Landscape Sensitivity, Resilience and Sustainable Watershed Management: A Co-evolutionary Perspective

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Introduction

The conservation, and future sustainability of vulnerable fluvio-coastal environments, along with the need for viable planning criteria and policy instruments for their long-term management, are some of the central issues at the heart of the contemporary environmental discourse[1]. For example, in the Mediterranean, coastal, riverine and wetland areas are subject to increasing and unprecedented changes, as a consequence of human-induced processes, such as industrial activities, commercial harbour construction, land reclamation, drainage, canal construction and growing urban encroachments (Falkenmark and Lindh 1993; Breton 1996; Breton *et al*. 1996). But perhaps the single most important threat to sustainability is to be seen in the effects of a rapidly expanding tourist sector, along with its attendant hotel and service industries and their ever-growing demands for water – something particularly acute in semi-arid regions of Spain (Breton and Sauri 1997). What is most worrying about such a situation and one that has largely developed over the last 40 years, is that historically such developments have frequently occurred in the absence of adequate planning and environmental controls. Indeed, in many cases, land-use planning has been short-termist, and decisions have been retro-active; that is, they have been concerned with 'sticking plaster' or coping solutions, rather than the implementation of long-term adaptive management strategies. An inevitable consequence of this tradition of *ad hoc* policy-making – and particularly the encouragement of mass tourist developments - has been the dramatic increase in pollution, soil erosion, pressure on water consumption and general degradation of the environment including its cultural and natural heritage (Pearson and Sullivan 1995;McGlade 2001a).

Indeed, in the semi-arid areas of the Mediterranean, particularly in the Middle East and Spain, water is even more of a critical commodity because of the extreme variations in rainfall and the ever-present threat of drought. Consequently there is a constant danger of conflict in river catchments and coastal regions where water supply and use is contested (Bulloch and Darwish 1993; Smith 1997). One of the most significant responses to this situation is to be seen in attempts to encourage the construction of integrated approaches to coastal zone and river basin management. These have stressed the need for coherent planning methods and cross-disciplinary approaches to data acquisition[2]. On the other hand, while much work has been devoted to the development of legislation and policy instruments within existing integrated coastal zone management schemes, nonetheless, they are often ineffective due to the lack of co-ordination between the various actors and institutions and their often conflicting world views. Moreover, the much-voiced support for cross-disciplinary cooperation is frequently not matched by practical action.

Perhaps the most significant barrier to addressing these issues stems from a lack of holistic thinking at governmental and managerial levels. In essence, this is due to a low-level understanding of the nature of complexity and the nonlinear connectivities that structure socio-natural systems; for example, solutions are often sought in large-scale decision-support systems models that generally are ill equipped to account for the levels of complexity involved, especially the array of power structures and counter-intuitive behaviours displayed by socio-political organizations, and/or the vested interests of individuals. In particular, there are frequently fundamental conflicts between those stakeholders focused on political and economic concepts of growth and others committed to approaches favouring conservation, the maintenance of biodiversity and local scale interventionist strategies. Significantly, these conflicts operate at local, regional, national and European scales and reflect fundamental differences in perception and value systems. Thus a crucial issue, for any conception of sustainable management, is the need to understand the socio-environmental driving forces of change at different spatio-temporal scales. What this means is an ability to assess the resilience of socio-natural landscapes to a variety of human and naturally induced pressures - effectively, developing an understanding of the variable sensitivities of ecological, economic and socio-cultural processes, so as to anticipate likely future outcomes and possible unforeseen evolutionary trajectories.

I address these issues by taking a critical look at the theoretical basis within which current research on socio-natural systems is undertaken, with specific relation to the current *AQUADAPT* initiative and its focus on river catchment systems. Specifically I shall focus on the relationships between resilience (as a manifestation of sustainability) and the notion of 'landscape sensitivity', assessing its potential usefulness as a theoretical construct that might contribute to a better understanding of watershed dynamics, in climatically marginal environments.

The Dimensions of Sustainability

Since it is impossible to separate landscape sensitivity issues from their wider context within the general sustainability discourse, we shall begin by examining the nature of sustainability as it impinges on our discussion.

At the heart of the AQUADAPT programme is the desire to contribute new insights into the nature of sustainability within the contested area defined by multi-stakeholder watersheds. This means that we are seeking a rapprochement between a wide spectrum of views and value systems that define the actions of scientists, managers, politicians, farmers and urban communities. Renewable resources, sustainable economic development, employment security, conservation of the cultural landscape, these are all voiced as preferred desires – and in some cases, demands. Their coexistence, however, is problematic and as we shall see later, requires carefully negotiated solutions.

It is something of a paradox that despite the wide coverage and prominence of the theme, 'sustainability' yet remains an exceedingly ambiguous term, occupying a territory in which it appears to be 'all things to all people'. Any survey of the literature necessarily must conclude that sustainability is best described as having an 'elastic' meaning, eminently malleable and infinitely variable in usage. Thus it can be invoked to support a variety of positions depending, for example, on our valuation of natural and man-made capital (e.g. Daly 1994; Faucheux and O'Connor 1998).

Sustainability: some problems

Broadly speaking, and with respect to ideas of sustainable development promoted by the *World Conservation Strategy*, sustainability should meet basic human needs while maintaining the basic life support systems along with ecological diversity (IUCN/UNEP/WWF 1980). As is well known the real popularisation of these concepts was the result of the document produced by the *World Commission on Environment and Development*, from which derives the classic definition of sustainable development as: "development that meets the needs of the present without compromising the ability of future generations to meet their needs" (WCED 1987: 8).

Most important, such a definition presages a shift towards putting decision-making into the hands of local communities, as opposed to national and/or supra-national bodies. Thus the idea of 'sustainable futures' such as it has any meaning, is inextricably related to a decentralization of power so individual localities assume responsibility for the management of their resources – a point later enshrined as Local Agenda 21 at the Rio summit. Importantly, such a structure is not meant as a replacement for management at supra-regional or national scales, rather it suggests the need for more local interventionist methods in landscape planning, as an important aspect of community well-being, for the health of the ecosystem and the maintenance of biodiversity.

These are bold ideas and it needs to be said that they have so far failed to be implemented to any satisfactory degree. In fact these ideas, which are central to any restructuring of human-environment issues, have effectively been marginalised; the debate has been hijacked by the search for rigorous quantifiable criteria, to cater for a scientific agenda which needs 'answers'. For example, the growing sub-fields of ecological economics and environmental impact assessment have sought to determine appropriate economic values for the natural world; *ergo* each object of nature - be it tree, river, mountain, coastal zone etc. has a potential dollar value which can be discounted against its exploitation or harvest. The utilitarian philosophy which underpins these approaches dominates the sustainability discourse, while issues of ethics and responsibility are secondary concerns - relegated as epiphenomena with respect to the more central quantitative concerns of predictive science and the pursuit of 'solutions' and 'answers'.

Within such a model, the worlds of agency, of communicative action, of values and intentionality are set aside from many environmental debates for they belong to the non-quantifiable realms of human experience. This 'life-world' with its messy ambiguities, irrational decision criteria and contingent histories is, for example, frequently relegated by model builders – even becoming parameterised in some models as a species of 'noise'. However, the omission of discussion on the moral and ethical basis of human-environmental problems can only succeed in further promoting a scientistic and technocratic discourse - one which believes that pollution, land degradation, coastal development etc. can be problematised within the conventional deductive methods of science, or rendered as a species of game theory with optimal solutions.

Before all else, problematising sustainability requires an acknowledgment that it is fundamentally about people; i.e. the capacity of social groups, not simply to survive, but to perpetuate themselves under conditions of food security and adequate welfare provision. This is pre-eminently a moral imperative that cuts across the neatly assembled packets of scientific knowledge and their instrumentalist projections within large-scale complex models.

Towards a working definition

While the search for a comprehensive definition of sustainability is destined to remain elusive, what is clear, however, is that an important distinction must be made, as to which kind of sustainability we are dealing with – be it environmental, economic or social – since each has a distinctive meaning as well as being relative to a specific spatio-temporal domain.

