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# IMPORTANCE OF BENEFIT IDENTIFICATION IN EVALUATING WATER POLLUTION CONTROL PROGRAMS

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## Abstract

Most economic studies dealing with water pollution abatement programs are carried out without properly identifying the benefits in physical terms. This is particularly so for policies and programs concentrating on abatement of one particular pollutant. Before benefits can be expressed in a dollar common denominator, they must be measured first in physical terms, namely the degree of water quality improvement for water consumption (uses). Water quality is dependent on physical, chemical, biological and aesthetic attributes of the water. Reducing one pollutant may have no effect on water quality if other pollutants keep the water unfit for use.

The paper explores the concept of water quality, how it is measured, and its significance for economic benefit evaluation. Examples from the literature are used to show how easily economic benefit evaluation can go astray if benefits are not measured in physical terms but are assumed to take place. Physical benefit evaluation is also a prerequisite for sequencing the abatement of various pollutants. Economic benefits do not solely depend on degree of water quality improvement, but also on water use. Water uses and users can differ greatly among watersheds, a fact commonly overlooked in most studies. The relevance of identifying physical benefits as well as (potential) uses and users for targeting limited funds for water quality improvement is illustrated. It is shown that targeting based on proper benefit identification and sound economic evaluation can deviate greatly from physical targeting criteria usually promoted.

## Introduction

After the second world war, water pollution control has assumed an increasing importance in Canada. At both the federal and provincial levels ministries of the environment, whose mandates still include water pollution control, were instituted. Large amounts of private and public funds are now being spent on pollution abatement. In spite of progress made, there is still confusion on how to effectively combat water pollution with the scarce resources available. Part of the confusion stems from the complicated nature of the problem. Not only do technical, physical, biological, and aesthetic aspects loom large, but economic, fiscal, and administrative needs must also be considered. Contributions of the natural and social sciences have not been well integrated into the solution of the problem.

A major policy question is how to control water pollution so that the nation gains not just ecologically and aesthetically but also economically. Not all abatement programs result in welfare gains for society. The above question is significant because funds to finance such programs are scarce and choices must be made on how best to spend limited monies for environmental improvement. A lack of clarity exists about the effect of water pollution abatement on water quality. Too often it is assumed that a reduction of any one pollutant which exceeds tolerable levels will result in water quality improvement and will therefore be beneficial to society. Moreover, it is frequently assumed that if choices must be made because of funding shortages, efforts should be directed to waters with the highest pollution levels. It will be shown that both assumptions may be erroneous. Implementation of policies based on such assumptions can lead to considerable waste of private and public funds.

Water quality is not necessarily improved by reducing one particular pollutant, as will be explained below. If water quality does not improve, such abatement does not consequently bestow any benefits on society. The magnitude of a change in water quality is the pivotal element in benefit evaluation, not the reduction in one or more pollutants. Reduction in pollutants may or may not improve water quality. The paper will explore water quality and requirements for quality improvement in greater detail.

Difficulties in benefit-cost calculations of water quality improvement are twofold; those associated with identification and measurement of water quality improvement and those associated with evaluating the improvement in terms of a dollar common denominator. Since few markets and hence few prices for water quality improvement exist, valuation is often undertaken through estimating synthetic or proxy prices. Several techniques exist to derive these shadow prices. This paper will not deal with such value estimation techniques. Instead, we will concentrate on problems associated with identifying benefits as well as on the impact of benefit identification for discriminating among abatement projects. If benefits are not properly identified, even the most sophisticated valuation technique will come up with a wrong answer. Since benefits can be derived only from water quality improvement, the link between pollution abatement and water quality is crucial and will be explored in greater detail.

The purpose of this study is: (1) to show that water quality improvement is not necessarily synonymous with reducing any one pollutant, as is often assumed, (2) to explore the relationship between pollution abatement and water quality improvement, (3) to show the necessity of proper benefit identification for determining socio-economic benefits of quality improvement and (4) to show the importance of economic evaluations for directing abatement efforts.

The paper is organized as follows. Since water quality is pivotal in benefit identification, the concept and measurement of quality is first explored. Then the relevance of water quality for benefit evaluation is examined. The next section deals with the efficiency of pollution abatement which is highly dependent on proper benefit identification. This section also covers problems associated with targeting, particularly under limited budgets for water pollution control. Lastly, some pertinent implications for environmental policy and management are considered.

