

# Leakage Targets and Socio-Economic Efficiency

F. J.-C. Bouchart\*, H. M. Salleh\*\*, J. W. Sawkins\*\*\* and P. W. Jowitt\*\*\*\*

## Abstract

During the last few years, the introduction of mandatory leakage targets for UK water companies has had the positive effect of reducing levels of leakage, while requiring the companies to operate at an economic level of leakage. Unfortunately, the determination of company-specific economic levels of leakage have been a source of disagreement between the water companies and the Government, with the Government view that water companies are not using the true long-term marginal costs of water abstraction, and therefore are not safeguarding the environment.

This paper (a) reviews the model which was used to define the economic level of leakage, (b) argues the case for resource management based on the impact of water abstractions on the socio-environmental quality of a resource rather than the myopic focus on leakage reductions, (c) presents the concepts of effectiveness and efficiency in relation to socio-environmental quality, and (d) proposes a new methodology which allows the determination of water abstraction rates while maintaining a desired level of socio-environmental quality.

**Key words:** Leakage; socio-economic quality; supply/demand balance; target.

## Introduction

The drought of 1995–96 was one of the worst ever experienced in England and Wales, and became the catalyst for the subsequent drive to reduce levels of leakage in the UK. Inquiries into the water companies' handling of the drought had led to their performance being scrutinised more closely in the areas of supply and conservation measures. The presence of high water losses in supply infrastructures across the UK suggested that water companies were not operating at economic levels of leakage. The Government's response was the introduction of mandatory leakage targets, and these have had the desired effect of forcing positive change within the UK water industry (Table 1).

Table 1. Actual and target leakage levels for water companies in England and Wales<sup>(1,2,3)</sup>

Water company	1996–97 Actual leakage (Ml/d)	1997–98 Actual leakage (Ml/d)	1998–99 Actual leakage (Ml/d)	1998–99 Target leakage (Ml/d)
1 Anglian	236	235	201	205
2 Dwr Cymru	357	329	306	308
3 North West	666	579	510	515
4 Northumbrian	192	184	171	173
5 Severn Trent	479	399	344	348
6 South West	129	101	92	96
7 Southern	113	99	95	95
8 Thames	1083	906	770	781
9 Wessex	129	110	100	103
10 Yorkshire	420	368	333	363
11 Bournemouth and West Hampshire	28	26	26	24
12 Bristol	65	59	56	57
13 Cambridge	16	14	13	15
14 Dee Valley	13	12	12	12
15 Essex and Suffolk	85	82	76	77
16 Folkestone and Dover	12	9	9	9
17 Hartlepool	6	5	5	5
18 Mid Kent	38	36	30	30
19 North Surrey	27	24	22	24
20 Portsmouth	30	32	31	31
21 South East	99	—	—	86
22 South Staffordshire	90	82	77	80
23 Sutton and East Surrey	27	26	25	25
24 Tendring Hundred	6	6	6	6
25 Three Valleys	172	148	135	136
26 York	10	9	9	9

N.B. For South East Water: OFWAT does not consider water-balance figures to be robust, hence their omission.

The mandatory leakage targets imposed by the Office of Water Services (OFWAT) are based on company-specific economic levels of leakage, and water companies are obliged to undertake robust analyses to determine these respective levels. However, the actual target imposed by OFWAT might differ from the level which is identified by a water company if the review process finds that the analysis is not sufficiently robust. Companies exhibiting high leakage levels and stringent water resource/supply provisions are expected to achieve greater leakage reductions, thereby improving their future supply/demand balance<sup>(2)</sup>.

For the 1999 periodic review, many of the water companies established sufficiently robust methodologies. Never-

\*Assistant Professor, Department of Civil Engineering, University of Calgary, Calgary, Canada.

\*\*Graduate Student, Department of Civil and Offshore Engineering, Heriot-Watt University, Edinburgh, UK.

\*\*\*Lecturer, Department of Economics, Heriot-Watt University, Edinburgh, UK.

