TAKING A SYSTEMS APPROACH TO ESTUARY MANAGEMENT

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Abstract

The NSW Estuary Management Program involves local communities in the management process via nominated representatives on estuary management committees. The vast range of issues involved in estuary management can be a challenge to these committees. Community representatives often enter the process focussing on a particular management issue that concerns the group they represent (e.g., a fishing club, a progress association, or a dune care group). It is essential that the understandings brought to the committee by these representatives are integrated into the management plan, but the complexity of the social-ecological system can make this difficult.

In this paper we describe the systems approach, developed by Newell and Proust, that is being used to support the development of an Estuary Management Plan for Pambula Lake on the NSW Far South Coast. The approach embraces complexity, and provides a way to integrate disparate or conflicting views. It thus complements and strengthens the standard estuary management process. The approach begins with the gathering of a broad ‘system history’ and the construction of ‘influence diagrams’ that help the management group to identify key variables of the social-ecological system. The influence diagrams provide a ‘common graphical language’ that enables group members to summarise and integrate their views of the complex feedback interactions that occur between the key variables and the state-change processes that control the values of these variables. Finally, a system dynamics analysis, which uses simple ‘stock-and-flow’ models, is used to identify the cross-sector cause-and-effect linkages that dominate the behaviour of the social-ecological system. Taking a systems approach should help the Pambula Lake estuary management group to address a wider than usual range of issues, and so gain perspective on how particular issues of concern relate to each other and to specific management decisions. In so doing it can help overcome barriers to the development of a truly integrated Estuary Management Plan.

Introduction – the integration imperative

Estuary management approaches around the world focus predominantly on protecting estuarine ecosystems from anthropogenic impacts (see e.g., Kennish 2002). But, given the immense complexity of the interactions between people and nature, we need to look beyond anthropogenic impacts (and the human actions that cause them) to the beliefs, worldviews and norms that drive human behaviour. In short, we need an “integrated or ‘ecosystem’ approach to management of the complex land-coast-sea continuum” that includes “socio-economic aspects of coastal management as these are the key drivers of degradation of coastal and marine systems” (Fearon, Wulf and Baird 2006). Integrated coastal zone management must employ management strategies that are “based on a systems perspective which recognizes the associations between coastal resources and processes” (Hildebrand and Norrena 1992, p.95). Hildebrand
and Norrena go on to say that it “is clear that integrated coastal zone management involves a non-sectorial approach to the management of coastal resources. It must consider the environmental, natural resource, socio-economic, political, cultural and geographic dimensions of the coastal zone in a multi-sectorial framework.” But we must do more than look at the way that humans affect the environment. We also need to look at the way that environmental conditions feed back to influence community beliefs, worldviews and norms. The first step towards a deeper understanding of the behaviour of social-ecological systems is to move beyond causal chains to develop an appreciation of the ubiquity and power of feedback dynamics. Feedback concepts provide a natural and necessary focus for integrative efforts.

Newell and Proust (hereinafter NP) have been working to develop a practical way to lower the conceptual barriers to the development of integrated management plans (Newell and Wasson 2002; Proust 2004; Newell and Proust 2004; Newell, Crumley, et al. 2005; Proust and Newell 2006; Newell, Proust, et al. 2007). NP’s approach draws on some 30 years of practical experience in education, industrial process improvement, public health, cultural heritage management, and natural resource management. Insights drawn from this practical involvement have been integrated with selected theoretical concepts from the disciplines of cognitive science (Lakoff and Johnson 1980, 1999), public and applied history (Stearns 1982; Neustadt and May 1986; Graham 1993; Proust 2004), feedback dynamics (Forrester 1961; Senge 1992; Richardson 1991; Sterman 2000), and complexity and general system theory (von Bertalanffy 1969; Gell-Mann 1995; Jervis 1997). The conceptual framework emerging from this work is designed to provide coherent, understandable, practical support to individuals and groups who are attempting to improve management practice and problem resolution in complex situations.

The strong resonance between the approach embodied in the NSW Estuary Management Program and that advocated by Newell and Proust led us to consider blending the two in the development the Pambula Lake Estuary Management Plan. We report here on the early phases of this endeavour.