Although the principles determining water quality apply equally to surface and ground water, quality always refers to a particular water body. Water use, an important factor affecting economic benefits of water quality improvement, also refers to a particular water body. The most obvious geographic extent of a surface water body is a watershed. However, smaller areas may be considered if water quality differs greatly within a watershed. Entire drainage basins could also be considered. A drainage basin approach is called for if water quality in upstream watersheds affect water quality downstream in the basin and if downstream water use is important. Another approach lies in delimiting an entire water system, incorporating both surface and ground water because of their interdependence. For the purposes of this paper, which are mainly expository, the focus is on surface water by watersheds.

## Water Quality

Central to benefit evaluation of water pollution control is water quality. Water quality is defined in terms of its fitness for a specific use, since each use has specific quality requirements. Water quality is dependent on physical, chemical, biological, and aesthetic attributes of the water. Each of these contains various elements, called quality parameters. For example, the physical characteristic includes sediment content, dissolved and suspended solids, temperature, and stream flow. The chemical characteristic includes nutrients, heavy metals, pesticides, dissolved oxygen, and hydrogen ion concentration (pH). Fecal coliform bacteria, algae growth and amoebae are elements establishing the biological characteristic of water quality. The aesthetic characteristic contains quality parameters such as odour and visual attractiveness. The term quality parameter encompasses more than the term pollutant. Since water quality for certain uses can also be affected by variables such as streamflow, temperature, dissolved oxygen, and pH levels, the term parameter is preferred over the term pollutant.

### *Measuring Water Quality*

The level of water quality for a specific use k depends on the level of the various quality parameters affecting that use and can be expressed by the following vector:

$$X_k = \{p_{k1}, p_{k2},\ldots, p_{kj},\ldots, p_{km}\} \qquad (k = 1\ldots m;\ j = 1\ldots n) \qquad \text{(a)}$$

$X_k$ is the water quality vector for use k and $p_{kj}$ is the magnitude of the jth quality parameter affecting use k. These quality parameters are measured in physical, chemical and biological units such as degrees Celsius, milligrams per litre (mg/l), and organisms per 100 ml.

Water quality can be measured in various ways. One way is to establish a standard $\overline{p_{kj}}$ to denote the level of tolerance for the jth parameter in use k. If the level of quality parameter j in use k exceeds the standard $\overline{p_{kj}}$ $(p_{kj} > \overline{p_{kj}})$ ,the water is unfit for use k. Note that any one quality parameter may make the water unfit for use k. If only one parameter exceeds its standard for use k while all others are below their standards, the water is still unfit for use k. Classifying water quality by means of one standard for each parameter is often preferred when dealing with toxic chemicals and bacteria affecting health. In that case, the level of the toxic chemical or of the bacteria cannot exceed a set standard. If it does, the water is rated unfit for those uses affecting health.

In general, water quality is better measured in various classes, scales or grades. The water is not necessarily either fit or unfit for a particular use, but less of a pollutant is generally better than more. For this grading system a water quality parameter index $I_{kj}$ for each parameter affecting use k can be constructed. This is done by means of water quality index functions, as explained by Ott (1978) and Willis *et al.* (1992). These functions translate the level of parameter j in use k into a water quality parameter index. These indices are normally scaled from 0 to 100, higher numbers indicating better water quality (Dinius, 1987).

Water quality can now be expressed as a vector of water quality parameter indices as follows:

$$W_k = \{I_{k1}, I_{k2},\ldots,I_{kj},\ldots I_{kn}\} \qquad (k = 1\ldots\ldots m; \qquad j = 1\ldots\ldots n) \qquad \text{(b)}$$

$W_k$ is the water quality vector for use k expressed in parameter indices. This vector of individual quality parameter indices for use k must be translated into an overall water quality index $Q_k$. This is done by the following aggregation form:

$$Q_k = g(I_{kj}) \qquad (k = 1\ldots\ldots m; \qquad j = 1\ldots\ldots n) \qquad (1)$$

$Q_k$ is the overall water quality index for use k

g represents a general aggregation form

$I_{kj}$ is the quality index number of the jth quality parameter for use k.

