CHAPTER 1  INTRODUCTION

1.1 Statement of the Problem

In 1987 the United Nations Commission on Environment and Development (the Bruntland Commission) called for 'a form of sustainable development which meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). It drew attention to the scale of environmental change and the growing uncertainty that the world now faces, and to the way in which economic development often leads to deterioration in the quality of people's lives. Nevertheless, while sustainable use of natural resources is a matter of growing concern to communities worldwide, human-induced degradation of those resources is accelerating. Inappropriate management of land, water, forests and fisheries has already produced devastating effects on the state of our soils, native vegetation, biodiversity, groundwater, inland rivers, estuaries and oceans. It is becoming clear that inappropriate management of Earth's resources is also producing long-term changes to climate (Steffen et al 2004).

Throughout history societies have attempted to exploit and control nature. In the drive to extract the greatest benefit from their natural surroundings, modern industrial societies have developed more and more sophisticated ways of removing the natural variability in their environment. Especially in the West, they have introduced increasingly efficient ways of extracting resources. But as well as conferring benefits, these attempts have brought unintended and unwanted consequences. In the worst cases the entire resource base has been destroyed (Adams 1981, Tainter 1988, Meadows et al 1992, Kurlansky 1997, Jackson et al 2001, Diamond 2003).

There is abundant evidence of unintended and unwanted consequences in the management of Earth's natural resources. It is found in the effects of large dams on ecosystems (WCD 2000), of river levees on floodplains settlements (Barry 1997), and of coastal defences on landscape processes (Bayliss-Smith 1990). It is apparent in the over-fishing of viable fisheries (Tenner 1997), land settlement beyond the limits for sustainable agriculture (Meinig 1962), land uses that bring massive soil erosion (Worster 1979, Breckwoldt 1988), and the extinction of biodiversity (Australian SEC 2001a). ‘Management and resource exploitation can overload waters with nutrients, turn forests into grasslands, trigger collapses in fisheries, and transform savannas into shrub-dominant semi-deserts.’ (Holling and Gunderson 2002:60)

In many attempts to exploit and control nature, the detrimental changes take place slowly, and are irreversible by the time they are evident. Timescales for effects to occur can be decades, centuries or longer, and effects often appear far from their source, kilometres further along a
coastline, or in a distant part of a river catchment. Where the response is delayed communities cannot readily observe the outcomes of their decisions and actions. In such cases it is hard to understand cause-and-effect relationships. These problems characterise most issues in natural resource management (NRM). They represent an enormous barrier in attempts to track the impact of policies on the sustainable use of Earth's natural resources.

The nature of NRM problems demands that policy makers must tackle complex environmental problems with strong natural, social, economic and perceptual dimensions. At the same time, they must face the contemporary consequences of past unwanted impacts on land, water, forests and biodiversity. Until we have an understanding of these complicated interactions, 'our attempts to balance extraction of ecosystem resources against sustainability will remain at best naive, at worst disastrous' (Holland 1995:4).

Learning from the past is essential in attempts to understand the dynamics of the complex relationships between nature and human beings. However, deliberate learning from the past presents a particular set of problems in NRM. It has been said that 'we need histories of environmental problems that examine the social relations, structural conditions, cultural myths, metaphors, and ethical presuppositions that constitute the social negotiations with nature that contribute to those problems' (Bird 1987). Such endeavours require an understanding of how human beings learn from experience in cases where 'signals' are noisy, timescales are so long that the consequences of decisions can be experienced only once in a human lifetime, and where human-environment relationships are complicated by system effects. In addition, a systems approach is needed to reveal the dynamical structures that drive NRM problems. Systems theory also provides a formal language to describe system behaviour and graphical tools to aid in the analysis of feedback structures.

Forrester (1961) recognised the importance of history in attempts to understand system behaviour, and how an understanding of the dynamics of complex systems should make historians more sensitive to system variables. To date, there has been no organised attempt to integrate the skills of the historian and the dynamicist. Yet an integration of their skills has the potential to reveal the nature of NRM issues and problems in a structured and coherent manner, and to contribute to an understanding of the dynamics of the systems that underlie them. In recent decades policy makers' access to reliable scientific information has been improving, but in many situations their performance is inhibited by the lack of a useful historical perspective. They often see the need for history, but usually lack the skills and the time to address it.

While historians have the experience and skills to bring an historical perspective to NRM issues, in general their interests lie elsewhere. Their training, in Australia at least, has not exposed them
to the problem-oriented world of policy making, either in NRM or other human-activity systems. Many are held back by their tendency to shun theory-based endeavours (McNeill 2003), particularly those involving concepts too close to science and mathematics. Scientists since the time of Charles Darwin have recognised the central distinction between *laws in the background* and *contingency in the details* (Gould 1989:290). Yet, in general, historians believe that human-activity systems are highly contingent, that the signals of generalised laws cannot be discerned, and that history cannot contribute to the study of dynamics. They are unaware also of the contribution that dynamics can make to historical scholarship (Neustadt and May 1986).

An attack on these problems requires a new approach that integrates historical perspectives with understandings of system behaviour. Thus, the approach developed in this thesis utilises a blend of concepts and techniques from the humanities and the sciences. It represents an attempt to bridge the gap between 'the two cultures' (Snow 1959) by augmenting the skills of the historian to give them an enhanced role in NRM. Such an approach should enable the NRM community to learn better from the past.

1.2 **Aim and Scope of the Thesis**

The aim of the thesis is to develop an approach that will allow historians to contribute better to the study of the dynamics of human-environment systems.

The research is focused on the interests of policy makers in natural resource management. The approach is developed using:

(a) concepts taken from historiography, system dynamics, and experiential learning theory and
(b) an historical study of irrigation focused on the NRM issue of salinity.

Because the approach is designed to capture characteristics of applied history and environmental history it is called Applied Environmental History (AEH).

1.3 **Overview and Structure of the Thesis**

The thesis has four parts:

I A framework for Applied Environment History
II The NRM context for the AEH study
III An exploratory Applied Environmental History study
IV Analysis and Conclusion

This structure is illustrated in Figure 1.1. A Preface provides an introduction to each Part.
Part I: A Framework for Applied Environmental History defines the theoretical and conceptual context for Applied Environmental History. It examines the theoretical material that could be useful to build a framework for the proposed approach.

Chapter 2 contains concepts from the discipline of history. It describes the limited ability of applied history to meet the needs of the modern policy-making community using existing techniques, and makes the case for a broader historiography.

Chapter 3 presents concepts from dynamical systems theory. It explains the need for an understanding of system models that exhibit feedback effects in order to identify generic patterns of behaviour in human-environment systems. It emphasises the importance of system structure to explain the behaviour of systems with many variables and causal connections.

Chapter 4 introduces concepts concerned with the process of experiential learning. A model, called the Cognitive Adaptation Process (CAP) model, has been developed specially for this thesis because existing models of experiential learning do not take account of learning from the past. Learning from the past is a particular form of learning from experience that requires an
historical perspective. The CAP model highlights the specific role of history in the process of experiential learning.

Because each of these domains is broad, it has not been practical to write an extensive literature review for each one. Instead, the material in Chapters 2, 3 and 4 is based on a wide reading of the foundations of each domain, from which I have selected concepts suitable for the AEH approach.

Chapter 5 outlines some guiding principles for Applied Environmental History. The principles integrate techniques and understandings described in Chapters 2, 3 and 4. They will be tested in the AEH study in Part III, and developed into operational guidelines in Part IV.

**Part II: The NRM Context for the AEH Study** presents salinity as a problem suitable for an exploratory AEH study. It sets up a context to understand irrigation salinity as a serious environmental problem worldwide, and how salinity is a good illustration of policy makers' failure to learn from the past.

Chapter 6 describes the bio-physical preconditions for salinisation, and the characteristics of the problem in irrigated agriculture. It explains the effect of over-watering from a technical perspective (by means of a stock-and-flow model), and from an historical perspective (by describing some of the earliest known effects of the problem on irrigated agriculture).

Chapter 7 focuses on salinity in south-eastern Australia. It outlines policy initiatives taken by Australian governments since the late 1960s, when irrigation salinity in the Murray-Darling Basin was recognised as a serious environmental and social problem. It includes a description of the current state of the problem in the southern portion of the Basin.

**Part III: An Exploratory Applied Environmental History Study** provides an historical context, using the AEH approach, to investigate the difficulty that NRM policy makers have in learning from the past. It is based on an historical narrative of irrigation development in parts of India and south-eastern Australia, with a focus on salinity. The study is organised around a sequence of three specific questions concerned with the inception, in 1906, of the Murrumbidgee Irrigation Scheme, the first intensive irrigation project in Australia.

Chapter 8 is organised around the question *Could planners and policy makers in New South Wales in 1906 have learnt from the past about irrigation salinity?* The chapter describes the problem of salinity, and attempts by scientists to understand it, in nineteenth century India. India was an important source of early colonial knowledge on irrigation salinity. By the 1870s there
was already a serious irrigation salinity problem in northern India. The chapter identifies the system behaviour that allowed irrigation salinity to expand largely unchecked by the Indian Government. It establishes, as a baseline, the knowledge of irrigation salinity in India that the Australian colonies could have drawn on to guide irrigation development in south-eastern Australia.

Chapter 9 is organised around the question *Should planners and policy makers in the Murrumbidgee Irrigation Scheme have learnt from the past, and been concerned about salinity?* It describes the growing awareness of salt in the south-eastern Australian landscape in the nineteenth century, and traces the progress of government science in irrigated agriculture. It discusses the divergent views, on the part of engineers and agricultural chemists, concerning the danger of salinity in irrigated agriculture.

Chapter 10 is organised around the question *Did planners and policy makers in the Murrumbidgee Irrigation Scheme learn from the past?* It describes the development of the Murrumbidgee Irrigation Scheme in New South Wales in the early decades of the twentieth century. Selected themes in the story capture the pressures and constraints (social, environmental, economic, political, cultural) on policy makers at that time.

An *Epilogue* briefly continues the story of water conservation and irrigation development in New South Wales to 1970, thereby linking the story to the discussion in Chapter 7.

**Part IV: Analysis and Conclusion** assesses the AEH study and approach.

Chapter 11 explores why planners and policy makers in the Murrumbidgee Irrigation Scheme did not learn from the past, and puts forward some dynamical hypotheses about common impediments to learning in complex human-environment systems.

Chapter 12 contains an evaluation of the AEH principles, and develops them into guidelines that can be used in other AEH studies. Finally, it outlines future opportunities for this kind of research.
PART I

A FRAMEWORK FOR APPLIED ENVIRONMENTAL HISTORY

Preface

Part I (Chapters 2-5) examines the theoretical concepts that are needed to build a framework for Applied Environmental History. The proposed approach needs to capture the historical perspective of the NRM issue or problem, to recognise the full range of dynamical effects that are operating, and to recognise the role of historical data in the process of experiential learning.

The discussion in Part I is guided by the knowledge that human beings are poor at learning from the past. One important reason is the difficulty of learning in complex systems. In addition, individuals will not learn from experience when they ignore failures in their own theories of how the world works. Nor will they learn from the past when they ignore the evidence from history of other people's experiences.

Cases of persistent NRM policy failure are found in policies for land use and settlement, the management of fisheries, forests, freshwater ecosystems, agriculture and biodiversity. Although NRM policy makers must deal with complex systems, they often do not pay attention to the underlying causes of persistent policy failures, and they rarely have an historical perspective of the NRM systems. At the same time, they have been hampered by the limited ability of the discipline of history to contribute to learning from the past.

In Moral Politics George Lakoff (1996) argued that many policies are driven by different concepts of morality, rather than based on genuine attempts to provide solutions to problems. While the situation is a depressing reality of life, this thesis is concerned with developing a method for policy makers who are genuinely concerned with learning from policy failures.

Chapter 2, with material from the discipline of history, addresses the contribution that history can make to learning from the past. It is focused particularly on public and applied history, and environmental history. Chapter 3 reviews the concepts and methods common to system dynamics, and describes generic patterns of system behaviour. The material in Chapter 4 is based on collaborative work about the process of experiential learning (Newell and Proust 2004). This work builds on existing models of experiential learning, and incorporates principles from adaptive control theory. Its development was prompted by that fact that the existing models gave little insight into the specific process of learning from the past. Chapter 5 takes concepts from all three domains and blends them to produce principles for Applied Environmental History.
The clock (1443) designed by Paolo Uccello for the Duomo in Florence. It is a rare example of a 24-hour dial with hands that move counterclockwise. Positive feedback effects drove clockwise designs to dominance after 1550. (www.kfki.hu/~arthp/html/u/uccello/3florenc)

An 18th century windmill with fantail is an example of a mechanical feedback system (Rowland 1974).
The aim of this chapter is to review briefly the contribution that the discipline of history can make to learning from the past.

2.1 Learning from the Past

Scholars have long pondered the question of whether a society can learn from the past and, if so, what lessons might be found there. Most believe that history can only explain a sequence of events in retrospect, but it cannot be used to predict. Furthermore, the question of how useful any lessons might be, when translated into other times and places, adds to the dilemma (e.g., Geyl 1957, Carr 1961, Plumb 1967, Tosh 1984, Tuchman 1984, Lowenthal 1985, Davison 1991, Rose 1993, Boulding and Boulding 1995, Evans 1997, Jordanova 2000).

In the eighteenth century, as society became more complex, and as perceived similarities between the present and past were fading, Europeans began to see the past as a different realm, 'a foreign country' as Lowenthal (1985) has described it. By the nineteenth century, social and technological developments were changing long-held views about history as a source of useful lessons. Historians were overwhelmed with the sense of difference and distance between the past and present. At the same time, the new approach to history writing represented by Ranke — presenting the past objectively 'as it really was' — was gaining ground.

Since then most historians have tended to believe that contemporary societies cannot draw useful lessons from the past because historical events and processes are highly contingent, and no two situations are ever identical. Nevertheless, for millennia, human beings have shown a natural curiosity about the past. They have developed ways to derive useful lessons from the past, allowing them to manage better and to survive longer (Diamond 1998). An historian of ancient Greece wrote that ‘From the earliest times man has endeavoured to record the prominent incidents of his own personal life, of the life of his family, clan and country', and that 'Man learns by experience, and experience lies in the past.’ (Rostovtzeff 1967). This curiosity is not confined to scholars. Ordinary people have been motivated to observe events, and patterns of events, to learn about their world, and particularly their relationships with the natural world. Table 2.1 contains several illustrations of ways in which human beings have used the past to serve the needs of society.

As a scientific interest in natural phenomena developed, the study of the past improved our models of causality in the natural world. Better models meant better predictions. Against this background, scholars laid the foundations for the modern historical sciences: cosmology,
astronomy, geology, geomorphology, palaeontology, evolutionary biology, ecology,
dendrochronology and climatology. A curiosity about the past has given rise to other history-
dependent fields of endeavour. Modern archaeology has acquired a range of scientific methods
and dating techniques to study the nature and development of past cultures. A similar interest in
human languages has given rise to the more recent field of linguistics. Hydrology, although not
included in the historical sciences, uses historical data to understand the nature of water, its
distribution and movement in and through the land. It also used the statistics of past events for
probabilistic prediction.

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<tr>
<th>Table 2.1: Learning from the past to serve the needs of society</th>
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<td>Lesson from the Past</td>
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<td>1. The location of essential resources</td>
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<td>2. The re-occurrence of certain natural events and the effect of natural phenomena</td>
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<td>3. Evolved skills and knowledge</td>
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<td>4. The virtues attributed to an exemplary life and the achievements of past individuals and groups</td>
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<td>5. That past events can be given significance</td>
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6. That past events can be endowed with supernatural significance

Societies have interpreted past events to explain their origins and the purpose of life, thereby creating myths, legends and belief systems.

7. That the significance of past events can be exploited to the advantage of individuals and groups

Societies have used the past to legitimise their position and authority. When individuals raised monuments to themselves they made conspicuous their association with significant events. During times of social and political unrest powerful groups have recorded their interpretation of events (e.g., the Bayeux Tapestry, an embroidery created in the 11th century, chronicles the Norman view of events leading to the invasion and conquest of England in 1066.)

8. That humans are part of a long continuum of events

Communities have used the past to enrich life and give humans a sense of purpose. Because the achievements of Classical Greece were held in high esteem in ancient Rome, wealthy Romans received part of their training in Athens. Similarly, the effect of the British past has been strong in shaping the values and on intellectual and cultural life of Australians.

A unique view of the human past was recently achieved using the techniques of modern geochemistry. In the case of Ötzi, The Iceman, scientists have studied the chemical composition of the human corpse discovered in 1991, and known to have remained for over 5000 years in the ice between Austria and Italy. Geochemists measured the isotopic ratios in tooth, bones and intestinal samples, and matched them with known isotopic ratios of the local geological strata. The analysis has revealed that Ötzi lived in a few valleys within 60 kilometres from the discovery site. The findings have demonstrated that the Alpine valleys of central Europe were permanently inhabited during the Neolithic-Copper Age of Europe (Müller et al 2003).
An important history-dependent concept developed by a social institution is the *Doctrine of Precedent* in the English Common Law. It dates from the twelfth century (Cross and Hall 1964). It developed first informally through experiential learning and long usage to meet the need for a unifying pattern of judicial decisions to assist legal decision-making. Since the eighteenth century the doctrine has formally made the decisions of superior courts binding on lower courts, and thereby provides a basis for consistency and prediction in legal decision-making.

2.2 The Discipline of History

Individual experiential learning is necessarily limited to patterns of events over short timescales. To learn from patterns occurring over long timescales, one must have a memory of the past, as it has been recorded by literate societies. This has become, relatively recently, the domain of the modern discipline of history.

Written accounts of the past have been produced since ancient times. Much of this takes the form of inscriptions discovered by archaeologists. For most of the historical past annals and chronicles have been the principal forms for recording events. These documents set down important events in order of occurrence without claim to objectivity, for example, Tacitus’ *Annals of Imperial Rome* (c.115 AD), the *Anglo-Saxon Chronicle* (from the beginning of Christianity to 1154), and Froissart’s *Les Chroniques de France, d’Angleterre, et des pais voisins* (14th century).

The practice and methods of modern historiography date from the nineteenth century. Leopold von Ranke (1798-1886) is representative of a new approach to history writing that developed in Germany around 1830. It emphasised factual accuracy by careful analysis of written records contemporary with their events. His belief, that the historian’s task was ‘simply to show how it really was (wie es eigentlich gewesen)’ (Carr 1961), marked a legitimate departure from the moralising annals and chronicles written in preceding centuries. His approach helped establish history as a discipline separate from philosophy or literature, and helped to shape the modern discipline of academic history writing in Germany, France and Britain. Modern historiography was influenced by moves towards empiricism in natural philosophy, and continues to develop an objective focus based on critical use of primary sources.

