ESTABLISHING MARKETS IN WATER RESOURCES

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Introduction

A need to develop improved mechanisms for allocating water resources amongst competing claims has resulted in an increased interest on the part of public agencies in market based approaches to resource allocation. While markets possess many desirable features as mechanisms for routinely resolving conflicting claims to resources, the feasibility of developing markets in water resources in particular, and renewable resources generally, is a matter that warrants careful consideration.

Markets enable the resolution of conflicting claims to resources by providing a formal mechanism for the exchange of property rights in those resources. The institution of a market requires then, the prior delineation of property rights. While the creation of proprty rights in water resources has recieved a deal of attention, much of that attention has focussed on the attenuation of property rights and the associated inefficiencies that attenuation entails (Musgrave 1991). Yet, as Bromley (1982a) and others have pointed out the creation of property rights involves a redistribution of current wealth and a redistribution of access to future income streams. Hence, the institution of markets in water resources involves the redistribution of current and future income.

The institution of property rights and the operation of markets in water resources may also alter the mix of resources available in riverine ecosystems. Given that ecosystems are complex and dynamic but are imperfectly, if not poorly, understood and that variations in the coupling of economic activity to an ecosystem will generate different emergent properties in that ecosystem, then the creation of property rights and markets may induce changes in the dynamic behaviour of ecosystems, in their emergent properties, and in the mix of resources available from them.

Given that the creation of property rights and the institution of markets in water resources will influence the portfolio of riverine resources available to society, and that the rights structure will also influence the access

of individuals to that portfolio and the distribution of wealth within society, then a framework is required which enables choices to be made between alternative market and rights structures. In this paper, one aspect of this framework, to do with the creation of rights and the emergent properties of ecosystems, is addressed.

Ecosystems as hierarchical systems

Ecosystems, such as riverine systems, may be concieved as being composed of 'nearly decomposable' hierarchies of systems (Simon 1973). In such hierarchies the dynamic behaviour of systems which constitute one level of the hierarchy are only weakly linked to the dynamic behaviours of systems at levels above and below it. For any given level in the hierarchy, that is, any given time scale for observation, the motion of the systems in the level beneath is so rapid that they appear to be in equilibrium. The motion of the systems in the next level up appear to be so slow that they will be unobservable and so these systems will appear to be fixed. Only those systems with a frequency of motion corresponding to the time scale selected will exhibit observable dynamic behaviours (see Figure 1). Note that these observable dynamics will be nearly independent of the detailed behaviours of the systems lower in the hierarchy, that is, the sub-systems of the systems of interest. Consequently, a theory of the dynamic behaviour of the systems that can be observed can be constructed in ignorance of the detailed structure at the next level down, and ignore the very slow interactions at the next level up (Simon 1973).

In a hierarchical ordering of systems or holons (Koestler 1967, O'Neill *et al.* 1986) the dynamic behaviour of holons at any one level depends, by first order approximation, on the behaviour of the other holons at that level, the nearly fixed values of the slow moving interactions between holons (which constitute the higher order holon at the next level up), and the equilibrium values of the fast moving lower order holons below. This vertical decomposition of systems permits stable assemblies to be constructed whose dynamic behaviour is irrelevant to the construction of larger structures. Only the equilibrium values of these stable assemblies influences the behaviour of larger structures.

