Developing Tools for Adaptive Integrated Water Resource Management in a Semi Arid Region: Possibilities, Probabilities and Uncertainties.

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Abstract: The objective of the AQUADAPT Project (www.aquadapt.net) is to develop strategic tools to inform adaptive integrated water resource policy using a co-evolutionary approach. In Spain a methodology has been developed in the framework of an integrative study to identify evidence of co-evolutionary processes between the hydrological system and the water-using communities of the Marina Baixa over a period of 50 years. The Marina Baixa is comprised of 18 municipalities each with radically different land-use patterns spread over an area of 671km^2. The research task is complicated by the fact that Spain is a country that is currently debating the merits of a move from demand management to supply augmentation for this water-using region. Models, processes and assessments are applied to reflect a co-evolutionary perspective of the relationships between water resources, ecological quality and sustainable development. A variety of mosaics have been assembled with which to identify couplings of elements that could have spawned a co-evolving process. The paper discusses both the challenges and the merits associated with designing new methodologies in an integrative study framework for dealing with the possibilities, probabilities and uncertainties of adaptive integrated water resource management.

Keywords: adaptive integrated water resource management; co-evolutionary approach; ecological quality; sustainable community development.

1. INTRODUCTION

The intellectual orientation of this policy relevant research is one of how to determine and then to identify evidence of the co-evolution[1] of natural resources and human societies. The application of a co-evolutionary perspective could further illuminate the rapid and unforeseen changes that are inherent to the environmental, socio-economic and governance contexts within which water supply and demand patterns develop. It could also lead to clearer understandings of the forces that direct the structure, processes and dynamics of socio-natural systems. (McIntosh & Jeffrey, 2003)

The use of a co-evolutionary approach might be the means with which to identify the characteristics of both resilience[2] and adaptive potential[3], as well as how these concepts link to the notion of sustainable management of a socio-natural system. These characteristics play a critical role in determining the relationship between water resources, ecological quality and sustainable community development in a semi-arid region. Particularly, the research is concerned with developing the types of models, processes and assessments that can be deployed to uncover: a) the pace and tempo of co-evolutionary processes b) the indicators (both quantitative and qualitative) which can be used to monitor co-evolutionary processes c) Best Practice Guidance on planning methods reflecting a co-evolutionary perspective and d) long term water management strategies for semi-arid regions.

[1] Co-evolution is understood to be reciprocal evolution in which 2 or more populations evolve in response to one another.

[2] Resilience relates to the potential of a system to reorganise, restructure or transform

[3] Adaptivity relates to the potential of a system to transform through innovation

This paper describes the challenges inherent to such a task and how the methodology is emerging. It documents attempts thus far at the Universidad de Alicante to integrate individual disciplinary understandings (the research team is comprised of ecologists, economists, sociologists and institutional theorists) of how to map and interpret the Marina Baixa , in terms of what is possible and probable in modelling in such a scenario, as well as how the research team is dealing with the uncertainties that are inherent to this type of policy relevant research.

1.1 The challenges of the research task

As the focus of this policy relevant research lies with changes to the state of natural and human systems as they evolve over time, when designing a methodology the primary challenge rested with how to frame[4] policy questions. And then to consider the implications framing has for the direction of future policy. Particularly, when it comes to the operationalisation of the terms 'ecological quality' and 'sustainable community development'.

The rationale for this approach is as follows. The terminology adaptive, integrated water resource management is synonymous with the terminology sustainable water management. Yet, there are distinct challenges associated with exactly how to operationalise these terms. There is a natural tendency to link the term sustainability with understandings of natural systems dynamics and to pay less attention to understanding the reciprocal relationships of a co-evolving socio-natural system (Jeffrey & McIntosh, 2004) especially when it involves the impact of water transfers.

