Decision rule*

The criterion requires that for an investment to be justified, the calculated IRR must exceed the prescribed social discount rate. Where multiple alternatives are being evaluated, ranking is made on the basis of the magnitude of the internal rate of return. The higher the IRR, the better the project.

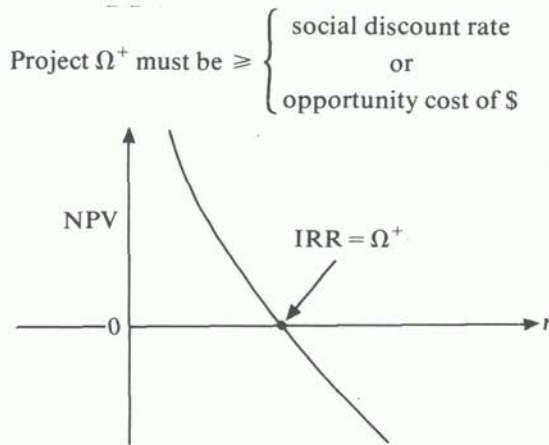


Figure 1 Graphical illustration of IRR

(ii) *Conflict between IRR vs NPV ranking of projects when r_1 is the appropriate discount rate*

In Figure 2, project (A) is superior when the IRR criterion is used for ranking since $\Omega^+(A) > \Omega^+(B)$. Using the NPV criterion on the other hand would reverse the ranking as the NPV for project (A) is, in fact, larger than that for project (B) when the prescribed discount rate is r_1 .

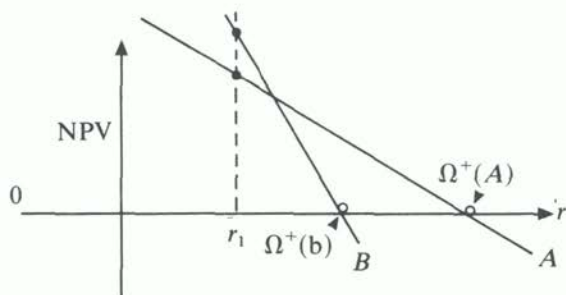


Figure 2 Illustration of conflict between the IRR and NPV ranking of two projects (A) and (B)

Thus, ranking of projects according to the internal rate of return will not invariably yield reliable results.

The IRR is also sensitive to the length of a project's economic life, inflating the returns on short-life projects compared with those with longer lives. It similarly will discriminate against projects which do not yield benefits during the early years (Pearce 1971). Still another disadvantage of the method is that multiple and/or undefined solutions are possible.

An argument in favour of the IRR criterion is, however, that decision-makers are accustomed to thinking in terms of rates of return, so that percentages have more meaning to them than the absolute magnitudes provided by the NPV method.

3 Benefit-cost ratio (B/C)

$$B/C = \sum_{t=0}^{t=n} \frac{B_t}{(1+r)^t} \bigg/ \sum_{t=0}^n \frac{C_t}{(1+r)^t}$$

There is no theoretical basis for using benefit-cost ratio (B/C) to rank projects. The ratio gives benefits per unit cost. Thus a smaller project can yield a higher benefit-cost ratio even though its NPV may be less, which violates the criterion for maximizing the net benefits. However, in the absence of a budget constraint, all projects where $B/C > 1$ should in principle be carried out. The rationale here is that all projects meeting this criterion are assumed to be carried out in the private sector. Thus, as long as $B/C > 1$, a transfer of resources from the private sector to public use will result in a social welfare gain.

Another problem with using the benefit-cost ratio is that the outcome depends on whether a cost is deducted from a benefit or added to other costs. This is why the total benefit-cost ratio is distorted from the net benefit-cost ratio and why it underestimates the productivity of projects with high annual cost in relation to initial investment (De Neufville and Stafford 1971).

While it is inappropriate to use the total discounted benefits and costs to rank alternatives, the incremental benefit-cost ratio can be used. Incremental benefits and costs generally refer to increases resulting from incremental increases in project scale. For example, when considering two mutually exclusive projects and the smaller project has a $B/C > 1$, the larger is selected if the incremental benefit-cost ratio is larger than

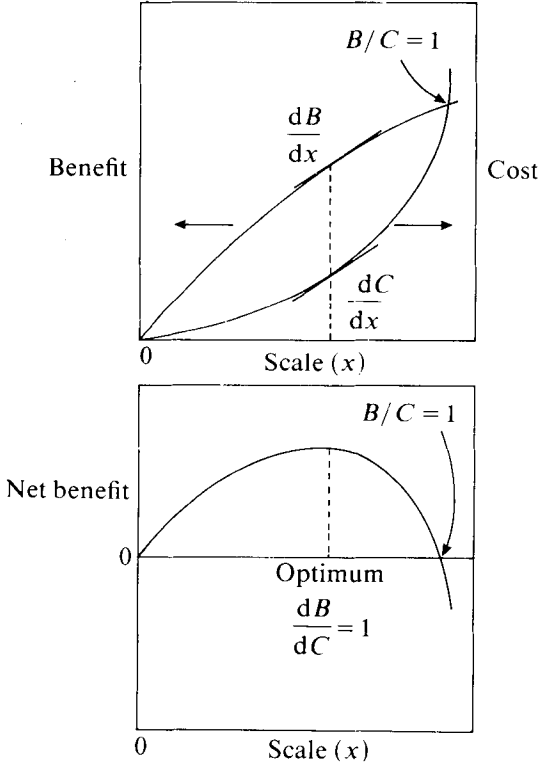


Figure 3 Choice criterion for optimum scale

one (i.e., the additional benefits generated by increasing the project scale exceeds the additional costs). The method in principle amounts to the application of the NPV criterion of maximizing net benefits. This is demonstrated graphically in Figure 3 when determining the optimum scale of an activity or project. It is seen that the NPV is maximized at the scale where the marginal benefit (dB/dx) equals the marginal cost (dC/dx), which is the rule employed in the incremental benefit-cost method. Thus, in the absence of a budget constraint, an activity should be carried out until its marginal benefits just equal its marginal costs. This decision rule provides a basis for setting environmental standards and control strategy when the cost-of-damage can be appropriately valued in monetary terms.

V Independent or interdependent project

When the net present value of a project is unaffected by decisions relating to other projects, it is said to be independent. Under this condition and in the presence of a budgetary constraint, it is appropriate to rank a series of proposals by the benefit-cost ratio as illustrated in the following example.

Example Budget constraint $C_0 = 10$

Project	Cost	NPV	B/C
A	10	10	1
B	2	3	2
C	2	5	4
D	2	3	3
E	2	3	2
F	2	2	1
G	2	2	2

Project ranking by NPV	Cost	Project ranking by B/C	Cost
A	10	C	2
C	2	D	2
B, D, E	6	B, E, G	6
F, G	4	A, F	12

} = 10

In this situation, ranking by NPV would have allowed only the implementation of project 'A', yielding net benefit value of 10. But by using B/C ranking, projects C, D, B, E, and G would be implemented, with net benefits to society = $5+3+3+3+2=16$. Thus, ranking by B/C maximizes the combined NPV of the projects chosen and is the correct decision rule.

However, when several projects are to be selected from among many proposals and their benefits and costs are interdependent, ranking by definition involves finding the possible or feasible (when there is a budgetary constraint) combinations of projects that will yield the largest NPV.

VI Summary of decision rules for CBA

Independent Projects

Choice problem	Budget constraint	Decision rule
To accept a project	none	$NPV > 0$
To select one among many alternatives	none	maximize NPV
To select the optimal scale	none	set $\frac{dB}{dC} = 1$
To select several among many alternatives	none	rank by $NPV > 0$
To select several among many alternatives	yes	rank by $B/C > 1$

Interdependent projects

Choice problem	Budget constraint	Decision rule
To select several among many alternatives	none	find possible sets that maximize NPV
To select several among many alternatives	yes	find feasible sets that maximize NPV

VII Concept of benefits and costs

The valuation philosophy of CBA is that the social value (that is, benefits) of a project is the sum of the benefits to the individual members of

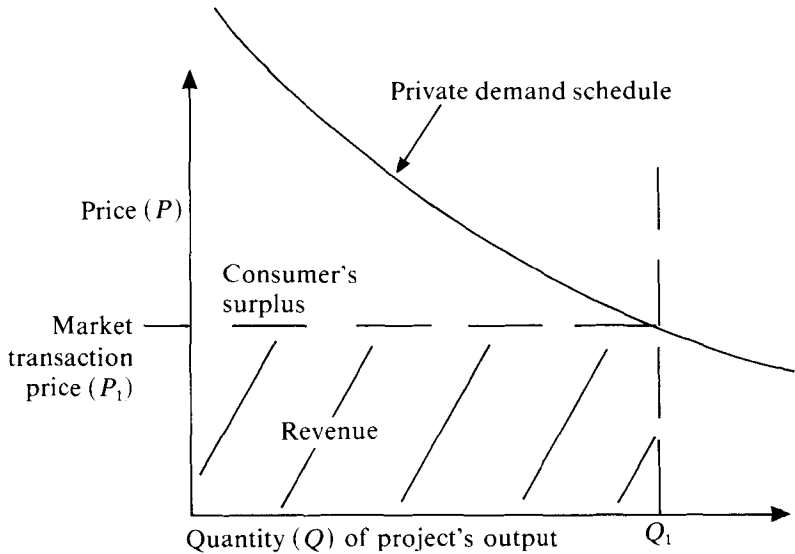


Figure 4 Quantification of benefits

society. The value to an individual is in turn equal to his 'willingness to pay' (WTP). Thus, the market price represents the willingness to pay *only* for the last unit of a project's output (see Figure 4).

The demand schedule (Figure 4) shows the willingness to pay for different levels of output from a project. Since environmental goods such as a community water supply or health protection measures confer collective benefits in addition to providing individual benefits, there is usually a divergence between private and social benefits. These collective benefits which are not perceived by individual consumers and are more highly valued by society as a whole are called 'external effects' or 'externalities' because they are not captured through market transactions or private accounting of benefits. Valuation of environmental 'goods' and 'bads' is usually complicated by this 'market failure' problem. Accordingly, the value of the social benefits due to a project's output is not limited to the sum of the willingness to pay (i.e., the project's revenue plus the consumer's surplus) but includes the value of the 'externalities', when they exist.

More generally, externalities arise when a project or activity causes benefits or costs (i.e., damages) to others who are neither charged nor

compensated for them. Since there is an absence of markets, many external-effects problems reduce to the issue of valuing 'intangibles'.

When demand is elastic (that is, responsive to small price changes), the consumer's surplus is proportionately small and the benefits valued by the market prices are good estimates of social value. Generally, this situation would be relevant, however, only if the project's output is small in relation to the total market of the good or service, a situation unlikely to be true almost by definition for most public undertakings. (The price elasticity of demand is defined by economists as the ratio of the percentage change in quantity demanded to a specified percentage change in price, i.e.

$$\eta = -\frac{dq}{dp} \frac{p}{q}$$

Clearly, the price elasticity (η) will generally vary from one point to another on the demand schedule.)

The demand functions for goods which cannot be easily substituted, such as a municipal water supply, are generally inelastic. This is because the demand does not respond to small price changes. In this situation, the consumer's surplus can be significant and may outweigh the revenues recouped from user fees. Studies conducted on consumption patterns of communities before and after water rates were increased by Katzman (1979) on Penang Island, Malaysia, for example, indicated the consumer's surplus was 150 per cent greater than the revenues generated by the water system. Thus, cost-revenue analysis, although essential for testing the financial feasibility of water supply projects, underestimates the benefits. The relative inelasticity of water supply demand is the reason why a water utility can always increase its overall revenues by increasing the water tariff.

Consumer's surplus can also be estimated from rent differential and land value changes. Bahl, Coelen and Warford (1973) estimated from time series data that investment in water supply and sewerage results in an increase of from 35 to 60 per cent in land value. They also showed increases of 20 to 50 per cent as a result of sewerage investment in Nairobi, Kenya. Katzman (1979) estimated a 36 per cent increase in rental value of dwellings in Penang resulting from the availability of municipal water supply.