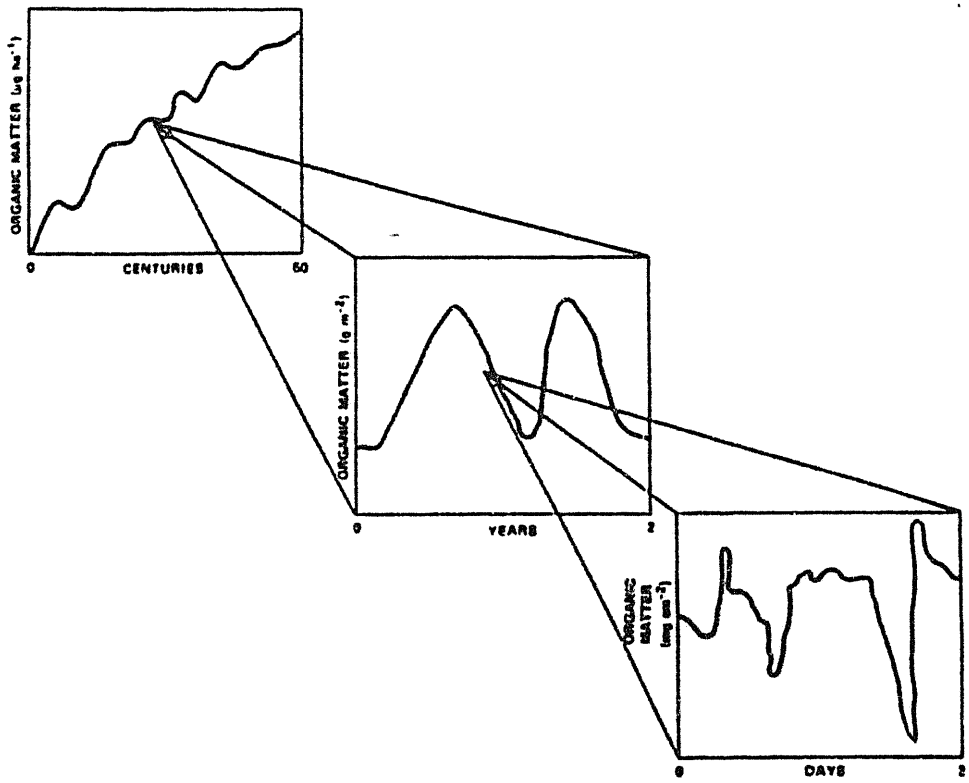

Figure 1
Changes in apparent dynamics of a litter-soil system with a change in time and space scales. Slow dynamics over centuries show accumulation of organic matter with oscillations due to succession. On a scale of years, seasonal decomposition processes are apparent, while an observation window of days reveals rapid fluctuations in litter due to wind and arthropods.

Source: O'Neill *et al.* (1986).

In addition to the vertical segregation of systems on the basis of the frequencies that characterise their dynamic behaviour, systems at the same heirarchic level may also be differentiated. Given that the dynamic behaviours that are observed at a particular level in the heirarchy represent the dynamic interactions between the set of holons which occupy the next level down in the hierarchy, then the frequencies of motion that define that lower level can be assigned to the particular holons with which they are associated. In other words, if the higher level interactions of the nearly decomposable system are ignored then the sub-systems at the next lower level in the hierarchy may be treated as being completely decoupled from each other. In other words, each system or holon at a particular level in the hierarchy is treated as being only 'loosely coupled' to the nieghbouring systems or holons at that level (Ashby 1960).

This loose horizontal coupling permits the internal dynamics of each holon to operate independently of the detail of the internal behaviour of the other holons at that level (Simon 1973:16). Given then that the internal dynamics of a holon is almost irrelevant to the behaviour of other holons, then the internal dynamics of holons can be changed without affecting the larger aspects of system behaviour provided that the equilibruim values of the changed holons are not altered and that the inputs into these holons remain unchanged. Hence, while the internal dynamics of a holon may change, provided the change in behaviour generates similar equilibrium values and requires no change in the inputs to the holon (that is, the equilibria of the holons at the next level down may remain the same) then the dynamic behaviour of the holon is 'functionally equivalent' from a system perspective (Simon 1973:16).

The characterisation of ecosystems in terms of hierarchies that has been suggested here provides a convenient conceptual framework, admittedly only partly developed here, which can be employed to address some aspects of the management of economic intervention in ecosystems. As already described, the dynamic behaviour of a holon at some level in the hierarchy depends on the equilibrium values of the holons at the level below and the essentially fixed parameters at the level above. Consider the consequences of altering the internal dynamics of a holon such that the equilibrium values of system variables associated with that holon are altered. While this may have no direct impact on the internal dynamics of the other loosely coupled holons at the same level in the hierarchy, the change in

equilibrium will alter the interactions between holons at the system level leading to novel emergent properties.

