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# INCENTIVES AND REGULATION FOR POLLUTION ABATEMENT WITH AN APPLICATION TO WASTE WATER TREATMENT


**Sudipto Mundle**
Economist
Economics and Development Resource Center
Asian Development Bank

**U. Shankar**
Director
Madras Institute of Development Studies

**Shekhar Mehta**
Visiting Scholar
Institute of Government and Public Affairs
University of Illinois



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## Foreword

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V.V. DESAI
Director and Chief Economist
Economics and Development Resource Center

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## Abstract

This paper first compares alternative regulation and fiscal-financial incentive based policy instruments for pollution control in terms of different choice criteria. Since no single instrument can be shown to dominate all others in either theory or actual experience, the paper goes on to spell out an experimental menu of alternative incentive structures for supporting predetermined standards. The practical implications of the proposed alternative systems of charges, taxes, and tradeable permits in terms of their financial "burdens" on product prices are then illustrated for waste water treatment using abatement cost functions estimated for the pulp and paper industry in India.

# I. Introduction

This paper addresses the question of choosing appropriate policy instruments for pollution control. Section II briefly reviews the static and dynamic efficiency characteristics of command and control measures as well as different types of market-based instruments which attempt to manipulate the decisions of producers and consumers indirectly through economic incentives. The problem of enforcement is also examined in this section since any policy is effective only to the extent that it is actually implemented. It turns out that no single instrument can be unambiguously identified as being superior to all others and that it may be best to use policy regimes which combine regulation with economic incentives. Accordingly, a menu of alternative policy regimes has been outlined in Section III, all of which combine elements of direct control with economic incentives in varying degrees. This is followed in Section IV by an actual application of these principles in the context of pulp and paper, one of the world's most polluting industries, using empirical data drawn from India. Abatement cost functions are estimated. Based on these estimates, taxes and charges are then designed which would induce polluters to achieve established standards of abatement. Finally, the implications of the pollution control regimes in terms of additional production cost and the return on investment in abatement plants by way of charges or revenues saved are worked out. The paper concludes that the proposed schemes would raise sale prices by no more than 5 or 6 percent, which would appear to be a modest price for the polluter to pay. Furthermore, the investment on effluent treatment would be recovered within one year in many cases, and at most within four to five years in other cases, depending on plant size and technology, by way of taxes or charges saved.

# II. Pollution Control Instruments and the Enforcement Problem

Historically, pollution control has largely taken the form of direct regulation: bans, setting of standards, etc., often described as command and control (CAC) policies. However, these CAC policies have increasingly come under criticism on the ground that they are suboptimal in terms of social welfare maximization, i.e., they do not in general yield production-pollution-abatement outcomes which equate the social marginal benefit of abatement with its social marginal cost. Economists since the time of Pigou have come up with various designs of market-based policy instruments (MBIs) which can satisfy these social welfare-maximizing conditions. However, these properties of MBIs have typically been demonstrated under highly simplifying assumptions with regard to information on the tastes of consumers, damage functions (abatement benefits), and the production and abatement costs of firms. Despite much progress on means of revealing such information over the past two decades (Cropper and Oates 1992), the assumptions under which MBIs yield optimal results remain unrealistic. Once these assumptions are gradually relaxed, it is no longer obvious that MBIs can generate socially optimal outcomes (Bohm and Russell 1985). There is, therefore, a growing consensus that economic instruments such as charges or permits should be combined with direct regulation measures like standards. According to Baumol and Oates (1988, 169), this combination of regulatory and economic instruments

> ... may be looked upon as a procedure which frankly abandons any attempt to obtain extensive information on benefits but which uses the pricing system where it is at its best, in the allocation of damage-reducing tasks in a manner that approximates minimization of costs, even though the detailed data on the costs of these tasks are unavailable.

There are a number of alternative economic instruments which are designed to internalize the external costs of pollution, making the polluter pay, and at the same time minimize the cost of a given level of abatement under given conditions with regard to tastes, production, abatement costs, etc. These include price instruments such as various forms of charges, subsidies, returnable deposits, liabilities, etc., which fix prices and let the agents respond through quantity adjustment, or quantity instruments like tradeable permits which fix emission quantities and allow agents to clear the pollution market through price adjustments. However, the relative advantage of these different instruments remains ambiguous.

Effluent charges are effective provided the rates are high enough to induce abatement, and differential taxes appear to have been very effective wherever they have been tried. Moreover, charges do not become problematic like permits when the effluent is not uniformly dispersed or when there are market imperfections. They also provide a stronger inducement to invest in new, cleaner, technologies and have greater potential as a source of revenue for the government as compared to charges. On the other hand, when charges are uniform rather than source-specific, they are not as cost-efficient as permits and the information requirements of source-specific charges are too demanding even in a developed country context. Hence permits have been found to be more cost-effective. They also act more directly on the ambient air or water quality as compared to charges. With charges a cumbersome and time-consuming process of trial and error, it is necessary to seek out the charge rates and source standards that will yield the desired level of ambient standards. Charges also require repeated administrative action to revise charges, as circumstances change, in order to maintain ambient standards. In the tradeable permits case, prices adjust automatically as conditions change without affecting ambient air or water quality.

Thus there are advantages and disadvantages with both charges and permits, though the balance is perhaps somewhat in favor of charges. Also, in the Indian context, tax-like charges would be more familiar and easier to administer. However, this is only a conjecture. Basically, the experience with charges in Europe and tradeable permits in the U.S. remains ambiguous with neither clearly preferable to the other. Given this background, the best way to graft economic incentives on to existing standards is to experiment with three or four different systems in different regions for a few years and finally opt for a standard and charges regime, or a standards and tradeable permits regime based on the results of the experiment.

The case for practical experimentation with alternative policy regimes is further strengthened by considerations of enforcement. We know that economic instruments minimize aggregate abatement costs by equating the marginal abatement costs across firms. However, Malik (1992) has shown that minimization of enforcement costs for achieving a total emission goal requires equating the derivatives of the marginal cost functions (i.e., the second derivatives of the total cost functions) and demonstrated that enforcement costs can be higher for incentive-based policies than for policies based on direct control. Unfortunately, no general result is available regarding which policy minimizes the sum of abatement and enforcement costs.

Harford and Harrington (1991) and Russell (1992) report some empirical evidence in favor of voluntary compliance on the part of many large industrial polluters in the U.S. and Western Europe. One reason for voluntary compliance is that some of the parties "do not want to be singled out as recalcitrant—as bad guys—because the public relations cost of such a designation strikes them as potentially enormous" (Russell 1992, 198-99). Harford and Harrington suggest the following mechanism to increase the compliance rate: (i) classify the polluters under different categories depending on the number of violations, (ii) increase the probability of monitoring as one falls into a higher category, (iii) increase the fine rates as one falls into a higher category, and (iv) blacklist firms with a large number of violations.

Pollution policy makers can also learn from the recent theoretical literature on enforcement in the field of taxation as well as from pollution compliance literature (see, for example, the recent paper by Grieson and Singh 1989 which builds on the earlier work of Graetaz, Reinganum, and Wilde 1986; Melumad and Mookherjee 1989; Becker 1968; and Polinsky and Shavell 1979, 1984). Theorems have been proven about the levels of noncompliance fines, intensity of testing (auditing), or testing fees that would be socially optimal. Most of these papers assume either that the enforcer's objective is to minimize the social cost of a negative externality or that the enforcers want to maximize their own career progress through good performance, etc. (Grieson and Singh 1989). One recent paper even examines the enforcement question on the assumption that enforcers are corrupt and want to maximize their own expected income (Gangopadhyay, Goswami, and Sanyal 1990).

This literature offers a number of important insights on the question of compliance in the context of pollution control in India. First, it is expedient to recognize that polluters and regulation inspectors are both eventually interested in maximizing own incomes subject to risks of detection, levels of penalties, etc. That being so, an enforcement regime must ensure that the expected income maximizing strategy for the polluter, adjusted for risk, penalty, etc., is to comply with the standard. At the same time, the enforcement regime must ensure that the enforcement inspectors' expected income, adjusted for risk, penalties, recoveries, etc., is maximized by honestly monitoring rather than colluding with the polluter.