Broadly speaking, an increase to water supply will stimulate land-use changes. Since 1999 there have been water transfers to the Marina Baixa from the Júcar River. Water transfers can be described as engineering responses to maintain resilience of a hydrological system. However, engineering resilience only seeks to preserve stability. (McGlade, 2002) While engineering resilience maintains stability (viz., sustainability) in short-term production, natural and social resilience will diminish even though engineering resilience might be great. The long-term result is a converse effect on natural diversity that reduces the resilience and adaptive potential of ecological systems (Gunderson & Holling, 2002) as well as social systems.

For the purposes of this study the characteristics of resilience and adaptive potential offer far more useful concepts through which to understand the implications of a move from demand management to supply augmentation and exactly how water transfers will determine future relationships between water resources, ecological quality and sustainable community development in the Marina Baixa. The focus then becomes one of how to identify the characteristics of the type of resilience that promotes innovation, or the capacity of a socio-natural system to adapt to shocks or surprise. Therefore, when framing the policy questions much consideration was devoted to the impact of past water transfers, as well as the potential impact of the Júcar-Vinalopó water transfers that will greatly increase supply to the Marina Baixa

2.0 Marina Baixa study area

The Marina Baixa catchment (671 km^2), with a complex topography, is characterised by a dense land use mosaic, with irrigated crops, dryland crops, urbanisation, and Mediterranean shrublands and woodlands. The area has undergone radical socio-economic change over recent decades that can be attributed to tourism development. The main change attractors are coastal proximity (tourism) and water availability (irrigated crops). We selected three municipalities with contrasting situations where we might model and illustrate these changes: Benidorm, on the coast (51873 inhabitants, 3860 has), Callosa d'en Sarriá (7057 inhabitants, 3430 has) and Guadalest (180 inhabitants, 1610 has). The former is one of the main tourist destinations in Europe, receiving more than 3 million tourists each year, and registering 20 million over-night stays. Guadalest – also a tourist destination - is situated inland and its development strategy is very different from Benidorm. Guadalest has more than 2 million tourists visit each year, but over-night stays. Whilst, Callosa d'en Sarriá, also situated inland, has developed monoculture (medlar and citrus trees).

2.1 Spatial characteristics

Traditional land use activities are at least partly responsible for maintaining the high levels of ecological quality found in Mediterranean landscapes (Blondel & Aronson 1999). Although the ecological concepts of balance and

[4] For a comprehensive account of the implications of framing policy refer to Schön & Rein (1994)

stability are contested (e.g. see Perry, 2002) we refer here to a state of dynamic equilibrium in which both socio-cultural activities and biological diversity and function are maintained. Changes in land cover, water use and management of the land have occurred throughout history in Mediterranean regions and other parts of the world. (Dale et al. 2002) The total land area dedicated to human usage has grown dramatically, and increasing production of goods and services, has intensified both use and control of the land. (Richards, 1990) Water availability throughout the landscape varies seasonally and from year to year in response to changing weather conditions and water-use demands. Water resources are already being influenced by climate and land-use changes. Land use and climate changes have a potential effect on hydrological cycles, on flow damages, groundwater recharge and demand for the resource (Turner et al. 2001). The consequences or impacts of such changes on risk or resource reliability depend not only on biophysical changes in landscapes, water recharge and water quality but also on the characteristics of the water management system.

2.2 Temporal characteristics

The history of this water management system indicates that the region could be typical of a complex co-evolving system.[5] The Marina Baixa has a history of water deficiency and water-using communities have devised complex supply and demand management arrangements to accommodate this deficiency. A distinguishing characteristic is that there has been no traditional separation of land and water rights as there have been in other parts of the Alicante province despite the fact that the history of irrigation in Callosa d'en Sarriá can be traced to the 15th century. The autonomy of water in the Alicante province dates back to the 13th century. Embedded[6] governance structures are numerous and are engaged in management activities that are duplicated. Management responsibilities overlap in a relatively complicated hierarchical arrangement. Institutions that we consider to be embedded function on at least six different layers – from local to catchment level. Because of their spatial and temporal embeddedness these governance structures operate quite differently from those disembedded governance structures at the level of the autonomous community of Valencia, Madrid, Brussels and the numerous international water management forums.