\*\*\*\*Professor, Department of Civil and Offshore Engineering, Heriot-Watt University, Edinburgh, UK.

theless, OFWAT still decreased the targets of some of the water companies on the basis of the quality of the analyses used, and how the targets proposed by the water companies compared to the targets derived by OFWAT. More importantly, where calculations suggested that leakage levels could increase, such relaxations of leakage targets were discounted. The rejection of any increase in leakage levels followed from the ministerial guidance to the Director General of Water Services and to the Environment Agency on the issue of leakage. Specifically, the Minister viewed any increase in leakage levels as 'wholly inappropriate ... with all the unnecessary burdens that leakage imposes on the water environment'<sup>(4)</sup>. This disagreement points to a fundamental difference in how the socio-environmental costs of leakage are defined and determined. These tensions are primarily due to the fact that water companies must operate at (or at least near) the economic level of leakage, while regulatory bodies such as the Environment Agency must ensure the proper use of water resources, and protect and enhance the environment.

## Economic Level of Leakage

Leakage and water losses throughout a water-supply system represent a waste of resources, as measured by (i) the water resources unnecessarily extracted from the environment, and (ii) the resources needed to treat and transport the volume of water wasted. The economic costs associated with water losses can be grouped into the costs of leakage and the costs of leakage management. The cost of leakage refers to the costs of actually producing water of an acceptable quality, and of delivering this water to consumers. As the level of leakage in the supply system increases, these leakage costs increase due to the need to provide excess capacity to ensure that water demands are still met, and the operational costs of treating and transporting these water losses within the system. Reductions in leakage allow further capital investment to be deferred, as well as reducing current operational expenditure<sup>(5)</sup>. On the other hand, the costs of leakage management decrease with increasing levels of leakage. Maintaining low leakage levels within a supply system requires investment to rehabilitate or replace ageing infrastructure, and to detect and arrest leaks. The result is the well-known u-shaped total cost curve depicted in Fig. 1. High leakage levels are undesirable due to the high investments needed to provide excess capacity within the supply system, while low leakage levels are also uneconomical due to the escalating costs of arresting ever-smaller leaks within the system.

The economic level of leakage can be defined as the leakage level where the total costs (i.e. leakage costs plus costs of leakage management – depicted by the dashed lines in Fig. 1) are minimised. This optimal leakage level,  $L^*$ , is defined as the level of leakage where the marginal cost of leakage is equal to the marginal cost of leakage management. Ideally, this calculation should reflect the regional factors under which the water-supply system must operate<sup>(6)</sup>. Furthermore, there is wide-spread recognition within the UK water industry that water abstractions (and hence water leakage) incur socio-environmental costs, which must be incorporated in the calculation of the economic level of leakage. The introduction of socio-environmental costs causes a shift in the economic level of leakage (depicted by the solid lines in Fig. 1) to a new and lower optimal level of leakage,  $L_e^*$ .

A significant difficulty with the identification of the socio-

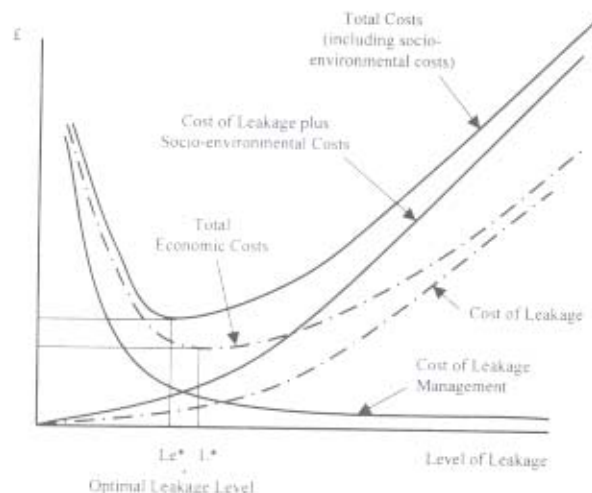


Fig. 1. Defining economic level of leakage

environmental level of leakage,  $L_e^*$ , is that the socio-environmental costs of leakage are difficult to quantify. A number of techniques have been developed to quantify these costs<sup>(7)</sup>, but each remains an imperfect surrogate of the value of the water resources being wasted. If the water resources are scarce relative to the demand for these resources, it is possible to assign an economic value to the water losses corresponding to the price which other users would be willing to pay for the water. However, when the value of the water resources is derived from non-monetary and non-use benefits (such as enhanced social and environmental qualities), the development of suitable models to quantify these benefits becomes much more difficult and remains open to criticism. This has led to disagreements between OFWAT and the water utilities on appropriate leakage targets due to the sensitivity of these targets to the environmental and societal cost figures used.