The main areas of interest of modern history were originally political and military affairs, followed by biography and the history of ideas. These subjects reflected their close connection with the development of the nation state from the nineteenth century. Later came economic, social and technological history as interest shifted from the state and its elites to whole societies and ordinary citizens. In political history, history and policy were strongly connected.
The economic, technological and social changes that followed World War I and the Great Depression shifted interest away from issues concerning the nation state and towards issues affecting ordinary people in society. In America this shift was marked by the New Deal and the subsequent government initiatives which formed the basis of post-war US social policy (Graham 1993). Similar changes were taking place elsewhere around the world in the post-war period. New administrative and policy systems were evolving in modern western democratic states, and these systems grew in complexity with those states. Consequently, the history profession found a new involvement with social history. Since the 1970s social history has replaced political history as the dominant area of concern on the part of historians. In Australia this interest was further encouraged by the bi-centenary of permanent European settlement in 1988. At that time, and under the same influences, in Australia grew an interest in historical archaeology (the archaeology of the colonial period). This further revealed and emphasised the history of ordinary people.

As interest in the social dimension grew, numerous new sub-fields evolved, along with their special techniques and approaches. These sub-fields cut across earlier classifications. The earlier divisions failed to recognise the web of interdependencies found in human history. The new fields encourage scholars to think about diverse historical phenomena in relation to one another, and provided new approaches to inquiry about the past. Examples include environmental history (focused on the relationship between nature and humans), quantitative history (using numerical data), oral history (using interviews), and the many themes found in cultural and social history, such as labour, minorities (women, ethnic groups), colonies and disease.

Because social history was developing its own research agendas with little attention to the state, the needs of policy history had to be met by other professionals (Graham 1993). From 1945 social science stepped in to produce people with the skills needed in a government system that was now more focused on, and had broad responsibility for, social issues. Governments needed people with skills that were designed to address immediate policy concerns and their outcomes: quantitative and analytical skills. Therefore, policy history became the domain of social scientists not historians. Because it ‘failed to become institutionalised in the history profession’ (Critchlow 1993), policy history has not developed as a sub-field of history. It is an outlier.

2.3 Public and Applied History

Amid the rise of interest in social history, public history emerged in 1975 as a field distinct from academic history. In that year Robert Kelley set up a course in public history at the University of California (Santa Barbara). This course was intended, in part, to provide new opportunities
for young historians when academic positions were declining in universities.¹ Other universities followed, and as a result public history has developed a strong presence in America, Australia and Britain.

The term public history conveys the ideas of serving the interests of the public and of publicly funded history. Because public historians are engaged in placing an account of events on the public record it is also seen as popular history. Davison (1991) regards it as the oldest history of all. Since ancient times ‘historians have drawn inspiration from their practical engagement in public life and have hoped, often vainly, to apply the lessons of history to the conduct of public policy’ (Davison 1991:4).

The subjects of public history fall into two streams. The first, and by far the larger of the two, includes issues that fit within cultural resource management: heritage conservation, historic site preservation and interpretation (salvaging the past), the writing of commemorative, institutional, local and family histories (the idea of place), and the interpretation of social history by museums. Museums built around themes in social and cultural history are now numerous in many countries. They cover themes as diverse as the French Resistance (at the Centre d'Histoire de la Résistance et de la Déportation in Lyon, France), and the nineteenth century convict history in New South Wales (at Hyde Park Barracks in Sydney, Australia). In this context, public history can be influential in shaping national identity.² In Australia, public history has taken on a significant role in support of legal claims to traditional lands by Aboriginal people under the Native Title Act, 1993.

The strength and success of this stream of public history has resulted in many individuals and communities having a deeper knowledge of particular aspects of their past. Community history projects and historic-preservation movements have made people value their heritage. But, as Lowenthal (1985:xvii) argued, the focus on preserving selected elements of the past has ‘dampened creative use of it’. A better understanding of heritage values is not contributing to the wider use of history beyond the domain of cultural resource management.

The second, less prominent, stream of public history covers public life in both government and business. Historians work in archival management, public relations, celebrating corporate anniversaries and in labour relations. A few corporate historians aspire to research (particularly on economic issues) and policy planning (Walkowitz 1986). Even fewer have shown a direct

¹ Since 1978 The Public Historian, published by the University of California (Santa Barbara), has been the main voice of the public history movement in USA.
² In Australia a committee, appointed by the conservative Commonwealth Government, strongly criticised the National Museum of Australia for its interpretation of the darker side of Aboriginal history after Europeans arrived (Carroll Committee 2003).
interest in public policy. The activities in this stream of public history have given rise to the term *applied history*, which has come to define the use of history in the problem-solving domains of policy analysis and policy making. Here practitioners are directly interested in learning from the past.

### 2.4 The Needs of the Policy Community

The past abounds in cases where policy makers have not learnt from history. This is particularly so in natural resource management (NRM). While NRM policy makers may see the need for history, they usually lack the skills and time to address the matter. Because historians are not generally interested in the details of current policy and policy-making processes (in any field), they have rarely applied their skills to the needs and problems of policy makers. Yet, NRM could benefit enormously from some form of collaborative relationship between policy makers and historians.

In Australia most historians engage with current issues in broad terms only, as do the members of most groups in society. Their involvement is usually in an *ad hoc* and idiosyncratic manner, making it difficult to recognise their contribution. Generally, they have shown little interest in *engaging with* (as distinct from *servicing*) the contemporary policy process.

A few Australian historians have engaged directly and vigorously in public debate on important social, and often controversial, issues (for example, in 1988, on the occasion of the bicentenary of European settlement of Australia). Some historians are involved in policy as members of formally constituted advisory committees, or act as expert witnesses in legal cases. Others are able to influence a wider audience on public policy issues as media commentators and by writing popular books. Historians have also found themselves as political speech-writers, and have gone on to publish political biographies that necessarily record their own involvement with policy issues. But these are exceptional. Nevertheless, since the demise of the so-called 'liberal education' few historians are engaged directly with policy issues in the government service. Nor is there an apparent framework for such engagement. Fewer are actively involved in problem solving across the range of policy issues that confront government. They see history as contingent, and therefore as contributing little to generic issues.

On the other hand, in the USA, historians whose interests are in political science and foreign relations have moved closer to the policy domain. Arthur Schlesinger, a professional historian, was senior policy advisor to President Kennedy in the 1960s. George McGovern, a US senator during the 1960s and 1970s, saw events from the perspective of a professional historian. In the

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3 Notable in this group are Manning Clark, Geoffrey Blainey, Henry Reynolds, Humphrey McQueen, Stuart Macintyre and Marilyn Lake.
1970s and 1980s at Harvard’s Kennedy School of Government, historian Ernest May taught in the areas of history and foreign policy. He saw the need for historians to supply ‘perspectives on events’, and wrote: ‘history is not likely to be better used in government unless those who advise on or make policy discover how better to use historians’ (May 1973:174).

Because policy makers generally do not see how historians could be directly useful to them, they have not sought collaborations. They have not put pressure on historians to develop their understandings, and adapt their approaches to be relevant in the problem-solving domain. A notable exception occurred in 1984 with the Victorian Standing Committee on River Improvement (Dovers 1994). In that case, environmental history had a powerful impact on policy when the effects of river degradation in Victoria were illustrated using sets of historic and contemporary photographs. More recently in Australia a small number of historians have been influential in the policy debate on indigenous matters (e.g., Henry Reynolds and Peter Read). Historians in this group are effective in areas of social justice. They have used history powerfully in cases of the 'stolen children', and to argue both general and specific legal claims (notably the Mabo and Wik Cases) to traditional lands by Aboriginal people. Similarly, Jane Carruthers has used environmental and social history in support of indigenous claims before the Land Claims Commission in South Africa (Carruthers 2003).

Despite the philosophical rhetoric about whether one can learn from the past, the challenges to society remain. Some scholars, including historians, believe that we must find ways to derive useful lessons from the past (May 1973, Auchenbaum 1983, Tosh 1984, Tuchman 1984, Kelley 1988, Neustadt and May 1986, Graham 1993, Boulding and Boulding 1995). Kenneth Boulding (1995:1) recognised that 'The great predicament of the human race is that all experiences are of the past, but all our decisions are about the future.' Tosh argued that there is a vital role for history to provide ‘a much-needed historical perspective on some of the most pressing problems of our times.’ As long as society expects an interpretation of the past that is relevant to the present and a basis of formulating decisions about the future, historians have a role to play. Kelley goes so far as to call it 'a duty and an obligation'. There is a need in public life to interpret history as a process. Most historians claim that they are concerned with the past not the present, and therefore it is not their role to draw lessons from the past. Tosh argues in reply that historians ‘are in fact the only people qualified to equip society with a truly historical perspective and to save it from the damaging effects of exposure to historical myth’.

In the dynamically complex world of public policy, learning from the experiences of history is essential. Communities, societies and governments have always needed to use the past to improve their models of causality. Table 2.1 summarises the types of situations where people through history have needed knowledge of the past to manage, to predict and to survive. As
Graham (1983) made clear: 'The past, along with its "lessons" and insights, is deeply involved in policymaking.' But public officials in general make extraordinarily poor use of history in decision making. They use the past 'mostly to reinforce bias and strengthen advocacy positions derived from other perspectives' (Graham 1983:6). Applied historians, therefore, can make an important contribution to policy history.4

The importance of history in policy making is self-evident. Both scholars and people in public office have expressed this view (May 1973, Stearns 1982; Schlesinger 1963, McGovern 1989). In general, historians have shown little interest in policy history, and have been reluctant to engage with policy issues. By virtue of their personal interests and nature they are more inclined to study the distant past. The recent past, where policy makers' responsibilities arise and where the origins of most contemporary policy issues lie, concerns them less.

Traditional historians become uneasy when they hear the word forecasting. Most argue strongly that no two examples of an event are ever the same, and therefore history cannot be used as a basis for prediction. They thereby miss the point. Historians do not need to predict, but they need to help policy makers build better understanding of the systems they are trying to manage. Historians can help policy makers improve their models of causality so that they can design better policy (which is necessary to predict). The epigram of Heraclitus that "one cannot step in the same river twice" still holds true. But this is unhelpful advice to policy makers — especially environmental managers and policy makers — whose areas of responsibility and deliberations are crying out for historical insights.

Despite the reticence of historians, the need to predict remains an unavoidable and fundamental aspect of management. I argue that historians confuse the need to predict with the need for predictions to be accurate. The responsibility of those holding public office for planning for the future does not carry with it the expectation that policy decisions be flawless. Scholars engaged in adaptive management support this (Dovers 2000b). When working at their best, responsible professionals from many disciplines provide advice and recommendations after due consideration of the relevant issues. Thus, forecasting must involve reflection, experience and judgment. The legal system is a good example. When members of the judiciary reach a decision

4 The material has been drawn largely from the experiences of American public historians, published in The Public Historian by the University of California (Santa Barbara) since 1985. In contrast to the situation in the United States of America, it is difficult to assess critically the role of historians in the policy-making arena in Australia. There seems to be little active participation on the part of Australian public historians in the problem-solving area of policy making. The Australian Government has sometimes called on professional associations to provide policy advice via ad hoc working parties. For example, in 1994 the Federal Government invited the Australian Committee of the International Council on Monuments and Sites (Australia ICOMOS) to prepare a policy statement on conservation of the built heritage. The statement was adopted in Creative Nation: Commonwealth Cultural Policy (Australia 1994). The present author co-ordinated this working party which comprised a small group of heritage conservation practitioners including an historian.
on a matter before them, that decision is usually called a *judgment*. It is not seen as a guaranteed watertight pronouncement on the issues at hand. It draws on the experience of precedent, and is subject to review by superior courts. With their strong focus on prediction, historians have lost sight of the fact that policy making and learning involve a process of iterative improvement.

Stearns (1982) has supported this view. He criticised the preoccupation of policy research with 'falsely exact forecasts' and urged 'a sense of orientation towards the future' in order to address 'the cultural bias towards seeking superficially exact projections' (Stearns 1982:25). These criticisms reflect the different perceptions that exist of the policy-making process. For several decades policy scientists have been developing models of the policy process. These models range from an incremental (trial-and-error) approach to policy evolution, as described by Lindblom (1959), to a rational (systematic) style which sets out to design learning mechanisms into the policy process (e.g., May 1992). Howlett and Ramesh (1995) have summarised the basic stages in the policy cycle: (1) agenda-setting, (2) policy formulation, (3) decision-making, (4) policy implementation, and (5) policy evaluation.

Policy issues are problem-centred and multi-disciplinary. The disciplinary culture of historians has made them less interested in government policy and process, and the essential need of governments and business to solve problems and to predict. But for those historians who embrace this field, practice and experience using necessary new skills will make them better adapted to a policy environment. As Karamanski (1990) said, it is a matter of 'returning history to public service'.

Applied history is more often criticised for its short-comings than commended for positive contributions. Criticisms are based on methodological difficulties, which have understandably stifled its growth. Applied historians recognise three ways in which our understanding of the past can inform the present: using argument by analogy, using trend analysis, and providing an historical context (Auchenbaum 1983, Davison 1991).

When historians warn about the misuses of history, they are addressing the fallacies of analogical reasoning (e.g., Geyl 1957, Plumb 1967, Fischer 1970, May 1973, Stearns 1982, Graham 1983 and 1986, Auchenbaum 1983, Tosh 1984, Neustadt and May 1986, Davison 2000). *Argument by analogy*, as defined here, relies on a form of logical inference that assumes, if two things are known to be alike in some respects, then they must be alike in other respects. May (1973) and Neustadt and May (1986) have provided a now-classic account of the misuses of history (via analogies) in America foreign policy. They documented how senior officials seized on inappropriate analogies, without examining how they might be misleading, to support disastrous policy initiatives in the twentieth century. They demonstrated that policy makers
were not only poor at using history (by focusing on false analogies), but also 'hopelessly addicted to doing so' (Graham 1983:7). Graham (1986:57) captured the attitude among applied historians nicely: 'an analogy is a way of transporting dangerous cargo.'

Tosh (1984) has discussed the appeal of history as a source of precedent and prediction. To illustrate the problem of conflicting precedents, he considered two cases of the arms race. In the precedent of World War I 'one of the causes was the relentless escalation in armaments from the 1890s onwards'. But from the experience of World War II comes the much-cited 'object lesson in the dangers of military weakness and of appeasing an aggressive power' (Tosh 1984:13). In the absence of necessary deeper analyses and understanding of each set of conflicts, the two cases continue to arm government decision makers with arguments that are superficial and ill-defined. In the use of either case decision makers fail to address the underlying system of cause and effect.

Richard Rose is a policy analyst with experience in Britain and America, and founder-director of the Centre for the Study of Public Policy at the University of Strathclyde in Scotland. He compared lesson-drawing from the past with the diffusion of ideas, and sees a lesson as 'a shortcut that relies on experience elsewhere as a source of knowledge' (Rose 1993:24). He is wary of reasoning by analogy in policy making. While analogies can be useful in communicating within an organisation about past situations familiar to everyone, policy makers use them to jump to conclusions. They lack the time or expertise necessary to analyse like-situations critically. Hence they can fail to understand the full range of feedback effects that are operating in the situations being compared.

Trend analysis is based on the assumption that recurrent patterns of behaviour in the past will continue into the future (Figure 2.1). But the constant process of historical contingency regularly introduces new variables. Of course, predictions can work in some cases, particularly where gross effects are concerned. For example, Tosh predicted in the 1960s that, in the presence of 'a white culture of extreme racial prejudice and an economy based on artificially cheap non-white labour, South Africa will experience an increasingly violent confrontation between the races for the foreseeable future’ (Tosh 1984:14). But, in general, trend analysis should be regarded with the same caution as analogical reasoning.
Figure 2.1: A simple trend analysis graph. The behaviour of a variable (Y) is plotted on the vertical axis, against time on the horizontal axis. The filled circles represent observations of Y. When reasoning by trend analysis, it is argued that the pattern of behaviour of the variable will continue into the future, as shown by the dashed line (A). But the pattern of behaviour of Y may display a steep increase (line B) or downturn (line C), as delayed dynamical effects come into play. Or, contingent events can completely invalidate the assumption of smooth changes.

Analogical reasoning and trend analysis have serious deficiencies. Both approaches compare like-events superficially, and fail to see patterns in those events, or to look at the mechanisms beneath the patterns. They ignore personal perceptions of events (based on individuals' different models of causality) and fail to recognise appropriate timescales. As neither can provide truly useful results, applied historians have often fallen back on the third approach, that of placing the problem or issue in historical context. In particular, they focus on change over time. As Davison (1991) has noted, this approach has the disadvantage of exposing a larger and more complex temporal and social context from which it is more difficult to draw lessons. Again, the art is in knowing how much history is enough, an issue regularly faced by the judiciary when writing legal judgments.

Let us look at a particular program aimed at helping policy makers to make better use of historical resources. From the 1970s Richard Neustadt and Ernest May ran a course entitled “Uses of History” at Harvard for senior government officials. In Thinking in Time (1986) they describe how they were influenced to start this course. They had a sense of there being ‘a host of people who did not know any history to speak of and were unaware of suffering any lack, who thought the world was new and all its problems fresh . . . and that decision in the public realm required only reason or emotion, as preferred.’ They were concerned to review the
processes of high-level decision making in US foreign policy, to examine the influences on the policy-making process, to improve policy making by a more systematic and critical use of historical sources, and, at the same time, to avoid the superficial use of analogies. Course participants developed skills with which to acquire a better understanding of the dynamics of historical events.

Policy design and analysis draws on a range of methods and approaches, and on skills and insights of different disciplines in the social sciences and law. Social scientists come from a range of backgrounds. Many have quantitative skills, and use rigorous analytical methods with specific applications to solving problems. They operate in areas such as economics, law, public administration and operations research. Their expertise is drawn from areas such as statistics, mathematics, optimisation theory, game theory, micro-economics, econometrics, linear programming, cost-benefit analysis, and computer modelling of dynamic systems. Most disciplines in the social sciences operate without any historical perspective. In this respect law is an exception. Nevertheless, the techniques of the social sciences are rarely useful for detecting the longer-term system effects of policy, and for explaining policy failures.

Although historians can provide a vital historical perspective to public policy, their impact in this area has been slight. They have remained marginal in the expanding professional world of policy analysts who advise decision makers (Stearns and Tarr 1993). Graham (1993:30) has explained this situation for America: 'The nation's historians have been abandoning the field of politics and policy, yielding it to policy scholars in the social sciences and law whose writings most American historians are neither inclined by interest to read nor equipped by training to understand.' This explanation is equally valid for Australia.