A practical systems approach

Newell and Proust stress the central importance of participative, action research that contributes to all participants’ understanding of cause-and-effect in the system of interest. Their approach is intended to be used by people throughout the community, whatever their background and level of operation. The basic ideas are relatively simple and are expressed in a form that ensures that they are easy to learn and apply. The focus is on helping individuals and groups to develop a better understanding of cause-and-effect in complex managed systems. Improved understanding of cause-and-effect, particularly feedback effects, can lead to better policy and management actions. It can also reduce conflict as participants begin to understand each other’s point-of-view, and to appreciate the interplay between different sectors (and between social and natural processes) that occurs in social-ecological systems.

System principles

Newell and Proust use seven system principles as the foundation for their approach. First, three ‘systems thinking’ principles that are a slightly modified version of principles suggested by Churchman (1968) are used to highlight the primary importance of each individual's understanding of cause-and-effect (Table 1). By strongly emphasising the
differences between worldviews, and the limitations of any one person’s worldview, these principles underline the need to integrate the worldviews of all the players (including those of technical experts) in any attempt to understand cause-and-effect in a social-ecological system. These principles also ensure a focus on the social aspects of the system under analysis. This emphasis counters the natural tendency for system analysts to push social processes to one side because they are “too hard to handle”.

<table>
<thead>
<tr>
<th>ST1</th>
<th>The systems approach begins when first you see the world through the eyes of another</th>
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<tbody>
<tr>
<td>ST2</td>
<td>The systems approach goes on to discover that every worldview is terribly restricted</td>
</tr>
<tr>
<td>ST3</td>
<td>No one person can see the whole system</td>
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**Table 1. Systems thinking principles**

Second, NP emphasise two ‘system dynamics’ principles (Table 2) that pick up key ideas developed by the System Dynamics community (Forrester 1961; Senge 1992; Sterman 2000). By establishing a focus on feedback and its effects, Principles SD1 and SD2 help capture generic aspects of system behaviour. Feedback occurs when the outcomes of an action ‘feed back’, around one or more causal loops, to amplify or oppose the effect of the original action (Figure 1).

<table>
<thead>
<tr>
<th>SD1</th>
<th>Feedback effects are important drivers of behaviour in any social-ecological system</th>
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<tbody>
<tr>
<td>SD2</td>
<td>Any action taken in a social-ecological system will have multiple outcomes, some wanted and some unwanted. The unwanted outcomes are usually delayed and therefore not associated with the triggering action</td>
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**Table 2. System dynamics principles**

The ‘causal loop diagram’ of Figure 1 illustrates a negative feedback loop. The *blocks of text* represent selected system variables. The *curved arrows* indicate flows of influence between these variables. Each arrow has a symbol that shows its ‘polarity’. A *plus sign* (+) indicates that a change in the value of the variable at the tail of the arrow will cause the value of the variable at the head of the arrow to change in the *same* direction, assuming that no other causal influences act to cancel out the effect. A *minus sign* (-) indicates that a change in the value of the variable at the tail of the arrow will cause the value of the variable at the head of the arrow to change in the *opposite* direction (all else being equal). The *short parallel lines* drawn across two of the influence arrows indicate delays in the system. The *encircled B* in the centre of the
feedback loop indicates that this is a ‘balancing’ (negative feedback) loop that acts to counteract any change in any of its four variables.

There are only two types of feedback. When change is opposed by the system the effect is called ‘negative feedback’. Negative feedback works to hold system variables at established levels, thus balancing or stabilising the system. Note that the term ‘negative’ indicates only that changes are resisted—it does not mean that the effects are necessarily bad. The various homeostasis mechanisms that maintain stable conditions inside the human body are all examples of ‘good’ negative feedback. When change is amplified by the system the effect is called ‘positive feedback’. Positive feedback effects are sometimes called runaway effects, bandwagon effects, or vicious circles. The term ‘positive’ indicates only that changes are amplified or reinforced—it does not mean that the effects are necessarily good. They can lead to exponential growth or collapse within social-ecological systems.

