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Briefing: N. G. Semple's 'Principles of environmental protection'

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In the 17 years since the publication of N. G. Semple's paper,[1] many 'chickens have come home to roost'. Despite the premise of the paper being mainly grounded in the economics of development, the problems of 'environmental protection' identified by Semple in 1991 connect strongly with our contemporary understanding of sustainability. Since then, 'global warming' mentioned by Semple has become a perceived fact; 'self-regulation' of polluters (which is every one of us) has been shown to be ineffective largely because the suggested allocation of market prices for pollution has not happened; the associated investment in gaining knowledge through research to help make more informed decisions has not happened—although there has been some success with the Stern review[2] and *Foresight Future Flooding* reports.[3,4] In policy and decision taking, despite the avowal by the UK government as one of the five sustainability principles of 'using sound science responsibly', there is clear evidence that much policy and decision making is actually despite, rather than because of, scientific evidence.[5] Spectacularly, in the intervening period, unchecked worldwide economic growth (without paying the true costs of consumption) and pollution stretching access to fossil fuels are now being reflected in higher costs (but still not the true costs) to consumers and shortages of associated commodities. There is prescience in the identification of 'alternative' energy sources being not necessarily more 'environmentally advantageous' due to the need to use fossil fuels in their manufacture and installation. There is not room in this paper to rehearse the arguments about the whole-life payback period for wind turbines or their reliance on other sources of energy as back-ups. However, this is now clear and illustrates consistent failure to invest in proper whole-systems research to really understand the issues, limitations and opportunities, especially in the energy sector—problems identified in successive Institution of Civil Engineers (ICE) *State of the Nation* reports.

Sympathetic decision making based on the views of 'an informed but impartial spectator' is called for by Semple with reference to the economist Adam Smith. It is notable that, despite EU aspirations for public engagement,[6] this is hardly meaningful in UK decision making. Proper and effective engagement requires the transfer of knowledge and building on the capacity to engage on the part of both decision makers and those being engaged with; there are, however, some instances of success.[7] Only now are the principles of 'fairness' (a fundamental moral concept) being considered in the allocation of resources for flood risk management planning, as in, for example, the *State of the Nation* report on flooding.[8]

Overall, Semple's paper shows clearly how one of the most significant changes required in 1991 was properly to cost 'environmental damage' by charging polluters and resource users to then fund the research and development (R&D) required to deliver the responses to cope with the impacts—literally finding the means to mitigate and adapt if necessary. Needless to say, the requisite actions have not been implemented, notwithstanding token 'carbon taxation', which simply allows major polluters to increase profits by astute permit trading and government to utilise the income for other purposes. Investment in R&D has failed significantly to be at the level required for the challenge. For example, in the water sector, investment in R&D has fallen progressively since water companies were privatised in 1989,[9] although this is vigorously denied by the UK water regulator Ofwat. Tyson[10] reported that an integrated approach should be taken to water and land use management, as concluded at the 4th Stockholm water symposium in 1994. This conclusion has been made clear in various studies since[3] and underlined by recent studies carried out under the UK Department for Environment, Food and Rural Affairs (Defra) integrated urban drainage pilots to determine the future of urban drainage in England and Wales.[11] Yet, so far, this is not acted upon as part of the game of 'postponing' hard decisions.[12] Tyson[10] also indicates that the use of high-technology 'end-of-pipe' treatment is 'an admission of failure'—despite this being the approach presumed as 'common sense' by UK water companies. Research to challenge this presumption has so far been inconclusive, largely because it has been under-funded and not perceived as important by the UK water industry.

It is instructive to review the development of 'environmental protection' since 1991 and this paper considers the water sector as an illustration. The global initiative that is attributed as the defining moment in conceptualising and starting the process of operationalising 'sustainable development' by the World Commission on Environment and Development (WCED) in 1987 had not, by 1991, been widely taken up, other than in a number of UN Agenda 21 initiatives. Hence interest was focused on 'environment' and, especially for engineers, the economics associated with environmental protection. Little work had been done on including the 'social' dimension in the planning of engineering developments, other than usual practice through the UK planning system.

In 1991 there was great interest in including 'environmental protection' in the planning of engineering developments. In that

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year, the EU urban wastewater treatment directive[13] was implemented, setting the standards for sewage discharges across Europe. However, this has led to a clear illustration of the 'law of diminishing returns' cited by Semple in 1991, with the construction of vast numbers of large energy- and chemical-intensive treatment plants across Europe. As an example, Tyson[10] cites plans to enhance the treatment of wastewater in Philadelphia, USA. The original energy used to treat the city's 1640 Ml of sewage to a standard such that it had a 20% residual biochemical oxygen demand (BOD) is equivalent to the consumption of 6 Ml of oil daily. With further investments in the treatment plant yielding improvements to 10% residual BOD, oil usage would rise to 38 Ml per day; for 2% BOD, up to 115 Ml per day. This type of investment was made across the EU in response to the wastewater directive.

Today, however, there is a much greater awareness of the potential impacts of over-zealous environmental improvements in one sector impacting on another (as pointed out by Semple 17 years ago). For example, Smullen *et al.*,[14] considering Philadelphia's wastewater systems more recently, demonstrated conclusively that disconnection of stormwater near source is a far more sustainable approach to managing high flows than building large storage tunnels—as is about to happen in London.

Only just beginning to appear in 1991, genetic algorithms are now being used to look for Pareto optimal solutions that can illustrate trade-off relationships between objectives. As noted by Fu *et al.*[15]

> Compared with a single objective solution, a set of Pareto optimal control strategies can be identified instead of a single one. This will allow the decision maker to have a more complete knowledge of the trade-off structure between conflicting objectives when making a decision.

However, such methodologies cannot yet (and probably never will) handle the important social and moral aspects of decision support highlighted by Semple.

Since 1991, new approaches have been developed for environmental impact assessment (EIA)[16] and the strategic environmental assessment (SEA) directive is now particularly significant especially for local authorities in the UK when planning developments; 'sustainability assessments' are now undertaken as a matter of course (EIA and sustainability assessments are fundamentally different, however, as the latter are more considerate of social and economic factors[17]). The main problems remaining in all these assessments are the temporal and spatial boundaries to be set in the analysis. Semple set the spatial boundary globally (and it is now possible to go wider with 'footprinting' techniques) and recognised the importance of the temporal boundary—now being addressed in the reprinting of Semple's paper some 17 years on.