Grobstein (1973:41) characterises an emergent property as a property arising from the transformation of a relationship by the action of context. Prior to the transformation the property is not present. Following the transformation, which is initiated by a specific context, the emergent property appears. Note that the appearance of the emergent property is context dependent, different emergent properties may arise when the relationship of interest is placed within different contexts.

The appearance of algal blooms in river systems may be interpreted as a new emergent property resulting from a change in the context within which the relationships describing the population dynamics of algae operate. The application of artificial fertilizers to farm land, together with land clearing activities, has the effect of raising the rate of phoshate discharges into riverine systems. In the context of increased phosphate inputs the dynamics of aquatic ecosystems may be transformed such that rapid increases and decreases occur in algal populations (Reeve and Kaine 1992). This behaviour may be regarded as an emergent property. Similarly, the incidence of land salination could be, at least loosely speaking, be regarded as an emergent property of a change in the dynamic characteristics at equilibrium of hydrologic systems brought about by land clearance and irrigation.

Hence, changes in the equilibrium values or properties of sub-systems may generate changes in the observed dynamic behaviour of the system and provoke new emergent properties. Eventually this change in the dynamic behaviour of the system will influence the dynamic behaviours of the other sub-systems and may provoke changed equilibria in those sub-systems. Ultimately, since these equilibria also influence the dynamics of the system, the equilibrium behaviour of the system may change, which will provoke changes at even higher levels in the hierachy. If at least some of the relationships within systems are non-linear and hysteretic then dynamic behaviours which are catastrophic and chaotic may emerge. Note that even though the sub-systems may be only loosely connected, the system as a whole may well present chaotic behaviour in attempting to reach a terminal state (Ashby 1960).

This brief description the way in which a change in one part of the structure of a hierarchy of systems may introduce complex changes throughout the hierarchy provides captures the flavour of the potential of economic activity to alter the behaviour of ecosystems and, in doing so, to provoke novel emergent properties which are not apparent in the initial state of the heirarchy. Given limited knowledge about the dynamics of systems at each level in the hierarchy, and the hierarchy itself for that matter, then the impact of economic activity on the dynamic behaviour of systems in the hierarchy and the emergent properties associated with changes in the equilibria of systems will be unpredictable. Consequently there will be extreme or gross uncertainty as to the impacts of economic activity on ecosystems. In essence, economic organisations will be operating in a turbulent field (Emery and Trist 1969).

Ecosystems as turbulent fields

Emery and Trist (1969) describe a causal typology of organisational environments and infer principles governing appropriate organisational behaviour in each of these environments. One of the environments they describe is termed the 'turbulent field'. This environment is characterised by extreme uncertainty as to the consequences of actions that organisations might contemplate. In the turbulent field actions taken by organisations trigger events that lead off in ways that are increasingly unpredictable. The impacts of actions do not necessarily decline with distance, but may be amplified beyond all expectations at some point (Emery and Trist 1969:249).

The extreme unpredictability that characterises the turbulent field, as conceptualised by Emery and Trist, is the product of the increasing scale, complexity and degree of interaction of organisations. Actions undertaken by these organisations can initiate unintended changes in the relationship between organisations and between organisations and the environment by unwittingly provoking changes in relationships within the environment itself.

The parallels in the nature of the relationships between organisations in this type of environment and between organisations and the physical environment as portrayed above is apparent. The increasing scale and complexity of the interactions between groups of organisations and ecosystems disturbs the behaviour of systems throughout the hierarchy of

systems that make up the latter, provoking changes within the hierarchy and the unanticipated appearance of emergent properties. These newly emergent properties may well, in turn, introduce interactions between organisations which previously appeared to be unconnected.

An organisation in a turbulent field cannot successfully adapt simply through its' own actions. The inherent unpredictability of the outcomes arising from the actions of an organisation implies that 'set' beliefs cannot be formulated and consequently 'chance' beliefs cannot be formulated with respect to the set of outcomes (Wright 1983). Emery and Trist (1965:252) argue that to cope with persistent areas of uncertainty 'values that have overriding significance for all members of the field' must emerge. These commonly shared social values, which may take the form of ethical codes, socially sanctioned rights or claims, or categorical rules, simplify the environment from the perspective of individual organisations. The actions that organisations may take are circumscribed by these shared values and the relevance or otherwise of unpredictable and unintended consequences of these sanctioned actions is defined by these values.