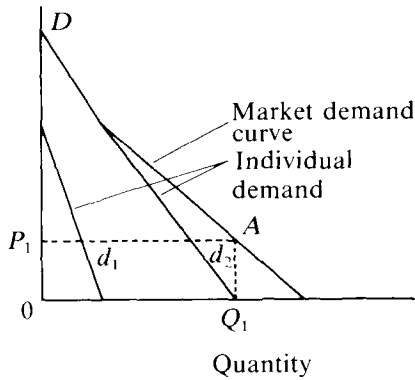
As a rule, whenever the output of a project is 'large' in relation to the total market, substantial social benefits are likely to be missed when the

consumer's surplus is ignored. This is because the project itself will increase supply sufficiently to drive down the market price. Eckstein (1976) states that the social benefits in this case will be somewhere between the limit of the output price without the project and the output price with the project and if "the change is not extreme national benefits can be approximated by applying a price which is an average of the two to the increase in output. If the change is very large . . . better approximations can be derived by dividing the demand into segments and seeing at what price the different segments can be sold".

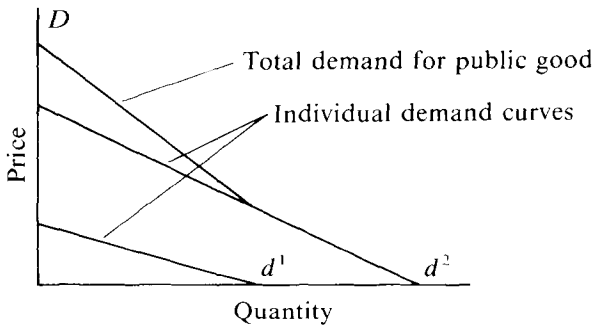
A drinking water supply is considered primarily to be a 'private' good as it is divisible and the benefits can be limited to the users of the good, even though a community water system *also* yields collective benefits. For these types of goods or services, the overall (i.e., the market) demand curve (Figure 5a) is derived by aggregating the individual demand curves horizontally since the consumption is additive.

Environmental 'externalities' on the other hand are typically 'public' goods because they are not divisible which means that their benefits (as well as disbenefits) cannot be limited to individual users, but extend to many persons or the general public. Examples are public health, clean air and landscape aesthetics. Accordingly, since the 'exclusion' and 'rivalry in use' principles do not operate, the total social demand curve (Figure 5b) is obtained by summing the individual demand curves vertically. It is important to stress that what are being added are areas under individual demand curves, that is to say, the summation of consumer surplus or the value in use for each consumer (Davidson 1972). Thus, the total benefit of a public good (say, the reduction of air pollution by 50 per cent) equals the collective sum of all that individuals would pay for the good. In contrast, the total benefit in the production of a private good includes only the value in use of those consumers who are willing to pay the market price for the good.

Since public goods are indivisible, a method for quantifying benefits without appeal to market demand must be adopted. Either some observable index (for example, changes in property values due to environmental improvement) must be used or reliance placed on independent judgement. Thus, unlike private goods, decisions about the impact of a public 'good' or 'bad' must rely on the political process (Davidson 1972; Dorfman 1972). Attempts to value the benefits of public goods through surveys are usually fraught with difficulties. People will not reveal their 'willingness to pay' voluntarily if they believe that the amount they pay



(a) Demand for a private good



(b) Demand for a public good

Figure 5 Valuation of public vs private good
Source: Davidson (1972)

(for example, tax assessment to support pollution control activities) will be related to the preference they reveal. Consumers will find it worthwhile to be 'free riders' (Dorfman 1972; Milliman and Sipe 1979).

Costs related to resource inputs are generally more easily identified but are not always simple to determine. Further, when there are substantial market imperfections (not an uncommon situation in developing countries), 'shadow' or accounting prices which reflect true social values must be used in lieu of 'market' prices when evaluating the 'cost' of the resources to be utilized in a project. (Such adjustments are, however,

usually extremely difficult to calculate and the advice of professional economists or the national economic planning authority will have to be sought).

The 'end-of-line' pollution control solutions usually present fewer problems. In this situation, filters and other control facilities are merely added to the production process without any change in inputs. Costs are accordingly the sum of the control facilities plus the operating expenses. Any benefits, such as recovery of by-products, are added to the benefit side of the equation.

However, when 'in-plant' changes are made, such as the use of a different technology, or when products are substituted to reduce pollution, costing can become very complex. This is because the impact can include effects on operating efficiency and personnel employment.

A few observations that can be made about pollution control costs are:

- there is a high degree of variability even within the same industry
- there are usually economies of scale
- cost accelerates rapidly when the degree of control reaches a level of about 70 to 90 per cent of the removal of pollutants

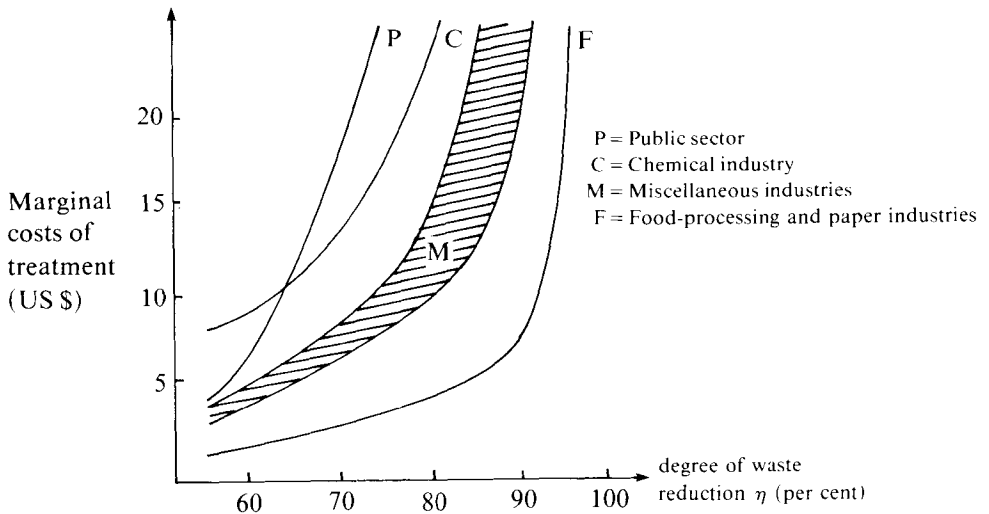
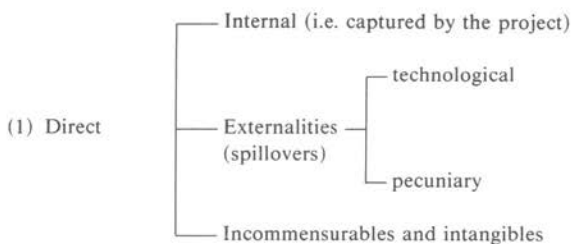


Figure 6 Examples of marginal cost functions for wastewater treatment for different industrial sectors

Examples of marginal cost (i.e., cost of an additional unit of production) functions for waste-water treatment plants from West German investigations are shown in Figure 6 (WHO/PEPAS report by H. Karpe).



(2) Secondary or Indirect — generally either 'stemmed from' or 'induced by' project activities i.e., increased production of project inputs, increased employment, etc.

Figure 7 Types of benefits and costs

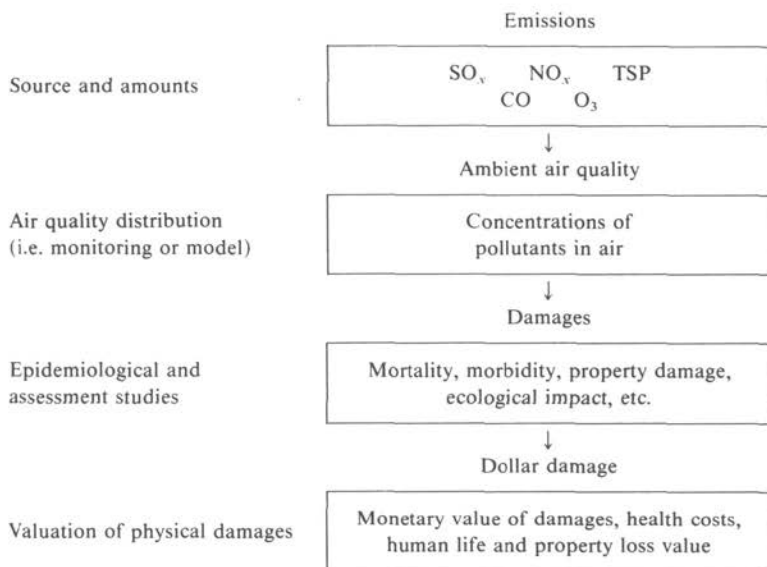
Benefits and costs are formally classified in CBA as shown in Figure 7. Pecuniary benefits and costs are effects due to changes in relative prices resulting from the activities of a project. These primarily affect income distribution and can be ignored. Similarly, secondary effects are generally also of a pecuniary nature and should be disregarded in periods of economic balance (McKean 1968; Eckstein 1976).

Technological spillover (externality) effects and the intangibles are the main concern of an EIA.

VIII Estimating benefits and costs of environmental impact

The distinction between benefits and costs due to environmental impact depends on the reference point from which environmental changes are measured. Benefits are damages avoided when public programmes are undertaken to abate or reduce pollution and other hazards. Costs are damages (or adverse social impacts) resulting from the effects of a project.

Estimating environmental and health impact in monetary terms involves at least four steps as shown in Figure 8. In the illustrated case for air pollution, source emissions can be approximated with relatively good accuracy. Analysing the time pattern of exposure of humans and other receptors to air pollutants is, however, plagued with practical difficulties and uncertainties. Translating exposure estimates to human health and



Adapted from: Milliman and Sipe

Figure 8 Steps in estimating damages due to air pollutants

other effects requires dose-response relationships that are still inadequately defined so that estimates should be treated only as order of magnitude indications (see Lave and Seskin 1977).

Converting physical damages such as crop losses and damage to properties to monetary units is fairly straightforward. Quantitative valuation on the impact on human health due to increased risk of morbidity and mortality, however, presents special difficulties.

Although many analysts and public policy makers question placing a monetary value on human mortality or disease probabilities, these trade-offs do occur in public decision-making. For example, decisions on expenditure for public health protection and other life saving programmes implicitly involve this type of consideration. The approaches that have been proposed for placing values on human health effects include:

- (1) Income forgone;
- (2) Savings in health care costs; and
- (3) Willingness to pay for reducing risk of disease.

(Mooney 1978; Freeman 1979; Brady and Bower 1981.) In economic theory, the correct *conceptual* basis for assigning monetary values is the 'willingness to pay' for a small reduction in health risk when a project is undertaken to reduce health hazards or, alternatively, the 'willingness to accept compensation' when an increased risk to health is imposed by pollution. In *practice*, risk of disease that is not life-threatening is usually valued by estimating its direct costs (i.e., lost earnings and medical expenses), unless it is feasible to use a willingness to pay measure (Freeman 1979; Snyder 1985). A commonly suggested source of information for valuing mortality risk is expenditure on public programmes to save lives. This is, however, circular since values are derived from past decisions. Further, the range of values that have been observed (in the U.S.A.) has spanned three orders of magnitude (Fisher 1981). Another source of information is values derived from wage risk studies. Direct surveys of people's willingness to pay for a programme carrying a specified reduction in probability of loss of life have also been attempted, but results varied widely. Where no information on 'willingness to pay' is available, forgone earnings and medical costs have been used as estimates of the economic value of mortality, *but* the measure is based on a productivity concept rather than consumer's sovereignty. Fisher (1981) states that "It may be useful, as a lower bound, where no better information is available."

