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**A MARKET APPROACH TO
SUSTAINABLE LAND MANAGEMENT**

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Introduction

The recent occurrence of algal blooms in the Murray and Darling Rivers is an indication that the phosphorus loadings generated by people and economic activity within the Murray-Darling Basin is displacing aquatic ecosystems towards states that result in poorer water quality than occurred in the past. The better water quality of the past, in fact, was one of the resources upon which economic development was based. While phosphate discharges, or at least the point sources, might be considered a subject amenable to analysis within the economic paradigm, there are grounds for believing that the catchment-wide cultural eutrophication phenomenon involves greater complexity and more dynamic behaviour than can be captured from within this paradigm. To gain an insight into this behaviour, it is first necessary to describe some of the concepts that are useful in dealing with complexity.

Open Dissipative Systems and Stratified Stability

The global biosphere, and any local part of it, is a thermodynamically open or dissipative system that receives solar radiation, which is dissipated by the metabolic activity of plants and the food chains arising from them (O'Neill *et al.* 1986). These plants, and the organisms that depend on them, together with the stored solar energy of fossil fuel, provide much of the resources and energy upon which economic activity is based. An important property of dissipative systems is their spontaneous tendency to hierarchically structured self-organisation. Such a tendency is thought to have been responsible for the synthesis of the carbon-based compounds that were the precursors to life, for the organisation of these compounds into simple life-forms, for the evolution of more complex life-forms and for the organisation of these life-forms into ecosystems. A key aspect of this process was termed 'stratified stability' by Bronowski (1973). This refers to the requirement that the entities at each level in the hierarchy be sufficiently stable to provide a basis for the organisation of the next highest level.

Hierarchical Systems

The intrinsically hierarchical organisation of the biosphere, and, indeed, of many social, economic and physical systems, has attracted much theoretical speculation and analysis (Simon 1973; Pattee 1973; Allen & Starr 1982; O'Neill *et al.* 1986). Hierarchy theory attempts to deal with complex systems, not necessarily in terms of components that are conceptually appealing at the spatio-temporal scale of human observation, but rather in terms of the rates at which system processes take place. This approach enables a chosen level in the hierarchy to be analysed as a mathematically tractable 'small-number system'¹. A complex 'medium-number' system is amenable to such an approach ('nearly-decomposable': Simon, 1973) if levels in the hierarchy are sufficiently separated from each other in terms of process rates, such that the fluctuations in behaviour at one level appear only as an average to the level above. For example, the capture of solar energy by a single phytoplanktonic organism, is characterised by a daily cycle. The annual production of the total phytoplankton population (the next level in the hierarchy) is, however, related to the average daily energy capture. This separation between the levels in a hierarchy was termed 'loose vertical coupling' by Simon (1973).

A nearly decomposable system is also characterised by 'loose horizontal coupling' within levels. The subsystems or holons (Koestler 1967) within a level are also distinguished by reference to process rates. The components within a holon interact frequently with each other, but infrequently with the components of other holons at the same level in the hierarchy. For example, if the holon is the organism mentioned above, then there are obviously far more frequent interactions among its internal components than with the internal components of other phytoplankton. In this example, the boundary of a holon is coincident with a biophysical boundary. This need not be so, as shown by the 'interflow' component in catchment hydrological models, which cannot be physically identified in real catchments (O'Neill *et al.* 1986). The less frequent interactions between holons comprise the behavioural dynamics of the level above, i.e. the collection of holons as a whole.

The interactions between holons are symmetrical in that they can act on each other. The interactions between levels are, however, asymmetrical. Any given level in the hierarchy, is relatively insensitive to the fluctuations in the outputs of the holons in the

¹'Small number systems' (such as are the subject of classical mechanics and dynamics) and 'large-number systems' (such as gases as treated in statistical mechanics) are amenable to mathematical analysis. 'Medium-number systems' which include most biotic, social and economic systems are not - at least without reformulation as described here (see O'Neill 1986).

level below, but is constrained in the range of behaviours available to it by the dynamics of the level above. For example, the annual production of a phytoplankton population, while insensitive to the daily fluctuations in individual production, may be constrained due to grazing by zooplankton, the levels of grazing being determined by the dynamics of the next level in the hierarchy—the plankton community.