## Quality of Water Environment

The perceived need to reduce leakage levels is based (to a large extent) on the philosophy that water represents a resource which is critical for maintaining the integrity of the natural environment, and must be managed to safeguard the interests of society, both now and in the future. Losses within water-supply systems must therefore be minimised in order to protect these socio-environmental benefits. The setting of leakage targets is then seen as a necessary mechanism to achieve such waste minimisation. However, reduction of leakage is not the goal in itself: it is only a mechanism to achieve a desired level of socio-environmental quality (SEQ) and long-term sustainability. This would suggest that methodologies which are aimed at protecting the environment and the interests of society should start from an examination of the socio-environmental status and quality of the water resource itself, rather than leakage.

In order to develop the argument against leakage targets, it might be useful to start with an idealised scenario where a single utility supplies water to a single urban centre using the available water resource from a nearby river. Water supplies are conveyed via an old distribution system exhibiting high levels of leakage. However, the total water abstraction from the river only represents a small fraction of the total flow – even at

times of low flow. In these circumstances, a socio-environmental impact assessment of this abstraction regime would reveal that the SEQ of the river (defined in a holistic sense) is not adversely affected by the abstraction. The natural environment is resilient enough and absorbs the slight change in the river discharges without loss of habitat or environmental quality. Similarly, the level of abstraction does not affect the societal benefits derived from the river. The SEQ of the water resource (the river) remains unaffected by the high levels of leakage. Of even greater importance is the fact that reductions in these leakage levels will not generate improvements in the natural environment. On the other hand, the implementation of active leakage management strategies, aimed at driving down the high losses in the supply system, might have a significant negative impact on the wider environment. The resource requirements might, in fact, exert greater pressure on the environment and result in unsustainable management practices.

It is acknowledged that the above scenario is highly idealised, and that few water-abstraction schemes exhibit such insignificant socio-environmental impacts. The more likely situation is that the SEQ of a water resource will decrease with increasing levels of abstraction. The actual rate of degradation will be site specific, but might be expected to follow a relationship similar to curve PQ in Fig. 2. It must be noted that the SEQ of the resource is not simply a function of water abstractions, but that many other factors can influence both the perceived and the actual quality of a water ecosystem. Therefore, the SEQ of a water resource can lie anywhere below curve PQ for a given level of abstraction. Curve PQ can then be interpreted as a technological frontier where the level of SEQ (at a given abstraction rate) corresponds to the highest level achievable with the current technology (defined as both physical and managerial technologies). All water users of the resource should then strive to ensure that their activities yield such 'best practice', thereby maintaining their position on or near the technological frontier. However, even when the water users exercise such best practices, it may be necessary to reduce water abstractions to ensure that the desired level of SEQ is maintained for the water resource. Water losses then become obvious targets for water-efficiency programmes.

An important point which must be raised concerning Fig. 2 is that the level of abstraction, L, represents the total water consumed by all users of the water resource. It would be naive to suggest that water wastage is exclusive to water-supply companies, or that leakage levels in water-distribution systems incur disproportionate SEQ degradations compared to other water users. For example, agricultural irrigation schemes typically have relatively poor conveyance and field

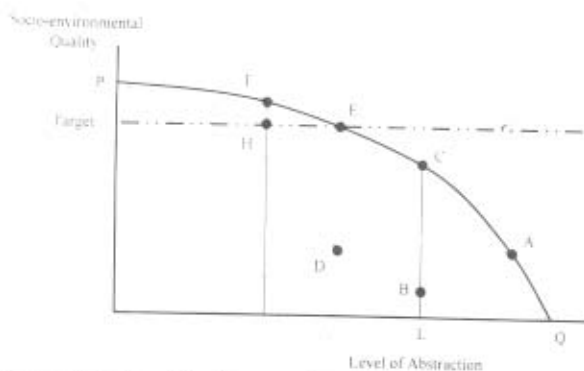


Fig. 2. Relationship between SEQ and water abstraction

efficiencies. In fact, many irrigation schemes require excess water applications to ensure that soil degradation does not occur<sup>(8)</sup>. The return flows, if untreated, could then represent a greater threat to the water environment than the losses of high-quality drinking water<sup>(9)</sup>.