Let the inspector have a reward $r$ for detecting noncompliance. Then the polluter would have to pay a bribe $b > r$ in order to induce the inspector to collude or $b = r.d$ where $d$ is the honesty premium and $d > 1$ (ceteris paribus people prefer legal income to illegal income). Suppose now the probability of a noncomplying polluter getting caught is $p$ ($0<p<1$) and (s)he is almost risk-neutral. The polluter would then comply or not comply depending on whether or not $(p.r.d. - c) \geq 0$, where $c$ is the cost of compliance. For $r \geq c/pd$ compliance would be ensured. At the boundary $r = c/pd$, the higher the probability of detection or the premium on legal (as compared to illegal) income, the lower would be the ratio of required reward to compliance cost, i.e.,

$$\frac{r}{c} = \frac{1}{pd}$$

Notice that in the context of pollution abatement compliance cost $c$ is nothing but the operating cost of the ETP. Finally, a polluter can take the risk of not complying and paying the penalty instead of the bribe. This option is ruled out if the penalty itself is set equal to the inspectors' reward, i.e., the reward would be financed by the penalty. Thus, incentive-compatible enforcement systems are feasible even if we assume that the regulators are prone to corruption.

The enforcement system discussed above is quite general and could apply regardless of whether compliance refers to a system of standards, or standards and charges, or standards and tradeable permits. However, it does not rule out the possibility of harassment. When an inspector is given the power to impose a penalty which would flow to him or her as a reward, this clearly creates opportunities for rent-seeking activities with or without compliance. To eliminate or minimize this possibility, the system of multiple sampling of effluents and sealing of samples—which has been working reasonably well in India so far—could be further streamlined to reduce time lags in test results. Further, for reliability and transparency of testing procedures, sealed samples, for example, could be opened and tested in the presence of whole batches of sampled parties, analogous to the opening of tenders.

Finally, an administrative problem that could arise with the enforcement system discussed here is the question of a chain of agents in the inspection, testing, and penalizing process. It is possible that all officials involved in any noncompliance case would have to share the rewards in order to get the system to work. If the noncomplying polluter could evade the penalty by bribing only one or two officials in the chain, then the rewards would have to be suitably calibrated to maintain the incentive compatibility of the enforcement regime. However, these are matters of administrative detail which would have to be sorted out, drawing on existing experience of reward systems in customs collection and elsewhere, once the essential principles of the enforcement mechanisms are accepted.

## III. A Menu of Alternative Pollution Control Incentive Regimes

Drawing on the choice considerations and enforcement issues discussed above, a menu of alternative incentive regimes for pollution control can now be outlined. The incentive-based regimes proposed here are intended for point sources. It should be clarified moreover that these alternatives are intended for polluting industries in India other than those releasing extremely hazardous or toxic wastes in air, soil, or water. For such highly polluting hazardous industries, indirect incentive-based controls are inappropriate and they should be strongly regulated according to strict standards, backed by heavy penalties in the enforcement mechanism. We outline below the features of each regime, highlighting both pollution control and enforcement policies.

### A. Option 1: Abatement Charges with Government Clean-up

The first possible option is a combination of abatement charges on volume and concentration of effluents/emissions for firms which do not achieve source-specific standards, with the government undertaking the responsibility for pollution abatement. Under this scheme, firms with clean technologies and firms with effluent treatment plants carrying out abatement up to the officially prescribed Minimum Acceptable Standards (MINAS) are not liable to pay any charge. The charge per unit of a pollutant should be set at a level which would encourage most firms with treatment plants to abate up to MINAS levels rather than pay charges to the government.[1] Firms with abatement operating costs higher than the charges payable to the government would prefer not to abate. Therefore, government has the responsibility of collecting charges from these firms and undertaking the effluent/emission treatment operations through a public agency.

The charges should be revised once a year on the basis of an index of prices of inputs used in the abatement operations. In order to ensure compliance with standards both by the private polluting firms as well as the public abatement firm, an independent monitoring and enforcing agency would be necessary. This agency must have free access to the effluent treatment plants (ETPs) set up by polluting firms or the public abatement firm for monitoring purposes, and the power to levy penalties for violation of standards. It must also decide on an audit procedure and a schedule of fines for noncompliance, with the amount of fine increasing with the extent of noncompliance and the number of violations. The amount of fine should be such that the expected cost of noncompliance is greater than the abatement cost up to MINAS levels. Voluntary nongovernment organizations (NGOs) could also monitor noncompliance on the part of polluting private firms and the public abatement firm as well as any lapses on the part of the formal monitoring and enforcement agency.

## B. Option 2: Abatement Charges with Third Party Clean-up

The main limitation of the first option is that it is highly interventionist, placing a major abatement responsibility on the government. It is well known that the incentive and management structures of public sector/government agencies in India are not particularly cost-effective. As such the publicly operated ETPs may take a long time to be established and prove expensive to operate and maintain. The charges collected from noncomplying polluters may not adequately cover the cost of the ETPs.

A more cost-effective option could be a combination of charges with third party clean up. Government would still collect charges from the noncomplying polluters, but it would now contract the setting up and operation of ETPs to private firms on the basis of competitive bidding. In view of the set-up and sunk costs in ETPs, the duration of the contract has to be for a fairly long period, say about 10 years. Government can also assist the private abatement firms by providing land for the ETPs and offering fiscal incentives on purchases of machinery and equipment for ETPs. The annual contract fees may also be indexed on the same basis as the charges.

The independent monitoring and enforcing agency will now have the responsibility of ensuring compliance from the polluting firms undertaking their own abatement and the private firm undertaking abatement for the noncomplying firms.

## C. Option 3: A Tax Subsidy Scheme

Under this scheme, a Pigouvian tax per unit of pollution based on the marginal abatement cost at the MINAS level will be levied on all firms which fail to achieve the source-specific standards, and a per unit subsidy will be offered to firms which carry on abatement beyond the MINAS point. This scheme provides an opportunity for firms with low abatement costs to achieve higher environmental standards.

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[1]The design of such a charge is discussed in section III below.

Under this scheme, the polluters must submit periodical returns to a tax authority indicating volume and concentration of pollution in the effluents and the tax payable or subsidy receivable. An independent monitoring authority will undertake periodic audits. It would collect samples of effluents/emissions and verify whether pollution levels found in the samples match with pollution levels in the returns submitted by the polluters.[2] A fine schedule for submitting false returns can be designed with expected fines greater than the tax and the expected fines increasing both with the extent of under reporting and with the number of violations.

The tax/subsidy rate should also be indexed by a price index of inputs used in the abatement. The NGOs are again needed to act as watchdogs in this case.

## D. Option 4: Tradeable Private Permit System

The three options using charges or taxes outlined above deal with source-specific standards. They also entail considerable government intervention, though the extent of intervention is less in the second and third options than in the first option. Tradeable permit schemes like those prevailing in the U.S. require specification of ambient standards by the government and leave pollution control operations to the firms. However, the government has to play an important role in the allocation of initial permits, creation of secondary markets for the permits, and monitoring of compliance by the firms. In the Indian context, given the prevailing administrative culture and the skill levels of personnel in the pollution control boards, it may be premature to attempt this type of innovative experiment. Hence, an alternative system of private tradeable permits is proposed.

First, the government specifies ambient standards in a region, e.g., water quality in a segment of river, ambient air quality in a town, etc. Once the standards are specified, the volume of pollution permits is determined. Next, the government auctions the pollution rights on the basis of competitive bidding to firms which will undertake to maintain the ambient standards. The bidder who quotes the lowest permit sale price is given the pollution rights. This firm then sells the pollution rights to the polluters at the quoted price.[3] The income received from the sale of permits can be used by the permit-selling firm for operating the enforcement mechanism, meeting the initial expenses for creating a secondary permit market, and for its own profit. The permit seller must certify and register transactions in the secondary permit market. A polluter is in a position to sell permits only when his permit holding exceeds his actual emissions. The permit seller has to ensure that the aggregate emissions/effluents are equal to or less than the value of total permits. This would be monitored by an independent agency and also possibly by some NGOs. Therefore, the permit seller has to develop and implement a mechanism for compliance on the part of the polluters. Otherwise it would be disqualified and sued for damages by the government for breaching the contract to maintain ambient standards.