Dynamics of Cultural Eutrophication

The constraints imposed downwards in hierarchies are relevant to the phenomenon of cultural eutrophication. If we conceptualise a catchment community² as a level in a hierarchy, then the long-term (in human time perception) trends in nutrient loadings which are determined by the dynamics of the interactions between the economic and ecological holons,³ are a constraint within which aquatic ecosystems function. These trends are also a constraint on the economic holon, although this is not generally discernible with the observation set⁴ of the neo-classical economic paradigm.

A recent review by Loehle (1989) concluded that the dynamics of many ecosystems can be usefully conceptualised within a catastrophe theory framework. This framework has been applied to aquatic ecosystems by Dubois (1978) and Duckstein, Casti and Kempf (1979) who employed dissolved oxygen and algal biomass, respectively, as response variables, and nutrient concentration as a control parameter. Loehle noted that, in the systems reviewed, catastrophic behaviour often involves a combination of fast moving and slow moving variables, the latter being constraints imposed from higher in the system hierarchy. In Figure 1 a hypothetical cusp manifold is illustrated where gradual long-term change in a control parameter (which might be the ten year average catchment phosphorus load) brings the system to a region on the manifold where the response variable (which might be total algal biomass) shifts rapidly from a low biomass equilibrium and a high biomass equilibrium.

²The term is used here to denote the totality of ecological and human communities, including all the abiotic artifacts of the latter, and the economic processes that produce them.

³Such a decomposition of the catchment community is based on tangible structuring rather than on process rate structuring—the implications of this are covered in the discussion.

⁴The term observation set, introduced by O'Neill *et al.* (1986) refers to the collection of state variables chosen for study and the spatio-temporal scale of their dynamics

In a recent extension to the understanding of ecosystem dynamics, Wilson *et al.* (1991) demonstrated that stable, energetically efficient, multispecies communities may be comprised of species whose populations vary chaotically with time.

In a manner analogous to the control parameters in catastrophe theory, chaos may be induced by constraints imposed by higher order interactions and dynamics.