Over past decades communities have become aware and highly critical of the a-historical character of many public policy initiatives. Management of the complex human-environment systems encountered in NRM has suffered as a result. Policy history, in the hands of those trained in the social sciences, has paid more attention to the state than to the social pressures on it.  

Graham (1993) has drawn a distinction between 'history in policy making' and 'history of policy making' (italics original). In the first case, non-academic applied historians 'have answered questions posed by others'. In the second, 'academic historians have long answered questions posed by themselves' (Graham 1993:21). He attributes this to the lack of an analytical

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5 A special issue of Journal of Social History on Applied History appeared in 1981. It was prompted by 'a wide belief that existing policy sciences have failed to resolve many social problems, at least in part, because of a lack of sufficient historical perspective' (Stearns et al 1981).
framework to study the development of the modern state and its public policies. Old approaches in history (particularly the use of narrative) have not been able to accommodate the complexity of the late twentieth-century state.

Kelley (1988) has made a plea for historians to focus on the policy process (as opposed to just policy content). Such an approach to policy history implies that historians examine the structure, and thus the underlying dynamics, of the larger policy system. This is an interdisciplinary endeavour. Stearns and Tarr (1993) have called for 'policy-useable history'. This requires 'reorientation from narrative to analysis' if history is to penetrate the policy-making domain, and applied historians are to fill a much-needed role there. Stearns and Tarr have made a strong case for more social history to inform policy, and for integrating policy concerns with an understanding of social trends. Reuss (1993) also supports the need for policy historians to be equipped with interdisciplinary skills.

Many scholars and lay observers argue that the interests of the state and society have diverged in many significant fields, but they need to be integrated again. Policy history has contributed to this situation because it has 'paid more attention to the state itself than to the social pressures on it' (Kirkendall, reported in Cole 1994:18). Therefore, integrated historical perspectives are vital in many areas of human activity, especially those concerned with human-environment system interactions (Newell et al 2004).

In the world of corporate management and business those committed to improving institutional learning also face problems of policy learning (Schön 1983, Morgan 1986, Senge 1992, Senge et al 2000, Argyris and Schön 1996, Sterman 2000). Here different learning tools have been developed, such as scenario planning (Schwartz 1991, van der Heijden 1996) and the Learning Histories developed at the Massachusetts Institute of Technology (e.g., Roth and Kleiner 1999).

One corporate historian has recently made a strong case for applied history in the business world (Cortada 2000). He sees how applied historians can play an important role to help managers avoid obvious fallacies drawn from history. Like government policy makers, strategists and managers are far too eager to use false analogies. He argues that historians have barely reached out to business executives to demonstrate how history can be useful to them.

2.5 Environmental History

Environmental history appeared in the late 1960s with the spread of environmental awareness and the consequent increasing desire to understand the background to contemporary

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6 It is worth noting that Tarr and Reuss are both environmental historians whose interests have taken them into public history. Joel Tarr, at Carnegie-Mellon University, is well known for his work in the urban environment, particularly on pollution. Martin Reuss, Senior Historian, Office of History, US Army Corps of Engineers, works in water resource management.
environmental problems. It takes on a range of tasks concerned with natural phenomena and the dynamics of human-environment relationships. It has been described as ‘the investigation and description of previous states of the biophysical environment, and the study of the history of human impacts on and relationships with the non-human setting’ (Dovers 1994:4). The relevance of the field is particularly important ‘to explain the landscapes and issues of today and their evolving and dynamic nature, and from this to elucidate the problems and opportunities of tomorrow’ (Dovers 1994:4).

As a result of its wide interest, environmental history has grown into a large interdisciplinary domain. Worster (1988) has identified three levels on which environmental history proceeds, three clusters of issues it addresses, and three sets of questions it seeks to answer. These are (a) an understanding of nature itself (including humans) as organised and functioning in the past; (b) human interactions with nature through evolving social and economic systems; and (c) the intellectual encounter with nature, which produces perceptions, myths and ethics as a basis for human interaction with nature.

Many of the tasks that environmental history assumes are also performed by people from other disciplines. For a long time geographers and geomorphologists, and later dendrochronologists and ecologists, have been studying a range of environmental phenomena that are generally characterised by change over very long timescales. Different environmental settings, and hence different histories, will pose different issues, questions, sources and approaches. Nevertheless, there are recurrent themes throughout environmental history. They reflect the core purposes of the field, irrespective of the primary discipline and nationality of the author. Some of the recurrent themes that environmental history has described and analysed include:

- Past states of the biophysical environment, the human influences on it, and our understanding of it, from earliest times. These themes represent histories written on a very large scale (e.g., Boyden 1987, McNeill 2000, Cook 2003).
- Human impacts on the environment in historical times, and human relationships with non-human setting, e.g., in Europe (Braudel 1949, Bloch 1931), in South Asia (Grove et al 1998).

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7 Bonyhady (2000) has shown that environmental awareness can be found in Australia from a much earlier date. For example, Krefft (1830-1881) a scientist with the Museum in Sydney was interested in how pastoralism was changing the environment and leading to the extinction of small marsupials (Krefft 1862).

8 This overview is confined to the literature available in English. Nevertheless, I recognise that significant contributions to environmental history have been made by scholars writing in other languages, notably German and Swedish (see McNeill 2003).
Environmental change, e.g., climate change (McIntosh et al 2000), in Europe (Le Roy Ladurie 1967), and as a result of human impacts on soil erosion in USA (Worster 1979) and on the Mississippi River valley (Barry 1997).

Effects of European colonisation (Crosby 1986, Grove 1995), which reflect the strong European notion of 'taming' nature (Beinart and Coates 1995).

Cultural systems that have emerged as a result of particular environments, e.g., in France (Bloch 1931), in India (Arnold and Guha 1995), in South Africa (Dovers et al 2002), in British colonies in the southern hemisphere (Griffiths and Robin 1997), and in Australia (Powell 1989, Blainey 1966). Bonyhady (2000) shows the particular response of one cultural system, the English Common Law, to the Australian environment.

How humans have perceived the biophysical world (Marsh 1864). The concepts of distance, wilderness, and the waterless and remote outback form a common backdrop in much Australian history (Blainey 1966, Powell 1989).

The development of environmentalism, e.g., in Australia (Hutton and Connors 1999, Robin 1998), and in Britain (Bramwell 1989).

The formation of the Earth's landscapes which is a component of most of the themes above, e.g., in south-eastern Australia (Hancock 1972). It has been a preoccupation of geographers as well.

A much smaller collection of themes is beginning to emerge as a result of successful collaborations between history and other disciplines. This new direction is welcomed by Jordanova (2000:199) who believes 'that integrating apparently diverse sources and approaches to produce more holistic accounts is an important goal of the discipline [of history]'. From these new collaborations themes are emerging which use historical data in the following ways:

- to reconstruct past climates, climate-related processes and natural disasters, e.g., in Europe (Pfister et al 2002), in Korea (Kang 2003).
- to investigate the emergence and spread of diseases (Whitcombe 1995, McMichael 2002).
- to investigate events connected with natural phenomena, e.g., El Niño events (Grove and Chappell 2000), and landscape change in Australia (Starr et al 1999, Cook 2001).
- to understand the extent of resource exploitation and ecological deterioration, e.g., river ecology in NSW (Roberts and Sainty 2000), Californian fisheries (Jackson et al 2001), forests in Africa (Fairhead and Leach 1996).
- to set baselines for use in resource-allocation processes, e.g., the presumed historical vegetation extent in Australia's Regional Forest Agreements (reported by Mobbs 2003).

In the United States there is a vibrant business in studying the environmental history of highly polluted industrial landscapes over which lawsuits have been launched. Historians work with
engineers from the Environmental Protection Agency (or the defendants) to assemble evidence to establish (or deny) culpability for pollution (e.g., Bookspan 1991).

In Australia when history has been used to inform environmental policy it has occurred in the general area of providing a context: by describing the history of particular NRM policies and how they have operated, or histories of particular institutions. Three recent examples of government agencies seeking an historical perspective on policies can be mentioned. The first was in 1993. *The Emergence of Bioregionalism in the Murray-Darling Basin* (Powell 1993) provided the important social, institutional and environmental contexts for the scientific and technical research that has been carried out in the Basin. It is the work of an historical geographer and was commissioned by the Murray-Darling Basin Commission (MDBC). The MDBC is an inter-governmental body representing the Commonwealth and five State and Territory Governments. Powell has also written commissioned histories of government agencies dealing with water management in Victoria (Powell 1989), Queensland (Powell 1991) and Western Australia (Powell 1998). These go some way towards addressing NRM policy issues.

The second appeared in 2002. Reeve et al (2002) provided the MDBC with a report on the broad policy history of agriculture and natural resource management in the Murray-Darling Basin. Their study examined broad trends over the twentieth century in trade and industry policy, farm policy and water resources and land resources policy in the Basin. The historical material used came from secondary sources. The study was initiated under the MDBC Human Dimension Strategy. It acknowledged the need to reverse the trend towards environmental degradation in the Basin, arising from unsustainable agricultural practices, and the need for new policy directions.

The third appeared in 2003. The Australian Alps Liaison Committee (AALC) commissioned a study on land use practices in, and management of, the national parks located in the Australian Alps (Crabb 2003). The study was for the several agencies that share responsible for the alpine area. Crabb, a geographer and policy analyst, undertook archival work and oral histories (interviews) spread over a year. Historical reports of this kind provide an effective answer to the loss of institutional memory or 'policy amnesia', as it has become known in Australia, as well as 'ad hocery' in policy initiatives (Dovers 1995 and 2000a).

In the USA, Cronon (1993) believed that most environmental historians 'aspire to contribute to contemporary environmental politics', and want their histories to be useful not just in understanding the past, but in influencing the public policy of contemporary environmental management. But, again, I see this as a case of historians being interested broadly in policy history, not engaging closely in policy processes (see §2.4).
A few scholars have addressed the contribution that the discipline can make to policy. Dovers (2000b) has proposed a potentially strong role for environmental history to inform the contemporary challenges of sustainability, and resource and environmental management. He spells out how environmental history can inform policy in three ways: (1) by providing a general historical perspective, (2) by establishing baselines, and (3) for policy and institution lessons. Uekoetter (1998) has argued that historians should focus on the process of organising responses to perceived environmental problems. While environmental history has come a long way in three decades, its contribution to the policy domain of environmental and resource management still lags behind progress it has made in other areas.

2.6 A Broader Historiography

Despite the emergence of many specialised fields, the discipline of history has not developed approaches and methods for learning from the past that assist decision makers dealing with public policy issues. Many areas of public policy are in grave need of an historical perspective, based on a rigorous and structured use of the past. The sustainable development of Earth's natural resources is an obvious case. Policy makers need to see the historical perspective of their programs — in other words, to be aware of the origins of current issues and problems. Such a perspective must distinguish factors that are recurring from those that are novel, and thereby indicate what is important when searching for useful learning from the past.

Before history can contribute to learning from the past in complex human-environment systems a more comprehensive and useful approach to learning from the past is necessary. Historians need to understand how human behaviour (activity) is guided by decision-making rules (policies) that are dependent on particular mental models. A centrally important set of models (for the policy maker or manager) is the systems models, which demands an understanding of systems concepts and the behaviour of systems. As Cronon (1993) has said: 'The lines and shapes we draw on the land reflect the lines and shapes we carry inside our own heads, and we cannot understand either without understanding both at the same time' (Cronon 1993:19). Therefore, a useful framework will integrate concepts from dynamical systems and takes account of the process by which humans learn from experience.

If applied historians are prepared to engage in the contemporary world of NRM policy, they will need more powerful techniques in order to distinguish patterns of generic behaviour from historical contingency. Such techniques must support deliberate cognitive adaptation. Therefore, they must take on some of the understandings, concepts and techniques of the behaviour of feedback systems (discussed in Chapter 3), and the cognitive adaptation process (discussed in Chapter 4).
The aim of this chapter is to review briefly concepts and methods from dynamical systems theory that can contribute to the proposed AEH approach.

3.1 Introduction

For a long time, scholars who study the dynamics of mechanical, social and natural systems have recognised the ability of these systems to produce characteristic patterns of behaviour. These patterns arise from the circular causality, or feedback, operating within them. Because feedback effects operate in a wide range of systems, a formal understanding of these effects has grown out of several intellectual fields over centuries. Richardson (1991) has shown that in the past 50 years the feedback concept, as used in the social sciences, has developed from five or six intellectual traditions: biology, engineering, the classical social science literature, mathematical models of biological, economic and social systems, and formal logic and computing.

Policy making in any system with complex relationships must allow for a wide range of causal connections and their feedback effects. Some effects will be proximate and clear. Others will be remote in time and place, and therefore obscure. Consider, for example, two attempts to control population. The first example comes from Sub-Saharan Africa. Since the early 1970s international initiatives to reduce resource demand worldwide have resulted in pressure on many governments to introduce population-control policies. In a review of population-growth studies in the developing world, sociologists Caldwell and Caldwell (1990) found that, while birth rates had begun to decline in many areas of the developing world, population-control strategies were remarkably unsuccessful in Sub-Saharan Africa. A second illustration of the failure of population-control measures comes from Romania (David and Wright 1971, Sterman 2000). In the 1960s the Romanian Government put in place measures designed to increase the birth rate. As well as propaganda extolling the virtues of large families and emphasising citizens' duty to have more children, the measures included making illegal the importation of contraceptive devices. Some modest tax incentives were introduced. In 1966 abortion was banned, though it had been freely available on demand since 1957. Immediately the birth rate rose sharply, but within months it began to fall. By 1971 the birth rate had returned to the vicinity of its pre-intervention level, and continued to fall slowly for the next 20 years.

What produces such contrary effects? In both cases policy makers failed to change existing trends in population growth. Caldwell and Caldwell showed that in the African case the program designers failed to allow for the full range of issues that ought to have been addressed
if their programs were to achieve controlled population growth. They identified a strong bias against small families, because embedded in the culture of the groups studied is a fear of dying without descendants. Other elements, such as the land tenure system (by clan), family structure and the practice of polygamy, also influenced family size. Moreover, the fact that food production is the domain of women and children meant that the cost of supporting a large family is not a disincentive to a man to produce more offspring. The culture of the groups studied has no simple concept of parent-dependent children, since raising children is seen as the responsibility of the larger social unit beyond the parents. Therefore, the negative economic consequences of large families, while dominant in other countries, are much less important in Sub-Saharan Africa.

In the Romanian case, the people, among the poorest in Europe, found ways around the policy. Women took unsanitary and life-threatening steps to terminate pregnancies, with the result that between 1965 and 1967 there was a near-tripling of deaths due to complications from abortions. Neo-natal deaths also increased. Later many families were forced to place children in state-run orphanages where conditions were appalling. The reality was that Romanians could not afford large families.

Figure 3.1: A self-regulating system resists change. The upper half of the diagram shows the policy makers' limited view of the problem. The shaded lower portion represents the many other factors that were ignored. Policy makers did not see these other factors, nor the mutual causal links between birth rate and these cultural, religious, economic or environmental factors. These unseen feedback effects operated to counteract the applied policies.
In the case of the two population-control strategies, the policy designers had not anticipated resistance to the programs arising from cultural, social and economic factors. Such strong 'policy resistance' was an unexpected endogenous effect, generated within each local community. In Sub-Saharan Africa it was generated by the dominant cultural and religious beliefs, and in Romania by the desperate economic conditions. In Africa the desire for large families persisted, and in Romania the desire for small families won the day, both against strong pressure to change. The overall effect is illustrated in Figure 3.1.

3.2 System Structure and Behaviour


Systems approaches cut across traditional disciplinary boundaries in order 'to understand a problem from an integrated vantage point' (Roberts et al 1983:5). An effective systems view of the African study would have included interactions between cultural, environmental, sociological and religious aspects of life, and put less emphasis on economics (as managers in the developed world understand that term). By contrast, the Romanian population-growth policy was driven by political agendas; a comprehensive systems view would have included economic factors as essential elements in the problem.

My definition of a feedback system comes from Newell and Wasson (2002):

A system is something composed of . . . parts (elements, agents) that interact to constrain each other's behaviour. It is these mutual constraints, operating between the parts of the system, that limit the range of behaviours available to the system as a whole—and thus gives rise to its “emergent” (or synergistic) properties. In other words, the characteristic (or lawful) behaviour of the system arises from the internally generated (endogenous) forces imposed on parts of the system by parts of the system.

A system can be regarded as an abstract model of some aspect of a real-world situation (Checkland 1984). Such a model will consist of a list of variables selected by a particular observer, and a specification of the way in which these variables interact mutually to control each other's behaviour (Ashby 1960). The structure of a system is its network of causal relationships. Systemic models describe self-contained entities ( wholes). Thus, they can be used to explain endogenously driven change and to predict characteristic responses to the application of exogenous forces.
Where one chooses to draw the boundary of a system plays a central role in defining the system’s structure. Within the system boundary are the variables that are considered essential to describe the observed behaviour. Outside the boundary are variables that are either treated as exogenous influences or considered irrelevant. The choice of which variables to include or exclude will depend on the character and focus of a particular study. By excluding religious beliefs and traditions from the African population-control strategies, the program designers had drawn the system boundary too narrowly. Consequently, vital feedback effects went undetected, leaving the designers unable to explain why their strategies were ineffective, when they had been successful elsewhere.

Systems can exhibit two types of complexity: detailed (or combinatorial) complexity and dynamic complexity. The former arises when there is a large number of components (or causal links) in a system. For example, the task of scheduling events, venues, officials and athletes for the Olympic Games is complex because of the large number of possible combinations. Dynamic complexity can occur in a simple system with only a few variables. It arises particularly when there is a change in feedback loop dominance. Even if it is structurally simple a system with dynamic complexity can produce unintended policy outcomes on widely varying temporal and spatial scales. It is seen, for example, in the system archetype 'Fixes that fail', described by Senge (1992). In this archetype a response to a persistent problem is effective in the short term, but brings unforeseen consequences on longer timescales. In the longer term the original response makes the existing problem worse. For example, burning wetland vegetation to destroy purple loosestrife (*Lythrum salicaria*) exposes the soils to sunlight, thereby hastening further germination of the unwanted plant which eventually becomes more prolific (Tenner 1997).