Hufschmidt and Hyman (1982) state, however, that the approaches proposed are all unsatisfactory measures of values when involving risks of health and premature death for low income people. They suggest two possible approaches for developing countries: use a shadow value for premature death based on some arbitrary amount greater than the wage rate; or avoid attaching monetary value altogether and simply quantify mortalities and morbidities in explicit non-monetary terms. Basically, the suggested approaches thus amount to leaving the weighing of these values to the political process.

IX Cost effectiveness analysis (CEA)

Shortcomings in techniques for the monetary evaluation of benefits, such as those related to environmental quality, health, and most other public goods often preclude the use of formal CBA.

Under such circumstances, a variation of CBA known as cost effectiveness analysis is used. The technique is a form of CBA with stipulated

objective(s). The analysis is to find the optimum solution (that is, most cost effective) to achieve the objective(s):

Goal setting—to optimize benefits subject to cost constraint

or—to minimize cost to achieve a given level of objective(s)

Even when it is not possible to specify explicitly a level of objective(s), the CEA approach can still be used to evaluate and test different alternative solutions. An example (Luken and Ostro 1985) is the U.S. EPA's evaluation of alternative strategies for controlling inorganic arsenic emissions from copper smelters.

In this situation, three options were considered by the Agency:

1. Require all existing smelters emitting inorganic arsenic at a rate of 6.5 kg/hr or greater (6 out of 14) to install control systems for converter operations at a combined annual cost of \$8.6 million.
2. Select plants to be controlled based on their proximity to the size of the population at risk. Sources would be divided into high density (10,000 people or more living within 20 km of the plant) and low density (fewer than 10,000 people). High density smelters with inorganic arsenic emission rates greater than 25 kg/hr and low density smelters with rates greater than 35 kg/hr would be required to install control systems. This option would require only three plants to install controls.
3. Control all sources whether they pose unacceptable individual or population risk. Sources with emissions resulting in unacceptable combinations of individual and population risk would be subject to regulation.

The results of the analysis are tabulated in Table 1. Inspection of the values shows that for approximately the same level of health protection (that is, remaining individuals at risk and lives saved), option 2 was the most cost effective and thus the preferred solution.

Figure 9 shows another example of CEA when benefits cannot be explicitly enumerated. In this case, the benefits due to the reduction of water pollution from the control of combined sewer overflow were difficult to estimate and the outcome would have depended on various assumptions. However, it was possible to determine the additional days when water quality would meet the standard for body contact recreation when various levels of controls are instituted.

Table 1 Benefit analysis for inorganic arsenic provides additional criteria for regulatory decisions

Regulatory criteria	Number of plants regulated	Annualized control costs (\$10 ⁶)	Highest remaining individual risk	Lives saved	Implicit cost/life saved (\$10 ⁶)
(1) Cost-effectiveness	6	8.6	3.8×10^{-3}	0.23	37
(2) Population density	3	3.4	3.8×10^{-3}	0.22	15
(3) Risks to individuals	5	7.9	3.8×10^{-3}	0.39	20

Source: U.S. Environmental Protection Agency. "National Emission Standards for Hazardous Air Pollutants: Proposed Standards for Inorganic Arsenic." Federal Register 48(140) 33112-33180 (July 20, 1983).

Source: EPA seminar publication: Benefit Analysis for Combined Sewer Overflow Control (1979)

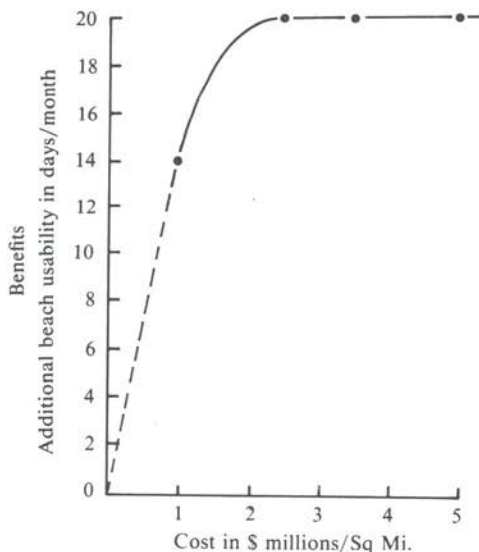


Figure 9 Relation between costs and benefits

Because the benefit measure (that is, additional beach usability in days per month) is not monetized, it is not possible to determine the optimal solution. However, the graph shows clearly the cost effective range does not extend beyond \$2 million where the effectiveness of control diminishes rapidly.

When an evaluation involves a combination of approaches to control pollution or attain other objective(s), the least cost strategy can be found geometrically by the use of isoquant lines and isocost lines. The method of solution is shown in Figure 10. Isoquant lines show different combinations of inputs which can produce equal amounts of an output (for example, the percentage of removal of pollutants). Isocost lines indicate the input combinations that can be purchased by a given budget. Production of a given level of output with the least cost combination of resources occurs where an isocost line is tangent to the isoquant.

In the illustration, the curved lines (isoquants) represent different combinations of pollution control alternatives (A) and (B). The straight lines (isocost) represent different levels of budgetary constraint. The expansion path is the locus of optimal solutions for different levels of pollution control. Points on the path represent the *minimum cost combination* of alternative (A) and (B) required to obtain any given level of pollution reduction. These optimal solutions can be transformed into a cost effectiveness function as shown in Figure 11 which can then be inspected to determine the cost effective range for control.

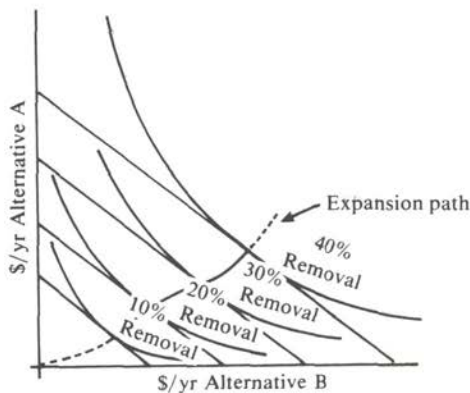


Figure 10 Optimum combination of control alternative (A) and (B) for specified level of achievement

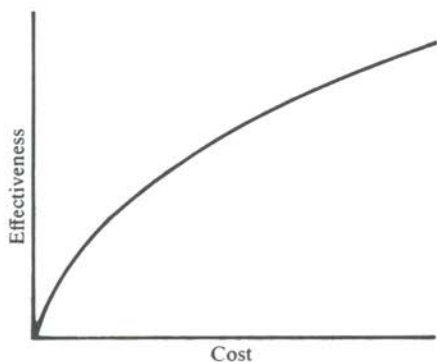


Figure 11 Cost-effectiveness function

X The discount rate

As the aggregation of costs and benefits over time is accomplished by computing the net present value of a project, the rate of discount used in CBA is a crucial parameter. It will affect whether the NPV is positive or less than zero and thus whether a project passes or fails the test for economic acceptability. Although less obvious, the rate can also affect the ranking order of alternative projects. Whether the discount rate is or is not significant in this regard depends on the comparative time streams of benefits and costs of the projects. Thus, CBA results should always include sensitivity analysis to evaluate the impact of a range of discount rates on the outcome.

Conceptually, the correct social discount rate (SDR) of public projects is that rate which, when applied to future benefits and costs, yields their present social values. In other words, it is the rate at which society collectively is willing to trade off present for future benefits and costs.

There are two primary viewpoints on how the social discount rate is to be estimated. One school of thought suggests that the SDR for use in public projects should reflect the pre-tax rate of return forgone on physical investments in the private sector. These advocates thus favour using the opportunity cost of capital, stressing that a public project must yield comparable return as private investments when resources are limited. The other school of thought argues that the SDR should reflect society's preference for present benefits over future benefits (or alternatively society's feelings about providing for the future as opposed to current

consumption). In addition to these two primary arguments, other approaches have been advanced, including the use of some weighted average of the opportunity cost of capital and the social time-preference rate (see Pearce and Nash 1981 or Howe 1981).

In theory, if there were no market imperfections, the rate of profitability on marginal private investments should equal the rate of return needed to induce people to save, i.e., the opportunity cost of capital would be the same as the social time-preference rate (Howe 1967; Marglin 1967; Pearce 1971). The two rates diverge and according to Baumol (1969) will not come into equilibrium because of the existence of risk and institutional barriers.

Hirshleifer, Dehaven and Milliman (1960), Baumol (1969) and Howe (1971) advocate using the opportunity cost of capital when evaluating public projects. Pearce (1971) argues, however, that "the correct presentation of the opportunity cost argument requires that the rate of return on the forgone project be measured in terms of social values." Thus, the discount rate used to evaluate a public project's merit should be lower than the rate of return available from investments in the private sector when there exist significant negative externalities (since the private rate would not have reflected the 'external' social costs).

In practice, the discount rate employed in the evaluation of public projects is typically imposed politically (Sassone and Schaffer 1978). Support for this position by some economists is reflected in the following comments by Nath (1969):

"There is no reason why the rate of national savings or the social rate of discount needs to be derived from anything, any more than there is any reason why the social expenditure on the old age pensioners needs to be derived from anything. They can be made to appear as though they are derived from something—e.g. on some very simplifying assumptions . . . the social rate of discount can be derived from the postulated rate of economic growth and the assumed marginal productivity of capital—but there is always a basic value judgement one step removed; . . . hence we must conclude that the social rate of discount and the rate of national savings have to be directly decided upon like any other element in a decision making or comment making social welfare function."

As an example of a government imposed policy, the rate for publicly financed water projects in the U.S.A. was specified by the Water Resources Development Act of 1974 as follows:

“... the interest rate ... shall be based upon the average yield during the preceding fiscal year on interest-bearing marketable securities of the United States which, at the time the computation is made, have terms of 15 years or more remaining to maturity: *Provided, however*, that in no event shall the rate be raised or lowered more than one-quarter of 1 per cent for any year. The average yield shall be computed as the average during the fiscal year of the daily bid prices.” (Federal Register 1974, p. 29243).

According to Fisher (1981), “one way of dealing with differing views about the discount rate, hence the weight accorded future impacts, is to examine the effects of varying the rate. Where there is uncertainty or controversy about the magnitude of an important parameter, such as the discount rate, this sort of sensitivity analysis is particularly appropriate. Less formally, information about the distribution of benefits and costs over time is likely to be relevant to a political decision and ought to be included in the evaluation of a proposed environmental standard or policy.”

In the context of developing countries where there is typically a scarcity of capital and people have low incomes, both the opportunity cost of capital and the social time-preference rate are relatively high. Under the circumstances, high discount rates will tend to be imposed on CBA. This situation has the following effects on environmental and health considerations: to the extent that environmental pollution control is a capital intensive activity producing benefits over a long period of time in the future, high discount rates reduce the weight given to environmental and health returns; similarly, environmental damages and latent health effects that occur in the distant future will also have a low present value and thus a minimal effect on reducing the attractiveness of a polluting project. Pearson (1982) states that “higher discount rates imply lower pollution abatement standards.” In order to make environmentally disruptive projects less attractive, he suggests that developing countries might consider factoring in the *increasing* costs of environmental deterioration over time as one alternative.

XI Time horizon

English (1978) states that “the time horizon is taken as the planning period beyond which the uncertainties of the future are such that any costs or benefits arising from a project are so unpredictable that they are

deemed to be better ignored." He further states that in general, the futurities of many predictions are necessarily short and therefore the horizon time may be much shorter than the long-range effects of the decision.

In practice, as the present worth of benefits and costs that occur beyond 20 years in the future drops off rapidly and usually becomes insignificant for the typical discount rates used in CBA, this factor usually sets the time horizon for analysis. For example, when the social discount rate is in the range of 5 to 10 per cent, benefits and costs beyond 50 years become immaterial. At 12 per cent, effects after 25 years become relatively insignificant in terms of present worth. Thus, because developing countries are typically faced with opportunity cost of capital exceeding 12 per cent, a 20-year time horizon is commonly used.