But beyond the terminological confusion and slack usage, there are more fundamental problems which need to be addressed if we are ever to consider incorporating sustainability as an important and potentially useful tool in the *AQUADAPT* project objectives. For example, with respect to watershed management issues, regardless of whether we are discussing resources, economies or societal systems, we must address a number of basic contextual questions:

- ***sustainable watersheds for whom?***

  It matters a great deal whether our target audience is regional water authorities, government agencies, industrialists, local communities, or indeed the individual farmer. The wide spectrum of interests, values and philosophies represented by these stakeholders demonstrates the futility of generalisation. Moreover, the ability to wield power (i.e. Who controls the water? Who owns the land?) has an important effect on which definition of sustainability will ultimately prevail.

- ***sustainable watersheds over what time period?***

  When speaking about a particular water resource, policy or type of socio-economic structure, the time span over which sustainability is envisaged is a critical factor – it matters a great deal whether we are talking about months, years, decades, or centuries.

- ***sustainable watersheds at what spatial scale?***

  In discussing ecological, social or economic processes, it needs to be established whether sustainability refers to geomorphological channel development, upstream, downstream or coastal delta regions. Within each of these levels are embedded local, regional and supra-regional vested interests identified by a variety of decision-making criteria – sustainability inevitably has a different meaning at each scalar level.

- ***sustainable watersheds for what purpose?***

  Political and economic organisations relative to different scales may achieve so-called sustainability, but at a cost to other humans; i.e. it may have significant ethical moral and welfare consequences for others. Whether water allocation policies preferentially favour tourism, commerce or agricultural needs, is ultimately related to policy decisions, which are themselves reflections of specific value systems and/or ideologies. In this sense, it is not the neutral category it is often portrayed as.

Thus, sustainability must not only be temporally and spatially defined, but most importantly, it must be contextualized with respect to specific political, ethical and social parameters. Unfortunately, as we have noted, the dominant model of western science within which the current sustainability discourse is situated, has meant that these contextual issues have been either poorly addressed, or relegated to secondary concerns.

Sustainability and historical knowledge

But there is another problem which needs to be addressed and that is the general *ahistorical* nature of the sustainability debate. If we are to learn anything of academic value about sustainability within the context of societal systems, then what is clear is that it must be studied from a *historical* perspective: people, institutions and the ecosystems they inhabit share one thing in common – they are all products of historical evolution. In a sense, the persistence of human societies is a consequence of their adaptive use of culture, which can be conceived as representing stocks of historically derived knowledge.

But this lack of historical perspective is best understood within the context of the dominant epistemology underpinning the current model of science. The contemporary debate within which sustainability is couched, is predicated on a model of knowledge that maintains a false separation between biophysical and societal phenomena – an expression of the erstwhile nature/culture dichotomy that has dominated western thought for centuries. While a number of integrated research programmes have attempted to tackle this problem – particularly in their critiques of reductionism and the poverty of neo-classical economics - little real progress has been made in recognising the need for a revised model of scientific enquiry, one which recognises the importance of establishing a dialogue between what have been perceived as mutually exclusive knowledge domains: *scientific* knowledge, *institutional* knowledge, *technical* knowledge and *local* knowledge (McGlade 2001b). What we are arguing is that real insight into the nature of complex socio-economic systems and their dynamics cannot be understood, unless we are prepared to inscribe a new research territory, one in which a variety of knowledge domains can co-habit. Such a framework must additionally recognise the primacy of historical processes – both determined and contingent – for an understanding of the nonlinear dynamics, which articulate socio-economic systems.

By contrast to this model of knowledge acquisition, contemporary scientific research practice seems to have an aversion to history and its lessons. Indeed as Tainter (1995) points out, it is curious that in our modern problem-solving world we do not seek to utilise the vast data resources represented by the reservoirs of historical experience and knowledge. Typically, most policy makers are only interested in the recent past in their search for precedents. In addition, conventional research strategies tend to recognise the systemic nature at the expense of the historical component. Thus, while we have a greater opportunity than at any previous time in our history to understand the role of long-term processes in the creation of contemporary problems, this opportunity is largely ignored.

Whether it is simply a question of arrogance and a belief in the superiority of our 21st century scientific reasoning is not clear. Nevertheless, what we are arguing here is that historical knowledge is not only important, but a pre-requisite for understanding the nature, current status and future evolutionary potential of complex socio-economic systems. Indeed, we might go further and claim that issues related to sustainability have no meaning if they are uncoupled from the larger long-term causalities of which they are an inevitable product. In short, history *matters*.

For example, with respect to the relationship between climate change and hydrology, Benito *et al*. (1996) have demonstrated the vital importance of understanding historical flood regimes as part of a long-term dynamic. Using historical data from the Iberian Peninsula, their analysis throws important light on the complex causalities linking hydrological responses to climate variability. Similarly, within the present *AQUADAPT* context and particularly its focus on semi-arid watersheds, there is a great deal of latent information resident in time-series data sets from the south-east of Spain, relating to long-term drought and precipitation trends. What these data demonstrate is the highly unpredictable nature of climatic phenomena and the existence of discontinuous 'phase changes' in precipitation patterns – circumstances that further complicate our understanding of hydrological regimes and their effects on land-use activities. Under such conditions of uncertainty, there is a real need to understand the vulnerability and sensitivity of landscapes to change.

Landscape sensitivity

The vulnerability of Euro-Mediterranean landscapes to change – and particularly their perceived sensitivity - has become a major research topic within the contemporary environment discourse. Paradoxically, while the term has wide usage (e.g. Thomas and Allison 1993), a survey of extant environmental literature suggests that landscape sensitivity is an elastic term that can be moulded to suit a variety of contexts spanning land use change, geomorophological evolution, ecological succession dynamics, and/or the assessment of tourist carrying capacity (Goudie 1986; Roberts 1989; Naveh and Lieberman 1990; Thomas and Allison 1993).

In fact, landscape sensitivity as it is conventionally found in various aspects of the environmental and geographic literature, has been conventionally associated with geo-biophysical phenomena. Thus, among the most common applications, are landscape assessments of geomorphic sensitivity – particularly in view of the wide spatial variation in the ability of landforms to incorporate change (Brunsden 1990). By contrast, another definition of sensitivity emphasises the ability of landscapes to resist change (Brunsden and Thornes 1977).

Conventional approaches seek to estimate the natural geomorphic sensitivity of landscapes and watersheds to a variety of land use activities (e.g. forestry, agriculture, urbanisation, tourism), which are characteristically viewed (and subsequently modelled) as 'disturbances'. In such studies, sensitivity analysis is designed to provide a quantifiable measure of the terrain's susceptibility to change (Turner and Gardner 1991; Loh and Hsieh 1995).

A key assumption here, is that landscapes can be classified in terms of their relative susceptibility to erosion, fire and landslide processes (perturbations), and therefore in their ability to cope with human imposed activities. This research orientation is, however, complicated by the fact that both hydrologic and geomorphic processes display wide variations in terms of their sensitivity to pollution generated by urban or industrial waste and/or the significant land use changes wrought by the growth of commercial and tourist construction projects. Nevertheless, predicting the probability of possible catastrophic change to river systems and flood regimes is a prominent research issue and this has led to the search for statistical indices of sensitivity, designed to help environmental managers with 'bottom line' scenarios from which they can anticipate future problems. Normally, GIS and Remote Sensing technologies are used in an effort to model the controls on soil erosion, vegetation growth, hillslope hydrology and water nutrient cycling. These studies are generally directed at evaluating potential land use change and include a variety of EC funded research programmes dealing with Mediterranean desertification (e.g. EFEDA, MEDALUS) and modelling landslides (NEWTECH). While these field-oriented, data-rich projects have been responsible for the collection of an important array of data sets on climate, soils, hydrological regimes and vegetation dynamics, as well as exploring functional responses of ecosystem variables, their *raison d'etre* has been that of physical measurement and prediction[13].

Beyond physical geography, perhaps one of the most common constructions of landscape sensitivity appears under the rubric of environmental impact assessment (EIA) and related methodologies used to assemble environmental inventories and audits (e.g. Canter 1996). Interaction matrices and checklists are common tools in these approaches and are used to generate quantitative estimates of the magnitude of potential impacts. Statistical summation of numerous attribute values forms the basis for insight into the future vulnerability and/or sustainability of the landscape (e.g. Canter 1979, 1986; ESCAP 1990).