The effectiveness of these shared values will depend on the degree to which they adequately represent environmental requirements and the extent to which they encapsulate goals which will lead to the convergence of the interests of all parties. In the context considered in this paper shared values need to be formulated which enable either areas of gross uncertainty concerning the ecosystem to be avoided, or defines a set of socially sanctioned actions that relieves organisations of responsibility for the unintended consequences of that set of actions. If such values are to be effective they must, of course, be formulated with due regard to the hierarchical structure of riverine ecosystems.

Returning to the characterisation of ecosystems as hierarchical structures of systems, a shared value which may provide an effective means of promoting the avoidance, or more precisely, the creation of areas of gross uncertainty would concern estabilishing mechanisms which generate functional equivalence in altered systems. As described earlier, when the dynamic behaviour of a system in the hierarchy is altered such that the equilibria of the system are changed, the change in the equilibria provokes changes in the behaviour of other systems in the hierarchy generating new emergent properties. If the behaviour of the system which was initially altered can be suitably modified such that the original equilibria are restored,

then the original behaviour of other systems in the hierarchy may also be restored and the new emergent properties may, in time, be eliminated.

Estabilishing functional equivalence

Following Coase (1968) the ownership and use of factors of production may be concieved of as the exercise of rights to undertake particular actions, or to prevent others from undertaking other actions. Hence, the economic activities of individuals or organisations may be conceptualised as the exercise of rights or claims which are defined by a constellation of contracts. When, in the course of exercising these rights, the economic activities of an organisation has impacts on the rights of others for which here are no contracts, then externalities occur (Bromley 1982a). When the exercise of a particular right conflicts with the rights of others, and no avenues exist for those others to seek redress or compensation for their loss, then the exercise of that particular right constitutes a privilege (Bromley 1982b).

The use of riverine resources by individuals and organisations may be characterised then, as the exercise of rights to appropriate those resources, thereby intervening in the functioning of riverine ecosystems. When these appropriations and interventions occur on a sufficient scale, the the dynamic behaviour of that system can be disrupted. The consequent alteration in the equilibrium behaviour of that system will, as described previously, provoke changes in the behaviour of other systems in the hierarchy leading to novel emergent properties.

To the degree that the emergent properties introduce interactions between organisations which previously appeared to be unrelated, in the sense that an emergent property entails a diminishment of the rights of others, then that emergent property is an externality. The exercise of rights to appropriate resources may now be interpreted as incorporating the right to alter the emergent properties of the riverine ecosystem. If the characterisation of the hierarchical system as a turbulent field is correct, then the consequences of sanctioning such rights is unpredictable. Hence, the exercise of rights to appropriate the resources of riverine ecosystems need to be limited in such a way that systems in the hierarchy remain functionally equivalent. By constraining appropriations such that systems in the hierarchy are functionally equivalent the consequences of the economic behaviour of individuals and organisations will be contained within

boundaries that are, at least relatively speaking, well understood and reasonably predictable. In effect, the exercise of claims to riverine resources are restricted to that which can be accomodated within the apparent dynamics of the ecosystem.

Just as the rationale for attempting to estabilish functional equivalence in systems is provided by the uncertainty, that is the lack of information, concerning the nature of the interactions between holons and the emergent properties of these interactions, this lack of information also provides a justification for attempting to estabilish functional equivalence by restricting appropriation rights. The informational requirements for identifying the restrictions on rights that are necessary are likely to be small, relatively speaking. Detailed knowledge of the other holons in the hierarchy is unnecessary. Only information as to the appropriations that are relevant to the emergent property is required. Clearly, this information entails the accumulation of some knowledge regarding the relationship between the emergent behaviour and the relevant appropriations. However, given that the functional impairment of the holon is probably diagnosed on the basis of the appearance of novel emergent properties, then the task of identifying the relevant appropriations becomes somewhat simpler. Particularly detailed knowledge concerning the nature of the relationship between appropriations and the emergent property may be unnecessary if adaptive mechanisms are used to limit appropriations (see Reeve and Kaine 1992, Reeve and Kaine 1991, Kaine *et al.* 1991). A substantially greater body of knowledge may be required to reconfigure or modify the relationships within the holon in order to achieve functional equivalence.