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[2]The actual level of pollution concentration in a water body or atmosphere depends partly on the activities of the polluters and partly on stochastic factors such as temperature and rainfall. The presence of stochastic elements in the observed outputs necessitates repeated sampling for verification. The auditing scheme can be designed to take these factors into account.

[3]It is possible that the demand for permits may exceed the supply of permits at the predetermined (auction) price. In such a situation, the permit seller might ration the permits on the basis of some criteria, e.g., initial pollution levels for the primary sale. Secondary market permit resale prices would then rise to clear the market.

The advantages of the tradeable permit system are the following: (i) The polluters can use their private information about technology, costs, etc. to achieve profit-maximizing levels of abatement. We know that the aggregate abatement costs are minimized under this system; and (ii) Government's responsibility is limited only to setting ambient standards and monitoring the behavior of the permit seller. The major disadvantage of the system is that the permit seller derives monopoly power once he gets the contract. However, his power over the initial sale price of permits is curbed as a result of competitive bidding on the permit price. His powers over the charges for permit transfers, fines, etc. can also be constrained by caps on their levels. Over a period of time, these charges may be revised on the basis of appropriate price indices which reflect the costs of providing these services. The duration of the permit may be, for example, 10 years or whatever it takes to ensure a reasonable return on the permit vendors' investment. Based on the experiences gained in the operation of the secondary market, the government can design and implement better auction schemes.

The first three options spelled out above are relevant for the source-specific standards regime while the fourth option is appropriate for the ambient standard regime. The specification of source-specific standards requires more information on the part of the regulator than specification of ambient standards. Hence, Option 4 is the most cost-effective. If monitoring and enforcement systems ensure full compliance from all the parties, environmental quality standards can be achieved under all options except Option 3. The degree of government intervention is the maximum with the first option and lowest with the fourth option. These observations are based mainly on a priori reasoning. For learning about the true relative costs and benefits of the four schemes, it would be necessary to experiment with these four schemes in selected regions in the country.

## IV. Incentive and the Cost of Effluent Treatment: The Case of Pulp and Paper

Four alternative systems were outlined above for incentive-based pollution control, each involving a different degree of government intervention in the control of industrial pollution. No matter which of these systems is adopted, the cost of abatement will play a central role in the calibration of the relevant economic instrument, be it charges, taxes, subsidies, or regulated prices. This section discusses the results of an illustrative exercise based on the pulp and paper industry, which was undertaken for analyzing the cost of cleaning up waste water and its "burden" relative to sales realization, which should serve as the basis for determining charges, taxes, or permit prices in the alternative schemes discussed above.

In undertaking this study of abatement in the paper industry, two different sets of data were used. A survey conducted by the National Institute of Public Finance and Policy (NIPFP), New Delhi, generated data on 12 paper units for the year 1991/1992. However, data for only nine units were found suitable for the study. In addition, the National Environment Engineering Research Institute (NEERI) made available data from a survey of 20 paper units, of which data for 12 units pertaining to 1989/1990 were found suitable. The analysis was therefore conducted on the basis of data drawn from 21 units in all, after adjusting the NEERI data to 1991/1992 prices.[4] However, a provision was made for identifying source-related differences between the NEERI data and NIPFP data in the statistical analysis.

## A. The Abatement Cost Function

The output of a paper mill (ETP) is a product of the quantity of treated waste water ($F$) and the change in the concentration of pollutants between the influent ($I$) and the effluent ($E$). The data show substantial variations across plants in the cost of producing this output. This is partly attributable to differences in technology. Thus, capital costs per kiloliter designed flow (*KLDF*) are typically higher in sulphate-based plants as compared to Krafta-based plants while operating costs are higher for the latter. Similarly, at the lower end of the size distribution, plants using a recycled waste process have higher capital costs per KLDF for their ETPs as compared to those preparing their own pulp. However, such technology-based cost differences notwithstanding, there are also cost differences relating to differences in influent quality and size. Both capital cost and operating costs rise with size of plant but not proportionately, implying that there are scale economies in both capital cost as well as operating cost.

A question now arises about the measurement of $F$, $I$, and $E$. $F$ is straightforward; it is the volume of treated water measured in kiloliters per day. $I$ and $E$ in principle represent whole vectors of different pollution parameters. However, in the Indian context the most important parameters are alkalinity (pH level), chemical oxygen demand (COD), and biological oxygen demand (BOD). Of these, pH and COD need to be first brought within certain tolerance limits in order to reduce BOD, such that the latter is often taken as a single parameter measure of the level of pollution concentration.[5] Hence, the BOD levels before and after treatment in the ETP, measured in milligrams per liter, may be taken as reasonable proxies for $I$ and $E$.

The pollution abatement cost literature suggests a nonlinear cost function. A popular choice is the Cobb-Douglas form, which is relatively easy to estimate. This form can be viewed as a first order log linear approximation of any nonlinear function. In the present case we start with a function of the form

$$C = e^{a} F^{b} I^{c} E^{g} \qquad C_f, C_I > 0 > C_E \tag{1}$$

where $C$ is the total operating cost of abatement; $F$, $I$, and $E$ are, respectively, quantities of treated water, pollution concentration in the influent and that in the effluent as explained earlier, and $e$ is the base of natural logarithm. $a$, $b$, $c$, and $g$ are the parameters to be estimated. The expected signs of $a$, $b$, and $c$ are positive.[6] Since $E$ denotes the pollution concentration in

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[4]It should be emphasized that the cost data relate to the amount of operating expenditure needed to achieve the desired level of abatement by each firm. Some firms reported desired abatement levels beyond the MINAS values.

[5]For a discussion of the technology of abatement, see Eckenfelder, Jr. (1989).

[6]Some papers in the abatement cost literature consider only two variables, $F$ and ($I$-$E$). From the engineering literature, we inferred that economies of scale could exist with respect to both the quantity of treated water and the volume of influent. Also, the relevant abatement cost for our exercise is abatement cost given $I$ and $F$. Equation (1) should be viewed as an operating cost function. A short-run cost function depends on output, variable input prices, and quantities of fixed inputs. We do not include variable input prices because we deal with cross section data for firms in a small region. We could not include fixed capital stock because of serious problems in measuring the value of land used for abatement. Given the nature of our data, we can interpret $F$ as a proxy for fixed capital. A test for misspecification is carried out later.

the effluent, a unit increase in $E$ implies a unit reduction in abatement and hence a decrease in cost $C$. The sign of coefficient $g$ is therefore expected to be negative. Differentiating (1 with respect to $E$ we get the marginal cost of a unit change in effluent quality $E$, given $F$ and $I$,

$$\frac{\partial C}{\partial E} = e^{a} g\, F^{b} I^{c} E^{(g-1)} \qquad (2)$$

The marginal operating cost of abatement is the negative of the RHS term in equation (2) since abatement implies a fall in the effluent BOD level $E$. It was mentioned earlier that two different sources of data have been used. In order to capture the effect of source-related differences between the NEERI data and NIPFP data, a dummy has been introduced with the value 0 for NEERI and 1 for NIPFP. Incorporating the dummy variable we can replace (1) by

$$C = F^{b} I^{c} E^{g} e^{(a+dD)} \qquad C_{f}, C_{I} > 0 > C_{E} \qquad (3)$$

where $D$ is the dummy variable with parameter $d$. Equation (3) was estimated by OLS method after transforming it into natural logs. The results are reported in Table 1 and discussed further below. The dummy variable $D$ turned out to be insignificant and was dropped.