Third, NP use two ‘system management’ principles that follow logically from Principles SD1 and SD2 (Table 3). Principles SM1 and SM2 must be taken in to account in any policy-making or management initiative. They are intended to counter the overwhelming tendency of our community (a) to focus on sub-problems contained within tight social ‘silos’, narrowly defined disciplines or institutional sectors, and (b) to put in place policies designed to solve each sub-problem separately. The feedback structure of complex systems guarantees that such fragmented approaches will fail in the long run. The design of effective NRM policies requires an integrative approach that blends insights from a wide range of disciplines and worldviews. The term ‘integrative’ implies an ongoing effort—integration can be achieved only as a result of steady effort over a period of time (Newell, Crumley, et al. 2005). The notion that the influence links between system variables cut across disciplinary, institutional and cultural boundaries makes clear the inadequacy of silo-bound approaches.

<table>
<thead>
<tr>
<th>SM1</th>
<th>The behaviour of a social-ecological system cannot be optimised by optimising the behaviour of its parts taken separately</th>
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<tbody>
<tr>
<td>SM2</td>
<td>The boundaries of a social-ecological system cut across the boundaries of traditional disciplines and institutions</td>
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Table 3. System management principles

The four inter-related activities

NP’s approach requires a group effort. The investigation begins with the group members’ existing knowledge and builds on that knowledge to develop a deeper, more integrated understanding of cause-and-effect structures in the social-ecological system of concern. As shown in Figure 2, there are four main activities: integrating the worldviews of group members, gathering a broad ‘system history’, identifying cause-and-effect structures that dominate the behaviour of the system, and identifying the implications that the system analysis has for managers and policy makers. These activities reinforce each other, and so will co-evolve. It is, for example, always necessary to cycle around the stages of developing an integrated worldview and gathering historical data. Nevertheless, the tendency will be to ‘complete’ each activity in the order listed. The nature of, and desired outcomes from, the four activities are outlined below.
Activity 1. Integrate worldviews

Each group member constructs an individual ‘influence diagram’ that captures his or her existing understanding (mental models) of the interactions that occur between the key variables and processes of the social-ecological system under investigation. Group members then work in pairs to combine their diagrams to form a single diagram that incorporates both worldviews. This kind of integration can be carried out relatively easily, because the individual diagrams are constructed using a common set of ‘grammatical rules’. Diagrams constructed this way constitute statements in a ‘shared graphical language’. This integrative process has three crucial outcomes:

- It enables group members to begin building a broad picture of the interactions between the variables and processes that control the behaviour of the system of interest.

- It provides an opportunity for group members to compare and contrast their understandings of the structure and behaviour of the system of interest. This is essential in any move towards the identification and resolution of conflicts that may exist between people with different aims and interests. Such conflicts typically arise because of narrow understandings of cause-and-effect. A broader, shared understanding can therefore work to reduce conflict—it can also reduce the necessity for trade-offs in policy construction (Schön 1993).

- It provides a disciplined way to produce an extensive list of variables that are candidates for inclusion in an analysis of the system’s dynamics.

Activity 2. Gather system history

This is the essential data-gathering process, and it begins from the list of variables generated from the influence diagrams. Group members will already have gathered some historical data, often implicitly, and the construction of a system history is intended to make the historiographic component more explicit and systemic. NP use the label ‘system history’ to emphasise the need to gather information that has an appropriate time depth, that ranges from anecdotal accounts to quantitative measurements, and that covers a wide range of social, cultural and environmental variables. History, particularly environmental history, can provide information that includes legacies of landscape formation processes (Hancock 1972), past states of the
bio-physical environment (McNeill 2000), anthropogenic impacts on the environment (Braudel 1949; Cioc 2002), human perceptions of the bio-physical world (Powell 1989), the dynamics of social-ecological relationships (Beinart and Coates 1995), and cultural and social systems that have emerged as a response to particular environments and that drive human behaviour (Blainey 1966). Such information includes the behaviour of the system over time (time series), the sources of dynamical complexity (i.e., feedback between variables and processes), the multiple drivers of current situations, and the multiple consequences of past actions. History of this type is essential if we are to learn from the past for sustainability (Dovers 2000; Proust 2004). Managers operating within complex social-ecological systems must deal with delayed responses to their actions, and thus find it difficult to learn from experience (Principle SD2). Furthermore, where jurisdictional responsibility has changed, institutional memory of the problem is usually lost. The history of an environmental problem invariably extends well beyond the administrative life of the responsible government agency—it can easily exceed the working life of individual policy makers and managers (Proust 2008). The process of gathering a broad, system history is intended to weaken these fundamental barriers to the establishment of management approaches that are truly adaptive (Holling 1978; Walters 1986).