Ignoring the complexities which are introduced by multiple users and their associated aggregate water losses, the relationship between the level of SEQ and the level of abstraction can be used to establish appropriate management targets. With the sole user of a given water resource being the water-supply company, increasing levels of leakage (and hence increasing abstraction rates) in the supply system result in degradations in the socio-environmental quality of the source. Conversely, any reductions in leakage provide improvements to the natural environment as measured by the SEQ scale. Such shifts in levels of SEQ are represented as movements along the technological frontier PQ. However, it might be expected that the marginal value (or utility) of incremental improvements in SEQ will decrease as SEQ increases. These diminishing returns on the value of additional units of SEQ are based on the concept that there is an upper bound to the level required for good environmental health, and that there is a finite limit to the value which society will place on this resource. Therefore a threshold SEQ level can be defined beyond which the socio-environmental objectives are satisfied.

The use of SEQ targets to define socio-environmental objectives is consistent with the new abstraction authorisation system which is being formulated by the Government<sup>(10)</sup>. Under the new abstraction rules, the environmental effects of a proposed abstraction would have to be determined as part of the application process. Such environmental-impact assessments could form the basis for the establishment of the relationship between SEQ and water-abstraction rates.

## Defining Effectiveness and Efficiency

The identification of a target for the SEQ of a water resource allows the performance of a water company to be measured, and it is now possible to determine the effectiveness of a water company in meeting the SEQ objective. A water company is effective if the SEQ of the water resource is equal to or greater than the threshold target; therefore leakage management policies yielding abstraction levels E, F, and H in Fig. 2 are effective. All water companies operating below the SEQ target remain ineffective and require changes in their management strategies.

'Effectiveness' is an absolute measure of performance as defined by an ideal level of performance<sup>(11)</sup>. The SEQ target therefore defines '100% effective', and a policy yielding a SEQ level below this target achieves only X% effectiveness ( $0\% \leq X\% \leq 100\%$ ). On the other hand, policies resulting in SEQ levels above the target could be viewed as being either effective or over-effective. Having exceeded the required SEQ target, Policy F might be viewed as performing better than Policy E, which just meets the target. However, the decision to move from Policy E to Policy F must result in a positive marginal increase in net benefits; otherwise, the marginal socio-environmental benefits which accrue from this shift in policy will be less than the additional financial investment which is required to achieve the shift.

A second useful concept in the assessment of SEQ, and the performance of individual water companies, is 'efficiency'. For the purposes of this discussion, technological efficiency is

defined as the ratio of the SEQ level achieved to the SEQ which can be technically achieved for the given level of abstraction. Graphically, the efficiency of Policy B in Fig. 2 corresponds to the ratio of LB to LC. Maximum efficiency is reached at the technological frontier PQ.

Using the above concepts of effectiveness and efficiency, it is possible to evaluate the performances of water companies. Consider two water companies extracting water from similar water sources, the first operating under Policy B and the second operating under Policy C (defined in Fig. 2). Both companies are ineffective in achieving the required SEQ target. However, the second company employs an efficient management policy which yields the maximum possible SEQ level for the given level of abstraction. This suggests that the company operating under Policy B can implement management changes that will improve the SEQ of the water resource, without necessarily reducing abstraction rates. Thus socio-environmental improvements are not necessarily achieved solely through reductions in levels of leakage. This observation is important when considering the suitability of OFWAT policies which require specific reductions in leakage to be achieved by the water companies.

If the underlying rationale for the required reductions in leakage levels is the protection of the water resources and the environment, the setting of SEQ targets would be more appropriate because the SEQ levels are not uniquely linked to leakage levels. It is only when a water company is operating on the technological frontier PQ that improvements to SEQ require reductions in leakage and/or abstraction rates. Consider a water company operating at point A in Fig. 2. The only way for this company to become effective is to reduce its abstraction rate. However, this shift in management policy must not only result in a reduction in water abstraction (a shift from A to D, possibly achieved through the implementation of an active leakage management strategy), but must also yield improvements in SEQ (a shift from D to E). Targets which are solely defined in terms of reductions in leakage do not guarantee the desired improvements to the socio-environmental quality of the water resource. Furthermore, the desired improvements might equally be achieved through a reduction in real water demands as a result of water-conservation measures. Situations could also arise where the complete elimination of water losses would still not yield the desired improvements to the socio-environmental quality.