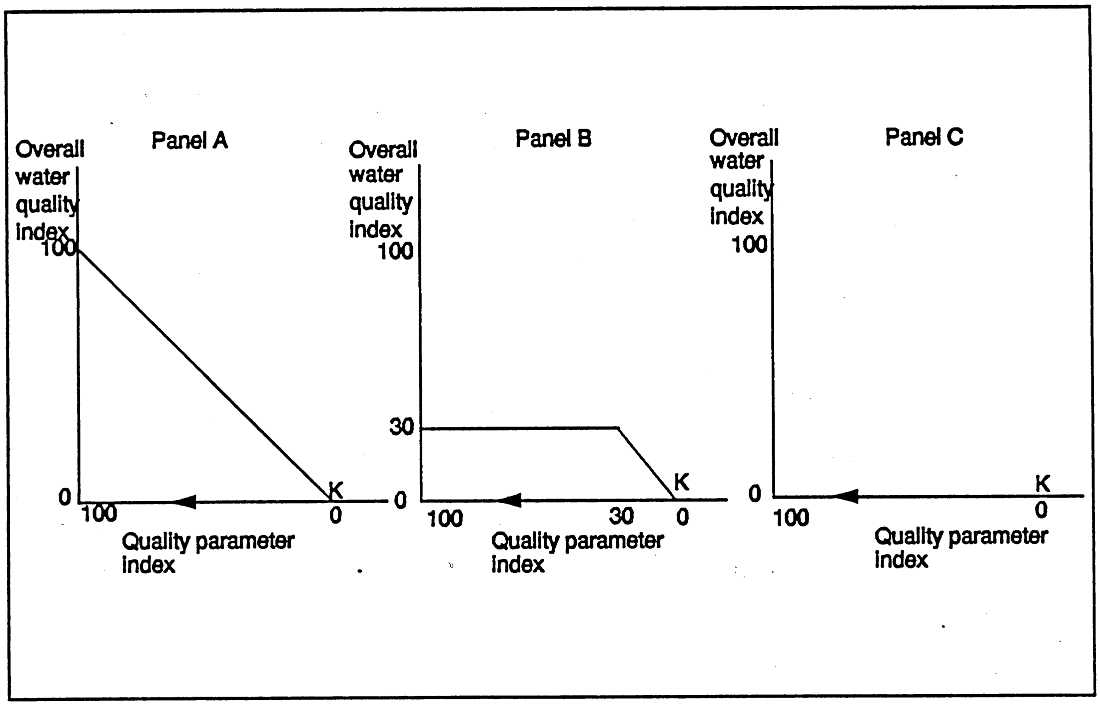
The functional form chosen for aggregating the individual parameter indices into an overall water quality index for each use is the "minimum operator rule" (Ott, 1978). This rule states that the overall water quality index for use k is equal to the smallest quality parameter index number from among all individual parameters affecting use k. This implies that the quality parameter that most limits use k is the one that determines overall water quality. The minimum operator rule thus can be expressed as:

$$Q_k = \min (I_{kj}) \qquad (2)$$

Willis *et al.* (1992) distinguish five classes. Very poor water quality for a particular use has an index range of 0 to 29.9 while perfect water quality ranks 100. Between these extremes are three more intermediate quality ranges: poor, good, and very good. It is important to note that the quality parameters affect the various uses in different ways. Therefore the index number given to a particular parameter can vary from use to use. Some parameters do not even affect all uses. In that case the magnitude of the parameter is irrelevant for water quality for that particular use.

### Graphical and Numerical Illustrations

The effect of a reduction in one particular pollutant on water quality for a particular use can be graphically illustrated in the following three panels. The index of that particular pollutant (quality parameter) is depicted on the horizontal axis, while the vertical axis represents the overall water quality index. Note that at the origin the overall water quality index is zero and the parameter index is 100. Suppose the parameter index is currently zero as indicated by K.



Panel A shows that the parameter under consideration is either the only one or the only limiting parameter affecting that use. Any reduction of the pollutant will increase water quality. If the reduction results in a quality parameter index of 100, overall water quality becomes perfect. In panel B the quality parameter under consideration is the only limiting factor till the quality parameter index reaches 30. Further reductions will not improve the overall water quality index beyond 30 since one or more of other quality parameters affecting that use now become the limiting factor(s). Panel C indicates that no improvement in water quality is possible through any reduction of the pollutant under consideration, since other limiting parameters are present from the outset.

A numerical example will illustrate how water quality levels are estimated in a watershed. The example is taken from the Kettle Creek in southern Ontario and relates to water quality determination for sport fishing. Average levels of major parameters affecting sport fishing for the most critical months of June, July and August between 1988 and 1992 are presented in column 2 of Table 1. This column represents vector (a). Functional forms from Willis *et al.* (1992) are used to calculate the quality index for each parameter affecting sport fishing. The numerical results as well as qualitative interpretations are expressed in the first 4 rows of columns 3 and 4 in Table 1. Index numbers in column 3 represent vector (b). The lowest index is for residue particulate and the highest for dissolved oxygen. Consequently, the most limiting parameter is residue particulate. The minimum operator rule is used to estimate overall water quality for sport fishing as expressed in equation (2). The corresponding index is found in the last row of column 3 in Table 1 and is consequently identical to the index for residue particulate, the most limiting parameter.