These issues are particularly pertinent to fluvial systems and catchments generally. In fact, watersheds occupy a particular position with respect to issues of sensitivity, and this is most acute at the land/water interface in any catchment system. For example, the location of upstream activities such as agriculture and industrial processes means that river systems are constantly endangered by the threats posed by nitrates, as well as the variable water quality imposed by ground water pollution and changing urban/industrial and tourist demands. This has led some researchers to compute 'natural' watershed sensitivity as an estimation of a watershed's natural ability to absorb land use disturbance without unacceptably high level of impact (USDA, 1988).

However, the response of watersheds to disturbance events is in reality, complicated by the enormous variety of spatial and temporal ranges involved – spanning macro-scale climatic events all the way down to the micro-level dynamics of soil formation processes. In fact many watershed effects have characteristic substantial delays (often over years and decades) before their effects are manifest. Moreover, since the variables and turnover rates involved in river catchment evolution differ from one watershed to another, this mitigates against the construction of any generic model of watershed sensitivity (Newson 1992).

Missing from many of these studies of landscape and watershed sensitivity, is a conception of the importance of scale. Importantly, landscape sensitivity issues are inevitably related to the temporal and spatial scale under investigation, rendering any scalar aggregation problematic. For example, behavioural aspects of geomorphological systems may be regarded as sensitive at one spatio-temporal scale but not at another. Understanding sensitivity is also made more difficult if we focus primarily on statistical approaches. These produce static descriptions of what are essentially *dynamic* processes; thus they misrepresent the inherent instability and nonlinear interactions that are the defining aspects of all complex socio-natural systems.

But perhaps the real weakness of the models discussed above concerns the way that they are frequently decoupled from human societal processes and especially the politics of management[4]. These latter are usually seen as the preserve of the social sciences and effectively relegated as problem sets for other disciplines. Perhaps the most problematic aspect of these studies is that anthropogenic factors are seen as external to the system; thus human intervention is modelled in terms of 'impacts' or 'perturbations' on the system[5].

Landscape Sensitivity Mapping

Attempts to go beyond the limitations of purely biophysical[i] models have focused on technological advances provided by more sophisticated GIS and Remote Sensing technologies, and their ability to examine interactions between environmental, economic and social data sets (Arroyo-Bishop and Carlà 1997; Schneider and Bartl 1998). Additionally, the use of GIS systems has also enabled the assessment of potential impacts of land use strategies on the cultural landscape generally and specifically with reference to threatened heritage sites and monuments at a regional level (Palumbo and Powlesland 1997; Hill and Aspinall 1999). For example, McGlade *et al*. (1999)[6] developed an integrated Landscape Sensitivity Mapping System (LSM) to investigate the sensitivity of the cultural landscape to threats posed by the contested territorial claims of conservation, agriculture and tourism. This pilot study in the Emporda region of north-east Spain was concerned with isolating the primary drivers of change, with data sets partitioned into three analytical categories: 1) *ecological sensitivity measures*, 2) *economic sensitivity measures*, and 3) *socio-cultural sensitivity measures*. Spatially referenced data collected from these sectors were overlain to search for incompatibilities, discontinuities and correspondences based on a variety of different analytical criteria. The LSM system isolated and mapped the spatial distribution of key combinations of variables that act to create potentially vulnerable outcomes. Crucially, this methodology, was designed, not as an input/output system, focused on single answers – as with EIA and conventional landscape sensitivity methods – but rather, to promote a species of knowledge based system (KBS). The system was designed to act as a repository for different knowledge domains (environmental, economic, cultural) and to provide decision support material to help generate negotiated solutions to the contested issues that characterise multiple stakeholder landscapes.

Landscape sensitivity: some representational problems

Despite the continuing popularity of concepts such as 'sensitivity' and 'vulnerability' and, indeed, their centrality to environmental impact assessment programmes, they are basically inadequate as descriptors of complex socio-natural systems. A clear problem shared by most methodologies is the separation between the physical environment and what is perceived as a distinctive social and cultural environment.

However, it needs to be remembered that the physical environment has evolved in concert with (and as a product of) human action, forming a reciprocal socio-natural system (McGlade 1995, 1999a, 2001a). Thus, any approach to landscape sensitivity that focuses exclusively on the biophysical aspects of the system (e.g. climate, geomorphological processes, hydrology etc.) is seriously incomplete as a representation of the complexity of human-environment relations. The decoupling of the social and political underpinnings of the landscape to facilitate impact assessment checklists and quantitative model building, will only serve to generate fictive landscapes in which human action is ascribed the role of an *external* variable 'driving' the system, or 'impacting' on the environment. This commonly invoked model of humans as 'perturbations' casts them as somehow separate from the environment; resulting in spurious conceptualisations such as 'human impact'.

Ultimately, sensitivity is based on the potential and likely magnitude of change within the landscape system, as well as its ability to absorb perturbation. In short, the ‘sensitivity’ of a system to change induced by either biophysical or social phenomena is ultimately a function of its inherent *resilience*. Thus, what we shall argue is that attempts to understand sensitivity or vulnerability criteria through indices or other statistically derived criteria, will always be compromised. In essence, a more productive way forward is to situate such issues within an evolutionary framework, so as to focus on one of the key aspects of sustainable systems, i.e. their *resilience*.

Resilience and Sensitivity

Resilience

Despite its frequent usage by ecologists, economists and some social scientists, resilience is not a unitary concept with precise and unambiguous definition. In the ecological literature, for example, it has two distinct meanings. The first emphasises stability, control and constancy (*engineering resilience)* – attributes of a desire for optimal performance, while the second, by contrast, focuses on persistence, adaptedness and unpredictability (*ecological resilience*) – attributes of an evolutionary perspective. These latter are consistent with sustainability (Holling 1996). Research using a model of engineering resilience, deals with stability near an equilibrium state and is concerned with resistance to disturbance and speed of return to equilibrium (e.g. De Angelis *et al.* 1980; Pimm 1984; Tilman and Downing 1994). By contrast, ecological resilience focuses on conditions far from equilibrium and is concerned with the role of instabilities in pushing the system beyond a threshold or bifurcation point, to a new stability domain. Here, resilience is measured by the magnitude of disturbance that can be absorbed before the system changes structure (Holling 1973). A wide variety of applications exploring ecological resilience now exists, spanning resource ecology, wildlife management, fisheries, animal ecology and plant-vegetation dynamics (e.g. Holling 1986; Walker *et al*. 1981; Walters 1986; Sinclair *et al*. 1990; Dublin *et al*. 1990).

Studies such as these have been instrumental in shifting the ecological debate from an evolutionary model based on the maintenance of stability, to one dominated by a sequence of interacting adaptive cycles based on a developmental sequence defined by four functions: exploitation, conservation, release and re-organisation (Holling 1986). More recently, these ideas have been extended to encompass the idea of *panarchy*, which emphasises the evolutionary nature of nested adaptive cycles, with each level going through the cycle of growth, maturation, destruction and renewal (Gunderson *et al*. 1995). A key emphasis in this model is that periods of gradual growth and rapid transformation not only coexist, but act to complement one another (see also Günther and Folke 1993).

Resilience and societal systems

All socio-economic systems seen to persist – particularly over long time periods – can be described as being characteristically resilient, in the sense that they are able to *incorporate* change and perturbation without collapsing. This ability to absorb changing circumstances as defined by environmental, social, political or cultural fluctuations is itself a function both of the flexibility of structural organisation and system history. The role of history is of crucial importance, in the sense that a particular regime that has been exposed to regular, periodic disturbance, will be more adapted to periodic change than a system which is visited by perturbation and/or extreme events on an irregular basis.

Any loss of resilience, will move a particular socio-economic system closer to unstable thresholds, causing it to flip from one attractor state to another (metastability); thus, for example, exploitation to extinction of a particular resource will have an effect on the local ecosystem, inducing system transformation and an irreversible change to an alternative state. Resilience can be said to be one of the primary properties of nonlinear, nonequilibrium systems and needs to be understood more fully if we are to come to terms with sustainable social-natural systems .

A major problem that we are faced with in pursuit of a model of social-natural resilience within the context of watershed management, is that this cannot be deduced from conventional approaches to landscape sensitivity. However, neither can it be derived by the simple superimposition of Holling's (1986) resilience cycle for ecological dynamics. As we have already noted, this general theory of ecosystem function - incorporating insights from hierarchy theory (Allen and Starr 1982; O'Neill *et al.* 1986) - has been argued as an appropriate basis for understanding the generic evolutionary behaviour underpinning ecological, economic and societal dynamics (e.g. Gunderson *et al*. 1995; Berkes and Folke 1998; Peterson 2000).