TABLE 1
**Estimated Operating Cost Function for Pulp and Paper Industry ETPs**
(Dependent Variable = Ln C)

| Coefficient of | Equation (3) | Equation (4) |
|---|---|---|
| LnF | 0.4775 | 0.5212 |
| | (2.2504)* | (2.7626)* |
| LnI | 0.8340 | 0.8104 |
| | (2.9007)* | (2.8188)* |
| LnE | -0.5602 | – |
| | (-2.0105)* | |
| E | – | -0.0111 |
| | | (-2.0680)* |
| Constant | -3.9463 | -5.7632 |
| $\bar{R}^2$ | 0.5884 | 0.5932 |
| F (4,16) | 8.1480 | 8.2900 |

Notes: Values in parentheses are t-values. Ln is natural logarithm.
* denotes significance at the 5 percent level.

Since there are large variations in both plant size as well as pollution concentration levels across plants, it was necessary to test for heteroskedasticity. A variety of tests including the Glesjer and Harvey test were applied but showed no presence of heteroskedasticity. Furthermore, the Ramsey RESET test was also applied to check for left-out variables.[7] The graph of OLS residuals plotted against estimated log C was also used to check the same thing. None of the tests suggested any left-out variable.

Although the above functional form appears to be appropriate for the abatement cost function, it has to be restricted to strictly positive values of $E$. An alternative functional form was also tried which is nonlinear but where E enters exponentially as follows:

$$C = e^{(a+dD)} F^{b} I^{c} e^{gE} \qquad C_{F}, C_{I} > 0 > C_{E} \qquad (4)$$

[7]The Ramsey RESET is an F test. The computed F values are as follows: RESET (2) F(1,15)=0.0720; RESET (3) F(2,14)=0.1536; RESET (4) F(3,13)=0.0993. None of them are significant. Furthermore, the DW statistic used to test for serial correlation in time series data can be used to test for specification bias on account of left-out variables in cross section data (Godfrey 1988).

Equation (4) has been estimated and the results are reported along with those of equation (3) in Table 1. Again, the dummy variable $D$ was insignificant, hence it was dropped. It is evident that both equations are highly significant since the F-values in both cases are much higher than the tabulated value of F at the 1 percent level, F(4,16)=4.77. Their $\overline{R}$ values are also very close at 0.5884 and 0.5932 for equations (3) and (4), respectively, the difference being statistically insignificant. The same holds for the PE test and Chi-square test. The coefficients for $F$, $I$, and $E$ are all significant at the 5 percent level. Since both equations perform equally well statistically, it is difficult to choose between them.[8]

B. The Marginal Cost of Abatement

Either of the two cost functions estimated above can now be employed to estimate the marginal cost of abatement for varying volumes of waste water treatment and different levels of influent or effluent concentrations of pollution. The marginal cost functions corresponding to equations 3 and 4 with $D$ equal to zero, are given by

$$MC1 = 100 \times (100{,}000/355) \times 0.5602\{e^{-3.9463} F^{(0.4775-1)} I^{0.8340} E^{-(0.5602+1)}\} \quad (5)$$

and

$$MC2 = 100 \times (100{,}000/355) \times 0.0111\{e^{-5.7632} F^{(0.5212-1)} I^{0.8104} e^{-0.0111E}\} \quad (6)$$

respectively. These functions give the marginal costs in rupees per 100 gram reduction in effluent BOD.[9]

These functions can now be used to estimate the cost of a reduction in $E$ for given levels of $F$ and $I$. Changes in either $F$ or $I$ can be accommodated as parametric shifts of the marginal cost function. In order to check the sensitivity of abatement marginal cost to differences in volume of waste water or influent quality, functions have been generated and marginal costs estimated for three different levels of $F$ and $I$ corresponding to the minimum, average, and maximum values of these variables in an ordered array of the observations.[10] This has been done for both equation 5 as well as equation 6. The graphs

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[8]It should be noted that a two-variable cost function of the form $C = f[F, (I-E)]$, where cost is a function of the volume of treated water and the difference between the influent and effluent BOD levels, was also estimated by OLS, yielding

$$\ln C = -5.9147 + 0.4613 \ln F + 0.8814 \ln (I-E)$$
$$(-4.229) \quad (4.436) \quad (5.536)$$
$$\overline{R}^2 = 0.7250$$

The coefficient of the two independent variables are of positive sign as expected and significant at the 5 percent level. The elasticity of operating cost with respect to quantity of water treated is 0.4613, implying economies of scale even in the short run. The elasticity of operating cost with respect to extent of abatement is 0.8814. However, this specification is inappropriate because the operating abatement cost would depend not only on the extent of abatement but also the absolute levels of $I$ and $E$. Consider two cases, one where $I$ and $E$ are equal to 130 and 30 respectively, and another where $I$ and $E$ are equal to 230 and 130. In both cases pollution is reduced by 100 units ($I$-$E$ = 100), however we know from the engineering literature that the cost of reducing BOD from 130 to 30 is much higher than reducing it from 230 to 130. Hence the functional forms of equations (3) and (4) were preferred for the estimation and application of marginal abatement cost.

[9]$F$ is given in units of kiloliters per day, while $I$ and $E$ are given in units of milligrams per liter. Therefore, the product of $F$ and $I$ or $E$ is in units of gms BOD per day. The cost data is given in units of lakh rupees per year. Hence, this must be multiplied by (100,000/355) to arrive at costs in rupees per gram per day where 355 is the average number of working days per year. Finally, multiplying by 100 yields marginal cost per 100 gm BOD reduction.

[10]The minimum and maximum values actually correspond to the fourth and eighteenth observations. The first three observations and the last three observations have been ignored in order to eliminate the effect of extreme values.

corresponding to equation 5 are reproduced in the Appendix. Figures A1 to A3 show the graphs for influent levels of 190 mg/liter (fourth lowest *I*), 333 mg/liter (average *I*), and 500 mg/liter (fourth highest *I*). These are henceforth referred to as the minimum, average, and maximum I (see footnote 10). Figures A4 to A6 give the corresponding graphs for equation 6.

Several observations can be made from these graphs. First, marginal costs are inversely related to volume of waste water as we already know from the less than unitary values of the coefficients of *F* in the cost functions, i.e., there are economies of scale even in operating cost, apart from the scale economies in capital cost. Second, costs rise much more sharply with equation 5, but they are generally higher with equation 6 in the relevant range. Third, costs escalate very sharply once the effluent BOD level has been brought down to 30 mg/liter. This is more clearly visible in the plots for equation 5. Hence to set the MINAS for waste water released in rivers at 50 mg/liter seems very appropriate.

TABLE 2
**Estimates of Marginal Cost per 100 gm BOD to Achieve MINAS Level of BOD (50 mg/liter)**
(Rs/100 gms BOD at 1991/1992 prices)

| Flow of Waste Water (KL/D) | Equation 5 Influent Concentration | | | Equation 6 Influent Concentration | | |
|---|---|---|---|---|---|---|
| | Minimum | Average | Maximum | Minimum | Average | Maximum |
| Minimum (5,400) | 0.61 | 0.97 | 1.36 | 0.65 | 1.02 | 1.42 |
| Average (32,256) | 0.24 | 0.38 | 0.53 | 0.27 | 0.43 | 0.60 |
| Maximum (55,540) | 0.18 | 0.29 | 0.40 | 0.21 | 0.33 | 0.46 |

Note: Here minimum and maximum mean the values relating to the fourth observation and the eighteenth observation in terms of the relevant variable.

The marginal cost of achieving MINAS starting from minimum, average, and maximum values of both *I* and *F* have been shown in Table 2 separately for equations 5 and 6. As expected, in all cases the cost of abatement to MINAS levels is higher when the influent concentration is higher. The marginal costs corresponding to these different influent concentration levels (*I*) for all observed levels of waste water flow (*F*) in the sample of plants for the two cost functions are shown in Table 3. These range from Rs 0.15 to Rs 2.45 and Rs 0.17 to Rs 2.43 per 100 gm BOD reduction for equations (5) and (6) respectively, indicating little difference between marginal costs as estimated by the two functions in the relevant range.