In the area of flooding, the Flood Hazard Research Centre (FHRC) had, by 1991, developed a number of ways to account for flood losses and deal with 'intangibles',[18] which were also later linked to the amenity values of rivers[19] and public perception.[20] Currently, these are now included in the main UK guide for the economics of flooding, the so-called multi-coloured manual.[21]

Equivalent in the sewerage area, the *Sewerage Rehabilitation Manual* (SRM) was first published in 1983 by the Water Research Centre. This introduced, over several editions (latest fourth edition in 2001), increasingly sophisticated methods for accounting for risk-based sewer rehabilitation. The fifth edition of the SRM, due for publication in 2008,[22] takes a major step in a more probabilistic and risk-based approach with a forward-looking view of risk in addition to the traditional historical view of flood management. The fifth edition anticipates greater use of above-ground flow modelling to establish the effect of any predicted escapes from the sewer system (e.g. local ponding on highways or open spaces, or property flooding). It also proposes the use of variable standards for the upgrading of existing sewer systems using a risk-based approach with a cost–benefit analysis. This may, in future, facilitate better harmonisation of the approaches across the different areas (river, coast and local urban) of flood risk as required under the EU floods directive enacted in 2007. It should also help link these areas, as far as sewer management is concerned, directly with water quality protection—a requirement of the water framework directive[7,23] for which methodologies have been given in the *Urban Pollution Management Manual*.[24]

Semple worked for many years in the Scottish civil service. In 1977, the Scottish Development Department (SDD) had developed rules for the design and operation of combined sewer overflow storage—rules that are still used in some instances today. Representing SDD at the time, Semple served on the national working party on the hydraulic design of storm sewers, which produced the 'Wallingford procedure' in 1981.[25] This described a procedure for the design of storm sewers to accommodate storms of any chosen severity and is still in use today. However, there remained the question, in 1981, of what severity to choose. That question was labelled 'economics' and Semple took part in this aspect of development of the procedure. Relevant to his 1991 paper, the key part was his work on identification of optimum design condition (reproduced here as Figure 1). A chapter in the Wallingford procedure (Economic appraisal and storm drainage) has been used more recently in the 'Building knowledge to adapt to climate change' programme of UKCIP/EPSRC.[26]

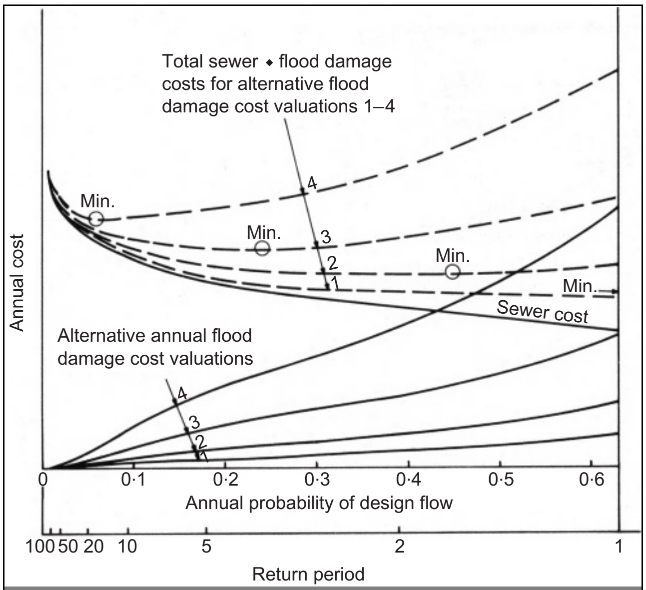

Figure 1. Identification of optimum design condition[25] (reproduced with permission from HR Wallingford Ltd)

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Blackwood *et al.*[27] outline an approach to decision making in wastewater system management that is based on utility considerations, drawn in part from the ideas provided in Semple's paper.[28] This utility-type approach is still in use and being 'rediscovered' recurrently as if it were a new idea.[29] Subsequent developments of methodologies to select the more sustainable water system asset management option (taking due account of moral considerations) extend utility-based thinking to take a more in-depth and comprehensive approach to decision making that attempts to balance criteria using multi-criteria assessment techniques.[30] Further developments in sustainability assessment are reviewed in two special issues of *Engineering Sustainability*.[31,32] Earlier, morality—as advocated by Semple in a global sense—was expressed in the inclusion of Maori cultural values in sustainability assessments, illustrating that certain human cultures may be better aligned than others with the carrying capacity of the planet.[33]

In Semple's approach there are, in principle in all cases, two costs for any case of avoiding protection—the cost of the works for a standard of protection and the corresponding cost of the environmental damage still remaining. As one of these costs increases the other correspondingly decreases in such a way that if all data are known there will, in all cases, be a minimum 'optimal' total cost. This is where a line can be drawn as to what degree of protection to provide because either more or less protection will not be worth it. However, while the cost of protection works can easily be evaluated, the cost of the corresponding residual environmental damage cannot. However, without some attempt at evaluation, chaos ensues.

The conundrum posed by Semple of 'costing environmental damage' has, to some extent, been turned on its head by the concept of 'ecosystem services'.[34] In 2005, Millennium Ecosystem Assessment produced a major global report on the state and future of the planet.[35] It recognised that ecosystems provide basic human requirements, each of which depends on a number of ecosystem processes. Hence the concept of 'ecosystem services' is defined as the benefits people obtain from ecosystems, explicitly linking ecosystem properties and processes to human wellbeing.[36] The approach should help ensure that the implementation of environmental policies such as the EU water framework directive provides not simply technical solutions to socio-technical problems. However, questions remain, for example, about the appropriate measure of 'value' (economic, social, ecological) and the nature and source of information used in an evaluation. Also, how are current costs and benefits to be weighted against future costs and benefits, given that future populations cannot express a preference?