Activity 3. Identify dominant cause-and-effect structures

Here group members construct ‘stock-and-flow’ maps (see Figure 3) that capture the interactions between key system variables and processes.

Figure 3. The visual language used to construct stock-and-flow maps

In Figure 3, rectangles represent state variables (stocks or accumulations), double-lined arrows represent processes that can change the values of state variables (often called ‘flows’ because many processes involve flows of material or energy), ‘clouds’ represent sources or sinks of flows, and single-lined arrows represent influence (or information) links. Process rates are represented by ‘tap’ or ‘control-valve’ symbols superimposed on the double-rulled arrows. These graphical conventions were introduced by the MIT System Dynamics community (Forrester 1961; Sterman 2000) and are used in the Stella® modelling package. Stock-and-flow maps and models support the development of shared understanding within a community because they depend metaphorically on peoples’ common experiences with the storage and flow of water (see Lakoff and Johnson 1980 for a discussion of the metaphorical basis of understanding).
Stock-and-flow maps provide a way to integrate information about (a) system states and (b) system processes, and so allow the feedback structure of the system to be described. No system variable (state variable) can affect the value of another state variable directly—one or more ‘state-change processes’ must always intervene. In a complex system the values of the state variables control the rates of the state-change processes and, at the same time, these processes change the values of the state variables. Such feedback interactions give rise to ‘dynamic complexity’ even in systems with only a few variables (see Senge (1992) and Sterman (2000) for extensive discussions). Work with stock-and-flow maps provides the basis for the construction of simple stock-and-flow models that allow selected aspects of system behaviour to be investigated (see, e.g., Proust and Newell 2006). It is important to approach this step in a spirit of isolating and explaining the general reasons for dominant behaviour, not as an attempt to build a working model of the whole system—the latter is bound to fail.

Activity 4. Draw management implications

This aspect of the NP approach involves the generation of insights into the possible impacts of various policy initiatives and management practices. The working stock-and-flow models provide a strongly integrated conceptual basis for this activity. Depending on the aims of the investigation, the output from this activity can range from simple descriptions of likely system behaviour (Proust and Newell 2006), through lists of suggested ‘leverage points’ for system-behaviour change (Senge 1992), to a fully developed set of management scenarios (Schwartz 1991; van der Heijden 1996; de Gues 1997).

Application to the Pambula Lake estuary management plan

Pambula Lake Estuary and Catchment Group is made up of community members representing the Southern Rivers Catchment Management Authority (CMA), Bega Valley Shire Council, Far South Coast Landcare, Pambula River oyster growers, Pambula Wetlands and Heritage Group, Eden Land Council, local farmers, NSW Government agencies (Department of Environment and Climate Change (DECC), Maritime Authority, Department of Primary Industries) and The Australian National University (Fenner School of Environment and Society).

The first Pambula Lake systems workshop was held in February 2008 at Jigamy Farm on the shores of the lake. Fourteen members of the management group participated. The aim of this workshop was to take the first step towards the integration of group members’ views of the structure of the social-ecological system that needed to be considered in the development of the Estuary Management Plan.

The workshop began with a discussion of the nature of system variables and the practice of drawing influence diagrams. Workshop participants gained experience in drawing influence diagrams by analysing a specific management situation that had been the subject of a letter to the Editor of the Bega District News. Attention then turned to the Pambula Lake system. The integrative procedure that followed, where participants produced individual and then paired diagrams, was the same as outlined above in Activity 1.

