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An Economic Approach to Allocating River Water to Estuaries in South Africa

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AN ECONOMIC APROACH TO ALLOCATING RIVER WATER TO ESTUARIES IN SOUTH AFRICA

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Estuaries are last in line as a recipient of river water and for this reason they are particularly vulnerable to negative environmental impacts due to water scarcity and pollution. They only receive the runoff that has not been abstracted or prevented from reaching rivers. When this runoff is substantially reduced their functionality is undermined and they often become less attractive for recreational use. This paper explores some aspects entailed in efficiently managing the allocation of water to estuaries problem and some associated problems. It is shown that efficient management requires the marginal social costs of the inflows to be brought into equivalence with the marginal social values of the inflows, and these values may be estimated, but that there are the challenges in this estimation and in linking these estimates to the welfare of the people in whom the managers of river systems are (presumed to be) interested.

Key words: Estuary, Allocating River Water, South Africa.

South Africa has a coastline of about 3 000 km (Baird 2002:37) and along this coastline there are a large number of estuaries – 289 by some counts (Hattingh *et al* 2002:5), 465 by others (Baird 2002:37). The status of an increasing proportion of the 255 South African estuaries, that can be classified as "functioning" (Lamberth and Turpie 2003:1), is being threatened by reduced freshwater inflows, especially the status of those estuaries classed as temporary open/closed (Schalacher and Wooldridge 1996). The main cause of the reduced freshwater inflow is increased abstraction to satisfy upstream freshwater demand, but another well documented cause of reduced inflows is the displacement of indigenous vegetation by higher water consuming alien vegetation within the river catchments (Hosking *et al* 2002).

Estuaries are reliant on uninhibited access to marine and freshwater links in order to function properly (Adams 2001, Lamberth and Turpie 2003:2) but because less water is reaching them they are yielding less services (Whitfield and Wood 2003), for instance, smaller areas available for recreational boating and losses of habitat for species of fish, birds and vegetation.

However, these consequences, unfortunate as they are, do not necessarily indicate that the freshwater in South African rivers is being misallocated, with too little being received by estuaries. River water yields value to many users in South Africa - to households, industrialists, farmers, foresters and government institutions. The demand for water inflows into estuaries by people wishing to use the services of these estuaries for recreation, is but one of many. Given the limits of supply, it is inevitable that some demand will not be satisfied. In fact this is a problem that is most likely to get even worse in the future. At current rates of growth in demand it has been estimated that by the year 2025 South Africa will have a population of 70 000 000 and all its exploitable freshwater resources will be fully exploited

(Schalacher and Wooldridge, 1996).

Nevertheless concerns have increased in South Africa during recent years, especially among government agencies charged with environmental conservation, that there may be a misallocation problem, with too little river water reaching the estuary, i.e., being allocated to the recreation users of estuary services (Adams 2001). The economic rationale underlying these concerns is not so much that there has been a deterioration in estuary service levels as that the services yielded by the estuaries have strong public good properties and that key relevant public policy makers have seemed up until recently to have been largely ignorant of the close connection between the river inflows and levels of service yielded by estuaries. Public good characteristics are well known to render the market deficient as a mechanism for signalling the demand, causing market failure. Ignorance of relevant information by public decision makers would most likely result in this information failing to be taken into account in public decisions, causing government failure (and hence a double failure).

Recent actions by South Africa's Department of Water Affairs and Forestry (DWAF) and Department of Environmental Affairs and Tourism (DEAT) reflect this concern. DWAF have set about re-examining the basis by which river water is allocated in South Africa, particularly with a view to incorporating conservation demand. The National Water Act of 1998 requires catchment management authorities to be established. One of its functions is to ensure that demand for freshwater inflows into estuaries is taken into account in the management of catchments.

Similarly, South Africa's Directorate of Marine and Coastal Management (which falls under DEAT) and local authorities have actively sought to formulate policies aimed at countering the degradation of estuaries. One of the requirements imposed upon local authorities is that they integrate into their development planning sensitivity to the ways estuaries work and the services and goods they deliver.[1] The relevant legislation making this a requirement is the Municipal Systems Act No. 32 of 2000.

This paper offers advice on the issue of managing current river inflows allocated to the estuaries of South Africa.[2] It is generally accepted that sound water resource management requires the benefits and costs of different water allocations be compared and an optimum determined (Loomis 1998). The same principle applies to the current allocation of river water (freshwater) inflow into estuaries.