Semple's paper was certainly prescient and, as illustrated at the start of this review, sadly largely ignored. Or perhaps it was already too late to effect any changes in time and avert the current, and clearly foreseeable, problems in the UK. A more recent paper[12] shows how, in the worldwide water sector, there is a clear discontinuity between 'presents, recent pasts and near futures'—the consequences of which are that decision makers in this area frequently fail to learn the lessons of history. This results in severe path-dependency of decisions ('we know this works because we have always done it this way') notwithstanding evidence that things should now be done differently (also echoed in a review of the history of flood risk management in Britain[37]). This is illustrated by institutional understandings of what is assumed to be 'common sense'.[38] This paradigm or 'regime' limits space for innovation and the exercising of critical judgements.

A contemporary illustration of this problem is the new Thames tideway sewer tunnel, now being built to address the 1991 urban wastewater treatment directive. The 2000 water framework directive would require a much more considered assessment of the sustainability implications of this 'path-dependent' and 'common sense' approach, which has a huge carbon footprint. This illustrates that, despite the intervening years, little advance in civil engineering has actually been made since Semple's 1991 paper. The profession is largely locked-in to a path-dependency that favours large technological 'solutions' rather than developing the much-needed incremental, adaptable, flexible and mixed 'responses'. This problem is not confined solely to the UK; in Australia, the promising take-up of 'water sensitive urban design' has stalled in a new rush to build desalination plants instead.[39]

It may be concluded that, notwithstanding considerable work since 1991, the current picture as regards environmental protection costs remains confused and inconsistent. There are already examples of over-zealous application of the water framework directive in parts of Europe, with excessive expenditure being demanded by environmental regulators. Expectations amongst many European citizens are often very high, exemplified by Copenhagen's inhabitants who wish to swim in the harbour and are committed to paying for ways to achieve this.[40] Presumably, health services, education and employment levels are all exemplary in Denmark and there is sufficient spare wealth to invest in the pristine environment required for city bathing; this is not true for most of the rest of Europe. Overall, it is possible to conclude that the sorts of principles espoused by Semple have not yet been fully worked out and more development is needed in this important area. Finally, it is appropriate to reiterate the two concluding paragraphs of Semple's 1991 paper as they still apply today.

> Complexities exist with regard to environmental protection. All is not perhaps as it seems. It is easy to arrive at policies that are superficial, facile, not efficacious and even counter-productive. The world is awash with good ideas but short of principles by which to judge their efficacy. An attempt has been made in the Paper to identify some of the correct principles and apparent contradictions, but much remains to be done.
>
> Consideration of the finite resources of fossil fuels and environmental sinks brings in overriding imperatives which require research on a national and international scale. The Institution of Civil Engineers is recommended to participate, in collaboration with other professional bodies, in developing a programme of research and education. The research results could have feedback to current engineering activities which may already be off-track.

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PAPER 9706 PROJECTS MANAGEMENT

Principles of environmental protection

N. G. SEMPLE, BSc, FICE, FIWEM*

The aim of the Paper is to establish the essential components of effective environmental management. One problem of the latter has been how to cost environmental damage, and the Paper sets out a technique, based on graphs, for overcoming this as far as is possible. The Paper outlines legal aspects of environmental protection and shows how the compensation due for each case of damage may be costed by means of the respective graph, and also suggests how this compensation might be dispensed. The case is made that, in order to achieve effective self regulation, all market prices must include the full costs of protection. Consideration is given to the problem of achieving an environmentally sustainable economy. Conclusions are drawn and recommendations made throughout on policy and practice pertaining to environmental protection.

Introduction

The Paper aims to establish the essential components of effective environmental management. It was written in the period soon after the publication of: *Blueprint for a green economy*,[1] *Pollution and it containment*,[2] and the issue of the Government's White Paper on the Environment (autumn 1990),[3] when policy for the protection of the environment was under rapid development. Although there appeared to be plenty of ideas, there was a lack of principles by which to judge the efficacy of those ideas. This Paper now offers principles for discussion.

2. A fundamental problem in environmental management has been how to cost environmental damage. The Paper describes a graphical technique for overcoming this difficulty, at least partly and so far as may ever be possible. It employs the well-known but little applied law of diminishing returns, from which the cost of the environmental damage that remains after a certain arbitrary degree of protection has been applied can be determined as a fact. This new information leads to an iterative review of the choice of the degree of protection to be applied until a reasonable, least total-cost, option has been found.

3. The Paper then outlines legal aspects of environmental protection and shows how the amount of compensation due for any unreasonable damage caused (through insufficient protection) may be costed from the graph for the case. It suggests how the compensation charged should be dispensed—mainly towards research—and supports the need for all market prices to include the full costs of protection so that there may be effective self-regulation. The contradiction between spending in one place to reduce pollution, and the pollution caused elsewhere by that very expenditure is examined.

4. These principles are then directed to the problem of achieving an environmentally sustainable economy, taking account of the finite resources of atmosphere and fossil fuels that are apparently available. The linkage is established between the above processes of environmental protection (through least costing) and the operation of the fundamental animal survival instinct to show that they are the same thing. The successful instinct has to be understood and applied to corporate problems. It is shown that, at a higher level, these principles are related also to processes of morality—physical pollution being simply an emission of behaviour.

5. Conclusions are drawn and recommendations made on the policy and the practice in respect of environmental protection, applicable from project design through to global management.

Environmental economics

6. By the term 'environment' is meant surroundings—from the immediate neighbourhood to the planet in general—as affected by the interaction of humankind with the rest of the physical world or the interaction of one person or party with another. The question of 'what is best' for the environment is an old problem, with a new meaning and significance. It is perhaps better stated as 'where to draw the line in providing protection'. The usual nature of the problem is how far it is reasonable to go in providing protection in a particular situation or scenario. This is a question of optimization, taking into account the cost of providing protection and the value to be derived from doing so. There is then the problem of deciding which is best between scenarios. Sometimes the decision is one of take it or leave it: for example, to preserve or to replace. Even here, however, the question may be to preserve or to replace to different extents, which takes the issue back to optimization and then to comparison.