Restricting rights to appropriate the resources of riverine ecosystems will result in functional equivalence provided the mechanism employed to limit appropriation, and thereby modify the behaviour of the holon, is sensitive to the appearance of the emergent property of interest. Given that the behaviour of the holon is dynamic, then restrictions on appropriations may need to be responsive to that dynamic. Hence, a desirable property of the distributive mechanism used to allocate the appropriation rights that are available between competing uses, is that it reflect changes in the relative scarcity of rights. Provided then that property rights in riverine resources can be defined in such a way that they are sensitive to the appearance of the emergent property, then markets may be estabilished to allocate the available rights amongst competing uses. For example, Kaine *et al.* (1991) describe a market in accession rights to aquifers where the volume of rights depends on

movements in the water-table. They also describe a market in rights to discharge saline waste in rivers. The volume of rights in this market varies over time in accord with variations in riverine salt concentrations. Similarly, Reeve and Kaine (1991) describe a market in phosphate discharges where discharge rights are limited on the basis of aquatic phosphate concentrations in streamwater.

Discussion

The conceptualisation of a riverine ecosystem as a hierarchical system, about which only a limited amount of information has been collected, leads to the conclusion that rights to appropriate riverine resources need to be restricted should the exercise of those rights result in novel emergent properties. Such restrictions may be interpreted as limiting the choice domain within which individuals and organisations conduct economic activity such that externalities entailed in novel emergent properties are avoided (see Bromley 1982a:840).

The right to appropriate riverine resources is, given the conceptualisation presented here, always contingent and not absolute. As noted earlier, the functional impairment of a holon may not be apparent until a novel emergent property appears, and the implications for the behaviour of the remainder of the ecosystem hierarchy of this new property are probably unpredictable. Consequently, the right to appropriate riverine resources must be regarded as contingent upon the absence of novel emergent properties. Clearly, the exercise of rights to riverine resources may, over time, generate a number of novel emergent properties. Hence, a number of restrictions may come to govern rights to riverine resources. This adaptive and evolutionary view of rights accords with Boer's (1990) observations regarding the formalisation of rights within legal systems.

A key implication of characterising riverine ecosystems as complex hierarchical structures which exhibit the characteristics of turbulent fields is that the principles of expected utility and and the marginal principles of economics may play only a limited role in informing social choice. As Ashby (1960) has shown, while a poorly joined set of sub-systems that has been disturbed will proceed toward a stable terminal state, the process of adaptation may well appear random and chaotic. Furthermore, knowledge of the interaction between sub-systems prior to the disturbance may provide

little or no information as to the nature of the interactions between the sub-systems following the disturbance. Hence,the behaviour of the riverine ecosystem, once disturbed, may well be characterised as a completely stochastic process. The time path of outcomes and the terminal stable state are so unpredictable that attempts to employ expected utility theory will be invalid. Similarly , the information that is available is unlikely to be sufficient to allow the calculation, a priori, of optimal trade-offs, nor to control outcomes by modifying the behaviour of individuals or organisations through the imposition of 'optimal' rates of taxes or subsidies.

The characterisation of riverine ecosystems as a hierarchy of loosely connected systems does not mean that by attempting to generate functional equivalence unpredictable consequences will not ensue from the interactions between ecosystems and the economic system. The scale at which interventions occur in the ecosystem would indicate that interactions between systems throughout the hierarchy have already been disrupted. Furthermore, even in a pristine state the hierarchy is unlikely to be a static structure. This suggests that the concept of functional equivalence has, itself, only a limited relevance in that ecosystems are probably already in a process of adaptation as a result of past disturbances. However, as Schutzenberger (1954) has argued the optimal strategy in a stochastic environment is the simple tactic of seeking purely local solutions.