Figures 4 and 5 show examples of influence diagrams produced by pairs of participants during the workshop. These blended diagrams represent the first steps towards an integrated view of issues that are important in the management of activities
around the lake. As these examples show, the workshop participants' diagrams were focused at different levels—together they provide a powerful mixture of high-level, broad views and more detailed, low-level views.

![Figure 4. A view of influences affecting estuary health and conservation](image)

![Figure 5. A high-level view of influences affecting oyster production](image)

The above diagrams provide the material for the development of more integrated diagrams focused on specific management themes and the identification of possible feedback loops—Figures 6, 7 and 8 are examples of these more developed diagrams.

On the right side of Figure 6 is a balancing (negative feedback) loop with four variables. The loop operates as follows: as the richness and abundance of aquatic pest species increases the likelihood of reports of sighting aquatic pests will tend to rise. This will lead to an increase in the level of community and industry engagement with the problem of aquatic pests, which can produce a decline in the degree of risk of artificially transferring pest species to the lake. Balancing loops work to counter change, and so can cause 'policy resistance' (Sterman 2000). For example, a successful campaign to reduce the abundance of a pest species in the lake can lead to
a reduction in sightings and a consequent falling off of community interest. Reduced interest can then allow new infestations to occur, so increasing the abundance of the pest. Such interactions can cause pest species abundance to oscillate over time.

Figure 6. Waterways management

There is another balancing feedback loop with four variables on the left-hand side of Figure 6. In this case, an increase in the attractiveness of the lake produces an increase in the extent of recreational boating. But boating brings an increase in the risk of pollution from boating incidents, which result in a decline in water quality, and this reduces the attractiveness of the lake. Once again the presence of negative feedback raises the possibility of policy resistance.

Figure 7. Aboriginal culture
Figure 7 presents issues that some workshop participants saw as important in the management of the lake for its indigenous cultural values. At the centre is a key variable *Efforts to keep Aboriginal culture alive*, which connects the two sides of the diagram, traditional cultural practices (right) and indigenous involvement in NRM (left). At the top right of the diagram there are four variables forming a reinforcing (positive) feedback loop containing *Extent of integration of traditional culture into contemporary Aboriginal life*. This loop shows the desirable outcome of improving Aboriginal nutrition and health, by increasing the use of traditional sites as a food source. Another reinforcing (positive) feedback loop (top left) shows the desirable outcome of increasing the effectiveness of laws and regulations protecting cultural sites, by increasing efforts to foster Aboriginal involvement in NRM. There are several other smaller feedback loops in the diagram; for example, the link between (a) water quality and (b) richness and abundance of shellfish populations reflects the importance of shellfish as filterers of lake water.

Figure 8. A broad NRM view of Pambula Lake

Figure 8 represents participants’ high-level view of issues that are important in the general management of Pambula Lake. The diagram shows some of the dominant interactions that must be considered in the development of an integrated estuary management plan.

The influence diagrams that were produced during the workshop had two immediate uses. First, they provided a disciplined way to identify variables that should be considered in the data compilation study called for by the NSW Estuary Management Program. The resultant list of variables was used to prepare the tender documents for the data compilation study. Note that the data compilation study is closely related to the system history studies called for by Proust (2004).

Second, they provided the material for the construction of a larger, more integrated diagram that provides a glimpse of the overall feedback structure of the social-ecological system that incorporates Pambula Lake and Estuary. This diagram (Figure
integrates the paired influence diagrams produced at the workshop. It will continue to evolve as the Management Group continues to learn about the system. Newell and Proust use the label “Jumbogram” for large influence diagrams. This term reflects their use of the story of *The Blind Men and the Elephant* (see version in Wikipedia) to explain the reasoning behind Principles ST1, ST2, and ST3. Jumbograms provide a compact representation of the complexity of the overall system, and so aid in the identification of feedback structures that cut across institutional, sectorial and disciplinary boundaries (Principle SM2).

So far the systems approach described here has provided a useful basis for discussion and data gathering in the Pambula Lake Estuary Management project. The next steps include the following:

- Use the results of the data compilation study to update the existing Jumbogram to identify gaps in the coverage of system variables and processes (iterate Activities 1 and 2, see Figure 2). This is one area where the systems approach can move the project beyond the usual focus on estuary processes to include a wider range of social, economic, and cultural variables and processes.