The suitability of leakage targets for water utilities which are effective with regard to SEQ is even more questionable than for utilities which are performing poorly. When a water company operates an effective but inefficient leakage management policy, for example Policy H in Fig. 2, improvements can be made by either shifting to Policy E or Policy F. Policy F would entail maintaining current abstraction rates (and hence the same level of leakage) while modifying other activities within the organisation. Conversely, improvements to the efficiency of the organisation can be achieved by adopting Policy E, where increased leakage levels are adopted (forcing abstraction levels to rise) without any loss of effectiveness. The actual decision is based on the financial costs associated with each alternative. In terms of the corporate objectives of effectiveness and efficiency (as defined above), Policies E and F may be viewed as equivalent (if the 'over-effectiveness' of Policy F has no significant value). However, the need for economic efficiency, as defined by the attainment of minimum total costs, will determine which of the effective management policies (policies above the SEQ target) is optimal. This optimisation task

requires an economic model of water abstraction (similar to Fig. 1) to be combined with the SEQ effectiveness model (Fig. 2), thereby yielding a definition for the economic level of abstraction which implicitly defines the economic level of leakage.

## Re-Defining Leakage Targets

A re-definition for the optimal level of leakage can be applied to the UK water industry, which allows for the achievement of socio-environmental objectives while permitting individual utilities to operate in an economically efficient manner. This definition is based on the incorporation of SEQ targets within an economic model of abstraction. Rather than attempting to quantify the socio-environmental cost of water losses, the requirement to be effective in terms of socio-environmental quality is used to constrain the economic model. This approach is illustrated in Figs. 3 and 4. All management policies failing to meet the SEQ target, thereby being deemed ineffective, represent unacceptable solutions. Because of the technological frontier associated with the specific water resource in Fig. 3, only policies incorporating abstraction targets below  $L_c$  have the potential of attaining the SEQ target. Management policies which are within this latter range of abstraction, but which remain ineffective, require modifications other than a reduction in leakage or water consumption.

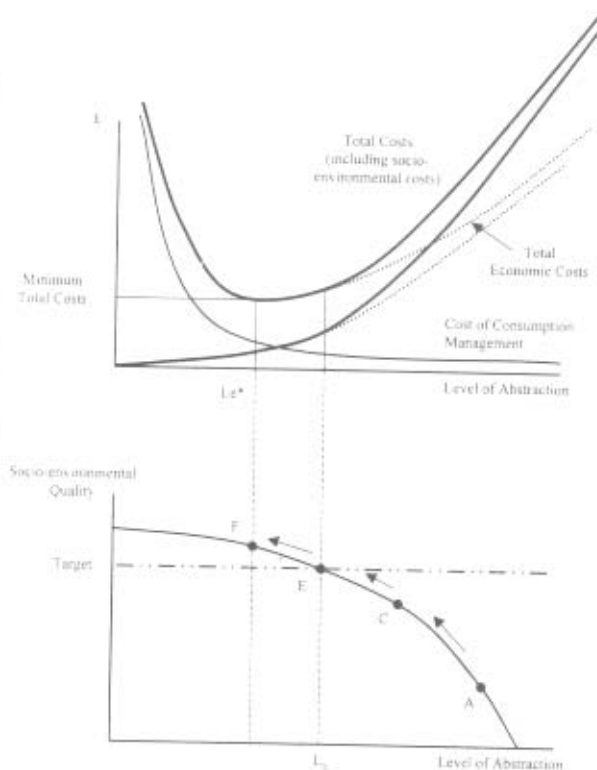


Fig. 3. Defining economic level of abstraction while maintaining a desired level of SEQ (SEQ constraint not binding)

Technological efficiency requires a policy on, or close to, the technological frontier. However, technological efficiency does not imply economic efficiency. The abstraction level, and hence the leakage level, corresponding to the minimum total cost must still be identified, but now the level of abstraction is