## C. Marginal Cost, Charges, and Taxes

The incentives approach to pollution control was outlined in section 1 along with four alternative institutional arrangements for implementing this approach spelled out in section II. In all cases, polluting firms can be expected to optimize their own costs and benefits of abatement at the margin. The marginal cost of abatement therefore serves as an anchor for calibration, regardless of which of the four alternative institutional arrangements is chosen. In the first two cases, where the pollution control authority itself undertakes the treatment of waste water or gives the clean-up contract to a third party for firms which do not undertake their own abatement, marginal cost should serve as a basis for setting clean-

TABLE 3
**Estimates of Marginal Cost per 100 gms BOD Reduction to Achieve MINAS Level of BOD (50 mg/liter) at Various Flow Levels**
(Rs/100 gm BOD at 1991/1992 prices)

| Waste Water (KL/D) | Equation 5 | | | Equation 6 | | |
|---|---|---|---|---|---|---|
| | Influent Concentration | | | Influent Concentration | | |
| | Minimum 190 | Average 500 | Maximum 330 | Minimum 190 | Average 500 | Maximum 330 |
| 1,750 | 1.10 | 1.75 | 2.45 | 1.11 | 1.75 | 2.43 |
| 3,360 | 0.78 | 1.24 | 1.75 | 0.81 | 1.28 | 1.78 |
| 4,000 | 0.71 | 1.14 | 1.59 | 0.75 | 1.18 | 1.64 |
| 5,400 | 0.61 | 0.97 | 1.36 | 0.65 | 1.02 | 1.42 |
| 5,500 | 0.60 | 0.96 | 1.35 | 0.64 | 1.01 | 1.40 |
| 6,200 | 0.57 | 0.90 | 1.27 | 0.61 | 0.95 | 1.33 |
| 26,000 | 0.27 | 0.43 | 0.60 | 0.30 | 0.48 | 0.67 |
| 27,140 | 0.26 | 0.42 | 0.59 | 0.30 | 0.47 | 0.65 |
| 28,500 | 0.25 | 0.41 | 0.57 | 0.29 | 0.46 | 0.64 |
| 31,200 | 0.24 | 0.39 | 0.54 | 0.28 | 0.44 | 0.61 |
| 32,500 | 0.24 | 0.38 | 0.53 | 0.27 | 0.43 | 0.60 |
| 37,500 | 0.22 | 0.35 | 0.49 | 0.26 | 0.40 | 0.56 |
| 40,000 | 0.21 | 0.34 | 0.48 | 0.25 | 0.39 | 0.54 |
| 41,250 | 0.21 | 0.34 | 0.47 | 0.24 | 0.38 | 0.54 |
| 41,500 | 0.21 | 0.33 | 0.47 | 0.24 | 0.38 | 0.53 |
| 43,400 | 0.20 | 0.33 | 0.46 | 0.24 | 0.38 | 0.52 |
| 50,000 | 0.19 | 0.30 | 0.43 | 0.22 | 0.35 | 0.49 |
| 55,540 | 0.18 | 0.29 | 0.40 | 0.21 | 0.33 | 0.46 |
| 56,137 | 0.18 | 0.29 | 0.40 | 0.21 | 0.33 | 0.46 |
| 57,500 | 0.18 | 0.28 | 0.40 | 0.21 | 0.33 | 0.46 |
| 83,000 | 0.15 | 0.23 | 0.33 | 0.17 | 0.28 | 0.38 |
| Average (32,256) | 0.24 | 0.53 | 0.38 | 0.27 | 0.60 | 0.43 |

up charges. In the tax-cum-subsidy arrangement, marginal costs should be the basis of setting the rates of tax or subsidy depending on the level of pollution.[11]

The question is, Whose marginal cost and at what level of abatement? This is critical since the marginal costs vary across firms, effluent pollution levels, and waste water volumes. It was mentioned earlier that the marginal costs of relatively high-cost producers should serve as the basis for setting charges and taxes. This would ensure that the pollution control authority or private abatement agency recovers the cost of clean-up from the large majority of polluting firms in the first case. In the tax-cum-subsidy case this would ensure that most producers find it cheaper to abate rather than pollute.[12] On the other hand, it would be clearly inappropriate to use the extreme values of the highest cost producers as the basis of setting charges, taxes, or regulated prices. It is suggested therefore that the marginal cost of the fourth smallest unit in terms of volume and the fourth highest unit in terms of influent pollution concentration be taken as the benchmarks for setting these rates. These were the benchmarks described earlier as the minimum value of *F* and maximum

[11]In the "tradeable permits–ambient standards" scheme there is no charge or tax (subsidy) rate to be set. However, the marginal abatement cost of individual firms would be equalized at the equilibrium permit price which clears the secondary market in permits.

[12]In this illustrative exercise, paper is taken as the representative industry. However, if all industries are included, as would be necessary for an operational policy, the same principle would suggest using large industries where abatement costs are high as the basis of setting taxes, charges, etc. Alternatively, industries can be banded into broad groups with a different rate for each group.

value of *I*, respectively. Either of the two cost functions can be used since in the relevant range the marginal costs as estimated by the two functions are very close.

Based on these considerations, it is suggested that under the first two options, the pollution control authority could set its charges at between Rs 1.35 to Rs 1.45 per 100 grams BOD reduction at 1991/1992 prices.[13] Under the tax-subsidy scheme this could be the rate of tax per 100 grams of extra BOD beyond MINAS (50 mg/liter BOD).[14]

The "burden" of this abatement charge/pollution tax as a proportion of sales has been shown in Table 4.[15] There are two units for which the burden appears to be exceptionally high. In the case of unit 9 this is because the reported effluent BOD level was abnormally high. In the case of unit 19 sales appear to have been exceptionally low in the reference year. The burden was also somewhat high in the case of unit 18. In all other cases, the burden was well below 10 percent, often even as low as 1 to 2 percent. The average burden works out to around 6 percent.

TABLE 4
**Abatement Bill/Pollution Tax to Sales Ratio**
(percent)

| Sl. No. | Waste Water (KL/D) | Charge/Tax to Sales Ratio | |
|---|---|---|---|
| | | at Rs 1.35per 100 gm BOD reduction | at Rs 1.45per 100 gm BOD reduction |
| 1 | 1,750 | 1.25 | 1.33 |
| 2 | 3,360 | 1.55 | 1.65 |
| 3 | 4,000 | 2.61 | 2.79 |
| 4 | 5,400 | 7.76 | 8.27 |
| 5 | 5,500 | 4.11 | 4.38 |
| 6 | 6,200 | 5.47 | 5.83 |
| 7 | 6,000 | 8.39 | 8.95 |
| 8 | 27,140 | 5.15 | 5.49 |
| 9 | 28,500 | 21.82 | 23.26 |
| 10 | 31,200 | 4.94 | 5.27 |
| 11 | 32,500 | 3.57 | 3.81 |
| 12 | 37,500 | 1.91 | 2.03 |
| 13 | 40,000 | 1.79 | 1.91 |
| 14 | 41,250 | 6.54 | 6.98 |
| 15 | 41,500 | 5.37 | 5.73 |
| 16 | 43,400 | – | – |
| 17 | 50,000 | 2.17 | 2.31 |
| 18 | 55,540 | 11.67 | 12.45 |
| 19 | 56,137 | 23.78 | 25.35 |
| 20 | 57,500 | – | – |
| 21 | 83,000 | 5.15 | 5.49 |
| Average | | 5.91 | 6.31 |

Notes:

1. Abatement bill/tax burden is calculated for pollution in excess of MINAS (50 mg per liter BOD).

2. Sales data were not available for units 16 and 20. These have been excluded in calculating the average.

[13]The actual cost per 100 gram BOD reduction for the reference unit works out to Rs 1.36 and Rs 1.42 for equations 5 and 6, respectively. These have been rounded off to a range of Rs 1.35 to Rs 1.45.

[14]These proposals are based on the marginal cost schedule in Table 3 for purely illustrative purposes. Operational policies would have to be preceded by a survey of a representative sample of firms for estimating the cost function.

[15]This is only the burden of operating cost. The capital cost of setting up an ETP has not been included here. The treatment of capital cost and its recovery is discussed further below.