The dynamics of some systems operate over such large spatial and temporal scales that an understanding of the system is difficult to achieve. A natural system that provides an example is the Thermohaline Circulation of the ocean. This is the system of ocean currents in which different water temperatures and levels of salinity cause deepwater circulation of the Earth’s oceans. Dense water, cooled in the northern polar region, sinks and flows slowly toward the equator along the bottom of the North Atlantic Ocean. The circulation continues into the Indian and Pacific Oceans. The water warms in the tropics and then retraces its path back to the polar region on the surface. Oceanographers have known of these fundamental processes for some time. It is only since the 1980s that they have come to a better understanding of the dynamics of this system (Steffen et al 2004).
3.3 Methods for Exploring System Dynamics

The important properties of system-dynamics problems are that they contain quantities that vary over time, that the pressures or constraints producing and controlling this variability can be described causally, and that important causal influences can be contained within a closed system of feedback loops (Roberts et al 1983). Figure 3.2 shows three representations of a system with these characteristics. Each one is examined below.

![Figure 3.2: Three possible representations of a simple system with two state variables \( S_1 \) and \( S_2 \): (a) a set of coupled differential equations, (b) a stock-and-flow diagram for a numerical integration model, and (c) a causal loop diagram. In each panel of the diagram the underlying feedback effect is the same: the value of \( S_1 \) influences the value of \( S_2 \), which in turn influences the value of \( S_1 \). See text in §3.3 for discussion.](image)
3.3.1 Analytic Integration

A system can be represented by a set of coupled differential equations (Figure 3.2(a)). In the example shown, the rates of change of $S_1$ and $S_2$ with respect to time are given as functions of the two state variables ($S_1$ and $S_2$). In simple cases mathematicians can integrate equations like this analytically, and so derive explicit expressions for the time-dependence of the state variables. The field of differential and integral calculus has evolved largely to study this area of mathematics. Historians are unlikely to use this analytical approach, unless they are also good mathematicians, and in an AEH study it can be left to the collaborating dynamicist. More fundamentally, analytic approaches are not generally useful to those who wish to model complex human-environment systems because sets of coupled, non-linear differential equations with more than a few variables cannot usually be solved analytically.

3.3.2 Numerical Integration

Complex sets of differential or difference equations can be integrated numerically using computer models. Forrester (1961) has developed a graphical language that is designed to assist non-mathematicians to construct computer models to explore the behaviour of complex systems. In his approach the structure of a dynamic system is represented using the concept of 'stocks and flows' (Figure 3.2(b)). The terminology is based on the hydraulic metaphor a system variable is a water tank. The mapping for this metaphor is:

- The tank $\rightarrow$ the state variable
- The volume $V$ of water in the tank $\rightarrow$ the value (size or level) of the state variable
- The water inflow rate $\rightarrow$ total rate of all processes that increase the value of the variable
- The water outflow rate $\rightarrow$ total rate of all processes that decrease the value of the variable

There are several graphical elements used in the stock-and-flow diagram in Figure 3.2(b):

- Rectangles represent state variables. These are called stocks. The amount of material accumulated in a stock, its 'level', represents the current value of the state variable.
- Broad arrows represent flows of materials into and out of a stock. In the diagram the arrows are double-headed, indicating that they are 'bi-flows' which represent net rates of change.
- 'Clouds' represent sources and sinks for the flows. The sources and sinks are external to the modelled system, and are assumed to have infinite capacity.
- Control values represent net flow rates $\frac{dS_1}{dt}$ and $\frac{dS_2}{dt}$.
- Thin curved arrows with small open circles at their tails represent flows of information or influence.
- Open circles at the tail end of influence arrows represent measurements that do not change the level of the stock.
A stock represents a state variable (e.g., amount of land, soil quality, number of species). Therefore, the levels of a set of stocks characterise the state of a system at a particular point in time. Flows are the rates at which state variables increase or decrease. Any systematic movement of energy, material, information or influence can be thought about as a flow of fluid. Stocks can be changed only by flows. Consequently, increasing or decreasing the rates of the different inflows or outflows is the only way to change the rate of change of the values of the state variables in the model.

The water-tank metaphor is the basis for the graphical conventions used in computer modelling and simulation packages, such as Stella® (iThink®), Vensim™ and Powersim™. Stella® was used to produce the diagram in Figure 3.2(b), as well as the Conceptual Model of Irrigation Development, introduced in Chapter 6.

Forrester (1961) made the point that historians would benefit from an ability to build stock-and-flow models. But, even with his graphical language, it takes significant time to develop the necessary programming skills and understanding of the processes of numerical integration. A useful first step would be for historians contemplating AEH studies to develop some familiarity with the techniques of stock-and-flow modelling, so that they can communicate more effectively with dynamicists.

### 3.3.3 Causal-Loop Diagrams

The feedback structure of a system can be captured using a causal-loop diagram (CLD), as shown in Figure 3.2(c). CLDs do not describe the detailed behaviour of the variables, but they can provide a useful preliminary step in defining a modelling problem. Recently, they have become popular in attempts to make system dynamics accessible to a wider range of people, particularly those who lack a strong background in mathematics. Sterman (2000) has given detailed specifications for the construction of CLDs and the conventions for their use.

The causal link conventions are outlined in Figure 3.3. The effect of one variable on another can be either positive or negative. If $S_1$ has a positive effect on $S_2$, then an increase (or decrease) in the value of $S_1$ will cause $S_2$ to rise above (or fall below) the value that it otherwise would have had. The arrow-head on the causal link is shown with a positive polarity. On the other hand, if $S_1$ has a negative effect on $S_2$, then an increase (or decrease) in the value of $S_1$ will cause $S_2$ to fall below (or rise above) the value that it otherwise would have had. In this case the causal link in the diagram is signed with a negative polarity. The influence of one variable on another is not instantaneous. Delays caused by accumulation can range from a few micro-seconds (when I put my hand on a hotplate) to decades or longer (in the case of environmental response times).
short line drawn across a causal link indicates a significant delay between a change in $S_1$ and a corresponding change in $S_2$.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{causal_links.png}
\caption{Causal link conventions (see text for discussion).}
\end{figure}

The aim of constructing a CLD is to represent the overall feedback structure proposed for a system. CLDs are tools 'to think with'; to use them effectively it is necessary to observe some basic rules (see Sterman 2000):

- Clear language is essential. Concepts and terms should be expressed as nouns or noun phrases: salt-content, number of dogs, quality of advice, need for reform.
- Variables should be used in their positive sense: happiness, not unhappiness.
- All variables must be capable of expressing increase or decrease in some useful sense: watertable height, catchment area, effectiveness of policy, desire to learn.
- Do not use verbal phrases, e.g., hunger, not getting hungry. The actions (verbs) in the system are automatically captured by the arrows (the causal links).
- Do not use phrases that indicate a specific direction of change, e.g., fewer participants, less interest. The direction of change will emerge as the CLD is used to think about the way in which the system changes over time.
- Always set the link polarity one link at a time, and always consider what happens to the affected variable when the affecting variable is increased.
• The signed links represent amplification or reduction of the changes around the loop, and
the cumulative effect will be positive or negative. If the cumulative effect reinforces the
original change, it is a positive feedback loop. If the cumulative effect opposes the original
change, it is a negative feedback loop. The arithmetic of the loop parallels the arithmetic of
multiplying signed numbers. A loop is positive if it contains an even number of negative
links, and is negative if it contains an odd number of negative links.

It is essential to recognise that the dynamics of a system cannot readily be inferred from CLDs.
Richardson (1986 and 1997) has described a variety of problems that one needs to be aware of
when using these diagrams. In particular, he has emphasised the importance of understanding
the underlying stock-and-flow mechanisms when attempting to infer dynamics. CLDs do not
distinguish between stocks and flows. It is dangerous to include rates directly, or concepts that
are often in essence rates: birth rate, productivity (= rate of production over time), adaptation (=
rate of adapting over time). The problem with rates in CLDs is that a change in a rate does not
produce an unambiguous change in the corresponding state variable (Richardson 1986). The
most obvious example is population change, where a decline in birth rate does not produce a
decline in population. Population is also influenced by the death rate. To change an increasing
population into a decreasing population requires the net rate of change (births minus deaths) to
change from positive to negative values. There is no way to represent this condition in a CLD.
In the present study rates are excluded from all CLDs.

Of the three methods described above to explore the feedback behaviour of systems, CLDs
present the most feasible technique for historians to adopt. If constructed competently, CLDs
can provide a useful summary of findings and initial dynamical hypotheses. They represent a
good starting point for discussions between historians and dynamicists in collaborative
endeavours to construct stock-and-flow models.

3.4 Feedback Effects

Feedback (or circular causality) is the defining characteristic of mechanical, social and natural
systems. The concept of feedback refers to the patterns of behaviour caused by closed loops of
interactions. As shown in Figure 3.2, a change in the value of \( S_1 \) works to change the value of \( S_2 \),
and then the change in the value of \( S_2 \) works to further change the value of \( S_1 \).

In general, most people assume simple, linear cause and effect. For example, a country bus
service between two towns can move twice as many passengers with two buses operating two
services a day than it can with only one. In nature and society, however, problems have many
more variables, and are almost entirely driven by non-linear processes. If the same bus company
were to schedule enough buses to create congestion on the narrow country roads, thereby
creating feedback effects with delays, the service would acquire the dynamic complexity of a non-linear system.

To the non-systemic thinker, feedback effects are hard to see, particularly when they are delayed or appear far from the source of influence. For these reasons they regularly give rise to unintended and unwanted consequences. Unwanted outcomes are common in human-environment systems. For example, it is well know that widespread clearing of native trees creates an accelerated rise in the groundwater. Native vegetation in arid and semi-arid regions has adapted to water-poor conditions by becoming deep-rooted. Such species can act as pumps to keep the watertable low. But a change in vegetation, particularly via the introduction of irrigated agriculture, produces a corresponding change in the groundwater level (see Chapter 6).

Studies of feedback behaviour are found in the literature on systems thinking (Checkland 1984, Senge 1992, Senge et al 1994, O'Connor and McDermott 1997, Midgley 2003), and in the management literature (Forrester 1968, Roberts et al 1983, Sterman 2000). Literature in the latter group is comprised largely of contributions from the System Dynamics Group at the MIT Sloan School of Management, and is also found in the journal *System Dynamics Review*. Work by scholars associated with the Santa Fe Institute covers a wide range of academic research projects on complex systems, and has a strong interdisciplinary focus (Waldrop 1992, Gell-Mann 1995, Tainter and Tainter 1996).

Some scholars have developed useful ways of summarising the behaviour of feedback systems. For example, Forrester (1969) identified some of the special responses of complex systems in industrial and management settings. Senge (1992) has provided a set of generic structures (which he calls *system archetypes*) that represent recurring system structures. Although they were designed for business and management situations, these structures can be used to explain the generic patterns of behaviour in mechanical, social or natural systems. Sterman (2000) has identified *fundamental modes* of dynamic behaviour (and their underlying feedback structures) that re-occur across human and natural systems. The structures generate common types of dynamic behaviour: exponential growth, exponential decay, goal-seeking behaviour and oscillation (Figure 3.4). These behaviours are driven by the *amplifying* (run-away) effect of positive feedback, the *balancing* (goal-seeking) effect of negative feedback, or the *oscillatory* effect of negative feedback with time delays.
Figure 3.4: The fundamental modes of dynamic behaviour. In each graph the horizontal axis shows time, and the vertical axis shows the behaviour of a selected state variable. Exponential growth is produced by positive feedback structures. Exponential decay and goal-seeking behaviour are the result of negative feedback, which acts to bring the state of the system in line with a 'goal' value. Negative feedback counteracts forces that tend to move the state of the system away from the goal. Oscillation can occur in any negative feedback loop where the response of the goal-seeking system is delayed.

3.4.1 Loops with positive feedback

Positive feedback is behaviour that tends to reinforce or amplify an effect in a system. It is associated with the ‘run-away’ effect recognisable in exponential growth. A simple example of positive feedback operates in the process of human population growth.

One must be aware of the possible confusion that can arise when thinking in terms of positive and negative loops, on the one hand, and positive and negative outcomes, on the other. Because positive feedback reinforces change it can have a good or desirable (positive) outcome, as seen Figure 3.5. It can also produce a bad or undesirable (negative) outcome, as shown in the case of coastal erosion (Figure 3.6).

Positive feedback is responsible for situations where small random events in the past have produced major long-term effects. In these situations once a system 'locks in' there is no turning back. The development of clock-face design is an interesting illustration of lock-in. Before 1550
no firm convention existed for clock faces and the direction in which the hands travelled. The cathedral clock on the Duomo in Florence is an example of a 24-hour dial with hands that move counter-clockwise. Designed by Paolo Uccello in 1443, it is one of the few surviving clocks of its kind. Arthur (1994:5) argues that competing designs were subject to 'increasing returns'; that is, as more clock faces of one kind were built, so more people became used to reading them. After 1550 clockwise designs displaying only 12 hours were dominant; positive feedback had determined the future development of this feature of clocks.

A more recent example of lock-in is the QWERTY keyboard (invented in 1870) which owes its popularity to positive feedback. Because so many people have been trained on QWERTY, and it is so widely used, the cost of replacing QWERTY with the superior Dvorak system outweighs the benefits. Hence, an inferior technology became locked in (Arthur 1994).

Positive feedback effects can also occur in broad social systems. In 1600 when a small group of English merchants received exclusive rights to trade with the East Indies, no one could have predicted what would follow. The success of those first dangerous sea voyages brought experience and more trading opportunities. The new trading opportunities, in turn, brought more wealth and so more voyages. This growing activity led eventually to the formation of the British East India Company, which operated until 1858 and formed the basis of Britain's colonial empire (Wild 1999).

![Diagram of positive feedback loop](image)

**Figure 3.5:** Positive feedback that reinforces or amplifies a desirable condition. A tree-planting program reduces surface water runoff, and hence reduces erosion. These results lead to satisfaction with the program, which encourages people to expand the program, thereby reducing erosion elsewhere. The notation R and the small clockwise arrow written in the centre of the diagram indicate a reinforcing or positive feedback loop.
Figure 3.6: Positive feedback that reinforces or amplifies an undesirable condition. Groynes were once seen as an effective engineering solution to minimise erosion along coastal beaches. They are long concrete structures built at right angles to the beach, designed to change the pattern of local ocean currents, and thus retain beach sand. However, changes to local currents tend to produce erosion further along the coast.

3.4.2 Loops with negative feedback

Negative feedback is behaviour that tends to reduce or counteract an effect in a system. It produces goal-seeking behaviour which keeps a system in a state of balance. This process lies behind all self-correcting, or self-regulating, systems, such as centrifugal governors, thermostats, fan-tail windmills and float regulators. In living organisms the same self-regulating mechanism is called homeostasis. In the environment it is evident in predator-prey systems.

The same possibility for confusion, described above for positive loops, can arise when thinking in terms of positive and negative outcomes in a negative loop. A negative feedback loop is capable of producing either desirable (Figure 3.7) or undesirable (Figure 3.8) outcomes.

Negative feedback also produces the phenomenon known as policy resistance, as illustrated at the beginning of the chapter by the failed attempts to control population.

An example of policy resistance, that will be investigated later, occurred in irrigation development in India. One of the reasons for introducing intensive irrigation in British India in the nineteenth century was to reduce the risk of famine by providing staple grains for redistribution during poor seasons. In some areas, the availability of water from irrigation canals (and the price of canal water) encouraged farmers to cultivate high-value crops (indigo, rice and sugar) which needed large volumes of water. Whitcombe (1972:90) claims that by the 1890s the attraction of the export market for these crops left stocks of staple grains low when drought
returned. Over-cropping and depletion of soil nutrients produced lower yields and an increased vulnerability to drought.

Figure 3.7: Negative feedback that produces a desirable effect. Water usage reduces the level in the tank. Water is pumped from a river to refill the tank. As pumping continues the water level in the tank approaches the desired level. When the actual level matches desired level (once the discrepancy between the two equals zero) the pumps are turned off. The notation B and the small clockwise arrow written in the centre of the diagram indicate a balancing or negative feedback loop.

Figure 3.8: Negative feedback that produces an undesirable effect. In this case, it produced policy resistance. Policies aimed at increasing the Romanian birth rate initially saw a rise in the number of birth. However, the strong effect of widespread poverty in Romania quickly operated to counteract the trend. Poverty reduced the ability of families to support more children, and generated strong resistance to the Romanian Government's population-control policies.
3.4.3 Change in loop dominance

Complex behaviour can often be understood as a result of competition between positive and negative feedback loops. A simple illustration of feedback competition is provided by the common phenomena of 'S-shaped growth' and 'overshoot and collapse' (Figure 3.9). S-shaped growth, for example, in the population dynamics of a species, is generated when positive feedback first dominates and then is swamped by negative feedback. When the population is small growth is initially exponential, and then levels off under the influence of negative feedback as the population comes up against the carrying capacity of the system. This type of behaviour is referred to as \textit{change in loop dominance}. The phenomenon of overshoot and collapse provides another example.

![Figure 3.9: Change in loop dominance. (a) S-shaped growth and (b) Overshoot and collapse. In both diagrams the horizontal axis shows time, and the vertical axis shows the state variable Population. See text for discussion.](image)

Overshoot and collapse is generated if, in addition to a change in loop dominance, there is a delay in the system's negative feedback response, and the carrying capacity is eroded at high population levels. This dynamic also begins with the positive feedback effects of exponential
growth. A delayed negative feedback response allows positive feedback to drive overshoot, leading to erosion of the carrying capacity. Then collapse occurs as negative feedback drives the population towards the falling carrying capacity.

3.5 Learning in Feedback Systems

One of the most important limitations to learning from experience is that we gain our life experiences working largely with simple systems. This level of learning 'creates a network of expectations and perceptions that could hardly be better designed to mislead the unwary when [they] move into the realm of complex systems' (Forrester 1969:109). Human beings, therefore, have evolved with deficient models of causality (connections between cause and effect) and a poor understanding of complex systems. This is the result of an event-oriented view of the world, whereby we focus on isolated events to the exclusion of the processes that created them. Because of this narrow focus, we have difficulty in addressing the causes of underlying processes, particularly when they are remote. We are not accustomed to look for and to recognise useful patterns in a series of events, and this leaves us ill-equipped to perceive feedback mechanisms when they are operating. An event-oriented worldview can cripple 'our ability to identify patterns of behaviour and the feedback structures generating them' (Sterman 2000:91).

Both positive and negative feedback can produce effects that are counter-intuitive, as seen in the operation of many flood-control measures. Levees-only policies encourage settlement in flood-prone areas by making it appear safe most of the time. But they increase the risk of property damage and loss of life (when a serious flood does occur), and remove the opportunity for people to learn how to deal with small flood events (Newell and Wasson 2002). Such is the history of flood-control levees along the Mississippi River and policy development by the US Corps of Army Engineers (Barry 1997).