Conclusion

In this paper an attempt has been made to outline a conceptual framework within which the management of riverine ecosystems might be analysed. Ecosystems were characterised as complex hierarchical structures composed of progessively higher order interactions. The disruption of the stable behaviour of a system at one level in the hierarchy disturbs higher order interactions between systems resulting in novel emergent properties. Such properties may be eliminated by modifying the disrupted system such that functional equivalence is obtained.

The inherent unpredictability of the consequences of disrupting the stability of a system at some level in the hierarchy lead to the view that the relationship between economic activity and ecosystems could be described as a turbulent field. The management of such a field requires the formulation of shared values by the individuals and organisations that form part of the

field. The purpose of these shared values is to impose limits on behaviour such that actions which entail gross uncertainties are avoided.

To be effective these values must reflect the requirements of the environment. In the context considered here, these requirements were interpreted as estabilishing functional equivalence so as to avoid provoking unpredictable changes in riverine ecosystems. Meeting this requirement involved restricting rights to riverine resources by linking property rights in those resources to the appearance of novel emergent properties. This enabled markets in those rights to function as allocative mechanisms while limiting access to the resources to a level that can be accomodated within the apparent dynamics of the ecosystem.

References

Ashby W.R. 1960. *Design for a Brain.* Wiley 2nd. Ed.

Boer, B. 1990. 'Some legal and ethical issues' in Boer, B. and James, D. *Property Rights and Environment Protection.* Environment Institute of Australia, Inc.

Bromley D. W. 1982a. 'Land and Water Problems: An Institutional Perspective'. *American Journal of Agricultural Economics.* 64(5):834-844.

Bromley D. W. 1982b. 'The rights of society versus the rights of land owners and operators'. in Halcrow H.G., Heady E.O. and Cotner M.L. (eds) *Soil Conservation Policies, Institutions and Incentives.,* Soil Conservation Society of America, Ankery, Iowa.

Coase, R. 1960. 'The problem of social cost '. *Journal of Law and Economics.* October 1960:1-44.

Emery, F.E. and Trist, E.L. 1969. 'The causal texture of organisational environments'. In: Emery, F.E. (ed.), *Systems thinking.* Penguin, Harmondsworth, UK, pp. 241-257.

Grobstein, C. 1973. 'Hierarchical order and neogenesis', in Hattee, J. (ed.) *Hierarchy Theory: The challenge of complex systems.* Doubleday, New York.

Kaine, G., Musgrave, W., Burton, J. and Bryant, M. 1991. 'Towards introducing markets for riverine resources'. Paper presented to the *Third Annual Ministerial Water Forum,* July, Sydney.

Koestler, A. 1968. 'Beyond atomism and holism—the concept of the holon'. In: Roestler, A. and Smythies, J.R. (eds.), *Beyond reductionism*. Hutchinson, London. pp.192-232.

Musgrave, W. 1991. 'Environmental and resource management: Exploring some new approaches'. Paper presented to the *Conference on New Environmentalism*, NSW Cabinet Office, Sydney, March.

O'Neill, R.V., De Angelis, D.L., Waide, J.B. and Allen, T.F.H. 1986. *A hierarchical concept of ecosystems*. Princeton University Press, Princeton, New Jersey.

Reeve, I. and Kaine, G. 1991 (in press). 'Ecosystem-coupled markets: a policy approach for sustainable land management'. Proceedings of *Int. Conf. on Sustainable Land Management*. International College of the Pacific, Palmerston North, NZ.

Reeve, I. and Kaine, G. 1992. 'A market approach to sustainable land management'. Contributed paper presented to the *36th Annual Conference of the Australian Agricultural Economics Society*, Canberra, February.

Shutzenberger, M.P. 1954. 'A tentative classification of goal-seeking behaviours'. *Journal of Mental Science*, Vol. 100:97-102.

Simon, H.A. 1973. 'The organisation of complex systems'. In: Pattee, H.H. (ed.), *Hierarchy theory*. George Braziller, New York, pp. 1-28.

Wright, V. 1983. 'Some bounds to the relevance of decision theory'. *Australian Journal of Agricultural Economics*, 27(3):221-230.