XII Inflation effects

When there is a general inflation of price levels, all relative prices should remain the same. In this case, it is appropriate to estimate prices in constant dollars in terms of a base year price index. The effects of inflation are assumed to be reflected in a premium being added to the real marginal rate of return on capital. Thus, to be consistent, the discounting of the benefit and cost streams should be based on the non-inflationary discount rate. Alternatively, projected nominal prices and discount rate can be used (Hanke, Carver and Bugg 1975).

The CBA results for either method will be the same.

XIII Summing-up

Decisions involving environmental impacts entail hard choices among related, and often competing, societal objectives. Despite its limitations, CBA or cost effectiveness analysis can be a useful tool in helping to make these choices, because it provides a framework for decision-makers to identify and evaluate trade-offs between alternatives.

Even when environmental statutes explicitly give primacy to concerns for public health, safety and well-being, the regulations usually give recognition to the need to use economically achievable solutions in devising pollution control strategies. The need for judgement about the relationship between costs and benefits is thus implicit. CBAs are attempts to compare these benefits and costs.

No claim is made that the CBA framework can fully take into account all social/environmental concerns or that decisions can be made without interacting with the political process. The technique is primarily an analytic tool to test the economic feasibility of a project. The central economic problem addressed is that of resource allocation.

The stress of the report throughout is on the operational problems of applying CBA to environmental assessment problems and the economic concepts required for the application of the technique.

Ultimately, government agencies in deciding on programmes that can affect human health and the environment have to make value judgements. CBA provides only a framework for quantitative analysis. But as observed by Bower, Brady and Lakhani (1982), "these judgements are likely to be better, in the sense of getting closer to efficiency in resource allocation, if they are informed by estimates of the values which individuals place on factors that affect their health and well-being. In a world where environmental standards and energy related concerns must increasingly be capable of passing cost- and efficiency-minded agencies . . . , serious attention to commensurate measures of value does not seem out of place." They further provide the following comments and guidance on the application of CBA to environmental problems:

"Systematic consideration of the benefits and costs of a project need not involve quantitative estimation of all effects to be useful in decision-making. Suppose just the readily estimated adverse effects on the environment exceed the gains. It would not be necessary to worry about our inability to evaluate more elusive damages. Of course, it is important to indicate the unevaluated damages in a qualitative way, to ensure that the quantitative estimate is indeed a lower bound.

"Where costs, and benefits, of such decisions are appropriately incorporated into the evaluation procedure, the objection to the use of benefit-cost analysis often takes the form of disagreement with the discount rate used to reduce these future values to present values. The choice of discount rates to properly reflect social time preference is an exceedingly complex problem; there is no easy answer. One might, however, use several discount rates—low, middle, high—to provide a range of estimates."

Appendix Examples and Case Studies

These case studies were selected to show various approaches in the use of CBA and CEA as a planning procedure to assess environmental impact.

Example 1

This study* was carried out by the General Motors Corporation Research Laboratories, U.S.A. in 1976 to examine the optimum automotive emission control levels within a CBA framework.

The scenario for the analysis was limited to the control of the internal combustion engine through add-on devices.

Benefit values and cost data were developed from literature surveys and independent studies. Various assumptions were made to partition and allocate the effects of air pollutants.

The economic component of the benefits was determined by summing the estimates of damages related to health, material, agricultural soiling and land value losses.

Other aspects of the analysis are as follows:

Benefits estimates:

- health benefits were inferred from published data and translated to economic terms;
- valuation of reduction of damage to material, vegetation, and soiling costs;
- psychological benefits were inferred from survey on consumers' willingness to pay;
- partitioning of the impacts of the various automotive pollutants was estimated from published literature and a linear dose-response function was used for calculating health benefits.

Cost estimates:

- price of control devices;
- present value of cost of operation and maintenance plus replacement;
- fuel penalty cost due to control devices;
- cost implications of predicated new technological development.

* General Motors Research Laboratories publication GMR-2265 "Benefit-Cost Analysis of Automotive Emission Reductions" (1976).

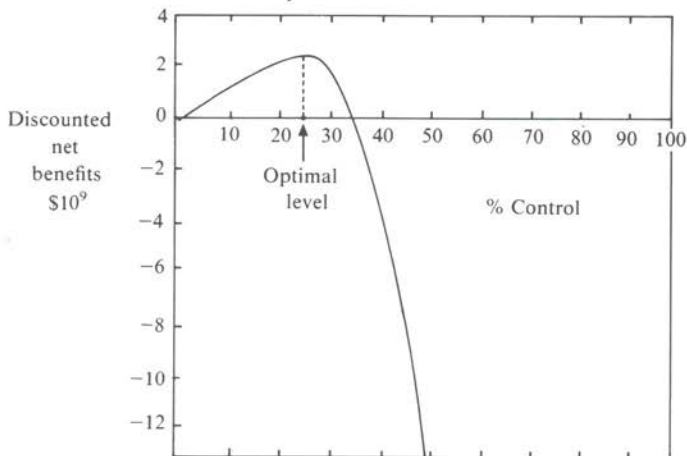
Scenario for CBA:

- country is U.S.A.;
- specification of control level based on 1960 (uncontrolled) as base year;
- social discount rate of 5 per cent;
- 30-year time horizon;
- values expressed in 1968 US\$;
- average life of auto was assumed to be 10 years.

Sensitivity tests on results of CBA run:

- social discount rates: 5 per cent-30 per cent;
- low, prime, high benefit estimates.

The plot for CO control as a function of net benefits derived from this study is shown below:



Thirty-year discounted net benefits due to CO control

The CO control-benefits function is significant in showing decisively the economic range for its control and the relative insensitivity of the optimal point to change in benefits estimates.

Example 2*

An example of the application of CBA to evaluate regulatory options is illustrated by the analysis on the impact of further reduction of lead in gasoline by the U.S. EPA. The impetus for reducing leaded gasoline

* Reference: Luken and Ostro (1985)

from the mandated limit of 1.1 g of lead content per gallon was due to increased recognition of serious health effects of lead even at low levels. The analysis shows that the benefits of reducing the lead content to 0.1 grams per gallon significantly exceed the costs.

In this simple balancing of costs against benefits, the problem of analysis primarily relates to the determination of damages and valuing these effects in economic terms.

Costs and monetized benefits of 0.10 grams of lead per gallon in 1986, assuming no misfueling
(millions of 1983 dollars)

	Current
Monetized benefits	
Child health effects	\$602
Adult blood pressure effects	5,927
Conventional pollutants from reduced misfueling	278
Maintenance savings	933
Fuel economy	190
Total monetized benefits	7,930
Total refining costs	607
Net benefits excluding blood pressure	\$1,396
Net benefits including blood pressure	7,323

Source: U.S. EPA, Office of Policy Analysis, *Costs and Benefits of Reducing Lead in Gasoline*, Final Regulatory Impact Analysis, February 1985.

Example 3

Table 1 summarizes the analysis performed by the U.S. EPA to evaluate the regulatory impact of adopting new proposed effluent guidelines. Projected changes in water quality and aquatic habitats for the sample river systems and the associated benefits were estimated. In these studies, human health effects were found to be insubstantial because there were few affected water supply intakes. The major economic benefits of improved water quality were determined to be from increased recreational value.

Although the analyses were admitted to be imprecise, they provided a rough indication that the anticipated improvement could be associated with dollar values of a general magnitude comparable to costs.

Table 1 Case study benefits and costs
(millions of 1980 dollars)

	Benefits Annual	Present value of costs	Probability that benefits exceed costs*
<i>Discount Rate = 6%</i>			
Black River	2.0-6.6	2.5-3.0	74-84
Mahoning River	2.1-11.1	3.8-5.4	58-76
Monogahela River	12.1-27.9	3.9-6.7	95+
<i>Discount Rate = 10%</i>			
Black River	2.0-6.6	3.0-3.5	63-74
Mahoning River	2.1-11.1	4.5-6.7	44-68
Monogahela river	12.1-27.9	4.5-7.7	95+

* This assumes a uniform probability distribution within the benefits range, and that the range defines a 90 per cent confidence interval. Source: U.S. Environmental Protection Agency.

Source: CEQ (1982).

Example 4* **Cost-effectiveness analysis**

Major pollution sources discharging to the confluence of the Des Moines and Raccoon Rivers are upstream flow, municipal waste-water, combined sewer overflow and urban runoff. The biochemical oxygen demand (BOD) contained in the waste loads depletes the oxygen in the water. Simulation results indicate that under existing conditions dissolved oxygen (DO) of less than 2 mg/ℓ occurs about 134 h/yr.

One of the receiving water quality goals is to avoid or minimize periods of DO levels below 2 mg/ℓ, as this leads to fish kills. Figure 1 shows the mortality of brook trout to DO levels.

A cost and effectiveness analysis was carried out to provide information showing the trade-off between cost and increased benefit of reducing the occurrence of DO below the level of 2 mg/ℓ.

Although the benefits of avoiding fish kills could have been estimated, cost effectiveness analysis avoids this need by postulating an objective

* Source: F. W. Ellis and R. L. Wycoff (1980), Cost effective water quality planning for urban areas, *J. Water Pollut. Control Fed.* 53(2).

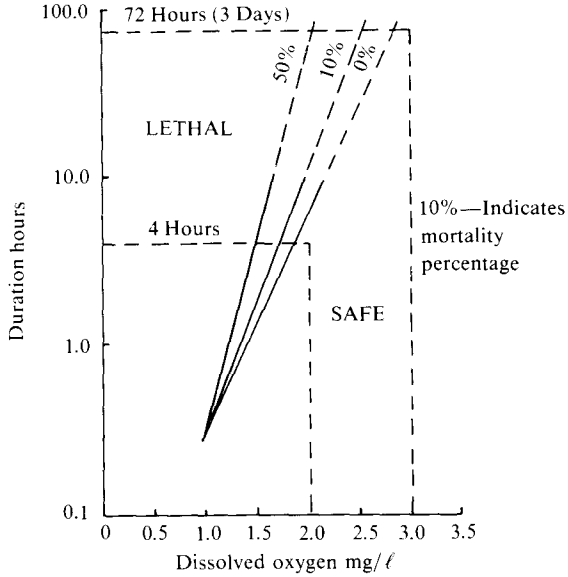


Figure 1 Mortality of juvenile brook trout caused by low DO levels
 Source: F. W. Ellis and R. L. Wycoff (1980)