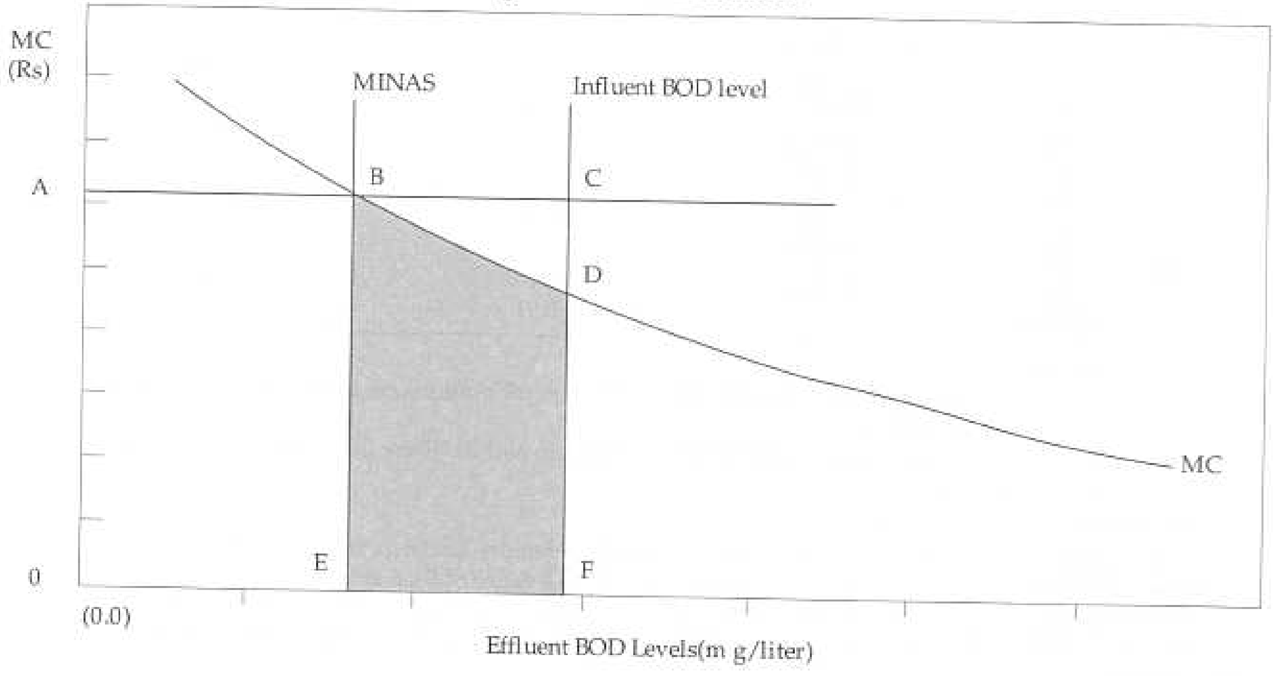
This is the order of increase in the operating cost of the product which would be involved if polluters were required to bear the cost of clean-up under any of the proposed incentive systems. A question now arises on who should bear this burden. In the first instance, cost would increase for the producers. However, given the market structure, it is reasonable to assume that the across-the-board increase in costs would be passed on to consumers. This would be generally true except in periods of recession or intensified competition, when some producers may choose to absorb at least a part of the cost increase in order to gain extra market share. Hence, the increase in cost would be largely borne by the ultimate consumers of paper, or for that matter, any other product where such pollution abatement incentives are introduced. As a consequence, there is likely to be some curtailment of consumption, depending on the elasticity of demand.

This should be so, in accordance with the "polluter pays" principle, i.e., consumers whose consumption imposes extra pollution on society ought to be required to bear the cost of clean-up. Of course, if society decides that it is in the public interest not to pass on the burden of abatement to certain groups of consumers, e.g., poor students buying text books, their consumption can be directly subsidized through a transparent government subsidy.

Strict adherence to the "polluter pays" principle would require that in addition to operating cost, polluters also bear the burden of capital cost. It should be noted in this context that since the abatement charge or pollution tax is based on marginal (operating) cost, which is rising, there is a surplus of charge or tax avoided over actual abatement cost which accrues to either the government or the polluting firm, as the case may be. This more than covers the annualized cost of capital.

In Figure 1 the curve MC depicts marginal cost of reducing BOD from an initial influent level *OI*. To get it down to the MINAS level *OE* (0.50 mg per liter) the marginal cost is *EB* which implies an abatement charge or pollution tax of *OA* per unit BOD.

FIGURE 1
**Marginal Cost of Abatement**



Hence, in the charge case, the total abatement charge is *EBCI* while the actual cost of abatement is the shaded area *EBDI* under the marginal cost curve. Hence, a surplus *BCD* accrues to the government. In the tax-subsidy case, EBDI is the abatement cost incurred by the firm in order to avoid paying the pollution tax EBCI, thus implying a net saving of BCD for the firm through abatement. If this net saving is at least as much as the annualized capital cost of abatement then the capital cost of abatement is also covered by the incentive system.

Table 5 gives an illustrative comparison of the likely savings based on the marginal cost-based charge/tax schemes and the capital cost of abatement, annualized at the going interest rate of 18.54 percent, for the NIPFP sample of firms. It will be evident from the table that the savings are always larger than the annualized capital cost and in some cases, particularly for the larger plants, several times larger. Another way of looking at the same comparison is to measure the recoupment period required to recover the capital outlay on an abatement plant by way of additional savings derived on account of the plant. Even for the small-sized, high-cost plants, the outlay is recovered within four to five years, and in five out of the nine cases it is recovered in less than a year.

Clearly, under the incentive schemes proposed here, abatement would be a good investment!

TABLE 5
**Abatement Capital Cost and Savings for NIPFP Survey Firms**
(Rs lakh)

| Plant Size (KLDF) | Capital Cost at 1991/1992 prices | Annualized Capital Cost | Saving at tax per 100 gm BOD | | Recoupment Period per 100 gm BOD (years) | |
|---|---|---|---|---|---|---|
| | | | Rs 1.35 | Rs1.45 | Rs 1.35 | Rs 1.45 |
| 2,000 | 37.88 | 7.03 | 8.98 | 7.07 | 4.2 | 5.4 |
| 3,750 | 29.81 | 5.53 | 17.65 | 15.27 | 1.7 | 2.0 |
| 5,400 | 77.02 | 14.28 | 103.89 | 96.93 | 0.7 | 0.8 |
| 8,000 | 83.90 | 15.56 | 120.63 | 113.37 | 0.7 | 0.7 |
| 11,000 | 139.53 | 25.88 | 65.70 | 59.94 | 2.1 | 2.3 |
| 12,000 | 97.98 | 18.17 | 33.03 | 29.06 | 3.0 | 3.4 |
| 41,725 | 574.04 | 106.46 | 810.24 | 805.89 | 0.7 | 0.7 |
| 47,000 | 307.84 | 57.09 | 475.30 | 467.85 | 0.6 | 0.7 |
| 54,000 | 391.16 | 72.54 | 474.54 | 469.55 | 0.8 | 0.8 |

Note: Annualized capital cost excludes the imputed interest on land value. To that extent, the recoupment period is also understated.