Notwithstanding the important insights that this evolutionary model provides, its essentially 'organic' nature is an inappropriate model for capturing the complexity of societal systems. In fact this organic formulation is consistent with a long philosophical tradition. For example classical authors [7] as well as early Christian writers [8] emphasised the similarity between natural and societal dynamics, believing that societies could be understood by direct analogy with organisms, following a cycle of growth, maturity, senesence and death (Tainter 2000). Such ideas, implicit in the later work of historians such as Oswald Spengler (1918) and Arnold Toynbee (1962) held sway in the social sciences until the 1980s when their structural shortcomings, particularly the under-developed relationship between agency and structure, as well as their inherent evolutionism, were critiqued by a number of sociologists and anthropologists, most notably Anthony Giddens. Importantly, Giddens (1979, 1984) provides a robust argument against the idea that societies 'adapt' to anything, since they are not equivalent to biological organisms (1979: 21). Instead, social change is seen as non-teleological – a set of contingent, discontinuous transitions which have no inherent developmental logic or pattern. However, despite these caveats, an increasing number of environmental scientists, resource managers and ecologists continue to apply ecosystem resilience ideas to socio-economic systems (e.g. Gunderson *et al*. 1995; Peterson 2000).

An additional problem in utilising ecological resilience as an analogy for societal systems, is that human systems are not *neutral*; they are an historical product of specific social, political and cultural relations: a factor running all the way from local relations of production to larger scale regional, national and global levels of interaction. Thus, if we are to attempt to isolate the important driving forces of irreversible change which represent a non-sustainable option for society - then we must situate such goals within a milieu that recognises that, l) all landscapes (*sic* environment) are embedded in webs of power relations, and 2) these networks of power act to both enable and constrain human aspirations and desires. It is in the exercise of such power that the moral and ethical universe within which humans are situated, is subject to substantial modification and even destruction.

In summary, what we can say from the perspective of the *AQUADAPT* project, is that while resilience is a useful concept for understanding the long-term evolution of human-modified watersheds, it needs to be reconfigured to take account of the specific human and socio-political contexts that drive system transformation and change. In essence, we might summarise the main attributes of resilience from a socio-natural perspective as having the following characteristics:

- The amount of re-organisation and change a social system can undergo, while still retaining the basic institutional and socio-economic structures
- The degree to which the system's structure is capable of self-repair and self-organisation

This implies:

- Institutional flexibility
- The conscious use of historical knowledge
- The desire to increase the capacity for knowledge production and learning
- Conscious management of change to incorporate uncertainty and unintended consequences

The River Catchment as a Complex Evolutionary System

In pursuit of a viable model of catchment management, we have already situated our discussion within the wider context of the sustainability discourse and identified a number of caveats with respect to landscape sensitivity and resilience criteria. In what follows we shall now attempt to incorporate the important evolutionary attributes of a resilience perspective, for a better understanding of catchment systems viewed as nested sets of social, political, economic and environmental processes. Given the clear difficulties involved in such an enterprise, we shall begin logically by examining the primary attributes of a complexity perspective.

The nature of complexity

Recent years have seen the arrival of a new interdisciplinary approach to the analysis of complex, nonlinear systems and a gradual incorporation of these ideas into fields as far apart as chemistry, physics, ecology, urban and regional geography and the social sciences generally (Edmonds 1996; Byrne 1998). Complex systems are those systems "whose aggregate behaviour is both due to, and gives rise to, multi-scale structural and dynamical patterns which are not inferable from a system description that spans only a narrow window of resolution" (Parrott and Kok 2000).

As a new interdisciplinary field, Complexity Theory (Waldrop 1992, Kauffman 1993) is essentially concerned with studying the general attributes of nonlinear systems and exploring their propensity to follow unstable and chaotic trajectories (van der Leeuw and McGlade 1997). Beginning in the early 1990s, this perspective and its central ideas has moved beyond the natural sciences to penetrate the social sciences, where complexity has been viewed as having potentially profound consequences for conventional epistemologies (Hayles l991; Byrne l998; Johnson 2001).

Despite the diversity apparent in the complexity literature, there are however a number of key features that seem to be resident in all complex systems and are of central relevance to understanding the behaviour of river catchment systems. Among these are:temporal and spatial self-organisation, emergence, adaptivity, and critical levels of connectivity (Parrott and Kok 2000). What we shall argue here is that a complexity perspective provides an appropriate context within which watershed dynamics - as a species of complex system - can profitably be analysed.

River catchments are complex and constantly evolving entities and like any ‘moving target’ they are difficult to analyse. This is rendered all the more problematic when we add the fact that their spatial evolution takes place at multi-scalar levels, as well as being articulated by a whole spectrum of different temporalities. Elsewhere (McGlade 1999b), I have argued that the socio-natural world is defined by sets of distinctive temporalities that can be defined as *intrinsic times*; thus the biological, social, political and technological systems within which humans are situated can be characterised by inherent system times. These are the times that inhere in all social and natural activities – the turnover or reproduction times – extending from the reproduction of the cell, through plant and animal cycles to large scale glacial and planetary time scales (*cf.* Bender and Wellbery 1991; Kummerer 1996).

These intrinsic times and their spatial correlates, collectively form a nested spatial-temporal hierarchy. From our current perspective, recent research in the Vera Basin, south-east Spain, has demonstrated that multi-scalar temporalities act to structure these semi-arid environments (Fedoroff and Courty 1995; McGlade 1995). The primary message of this research is that landscape structure emerges as a result of the intersection of temporalities, ranging from the slowest processes such as tectonic movements (10^7), climatic cycles (10^5), all the way to population dynamics (10^2) and other micro-level phenomena (10^{-1}). Importantly, these temporalities are consistent with differential rates of change. Thus, we have slow, cumulative rates represented by glacial and tectonic movements, on which are superimposed annual and seasonal vegetational dynamics, along with micro-morphological soil structuring and intensive precipitation events (‘gotas frias’). Research on a number of ecological systems shows that discontinuity - and frequently catastrophic outcomes - can be the result of the conjuncture of 'fast' and 'slow' variables (Holling 1986). Such complexity is further enhanced by the superimposition of the array of time ‘signatures’ that characterise human social, political and economic systems. What we have in effect, are sets of *intertemporal dependencies*, defining a reciprocal dynamic that maps the social on to the natural and the natural on to the social. (McGlade 1995, 1999b).

With respect to our focus on catchment systems, this emphasis on intrinsic times and their scalar attributes underlines the importance of studying evolutionary processes, not simply in terms of change, but from a perspective that emphasises the role of self-reinforcing (positive feedback) processes in generating structure. Moreover, it is not change *per se* that is important, rather we must shift our focus to questions which deal with (i) the *rate* of change and perhaps, more important, (ii) the *changing* rate of change. It is these attributes which, above all, define the evolutionary dynamics of socio-natural systems. It is within this specific context that we must place our research; that is with a view to understanding the relationships between climate variability, fluctuations in agricultural production, environmental pollution and management regimes. Watershed sensitivity is thus an evolutionary concept.

In recent years, research on river systems has gradually moved from equilibrium ideas to a recognition that river dynamics are characteristically metastable, i.e. periods of apparent stability are interrupted by episodes of rapid change as the system moves to an alternative stability regime. This model of resilience is focused on the notion of thresholds (Newson l992:3l) as underpinning river basin morphology, and replacing two dominant evolutionary approaches which have emphasised I) catastrophic change and II) gradualism, or slow progressive change. The inherent instability in the system is an endogenous source of change producing threshold phenomena. Threshold dynamics are observed in river basins:

a) modified by artificial development, such as dams, irrigation projects or urbanisation;

b) semi-arid river basins where sediment supply is affected by alternating drought and flood regimes. Basins are also affected by periodic fire.

It is in this sense that catchments and the nonlinear transformations in biophysical properties that they display, can be defined within the context of the model of resilience discussed above.

Catchment systems and the role of climate

In addition to these endogenous sources of change, the sensitivity and vulnerability of watersheds – and their resilience - is also a function of exposure to specific climatic regimes. If we are to understand the resilience of watershed systems to climatic conditions, then this requires an initial classificatory distinction between;

a) the sensitivity of hydrological systems to *climate change,* which is characteristically slow, and

b) the sensitivity of hydrological systems to *climate variability*, which is, by comparison, relatively fast.