Many writers in the fields of operational research, systems thinking and management have addressed the nature of human learning and the limitations inherent in human thinking (e.g., Forrester 1969, Schön 1983, Morgan 1986, Senge 1992, Argyris and Schön 1996, Dörner 1996, O’Connor and McDermott 1997, Senge et al 2000). Sterman has described the importance of feedback in the learning process, and the main ways in which it can fail. Table 3.1 sets out the areas where impediments to learning most commonly occur and the form that they may take.
<table>
<thead>
<tr>
<th>Area where impediments occur</th>
<th>Nature of the impediment</th>
</tr>
</thead>
</table>
| Events and processes in the real world | Unknown structure  
Limited information  
Dynamic complexity  
Time delays  
Inability to conduct controlled experiments |
| Information feedback from events and processes | Selective perception  
Missing feedback  
Delay  
Bias, distortion, error  
Ambiguity |
| Mental models of the players | Flawed cognitive maps leading to misperception of feedback  
Inability to handle complexity  
Unscientific reasoning  
Judgmental biases  
Defensive routines |
| Strategy, structure and decision rules used to guide decision making in the real world | Inability to infer dynamics from mental models |
| Decisions | Implementation failure  
Game playing  
Inconsistency  
Performance is goal |

### 3.6 Summary

An understanding of system effects is important in many fields of endeavour. It is essential in the area of natural resource management where policy makers and managers must plan and make decisions that recognise human-environment relationships characterised by feedback and high levels of dynamic complexity.
CHAPTER 4 LEARNING FROM EXPERIENCE

The aim of this chapter is to review briefly concepts and methods from the theory of experiential learning that can contribute to the proposed AEH approach.

4.1 Introduction

Human beings perform poorly at learning from the past. In our society, errors are usually suppressed or dismissed, and the opportunities to learn from them are lost. For most people, focusing on the history of the errors, on failure or surprise, is not a valued feature of every-day life. It is certainly not regarded as an essential part of human cognitive training.

Yet learning from past experience is crucial to a society where that experience is often achieved at a high cost (involving loss of life or great social distress), or as a result of extreme events. Jervis (1997:136) refers to the ‘painful learning that led the victors [in the Napoleonic Wars] to understand . . . that the eighteenth-century practice of compensation and indemnities led to endless cycles of warfare.’ After World War II, the treatment of Japan by the Allies was based on a conscious desire to promote Japan’s recovery, and to avoid the mistakes of the harsh policies that were imposed on Germany in 1919 under the Treaty of Versailles. Similarly, the Marshall Plan was designed to avoid an impending economic crisis in post-war Europe and to promote reconstruction after 1945 (Janis 1972). In these cases, the devastating experiences of war produced powerful incentives to avoid repetition of policy failures. Learning from experience is also essential where the public interest demands high levels of safety and performance. Areas of operation that are seen as involving potentially high-risk activities, such as those encountered in the space and aviation industries, and in the military, engineering and medical fields, have processes and procedures that ensure learning from unwanted and unintended outcomes.¹

Social institutions have evolved in which systems of review are designed to help communities learn from the past (audits, royal commissions and committees of inquiry with powers to make recommendations for reform). Since the twelfth century, the office of the Coroner has existed in English Common Law (Cross and Hall 1964). A coronial inquiry is designed to help us learn from experience. Today's coroner investigates tragic events, arising from natural causes or criminal behaviour, to ascertain their causes and recommend system changes to prevent similar formalised level, any trial-and-error process, aimed at innovation development or improvement,

¹ *Flight Safety Australia* is an aviation industry journal with a strong focus on learning from error. In a regular feature called ‘What Went Wrong?’ large and small incidents are analysed. The medical journal *Lancet* has a section entitled 'Uses of Error'.
tragedies from occurring in the future. In much of the developed world an expectation that
government authorities investigate these kinds of failure is written into legislation. On a less
formalised level, any trial-and-error process, aimed at innovation development or improvement,
illustrates the process of learning from experience. Sporting teams and players regularly analyse
their latest performance, especially their failures.

Learning from experience is a form of adaptation. Adaptation is essential for sustainability, and
underlies the principles of adaptive management of Earth's natural resources, as put forward and
developed by Holling (1978) and Walters (1978) and their collaborators. In the sense that is
important here, adaptation means cognitive adaptation, learning from the past. Learning from
the past requires a particular form of historiography. In order to discern what form that
historiography must take, we need to understand the process of cognitive adaptation.

4.1.1 Adaptation

Adaptation operates in biological, social and cultural evolution, and in the cognitive
development of individual human beings (Boyden 1987). In biological evolution, adaptation to
the diversity of environmental conditions allows an organism to achieve a better fit with its
world. Gell-Mann has described the need for every complex adaptive system to acquire
‘information about its environment and its own interactions with that environment, identifying
regularities in that information, condensing those regularities into a kind of “schema” or model,
and acting in the real world on the basis of that schema’ (Gell-Mann 1995:17). Adaptation over
millions of years accounts for the evolution, for example, of flowering plants (angiosperms)
from simple algae, mosses and fungi. An organism’s genome carries a ‘highly compressed
package of information’ representing the current stage in the sequence of biological changes it
has experienced due to past random variation and natural selection. Gell-Mann describes this
genetic information, which is handed down to future generations, as an organism’s schema.
Biological evolution — that is, a change in the genome of an organism — represents millions of
cycles around a feedback loop, as adaptation gradually takes place. The adaptive process
includes random moves, which produce variations in an organism’s structure, and some of them
confer an advantage over other organisms in the same environment. The angiosperms, for
example, have evolved as a highly successful class of plants capable of survival under a wide
variety of conditions.

McMichael (2001) has described the opportunistic nature of the evolutionary process. It is an
adaptive response that confers a benefit; it does not provide ‘biological capacity surplus to
current circumstances’. Hence, this biological variation has only to work a ‘bit better’, rather
than work well, for the adaptation to be successful. Because biological evolution involves a
process that builds on random moves to produce slow variation in the structure of an organism,
each successful move is determined by the previous moves (Alland 1970). Its history is important. In his seminal work on adaptation in natural and artificial systems, first published in 1975, John Holland made the point that adaptive plans in genetic systems must retain advances already achieved, along with part of the history of previous interactions with the environment. Therefore, the retention of history is essential to the robustness of the adaptive plan. ‘The plan must use the retained history to increase the proportion of fit structures generated as the overall history lengthens.’ (Holland 1992:18)

Not all biological adaptation requires huge timescales. Some of the genetic variation in human beings has arisen over the 150,000 years of existence of Homo sapiens. It has occurred in response to our ancestors colonising a wide range of physical, dietary and microbiological environments (McMichael 2001). From antiquity to the present day, timescales for the managed evolution of domesticated plants and animals have been even shorter.

In social and cultural adaptation, timescales for learning can be much shorter than in the biological domain. Archaeological evidence indicates that, in the Fertile Crescent, the transition from hunting and gathering to food production took place over only about 3000 years (between 9000 and 6000 BCE) (Diamond 1998). The most complex social institutions have taken centuries to evolve: the city-states of ancient Greece, ecclesiastical institutions and the Common Law. Others may appear over very much shorter timescales: a co-operative community or a symphony orchestra. All are operating in, and responding to, environments that are continually changing. Some will survive longer than others. Social systems are based on cultural schemata in the form of beliefs, traditions, myths, laws and institutions. The schemata ‘encapsulate the shared experiences of many generations’ (Gell-Mann 1995:292). Successful schemata, by offering advantages in responding to changing social and environmental conditions, capture a form of social learning. The learning and adaptation process is evident when a society adopts successful schemata and abandons unsuccessful schemata. Holding onto unsuccessful schemata will eventually lead to failure to survive in the face of environmental change.

An example of successful and rapid social adaptation was demonstrated by the industries that produced chlorofluorocarbons (CFCs). CFCs are non-toxic, non-flammable chemicals containing atoms of carbon, chlorine, and fluorine. From the 1930s they were used widely as refrigerants, and later in the manufacture of aerosol sprays, blowing agents for foams and packing materials, and as solvents. In 1974 scientists showed that CFCs could be a major source of inorganic chlorine in the stratosphere, thus contributing to the destruction of stratospheric ozone. Initially, much of the scientific community was unconvinced by these findings, because the instrumental data from space satellites did not support the existence of such an environmental problem. Then in 1985 new and conclusive evidence showed a deep hole in the
ozone layer above Antarctica. Re-analysis of original data from NASA’s *Nimbus 7* satellite, archived since 1978, produced evidence for the presence of the ozone hole. Scientists had not previously been alert to the problem because the ‘computers had been programmed to reject very low ozone readings on the assumption that such low readings must indicate instrument error.’ (Meadows et al 1992:152) This evidence, published in 1985, was enough to prompt industries world-wide to cease CFC production immediately.

Nevertheless, in the case of some cultural adaptation, much more time is required than might be expected. Referring to the highly controversial and unsuccessful Australian referendum for a republic in 2000, Justice Kirby (2000) said, 'To change the Constitution in such a significant respect, within the space of five years, imposed requirements of comprehension and adaptation to change which proved unacceptable to the majority of Australians.'

It is difficult to learn from experience: we often learn far too slowly, or we fail to learn at all. A long delay in learning is a familiar theme in Australian colonial history. This is well illustrated in the case of remote settlements. Between 1824 and 1838 the British Admiralty attempted to set up a number of settlements in far northern Australia (Allen 1972). These settlements were designed both for access to the trade routes of East Asia and for strategic purposes. All were failures. The first settlement at Fort Dundas on Melville Island (1824) and a second at Fort Wellington, on Raffles Bay (1828), lasted less than three years. A third site, Port Essington on the Coburg Peninsular (1838), was finally abandoned in 1849. All these settlements were managed from London, via Sydney, with time delays of up to 18 months for the exchange of information between policy makers in London and the remote outposts. The settlers had little or no experience of living in the tropics. Their rate of learning and adaptation to the hazards of this environment was far too slow for the long-term survival of the settlements. Their ability to adapt was severely hampered by available resources, by the long delay in communication between Sydney and London, and by the further delay in receiving stores and instructions from Sydney.

History provides many cases of failure of institutions to learn from experience. The British public health movement of the nineteenth century promoted the system of government responsibility for drainage, sanitation, water supply and clean air. Yet delay characterised the adoption of measures to achieve public facilities in areas which we take for granted today (Boyden 1987). During the Renaissance the Roman Papacy was tainted by the excessive lifestyle of six successive popes (1470-1530). Their personal self-interest and greed, and the failure of the institution to learn from experience, produced the seeds of the Protestant Reformation (Tuchman 1984). It took an even longer time, from 1601 to 1865, for the British Navy to learn from clear evidence that citrus juice could be used to prevent scurvy, and to put routine control measures in place (Mosteller 1981).
4.1.2 Human Cognition

Many of the difficulties encountered when we try to learn from experience arise directly from the limitations of human cognition. Other difficulties occur because learning must take place in the domain of dynamically complex systems. Others, still, are the result of social and psychological impediments.

Most cognitive scientists agree that human beings understand the world by constructing mental models (Lakoff and Johnson 1980, Johnson-Laird 1983, Gardner 1987, Thagard 1996). That is, at the psychological core of human understanding is the notion that an understanding of some phenomenon in our world amounts to having a working mental model of the phenomenon. To be useful, mental models must correspond to some extent in structure to the situations they represent. When he published *The Nature of Explanation* in 1943, Kenneth Craik was the first to propose the idea that ‘thinking is a manipulation of internal mental representations of the world’ (Johnson-Laird 1983:2). According to this view, when we say that we understand ‘the ocean’, what we mean is that we have a working mental model that we can 'run' to predict how the ocean will behave. Mental models of how the world works need not be wholly accurate, nor correspond completely with what they model, in order to be useful. A model has only to be adequate for its purpose. A child's mental model of the ocean will be a highly simplified version of what the concept means to a fisherman, and different again for a marine biologist. Gardner (1987:383) regards ‘the clear demonstration of the validity of positing a level of mental representation’ as the major accomplishment of early cognitive science.

Mental models are constructed on the basis of our experiences. According to O’Connor and McDermott (1997:63) ‘They are our general ideas that shape our thoughts and actions and lead us to expect certain results. They are our theories in use, based mostly on observation and experience, but with a sprinkle of received wisdom and a dash of hope. They are what have worked in the past and therefore what we expect to work in the future.’ Meadows et al (1972:20) describe how decision-makers use their mental models ‘to choose among policies that will shape our future world.’ Forrester (1961:49) refers to mental models as ‘the mental images or verbal descriptions that a manager must deal with as a model of a corporate organisation and its processes.’ Compared with the reality from which they are abstracted, mental models are necessarily simple. Because they affect what we see, they can produce biased perceptions and flawed understanding of causality; they affect our choice of information, and the boundary settings with which we frame a problem. The relationship between our mental models and selective perception is the basis for the argument that all observations are theory-dependent (see e.g., Kuhn 1962, Chalmers 1976).
An important factor in learning from experience is the phenomenon known as 'cognitive dissonance'. The theory of cognitive dissonance, developed by Festinger (1957), refers to the psychological phenomenon whereby there is an inconsistency between what individuals expect and what actually occurs. Cognitive dissonance can alert us to the need to learn, to change our mental models, but it is also at work when the mind is presented with information that it ignores, rejects or actually changes to suit expectations. May (1973:xi) found that most statesmen are victims of the latter phenomenon at some stage in their political life, and that it contributed to much of the misuse of historical data in the examples of American foreign policy examined in his "Lesson of the Past (see §2.4). Cognitive dissonance has been used to explain the perceptual failures that occurred with European settlement in Australia. Cook (2001) argues the case convincingly in her thesis on the environmental history of Victoria's Goulburn Valley. There, policy makers and landholders were both 'unreceptive to information that was in disaccord with their resource use goals'. This approach has produced immense environmental damage as a result of inappropriate land and water use practices over more than a century (Cook 2001:223).

Dörner (1996) has examined the cognitive impediments that contribute to human beings' failure to learn, particularly when they are dealing with complex systems. There is the slowness of our thinking; the small amount of data we can process at any one time; the tendency to protect our sense of our own competence; the limited inflow capacity of our memory; and the tendency for us to focus only on immediate problems. He wrote: ‘We do not plan for problems we may not have at the moment, but that may later emerge as side effects. We are captives of the moment.’ Dörner (1996:190)

Anderson (2001) has presented an evolutionary approach drawn from cognitive psychology to explain human beings' deficient cognitive processes, as observed in the area of conservation biology. She described the evolved abilities with which humans can readily deal with certain tasks. According to Anderson, we are well-equipped to package information, to focus on the frequency of occurrence of events, and to tell stories. However, we are poor at dealing with continuous processes, using decimal probabilities and making decisions in the absence of experience. Several arguments suggest that the evolved abilities had survival value for our stone-age ancestors, but are inadequate in our modern world.
4.1.3 Available Models of Learning from Experience

Extant theories of experiential learning have their origins predominantly in the work of John Dewey, Kurt Lewin and Jean Piaget, and draw on research in the areas of psychology, philosophy and physiology. Dewey has contributed to the discussion of experiential learning in the field of higher education, Lewin in training and organisational development, and Piaget in cognitive development. The famous Russian cognitive theorist, L.S. Vygotsky (1896-1962), described learning from experience as 'the process whereby human development occurs' (Kolb 1984). Experiential learning plays a vital role throughout life and is central to the notion of lifelong learning.

Kolb's (1984) model of learning from experience is essentially the experiential learning model of Lewin, who conceived learning as a four-stage cycle (Figure 4.1). Immediate concrete experience is the basis for observation and reflection. The observations are assimilated into a 'theory' from which new implications for action can be deduced. These implications or hypotheses then serve as guides for action, which leads to new experience. Lewin incorporates feedback concepts from electrical engineering into his model 'to provide the basis of a continuous process of goal-directed action and evaluation of the consequences of that action'. (Kolb 1984:22)

![Figure 4.1: Kurt Lewin's model of experiential learning (Kolb 1984)](image-url)
Kolb developed an approach to learning that involved the integration of cognitive and socio-emotional factors into a theory of experiential learning. Drawing on Lewin's model, Kolb saw learning as a continuous process, grounded in experience, which takes place when there is cognitive dissonance, a mismatch between expectations and experience. He therefore described it as a 'tension- and conflict-filled process', and sees learning as the major process of human adaptation to the world.

From the 1940s the application of feedback concepts spread to the social sciences (Richardson 1991). As a result of the work of scholars in organisational learning, the concept of experiential learning began to influence thinking in the management world (e.g., Forrester 1961, Argyris and Schön 1996, Schön 1983, Morgan 1986, Senge 1992, Sterman 2000). From this background grew the ideas of single- and double-loop learning, and these ideas were taken up, in particular, by Argyris and Schön. Their approach to experiential learning is based on the work of the neurophysiologist, W. Ross Ashby, who made an important contribution to the general field of systems theory with his early texts on cybernetics. In Design for a Brain, Ashby (1960) investigated the problem of how the brain produces adaptive behaviour, 'the nature of change which shows as learning', and 'why such changes should tend to cause better adaptation for the whole organism' (Ashby 1960: 1/17 p.12).

Ashby's work influenced Argyris and Schön's (1996) development of the concept of single- and double-loop learning. Figure 4.2 shows Sterman's (1994) version of the double-loop learning model which, as Sterman (2000) acknowledges, has appeared in several guises throughout the social sciences literature.

![Figure 4.2: Model of double-loop learning (Sterman 1994)](image-url)
In Figure 4.2 the upper loop indicates that we make decisions, and then take action (on the basis of those decisions) to alter the real world. We then gather information about the changes that we have produced in the real world. We use the new information to revise our decisions in an attempt to bring outcomes closer to our goals. An example of a 'single-loop' operation is an inventory system in a manufacturing operation, which keeps track of the components for a production line. As information about stock usage accumulates the operators change their ordering rate to keep inventory levels on target.

The lower loop indicates that we also use our observations of outcomes to revise our understanding of the world. Our current mental models influence how we interpret the information feedback from our decisions and actions. They also help us to construct coherent cognitive structures, and underlie our strategies and decision rules. According to this model, we change our mental models when outcomes of our actions are judged to be unacceptable. As our mental models change we change the structures, strategies and decision rules that control our decision-making processes. And so our management behaviour evolves.

Argyris and Schön have been influential in applying the concepts of single- and double-loop learning in organisational settings. They regard single-loop learning as taking place when strategies, rules or assumptions are modified, but only to the extent that they fit within the existing high-level policies, goals, values or norms of the organisation. Double-loop learning, on the other hand, produces changes at the higher level. As Morgan (1986:88) says, ‘Single-loop learning rests in an ability to detect and correct errors in relation to a given set of operating norms’, whereas ‘double-loop learning depends on being able to take a “double look” at the situation by questioning the relevance of operating norms’.