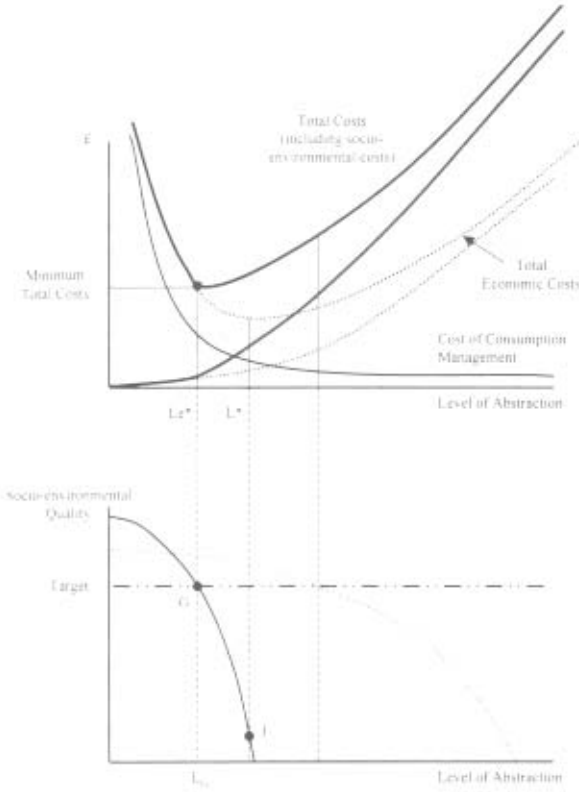


Fig. 4. Defining economic level of abstraction while maintaining a desired level of SEQ (SEQ constraint binding)

confined to levels below  $L_c$ . In the case depicted in Fig. 3, the optimal abstraction level corresponds to the economic level  $L^*$ . This optimal abstraction rate does not have any associated socio-environmental costs because it is possible to attain the required SEQ target at this level of abstraction. If the company remains ineffective (SEQ below the target), improvements to the SEQ of the resource can be achieved by a modification of the policy other than a reduction in abstraction rates. It should be noted that socio-environmental costs only arise for levels above  $L_c$  (as represented by the difference between the solid and dotted total cost curves in Fig. 3). Because abstraction levels above  $L_c$  are no longer deemed to be acceptable, they are excluded from the cost minimisation task, and therefore the socio-environmental costs do not need to be quantified.

The use of a SEQ target to constrain water abstractions, thereby safeguarding the socio-environmental quality of the resource, shares its conceptual roots with the 'safe minimum standards' (SMS) approach to conservation<sup>(12)</sup>. Sustainability of human (and non-human) activities requires that these minimum standards should be maintained. Similarly, the SEQ target defines a minimum level which must be achieved. However, while the SMS approach defines an almost absolute minimum standard which must be maintained to avoid unacceptable hardships (either to humans or other lifeforms), the SEQ target represents a desired or acceptable level of socio-environmental protection. Therefore the use of SEQ targets provides the opportunity to constrain water abstractions to limits which are well within the bounds of sustainability. However, the determination of the SEQ target requires negotiation between all stakeholders and the implementation of suitable approaches to multi-stakeholder decision-making.

The technological frontier has previously been shown to

be specific to the water resource being investigated; therefore, a unique technological frontier must be developed for each water resource, and the optimal water abstraction rate must be identified. Consider a water resource which is sensitive to water abstractions; such a resource might have a technological frontier as defined in Fig. 4. This curve reflects the fact that excessive abstractions incurred due to supply system losses have a substantial impact on the SEQ level. Abstraction rates for this resource must therefore be significantly lower to ensure effectiveness. Policy G must now be implemented compared to Policy E, which was appropriate for the previous water resource. Policy J, which corresponds to the purely economic level of water abstraction (excluding socio-economic costs), is completely unacceptable and is not a viable management strategy.

The approach of using a SEQ target to constrain the acceptable range of abstraction rates is analogous to the use of economic instruments to achieve global economic efficiency between polluters<sup>(13)</sup>. A quality standard is defined which the polluters must, collectively, achieve. However, rather than regulating the pollution discharges of individual polluters, the polluters are allowed to achieve economic efficiency within the confines of the specified standard. Market forces then define the level of pollution which is discharged by each polluter. The environment is protected from excessive pollution by the quality standard that must be attained.