The paper is organised in the following way: an optimum current inflow is defined in terms of marginal values, a method is identified by which to estimate these values and various complications are discussed relating to the use of these estimates as proxies for the relevant marginal values.

AN ECONOMIC OPTIMUM FRESHWATER INFLOW INTO ESTUARIES

Optimising conditions

The optimum freshwater (river) inflow (Q*) into a given estuary at any given time is defined at that level where the positive difference between the total social value and the total social cost of this inflow is maximised, or put differently, where the marginal

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[1] In addition to stipulating how much freshwater they will permit to be removed from the inflow into the estuary, local authorities are required to formulate plans to guide what emissions they will allow into the estuary, what land uses they will permit on the banks and what resources (like fish, bait and mangrove trees) they will allow to be extracted from the estuary.

[2] The optimum flows over time are not discussed in this paper.

social value of the inflow equals the marginal social cost. The services generated from river inflow into estuaries are yielded and consumed mainly in the form of public goods, for instance, in areas suitable for boating, swimming and fishing.[3] Total value is what the public would be willing to pay to consume the services, and the marginal value is what they would be willing to pay for an increment or decrement of the service, that is the sum of each individual's (i = 1….n people) marginal value for this change, $\sum MVi$. The willingness to pay concept employed here is a composite one, including payments made directly and those made indirectly, for instance, through government. It specifically includes willingness to pay of the current cohort of recreation users of the estuary, a scarcity cost component and an external cost component. The scarcity cost component is the present discounted value of future willingness to pay for services foregone in the future as a result of the water reallocation being considered - where there is long term damage done to the estuary service yield potential. The external cost component is the payment that user groups, other than the estuary recreation group, would be willing to make for water that is allowed to flow to the estuary, below the point at which abstraction is being considered.

The total cost referred to above is the opportunity cost of the water flowing into the estuary, that is, the value of the water in its best alternative use, for example, in irrigating agricultural crops. It too is a composite value. It includes not only the willingness of the current user to pay, but also an external cost component. The external cost component refers to the net willingness to pay of users, other than the abstractors, of the facilities built to abstract the water, e.g., the dams, canals and

[3] Public goods provide nonexclusive benefits to everyone in a group and can be provided to one more user at zero marginal cost.

regulation/redirection of river water flows. There may be a positive net willingness to pay for using these facilities. There is considerable recreational use made in South Africa of these constructed water facilities, but in some cases this infrastructure also has undermined other recreational uses (like fly fishing).

A model for allocating river water

The concepts relevant to a model for allocating freshwater inflow into the estuary are defined below.

Q = Freshwater inflow into estuary in m^3

Q* = Optimum freshwater inflow into estuary in m^3

ΔQ = Change in freshwater inflow into an estuary in m^3

P1 = Social value per m^3 of a specified quantity of freshwater in the best alternative use to the estuary

P2 = Social value per m^3 of a specified quantity of freshwater inflow into the estuary to all users (including passive) of the estuary

TC = Total opportunity cost per m^3 of freshwater inflow into the estuary (for all people)

= f(P1; Q)

MC = Marginal social cost of an incremental freshwater inflow into an estuary

= dTC/dQ

= $P1.\Delta Q$

TV = Total value of freshwater inflow into an estuary (for all people)

= f(P2; Q)

MV = Marginal social value of freshwater incremental inflow into the estuary (for all people)

= dTV/dQ

= $\sum MV_i$ (because of the public good nature of the services generated by the inflow)

= $P2. \Delta Q$

where

i = 1……..n people deriving utility from the freshwater inflow into the estuary.

$MC = P1$ if $\Delta Q = 1$ and

$MV = P2$ if $\Delta Q = 1$.

Optimisation takes place at the level of Q where the excess of TV over TC is maximised. A necessary condition for this optimisation to take place is that:

$$MC = MV \quad (1)$$

which implies

$$P1 = P2. \quad (2)$$

It follows that

if $P1 > P2$,

then (the current inflow of freshwater into the estuary) $Q > Q^*$ (the optimum inflow)

and if

$P1 < P2$,

then $Q < Q^*$.

A priori:

$P1 = f(Q)$ and $dP1/dQ > 0$ (3)

$P2 = f(Q)$ and $dP2/dQ < 0$ (4)

The P1 and P2 functions would be expected to change over time and, for this reason, the optimising conditions (Equations 1 and 2) would be expected to yield different values at different moments in, or periods of, time. Given the nature of P1 and P2 functions (Equations 3 and 4) it would be expected that at Q*:

$TC < TV$

THE MARGINAL SOCIAL VALUE AND MARGINAL SOCIAL COST FUNCTIONS

The expected nature of the marginal value and marginal cost functions (also see Equations 3 and 4) are shown in Figure 1.