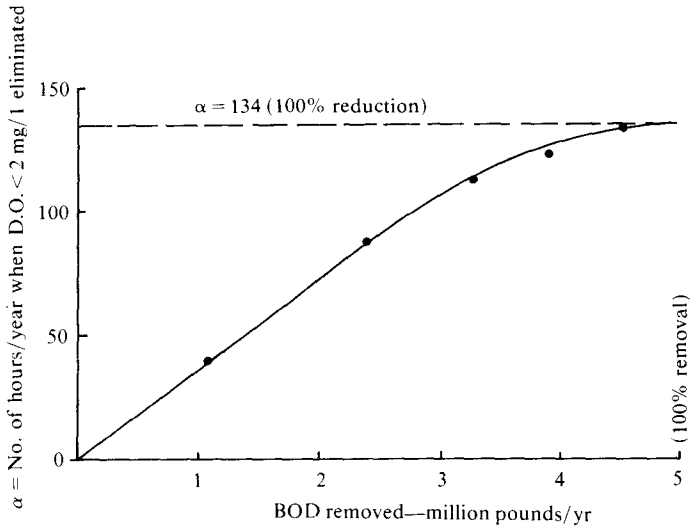


Figure 2 Production function for control

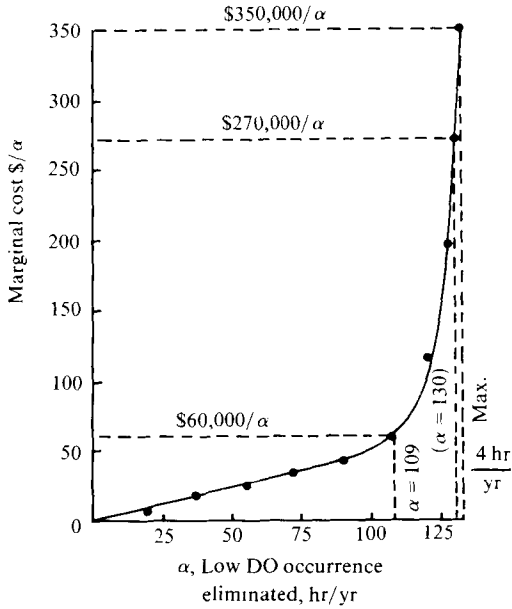


Figure 3 Marginal cost curve for optimum control alternatives

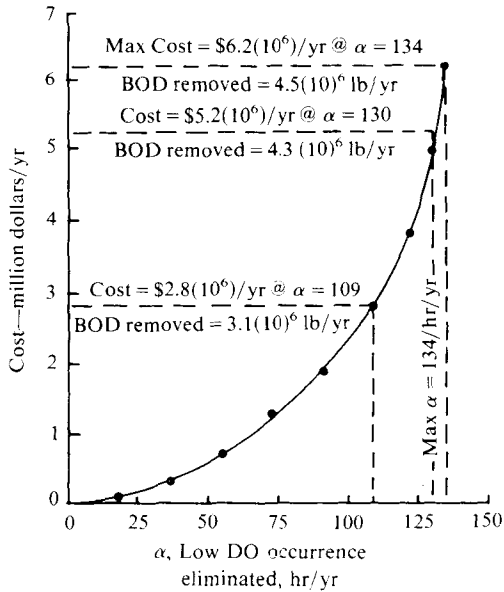


Figure 4 Total cost curve for optimum control alternatives

function α (namely, hours of low DO occurrence eliminated annually) and the problem reduces to weighing whether the last incremental desired α achievement is worth the marginal cost, providing the control solution is optimal.

Figure 2 shows the functional relationship between the level of control effort (i.e., BOD removed from the waste loads) and the resultant reduction of low DO periods which produce fish kills. The relationships between control costs and the level of goal achievement (i.e., α) are shown in Figures 3 and 4. Inspection of the marginal (i.e., incremental) cost function (Figure 3) shows that the cost effectiveness zone for control does not extend beyond the elimination of more than 109 hours of low DO occurrence per year (equal to the avoidance of about 80 per cent of the expected fish kills when there is no control).

Example 5* **Ordering of CBA information**

The proposal involves the creation of a national park covering 424,000 acres in New South Wales, Australia. To establish the park, the Government would have to buy out land leases and displace farm families and mining activities.

Creation of the park will enhance and preserve gorgeland scenery, natural habitats and vegetation, and promote scientific research through its permanence as an experimental station.

Information on impacts for various proposed alternative land use plans are tabulated according to objectives as shown in Table 1.

Net monetary benefits in Table 1 were recalculated as net social benefits to include consumer's surplus where possible and to correct distortions in market prices and presented as Table 2.

* Source: *Unpriced Values, Decisions Without Market Prices*, J. A. Sinden and A. C. Worrel, Wiley-Interscience Publishers (1977).

Table 1 Outcomes of four alternative land use plans for a gorgelands park

Outcomes	Alternative			
	Existing	A	B	C
	1	2	3	4
Present uses retained	Cattle, mining	Less cattle, mining	No cattle, mining	No cattle, no mining
Area of park (1,000 acres)	0	292	424	242
Objectives				
1. Net monetary benefits ^a				
(a) From cattle	51	12	0	0
(b) From mining	455	455	455	0
(c) Acquisition cost	0	-74	-90	-545
(d) Operating cost		-100	-100	-100
Total	506	293	265	-645
2. Acquisition cost ^a				
	0	74	90	545
3. Distribution of income				
Number of farm facilities supported by area	32	25	24	24
4. Number of recreation visits				
	58,200	62,700	64,300	64,300
5. Preservation of				
(a) Major scientific projects (numbers)	1	1	1	1
(b) Habitat of endangered kangaroo	No	No	Yes	Yes
(c) Habitat of rare eucalypt	No	No	No	Yes
(d) Natural landscape vistas	No	Yes	Yes	Yes
Quantitative index ^b				
	1	2	3	4
Qualitative index				
	Little	Improved	More improved	Most improved

^a Thousands of dollars present worth expressed as annuities at 10 per cent.

^b Number of the preceding (a) to (d) preserved.

Table 2 First stage in the monetary approach—net social benefits replacing net monetary benefits

Objectives	Alternatives			
	Existing situation	A	B	C
1	2	3	4	5
<i>With monetary outcomes^a</i>				
Net social benefit—cattle	30	7	0	0
Net social benefit—mining	455	455	455	0
Subtotal—net social benefit	485	462	455	0
Acquisition costs—farms	0	-74	-90	-90
Acquisition costs—mine	0	0	0	-455
Subtotal—acquisition cost	0	-74	-90	-545
Operating cost of park	0	-100	-100	-100
Total money value	485	288	265	-645
<i>With non-monetary outcomes</i>				
Income distribution (number of farm families wholly supported)	8	1	0	0
Recreation (100 family visits)	58.2	62.7	64.3	64.3
Research projects (number)	1	1	1	2
Preservation of:				
Natural landscapes	No	Yes	Yes	Yes
Endangered kangaroo	No	No	Yes	Yes
Rare eucalypt	No	No	No	Yes

^a As present worths in thousands of dollars expressed as annuities at 10 per cent.

Table 2 was further refined by placing monetary values on the impact resulting from the displacement of farm families, increased recreation potential, and savings in research projects.

Table 3 shows the final ordering of information, composed of a CBA component and environmental impacts that cannot be quantified in monetary terms.

Table 3 Final ordering of information

Objectives	Alternatives				
	Existing situation	A	B	C	
	2	3	4	5	
1					
<i>With monetary outcomes^a</i>					
CBA	Net social benefit—cattle	30	7	0	0
	Net social benefit—mining	455	455	455	-90
	Acquisition cost—farms	0	-74	-90	-90
	Acquisition cost—mines	0	0	0	-455
	Operating cost of park	0	-100	-100	-100
	Income distribution—compensation	0	-35	-40	-40
	Recreation—net social benefit	524	565	579	579
	Research—net social benefit ^b	0	0	0	100
Total monetary value	1,009	817	804	-6	
<i>With non-monetary outcomes</i>					
EIA	Preservation of:				
	Natural landscapes	No	Yes	Yes	Yes
	Endangered kangaroo	No	No	Yes	Yes
Rare eucalypt	No	No	No	Yes	

^a As present worths in thousands of dollars expressed as annuities at 10 per cent.

^b As the cost saving on the additional project in alternative C.

The ordering of information shown in Table 3 has reduced the decision-making to a trade-off between monetary values and the significant environmental impacts. Achievement in conservation under each alternative can be compared in relation to incremental net monetary benefits.

Case Study 1 Document EPA-230-11-85-017 *A Methodological Approach to an Economic Analysis of the Beneficial Outcomes of Water Quality Improvements from Sewage Treatment Plant Upgrading and combined Sewer Overflow Controls*, by Meta Systems Inc.

The study was carried out to compare the costs and benefits of alternative proposals for reducing the pollution of waters around Boston Harbour due to combined sewer overflows (CSO).

A schematic diagram of the CSO system is shown in Figure 1-1. The three alternatives studied were:

1. CSO control schemes;
2. CSO controls combined with ocean outfall control option;
3. CSO controls along with secondary treatment control option.

The CSO planning areas and water quality problems are tabulated in Table 1-1.

Benefits were estimated by various methods as tabulated in Table 1-2. Health benefits to swimmers and shellfish consumers were estimated using a dose-response relationship between enterococci density and the number of cases of gastrointestinal sickness. Benefits were calculated by summing lost work days and cost of illness.

The results of the costs and benefits of the three alternatives are tabulated in Table 1-3, 1-4 and 1-5. As with any complex situation with an array of benefits and costs, not all the potential benefits could be addressed because of inadequate data or because of the inherent unquantifiable nature of impact. Thus, the estimates of benefits are lower bound values. Examination of the three options shows that only the CSO alternative yields benefits approximating costs and thus is justifiable on economic grounds. Further, if there is a budget constraint, the analysis provides a basis for: prioritizing the different segments of the CSO scheme based on B/C ratios.

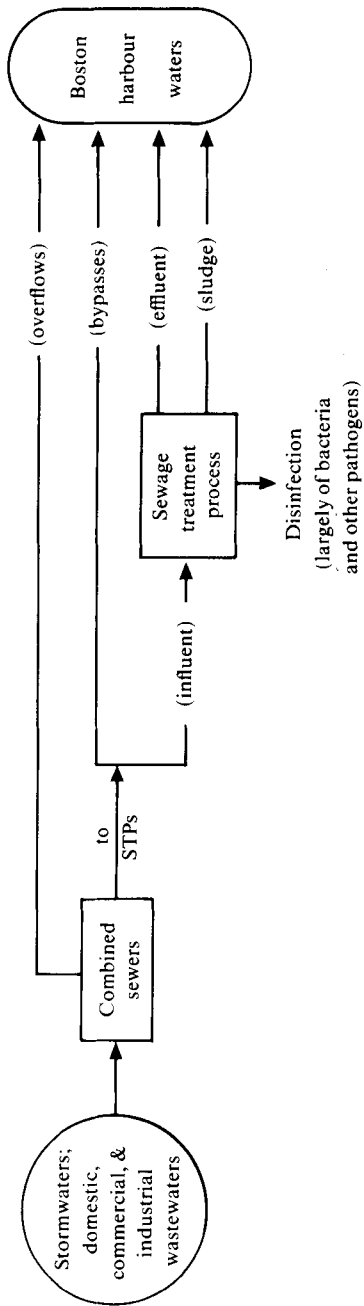


Figure 1-1 Schematic of sources of pollutant loadings to Boston Harbour

Table 1-1 CSO planning area characteristics

Planning area	Annualized capital costs ^a (MM 1982\$)	Annual O & M costs (MM 1982\$)	Total annualized costs (MM 1982\$)	Receptors	Water quality classification			Suspended solids mg/ℓ	Turbidity NTU	BOD ₅ mg/ℓ	Total phosphorus mg/ℓ	Dissolved oxygen mg/ℓ
					Faecal coliform per 100 mℓ	Total coliform per 100 mℓ	SC					
Inner Harbour ^c Constitution Only	14.63	1.97	16.61	Shellfish Airport Beaches	SC	36- 1.5 × 10 ⁶	230- 4.6 × 10 ⁶	0-27	1.0-3.1	0.7-9.2	0.08-0.86	1.3-12.2
					T. col 1,000	DO 6.0						
Dorchester Bay ^c	4.97	0.37	5.34	Shellfish Dorchester Bay Beaches	SB	36-46,000	36-14.0	3.0-0.1	0.8-79	0.3-0.6	3.6	
					9,300 T. col 700 DO 6.0							
Neponset River ^b	0.61	0.10	0.71	Shellfish Neponset Estuary Beaches	Sb	geom mean 6,800	geom mean 38,000	4.5	1.5	3.2	0.22	5.2
					T. col 700 DO 6.0							
Charles River ^d	8.87	1.56	10.53	No shellfishing or swimming	C		300-112,000	0.09-34.0	0.2-5.0	0.4-9.6	0.01-0.61	0.0-12.6
					T. col 1,000 DO 6.0							
Quincy ^e	0.25	-0.02	0.27	Shellfish Quincy Bay Beaches	SA	500-18,000	800-34,000	5-50	1-5.0	6-10		
					T. col 70 DO 6.0							
				Wollaston Quincy								

^a Based on 8% per cent interest and a 20-year pay-back period.