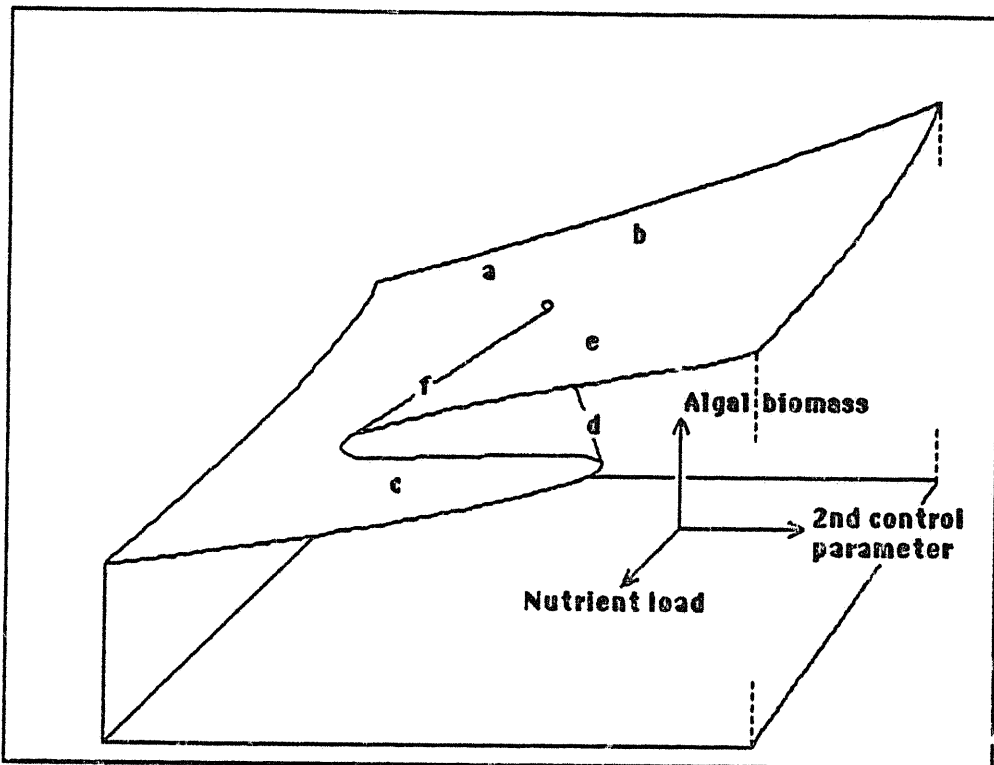


Figure 1

Hypothetical cusp manifold showing how equilibrium algal biomass varies smoothly with changes in the second control parameter (e.g. between a and b.) when nutrient loads are low. When nutrient loads increase, and the system moves into the fold of the cusp (c), variation in the second control parameter results in discontinuous and hysteretic variation in the equilibrium algal biomass (e.g. as the second control parameter increases, the system moves from c to d, at which stage there is a sudden increase in algal biomass as the system moves to e. If the control parameter were then to start decreasing, the system would move from e to f, at which a sudden fall in biomass would occur).

Implications for Environmental Policy

From the perspective of human organisations attempting to manage their relationship with aquatic ecosystems, the combination of catastrophic and chaotic (mathematically, but sometimes economically as well) behaviour and substantively incomplete knowledge is analogous to the organisational environment that Emery and Trist (1969) termed a 'turbulent field'. For an organisation operating in a turbulent field, the consequences of its actions are not necessarily attenuated with time and distance, but rather may be amplified unexpectedly. Further, the consequences of distant, seemingly irrelevant, events may amplify to extreme perturbations in the organisations immediate environment. Emery and Trist argue that the survival of organisations in such an environment requires the development of shared values, across the membership of all organisations, that act to constrain the behaviour of organisations. If organisations constrain their activities according to these values, the environment within which they operate is simplified by avoiding actions which entail gross uncertainties.

From the perspective of hierarchy theory, this is equivalent to imposing constraints on the behaviour of holons such that the dynamic interactions between them are not altered. The interactions between holons, which appear as slow moving variables when viewed from within the holons may be interpreted as control parameters governing the internal behaviour of holons. Hence, by preserving the original dynamics of the interactions between holons, control may be exerted over the behaviour of holons such that regions characterised by catastrophic or chaotic behaviour are avoided.

There is one critical difference, however, from the biotic hierarchies that do not involve human intervention. In the natural world, holons do not consciously constrain their behaviour to achieve desired dynamic behaviour of the level as a whole.⁵ As Boulding (1978) argued, in ecosystems that are being influenced by human intervention, the observed species composition and ecosystem functioning is as much an outcome of human values as it is of ecological processes. Hierarchical systems that involve ecosystems and economies therefore exhibit symmetrical rather than asymmetrical vertical loose coupling.

The important implication for policy that emerges from the perspectives discussed above, is that instruments which act within the spatio-temporal scale of a holon at a particular

⁵Although there has been some debate as to whether eucalypts evolve particular flammability characteristics to achieve fire dynamics at the community level that favour their survival (Mount 1964; Webb, 1968 in O'Neill, 1986).

level will produce fluctuations in behaviour at the scale of the holon. Unless these instruments achieve long-term changes in the average or equilibrium values of the holon state variables, the fluctuations will be averaged out and rendered ineffective in the dynamics of the level as a whole. Policy instruments whose goal is to change long-term trends in the Murray Darling Basin, like salinisation and cultural eutrophication, that are clearly manifestations of the dynamic behaviour of the catchment community (i.e. ecological and economic holons) need to be devised at a matching spatio-temporal scale and not at the scale pertaining within either holon in isolation. Examples of approaches at the latter scale include the mechanical and chemical techniques discussed by Crisman (1986), i.e. approaches internal to the ecological holon, and most of the economic instruments reviewed by Hahn (1989), i.e. approaches internal to the economic holon. Furthermore, policy instruments designed to influence the dynamics of the interaction between the ecological and economic holons will need to be richly endowed with mechanisms to link the two—an aspect that is lacking in the approaches referred to above.

The concept of the ecosystem-coupled market described below is proposed as an example of a policy instrument to intervene in the dynamics of cultural eutrophication in non-urban catchments where long-term increases in phosphate loadings are mainly a consequence of the import of phosphorus to the catchment due to agricultural activity.

An Ecosystem-coupled Market in Phosphate Discharge Permits

Over 85 per cent of all phosphorus entering Australian waterways is estimated to have come from diffuse sources of which agriculture is a major contributor, both from applied phosphatic fertilizers and faecal contamination by livestock (Marine and Inland Waters Advisory Committee 1987). Soil loss from agricultural catchments is also an important contributor to the phosphate loads received by streams.