7. Starting then from the position that, in the first place, the problem is one primarily of optimization, the factors involved can best be assembled graphically as proposed in Fig. 1. The features of the graph are as follows.

(*a*) The base axis is the degree of protection provided—the proportion of the emission curtailed (0–100%).

(*b*) The vertical axis is the cost—expressed in £ per annum—as a means of including capital and operating costs together in the long term.

Written discussion closes 15 October 1991; for further details see p. ii.

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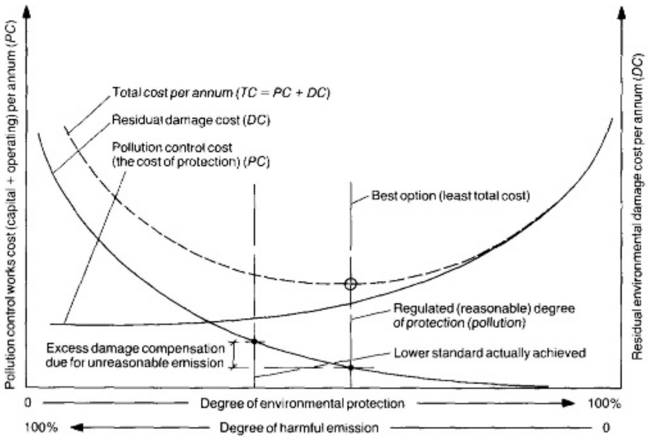

Fig. 1. Optimization in environmental management

(*c*) The damage cost (*DC*) is the cost of the residual damage, which is to say the environmental damage sustained even after the particular degree of protection has been provided at the particular cost indicated by the other provision cost (*PC*) curve for that same degree of protection.

(*d*) The best option as to the degree of protection is at the point where the total cost of the two cost components ($PC + DC$) is a minimum: i.e. at the low point of the curve.

(*e*) At that point, the gradients of the two curves are equal and opposite. Therefore, the one cost is going up at the same rate as the other is going down, which means that no more and no less protection would be advantageous; the marginal cost of environmental benefit is equal to the marginal cost of environmental protection.

(*f*) The other features of the graph are discussed later under the subject of compensation.

If all the data for the graph are available, the scenario will have been optimized by finding the best, least-cost, option. That cost can then be compared with that of other scenarios for final choice.

8. Environmental protection can be expressed in the most general terms, as the control of emissions affecting others—either physical emissions or emissions of behaviour. Reflection will show, however, that physical emissions are simply emissions of behaviour; so all is one. Surprisingly, perhaps, the law of diminishing returns is an expression of behaviour, sometimes for self interest, sometimes taking into account the interests of others (morality). Although used for economical design purposes, it is not a physical law; it is related to the legal principle of the duty of care owed to one's neighbour.

9. The engineering designs for physical processes for environmental protection (such as sedimentation, filtration, flooding, insulation, etc.) are all subject to the laws of diminishing returns; although for want of a practical alternative, the question of where to draw the line is often resolved by rule of thumb. However, in the case, for example, of thermal insulation, an economic relationship can be calculated—to determine where to draw the line in providing protection against the financially damaging cost of emission of heat. This is a simple application because the costs are all incurred by the same party and are all measurable. It is a matter only of self-interest, with perhaps moral choice concerning the time horizon: pay extra now to save more later. The problem is then simply one of numerical or graphical economics resolved as described.

Costing environmental damage

10. The more general and more difficult situation is the one where the costs of the provision, and of the effects of the emission are not incurred by the same person, and where the costs are not all measurable directly in terms of money. Emissions from industrial processes and public works that cause distress to people or the living environment are in this category.

11. Because environmental damage costs cannot generally be measured in cash, this has previously been accepted as rendering the described processes of economics ineffective. However, there is a device which gets half-way round this problem. (This approach was developed by the Author when serving on the Working Group that developed the Wallingford procedure for the design of urban storm drainage;[4] the question there was where to draw the line in providing storm drainage.) The trick is to draw the graph as in Fig. 1 but to express the financially unmeasurable cost of the environmental damage to some arbitrary scale in the first place. This shape defines the relative (although not the money cost) of the residual damage sustained. Curves of that same shape can then be drawn to different scales on the graph to bring out different best options as to the degree of protection to be provided (see Fig. 2). (If the shape of the curve is not known even approximately then, for lack of knowledge, the decision taker is in no position to take a decision of any kind and must find the shape by investigation.)

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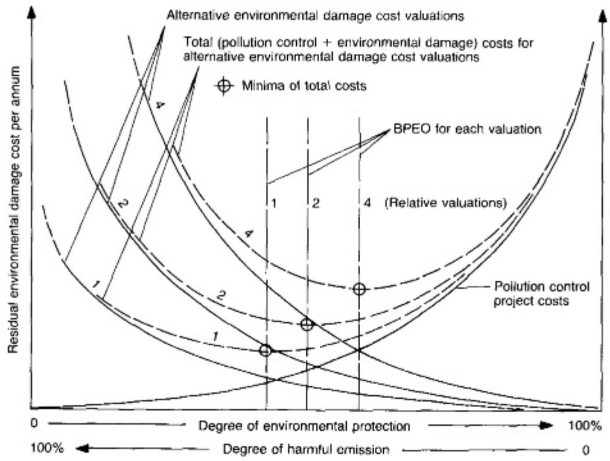

Fig. 2. Best practicable environmental option (BPEO) selection diagram

12. An arbitrary choice for the best degree of protection can then be made as a starting point; this would be the choice that would have been made before this approach was known and applied. From the graph, the one single residual damage cost curve that would bring about the selected degree of protection as the best option can then be found. In turn, that will define (as a fact) in monetary terms the residual damage cost inherent in that choice. This new information, not previously available, can then be fed back into the decision process. The new question will be: is the now-available residual damage cost appropriate or would, in fact, another option be better? The process then becomes one of trial and review.

13. In the last resort, of course, the answer is still judgemental but better founded. A proper moral judgement is made by respecting the 'sympathetic feelings of the impartial well-informed spectator';[5] the role of this Spectator as the bystanding judge or god-figure is crucial to the process. Furthermore, there is more accountability, as the acceptable degree of residual damage that goes with the final decision taken is now available as a fact to be put alongside the cost of the protection required. That is better than the present system of usually quite arbitrary choice applied by regulators and politicians alike.