INSERT FIGURE 1

In Figure 1 the river inflow into the estuary is shown in m^3 on the X-axis and the marginal value and marginal cost of it in Rand is shown on the Y-axis. As freshwater inflow into the estuary increases, the marginal value of this inflow decreases (by Equation 4), but the marginal costs associated with securing more freshwater increases (by Equation 3).

At the intersection of MV and MC the optimal freshwater inflow (Q*) is identified. At this level the excess of TV over TC is maximised. At any given time the actual freshwater inflow (Q) may, and most probably will, differ from the optimal inflow

(Q*). Such a situation, for instance, would be where Q = Q1.

At Q1:

MV2" > MC1" and net TV (or TV – TC) can be increased by increasing Q.

For instance, if an increase of Q1Q2 is brought about, net TV increases by the vertical area between Q1 and Q2 and the MC and MV functions. After the increase, MV would have declined from MV2" to MV2' and MC would have increased from MC1" to MC1'.

As it happens, in this case, further increases of Q would also be efficient. The optimum inflow into the estuary is Q*.

THE OPTIMAL INFLOW GUIDE VERSUS THE ENVIRONMENTAL RESERVE GUIDE FOR MANAGING FRESHWATER INFLOWS

One alternative to the optimal efficient inflow approach to guiding the allocation of freshwater inflows into estuaries is the environmental reserve approach. In terms of this approach a certain amount of the mean annual runoff is set aside for the estuary and may not be abstracted. This amount is set with reference to the minimum freshwater inflow needed to sustain a desirable level of environmental services and with reference to historical levels of environmental service delivery for that estuary (Adams, 2001).

It could be expected that for many cases the two guidelines (efficient optimum and minimum reserve requirement) would coincide in their recommendation, even though there are fundamental differences between the two. There are at least two reasons to expect some measure of overlap between the two guidelines – a step like feature in the marginal value function where the minimum is defined, and the effect on the efficiency calculus of incorporating future generation demands (scarcity costs).

Where the environmental services of the estuary are in demand, it stands to reason that if there is a precipitous fall in these services, their marginal value would increase, perhaps dramatically. As a result, declines in freshwater allocation below an ecologically determined minimum would most likely be sub-optimal – because marginal values would become markedly higher (in a step like way) for freshwater inflows at base levels less than this ecologically defined minimum. Moreover, if the consequent decline in service yields were expected to be enduring, a fall below an ecologically defined minimum inflow of freshwater, would be very difficult to justify in terms of multi-generational efficiency criteria, unless suitable compensation could be determined, and this is difficult to conceive (Holland 2002).

Notwithstanding there being many cases where the conclusions and recommendations yielded from these two guidelines converge (namely the environmental reserve requirement and efficiency criteria), there may be many other cases where the two guidelines yield conclusions and recommendations that diverge. In the latter cases the question will arise of what is most important to society – the efficiency of the economy or the conservation of the environment. Economics has tended to favour the former.

MEASURING THE RELEVANT MARGINAL VALUES

Methods

Efficient allocation of river water in South Africa requires management to be informed on both the MV and MC. There have been numerous attempts to estimate (or infer) values for MC in South Africa – using a mixture of marginal and average cost reference values (Hosking *et al* 2002) - but there has been less work undertaken on estimating (or inferring) values for the MV in South Africa.

Given the relative lack of work done on estimating P2 there would appear to be a strong case currently for devoting a bit more attention to doing so. In order to generate an estimate for P2, the first question one is faced with is which MV2 should be targeted for its estimation? The question is whether MV2" or MV2' or MV2 should be targeted (see Figure 1)? Ideally the MV gained through the increase in inflow of Q1Q2 is estimated by MV2, where the excess valuation of Q3Q2 (value area CDE) is exactly offset by the undervaluation of Q1Q3 (value area ABC). The alternative of MV2" would yield too high an estimate of the MV (by value area AGE), while MV2' would yield too low an estimate (by value area AFE).

In practice it is one of MV2" or MV2' that is likely to be identified by empirical research – the value prior to an increment in freshwater inflow or a decrement. It follows that for a decrement of freshwater inflow, the price identified is likely to be MV2', that is too low, but for an increment it is likely to be MV2", that is too high. It would be expected that the error will be greater the greater the derivative of the P2 function with respect to Q exceeds zero (see Equation 4) and the greater the change in Q being considered.