3.0 Methodology

The first exercise was to analyse the contemporary literature relating to co-evolution, resilience and adaptive potential and to make an assessment of its relevance or non-relevance for the study. Three key references were selected: Norgaard's (1995) approach to co-evolution where all variables are endogenous; Panarchical connections (Gunderson & Holling, 2002) that attempts to reduce complexity to a single theory of metaphor with which to describe resilience and adaptive potential through the use of a nested set of adaptive cycles; and McGlade's (2002) mosaic approach to connect the hierarchal overlapping of systems, as well as to accommodate the emergence of new systems

The methodology is designed using a series of mosaics[7] to provide the required mapping and interpretation space. (Eisenhuth, 2003) The mosaics take the following form. A geographic mosaic to characterise co-evolutionary processes between different land-uses and their corresponding hydrological balances and a cultural mosaic with which to overlay social and institutional layers to detect differential response to change (social resilience, or adaptive capacity) as well as to determine the relationships between water resources, ecological quality and sustainable community development.

3.1 Applying mosaics

To study changes in the landscape, georeferenced land use (LU) /land cover (LC) maps (1:10.000) from aerial photographs (1956, 1978, 2000) of the study areas are created (Dunn et al. 1991), and 6 LU/LC categories: urban, dry crops, irrigation crops, shrublands, woodlands and others (water bodies, dams) were defined. The analysis of this chronosequence is executed through the importation of created maps using GIS. In addition, the proportional rate change for each land use can be determined. Finally, the

[5] For a comprehensive account of complex societies and co-evolution see Tainter (1988)

[6] Embedded governance structures are defined as those local cognitive, cultural, structural and political institutions that allocate environmental resources (Zukin & DiMaggio, 1990)

[7] A mosaic provides a cognitive map that represents units of spatial heterogeneity in which objects are aggregated to form a structure that can change over time.

proportional historical changes for each land use are calculated. The proposition is that selected quantitative indicators can be used to indicate changes in the landscape structure. (Farina, 1998)

To model and evaluate the changes, a simple non-spatial landscape model analogous to the method of Markov-chain transition probabilities for each two-year combination of land use changes (1956-1978, 1978-2000 and 1956-2000) is constructed (Dale et al., 2002). The alterations that the land use changes have on the ecological quality of the zones are evaluated through qualified transition model matrices, where ecological complexity, environmental stability and the sustainability of the water management system are considered.

These criteria of transition qualification take into account the increase in or decrease of the ecosystem and water indicators such as the vegetation biomass, successional status, the potential to reverse a change, variation in water consumption, the evaporation and evapo-transpiration of vegetation cover and land fragmentation. Transitions are then grouped in terms of the processes that the territory has experienced (succession, degradation, etc.), in progressive (P), degradative (D) and stable (S) with a possible combination of 5x5=25 types of transition. Thus, any transformation of pine forest or natural vegetation would be degradative, meanwhile transformations of urban land use would be progressive. In this context the transition of dryland crops to irrigated crops could be qualified as degradative, meanwhile irrigated to dryland crop is progressive as identified in the Transition Matrix Analysis. (Refer Figure 1)

	Urban	**Dry crops**	**Irrigated crops**	**Shrub land**	**Wood land**
Urban	Stable	Progressive	Progressive	Progressive	Progressive
Dry crops	Degradative	Stable	Degradative	Progressive	Progressive
Irrigated crops	Degradative	Progressive	Stable	Progressive	Progressive
Shrubland	Degradative	Degradative	Degradative	Stable	Progressive
Woodland	Degradative	Degradative	Degradative	Degradative	Stable

Figure 1. **Transition matrix analysis**.

Hydrological balances are modelled and used to estimate contributions to the Marina Baixa hydrological system, during the study period using water balance models at plot level for each land use type (Bellot et al, 1999), and land surfaces calculated from LU/ LC maps, thematic maps produced by GIS, and climatic data series provided by meteorological stations. Finally, the implications of changes in water use in the study area can be analysed by means of the comparison with the water flows in each main land use type and the general balance (Refer Fig. 2) of the study zone during the period 1956 to 2000.