It is this second definition which is of primary concern for any research directed at the relationship between climate and watershed sensitivity. Knowledge of climate variability (Ruttenberg 1981:27) suggests that three different types of information must be taken into account:

1. *normal, expected fluctuations around some mean value derived over a long period of climate history, which generally has a range which can be determined from long-term records. These types of fluctuations are generally oscillatory, but not cyclical;*

2. *rare and extreme events, such as frequent floods and prolonged droughts;*

3. *long-term events, such as cooling or warming periods which span a century or more. The importance of these in promoting significant social effects such as migration needs to be emphasised.*

In addition, when discussing the evolution of river systems with respect to climatic phenomena, we must account for the impact of shifts in global atmospheric circulation on river flood behaviour. For example, it is well known that changes in the magnitude and frequency of extreme events are significant in terms of the impact of climate change on sediment and *P, N* and *C* transport in fluvial systems (Wasson 1996). Most important, the interdependence which arises between seasonal flooding and agricultural production is vulnerable to shifts in the global atmospheric circulation, causing significant shifts in regional rainfall patterns; e.g. the *El Niño* event of 1983 was reflected in a substantially reduced flood peak on the lower Amazon, while records from the Parana river for the same period indicate that the same *El Niño* event was reflected in substantially increased flows (Vorosmarty *et al*. 1996). The more recent *El Niño* manifestation of 1997 has already demonstrated a variety of extreme weather conditions such as floods and catastrophic landslides, showing the rapid manner in which societies must adjust if they are to avoid potential disaster.

Generally speaking, we need to understand the role of long-term processes in generating social-natural dynamics. More specifically, the dynamics of long-term trends, upon which short-term fluctuations and responses are superimposed, can only be detected and quantified within a historical framework (Wasson 1996). Most importantly, threshold phenomena change our perception of temporal scales over which change occurs, as well as providing an intrinsic source of change - i.e. it is not necessary to invoke external events such as climate or extreme floods.

Managerial and political dimensions

Hydrological and watershed sensitivity is, of course, not simply a function of climatic and biophysical processes. As we have noted earlier, the biophysical environment is but a small part of a much larger and more complicated equation, for the river basin, as a socio-natural product, is fundamentally and inescapably governed by political forces. These political forces, both intended and contingent, operate on a variety of local, regional and national scales. Thus, water utilisation patterns are characterised by cross-scale and inter-catchment administrative dynamics that are constantly in flux. This is as much through contested territorial issues promoted by commercial and urban stakeholders, as by changing tourist and conservation issues, and is particularly acute in the semi-arid zones that currently form a focus of the *AQUADAPT* project.

It is here that we encounter the various faces of legal, bureaucratic and managerial control over resources that constitute the sources of political power, particularly acute with respect to debates on ownership of water resources. One of the consequences of the reality of watershed systems as a series of contested spaces, is the need for appropriate policy exploration tools; indeed, this is a critical aspect of any watershed management initiative that aspires to integrative planning and sustainable outcomes. To this end, the need for decision-support tools is frequently argued, though the instrumentalist nature of many of these systems, while useful for exploring functional linkages between measurable variables, means that they are frequently found wanting when it comes to real-world policy exploration. The curious mix of determined and contingent processes that define societal systems is notoriously resistant to rule-based computational logic. Moreover, these difficulties are compounded by the realisation that large decision-support computer models will always find acceptance and implementation difficult within multi-user communities. They belong to a scientific discourse that by nature actively excludes large sectors of the community. For these reasons, the design of alternative conceptual frameworks of enquiry based on the interaction between knowledge communities, scenario construction and more democratic, inclusive participation, must be a major research priority.

Engaging the Past with the Present

The lessons of history: resilient water management strategies

As we have already argued, much of the science directed at the management and resolution of water-use management conflicts seems to have little room for historical context. The persistence of a modernist scientific worldview encourages the preference for engineering ('technofix') solutions to perceived problems; moreover, this is based on short-termism and is often a response to political pressure and the need to create demonstrable solutions. For these reasons, exposing the reality and intractability of many human-induced problems is not an option – preaching on the need to understand complexity is often dismissed as obfuscation and, more importantly, it does not win votes.

But history, as we have seen, has much to teach us, not least of which are some important lessons relating to the maintenance of resilient water management systems. Historically, the river catchment, seen as the locus of the control and management of water, floodplain and irrigation management has played a vital role in the resilience and long-term persistence of human communities. The ancient civilizations of Mesopotamia, Egypt, China and Peru, for example, were founded upon the management of water resources, and archaeology, as well as historical texts, has furnished us with remarkable evidence of the ability of water control systems such as irrigation, to sustain large urban civilisations. This evidence became the basis of Wittfogel's (1957) famous hydraulic hypothesis for the origin of the state, according to which the control of water requires an elaborate system of management and mass labour – something that can only be achieved by centralised power.

However, a variety of anthropological studies have demonstrated that the structures involved in irrigation agriculture cover a wide spectrum of social and political organisational types (e.g. Carneiro 1970). Indeed, a number of successful systems are characterised by decentralised social structures, for example, the medieval *huertas* in Valencia (Glick 1970) provide an outstanding case of a resilient water management system. In fact these *huerta* systems, which can be traced back to the Islamic period, were self-governing communes that were only disrupted during the period of 19th century industrialisation and agrarian reform; thus, they persisted for more than a thousand years – the social and political organisation of the Commons remaining relatively unchanged. In this sense, it is interesting to note that the arrival of feudal modes of production had little effect on the *huerta* systems, so thoroughly were they embedded, both culturally and economically, in society. With respect to our current discussion, here we have, by definition, a resilient socio-economic system that clearly merits more study.

So total is our focus on the 'now', the immediate present, that the historical context of events is lost, or at least disconnected, from the orbit of decision-makers and their knowledge systems. In fact, it is this very disarticulation that is at least partly responsible for the loss of resilience and collapse of many human-modified systems across the globe. A critical omission in this latter respect has been the continuing devaluation of systems of indigenous knowledge as being non-scientific, and hence of only anecdotal value.

For example, the Inca were skilled farmers – their irrigation systems have been mapped and archaeological research has revealed that they were involved, if not consciously, in the creation of sustainable environments then, at least, focused on the creation of resilient agricultural systems. Their sophisticated terraced irrigation systems produced biannual cropping of maize and potatoes (Guaman Poma 1613). Remarkably, their stone wall terracing structures and canal systems endured due to an elaborate system of delegating maintenance activities within the community. Significantly, what we would refer to as 'economic' or 'subsistence' systems, were indivisible from the social and religious mores of the society. Once again, as with the Valencian systems, it should be of no little interest to us that for these reasons, irrigation systems lasted for up to one thousand years (Kendall 1997:4).

The need for a long term perspective is particularly important if we are to gain an understanding of the wider historical compass; i.e. the co-evolutionary dynamic which defines human intervention in soil, vegetation and hydrological cycles. From our current watershed perspective, we can thus usefully ask, what are the lessons of the past? Can we identify specific ways in which water control and management have contributed to societal persistence and/or collapse? Clearly a variety of evidence can be brought to bear on this question from the early hydraulic civilisations as well as examples from the Roman Empire. Newson (1992) has provided a summary drawn from a number of well-known archaeological examples:

- Social aspects of co-ordination and control have been as important - if not more so - than technological aspects (the Sumerian lesson).

- Distributional aspects of water management (e.g. irrigation, drainage, and flood control) can produce highly efficient developments (the Roman example).

- The fundamental legal principles upon which a society bases its approach to water management will powerfully influence and constrain the environmental outcome.

- Scale issues are critical (the Indus lesson) because they control the distribution of information in the system, both technological and social.

Summary

In line with our previous discussion of resilience that stressed the adoption of cultural mechanisms for gathering, storing and evaluating information, one way to view the river basin from a complexity perspective is to see it as a *knowledge mosaic,* enabled and constrained by a variety of political and economic organisational forms. Over time the connectivities between the institutional, administrative and scientific knowledge domains allow the flow of information and energy to generate emergent self-organising structure. Thus, what we can say, is that a measure of the resilience of a catchment is the degree of congruence between knowledge domains: scientific, institutional, technological and local. This implies convergence at a number of scales as well as administrative agreements across political and planning boundaries. Without such cross-scale institutional cooperation, conflict can inevitably arise, as a consequence of fragmented planning and legislation. From a sustainability perspective, problems arise when there is a mismatch between knowledge domains, in effect a form of *cognitive dissonance* – effectively the rate of divergence between knowledge categories.