The second question one is faced with in estimating P2 is which method of valuation to employ. In principle there are several methods by which MV2 may be identified, for instance, hedonic price method, travel cost method and the contingent valuation method (CVM). Of these the latter is the one most amenable to the required fine-tuning. This method may be used to generate average WTP per annum for a specified ΔQ at a given estuary. The estimated (or inferred) P2 (viz. $\underline{P2}$) is defined as the product of this average and the total number of people with a demand for the services derived from the ΔQ, divided by the ΔQ:

$\underline{P2} = TWTP/\Delta Q$ (5)

where total willingness-to-pay (TWTP) is defined as follows:

$TWTP = \sum MVi = n(AWTP)$,

where,

i = 1…n people with a demand for estuary services.

and

AWTP = a before-the-ΔQ average WTP for a specified change in water inflow into the estuary, as estimated by the CVM (either MV2' or MV2" in Figure 1, depending on the direction of the specified change)

and

ΔQ = specified change in freshwater inflow measured in m^3.

Related to this second question is a credibility issue – in what sense the measure generated for P2 (in the case of CVM it is a stated preference measure) is indeed an acceptable proxy for the marginal social value of freshwater flowing into the estuary. This problem is three-fold. One aspect relates to the use of a response to a hypothetical question on willingness to pay as equivalent to a market generated value based on what people actually do pay – the contingent valuation debate. Another aspect relates to the omission of scarcity and external costs components. Yet another aspect relates to the plausibility of these responses reflecting social values, taking into account welfare complications that could be anticipated.

Controversy over contingent valuations

The CVM is a widely applied but controversial valuation technique (Azevedo *et al* 2003). It is widely used because it is very flexible and may be used to assess the values of a wide variety of non-market goods and services (Carson *et al* 2001). In particular, it has advantages in incorporating passive values into the total value estimate. Its credibility depends on there being a close correspondence between expressed answers given to hypothetical questions (stated willingness to pay) and voluntary exchanges in competitive markets that would be entered into if money did actually change hands.

The fact that it has proved very difficult to establish this correspondence has led to CVM being subject to criticism. At the empirical level some authors have argued that it is much better not to generate any numbers at all than the misleading ones that some past CV studies have generated (Diamond and Hausman 1994). At the theoretical level some authors have argued that those researchers applying the CVM make 'category' mistakes by attempting to value (moral) judgements as if they were (economic) preferences (Keat 2002).

Many aspects of the 'obvious' errors in the ways the CVM has sometimes been applied, have been addressed - in the form of using standard methods to reduce biases, the adoption of conservative elicitation formats and the reporting of tests for consistency with economic theory. Subject to these checks and balances being taken into account many feel that the results should be taken seriously by decision makers (Carson *et al* 2001). One of the common checks is for consistency with economic theory. Recommended guidelines for applying the method have emerged during the past 25 years, e.g., those drawn up by the Blue-Ribbon panel and Arrow *et al* (1993). These guidelines are ideals, but are frequently not fully adhered to – often because budget limitations preclude this, for instance, that relating to sample size.

Omissions of marginal scarcity and marginal external costs

The estimated value, P2, is a valuation of willingness to pay for freshwater inflow by recreation users of the estuary. It is only part of the complete social benefit of water being allowed to flow into the estuary. Other potentially important components of the social benefit are the scarcity cost of any future estuary services foregone as a result of abstraction of the freshwater upstream, and the willingness to pay of groups beside the estuary recreation users, for the water not to be abstracted upstream.

Plausible reasons for discounting these omissions are that the values of these components would be expected to be negligible or that there are exact equal offsetting external benefits derived through the infrastructure built to abstract the water upstream. It may be reasonable in some cases to argue cases along these lines, but clearly it cannot be assumed to be generally true. The researcher seeking to provide guidance on the issue of water allocation to the decision makers will have to consider the merits of each case with respect to the marginal scarcity and external costs.

Welfare complications in applying the equivalent pricing rule as a guide to efficiency

One additional way of checking the efficiency analysis results for credibility is through the direct consideration of social welfare issues. If the social efficiency analysis is accurate a welfare analysis should yield results that are consistent with it.