4.2 The Basis of a New Approach

Newell and Proust (2004) have proposed an extended model of the cognitive adaptation process to address specific deficiencies in the current views of experiential learning. Most discussions of experiential learning (Kolb 1984, Argyris and Schön 1996, Senge 1992, Sterman 2000) give the impression that learning is a continuous process. We argue that, for reasons of cognitive stability, learning is not something that human beings can afford to do all the time. A stable operation requires that one pays attention to the central question of when to learn. Therefore, our model involves two distinct activities, operating (without learning) and learning, which run asynchronously. It also brings into sharp focus the need to gather historical data as an essential aspect of the learning process.
4.2.1 Definitions and Assumptions

Human beings interact with the world in a purpose-driven, manipulative manner. We make observations that are intended to reveal the state of some aspect of the world and then use our observations as the basis for an assessment of the desirability of that state. If our assessment is positive, we relax but keep observing. If our assessment is negative, we take action in an attempt to improve the situation, and then return to our observations. In one form or another this iterative process underlies all aspects of our behaviour, from relatively simple personal activities (such as deciding what clothes to wear) to complex social activities (such as governing a nation or conserving the natural environment). Sometimes we are aware of the process, but we often react to events automatically without being conscious that we are making decisions.

In this discussion we will use the term *management* quite generally to refer to the process of converting observation into action. The conversion process will be called *decision making*. We will assume that the decision-making process depends on a set of underlying rules of behaviour, or *policies*, many of which are used unconsciously (Forrester 1961:93).

We will consider a manager to be managing an operation when the goal or purpose of his or her efforts is to obtain an *explicitly stated* outcome or result. In practice, even apparently simple operations involve the management of complex systems. The behaviour of such managed systems will be determined by the interaction of a variety of state variables. In addition to the formal goals of the operation, each person involved will have personal expectations of outcomes. Some of these will conflict with each other and with the formal goals. There will normally be many operations running simultaneously at different speeds. Some will be relatively independent while others will interact strongly. Some will be deliberately shared among a number of individuals, and others will be private, even unconscious and unnoticed.

We assume that all management decisions are based on predictions of the likely outcomes of possible alternative actions. The predictions emerge as answers to questions of the form: "What will happen if I do X? What different thing will happen if I do Y?" Experienced individuals have their answers to these questions encoded in well-worn decision-making rules, which are sometimes used consciously, but that are mostly applied unconsciously and effortlessly. These behavioural policies are in turn based on an individual's models of causality, that is, understanding of cause-and-effect in a given domain of activity, and of what constitutes good decisions and good outcomes in that domain. Such models range from unconscious and conscious cognitive models (schemata), through the informal folk wisdom shared within a community, to formal scientific theories. Note particularly that an individual's models of causality include his or her high-level values and goals, since these provide the basis for assessing management behaviour and operational outcomes. We will call an individual's set of
models of a particular activity domain his or her worldview of that domain. Worldviews, via the policies derived from their constituent models, exert a controlling influence over the behaviour of individuals, organisations and societies.

We define learning to be the process of modifying one's controlling models or policies. This process can be undertaken deliberately, but much human learning occurs unconsciously as the tacit aspects of individuals' worldviews are found to be inadequate. Similarly, we can define learning from experience quite generally to mean the activity of assessing one's operating models and policies, on the basis of operational performance, and changing them in an attempt to improve management outcomes.

Finally, we will define cognitive adaptation to be the process of improving operational performance by improving the controlling models and policies. In practice this almost always means selecting the best of a number of competing worldviews by comparing the quality of the decisions produced within each worldview. In many cases the competition will be between successive stages in the evolution of a single aspect of a single worldview. In this on-the-job process, those models and policies that develop a reputation for producing mostly good decisions (decisions which have desirable or advantageous outcomes) are retained, while those that produce predominantly bad decisions (decisions which have unwanted or disadvantageous outcomes) are modified or discarded. This, in broad outline, is the process of learning from experience.

Learning from experience is not a trouble-free survival strategy. In cases of poor management it can be extremely difficult to discover which aspects of the controlling worldview are inadequate. The possibilities range over the full set of models and policies, including the manager's models of how cause-and-effect operate in the managed system and his or her high-level values. Even when a promising aspect has been identified, it remains difficult to know how to change that part of the control scheme to improve its performance. There will often need to be a lengthy period of trial-and-error experimentation with alternative changes. Furthermore, it is always risky to make changes to operating policies and models, particularly if they have been honed over a significant period of time and are performing well in a number of respects. There is the ever-present danger that a change that is intended to improve one aspect of a worldview's performance will cause a deterioration in some other aspect of its performance. For this reason, behavioural policies should be changed only when there is good evidence that a change is really necessary. Indeed, to change polices too easily is the same as having no polices at all. Changes to the underlying models or values can be even more threatening, because such changes can jeopardise an entire worldview.
How, then, is a natural inhibition to changing one's worldview to be reconciled with the notion of life-long learning? Kolb (1981) raised a similar matter in relation to Lewin's model (Figure 4.1). He questioned how one can be concrete and immediate and still be theoretical. In computer science the dual nature of this problem of learning has been called 'the plasticity-stability dilemma' (Carpenter and Grossberg 1988). The phrase is used in relation to the design of machines capable of autonomous learning, where the aim is to design systems that remain adaptive (plastic) in response to significant events, but stable in response to irrelevant events. Designers of these systems aim to achieve a balance so that the system preserves previously learned knowledge while it continues to learn new things at the same time. In the field of mathematics education Newell (1989) has referred to the problem in human beings as 'the belief-disbelief dilemma'. He wrote that it is necessary to believe in our models in order to survive. But 'to learn we must change our models — and that means that we must be able to disbelieve them to some extent' (Newell 1989:23).

If a natural inhibition prevents humans beings from changing worldviews too readily, then under what conditions is it appropriate to make a change, and hence to learn? With biological evolution, a change in the genome of an organism is a random event, and by chance may give the organism an advantage. This long process allows it to adapt better and survive longer. With human learning, cognitive adaptation can work quickly, and it provides a survival advantage by helping us to anticipate future events. However, there is a fundamental limitation to the effectiveness and speed with which cognitive adaptation can be accomplished. It is always necessary to balance stability of control (which requires that models and policies be altered cautiously, preferably in a large number of small steps) against speed of adaptation (which requires that alterations be made boldly, in a small number of large steps). In order for a manager to assess the effect of an alteration in his or her worldview he or she must closely observe the managed system and look for significant behavioural changes. Assessment takes time, and the time required can increase rapidly as the quality of the observations decreases or the complexity of the managed system increases. Each increase in assessment time decreases the manager's ability to adapt rapidly enough to track changes in the environment.

Given the negative effects of operational complexity, the difficulty of knowing which aspects of which model or policy to modify in response to the detection of poor decisions, and the dangers of changing control schemes in mid-stream, how can cognitive adaptation possibly work as a stable survival strategy? We can approach this question by first considering what it is like to be well adapted.
4.2.2 Basic cognitive-adaptation mechanism

When we are dealing with cognition-driven behaviour, we will assume that well adapted means having controlling models and behavioural policies that lead to effective action in a wide range of circumstances. That is, we will consider well-adapted individuals and organisations to have what Ashby (1964) calls 'requisite variety'. They have enough variety in their behavioural repertoire to be able to respond in an appropriate way to most eventualities. Individuals who have achieved this state will rarely encounter situations that force them to consider changing their worldviews. In other words, the behavioural policies of well-adapted individuals will almost always pass the test of providing acceptable decisions. Ashby (1960) expressed this idea elegantly:

What is really important to the living and learning organism is the great number of times on which it can display that it has already achieved adaptation; in fact, unless these circumstances allow this number to be fairly large, and the number of trial-failures to be fairly small, there is no gain to the organism having a brain that can learn. (Ashby 1960:97)

The behaviour of our hypothetical well-adapted individuals makes it clear that they mostly operate without changing their worldviews. Indeed, it is clear that a workable cognitive adaptation strategy requires pure operation phases during which controlling models and policies are not altered. Such periods are necessary if the performance of the current models and policies is to be tested in a stable manner. They allow an unbroken run of observations to be accumulated under fixed conditions. As the observations accumulate the effects of random fluctuations (noise) will begin to be averaged out. Eventually, a point will be reached where enough information has been gathered to indicate reliably the extent to which the current control scheme is succeeding. The relevant aspects of an individual's worldview are not modified as long as his or her operations are judged sufficiently successful. It is only when there is a clear history of decision failure that the adequacy of the controlling models and policies is brought into question, and changes are considered. When the worldview is modified the observational record is broken, and the accumulation of a new series of observations must begin. Thus, the process of cognitive adaptation (learning from experience) requires periods of steady (learning-free) operation punctuated by more-exciting, potentially destabilising episodes during which the controlling models and policies are modified. As an individual becomes better adapted the learning episodes become less and less frequent and the business-as-usual operations begin to dominate.

The above considerations lead us to suggest that the basic cognitive-adaptation mechanism can be usefully thought about as comprising a pair of nested control loops: an inner or operating loop and an outer or learning loop (Figure 4.3). We justify this subdivision on the basis that the
two activities play very different roles in the cognitive adaptation process and so have very different characteristics (for a detailed discussion see §4.3).

Figure 4.3: The process of cognitive adaptation is assumed to consist of sets of nested, iterative activities: operating and learning. In this diagram the learning activities are represented by a closed-loop of grey arrows labelled Learning Loops. The operating activities are represented by the closed-loop of black arrows labelled Operating Loops. The operating loops are embedded in the learning loops. In normal human activity there will be many different operating and learning loops running simultaneously. While there will be a general tendency for operating and learning loops to occur in pairs, there will also be cross-talk between such pairs. Both sets of activities are guided by policies (decision rules) that are based on an individual's models of causality for each activity. An individual's models of causality include the personal aims and values that provide the basis for his or her assessment of operational outcomes.

In Figure 4.3 the operating loops are shown embedded in the learning loops. We will assume that both activities can be usefully thought about as negative-feedback control loops that require iteration of an ordered sequence of four basic actions: observing, analysing, deciding, and implementing (see Figure 4.4). While it may sometimes be necessary to iterate over a sub-set of these actions (for example, to cycle through the observe-analyse sequence a number of times in order to obtain an adequate result), the full sequence of four steps must be completed in order to complete one iteration (one full cycle) of either an operating loop or a learning loop. Each of the four basic actions is carried out under the guidance of a manager's polices (rules of behaviour) for that action. These policies are, in turn, based on the manager's models of the nature and role of each type of action. Given the idiosyncratic nature of an individual's models and policies, each of the actions will be performed differently by different managers, and a given manager's perceptions of the results of these actions will always be subjective and selective.
Because the operating loops are embedded in the learning loops we will refer to learning as a higher-level process than operating. While the four basic actions are in essence the same in both the operating and learning loops, they involve different detailed processes at the two levels. Under these assumptions, the process of cognitive adaptation (learning from experience) is seen as involving eight distinct sub-processes (four per level).

Figure 4.4: Suggested hierarchical decomposition of the process of cognitive adaptation. According to the view proposed here, in order to adapt a cognitive individual has to learn by modifying his or her worldview. In order to make experience-based modifications he or she has to operate using the same worldview. Finally, in order to either operate or learn he or she has to observe, analyse, decide and implement (represented in the diagram by the letters O, A, D and I, respectively). The diagram illustrates our assumption that, while learning is a higher-level activity than operating, both of these activities can be considered to involve the same basic actions (O, A, D, I). The grey rectangles are intended to emphasise the nested relationship of operating and learning, with the operating loops embedded in the learning loops.

4.3 A Model of the Cognitive Adaptation Process

The above ideas provide the basis for a model of the cognitive adaptation process (CAP). The development of a plausible model can help us to extend our understanding of possible operating and learning mechanisms, and of the way that these two activities can interact. In addition, a CAP model can help us to test our basic assumptions by making clear some of their implications for managers and policy makers.

4.3.1 Operating

The activity that we have called operating is an example of what control engineers commonly call an iterative, negative-feedback control scheme. Observations are made of the state of a managed system and, if the observed state differs significantly from the desired (or goal) state, then some attribute of the managed system is adjusted in an attempt to bring the observed state back towards the goal state. Such a process is called 'regulation' if the goal state is constant over
time, and 'tracking' if the goal state varies over time. The selected goal state reflects the manager's understanding of what constitutes sustainable operations.

In Figure 4.5 we illustrate the activity of operating in the simple case of a manager who wants to hold constant the value of a single state variable. As an example, consider a farmer who is managing an agricultural irrigation enterprise. According to his model the managed system consists of the crop and the soil. He understands that crop yields depend on the moisture content of the soil. We will use the symbol $M$ to represent soil moisture level. Note that $M$ represents the value of the state variable soil moisture. That is, it corresponds to the generic symbol $S$ used in Figure 4.5.

![Figure 4.5: The basic structure of an operating loop.](image)

The symbols $S$, $S_a$ and $S_{goal}$ represent, respectively, the current value, the apparent value (subject to observational error and delays) and the required (or goal) value of the state variable.
When $M$ is too low crop yields are low. As $M$ increases so crop yields increase to a maximum. If $M$ is allowed to rise too far, however, the soil will become waterlogged and crop yields will decline rapidly. During the first few years of operation of the irrigation scheme, district farmers pooled their experience to build up some understanding of the local relationship between soil moisture and crop yields. The optimum soil moisture was determined. It is generally agreed that holding $M$ close to this optimum value (which we will call $M_{\text{goal}}$) will produce maximum yields.

The variation of $M$ over time reflects the varying balance between (a) the drying influence of seepage and evapo-transpiration, and (b) the wetting influence of rainfall and irrigation. Thus, according to his models, the farmer needs to hold $M$ at or near to $M_{\text{goal}}$ by adjusting the rate at which he applies irrigation water. To complete one cycle of his operating loop, he makes a series of observations that yield an estimate $M_a$ of the current soil moisture content averaged over his property. He then compares his value of $M_a$ with the required level ($M_{\text{goal}}$). He assesses the condition of the soil ($M_a$ greater than, equal to, or less than $M_{\text{goal}}$) and then decides what action to take by inserting the assessed condition into a set of decision rules that have the general IF-THEN form. In this case the farmer has three choices (decrease soil moisture, do nothing, increase soil moisture). Once he has made his decision, he can adjust the irrigation rate in an attempt to bring about the required change in soil moisture. Note that, while the farmer can change the irrigation rate suddenly, as soon as he decides that soil moisture needs to be altered, soil moisture is a stock (state variable) whose level $M$ will change smoothly as water accumulates in, or leaves, the soil. The farmer iterates the process, regularly monitoring the behaviour of $M$ over time, and makes adjustments to the water delivery rate as needed.

At the operation level the four basic actions are defined, and have characteristics, as follows:

**Observe:** Attempt to determine the *state* of the managed system at a specific time. The act of observing yields *raw data* that can be qualitative or quantitative. In general, the data are distorted, noisy, and delayed, and thus reveal only *apparent* states. The observations are made under the control of the manager's observational policies. These policies in turn depend on models of the techniques and processes of observing, and on causal models of the dynamics of the managed system. Observations are always subjective and selective because the manager's models of causality, which include his or her idiosyncratic understanding of what is required for sustainable operations, play a critical role in establishing operational values and goals. They also influence his or her perceptions of which attributes (state variables) of the managed system need to be observed and controlled.

**Analyse:** Attempt to assess the current *condition* of the managed system. The act of analysing involves (a) transforming the observationally derived raw data into a form that is suitable for comparison with the manager's statement of the required state of the system (the goal state), and
(b) making the comparison in order to determine the acceptability of the perceived (apparent) state of the system. The comparison must yield at least an estimate of the sense of the discrepancy between the perceived state of the system and the goal state; it is more useful if it also yields an estimate of the size of the discrepancy. Analyses depend on the manager's analysis policies which in turn depend on his or her models (understanding) of the techniques and processes of analysing.

**Decide:** Select the most appropriate change to make within the managed system, or its environment, to drive the apparent current state of the system towards the goal state. The decision is based on policies that in practice often have the form of IF-THEN rules. Decisions depend on the manager's decision-making policies, which in turn depend on his or her models of the process of deciding and of causality in the managed system.

**Implement:** Adjust one or more control parameters of the managed system to initiate the selected change. Once again, action is taken on the basis of controlling policies and models. The manager's implementation policies are based on his or her models of the likely reaction of the managed system to changes in its control parameters. In general, the state of a managed system cannot be changed immediately. When an adjustment is made to the setting of a control parameter, the system state will begin to change. If the manager has a good understanding of the dynamics of the system, then the new parameter setting should result in the system state moving towards the goal state. If, however, the manager does not fully understand the dynamics of the managed system, then he or she might well be surprised at the outcomes of the intervention.

### 4.3.2 Learning

The overall aim of the activity of *learning* is to increase the likelihood of achieving sustainable operations by improving the manager's understanding of the dynamics of the managed system and of sustainability issues. At the learning level the *managed system* includes the managed operation, its environment, the full set of operating loops, and the manager. Note that successful adaptation can require the manager to modify his or her worldview.

In Figure 4.6 we outline the basic steps required to complete a cycle of a learning loop. As an example we return to the irrigation farmer whose operations were sketched above. It is now several growing seasons later, and the farmer has been operating without any significant change to his operating models and policies. In particular, he still equates optimum soil moisture with the original $M_{\text{goal}}$ value. He has, however, been keeping records of soil moisture levels, $M$, and crop yields. In addition, he has regularly made a note of the general condition of his property and any aspects of his own operations that he thinks merit thought. And he has begun to notice some disturbing trends. First, it seems that his fields are becoming somewhat more prone to
waterlogging. Second, there are a few locations on the property where the average crop yield is permanently low. He discovers that other local farmers have noticed similar trends. One neighbour has even detected patches of a white efflorescence in some low-lying areas of her property.

Figure 4.6: The basic structure of a learning loop. The shaded circle labelled Operating Loops represents the managed system. At this level the managed system comprises the managed operation, its environment, the full set of operating loops, and the manager. The black arrows represent the four actions that must be taken to complete one cycle of the learning loop. The rounded boxes represent the outcomes of actions. The large oval in the centre of the diagram represents the manager's models of each of the actions involved in the activity of learning, and the small ovals represent the policies that he or she uses to guide each of these actions. The grey arrows represent the influence of the models, via the learning policies, on each type of action. The blocks of text around the edges of the diagram provide summary definitions. See text for details.