Finally, given the importance of the various legal, administrative and institutional processes involved in watershed development, we can usefully talk of *institutional resilience* and its analysis as a viable research goal.

Towards a Co-evolutionary Framework

So far we have argued the need to understand watersheds from a complexity perspective, so as to emphasise their nonequilibrium, evolutionary nature. We shall now go one step further and outline the rudiments of a more sophisticated evolutionary perspective – that provided by a *co-evolutionary* model.

Elsewhere (McGlade 1995, 1999a,b) I have suggested that at a general level, human-environment interaction must be conceived as a coevolutionary process and seen in terms of a model of *human ecodynamics*; i.e. as a reciprocal set of interactions driven by positive feedback processes. This coevolutionary perspective, argues for a non functionalist human ecology in which human agency plays a vital role in creating environmental outcomes that are subsequently seen to act back on human societal processes. Thus the reproduction of society is a consequence of this continuous reciprocal dynamic[9]. Consistent with these ideas is the need to view any coevolutionary dynamic from long-term perspective, thus, recognising the importance of history in creating the enabling and constraining conditions within which socio-natural systems coevolve. Such a research agenda is designed to present a more complete and integrated view of human societal structuring; it thus eschews current developmental evolutionary models, emphasising in their place, a discontinuous, non linear perspective, that acknowledges the crucial importance of different temporalities and scale-dependent dynamics in the emergence of societal structure (McGlade 1999b).

Generally speaking, a co-evolutionary perspective focuses on the way that self-organising processes at work in socio-natural systems, act to generate the system's evolutionary character. In an important contribution to this topic, Norgaard (1994) has presented a model within the context of sustainable development, based on the mutual feedbacks and nonlinearities between values, knowledge, social organisation, technology and environment.

The most significant aspect of Norgaard's model is that it contains no external relationships, everything is 'symmetrically' related. All component processes are involved in a co-evolutionary dynamic that is constantly changing in ways that are not necessarily predictable. Importantly, each of the subsystems defined (values, knowledge, organisation, technology and environment) is composed of different types of ways of valuing, knowing, organising and doing things (*ibid*: 35). The metaphor of biological fitness is employed to explain the co-evolutionary process; i.e. selective pressures determine subsystem survival. In this sense, values and beliefs that enhance the co-evolutionary process survive and multiply, while less 'fit' ones disappear. From a developmental perspective, there is no implied teleology in co-evolutionary development; thus:

"………*knowledge, technologies and social organisation merely change, rather than advance, and the 'betterness' of each is only relative to how well it fits with the others and values. Change in the co-evolutionary explanation, rather than a process of rational design and improvement, is a process of experimentation, partly conscious, and selection by whether things work or not*" (*ibid*: 37)

What is being argued is that the environment acts as a determinant in the way people behave as guided by knowledge, social organisation and technologies, while at the same time, "how people know, organise and use tools determines the fitness of characteristics of an evolving environment" (*ibid*: 46).

As a general theory of development and as a contribution to the sustainability discourse, Norgaard's work is highly significant. Yet there are a number of aspects of his model that require scrutiny. First the notion that socio-natural dynamics can be reduced to discrete subsystems is problematic. As a residue of systems theory it suggests, for example, that societies can be neatly partitioned into functional categories and thereby analysed. There is also a 'fearful' symmetry in the relationships between the subsystems, such that the causal linkages are defined as being equal. In reality the relationship between such linkages – comprising a variety of weak and strong links - is constantly changing since socio-natural systems are perforce, *evolutionary* systems. Moreover, in reality, the so-called 'subsystems' evolve at different rates.

Consistent with other models of sustainability, a key component missing from this framework is an expression of the central role exercised by power and agency and their various manifestations, in articulating societal systems. Curiously, while making the astute comment that environmental problems are essentially problems of 'social organization' (as opposed to seeing them in terms of the need for purely technological solutions), no mention is made of the crucial role of the circuits of power and authority that articulate all social and political structures.

Networks of power and agency

However, as is well known, the real world of socio-spatial interaction is rather more complex and is fundamentally irreducible, resisting attempts at reductionist explanation. Moreover, far from having any 'neutral' status, the flows of knowledge and information across time and space are primarily articulated by a variety of social and political imperatives, which are themselves inevitably manifestations of power. For this reason, any discussions of socio-natural systems that ignore the centrality of power relations in their construction and evolution, are not just inadequate representations, but actively distort the real essence of socio-political interactions as they occur in time and space.

A key issue here is the relationship between power and agency and how they are constituted in structuring processes (e.g. Lukes 1974, 1977; Giddens 1979, 1984). For these authors, action intrinsically involves the application of 'means' to achieve 'outcomes; thus, power represents the capacity of the agent to mobilise resources to constitute those 'means'. In short, for Giddens, power refers to the *transformative* capacity of human action.[10]

But any generally useful theory of power is also, of necessity, a theory of organisation (Clegg 1989:17), something implied by Mann (1986) when he discusses overlapping socio-spatial networks of power. Mann proposes four distinct sources of power which, he argues, must be factored into any interpretation of human history: ideological, economic, military and political. By extension, he argues that these must be viewed in terms of 'political culture'; i.e. with respect to the political knowledge, ideas and sentiments current in a given place and time. But the 'networks of power' model presented by Mann is very much focused on a limited reading of the power/authority nexus and is ultimately restricted to the Marxian sense of power, i.e. as domination (power *over*), and its role in producing unequal access to goods and resources. In fact a cursory glance at the literature on power relations in the social sciences – at least until recent post-modern debates – reveals a narrow perspective focused on issues of organisational obedience. Agency, that is the ability of humans to act and influence their own lives, is thus underplayed. It is in this sense that Benton (1981) has made the important distinction, separating "power over" from "power to"; i.e. conforming to the enabling and constraining factors in social relations. Here, "power to" denotes the capacity to alter and affect the social conditions within which people operate and "power over" represents the means by which social control is exercised.

Such ideas are consistent with Foucault's (1977) seminal critique, arguing that the entire discourse of power needs to be freed from its ideological and prohibitory concepts. Championing the emancipatory face of power, i.e. 'power to', Foucault's writings (1972, 1977) introduced an important focus on the relationships between power, structure and agency - something that is, from our perspective, critical to any discussion on the structural aspects of co-evolution. In many ways this work was prefigured by Machiavelli's demonstration of the *strategic* importance of power relations and the key contribution played by networks, alliances, points of resistance and instability (Clegg 1989). Machiavelli's (1958, 1970) observations are particularly prescient – especially the emphasis on instability as an endemic source of change - since they form central issues in our contemporary understanding of what we have earlier discussed in relation to complexity theory.

Actor-networks

The relationship between social networks and power is also at the heart of Actor-Network Theory (Law 1992). This essentially materialist approach to the question of social relations and network effects, is largely the outgrowth of a body of work emanating from the sociology of knowledge (e.g. Callon 1986, 1991; Latour 1987, 1988; Law 1986, 1991, 1992). In this theory, all of social life – humans, families, organisations, economies, technology – are equal in the sense that they can be described as *networks of heterogeneous materials*. The important issue here is that that which is social is not simply human but includes all other material entities; indeed, there is a deliberate dissolving of the opposition between the human realm and the world of objects (Law 1992; 383). One interesting contribution of this research is that it attempts to 'solve' the erstwhile dualism between agency and structure – a central concern of social theory since its inception more than a century ago. Additionally, actor-network theory aligns itself with Foucauldian/Machiavellian ideas of power, seeing it as hidden but all pervasive. Essentially, it is a theory that seeks to tease out the nature of organisation, focusing on the distinction between the *materials* of organisation and the *strategy* of organisation. While the type of relational materialism promoted by these authors is contentious, and has been the subject of much criticism, perhaps its real strength from our current perspective on co-evolution, is that it actively promotes a *process-oriented* view of society and its structuration.

A revised co-evolutionary model

In an effort to promote an alternative model of co-evolution – one that encompasses some of the structural issues described above, particularly the interdependence between agency and structure - Figure 1 presents a revised schema based on the mutual interaction of values, knowledge, agency, social organisation and resources:

By contrast to Norgaard's model, each of the five domains is not considered as a subsystem, but rather as the locus of *processes* that are connected to each other through self-organising dynamics. The connectivities involved are periodically weak and strong as expansion and contraction takes place continuously. Some domains are more tightly coupled and this is dependent on the capacity of a single domain or cluster to dominate or exercise control on the evolutionary trajectory of the socio-natural system. Discontinuous change, collapse, transformation and re-constitution comprise the 'normal' co-evolutionary behaviour.