For the purpose of considering the welfare implications relevant to the efficient allocation of river water it is convenient to define social welfare in terms of the utility derived from two groups of water users – the upstream abstractors and the estuary recreation users. The social welfare (W) implications of changes in river inflows may then be considered in terms of the utility (U_1) derived by those abstracting water upstream (-Q) and the utility (U_2) derived by those using services dependent on river inflow into the estuary (Q):

$$W = W[U_1(-Q); U_2(Q)] \quad (6)$$

It would be expected that the respective utilities would be increasing functions in –Q and Q, and welfare an increasing function in the respective utilities.

Assuming a linear welfare function in the respective utilities and equal welfare weighting, a first order condition for a welfare optimum of the constrained maximisation problem is:

$$MU1 = MU2 \quad (8)$$

where MU1 and MU2 are the partial derivatives of user groups 1 and 2 with respect to m^3 water allocations.

The main implication of this condition is that under the relevant assumptions, welfare optimality requires MU1 to equal MU2. For this reason, if the estimated prices (P1 and P2) are brought into equivalence through appropriate management actions, welfare analysis would require that this allocation also make MU1 to equal MU2. However, it may not do so. There are many factors that may prevent this marginal utility condition from being met. For instance, if one group are using the water as a necessity and the other as a luxury, or if one group enjoys high incomes and the other low incomes, this MU equivalence may not be met, *a priori*.

These factors will now be considered.

DIFFERENCES IN USE OF THE WATER ALLOCATION

Marginal utilities in the consumption of water will differ widely among the users of upstream river water. Households in South Africa are entitled to a minimum of 30 kl of fresh water as a basic human right, but many have yet to receive this right, and among those that have, there is wide variation in consumption levels. Similarly in production, some firms are more productive with the water they use than others, and the goods the water is used to produce vary from luxury type goods to necessities.

The relevance of this variation is that marginal utility foregone (and marginal output foregone) through reallocations of water will differ widely. For this reason, there may be welfare reasons for re-allocating water even when estimated water prices are brought into equivalence, or alternatively, not re-allocating water even where estimated prices suggest that it would be efficient to do so. For instance, the finding that P2>P1 would suggest that efficiency could be improved by re-allocating water from upstream users to the users of estuary services. However, if the upstream abstraction of water under consideration is targeted at satisfying basic needs for water in poor households and the estuary service users are mainly ski boat fishermen on holidays, a welfare analysis would suggest the exact opposite to be the preferred management action in terms of the efficiency analysis. In this case it would seem likely that the marginal utility of the upstream water users would be higher than the marginal utility of the estuary service recreation users, and welfare would not be increased by allocating more water to the recreation users of estuary services.

On the other hand, if the upstream abstraction of water being considered is targeted at sustaining gardens of alien vegetation, topping up private swimming pools, etc., i.e., at facilitating the consumption of luxury goods, *a priori* there would be no marginal utility complications corresponding with a finding that it would be efficient to allocate more water from upstream abstractors to users of estuary services, because P2 > P1. For this reason, in addition to estimating P1 and P2 it would seem prudent for those aiming to provide guidance to decision makers on water allocations to include consideration of what change in usage of this water will be entailed through a reallocation, and if the marginal utility implications of that reallocation yield welfare results that are consistent with the efficiency implications. Due to the diverse nature of consumption patterns within the relevant user groups, identification of the appropriate users may be difficult.

DIFFERENCES IN INCOME BETWEEN THE USER GROUPS

There are many factors that influence willingness to pay values, besides expected marginal utility, for instance, income levels and the prices of related goods. That the value of water should be influenced by the prices of related goods is important from an efficiency perspective. However, the fact that higher levels of income will generally induce higher willingness to pay, *ceteris paribus*, is problematic from a welfare perspective.

The relation between income and utility/welfare is indirect and controversial, but to the extent that there is any consensus on the relation, it is that diminishing marginal utility from income is more likely to be experienced by people than constant or increasing marginal utility from income. If one accepts this proposition one is led to the conclusion that where income levels differ between the two users, the relative prices paid by people will not correspond with the relative respective relative marginal utilities. In terms of the theory of diminishing marginal utility of income the price being paid by the user group with the lower income should correspond with a higher marginal utility than the equivalent price paid by the higher income group.

It follows that for those seeking to provide guidance to decision makers on the allocation of river water, they should carefully consider whether there are significant differences in income levels between the two water using groups. For instance, it would be relevant if the income levels were higher of the recreation users of estuary services than were those targeted for the water upstream. Once again, due to the diverse spread of incomes within the relevant water user groups, identification of the income of the appropriate users may be difficult.