^b Values for Neponset River are from data gathered in August 1978 (DEQE 1982).

^c Values for Dorchester Bay and Inner Harbour are from the CSO Facilities Plans (O'Brien and O'Gere 1980; Camp Dresser and McKee 1981).

^d Values for the Charles River are from data gathered by the MDC (Ferrillo 1981)

^e Values for Quincy are from sampling conducted in June-August 1982.

Table 1-2 Benefit categories and methodologies for Boston Harbour study area

Benefit/Effect	Benefit estimation approach	Reliability of methodology	Reliability/ Availability/ data
<i>Recreation</i>			
Swimming	Travel cost (logit model)	excellent	excellent
	Regional participation	good	fair to good
	Beach closings cost savings	fair	fair
Boating	Regional participation	fair	fair
Fishing	Regional participation	fair	fair
<i>Health</i>			
Swimming	Dose-response function (incidence of disease)	excellent	good
Food consumption	Dose reponse function (incidence of disease)	good	fair to good
<i>Commercial Fisheries</i>			
	Demand and supply	good	poor
<i>Intrinsic Benefits</i>			
	Contingent valuation survey	fair	fair
	Direct % of recreation benefits	good	good
<i>Ecological</i>			
	No approach available to apply a dollar value for benefits	—	—
<i>Secondary</i>			
	Input-output multipliers	fair	fair

Table 1-3 Annual benefits and costs of combined sewer overflow controls
(Millions 1982\$)

Pollution control option	Benefit estimates by category ^a						Total annual costs ^b		
	Swimming ^b	Recreational boating	Recreational fishing	Health ^d	Commercial shell-fishing	Intrinsic ^c		Ecological	Total
<i>Combined sewer overflows</i>									
Constitution Beach	0.91-1.36 Range: Moderate:	Not available for this option since boating and fishing are only calculated harbour-wide for combined STP and CSO options.	0.005-0.077 0.041	0.0005	0-0.005	Based on total recreational benefits. Not available for this option since boating and fishing benefits are only calculated Harbour-wide for combined STP and CSO options.	Cannot be quantified but includes value of highly productive saltmarshes in Boston Harbour. These marshes in turn support many species of fish and invertebrates as well as animals, shorebirds and waterfowl	0.92-1.44 1.18 6.23-9.62 7.92	0.05 ^b 6.06
Dorchester Bay	6.21-9.29 Range: Moderate:		0.021-0.317 0.169	0.001-0.009 0.005					
Neponset River	7.75 Range: Moderate:								
Quincy Bay	5.29-7.91 Range: Moderate:		0.086-1.275 0.681	0-0.004 0.002				5.38-9.19 7.28	0.25 6.06 ^c
Hingham Bay	-0- Range: Moderate:		-0- 0.001-1.716 0.92	-0- 0.001-0.018 0.010				-0- -0- 12.18-19.73* 15.95	-0- -0- 6.36-12.17 ^b
Massachusetts Bay/ Nantucket	-0- Range: Moderate:								
Entire Harbour (not including Charles River)	12.05-18.0 ^e Range: Moderate:								
Charles River	-0- Range: Moderate:	0.05-0.96 0.51	-0- 0.001-0.014 0.008			3.14-6.28* 4.71		3.19-7.24 5.22	10.43
Four MDC CSO Plans (Constitution, Dorchester, Neponset, Charles River)	7.12-10.65 Range: Moderate:	0.05-0.96 0.51	0.027-0.394 0.21			3.14-6.28* 4.71		10.34-18.3 14.3	16.54 ^b

^a Moderate benefits represent best estimates except for those categories where best estimate is marked by *. Range includes high and low estimate.
^b Swimming benefits based on conditional logit model. For Quincy, Hingham and Nantucket beaches, benefits from increased participation are added since logit model did not include these beaches. All benefits are derived using day value from logit model.
^c Includes general recreation benefits at Boston Harbour islands.
^d Health benefits for individual areas based on swimming; for entire harbour benefits based on shellfish consumption are also included.
^e Commercial fishing benefits based on shellfishing; estimates for finfishing and lobstering not available.
^f Intrinsic benefits based on 50 per cent of all recreational benefits, except for Charles River, which includes willingness to pay for user and non-user values.
^g Annualized capital costs (assuming a 8 $\frac{1}{2}$ per cent interest, 20-year period) plus annual operation and maintenance costs.
^h Excludes cost of Inner Harbour CSO plan except for Constitution Beach portion; total annual cost of Inner Harbour CSO plan is \$16.61 million.
ⁱ Cost estimates for Quincy storm sewers are still preliminary. High estimate is equivalent to costs for CSO control in Dorchester Bay.

Table 1-4 Annual benefits and costs of combined sewer overflow controls and ocean outfall control option
(Millions 1982\$)

Pollution control option	Benefit estimates by category ^a							Total annual costs ^b
	Swimming ^b	Recreational boating	Recreational fishing	Health	Commercial shell fishing ^e	Intrinsic ^d	Ecological	
<i>Combined sewer overflows and ocean outfall</i>								
Constitution Beach	Range: 1.05-1.57 Moderate: 1.31			0.008-0.119 0.064			Potentially large beneficial impact on shoreline saltmarshes supporting fish and invertebrates as well as animals, shore-birds and waterfowl. But negative impact on Massachusetts Bay with its finfish, lobster, crab and migratory whales and other species	1.06-1.69 1.37
Dorchester Bay/Neponset River	Range: 7.41-11.08 Moderate: 9.25			0.032-0.477 0.255				7.44-11.56 9.51
Quincy Bay	Range: 6.24-9.33 Moderate: 7.78			0.146-2.15 1.15				6.39-11.48 8.93
Hingham Bay	Range: 0.215-0.322 Moderate: 0.269			0.003-0.039 0.021				0.22-0.36 0.29
Massachusetts Bay/ Nantucket	Range: (-0.772) Moderate: 15.23-23.6 ^e			(-0.011)-(-0.169) 0.189-2.67				(-0.78)- (-0.94) (-0.86)
Entire Harbour (not including Charles River)	Range: 19.03 Moderate: 5.39-12.13* Range: -0-0.51 Moderate: 0.51	8.76	0.30-7.91*	(-0.090)	0.022-0.124	10.1-21.8		49.29
Charles River	Range: -0-0.51 Moderate: 0.51	0.05-0.96	-0-	-0-	-0-	15.9		3.19-7.24
Four MDC CSO Plants (Constitution, Dorchester, Neponset, Charles River)	Range: -0-0.51 Moderate: 0.51	0.05-0.96	-0-	-0-	-0-	3.14-6.28* 4.71		5.22

^a Moderate benefits represent best estimates except for those categories where best estimate is marked by *. Range includes high and low estimate.
^b Swimming benefits based on conditional logit model. For Quincy town beaches, benefits from increased participation are added since logit model did not include these beaches. All benefits are derived using user day values from logit model.
^c Includes general recreation benefits at Boston Harbour Islands.
^d Health benefits for individual areas based on swimming, for entire harbour benefits based on shellfish consumption are also included.
^e Commercial fishing benefits based on shellfishing; estimates for finfishing and lobstering not available.
^f Intrinsic benefits based on 50 per cent of all recreational benefits; except for Charles River, which includes willingness to pay for user and non-user values.
^g Annualized capital costs (assuming 8% per cent interest, 20-year period) plus annual operation and maintenance costs.
^h Excludes cost of Inner Harbour CSO plan except for Constitution Beach portion; total annual cost of Inner Harbour CSO plan is \$16.61 million.
ⁱ Cost estimates for Quincy storm sewers are still preliminary. High estimate is equivalent to costs for CSO control in Dorchester Bay.

Table 1-5 Annual benefits and costs of combined sewer overflow controls and secondary treatment control option
(Millions 1982\$)

Pollution control option	Benefit Estimates by Category ^a						Total annual costs ^b	
	Swimming ^b	Recreational boating	Recreational fishing	Health ^d	Commercial shell-fishing	Intrinsic ^e		Ecological
<i>Combined sewer overflows and secondary treatment</i>								
Constitution Beach	Range: 0.98-1.46 Moderate: 1.22			0.007-0.096 0.51			Potentially large beneficial impact on shoreline	0.99-1.56 1.27
Dorchester Bay/Neponset river	Range: 7.41-11.08 Moderate: 9.25			0.032-0.477 0.255			saltmarshes supporting fish and invertebrates as well as animals, shorebirds and waterfowl.	7.44-11.56 9.51
Quincy Bay	Range: 6.24-9.33 Moderate: 7.78			0.146-2.15 1.15				6.39-11.48 8.93
Hingham Bay	Range: 0.215-0.322 Moderate: 0.269			0.003-0.039 0.021				0.22-0.36 0.29
Massachusetts Bay/Naantucket	Range: -0- Moderate:			-0- 0.021				-0- 0.29
Entire Harbour (not including Charles River)	Range: 14.22-22.4 ^c Moderate: 18.32	6.46-14.57*	0.75-9.49	0.198-2.81	0.022-0.124	10.7-23.2		32.35-72.61* 137.4-143.2 ^{b,i}
Charles River	Range: -0- Moderate: 0.51	10.52 0.05-0.96	5.12 -0-	1.51 -0-	0.064 -0-	17.0 4.71		52.53 3.19-7.24 5.22
Four MDC CSO Plans (Constitution, Dorchester, Neponset, Charles River)	Range: -0- Moderate: 0.51							

^a Moderate benefits represent best estimates except for those categories where best estimate is marked by *. Range includes high and low estimate.

^b Swimming benefits based on conditional logit model. For Quincy town beaches, benefits from increased participation are added since logit model did not include these beaches. All benefits are derived using day values from logit model.

^c Includes general recreation benefits at Boston Harbour Islands.

^d Health benefits for individual areas based on swimming; for entire harbour benefits based on shellfish consumption are also included.

^e Commercial fishing benefits based on shellfishing; estimates for finifishing and lobstering not available.

^f Intrinsic benefits based on 50 per cent of all recreational benefits, except for Charles River, which includes willingness to pay for user and non-user values.

^g Annualized capital costs (assuming 8% per cent increase, 20-year period) plus annual operation and maintenance costs.

^h Excludes cost of Inner Harbour CSO plan except for Constitution Beach portion; total annual cost of Inner Harbour CSO plan is \$16.61 million.

ⁱ Cost estimates for Quincy storm sewers are still preliminary. High estimate is equivalent to costs for CSO control in Dorchester Bay.

Seattle

Metropolitan Seattle (Metro) has 110 sewer overflow locations. Overflow averages 40 occurrences per year, with approximately 6 during the summer recreation season. Planning for control of pollution from overflows, conducted under Section 201 of the Clean Water Act, involved two major technical phases—evaluation and optimization of control alternatives and quantification of benefit or effects of proposed facilities. Optimizing control alternatives was a straightforward process of comparing appropriate alternatives and establishing the overall least cost facility configuration. Quantification of benefits was complicated by the existence of multiple receiving waters with a wide range of beneficial uses and sensitivities to pollution.

The seven distinct steps in the study were:

- Development of a collection system model with flexibility to allow optimization at successive levels of control.
- Application of a collection system model to establish optimum controls as a function of a storm recurrence interval.
- Application of a collection system model to establish effectiveness of controls as a function of recurrence.
- Determination of combined sewer overflow quality parameters.
- Measurement of impacts on receiving waters.
- Identification of beneficial uses for all receiving waters and determination of sensitivity to pollution by CSOs.
- Relating CSO impacts to beneficial uses.

Collection system analysis

Several hundred storm sewer network simulation models are available in the current literature; however, none could handle the complexities inherent in the Seattle system without extensive modifications. Those models that did have the basic sophistication to handle the flood routing aspects were too detailed and thus too time consuming for the planning effort. Consequently, at the start of the planning it was decided to custom-build a model that would not only address the needs of the study

but would also, with minimum refinement, be suitable for subsequent detailed design and be a useful tool for future Metro planning.