14. From the viewpoint of the Spectator, if the residual damage justifying the chosen degree of protection is (from the evidence of its effect) very high, then the standard will have been chosen too high and another trial will be needed, and so on, until the Spectator is thought content. The high degree of residual damage justifying the too-high standard may appal those affected by the damage and may be used as a reason for a higher standard still. However, that is not the point, nor the standpoint from which the balanced judgement will be made; that might come as a surprise to those affected but it will be salutary and in the nature of education. The cost of protection too is a legitimate and essential consideration. The Spectator may decide that the first choice of standard was too low, and then the reverse would apply. It is necessary that the Spectator should be sympathetic, impartial and well-informed in respect of all the relevant circumstances.

15. Figure 2 expresses the intentions of the Twelfth Report of the Royal Commission on Environmental Protection,[6] on finding the *Best practicable environmental option* (BPEO). (For convenience, the figure can be referred to as the BPEO diagram.) The Commission expressed the problem as one of 'balancing' the cost of the provision of protection against the cost of the damage sustained. The solution proposed here is one of optimization to that end. The current policy of the European Commission is that the best answer is the best available technology not entailing excessive cost (BATNEEC); this is a rough way of encouraging high standards but is not sufficiently rigorous in economic terms and can be environmentally counterproductive in resource and global terms. There is such a thing as over-protection: i.e. a misdirection of finite resources through 'straining after gnats'.

The law and charging for pollution

16. The next principle is charging for pollution. Policy here starts from the principle in law of the duty of care owed to one's neighbour—the well-known area of tort (known as delict in Scotland). Broadly speaking, a tort is a legal wrong—the harmful conduct by one person which causes loss or injury to another. The person responsible for causing the harm is subject to a liability to make good by paying compensating damages. The damages may apparently include not only for financial loss but for hurt, including distress. In terms of the diagram, this means that the legal principle is established, requiring that steps are taken by a person to prevent damage to neighbours. This is indicated by the provision cost curve. However, it is apparently a defence in law that there was no negligence—that the standard of care provided was that of a reasonable person. (This is fortunate as otherwise no activity affecting others, except to their advantage, would be legal.) Owing to the influence of the European Community, the principles of law in this area are changing; it would seem that no-fault will no longer be a defence. In practice, however, the result may perhaps be much the same.

17. The question is then: where is it reasonable to draw the line? On the diagram, the line would be the degree of protection to be provided (usually at a cost) which would cause only acceptable residual damage to others, as set by the law as to what is reasonable to expect. The cost of the damage above that level would be the amount of compensation due (see Fig. 1).

18. In the case of standards of protection set by regulatory authorities, no statutory compensation would be due if the set standards were complied with. In providing the set degree of protection (at a cost), the polluter would have paid, as is the policy. However, if the polluter had not complied with the set standard, compensation would also be due for the amount of damage in excess. The same principle could be applied (it is not now) to the case where a polluter has a plant which complies with a standard which has since been raised. This polluter (for equity with those complying with the new standard) should pay for the extra damage as soon as the standard is raised—at a rate per annum which can be determined from the diagram.

19. Likewise, the environmental damage inherent in a product could be charged at source so that all residual environmentally damaging costs are included in the cost of the product. Only in such a way, by the operation of market prices, can environmentally sensible decisions be taken by everyone—the full damage cost would be built into the price of the product or operation.

20. Compensation, even in place of regulated standards, would be appropriate in particular cases: where the application of standards was impractical (perhaps because the pollution was too diffuse and widespread or the effective technology was not available); and where the standard could not be applied immediately (perhaps when it had only recently been raised). The revenue from the compensation charged could go to the following: to those suffering damage (which is usually not practical); to remedying environmental damage caused in the past; to financing adequate regulation; but especially to funding badly needed environmental research.

Aspects of determination of environmental damage and control provision costs

21. The book *Blueprint for a green economy*,[1] commissioned by the Department of the Environment, was a landmark. It investigates and makes recommendations on: sustainable development; valuing the environment; accounting for the environment; project appraisal; discounting the future; and prices and incentives for environmental improvement.

22. The way of evaluating, in money, the environmental consequences of the chosen option (as in Fig. 2) is apparently of value to the process described in reference 1 of accounting nationally for the environmental damage, either caused or avoided. This is a process now being developed and the graphical approach has much to offer here. The (approximate) environmental damage cost inherent in the chosen option can, by definition, be simply read off the diagram as a fact; the cost of providing the selected degree of protection and an indication of the reduction in environmental damage obtained can also be read off.

23. The shape of the residual environmental damage curve will often be simply concave upwards or a straight line, but other shapes will occur. For example, it may be that, in some cases—such as where sensitivity to noise, smell or taste is a measure of pollution—protection will be largely ineffective until a perception or safety threshold is reached and just passed. This will produce an S-shaped damage curve but will not invalidate the mode of analysis proposed; a minimum total cost case will still emerge from the diagram. This is the kind of case where the degree of tolerable pollution can usually be firmly defined by a limit.

24. Where the protective works consist of staged or separate elements, the cost of providing protection will be a curve which is stepped or scalloped (see Fig. 3). For example, in a sewage treatment works or chimney filter, where a secondary treatment process is added to the first in order to provide the next element of protection, the primary treatment cost curve will be followed by a section of new curve of the appropriate shape to represent the new trend. The curve of the cost of provision will usually start not from a zero value but from the amount required to carry out even the minimal works of the kind to be employed.

25. As will be discussed later, an overriding consideration in all that has been described so far in the finding of the BPEO is that the cost of providing protection should include the compensation due on account of any globally unsustainable resource depletion or unsustainable pollution arising from the production of its constituents. Otherwise, the cost of protection will be underestimated and the overall BPEO will not have been found.