CONCLUDING REMARKS

That there are adverse consequences for estuaries in South Africa of freshwater deprivation has been widely documented (Lamberth and Turpie 2003:2, Whitfield and Wood 2003). As could be expected, the government has acted to address the problem with new legislation that creates catchment management authorities to take estuary freshwater needs into account, *inter alia,* and compels local authorities to incorporate sensitivity to estuary services in their development planning (where this is applicable). The current state of thinking within catchment management authorities and local development planners about how to incorporate the required sensitivity is still at the formative stage. Much of the discussion has been orientated around the idea of setting aside freshwater reserves for estuaries in order attain target estuary quality standards (Adams 2001).

This paper has advocated that management of freshwater allocations to estuaries should be guided by the idea of an optimal freshwater inflow rather than the idea of a freshwater reserve. The allocations of freshwater inflow into South African estuaries are optimal when the marginal social values of the inflow are brought into equivalence with the marginal social costs. For this reason catchment management may be guided towards optimal allocation of freshwater inflow into estuaries, by reference to estimates of the relevant marginal social costs and marginal social values. The CVM may be usefully employed for the purpose of estimating the marginal social values – arguably the more difficult of the two to estimate.

However, there are notable complications in attempting to employ this apparently simple decision rule for the purpose of allocating river water to estuaries. Stated preference valuations are inherently controversial in character, and for this reason estimates generated this way need to be qualified. Secondly, irrespective of whether stated or revealed preference valuations are employed, there are checks that should be made for relevant value omissions and for welfare inconsistencies. In order to address some of the complications associated with the latter, there may be advantage in guiding management decision making by simultaneously (in the same analysis) presenting several other appraisal criteria together with the efficiency criterion (of bringing the relevant prices into equivalence) – a multi-criteria mapping approach (such as is advocated by Stirling 2002).

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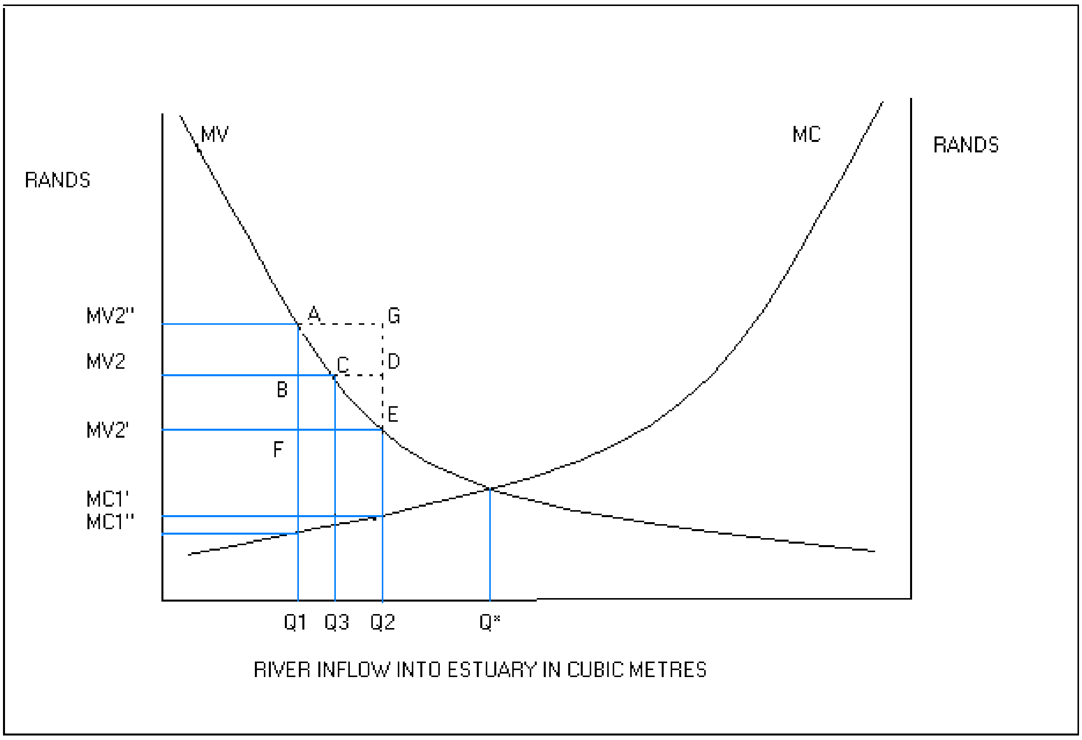

Figure 1: Expected Marginal Social Value and Marginal Social Cost functions