The spreading of phosphatic fertilizers may be regarded as the exercise of a right to discharge phosphates into water courses. Such a view is consistent with the concept of factors of production as rights (Coase 1960), i.e. the right to discharge phosphates into a stream is as much a factor of production as labour, machinery and fertilizers themselves. The concept of rights to intervene in ecosystem functions is discussed at greater length in Reeve and Kaine (1991) and Kaine *et al.* (1992).

Given that streams have a limited capacity to assimilate phosphates without degrading other useful or desirable attributes, then the importation of fertilizers into a catchment must reflect this capacity (allowing for exports in farm produce) if degradation is to be avoided. The market proposed is intended to link importation of phosphatic fertilizers to the assimilative capacity of streams in a catchment through a permit or entitlement system. These permits are specific to the catchment in which it is sought to reduce eutrophication and are expressed in terms of kilograms per year total phosphorus discharge to waterways. The permit or licence is held permanently by the individual unless traded or gifted to another individual. Permits may also be leased or temporarily transferred on an annual basis.

The permits function as import licences for phosphatic fertilizers via the multiplication by a usage coefficient which is determined from the average ratio of annual fertilizer application to annual rate of phosphorus discharge for given soil type, agricultural practice and fertilizer type. For example, for single super used in horticulture on deep sands, the coefficient might be of the order of 0.022, i.e. a horticulturalist farming deep sands is entitled to import and apply 0.022 tonnes or 22 kilograms of single super for each permit unit held. Improved pastures on clay soils with rock phosphate application might attract a coefficient of 1.1, reflecting the much lower non-point phosphorus load under this land use. Farms with vegetation buffer strips might be accorded a further multiplier of perhaps 1.5.

The phosphorus discharge permit is also subject to an annual announced allocation as is currently done with irrigation licences. For our horticulturalist, an announced allocation of 150 per cent of permit entitlement would mean, for the year of the announcement, a total of 0.033 tonnes of single super for each permit unit held could be imported. The announced allocation system provides the capability, if required, to match the coming years phosphorus discharge to the estimated assimilative capacity of the waterway, which may vary somewhat with time. For example, unusual seasonal conditions in one year might result in the flushing of more phosphorus than usual through the waterway, enabling the announced allocation to rise to 170 per cent in the following year.

The number of permit units available on the catchment is determined by an extension of the methods envisaged in the proposed amendments to the New South Wales Clean Waters Act, 1970 (State Pollution Control Commission 1990), *viz.* an act of social choice (via public participation, Total Catchment Management structures, or political processes) to choose the Protection Category (i.e. values and uses of the waterways to be preserved), followed by scientific prescription of the water quality goals or benchmark

concentration necessary to preserve those values and uses. The benchmark concentration for our hypothetical catchment might be 50 micrograms per litre which provides water quality suitable for recreational use (Marine and Inland Waters Advisory Committee 1987). The extension required is to arrive at a total catchment phosphorus load that will meet this benchmark with an acceptable level of frequency. The methodology to do this would appear to be in reach, if not already possible (see, for example, Cullen 1991). On the hypothetical catchment, the total number of kilograms of annual phosphorus load that results in a 5 per cent probability of exceeding the benchmark at defined monitoring points might be 3000 kilograms per year. This means there are 3000 units of permits available for the catchment. Of course this establishment could be revised by further acts of social choice if different uses or values are to be protected.

The distribution of the 3000 units among catchment land users, once the market in permits is established, is determined by transactions among the land users. Such a market might be established as follows:

- i) A flat rate 'eutrophication' levy is imposed on ratepayers (urban and rural) in the catchment with the proceeds supporting a research program to establish the point and non-point phosphorus loads across the catchment.
- ii) When the catchment distribution of phosphorus loads has been estimated, the funding levy is adjusted to a 'user pays' basis with major contributors of phosphorus paying proportionately more. The research program now focuses on techniques for reducing the loads of the major contributors, e.g. research into less soluble phosphatic fertilizers, or improved sewerage treatment.
- iii) The results of the first research program are used to establish the total permit units available and to distribute them in proportion to estimates of land users current contribution to the phosphorus load in the catchment. Because the number of permits issued is commensurate with avoiding eutrophication, the number of units issued to each land user will be less than their actual discharge. The announced allocation is used to increase the entitlement to import fertilizer so that all land users are able to discharge the same amount of phosphorus as in the past. Results from the research program are also used to establish nominal usage coefficients for soils, practices and fertilizers. Land users are now free to trade their permits.
- iv) As the setting of the announced allocation lies with the public agency monitoring water quality, the agency can then use this instrument to decrease imports of phosphorus into the catchment. Announced allocations may be reduced over time from the 'grandfathering' level of perhaps 200 per cent to the level of 100 per cent at which the benchmark concentration or water quality goals chosen by the catchment community is achieved. The rate of decrease of the announced allocation may be sufficiently slow as to allow structural adjustments and technological changes to take place without social dislocation. As the announced allocation is reduced scarcity in discharge rights will emerge, reflecting the scarcity in waterway assimilative capacity. Since land users may well adopt phosphorus conserving strategies as scarcity emerges a mechanism must exist which allows land users to re-negotiate their usage coefficient with the managing agency.

The outlines of a market in phosphate discharge have been sketched here. In principle, such a market could be implemented, and in fact this has been achieved, though in a simpler form, in the catchment of the Dillon Reservoir in Colorado (Hahn 1989).

Discussion and Conclusions

At a practical level, the ecosystem-coupled market has a number of attractive features, including:

- minimal research and monitoring by the managing agency⁶ ;
- incentives to improve the agronomic efficiency of nutrient use;
- incentives for private sector investment in monitoring of phosphate discharge;
- incentives for industries that fix stream water phosphates in biomass and export it from the catchment, and
- opportunities for conservationists to fund further improvements in water quality by purchasing and retiring permits.

It is important to note that, from the perspective of hierarchy theory and ecosystem dynamics, the merit of the ecosystem-coupled market lies not so much in its allocative efficiency as in its adaptability to ecosystem constraints through the establishment of a dynamic link between economic and ecological holons and, most importantly, its concordance with the spatio-temporal scale of the problem being addressed.

To be successful, the link between the economic and ecological holons has to reflect the constraints originating in the higher order dynamics of the catchment community (ecological and economic holons). As Emery and Trist pointed out, the shared values that are essential to survival in the turbulent field must 'gain their authority from reference to the requirements of the larger system'. Considerable caution is necessary, however, in moving to any practical implementation of policy instruments that are justified by reference to the requirements of higher order dynamics. As Pepper (1984) has pointed out with examples from nuclear and economic debates, the success of vested interests in the dialectic accompanying policy choice is often achieved by establishing a false legitimacy based on scientific appeals to 'imperatives' or 'universal laws' that are in fact

⁶Compare for example the requirements for adaptive management of fish stocks (Walters 1986).

only valid within the narrow observation set of a particular discipline like nuclear engineering or macroeconomics.

The example of an ecosystem-coupled market described above is suggestive of a more general principle that has considerable implication for environmental policy making in systems where many components may be behaving chaotically. The Newtonian reductionist metaphysical tradition, which underpins most sciences, is based on the premise that the more that is known about the past behaviour of the components of a system, and the greater the number of components that the system can be reduced to, the better will predictions be able to be made of its future behaviour. This clearly does not hold for chaotic behaviour. Reductionist approaches will yield explanation for past behaviour, but cannot, within the practicalities of measurement, predict future behaviour (Wilson *et al.* 1991). Prediction may only be achieved where the system is hierarchly organised and nearly-decomposable.

There is, however, no guarantee that the level in the hierarchy that can be decomposed to a tractable small-number problem is meaningful at the human spatio-temporal scale of observation. We suggest that the current concern with 'sustainability' marks the early stages of relating what is observable at the human spatio-temporal scale to the higher order dynamics of interacting economies and ecosystems. If the sciences that inform policy intend to respond to these concerns, they will first have to critically appraise whether or not a substantive response can be made within existing paradigms (Batie 1989; Callicott 1990; Beus & Dunlap 1990; Norgaard 1991).

Finally, it is necessary to emphasise that the decomposition into ecological and economic holons that has been employed in this paper is a naive, tangible structuring for the purposes of exposition. A more rigorous structuring based on process rates might reveal, for example, that holons are comprised of entities that are mixtures of frequently interacting economic and ecological components, mixtures that remain unidentified in our current observation set.

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