Comparison of scenarios

26. In cases where there are a number of ways of proceeding, each scenario, in which the degree of protection is variable, is first optimized as described; then the different optimized scenarios are compared to arrive at the best (least-cost) solution. Where a scenario is not optimizable—for example, in a take-it-or-leave-it (yes–no) situation—at least the cost of its provision will be known and it will be possible by comparison with other scenarios to see what cost of residual environmental damage would justify selection or rejection of that scenario in preference to the others optimized.

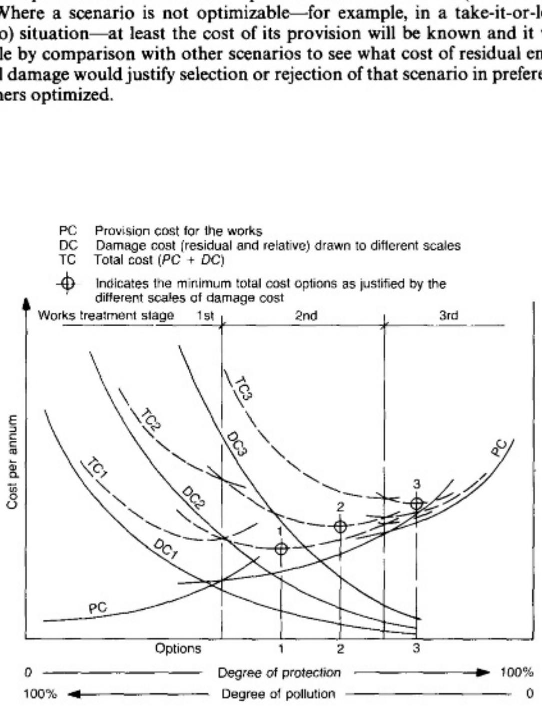

Fig. 3. Finding the BPEO for staged treatment works

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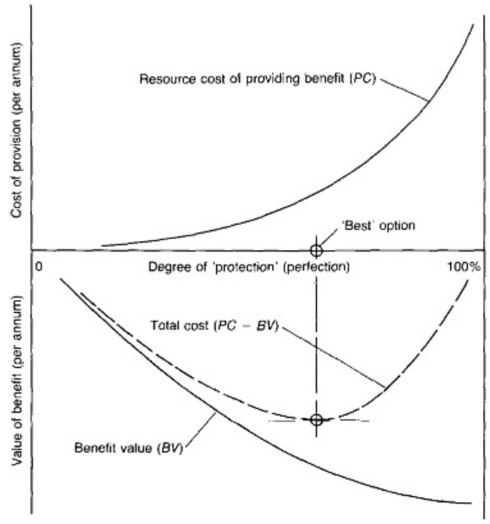

Fig. 4. Provision of environmental benefit (enhancement)

27. If all the options are optimizable, then, strictly speaking, that process will be purely arithmetical as the total cost of each scenario will have been established in the optimizing process. However, it may be found useful to lay out the scenario protection and damage cost elements for diagrammatic comparison, as interaction between the scenarios may lead to some modification of the degrees of protection chosen in consequence of the feedback from the comparison; some inconsistency may be perceived in the setting of standards, and the scenarios may need to be tuned-in to one another.

Environmental benefit

28. It is interesting that the BPEO diagram also covers the situation where the consequence of an activity, at a cost, is to produce benefit by enhancement of the environment. That case is illustrated if the residual damage cost curve is slid on the diagram to below the line where it counts as a negative cost or benefit (Fig. 4). The law of least total cost and diminishing returns operates once again.

Yes–no (take-it-or-leave-it) scenarios

29. Some scenarios may be ones which are set and where the question is not one of degree of environmental protection within scenarios but selection from only the few fixed choices available. For example, the choice for a development might be between complete demolition and replacement, with a range of completely new buildings or with preservation of the facade with normal development behind. The BPEO technique illustrated in Fig. 2 is still applicable. The cost of implementing the various options can be readily obtained. The *relative* environmental impact of each case has then to be quantified on some convenient but arbitrary scale of values (perhaps 0–100). An illustrative range of scenarios is shown in Fig. 5.

30. The provision cost and the relative damage (or benefit) values for the various options to be chosen between are plotted to form two curves in ascending order of provision cost; the damage curve is plotted to any graphically convenient cost scale in the first place. The curves may be quite irregular but the irregularity will contain its own meaning. The damage (or benefit) values are then plotted at a variety of scales. The diagram is then questioned by supposing what seems at first to be the best choice, and reading off from the diagram what is the actual financial cost of damage or benefit that will justify that assumption: that will be the damage (or benefit) read from the curve that brings out the least total cost at the choice being examined. This new information is then used to review the assumption made in relation to the corresponding information associated with other assumptions.

31. The 'best' answer will be the one at which it seems appropriate to draw the line on the ascending cost of provision. It will be seen as not worth going beyond that point because the extra cost of provision will then start to exceed the extra damage or benefit cost to be gained. Another approach would be to space the options horizontally, so that the perceived benefits are in a straight line gradient, and to study the trends accordingly.

32. By this procedure, the decision process should be better, more systematic and financially accountable than if carried out purely by individual personal instinct. However, the answer may well be about the same. That will be because the process is used by the instinct but less methodically. This aspect of instinct is developed later.

33. The example under examination here also illustrates the concept that an action may result in environmental benefit (enhancement) not damage, such as where a structure is to be embellished to improve its appearance, but at increasing extra cost. The question this time is where to draw the line in providing extra benefit as distinct from reducing damage. When comparing cases, the best will still be the least cost solution but the benefit will count as a negative cost.

Sustainability

34. Important and large global damage costs may be incurred by the pollution from the combustion of fuels and the release of volatile chemicals to the atmosphere. So the question of how to bring this into account is an essential consideration.

35. There are three finite resources, the consumption of which is of major concern at present: the capacity of the atmosphere for the products of combustion; the capacity of the tropospheric ozone layer for certain volatile chemicals; and the reserves of fossil fuels (as both fuels and a major chemical feedstock). As pointed out by Pearce *et al.*,[1] the global pollution 'sink' (atmospheric and oceanic) is a resource of apparently limited capacity, which is being exploited free of charge at present.