The adopted two-part model consists of a runoff model based on the unit hydrograph technique that provided the input to the transport model that simulates the flow of the runoff through the system.

Once the model was built and calibrated, the tool was available to evaluate and optimize control alternatives and to determine CSO volume reductions for specific control levels.

CSO control alternatives evaluated included the following:

- Full separation in partially separated areas
- Full and partial separation in combined areas
- Roof-top storage
- *In-line storage of existing system (CATAD, or Computer Augmented Treatment and Disposal)*
- In-line storage with new pipe/tunnels
- Off-line storage
- Localized storage/transfer and centralized storage
- Local off-shore discharge
- Local treatment, and
- Transfer and centralized treatment.

Controls were optimized for 114 sub-basins, considering overall cost based on a range of permitted overflow frequencies from the present 40 per year to 10 per year, one per year, and one in 10 years.

In basins tributary to the fresh inland waters of Lake Washington and the ship canal downstream to the outlet of Lake Union, control alternatives were limited to storage, transport, and source control. In other drainage basins, additional alternatives of localized treatment or upgraded outfalls were evaluated. Once the range of alternatives was established, the analysis was conducted for each drainage basin by detailing the size of physical facilities required and establishing their cost.

Systemwide cost optimization was accomplished by matching flows at drainage boundaries and apportioning the cost for downstream facilities based on their proportion of total facility required. Selected facilities were based on flexibility for areal emphasis and stageable controls within specific areas.

The facility arrangements that yielded most economical control at the three selected storm frequency control levels were identified. In general,

localized and/or centralized holding was found to be the most cost effective in the areas remote from the treatment plants. A combination of holding, transport, and increased treatment capacity was found to be the most economical for controlling overflows closer to the plants.

At the conclusion of this phase, the tools were available to find the least cost for controlling any combination of overflows, and incremental control level and corresponding reduction in overflows could be determined.

CSO characteristics

Of the 110 overflow points, five were selected from representative runoff areas and subjected to detailed analysis. Investigation included analysis of the overflows, dye studies, coliform die-off studies, and benthic studies. Grab and composite site sampling was conducted at each point through a representative range of storms. A large range of values was obtained from the analyses (Table 1), but some general conclusions could be

Table 1 Average CSO pollutant levels—Seattle*

Pollutant	Minimum	Maximum	Average
BOD	15	82	60
COD	100	330	236
SS	141	296	217
NH ₄ -N	0.5	1.5	0.9
P	1.2	1.7	1.4
Cu	0.1	0.3	0.2
Pb	0.5	0.9	0.6
Hg	0.01	0.01	0.01
Cr	0.02	0.20	0.10
Cd	0.01	0.02	0.01
Zn	0.2	0.5	0.4
Total coliforms	8×10^3	$7,000 \times 10^3$	—
Faecal coliforms	3.6×10^3	780×10^3	—

* All values in mg/ℓ except for coliform units, which are in colonies/100 mℓ.

Source: Warburton, J., "Seattle's Approach to Evaluating Costs and Benefits of Combined Sewer Overflow Control per PGM-61", p. 8, presented at U.S. EPA Technology Transfer Seminars on Combined Sewer Overflow Assessment and Control Procedures, 1978.

made: tributary land use did not significantly affect conventional pollutant concentrations; the phenomenon of the first flush was not evident; season was not significant; and the size of the storm was not significant. Average pollutant concentrations could therefore be used for determination of pollutant loadings throughout the area and for various sizes of storms.

Dye studies indicated that the impact of overflows was typically localized within one-half mile for specific wind and localized current conditions. Coliform levels exceeded local public health water contact quality standards for up to three days. Benthic analysis at the overflow indicated significant dead areas overlain by sludge deposits.

Identification of beneficial uses and sensitivity of receiving waters

Recognizing that the impact of overflows differs depending on the sensitivity of the receiving water and their attendant uses, Seattle's consultants prepared a geographical inventory of water use areas, aquatic life habitats, and ranking of relative risk to pollutant loadings based on physical characteristics (e.g., water circulation, dilution factors, and flushing) to assist in ranking overall sensitivity of the various water bodies to degradation from pollution loads.

Individual environmental risk maps, depicting recreational use (Figure 1), biotic life zones (Figure 2), and water quality sensitivity (Figure 3) were combined utilizing the overlay technique developed by Ian McHarg, and three levels of risk were identified for locations with combined sewer overflow (Figure 4). This prioritization does not constitute a cost effective analysis for abatement techniques but simply groups the overflows relative to their degree of environmental risk. It is the first step in grouping overflows with specific beneficial uses. The more localized the analysis, the easier it is to identify the relationships between beneficial use and CSO impact.

The next step was an evaluation of the commonality of collection subsystems, CSO impact overlaps, water body physical characteristics and dominant beneficial uses. This evaluation resulted in defining nine separate overflow areas that were then prioritized utilizing the initial risk analysis concept.

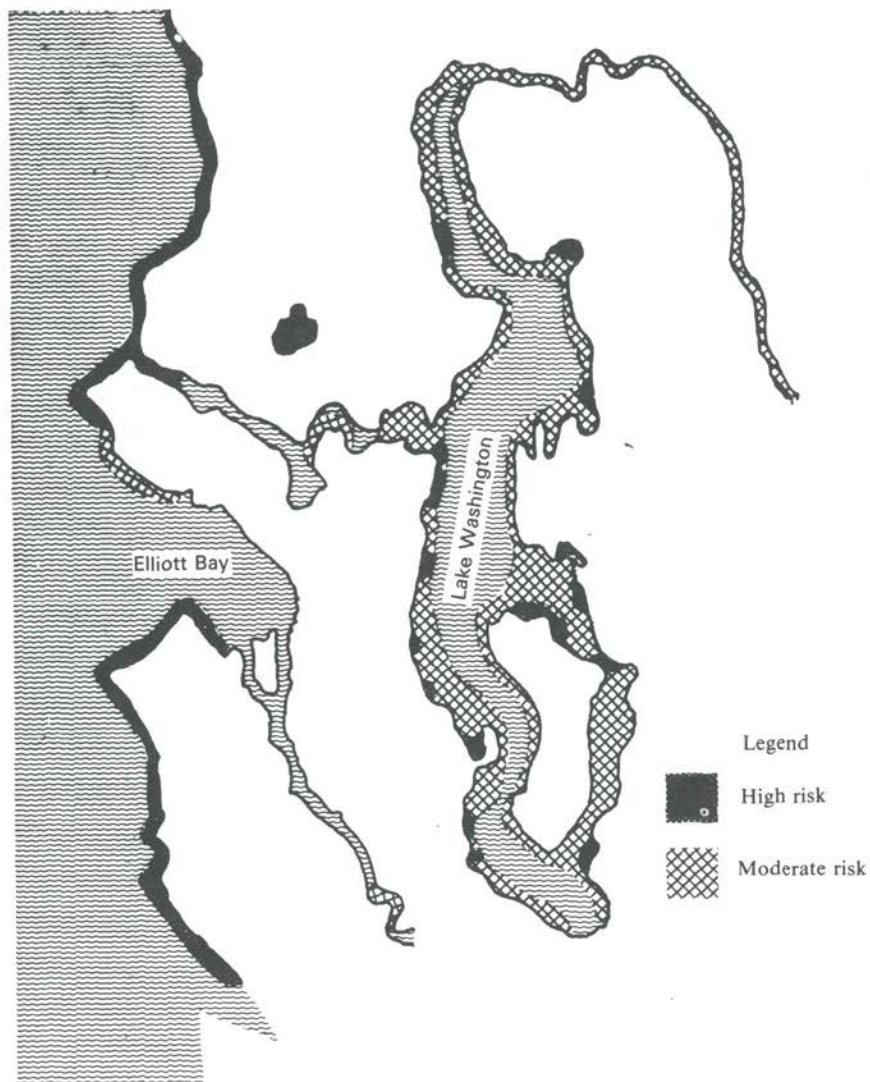


Figure 1 Water contact recreation: risk of degradation from combined sewer overflows

Source: Brown and Caldwell, Consulting Engineers for Municipality of Metropolitan Seattle, *Combined Sewer Overflow Control Program*, p. 6-23, January 1979

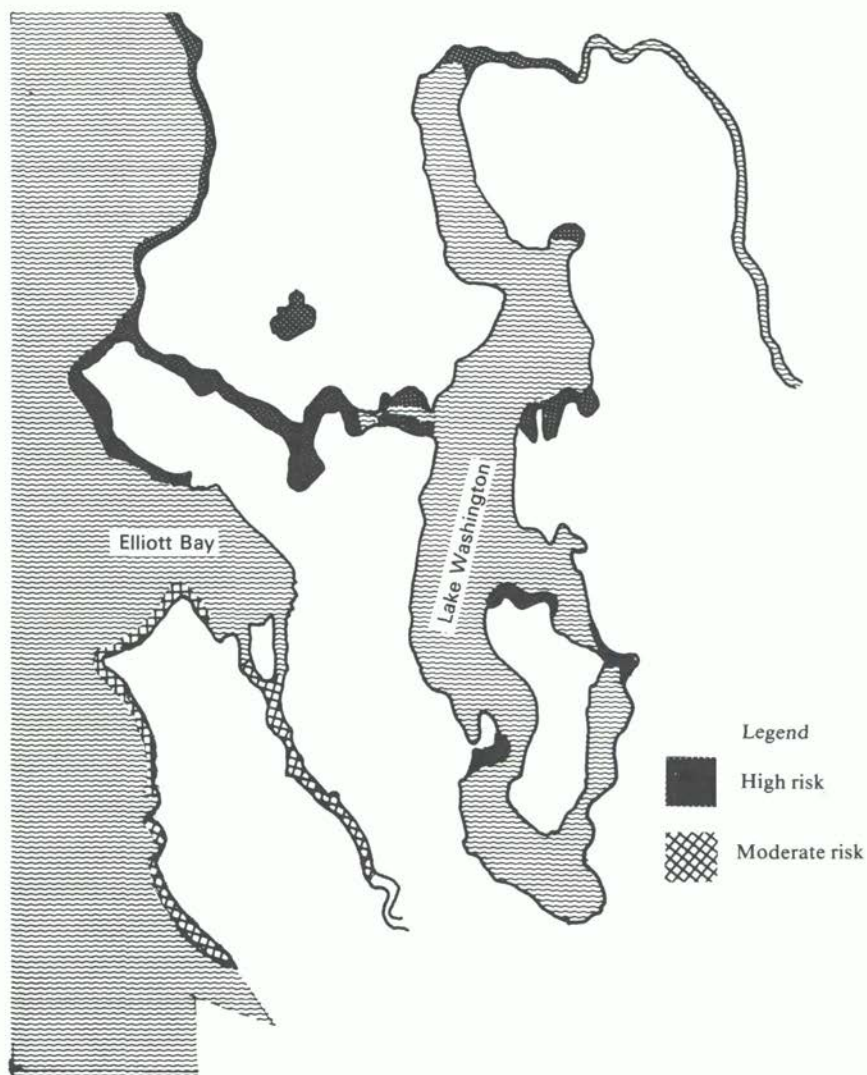


Figure 2 Biotic life zones and critical habitats: risk of degradation from combined sewer overflows

Source: Brown and Caldwell, Consulting Engineers for Municipality of Metropolitan Seattle, *Combined Sewer Overflow Control Program*, p. 6-24, January 1979