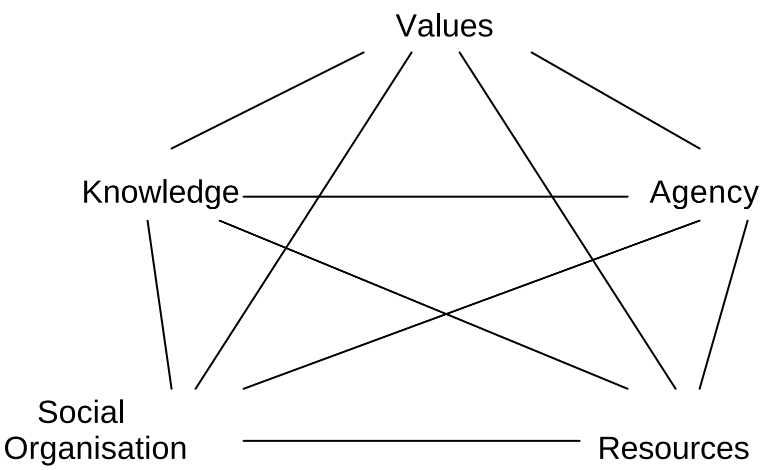

Figure 1: a co-evolutionary model of the socio-natural system

While the manifest complexities underpinning these connectivities are daunting, we can usefully summarise the main attributes of the processes involved thus:

Values: as with Norgaard's model, these assume a key role, since values, philosophies and beliefs comprise the cultural knowledge of a society that ultimately finds expression in ideology. This is a critical domain, for it comprises the engine of socio-natural systems, responsible for both its practical goals and its highest aspirations. Moreover, it stands in opposition to instrumentalist perspectives that view entities such as agriculture and irrigation as simply material technologies. By contrast, we are arguing that technologies are expressions of value systems.

Knowledge: a key difference from Norgaard's model is that Knowledge is here conceived as four mutually interdependent but semi-autonomous communities, comprising: *scientific, institutional, technical*, and *local* knowledge categories. The importance of this distinction as a pre-requisite for representing complexity was discussed earlier. Our definition of societal resilience was based on the capacity of a society to continuously renew its stocks of knowledge and consign those that are perceived to be redundant; in fact, failure to allow knowledge exchange in this way can lead to fossilisation and possible collapse. Co-evolution, then, can be thought of as a 'knowledge intensive' process.

Agency: actions are here viewed as human interventions in the system. These may be purposive or contingent and given the nonlinearities structuring socio-natural processes, they can result in wholly unintended consequences. As we have earlier noted, agency is intrinsically related to the application of 'means' to achieve 'outcomes'; thus, it is intimately related to power. The distinction, separating "power over" from "power to" is an important structuring principal for it recognises the capacity of human agency to engage in either exploitative relations or alternatively, to empower people.

Resources: in the sense used here, resources follow Giddens (1979, 1984) distinction between *allocative resources* (those involving control over nature) and *authoritative resources* (those involving control over social interactions). Allocative resources thus comprise the material features of the environment (raw materials) as well as the instruments of production, technology and their products. By contrast, authoritative resources comprise the organisational elements of human spatial interaction as well as the communication and information content defining human social interaction. Crucially, it is the specific interrelationship between these two types of resources that accounts for the variety of asymmetric power relations (enabling or constraining) that characterise all human social institutions.

Social organisation: the connectivity that characterises all societal systems is the product of a diverse array of social, political, economic and ideological linkages. These comprise networks of interactions that act to generate various types of order and organisation. In the most generic sense, networks arise as a solution to coping with complex societal problems. Social networks are usefully conceptualised as distributed systems *i.e*. a *heterarchy* comprising clusters of relatively decentralised social groups, rather than a single all-inclusive hierarchy. Control in such systems is not so much absent as fluid, circular, and essentially discontinuous - rather like solving a jig-saw puzzle. What is most significant, is that within such a heterarchy, comprising a diverse array of semi-autonomous nodes – e.g. local, regional and national administrative bodies - novel structure can emerge spontaneously from the increasing and decreasing rates of connectivity across the system enacted by political decision making processes.

The difficulties in conceptualizing such 4-dimensional dynamics is clear and can only be imperfectly captured by a 2-dimensional figure. Perhaps the best way to grasp the coevolutionary framework is to conceive of it as a topological 'rubber sheet' model, with a variety of possible streching and folding capabilities as it is 'pushed' and 'pulled' in a number of directions over time. This sequence of asymmetric topologies best defines the self-organizing features of evolutionary development.

The real advantage of a co-evolutionary approach is that it challenges our conventional scientific methodologies, forcing us to think in terms of 'wholes' instead of parts. However logical this may seem, its implementation is not easily achieved, for it requires us to jettison reductionist models upon which scientific enquiry has been based for the past 200 years. Co-evolution is attractive precisely because it presents us with a model of reciprocal human-environment dynamics that is intuitively satisfying and moreover, suggests new pathways along which we can confront complexity. On the other hand, from a practical perspective, any approach that cuts across disciplinary boundaries carries with it a particular set of difficulties (and even mistrust) that comes with any attempt to restructure conventional scientific discourse.

Ultimately we need, therefore, to replace ideas such as 'environmental sensitivity' with terminology able to encompass the coexistence and interpenetration of a variety of different knowledge communities. Essentially, we are arguing for the coalescence of scientific, institutional, governmental and local (indigenous) modes of knowing – domains that are conventionally mutually exclusive.

Such an epistemological shift has the added advantage that it encourages a pluralistic approach to knowledge acquisition and hence actively reconfigures the territory of decision-making. Practically, this involves a move from a search for deterministic causal linkages between risk and planning strategies to an arena of negotiated solutions, for a *dialogic* methodology (*cf.* McGlade 1995). This proposal is consistent with Norgaard's (1994: 102) call for 'conceptual pluralism' and the promotion of a more democratic situation – one based on increasing decentralisation and local community participation.

Towards Sustainable Policy Environments

What then are the implications of our co-evolutionary model at the level of policy formulation and delivery? Crucially, the implementation of any new conceptual and methodological approach must be organised so as to work within existing political, social and economic constraints (Von Droste *et al*.1995). Frequently, there are significant barriers that need to be overcome, since the promotion of any new conceptual approach will generally be seen as a threat to existing infrastructures and/or watershed management methods. Given the fact that across the Mediterranean, current institutional structures relating to the management of catchment systems are weakly articulated or fragmented, the co-evolutionary perspective promoted here must actively seek to initiate new policy regimes that incorporate the lessons of complex socio-natural systems, described above.

Actions and motives that are policy-relevant are deemed to be 'a good thing', yet such actions when wedded to a particular political regime or dominant ideology may be geared to short-term needs; they may have no long-term utility and worse still, may be responsible for creating environmental pathologies – however unintended. Even worse still, policy formulation if it is based on an incomplete view of system complexity – i.e. a lack of understanding of co-evolutionary processes - can actively result in wholly inaccurate predictions, especially if these are based on complicated mathematical models. For example, the idea of maximum sustainable yield models (MSY) in fisheries and wildlife management, was based on the implementation of harvesting strategies that were consistent with policies that were relevant only within the context of a specific economic philosophy of conservation and governance. With hindsight, the notion of extracting as much as possible from a resource to artificially maintain jobs, while at the same time enhancing the profiles of local and regional politicians, has been seen to be both wrong-headed and scientifically unsustainable. We cannot shape resource management to fit the changing whims of political regimes and short-termist ideas of economic investment. For this reason, policy must be developed and grown on the back of a rigorous research programme on co-evolutionary dynamics.

As we have seen above, progress in this area demands that we jettison the belief that science and its practitioners alone have the necessary knowledge and expertise to tackle complex socio-natural issues, such as those presented by multi-user watersheds. So too, the confident declarations by institutions and/or governmental agencies that actions must be 'policy-relevant' must be contested, on the grounds that this conforms to the worst excesses of linear scientistic thinking. We might legitimately ask, Policy-relevant for whom? Policy-relevant for which sector of the community? In fact, such concepts have no place in the co-evolutionary model we are promoting, for they champion official bureaucratic knowledge domains and a command and control philosophy. Clearly such approaches are inadequate, first, with respect to the problems posed by multiple resource use and contested land use claims, and secondly, since their rational, legalistic hierarchical perspective sits awkwardly with the heterarchical reality that characterises complex co-evolutionary systems.