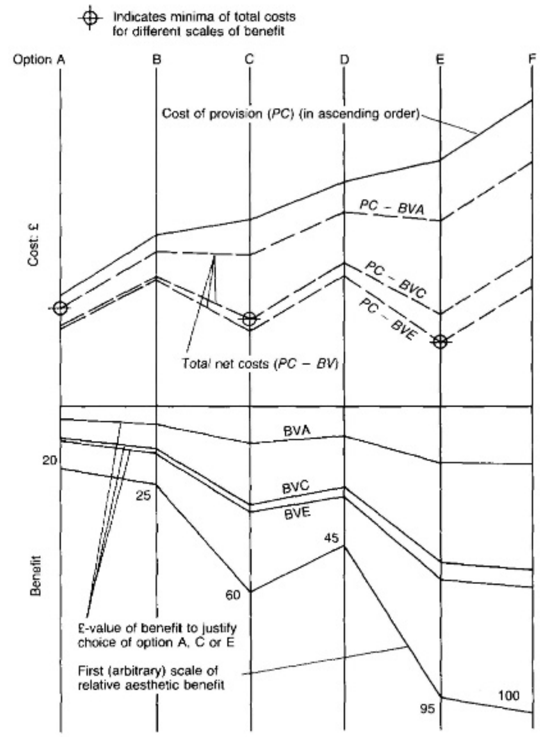

Fig. 5. Choosing between yes–no options

36. The Author of this Paper claims no special scientific knowledge of these problems, and the concern here is only with the principles of how to deal with the questions. The irrefutable position seems to be that there is insufficient knowledge, as yet, about any of the three above problems, even though this ignorance might literally be fatal. So more needs to be known. If the consequence is bad news, it is better to know sooner rather than later. If, on the other hand, it is found that there is in fact no problem and that sustainability can easily be achieved, then this will be good news worth paying for.

37. A starting point would therefore be at least to fund more research—such as by charges made on the prime sources (the chemicals) assumed to be causing the pollution and depletion damage—for the examination of use and practice. The process has the other constructive effect of applying at least some immediate price restraint to the direct use of the resources.

38. The possible over-uses of both the atmosphere and fossil fuels are related, although the use of the atmospheric sink may be the more urgent question. The underlying problem seems to be that energy is probably being used too fast. As economic activity is dependent on and, indeed, is a function of energy consumption, this suggests that the present and accelerating rate of economic activity may well be unsustainable.

39. In this connection, it is misleading, to think of costs as other than a measure of economic activity; and as economic activity is at present fuelled largely by fossil fuels, costs are a broad measure—proportionally—of the amount of fossil-fuel consumed directly and indirectly in the activities they represent. It is contended here, therefore, that relative costs are a reasonable measure of relative fossil-fuel depletion and associated pollution.

40. Energy is of two kinds: capital energy (i.e. mined energy from oil, coal and uranium); and current energy (i.e. that produced or farmed without any resort to capital energy on or off-site directly or indirectly). It seems to be beyond dispute that the present-day level of economic activity world-wide is supported very largely by the consumption of mined energy and the technological development that has flowed from it over the past 200 years or so. Economic activity can be measured as population × unit activity. In this country alone, the population has grown about five-fold since the production of power from fossil fuels was invented and developed; and the unit activity has grown by perhaps at least the same again. It seems only reasonable to conclude from this that by far the greater part of economic activity is supported at present by mined energy. If this capital (stored) energy is used up without development of a current replacement (or without development of a new form of energy to mine, such as nuclear fusion), a huge decline is in prospect. When that will be—perhaps in 50–200 years—can only be estimated; but whenever it may be, it is inexcusable not to face the prospect. If it is not a fact then let it be proven. If it is the case then let it be faced.

41. The first step then is to research the problems of atmospheric, ozone layer and fossil fuel depletion, funding it at national and international level from compensation to be charged on all users of these resources. Thereafter, when the facts are established scientifically as to what is sustainable, a pricing policy can be developed (if necessary) world-wide to achieve the required level of protection. The picture of this process is shown on a sketched version of the BPEO diagram in Fig. 6.

42. The global situation depicted is where there is a sustainable degree of pollution and it is to be found from scientific investigation. The general shape of the residual damage curve is therefore as shown. The exercise of even sketching the diagram is revealing. The residual damage curve is approximately L-shaped; it cannot be drawn otherwise. The sustainable limit is absolute, compromised only by the accuracy of knowledge and the time-scale adopted for reaching it, with long-term consequences. The BPEO is bound to be at the point of sustainability.

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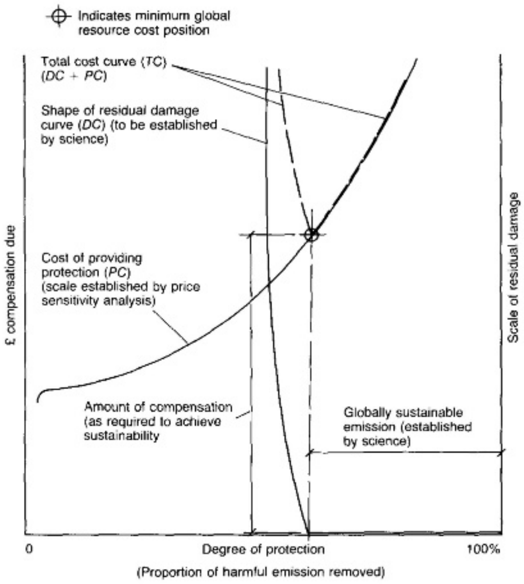

Fig. 6. Establishing global sustainability for a pollutant

43. When established by price-sensitivity analysis, the (probably high) compensation costs of providing protection will have the effect of bringing about self-correction by the operators of activities causing pollution. Another consequence will be that the new price paid by the polluter will bring about the development and marketing of devices to replace the ones that cause the pollution. This may lead to the emergence of an all-electric world, but the economic and engineering viability of that scenario has not yet been established. However, the technical development of it will have to be fuelled by the fossil-fuel it is designed to replace—a time-trap.

44. This suggests that a programme for the transition is needed, with feedback to the present. It is not possible to go on indefinitely, doing tomorrow what is being done today but to a greater degree.