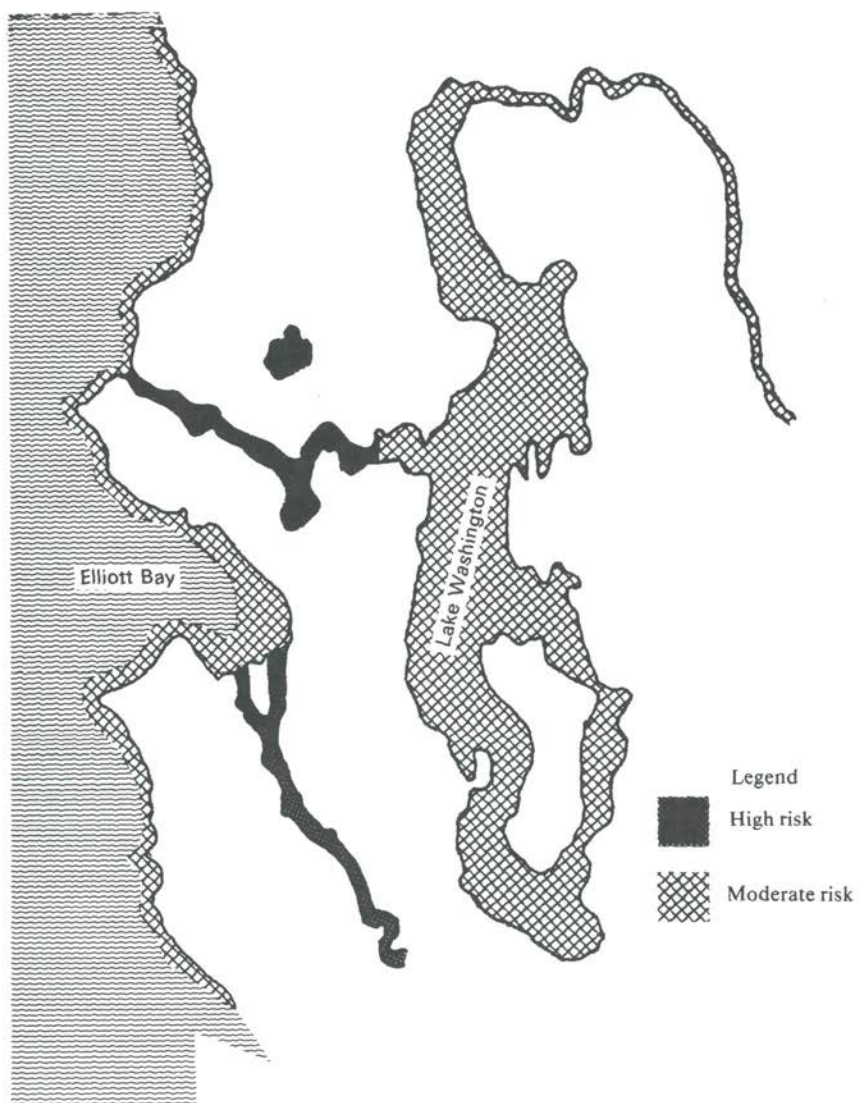


Figure 3 Water quality: relative sensitivity to pollutant loading

Source: Brown and Caldwell, Consulting Engineers for Municipality of Metropolitan Seattle, *Combined Sewer Overflow Control Program*, p. 6-25, January 1979

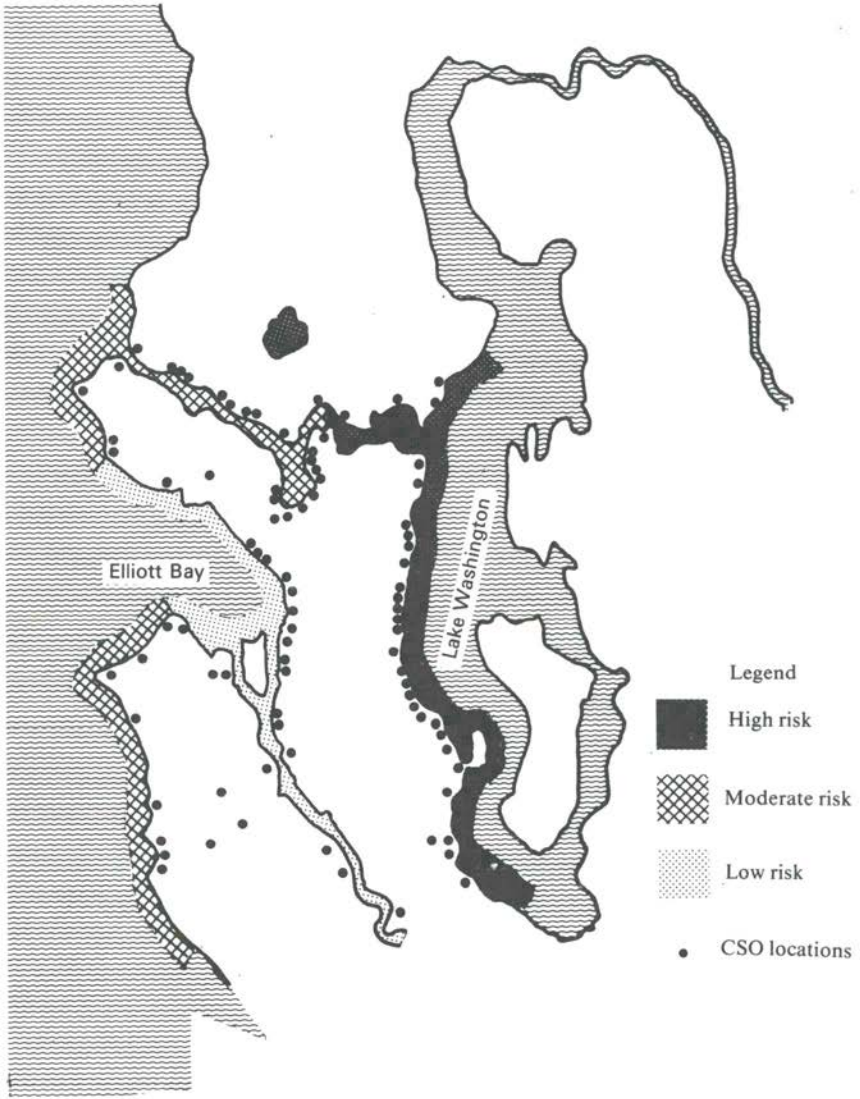


Figure 4 Relative priority in terms of pollution risk from combined sewer overflows
 Source: Brown and Caldwell, Consulting Engineers for Municipality of Metropolitan Seattle, *Combined Sewer Overflow Control Program*, p. 6-26, January 1979

Cost control relationship

For each of the overflow areas, a plot of cost versus control level was made utilizing data developed in the control level optimization (Figure 5). In all cases, a pronounced 'knee' (indicating a dramatic increase in control costs) was indicated in the one-per-year to one-per-ten-year overflow limit range. This knee of the curve is significant because it represents a point where marginal costs begin to increase quite rapidly. In other words, the cost for each additional unit of pollution control above the knee is much greater than the cost for a comparable increment

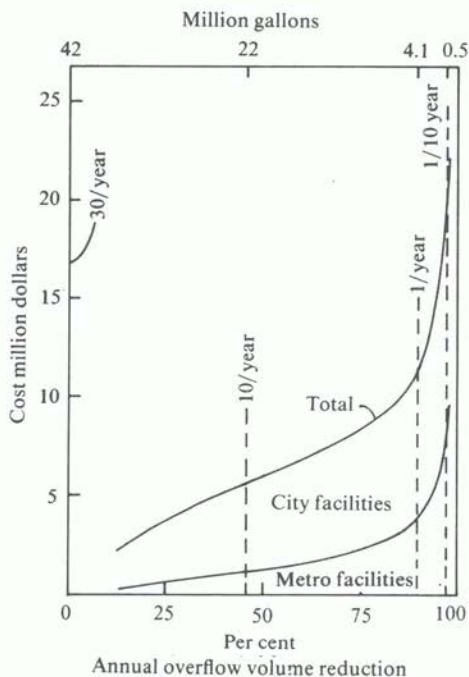


Figure 5 Cost-overflow control curve—priority 5 overflow area: Lake Union (south and east shores) and Portage Bay

Source: Warburton, J., "Seattle's Approach to Evaluating Costs and Benefits of Combined Sewer Overflow Control per PGM 61", p. 11, presented at U.S. EPA Technology Transfer Seminars on Combined Sewer Overflow Assessment and Control Procedures, 1978

below it. EPA examines this relationship critically in deciding whether marginal costs are substantial in comparison to marginal benefits.

The next step was to relate the reduction in pollutant to increase in benefit.

Water body beneficial use

A list of all existing beneficial uses and potential beneficial uses lost because of the existing CSOs was prepared for each of the overflow areas. Use information was based on field observations, state environmental and wildlife departments, local universities and colleges, the county health department, the city parks department, local community groups, and comments made during the public hearing. The beneficial uses were then listed in order of importance, based on a combination of factors including public risk, biota sensitivity, and city zoning/planning policies for the area. A list of identified beneficial uses is shown in Table 2.

Table 2 Beneficial uses and CSO pollutants—Seattle

Use	CSO pollutants
Residential	Coliforms/floatables
Swimming	Coliforms/floatables
Shell fishing	Coliforms/virus
Fish spawning/rearing	Toxicity/suspended solids
Juvenile fish migration	Toxicity
Recreational boating	Floatables
Shoreline parks	Floatables
Commerce	Minimal
Industry	Negligible

Source: Warburton, J., "Seattle's Approach to Evaluating Costs and Benefits of Combined Sewer Overflow Control per PGM-61", p. 8, presented at U.S. EPA Technology Transfer Seminars on Combined Sewer Overflow Assessment and Control Procedures, 1978.

CSO control levels and beneficial uses

For each of the nine overflow areas and for each beneficial use within each area, the relationship of CSO control to beneficial use was evaluated,

assessing existing conditions and projecting the benefits that would accrue by increased reductions in overflow events.

For illustrative purposes, priority 2 area, Lake Washington South is shown. The prioritized beneficial uses were:

- Swimming,
- Fish rearing,
- Fish spawning,
- Recreational boating, and
- Shoreline parks.

Swimming. Up to 20 overflows per year were discharging near the shore, resulting in up to three days of health standard coliform count violations for each occurrence. Up to five overflows occurred during the summer recreation season. CSOs did not preclude swimming activity, because beach closing procedures were not in effect, but participants were subjected to risk when swimming during the effects of CSOs. Thus, on a strict use definition basis, elimination of CSOs would not increase swimming activity, only reduce a potential health risk. However, the reduction in risk was a sufficient argument to meet EPA guidelines. Legal substantiation for this approach has recently been provided in a court case involving the State of Illinois versus the City of Milwaukee, Wisconsin. The judge stated that “exposure to a hazard is itself actionable, whether or not that exposure results in the actual contraction of a disease.”

Other factors taken into consideration were prior community commitment to CSO control, local political policy to reduce overflows to one per year, the large percentage of the shoreline accessible by public park, and the number of swimming areas operated by the city within the CSO’s areas of influence. For swimming use, funding of facilities to control overflows to one event per year was agreed upon; this is equivalent to one summer overflow every two years.

Fish rearing/Spawning. Combined sewer overflows are potentially toxic to fish, particularly during spawning and early development. It was the opinion of fishery experts as well as the regulatory agencies that overflows do affect these processes adversely, but available information on the degree of CSO stress was lacking. Until a closer definition of stress can be determined, the funding agencies would not participate in CSO controls to protect fish rearing/spawning.

Recreational boating/Shoreline parks. Control levels beyond those developed for swimming would not be necessary to protect recreational boating or shoreline park use.

Similar analyses were conducted for each water body, and in each case it was only the human health-related beneficial uses that could meet the EPA benefit requirements—namely, residential areas subjected to CSOs, swimming, and shellfish harvesting.

Conclusions of Seattle case

Success of technical aspects of planning, facilities optimization and control effectiveness estimation is highly dependent on the collection system model used. In this case, the model used was highly flexible and readily adaptable to various control alternatives.

Available data on actual effects of CSO discharge to local receiving waters were sufficient only to justify control of overflows to receiving water segments where human contact recreation is the controlling beneficial use. Receiving water effects considered did not include those from the comprehensive list of EPA priority pollutants.

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