TABLE 1

**AVERAGE QUALITY PARAMETER LEVELS AND THEIR INDICES AND CORRESPONDING WATER QUALITY INDEX FOR SPORT FISHING IN THE KETTLE CREEK, 1988 - 1992**

| Quality parameters and water quality | Mean parameter levels | Indices | Quality classification |
|---|---|---|---|
| Residue particulate | 75.5 mg/l | 0 | very poor |
| Temperature | 22.9 degr. Cel. | 48 | poor |
| Dissolved oxygen | 9 mg/l | 100 | perfect |
| Phosphate | 0.277 mg/l | 19 | very poor |
| Overall water quality | | 0 | very poor |

Greater numbers of sport fish species and their levels can be supported, the better the overall water quality for sport fishing is. It can be seen from Table I that overall water quality for sport fishing in the Kettle Creek is very poor. An increase in any index other than that for residue particulate through improving the corresponding quality parameters will have no effect on overall water quality relative to sport fishing. To improve water quality for this purpose, a reduction in residue particulate and phosphate is needed such that their indices reach at least 30, thus improving water quality for sport fishing from very poor to poor.

### *Measuring Water Quality in Canada*

The above index analysis is not used in Canada. Instead the standard approach is used for all quality parameters. Water quality thus is determined by those parameters exceeding their standards which are measured in their own units of measurement. Therefore water quality is seen as either fit or unfit for a particular use. Suppose a particular use is affected by five quality parameters, four of them being below and one exceeding parameter standards. The result is that the water is considered unfit for that particular use. As indicated, a standard is a rough indicator for most uses, because generally the water is neither fit nor unfit but displays various degrees of fitness. This bears important consequences for benefit evaluation because willingness to pay for water quality improvement depends on the degree of improvement.

### *Difficulties and Shortcomings in Water Quality Determination*

The determination of water quality is based mainly on the natural sciences, which is of crucial importance to economic evaluation of water pollution control programs. Apart from developing water quality functions, other difficulties still remain in water quality evaluation, among them those related to space and time components of quality. The most obvious spatial unit of measurement is a watershed, although quality can differ greatly within a watershed. In that case the watershed must be subdivided into sub-watersheds. Quality also changes over time due to many factors such as rainfall or snowmelt which occur randomly over time. In that case quality is determined by the expected value of the probability distribution of the quality parameter levels over time. Many shortcomings exist in water quality measurement and more work is still needed in this area (Bodo, n.d.). For the remainder of this paper water quality is assumed to be homogeneous within a watershed, not because this reflects reality, but for ease of exposition.

## Water Quality and Benefit Evaluation

### *Danger of Unilateral Approach*

Reliable water quality information is essential for benefit evaluation of water quality control. Economic benefit evaluation is, however, often pursued in isolation of water quality improvement data. Many policies and programs exist or remedial actions recommended that concentrate on the reduction of one particular pollutant, usually from one particular source. Reduction in sediment loading from agriculture is a case in point. Benefit evaluation of such programs and activities usually assumes that water quality improves with a reduction in sediment loading (Clark, 1985; Nielson, 1986; Fox and Dickson, 1990; Agriculture Canada, 1992; Fox *et al.*, 1993;). Evaluation is then based on the paradigm expressed in Panel A. From the previous example, as noted in Table 1, it is obvious that water quality can only improve if sediment is the parameter that most limits water quality for a particular use and if the reduction is large enough to increase the sediment index to at least the next grade. If indices of other parameters occur at the same or a lower grade as that for sediment then a reduction in sediment alone has no effect on water quality. If the index of residue particulate increases to 30 through sediment reduction but the phosphate index remains far below 30, perhaps because phosphate pollution from other sources remains unabated, no water quality improvement for sport fishing will occur. Even at zero sediment loading the water is still very poor for sport fishing.

If sediment is the only parameter affecting a particular use, then a reduction in sediment will result in a benefit regardless of other pollutants in the water. For example, a reduction in sediment loading avoids the necessity of periodic dredging of harbors and waterways. Moreover, maintenance costs of water-using machinery and appliances will be reduced by a decrease in