Economic regulation

45. It is contended that there should be economic regulation so that the market price will indicate the appropriate cost of a product or service, including the environmental protection cost and excess (unreasonable) residual damage cost of all its components; only then can all the innumerable everyday decisions be made that will lead to environmentally effective conclusions. This supports the proposals by Pearce *et al.*[1] to that effect.

46. One consequence of this will be to expose any fallacies as to what is or is not environmentally beneficial in order to avoid well-meant decisions being taken which are in fact environmentally counter-productive. For example, a rigorous costing of this kind may show that so-called alternative, renewable, energy solutions (those using no fossil fuels to drive them) are, in fact, less not more environmentally advantageous. This is because if they cost more, it will indicate that the fossil fuels used in all the components of their production and operation are more than will be saved in their lifetime compared with conventional systems. Even a less rigorous, present-day, costing should show this to be so.

47. The concept that a source of energy is best and 'renewable' simply because it is not driven visibly by fossil fuel on site, although through its cost it expends fossil fuel off site, seems highly questionable. Similarly, claims for nuclear fission as a carbon-dioxide and pollution-free replacement for fossil-fuel power are dubious; even the nuclear fuel itself is mined and processed using fossil fuels and fossil-fuel based technology. The test is cost as a measure of relative on- and off-site fossil-fuel depletion and associated pollution. However, more expensive alternative energy systems can be justified as research and development of part, but only part, of a whole post-fossil-fuel scenario.

48. Complexities and contradictions abound. Seemingly good ideas are not enough. Only rigorous environmental economics leading to environmentally based market pricing will allow effective decisions to be made. Such a system will also lead the market to develop effective, alternative, truly 'environmentally-friendly', products and processes which otherwise would be too speculative.

49. However, it is unfortunate that the more a given degree of protection costs, the less it can be afforded. The higher the cost of fossil fuel (including damage compensation), the higher the cost of pollution prevention, and so the less it can be afforded. On the diagram (Fig. 2), the larger the scale of the protection cost curve, the less justification there is for setting the acceptable standard of protection at a high level. As the protection of the global environment at a sustainable level is the overriding imperative, it can be seen that to pay for the compensation required to achieve this, either the standards for what is locally congenial may have to suffer, or the general level of economic activity may have to decline, or both.

50. Levying a carbon tax to reduce global pollution from that source and then recirculating the levy, such as by a cut in income tax, will therefore achieve nothing. The levy has to be destroyed to reduce total economic activity or else directed towards research and development aimed at the effective reduction of fossil-fuel consumption and global pollution. The latter seems highly preferable—provided, of course, that the research is effective in the long term.

51. With matters of this magnitude at stake, the immediate need is for research at all levels: by companies looking for the way ahead; by governments in promoting large-scale investigation; and by learned institutions joining with other specialists to look at the problems altruistically and long term. As is well-known, government and industry are not in the business of long-term issues unless pressed or motivated, nor are their motives always altruistic; therefore, professionals have an important role to play.

The survival instinct

52. In the ultimate generalization, the two-curve, action–consequences, cost diagram expresses the operation of the human, or just animal, instinct. The BPEO graph for global environmental protection becomes the diagram for instinctive self-protection. In the most primitive general terms, the Author contends (as perhaps others have before now) that the process of instinct revolves on the consideration of the cost of care, the cost of lack of care, and the degree of care appropriate in the circumstances—taking into account the constraint of available resources, especially energy. (This links with the considerable research work done on risk assessment in the USA, and by the Royal Society and the Health and Safety Executive in the UK; where the question on protection is in terms of the degree of risk—or probability—of damage.)

53. The terminology varies with the scenario: hunting, being hunted, facing general danger or threat, etc. An understanding of this is relevant to environmental protection in the contemporary sense, as this is simply a process of dealing instinctively with a modern threat. For purposes of illustration, a more mundane modern use of the self-preservation instinct is in crossing a busy street. It gives the physical feel of instinctive protection and the operation of the survival instinct in terms of diminishing returns.

54. The question now is how to apply this (usually) successful survival instinct to corporate decision-taking. It is already applied roughly, but not in a rigorous, explicit or accountable way, as is made possible by the graphical approach—even if only somewhat diagrammatically for want of precise information.

55. The diagram takes account of long-term considerations by costing in terms of the present value per annum of all future costs. This is a moral decision; one which rejects short-term thinking. Discounted cash-flow is not enough.

56. The only means of taking non-calculable decisions is by use of this instinct. The Paper has attempted to explain how it works. The BPEO diagram (Fig. 2), expressing the instinct at work, gives the means of applying instinct systematically to the taking of corporate survival, but also sociable (moral), decisions.

57. Applying simple instinct to the present situation on global warming (even without resort to the diagram) it seems obvious that, faced with even just uncertainty on the road ahead, the instinctive first reaction is to take the foot off the hard-pressed accelerator (the economy), look hard ahead (research) and consider the braking distance (technological and administrative lead-time). Later instinctive reactions depend on the new information then available.

Professional action

58. The subject of environmental protection in its widest behavioural sense is all-embracing. Even the control of the activity of physical pollution in relation to global effects is a very wide interdisciplinary field. The opportunities for interdisciplinary discussion are limited by the historical division of professionals into separate institutional societies. There is therefore a strong case for ever wider collaboration to bring together all those concerned. The Institution of Civil Engineers is uniquely placed to act as a forum for such wide-ranging discussions, and it is recommended that it should look at how this might be achieved.

Conclusions and recommendations

59. Complexities exist with regard to environmental protection. All is not perhaps as it seems. It is easy to arrive at policies that are superficial, facile, not efficacious and even counter-productive. The world is awash with good ideas but short of principles by which to judge their efficacy. An attempt has been made in the Paper to identify some of the correct principles and apparent contradictions, but much remains to be done.

60. Consideration of the finite resources of fossil fuels and environmental sinks brings in overriding imperatives which require research on a national and international scale. The Institution of Civil Engineers is recommended to participate, in collaboration with other professional bodies, in developing a programme of research and education. The research results could have feedback to current engineering activities which may already be off-track.

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