Over the next year, as the production problems become more obvious and widespread, the community begins to admit that a clear pattern of crop failure is emerging. Investigations have revealed that it is difficult to explain these failures as the consequence of anything other than the irrigation activities themselves. Reluctantly the community comes to the conclusion that their operating policies are to blame.
Once this assessment has been made the group progresses rapidly. They consult an irrigation extension officer to help them improve their models of cause-and-effect in the irrigation systems that they are managing. The extension officer suggests that they may be over-watering. She explains that, in many locations, maximum crop yields occur at soil moisture levels that exceed the soil's capacity to hold water. When that happens the excess water seeps into the groundwater and, given the right geology, can cause the watertable to rise. As the watertable approaches the root zone it will cause waterlogging. In addition, in areas where the subsoil is salty, the rising groundwater will transport salt into the root zone and begin to kill the irrigated crops. If the salty groundwater reaches the surface and evaporates it can leave behind salt efflorescence. She explains that the group should study the local soils to determine their field capacity $M_{fc}$ (the soil moisture level beyond which water begins to seep out of the soil), and that they should set $M_{goal}$ to a value that is a safe distance below $M_{fc}$. This will mean lower crop yields, but will prevent the watertable from rising further, and so should contribute to the longevity of the local irrigation operations. She also cautions that it can take a long time to rehabilitate salt-effected soil. Armed with their new operational models and policies, and a new awareness of the tentative nature of those models and policies, the group sets out to run a more sustainable operation.

At the learning level the four basic actions are defined, and have characteristics, as follows:

**Observe**: Attempt to determine the outcomes of the current approach to operating. The act of observing yields historical data in the form of time series. The time series consist of observations of the variation of a range of system variables and operational effectiveness. They run over a spectrum of timescales. At the shortest timescales, effectiveness is judged by the manager's ability to hold or track a preset goal state. At the longest timescales effectiveness is judged by the operation's longevity (which amounts to assessing the aptness of the preset goal state). Historical data have the same range of characteristics, and suffer from the same limitations, as the raw data used in the operating loops. The observations are made under the control of the manager's learning policies and models. The models cover a wide range of issues: the skills and actions needed to obtain and record historical data, the nature of operating processes, the nature and dynamics of the managed system, and the nature of sustainable operations.

**Analyse**: Attempt to assess the likelihood that the current operational models and policies will produce sustainable operations. The act of analysing involves searching the historical data for persistent patterns of operational success or failure. Persistent failures are taken as a signal that operational policies or models are inadequate and need modification. Analyses depend on the manager's analysis policies which depend in turn on his or her models of the techniques and
processes of data and pattern analysis, and of the dynamics of the managed system. At this stage in the learning loop a manager might become aware of potentially significant patterns in the behaviour of variables other than those usually monitored. Such discoveries provide the manager with an opportunity to enrich his or her understanding of the extent and nature of the managed system and its dynamics.

**Decide:** Select one or more aspects of the operating policies or models to modify in order to improve the performance of the managed system. It will often not be clear what aspects of the operating policies and models should be changed. Given that a manager will be unaware of major parts of his or her models and policies, and will be highly protective of other parts, it can be particularly difficult to identify opportunities for improvement. Learning decisions depend on decision policies which in turn depend on the manager's awareness of his or her own models of cause-and-effect in the managed system, of possible limitations in those models, and of how the models might be modified to improve their performance.

**Implement:** Change the selected aspects of the manager's operational policies or models in an attempt to improve operational performance. It will often not be clear how the operating policies and models should be changed. Given the unconscious and protected nature of much of the manager's worldview, it can be particularly difficult to implement significant changes. Any change carries with it a risk that operational performance will degrade. Thus, the modification of operating policies and models is an experimental endeavour that requires a creative approach, and can require considerable courage. Implementation actions depend on implementation policies which in turn depend on the manager's understanding of his or her own models of causality, of possible limitations of those models, and of what effect any feasible modification will have on the performance of the models.

In Figure 4.7 we summarise the main features of the proposed CAP model. One of the shortcomings of this schematic representation is that it tends to hide the complexity of the process. It is essential to remember that, in even the simplest management situations, there will be a multitude of operating and learning loops running simultaneously. There will usually be a set of operating loops, each focussed on a particular state variable, and running with its own characteristic cycle-time. Furthermore, a given operating loop might well be a part of several learning loops, each one involving a different aspect of the operating policies or models, and each one running at a different speed. Thus, learning can take place over a wide range of timescales and levels. The possibilities extend from rapid small adjustments of a control parameter (which is designed to be reset) to slow major revisions of a manager's high-level goals and values.
In order to cycle satisfactorily around the learning loop it is necessary to decide on the selected focus for changing the operating models and policies. The choices are many. Action could take the form of a change to a model or policy affecting any of the sub-processes in the operating loop. For example, the manager of an irrigated farm may change one or more of the following:

- his worldview about the results obtainable from irrigated agriculture
- the goal for the amount of land to be cultivated under irrigation
- her rule about deciding when and how often to irrigate
- a belief about what kind of useful information can be generated by analysing data
- a tradition that encouraged over-watering
- a parameter in the observing process, for example, to double the number of observation points per unit time.
4.3.3 The Interface between Learning and Operating

One of the primary features of our proposed CAP model is the division of the process of learning from experience into two main activities: operating (without learning) and learning. Our proposed strict separation amounts to the claim that there is a natural interface between these two parts (or layers) of the cognition-based system of adaptive control used by humans. What makes this separation an interface, rather than an arbitrary boundary that we have simply imposed on the system? A boundary can be defined to be an interface if either (a) the information flows across it differ in some significant way from the rest of the information flows within the system, or (b) the sub-systems (or layers) that it separates are of different kinds (i.e., play different roles within the system).

The proposed interface satisfies both criteria. First, the information flows between the operating and learning loops differ from those within the loops. Inside both loops information passes from one sub-process to the next around the loop, and is acted on as soon as it arrives at its destination. In addition, both loops involve the same basic actions performed in the same sequence (O, A, D, I). In contrast, the flows between the loops, while bi-directional, are asymmetric. The information flow from the operating loops into the learning loops tends to be relatively large-volume, reasonably constant, and consists of observations of the same type as those that are used within the operating loops. The flows in the reverse direction, however, will tend to be low-volume, episodic, decreasing in volume with time, and of a unique kind. They represent suggested modifications to the policies and models that control the operating loops. This latter type of flow occurs nowhere else in the system. Furthermore, the observations that flow from the operating loops into the historical database are not acted on immediately. They necessarily accumulate until there is convincing evidence of persistent patterns of operational success or failure. Suggested model or policy modifications do not necessarily accumulate in the operating loops.

Second, the activities of operating and learning have significantly different characteristics (see Table 4.1). The two activities play different roles. Operating provides information about the state of the world and the outcomes of management decisions. In the present two-level model, operating does not lead to changes in learning models and policies. Learning provides assessments of operational outcomes and generates suggested changes to operating model and policies.

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2 If the operating-learning hierarchy is extended upward to include a meta-learning level, then such flows will occur from the meta-learning loops into the learning loops.
Table 4.1:
Summary of Distinguishing Characteristics of Operating and Learning

<table>
<thead>
<tr>
<th>Operating</th>
<th>Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>use operating models and policies</td>
<td>improve operating models and policies</td>
</tr>
<tr>
<td>periodic</td>
<td>episodic</td>
</tr>
<tr>
<td>fast: short cycle-times $t_{op} &lt; t_{ms}$</td>
<td>slow: long cycle-times $t_{learn} &gt; t_{op}$</td>
</tr>
<tr>
<td>cycle-time constant over time</td>
<td>cycle-time increases as manager adapts</td>
</tr>
<tr>
<td>long-term memory not required</td>
<td>long-term memory required</td>
</tr>
</tbody>
</table>

One cycle of an operating loop corresponds to one look at the state of the managed system. Thus, operating loops will tend to be periodic, so that managers can regularly monitor the behaviour of the managed system. In practice, many operating loops will run like clockwork, with a near-constant cycle-time. One cycle of a learning loop corresponds to one attempt to modify operating models or policies, and that will happen only when a persistent pattern of failure has been detected in the accumulated historical data. For this reason, learning loops will tend to run episodically.

Successful regulation or tracking requires that operating cycle-times $t_{op}$ be less than the characteristic times $t_{ms}$ for significant differences to develop between the current state $S$ of the managed system and the goal state $S_{goal}$. Successful learning requires an accumulation of observations, typically generated at the rate of one per operating cycle, so learning cycle-times $t_{learn}$ will tend to be greater than the corresponding $t_{op}$ values. In general, $t_{learn} \sim n \times t_{op}$, where $n$ is the number of operating cycles that must be competed to generate an adequate historical database. The value of $n$ will increase rapidly as the quality of the observations decreases (noise increases) and as system complexity increases (the number of observed and unobserved variables increases).

Operating cycle-times $t_{op}$ are set by the characteristic times $t_{ms}$ for variation in the managed system and its environment. Provided that the structure of the managed system is not changed significantly, $t_{ms}$ will not depend on the level of adaptation of the manager. In such cases $t_{op}$ will not depend on the level of adaptation. Learning cycle-times $t_{learn}$ do depend on the manager's level of adaptation, however, because the frequency of operational failures will decrease as adaptation improves (Ashby 1960: 97).

Operating requires very little memory; in essence, the output from a given sub-process ($O, A, D, I$) has to be remembered just long enough for it to become the input to the next sub-process. Learning requires the accumulation of observations of a number of variables, some of which
may change very slowly. In many natural resource management situations, for example, timescales can stretch over decades or centuries. For this reason, learning requires long-term memory (history).

Operations involve regulating to, or tracking, a preset goal. They are routine, business-as-usual processes. When operational models and policies are well adapted, the outcomes are highly predictable. At the lowest levels learning can be routine. For example, if the historical data make it clear that the setting of a control parameter is too low, then it does not take much imagination to decide how to modify the corresponding operational policy. At the higher levels, however, learning is a creative activity where suggested modifications to worldviews are devised by induction, by guesswork, in discussions, by any means available. At these levels learning can require a bold step into the unknown, and the outcomes are often unpredictable.

Stable cognitive adaptation requires periods of pure operation, that is, periods of operation where operating models and policies are not modified in any respect, so that the characteristics of the extant management approach can be clearly determined. Learning, by definition, produces changes to operating models and policies and some of these changes may be deleterious. Learning, therefore, can destabilise the cognitive adaptation process if operating models or policies are changed too rapidly. But cognitive adaptation can fail also if learning is too slow, if old models and policies are retained for too long. Thus, optimal adaptation requires that a balance be maintained between operating (without learning) and learning. This is the classic stability-plasticity dilemma faced by any adaptive control system (Carpenter and Grossberg 1988; Principe et al 2000).

4.4 Implications of the CAP Model for Policy Makers

The CAP model provides a conceptual framework that links high-level processes (learning, adaptation) and products (world models, policies) with low-level processes (observing, interpreting, deciding, acting) and products (raw data, assessments, decision rules). As well as providing the foundation for a clearly defined technical language, the model reveals the disciplines that must be included in any attempt to understand cognitive adaptation (cognitive science, system dynamics, history, management), as well as the disciplines relevant to the context. It shows how the disciplines relate to each other, and how they can be integrated. The CAP model is designed to make four issues explicit. They are: why the when to learn question is important; why detected 'survivable' errors represent an opportunity to learn; why history is essential; and why time is needed to learn from experience.
The central question of when to learn

The CAP model suggests that human learning is not a continuous process. Although many scholars remark on the favourable characteristic in some people of being 'life-long learners', and of 'learning organisations . . . where people are continually learning' (Senge 1992:3), the notion that human beings can learn all the time is incorrect. Rather, good learners are seen as willing to learn throughout their life, and are receptive to new ideas. But their cognitive processes are not constantly engaged in changing models and policies in response to every piece of new data that comes by. A stable operation requires a natural inhibition to learning. A presumption that policy makers will be learning all the time is also inaccurate.

Social systems show a strong inhibition to change. The law rarely leads social change, but follows slowly behind movements for social and political reform. Kuhn (1962) has demonstrated this inhibition in his study of major discoveries in science. He describes how the progress of normal science has been characterised by resistance to a change in the established paradigms. 'Normal science' means research based firmly on past scientific achievements. It does not aim at novelty of fact or theory, but builds carefully and logically on a growing body of accepted methods, laws and theories. Nevertheless, against this background, some key scientific discoveries have been unexpected, and at the time were unacceptable to, and resisted by, scientists operating under the existing paradigm. In science 'novelty emerges only with difficulty, manifested by resistance, against a background provided by expectation' (Kuhn 1962:64).

In his studies on the diffusion of innovations, Rogers (1995) gives examples of situations where innovation failed to take root because a community was reluctant to make the necessary changes to their shared schemata. These are cases where cognitive change was a precondition to adopting the innovation. Rogers describes the case of a Peruvian village where a program was in place to improve public health by getting women to boil drinking water. For these villagers the argument for boiling drinking water was incompatible with local values and beliefs. Their belief system assigned to all foods and liquids a 'hot' or 'cold' quality, irrespective of its actual temperature. Foods designated 'hot' were given to sick people, who avoided 'cold' foods. According to this belief system boiled water was 'hot', and therefore consumed only when sick. A change to the women's schemata, that would allow them regularly to drink boiled water, presented a serious threat to prevailing values. The program failed because the villagers were not prepared to risk the change in their schemata.

There are also examples from political history. Tuchman (1984) described an inhibition to change, and therefore to learning, in the case of the British treatment of the American colonies. The British put immense value on the colonies as trading partners, but by insisting on the right
to tax the colonies, the British Parliament pursued a policy contrary to its own self-interest. The
government knew it could not implement the tax without a risk of damaging the voluntary
allegiance of the colonies. Yet, it insisted on exercising its legislative supremacy, despite the
knowledge that loss of the colonies would ruin trading opportunities. Among many other things,
the British refused to make the paradigm shift that would allow them to regard the American
colonists as equals with whom to negotiate. Reluctant to change, the British chose coercion.
Revolt and independence of the colonies followed in 1783. For the British, changing their
beliefs about the Americans threatened British perceptions of the superiority of their system of
government, of the supremacy of parliament, and of themselves in the eyes of the world
(including their other colonies).

The CAP model makes it clear that the question of when to learn is central to successful
cognitive adaptation and social change programs. It is unrealistic to expect people to change
their behaviour without convincing evidence that change is necessary.

- The opportunity to learn represented by detected 'survivable' errors

In science careful and persistent attempts to isolate and eliminate error continues to be a sign of
intellectual progress. Yet in many areas of society there is reluctance to face up to errors. This
reluctance is particularly strong in business and politics, where a structured analysis of errors is
rarely used as a force for improved understanding. On the contrary, society punishes error,
thereby discouraging individual responsibility and stifling learning.

In the preface to the first edition of his Conjectures and Refutations, Karl Popper wrote that ‘we
can learn from our mistakes’ (Popper 1962:vii). He strengthened this statement in the second
edition (Popper 1965:ix), when he wrote that ‘all our knowledge grows only through the
correcting of our mistakes’. In a similar vein, Kuhn argued that crises are a necessary
precondition for the emergence of novel theories in science, for they 'simultaneously loosen the
stereotypes and provide the incremental data necessary for a fundamental paradigm shift.' (Kuhn
1962:89) We know that it is time to change our mental models when our predictions fail, when
we detect errors in our thinking, or when we experience surprise. Since successful predictions
provide no tests of our models, we cannot learn under routine, familiar conditions.

Social scientist Wildavsky (1985:7) regards error as 'the spur to change'. By means of feedback,
we become aware of the differences between what is desired from, and what occurs as a result
of, our actions. He argued that a society becomes more vulnerable to surprise, as a 'decline in
innovativeness' reduces the variety of responses it equips itself to handle. Social scientists E.
von Weizsäcker and C. von Weizsäcker (1987:225) stated that there is 'no real learning without
allowing for survivable mistakes'. According to historian Saul, errors play an important part of
learning; and 'errors that lead to altered policies are the building blocks of civilization.' (Saul 1994:121).

Learning from errors was included in the theme of the 2002 Congress of the International Commission on Irrigation and Drainage (ICID). Since 1981, with each triennial congress, the ICID has held a regular session on aspects of irrigation history. In 2002 the theme was food production under conditions of water scarcity, increasing population and environmental pressures. On that occasion, the members of this predominantly engineering community used the history session to examine learning from failures in irrigation, drainage and flood control systems. Selected papers from the congress were published in a special issue of *Irrigation and Drainage* (ICID 2003). The editor of this issue made the point that policy makers concerned with the development of water and food-related issues should take the lessons from the past very seriously into consideration (see, for example, Proust (2003)).

In the case of floodplain development, Newell and Wasson (2002) argue that the practice of erecting levees along flood-prone rivers has seriously undermined the ability of riparian communities to learn from experience. Levees offer protection under small-to-medium-flood events. As a result, communities have fewer opportunities to learn from average flood events, and so their ability to handle serious major floods declines. Over time they become more inexperienced (rather than more experienced) and therefore more vulnerable. In the longer term, 'increased actual vulnerability means increased actual risk and increased flood losses' (Newell and Wasson 2002:11).

Professional historians in the area of public history have been undertaking a growing amount of research for commissioned histories from governmental agencies, corporations and other public bodies (Walkowitz 1986, Jordanova 2000). But, because commissioned histories are designed to celebrate the achievements of the commissioning entity, 'they construct a particular kind of public face' (Jordanova 2000). These histories rarely address the issue of errors or failure, and how learning from those errors has shaped the development of the commissioning entity.

The CAP model makes it clear that we learn from our failures, rather than our successes. Failures alert us clearly to situations where our operating models and policies have been deficient in some important way. On the other hand, our successes can do little more than indicate that events have not significantly challenged our models and policies.
The essential role of history

According to Holland (1992) history is essential for adaptation, and the CAP model makes this explicit.

When policy makers think about timescales, they need to be aware of the different rates of change operating across their fields of interest. This point is made clearly by Braudel (1969), an historian of the Annales School. He distinguished between change that takes place slowly over geographical timescales (la longue durée), and change at a level relevant to society or an individual (histoire événementielle). The rates of change of the fundamental natural and human processes will limit the rate at which each policy maker will be able to learn from history. Like studies in epidemiology, demography and economic history, studies of the natural environment must work across very long time periods. Long time series are necessary in order to see strings of events as evolving patterns. They are essential for the effect and significance of changes to become apparent. Fischer (1996) illustrated the significance of very long time series in his study of economic cycles from the Middle Ages to the present. He noted the importance of 'learning to think in the long run'. He wrote that 'the two leading errors of economic planning are to impose short-term thinking on long-term problems, and to adopt atemporal and anachronistic policies which do not recognise that the world has changed' (Fischer 1996:253). This approach is even more applicable to natural resource studies.