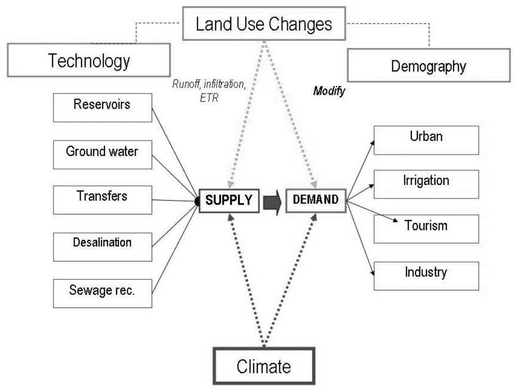

Figure 2 Marina Baixa general balance model

3.2 Formulation of policy questions using geographic and cultural mosaics

The Marina Baixa represents an overlapping hierarchical arrangement of systems that can be better interpreted using mosaics. In this sense, each of the 18 municipalities is described as a territory, or population, that interacts one with the other, using a geographical grid in a time sequence and modelling transitions. Using a mosaic approach it is possible to analyse the socio-economic behaviour and the appropriateness of governance structures in the three water using municipalities by contrasting the structures, processes and dynamics that have driven land-use patterns. Some examples of the policy questions that have been formulated are as follows: What drives competition in demand for water for contrasting uses:, eg., tourism versus irrigated and dryland crops? How price is influenced by demand? Why alliances were formed to manage the resource more efficiently, and why some municipalities have elected not to be part of such alliances? What drives changes in human behaviour e.g., in times of water shortages and climatic limitations? How to interpret the water budget of uniform hydrological response units (Bellot et al. 1999) using different types of models? These units can be LU/LC categories.

Using this simplified process-based approach it is possible to select inputs and outputs, e.g., rainfall, aquifer pumping, evapo-transpiration, run-off and then to calculate the budget for the Marina Baixa using the surfaces of each land use calculated by using GIS. The results of the models form a kind of metric to inform end-users regarding the severity of water deficit or the lowering of aquifer levels (Bellot et al. 2001.) calculated for each study period: 1956, 1978, 2000. In some cases the hydrological budget in each unit of land changes over time. There may be an increase in urban supply because of increases to per capita water use. Conversely, there may be a decrease in water use for irrigated crops if technology is improved. In other L/Us such as shrubland or woodland it is possible to isolate smaller changes in water usage over the same time scale. The rates of change from one category to another can be modelled according to social or economic trends observed by other researchers from the study group.

Other policy questions relate to the effect of water transfers on ecological quality and social resilience and if this could lead to the emergence of a socio-natural system that can respond to surprise or shock. This can be determined by analysing the relationship between land-use change and water usage, as well as determining what types of institutions, (viz., embedded or disembedded) nurture social resilience, or receptivity to change. Finally, how knowledge about this socio-natural system is transferred. This list of policy questions is not a conclusive list as integrative research has to be an iterative process. (Winder, 2002)

4.0 Conclusions

The strengths associated with the use of a co-evolutionary approach can be best described as follows. A better opportunity to pool individual disciplinary knowledge relating to adaptive, integrated water resource management. Greater potential to track the pace and tempo of reciprocal evolutionary processes. The means with which to assess the impact of the politics of water transfers as they are applied to a situation that is currently unsustainable. An opportunity to analyse institutional transformation and transaction costs and the implications these have for water management efficiency. Finally, a clearer understanding of the terms resilience and adaptive potential and how these concepts relate to adaptive, integrated water resource management of a semi-arid region.

The major challenges lie with selection of a research methodology for adapting the analogy of co-evolution for socio-natural policy relevant research. And then to identify the populations that could be co-evolving. Another challenge is the framing of policy questions and the impact this has for the future direction of governance arrangements, the formulation of announced policy such that it can be translated into policy in practice and technology choice. [8]

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