Finally, the shift from leakage targets to socio-environmental quality provides a framework which explicitly recognises the unique responses of individual water resources to water abstractions. Rather than applying a blanket policy on all water companies, and subsequently on all water resources, the SEQ approach is based on the site-specific relationship between SEQ and water abstraction. Water abstractions from sensitive aquatic environments then require greater water-efficiency measures to be undertaken to protect their socio-environmental quality, while not forcing economic inefficiencies in areas where there is a greater capacity to sustain losses. Such an approach is consistent with the urban waste water treatment Directive<sup>(14)</sup> where governments can apply for 'derogation' for less sensitive areas<sup>(15)</sup>. Under this scheme, governments may provide lower treatment levels provided they demonstrate that discharges will not adversely affect the environment. Comprehensive studies of the specific environment being affected provide the justification for any lowering of the treatment requirements. A similar mechanism could be applied to the proposed approach, where appropriate studies would be undertaken to establish the relationship between SEQ and water abstractions.

**Conclusions**

1. The socio-environmental quality of a water resource is a function of total water abstraction rate rather than the level of water wastage exhibited by any one single water-user group.
2. Methodologies which are aimed at protecting the environment and the interests of society must focus on the socio-environmental status and quality of the water resource, and the impact of water abstractions on such quality indicators.
3. Leakage reduction is not the sole mechanism for achieving improvements in socio-environmental quality, therefore placing limits on leakage levels might force inefficiencies.

4. The development of abstraction-management strategies requires socio-environmental effectiveness and efficiency to be defined, thereby facilitating the identification of an appropriate SEQ target.
5. A methodology has been presented which allows a water company to operate at the optimal economic level of efficiency while achieving a specified level of socio-environmental quality for the water resource.
6. The proposed methodology shifts the debate from environmental marginal costs to levels of SEQ, thereby forcing all stakeholders to focus on what can (or should) be achieved in terms of SEQ – given the real and significant pressures on water resource.

- (5) GERMANOPOULOS, G. AND JOWITT, P. W. Leakage reduction by excess pressure minimisation in a water supply network. *J. Instn. Civ. Engrs.*, 1989, **87** (2), 195
- (6) SKIRWORTH, P. J., SALL, A. J. AND MACHELL, J. The effect of regional factors on leakage levels and the role of performance indicators. *J. Ch. Instn. Wat. & Envir. Managt.*, 1999, **13** (3), 184
- (7) HOWARTH, D. A. Arriving at the economic level of leakage: environmental aspects. *J. Ch. Instn. Wat. & Envir. Managt.*, 1998, **12** (3), 197
- (8) JAMES, L. G. *Principles of Farm Irrigation System Design*. John Wiley and Sons, New York, 1988
- (9) SKODERBE, G. V. AND WALKER, W. R. Impact of irrigation on the quality of groundwater and river flows. *Salinity in Irrigation and Water Resources* (Yaron, D. (Ed.)) Marcel Dekker Inc., New York, 1981, 121
- (10) DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGIONS. *Taking Water Responsibly*. HMSO, London, 1999
- (11) HITCHINS, D. K. *Putting Systems to Work*. John Wiley & Sons, Chichester, 1992
- (12) RANDALL, A. AND FARMER, M. C. Benefits, costs, and the safe minimum standard of conservation. *The Handbook of Environmental Economics* (Bromley, D. W. (Ed.)) Blackwell, Cambridge, Mass., 1995, 26
- (13) BAUMOL, W. J. AND OATES, W. E. Marketable emission permits for protection of the environment. *The Theory of Environmental Policy* (2nd Edn.) Cambridge University Press, 1988, 177
- (14) COUNCIL OF EUROPEAN COMMUNITIES. Directive concerning urban waste water treatment (91/271/EEC). *Official Journal* L135/40, 30 May 1991
- (15) FRIENDS OF THE EARTH, SCOTLAND. The urban waste water treatment Directive 271/91/EC Briefing, 1996

## References

- (1) OFFICE OF WATER SERVICES. 1996–97 Report on Leakage and Water Efficiency. OFWAT, Birmingham, 1997
- (2) OFFICE OF WATER SERVICES. 1997–98 Report on Leakage and Water Efficiency. OFWAT, Birmingham, 1998
- (3) OFFICE OF WATER SERVICES. 1998–99 Report on Leakage and Water Efficiency. OFWAT, Birmingham, 1999
- (4) DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGIONS. *Maintaining Public Water Supplies – Ministerial Guidance*. HMSO, London, 1999