The absence of a clear historical perspective from the social sciences, as it relates to economics, is the central theme of another economic historian. Snooks (1993) criticised strongly the 'timeless approach to economics' which has produced a discipline that is unable 'to identify, let alone analyse, [the] longrun forces that are critical to the future of human society' (Snooks 1993:10). He demonstrated the importance of a rigorous use of historical data, and like Fischer (1996), has used history to describe the great waves of economic change that have influenced European history since the pre-modern period.

The importance of observations over long timescales is clear to scholars concerned with dynamical studies and learning in complex systems. Senge (1992) discussed the difficulty of learning in situations where feedback is delayed so long that decision makers are no longer around to experience the outcomes of past decisions. Lee (1993) made a similar point for NRM situations, where a professional life is shorter that the scale of change produced in the managed system. Sterman (2000) emphasised the importance of long time horizons for analysing dynamical problems: 'A long time horizon is a critical antidote to the event-oriented worldview so crippling to our ability to identify patterns of behavior and the feedback structures generating them' (Sterman 2000:90). In attempts to analyse the processes behind failure, Dörner (1996) emphasised the need to take account of delayed feedback.
• **Learning from experience takes time**

Learning from experience requires practice and repetition. Time is needed to perform numerous cycles of the operating loop, to gather data and to recognise useful patterns of behaviour. Cycle-time will vary according to the nature of the particular operation. It took 14 years for industries to cease production of the CFCs that were creating the hole in the ozone layer.

In 1988 devastating bush fires occurred in Yellowstone National Park. The Parks Service had adopted a new scientific management plan in 1972 which attempted to restore Yellowstone National Park to pre-contact conditions by allowing lightning-caused fires to burn within certain limits. Scientists understood that the pre-contact landscape had been shaped by both natural fires and those set by indigenous people. But their perceptions of a managed landscape were influenced by the relatively short history of European-American experience. This experience was inadequate for a fire plan suited to handle the 1988 fire, which followed a severe drought. Policy makers were too narrowly focused on recent history, and the plan failed to incorporate the range of environmental responses over long time spans that characterised the park's natural history (Norwood 2001).

The slow rate of change in most bio-physical systems presents particular problems for NRM professionals. They need sufficient time to gather evidence that a problem exists before changing their models and policies. And here the timescales for observing change can be indeed long. In Australia, Europeans have been observing 'cycles' of drought and good seasons over a relatively short time. It is clear that 200 years is barely long enough for observers to develop a good understanding of a highly variable climate, and to adopt appropriate NRM strategies. With intensive irrigation development, it may take decades for an irrigation system to manifest signs of salinity, and still longer for a community to recognise that a problem actually exists (WCD 2000). Patterns of error, failure and surprise in the policies connected with bio-physical systems generally emerge slowly. Learning in this area is further compromised because the rate of learning about the bio-physical system has not keep pace with the rate of change of social policies (particularly those affecting agricultural development).

### 4.5 Summary

The CAP model highlights the fact that individuals learn from experience when they detect error patterns that they regard as important. The four issues discussed in §4.4 — the *when to learn* question; the importance of detected 'survivable' errors; the essential role of history; and the need to allow time to learn from experience — are important issues in the AEH approach. They will be examined further in Chapter 5.
5.1 Introduction

The approach proposed in this chapter, which can help historians contribute better to the study of the dynamics of human-environment systems, draws on ideas from several disciplines and fields. It is influenced by studies by non-historians who have pointed out the fundamental importance of integrating concepts from history and dynamics (e.g., Forrester 1961, Bertalanffy 1969, Holland 1975, Boulding 1995, Gell-Mann 1995, Jervis 1997). These scholars have emphasised the importance of this blend in attempts to improve policy and decision making.

In the context of General System Theory, Bertalanffy advocated that 'history can learn from the system theorists not ultimate solutions but a sounder methodological outlook' (Bertalanffy 1969:110). In the study of complex systems Holland has stated that adaptive systems must retain part of the history of previous interactions with the environment. The retention of history is essential to the robustness of the adaptive plan. ‘The plan must use the retained history to increase the proportion of fit structures generated as the overall history lengthens.’ (Holland 1992:18). Gell-Mann (1995) has also shown how history is an essential part of our capacity to learn from experience in biological and cultural evolution.

In the field of business and management, Forrester has been concerned with the problems of management decisions and their dynamics in industrial settings, taking account of the larger social and economic systems. In *Industrial Dynamics* he wrote of the importance of history in attempts to understand system behaviour, and the benefit to historians of understanding the dynamics of systems (Forrester 1961:352):

A perceptive history of past managerial situations is one of the inputs to the better understanding of system dynamics. The ability to build models of complex systems and to study their behaviour should make historians more sensitive to the important system variables.

The economist, Kenneth Boulding saw a strong connection between decision making, dynamics and history. He described the predicament in which human beings find themselves: 'all experiences are of the past but all our decisions are about the future'. He recognised that 'What unites the past and the future is the study of dynamics, and dynamics is the study of the space-time continuum and the patterns it contains.' (Boulding 1995:1) In advocating an approach to improve the management of non-equilibrium environmental systems, Slocombe (1989) has called for a combination of dynamics and history in attempts to understand the processes of change. The field of international politics also needs a partnership between dynamics and history. Jervis (1997) has described the strong interconnectedness of international political
decisions and actions, and the unintended consequences that arise from the complex relationships in this arena.

Elsewhere, scholars in economic history have lamented the absence of historical and dynamical perspectives in the highly influential field of modern economics. Notable among these are Snoooks (1993) in Australia, and Fischer (1996) in the United States. McNeill has commented on the need for the discipline of environmental history to move beyond its comfortable position integrated within the traditions of history, where 'its sources, methods and subjects are all familiar to intellectual history' (McNeill 2003:8). He encourages scholars in material (as distinct from cultural and intellectual) environmental history to develop 'skills to make technical matters comprehensible', and to build 'real intellectual bridges to the territories of other specialists'. He has also argued specifically for using history to inform the ecological sciences (McNeill 2000:359).

Archaeology also provides an important study of the past, and has contributed to the approach proposed here. Recent developments in that field have shown that some scholars are using archaeological evidence to explore bigger questions, for example, those relating to collapse of civilisations (social systems). Tainter (1988) has attempted to draw useful lessons by comparing the fates of earlier civilisations. In The Collapse of Complex Societies he was concerned to understand social collapse as a general phenomenon, not limited to specific cases, and to draw out generic principles. His approach is in sharp contract to approaches common in the discipline of history, which he described as having been 'overwhelmingly particularistic' (Tainter 1988:43). The challenge of isolating the generic from the contingent is central to the AEH approach.

5.2 Natural Resource Management

The issues that face policy makers in natural resource management (NRM) demand a high level of understanding of the dynamics of human-environment systems. They must manage systems which are inherently variable, and where the demands of communities often exceed the resource base in many years. There is strong evidence that existing policy disciplines have proved inadequate to the task of designing policies to deal with complex human-environment problems. An obvious example is the focus on the immediate economic performance of rural industries, without regard to the sustainability of the resource base or the communities themselves. Similarly, public policy rarely comprehends the long timescales operating in human-environment system interactions. Those who practise history have been only marginally involved in helping NRM practitioners to analyse environmental problems and devise contemporary solutions.
Long timescales are characteristic of most environmental issues and problems. The CAP model of experiential learning, developed in Chapter 4, is designed to prompt NRM policy makers to improve their models of causality by observing patterns of success or failure of their policies. A focus on patterns of events prompts policy makers to pay attention to the dynamical characteristics of the various processes that unroll over time. To understand the behaviour that produces the observed patterns, policy makers need to understand the systems beneath the patterns.

If historians are to help NRM practitioners, they need to engage with dynamicists in the study of human-environment systems. To do this successfully they need practical, structured methods. Below, I present some guiding principles as a first step towards the Applied Environmental History (AEH) approach. These principles form the basis of the operational guidelines developed in Chapter 12. As AEH studies are relevant to many areas of learning from experience in dynamically complex systems, they may be conducted mutatis mutandis in management domains beyond that of the natural environment.

5.3 Applied Environmental History

The aims of Applied Environmental History are:

- to help establish an area of common conceptual ground between NRM practitioners, policy makers, historians and dynamicists.
- to provide a framework that can help NRM practitioners and policy makers to take account of the historical and dynamical issues that characterise human-environment relationships.
- to help NRM practitioners and policy makers improve their capacity to learn from the past.

As steps towards development of operational guidelines, I propose the following principles of Applied Environmental History:

| P1 | AEH must integrate the humanities and the sciences |

A strong division has long existed between the humanities and the sciences (Snow 1959, Tindemans et al 2002). Because NRM encompasses factors from both domains, AEH must blend both ways of thinking about NRM issues and problems. From the humanities it must draw on the concepts and methods used in the discipline of history, particularly public and environmental history; from the natural sciences, concepts and methods, particularly those concerned with system dynamics, and an understanding of ecological systems (P4); and from cognitive science, concepts and insights about the process of experiential learning (P5).
While many historians reject the notion that they could contribute to dynamical studies, in fact they have much to offer. Much historical writing is concerned with change, and with attempts to analyse and explain the causes of change. Trained historians have both specific subject knowledge and knowledge of broad cultural settings. They have the ability to see events from different points of view. Their historical consciousness equips them well to identify changing time frames, and to deal with multiple causation. Graham (1986:62) has valued the historian's ability to discern where we are in the stream of time and 'where time has brought change'. He has regarded historians, at their best, as suspicious of generalisation, patient with complexity, unperturbed by surprise, and prepared to trace and explain unintended consequences. Hence, history has the potential to be an integrative discipline because it can blend the multiple causal factors (social, cultural, political) that bear on an issue or problem. One of history's strengths is in 'seeing matters whole' (Graham 1983:11).

By integrating history and dynamics, applied history gains a new dimension that can enhance its relevance to institutional and policy learning, and adaptive management in NRM. In this way, AEH answers the call for history to take on new partnerships, as expressed recently by historians such as Jordanova (2000) and McNeill (2003). In addition, AEH responds to those public historians who have identified the lack of useful methods for historians to deal with contemporary policy-related problems (e.g., Graham 1993, Reuss 1993). It opens up one avenue for history to play a more pro-active role in the policy making process, particularly at the problem-solving end.

**P2** **AEH must begin with the techniques of good historiography**

AEH must use the sources, research methods, insights and critical processes that characterise good historiography.

Good historical scholarship makes critical use of a wide range of source material. It relies on the historian's skill and experience in evaluating the comparative usefulness of sources. This task requires an understanding of how the sources have come into existence, and a recognition of their richness and their limitations. The experienced historian knows how to locate and access relevant sources, and how sources can complement one other.

Modern historiography uses a mix of both primary and secondary sources. Primary sources are seen as those written records and other accounts of the past that were contemporary with the events that they describe. These sources take a variety of forms, most often documents with an official or quasi-official status, but also personal accounts and images. Oral history may be used to supplement other sources, or may be the only way of discovering important historical data.
Secondary sources are scholarly commentaries on the past created some time after the events which they describe. Trained historians will be alert to uncritical secondary sources and other subtleties in the records much more so than scientists and policy makers.

For centuries historical writing has focused largely on narrative. As the narrative style developed, historians in more recent times sought also to explain historical phenomena. But Jordanova (2000:108) claims that over the last 30 years there has been a 'loss of confidence in causal explanation, in our ability to give clear answers to why questions'. As we have become more aware of the growing complexity of the world, the 'conventional hierarchies of explanation no longer seem as plausible as they once did'. In many cases, questions of why have been left to scholars in other fields.

**P3  AEH studies must incorporate good scientific methods**

Because AEH studies are designed to help establish an area of common conceptual ground between NRM practitioners, policy makers, historians and dynamicists, they must incorporate the methods of good science. Good science works according to well-established rules of progress. It begins with the observation of patterns to reveal generic behaviour, followed by the construction of theories or models to explain the patterns. Then hypotheses are derived from the theories, and those hypotheses can be tested. Science advances by the disconfirmation of hypotheses, eventually leading to better theory.

AEH studies need to focus on alternative ways of setting the NRM issue or problem (Schön 1993). The problem-setting process may be seen as moving from the diffuse detection of a worry, to the telling of a story about the problematic situation, to the construction of a theory that makes explicit the causal linkages suggested in the story, to the formulation of a model that displays the hierarchical interrelationships of the essential elements of the story' (Rein and Schön 1977).

The methods of good science have three main implications for AEH practice. First, in order to find explanations for the behaviour of NRM systems, AEH practitioners need to look for the generic signals that are buried in the noise of historical data. Because the identification of generic patterns requires replications, an AEH study needs to include a number of cases that illustrate a given NRM issue or problem. AEH practitioners must look for the same patterns of behaviour across a number of cases before claiming to have found behaviour that is generic.

Laws and regularities, on the one hand, and contingency, on the other, play important roles in the behaviour of physical, biological and human systems. While scholars in the physical
sciences and some in the social sciences recognise the operation of generalised laws that can be distinguished from the contingent, typically historians focus overwhelmingly on the contingent. Kornet (2002) argues the case for the natural and social sciences to invest in the formulation of generalised patterns (the structural approach), and thereby to go beyond the description of mere contingent facts (the historical approach) to explain behaviour in natural and social systems. Historians too must look for generalised patterns of behaviour in human-environment system in any attempt to learn from the past.

Second, the guiding question(s) of an AEH study must be clearly set out. A guiding question may appear to narrow the focus of the study, but a strong concern for the broader context of the issue can act as a counterbalance (P4). It is a matter of maintaining the essential tension between reductive science on the one hand, and system science and good historiography on the other.

Third, AEH studies must be driven by clearly articulated theories and hypotheses. This approach may be seen as moving outside the canons of good historiography (P2), but is necessary for the AEH study to progress beyond narrative, into the more speculative phase where one investigates cause and effect. Like good science, AEH studies need to generate alternative explanations and consider rival hypotheses. They need to be prepared for the possibility of random events, and judgmental biases. They must avoid the tendency to seek evidence consistent with current beliefs, rather than evidence that has potential to undermine cherished beliefs (Wason 1960).

**P4  AEH studies must establish a broad system context**

The major causes underlying NRM issues and problems are found in the connections and interactions between sub-systems (bio-physical, social, cultural, economic, technological) of the larger human-environment system. Therefore, NRM issues must be set in as broad a system context as possible.

To satisfy this requirement AEH must use a wide range of historical data. AEH must engage in both diachronic and a synchronic studies (Figure 5.1). A diachronic study can reveal information about the system by tracking changes in a given state variable through time. A synchronic study can reveal different views of the system by examining the level of many state variables at the same time.

An analysis of events can help reveal the state variables of the system. Key historical events usually produce more than one change in important variables. The behaviour of these variables can help explain underlying dynamics.
Attention to spatial and temporal scale can help the AEH practitioner map the broader system. Environmental scientists and modellers already emphasise the importance of the choice of scale in the bio-physical aspects of NRM (Wiens et al 1986, Lindenmayer 2000). Different manifestations of a problem become clearer when observed at different scales, and different scales will provide new insights about the kind of useful questions that can be asked. The importance of problems of scale is nicely summarised by one archaeologist of the American Southwest. McGuire (1994:198) wrote, ‘As we change the effective scale of analysis, we frame a different web of relations.’

AEH studies should extend over timescales that are adequate to reveal important changes in the key variables of the NRM issue. The key variables should particularly take account of those interactions between the human and natural processes that bear on overall system stability.

The concepts of *longue durée* history and *histoire totale* of the French *Annales* School provide a precedent for the historian. When Braudel coined the term *longue durée* history, to distinguish it from the history of events (*histoire événementielle*) that focused on short time spans, he was referring to what we would call 'systems'. He wrote: ‘The *longue durée* is the endless,
inexhaustible history of structures and groups of structures. For the historian a structure is not just a thing built, put together; it also means permanence, something for more than centuries . . . This great structure travels through vast tracts of time without changing; . . .' (Braudel 1980:75). The Annales approach to history also recognised a need for integrated methods (Hughes-Warrington 2000).

A broad system context will ensure that AEH studies take account of the human dimension of NRM issues. Policy makers have neglected this aspect of NRM. Indeed, in Australia the first research programs to focus specifically on the social, economic, commercial, legal, policy and institutional dimensions of NRM are recent. Land and Water Australia (LWA 2000) established its Social and Institutional Research Program in 1999. The Murray-Darling Basin Commission (MDBC 1999a) introduced a Human Dimension Strategy into its Murray-Darling Basin Initiative in 2000.

Investigating the influence of key players, particularly organisations and networks (Uekoetter 1998, Connor and Dovers 2004) in the history of NRM issues adds an important perspective to AEH studies. In particular, the worldviews of past policy makers can be glimpsed through well-focused biographical studies. A study of individuals' behaviour can reveal the issues that they pay attention to, and those that they ignore. Since words and actions usually reflect worldviews, biographical studies are important in helping to uncover the beliefs that drive decisions in NRM. As well as being a popular form of historical writing, biography is an effective way of setting key players in their broad cultural context. Biography can reveal formative influences on individuals, and the pressures and constraints in life and career that led them to adopt certain stances.

Biographies also have a place in establishing the broad system context of an NRM issue (P4). They go some way to meeting the implicit challenge to historians issued by Forrester: 'History does not often enough treat the interacting forces of organizational stresses, personal interest, technological factors, reluctance to reach decisions, conflicting objectives, and the multitude of circumstances that eventually resolve themselves into a course of action' (Forrester 1961:352).

AEH practitioners need to understand the nature and influence of mental models (worldviews) and human cognition. Nevertheless, when historians have attempted to investigate human behaviour and cognition they have usually been drawn to the branch of history known as psychohistory. Psychohistory appeared in the 1970s, in an attempt to provide a framework for interpreting the behaviour of people in the past, particularly famous and infamous historical
figures (Barzun 1974, Stannard 1982, Mazlish 1990). Psychohistory draws on the theory of psychoanalysis, as developed by Freud (1856-1939). Many of Freud's principles were formulated before important advances were made in medical and cognitive science, and are now widely discredited. For example, scientists have criticised strongly the practice of applying 'psychotherapy to the victims of organic diseases of the nervous system' (Medawar 1982). Despite the status of its parent discipline, psychohistory is still popular among some historians (according to Tosh 1984 and Jordanova 2000).

Cognitive science is a rich source of understanding about human cognition and mental models. AEH needs to be aware of recent developments in this field (e.g., Lakoff and Johnson 1999). In the management arena, Senge (1992) has discussed the importance of mental models in decision making. The CAP model illustrates a particular application of insights from this domain.

5.4 Summary

The principles outlined here are applied in Part III to guide the exploratory AEH study. The primary purpose of this study is to test the AEH Principles in practice. In Part IV the principles are used, together with insights generated from the AEH study, as the basis for the design of AEH Guidelines.