- Work to identify dominant cause-and-effect structures in the Pambula Lake system (Activity 3). Express these structures as stock-and-flow maps and, where possible and appropriate, work these maps up into computer-based dynamical models. Stock-and-flow maps and models do not need to be complicated to be useful. For example, the map shown in Figure 10 has only two state variables, yet it can be used to guide discussions of feedback structures in a social-ecological system. Efforts to convert ‘conceptual’ stock-and-flow maps (Figure 10) into specifically focused working models can provide the impetus and co-ordinating framework for a disciplined investigation of aspects of the behaviour of the social-ecological system of interest. This process is challenging but it is practical provided that the number of state variables is kept small.

- Investigate the management implications of the suggested cause-and-effect structure (Activity 4).

- Finally, participants in the Southern Rivers Local Leaders Program, being developed by the Southern Rivers CMA, Far South Coast Landcare Association and Australian National University, will be invited to engage with the Pambula Lake Estuary Management Group. Collaboration between the two groups should provide mutually beneficial, and will certainly strengthen the Pambula Lake Management Plan.

Figure 10 displays a generic stock-and-flow map of possible feedback interactions between social-cultural and environmental variables (see Figure 3 for graphical conventions). The rectangles represent the current values of selected ecological and social-cultural variables. The influence links shown indicate that the values of the social and cultural variables can control the rates of state-change processes that impact the selected ecological variables. The values of the ecological variables can, in their turn, directly drive processes of social and cultural change (of the kind shown in Figure 1). In addition, if the difference between the actual and desired state of the ecology becomes too great, then (with a perception delay) management will respond to counter the disturbance. This can be done both by efforts to alter social and cultural variables and by direct attack on the processes that impact the ecology. In both cases the effectiveness of management’s response will be controlled by (a) the sensitivity of the selected processes to the actions chosen by management, and (b) the upper and lower limits imposed on the extent of management’s response by the finite nature of available resources.
Figure 9. An initial Jumbogram for Pambula Lake estuary
Conclusion

The initial results from this project have been encouraging. Participants in the Pambula Lake Estuary Management workshop were enthusiastic, and the preparation of influence diagrams provided fertile grounds for discussion. The process of integrating influence diagrams on a pair-wise basis worked well. In general, participants found it to be much easier than they had anticipated.

So far, in the management group’s discussions, the focus has been more on ecological processes within the Pambula Lake estuary and catchment, and less on social and economic processes. This natural focus parallels the emphasis in the NSW Estuary Management Program. The project discussed in this paper can, therefore, contribute in at least two main ways to the evolution of that Program:

- By demonstrating a way of expanding the range of social, economic and cultural variables that are taken into account in the development of an estuary management plan. Such an expansion of the system boundaries is necessary if an estuary management plan is to meet the criteria expressed in the framework document National Cooperative Approach to Integrated Coastal Zone Management (Natural Resource Management Ministerial Council 2006).

- By demonstrating the possibility of using stock-and-flow maps to clarify the relationships between key system variables and the state-change processes that control them. This should encourage the necessary shift to feedback thinking and a willingness to ‘wrestle with the complexity’.

This last point is particularly important. The identification of leverage points, that can move a social-ecological system into a more sustainable state, requires an understanding of
feedback dynamics. In such an endeavour, it is absolutely essential to allow adequate time to map the complexity of the system before trying to distil out the basic feedback loops that dominate system behaviour. Failure to do this can result in models of cause-and-effect that, while simple, are also simplistic. Policy based on simplistic models of cause-and-effect is rarely sustainable. Simplistic policies tend to produce the expected results at first. Then, after some time has elapsed, these desired outcomes are overwhelmed by a number of undesirable outcomes—and the policy fails [Principle SD2]. Such policy resistance is counter-intuitive, and thus surprising, when policy makers fail to understand the feedback structure of the system of interest. Policies that avoid policy resistance are difficult to establish and maintain. But they are necessary if we are to create sustainable coastal communities.

References