# Appendix

FIGURE A1
**Marginal Cost of BOD Reduction at Initial BOD 190 mg/liter**
(Equation 5)

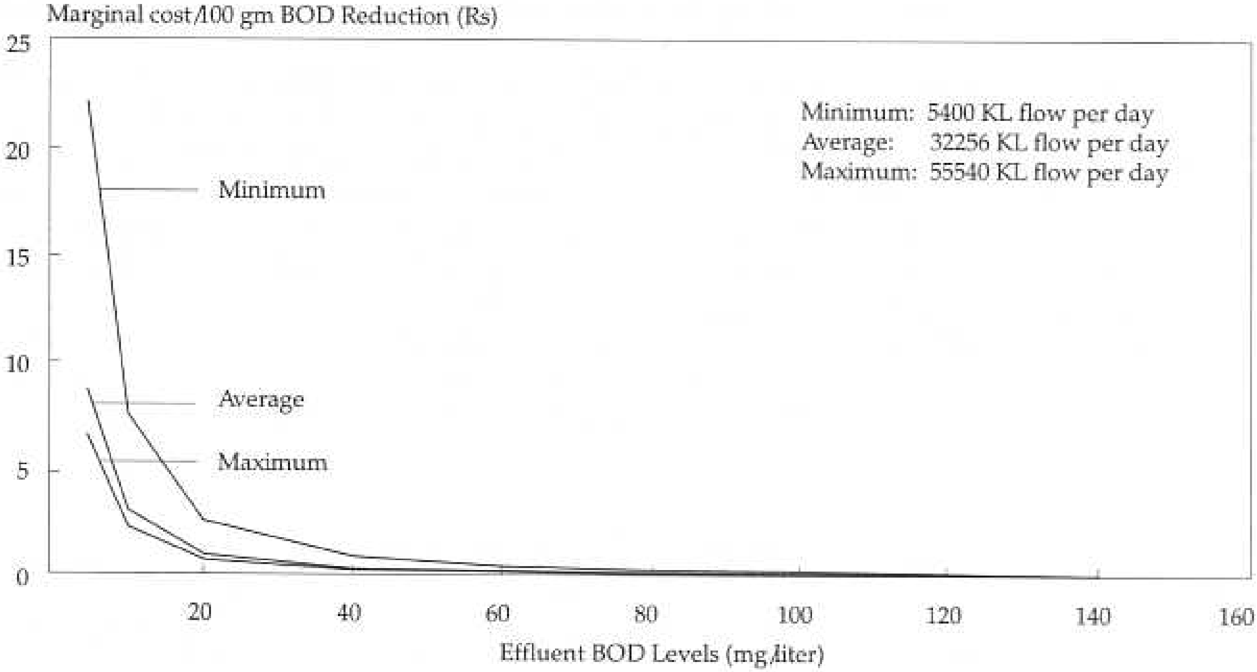



FIGURE A2
**Marginal Cost of BOD Reduction at Initial BOD 333 mg/liter**
(Equation 5)

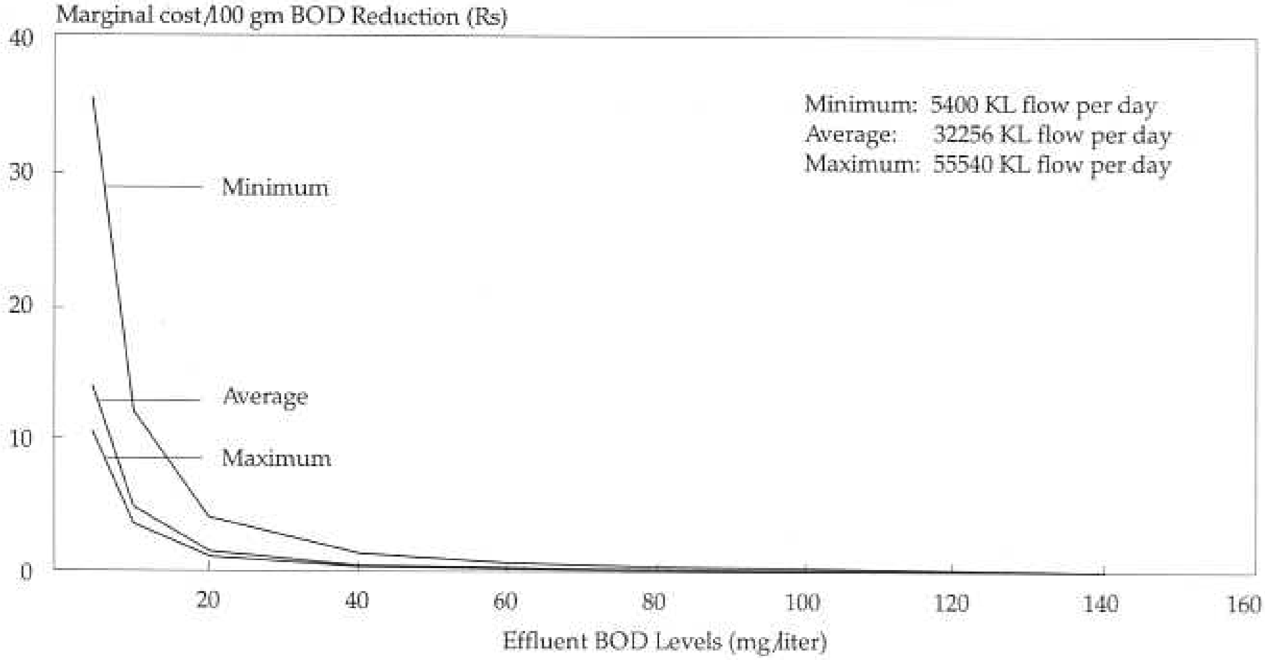


FIGURE A3
**Marginal Cost of BOD Reduction at Initial BOD 500 mg/liter**
(Equation 5)

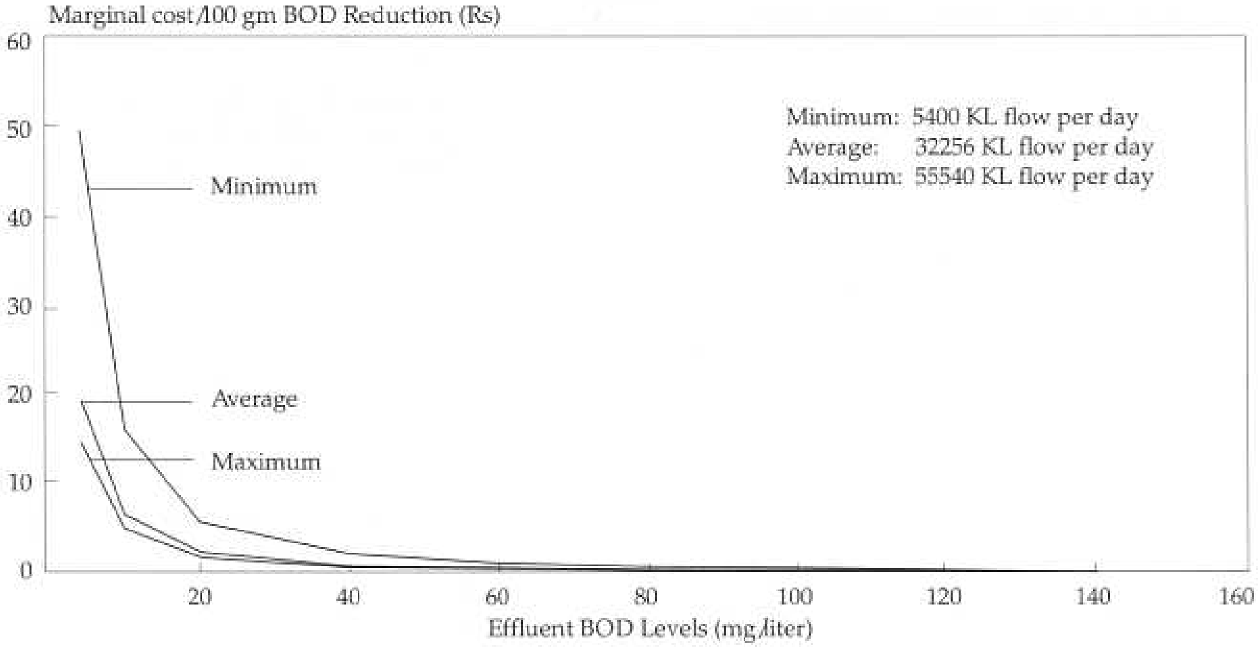



FIGURE A4
**Marginal Cost of BOD Reduction at Initial BOD 190 mg/liter**
(Equation 6)