Local empowerment.

Coupled with this desire to transform the policy environment, is the need to work towards the creation of long-term institutional stability at the catchment scale. This requires a radical shift in structural and procedural aspects and an emphasis on increased local participation in the decision-making processes that affect the landscape/watershed interface. In keeping with the recommendations of *Local Agenda 21*, one of the primary objectives of the *AQUADAPT* initiative is to generate new knowledge and knowledge transfer infrastructures aimed at lasting sustainable development. This can be more effectively achieved by adopting policies that encourage local community involvement in planning and management schemes. A prominent theme here is that active citizenship and/or neighbourhoods are best placed to assume collective responsibility for the needs of their own area within the watershed. What we are stressing is that if people are empowered to respond to local environmental issues, they are more likely to become involved in the promotion of sustainable water use and management issues across the cultural landscape. Significantly, one of the most important aspects of this focus on local empowerment, community ownership and multi-stakeholder group initiatives, is that these strategies promote a more democratic, dialogic platform. It is within such a framework that scientists, regional agencies and water authorities can coexist as equal partners and with equal interest in the promotion of sustainable policy options. Importantly, over the long run, such initiatives can generate institutional as well as environmental resilience.

What we are suggesting is nothing less than the need for an alternative approach to the management of information and knowledge within the watershed and the larger cultural landscapes which impinge on it. This reiterates our argument on the limitations and incompleteness of an exclusive emphasis on conventional methods of *scientific* enquiry as the sole means of acquiring knowledge. In fact at root, it is possible to argue that all our problems are a consequence of the coexistence of incompatible knowledge domains.

By way of summary, perhaps the simplest observation we can make is to recognise that environmental systems are inescapably *knowledge systems* in the sense that they continuously exchange information between a diversity of environments. For example, ecosystem integrity is the ability to process ‘historical’ information on past events such as fire, storm and flood. This ecosystem ‘memory’ ultimately confers resilience. Similarly, the adaptability of social systems is a function of their ability to learn from and utilise the stocks of historical knowledge that constitute the basis of their subsistence and socio-cultural structures. Co-evolution, being then the reciprocal interaction of these two domains, can usefully be referred to as a ‘knowledge intensive’ process. In the end, the resilience of socio-natural systems depends on their ability to use these existing stocks of knowledge to create new (emergent) opportunities as well as solutions for socio-environment dilemmas. This is co-evolutionary learning in action.

Conclusion: towards an alternative discourse for watershed management

By way of conclusion, it is important to emphasise that the various strands of our discussion cannot be easily woven into a single coherent whole. For our present purposes, any attempt at synthesis by recourse to the reductionist conventions of scientific method is an intellectual cul-de-sac. Thus any attempt to invoke *Ockham's Razor* is to miss the point of complex, co-evolutionary systems: they are fundamentally *irreducible*.

Instead, we must be content with the 'braided narratives' that constitute the outcome of our exploratory discussion, and reiterate the main thematic outcomes that have contributed to the construction of our co-evolutionary enquiry:

Sustainability: the ubiquity of the term is unfortunately not matched by a clear and unambiguous usage with respect to environmental, economic or social criteria. Moreover, unless sustainability is contextualised in terms of specified political, ethical and social parameters, as well as in relation to specific spatio-temporal criteria, it has no meaning.

Epistemology: perhaps the most radical aspect of a co-evolutionary framework, its implementation requires an epistemological shift of gears, so as to encompass a pluralistic approach to knowledge acquisition. The roles of distinctive knowledge communities – scientific, institutional, technological and local – are seen to form the underpinning of socio-natural dynamics.

Model of science: related to this revisioning of knowledge categories, and in line with Norgaard and others, we have argued that the present environmental crisis is a demonstration of the failure of modern western science – particularly its rationalist stance – to come to terms with the true nature of complex socio-natural systems. Thus, for example, watershed management schemes that are predicated on purely techno-engineering solutions are doomed to failure in the long-term. This is exacerbated by promoting scientific ways of knowing as the only viable explanation of phenomena; the problem is compounded by the fact that public institutions, planning authorities and other government bodies base their decisions and actions on such premises.

Resilience: our discussion focusing on the meaning of terms such as 'sensitivity' and 'sustainability', concluded that the only legitimate way to deal with such terms was within the larger compass provided by the concept of resilience. From a societal perspective, this was defined as the amount of re-organisation and change the system can undergo, while still retaining its basic institutional and socio-economic structures. The degree to which the system is capable of self-repair and self-organisation is a function of institutional flexibility and it's capacity for knowledge production and learning.

Complexity: catchments viewed as complex systems are characterised by nonlinear relationships between social and natural processes, and hence the possibility of emergent (unintended) outcomes. The role of temporal and spatial self-organisation, adaptivity, emergence and critical levels of connectivity are attributes of complexity that are crucial to understanding the behaviour of river catchment systems. Problems arise from a policy formulation and management perspective, since complex systems are characterised by low levels of predictability.

History: any adequate understanding of complex socio-natural systems – and specifically water management systems – must understand that as evolutionary systems, they are the product of history. Disciplines such as archaeology, anthropology and palaeohydrology are more than simply exotic footnotes; they must be seen as important sources of knowledge that require integration in any research programmes devoted to an understanding of contemporary issues.

Policy: given the inherent complexity of watershed systems, in particular their capacity to generate unforeseen outcomes, policy makers must take cognisance of the way these may lead to a variety of unintended consequences for local communities and their political, legal and institutional infrastructures. There is thus a need to provide a more comprehensive and pluralistic approach to policy formulation as the basis for arriving at negotiated solutions for the sustainable futures of threatened watershed systems. These initiatives must also recognise the need to incorporate local community involvement in planning and management schemes.

Co-evolution: as the basis of our complex systems understanding, the co-evolution of social and natural processes involves reciprocal dynamics that are responsible for generating emergent self-organising outcomes. These can, of course, be either benign or pathological. Structurally, a co-evolutionary framework is based on the idea of 'conceptual pluralism', and the implementation of a dialogic methodology. This has been stressed as potentially the most productive research format within which transdisciplinary knowledge can be encountered. This is, above all, an essential ingredient in any research project designed to shed light on the nature of complex socio-natural systems.

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Footnotes

[1] As a key concern of the European Community, these issues have been enshrined in legislation such as the *Treaty on European Union* (Article 130S).

[2] For example, the EC Programme “Towards Sustainable Development, 1993 and the “Proceedings of the Corfu European Summit”, 1994.

[3] The goal of prediction is the *sine qua non* of our western society. However, despite a substantial body of research in a number of fields, demonstrating that our embeddedness in a complex evolutionary system *precludes* long-term prediction, much research still proceeds as though complexity resides in some hyper-theoretical arena; thus for all practical purposes it can be put to one side, while conventional analytical methods prevail

[4] For an exception, see the ARCHAEOMEDES Programme (van der Leeuw 1998) which attempted to provide research contexts for the study of human-environment interaction.

[5] This is essentially an equilibrium view, with humans disturbing some hypothesised steady state to which the system aspires. In essence it perpetuates the age-old dichotomy, viewing the natural landscape as separate from the social and cultural realms.

[6] This study was carried out within the EC ARCHAEOMEDES Project,1996-1999 (McGlade and Picazo 1999).

[7] Polybius, writing in the 2nd century BC, when accounting for the defeat of Carthage by Rome noted: “Every organism, every state and every activity passes through a natural cycle, first of growth, then of maturity and finally decay”. Thus, at the time of their original conflict, Rome was in the ascending phase of the cycle, while Carthage was in decline.

[8] The third century Christian writer Cyprian in a passage quoted in Toynbee (1962) deplores the cycle of senescence and decay that can be seen in the world around him as part of the natural order of things.

[9] This is consistent with Alain Touraine’s (1977) argument when he states that understanding human societies from an evolutionary perspective is not just about production *per se*, but more importantly, the process of self-production.

[10] Giddens here echoes Marx, who saw this ‘transformative capacity’ of human action as the key element in the notion of *Praxis*; i.e. the transformation of nature by society.