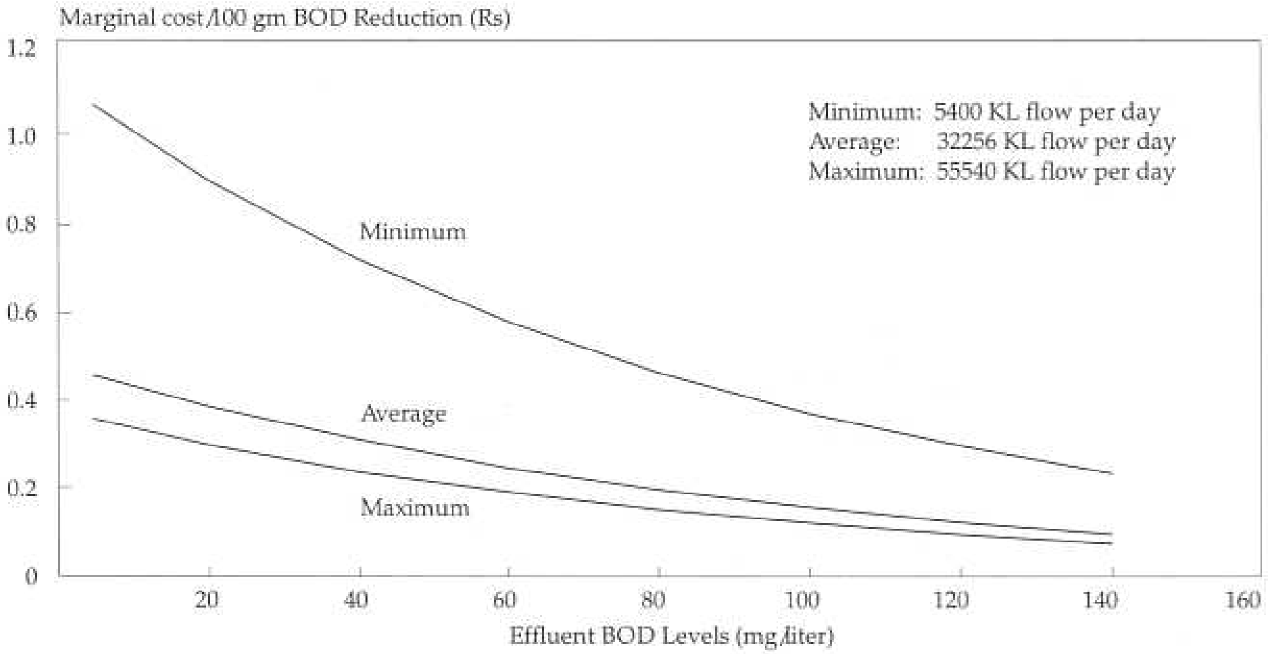


FIGURE A5

**Marginal Cost of BOD Reduction at Initial BOD 333 mg/liter**

(Equation 6)

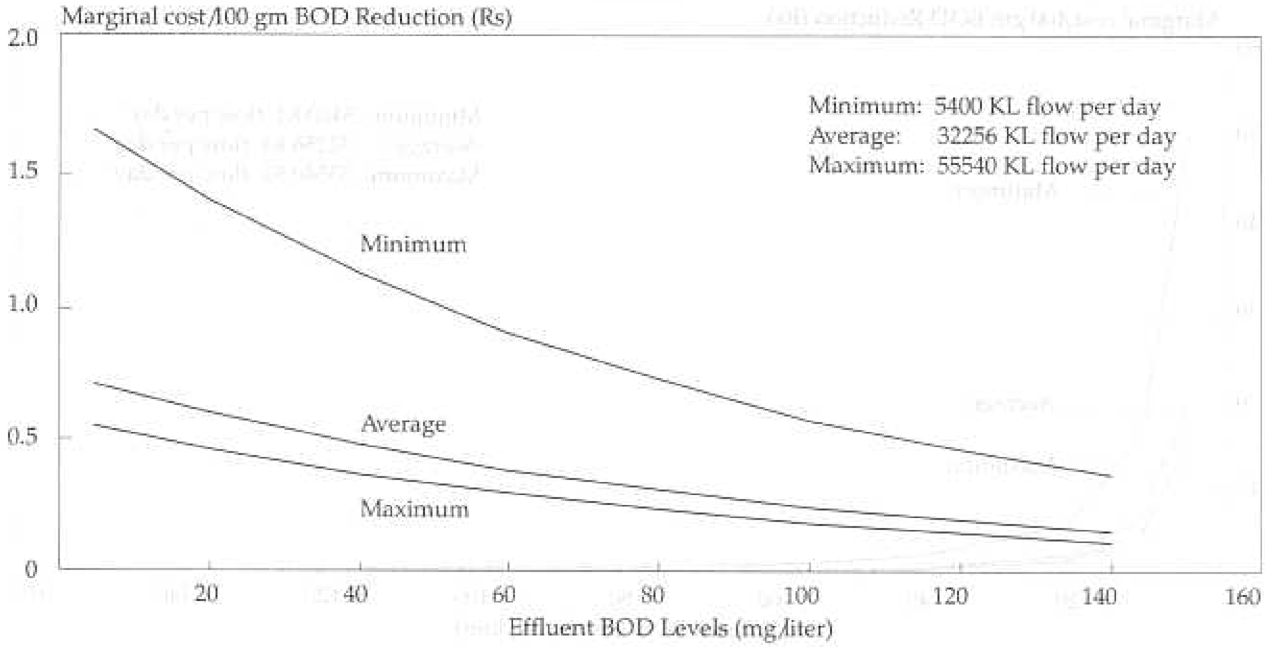
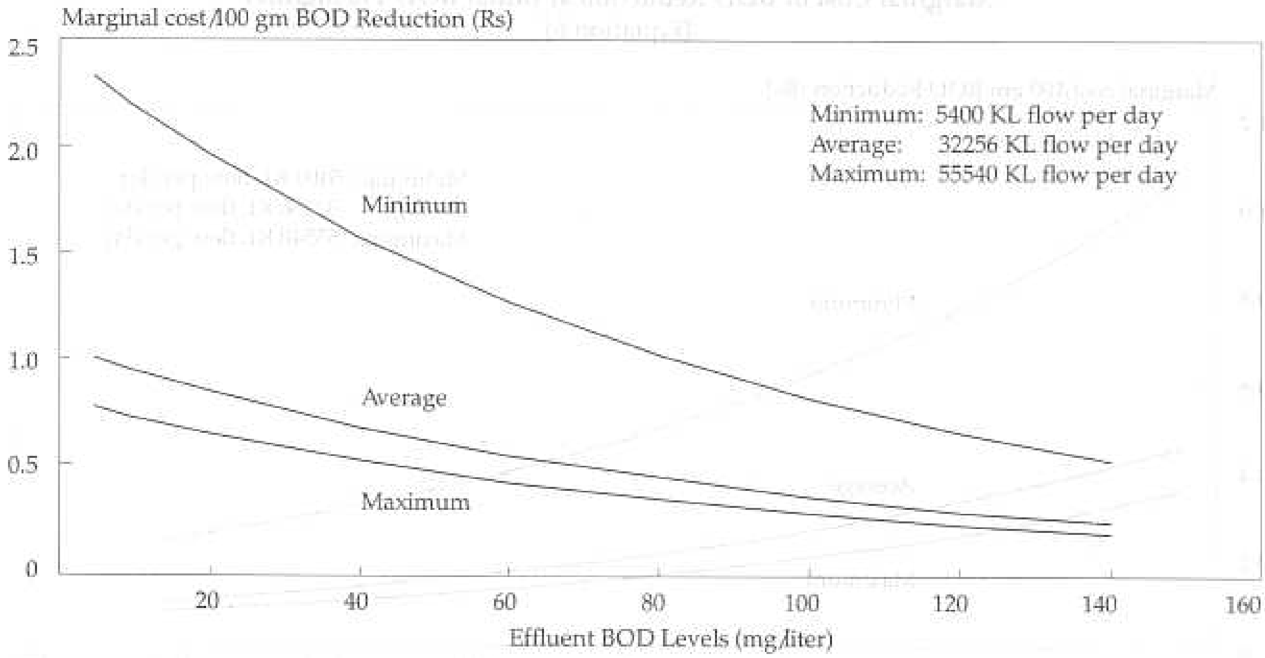



FIGURE A6

**Marginal Cost of BOD Reduction at Initial BOD 500 mg per Litre**

(Equation 6)



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