

Water connecting People adapting

Integrated surface water and groundwater
management in the Murray-Darling Basin
Colorado and Idaho

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Candidates Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person except where due reference is made in the text.

Andrew Ross	
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Abstract

Integrated water management helps adaption to variable rainfall by using more groundwater during dry years and more surface water during wet years. Integrated water management techniques including aquifer storage and recovery, and water banking are extensively practised in other dry regions such as the western USA and Spain. These techniques are not used in the Murray-Darling Basin. This thesis explores integrated water management in the Murray-Darling Basin, and in the states of Colorado and Idaho in the USA.

The most important contribution of this research is that it sets out the advantages of integrated cyclical water management, and points to the opportunities for aquifer storage and recovery and water banking. Integrated surface water and groundwater storage is the missing link in Australia's otherwise comprehensive water reform.

This thesis uses a narrative synthesis approach for analysing factors that have affected integrated water management. This approach relies on qualitative analysis of findings from existing studies and documentary evidence, supplemented and cross checked by interviews. It is proposed that integrated water management be considered as a process taking place in a complex social and ecological system. Fourteen key variables that affect integrated water management were selected drawing on Ostrom's framework for the analysis of social and ecological systems, relevant scientific literature and discussions with water managers and experts. The relationship between these variables and integrated water management was explored in two comparative case studies. The first case study enabled a broad assessment of factors affecting integrated water management at a jurisdictional scale in the Murray-Darling Basin. The second case study enabled a more detailed exploration of the impact of water entitlements, operational rules and management organisation(s) on integrated water management in tributary catchments in New South Wales, Colorado and Idaho.

The development of integrated surface water and groundwater management, especially in the Murray-Darling Basin has been constrained by the surface water centric development of water resources and governance arrangements, gaps in knowledge about surface water and groundwater connectivity, the lack of a comprehensive, flexible and balanced system of water entitlements and rules, and implementation difficulties. Further development of integrated water management requires better knowledge and improved management capacity. Further research and development needs to be devoted to the integrated management of water stocks

and storages - a missing link in Australian water reform. Further research is also required to improve understanding about surface water and groundwater connectivity and to develop strategies for managing long term impacts of groundwater use. Ongoing development of flexible systems of water entitlements and rules is needed to enable cyclical surface water and groundwater management. Finally the capacity for the implementation of integrated water management at local and regional scales needs to be improved together with collaboration between higher-level governments and local organisations and stakeholders.

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Part I

Part I introduces integrated surface water and groundwater management, and sets out the framework and methodology for the research.

Chapter 1: Introduction to integrated surface water and groundwater management

1.1 Rationale for integrated water management

Water availability and management is a key issue for Australia, especially in its largest river basin, the Murray-Darling (Stoeckel and Abrahams 2007). The goals of water management are shifting from a focus on supply to sustainable and equitable water management, integrating human consumptive uses, water quality, health and environmental requirements (Gleick 1996).

Although Australia is not short of water in aggregate, water resources are often located far from growing population centres and rural industries reliant on irrigation. Also Australia experiences extreme climate variability, with droughts and floods that are predicted to become more severe owing to climate change (CSIRO 2008). Hence all of the available water resources need to be used in an efficient and coordinated way, and water governance needs to be improved to ensure that the needs of consumers, industry and ecosystems are met.

Integrated management of surface water and groundwater resources can potentially increase the yield, efficiency, supply reliability and cost effectiveness of water supply. Integrated water management also helps to prevent adverse impacts of surface water and groundwater use. The research in this thesis considers factors that affect the development and implementation of integrated surface water and groundwater management, and opportunities for improving the integration of water management¹.

Surface water is visible, moves quickly and is easy to deliver, but surface water flows are often highly variable over time (Spellman 2008). Groundwater is a more stable and reliable source of supply, and underground storage avoids losses through evaporation (Llamas and Custodio 2003). The combined use of surface water and groundwater is known as conjunctive or integrated water use. When surface water and groundwater

¹ In this thesis integrated water management has the relatively narrow meaning of the integrated management of surface water and groundwater, as opposed to the coordinated management of water, land and other resources. For further details and explanation see Attachment 1.

resources are managed jointly to achieve common objectives, this can be called integrated water management².

Most surface water is connected to groundwater and vice versa. Pumping too much groundwater reduces river flows, and excessive diversion of rivers reduces groundwater recharge. When surface water is connected to groundwater, integrated water management can manage and mitigate the impacts of the exploitation of one resource on users of other resources, third parties and the environment (Winter et al 1998, Evans 2007).

Flexible integrated water management can help people to adapt to climatic variation and uncertainty by means of supply diversification, underground storage and exchange (Halstead and O'Shea 1989, Agrawal 2009). Diversification helps to match variable supply with demand and reduces the risk of supply failure. Underground storage reduces evaporative losses, can cost less than surface water reservoirs and can provide a secure, reliable long term water storage or "banking" facility. Cyclical, integrated surface water and groundwater management can exploit the advantages of both resources by storing water underground in wet periods and using it in drier times (Blomquist et al 2004, Fullagar 2004). Water exchanges (trading) allocate scarce water to high value uses, and can increase the flexibility of water use and storage over time.

1.2 Integrated surface water and groundwater management in the Murray-Darling Basin (MDB)

Methods of integrated water management can be broadly divided into non-engineered such as cyclical use of surface water and groundwater, and engineered such as aquifer storage and recovery. Engineered methods usually require infrastructure for conveying water, recharge and extraction (Blomquist et al 2004, Brodie et al 2007). Cyclical use of surface and groundwater has been widely practiced by individual users in the MDB, but integrated cyclical surface water and groundwater management including aquifer storage and recovery has not been developed.

² Attachment 1 contains a further discussion of some keywords in this thesis: integrated water management, governance, management organisation and management organisations.

Groundwater supplies about 16% of water use across the MDB rising to 27% in the northern basin. Surface water and groundwater is used cyclically to optimise the use of available water supplies. The proportion of groundwater in total water use varied from about 10-25% during the last decade. In 1995 the extraction of surface water in the MDB was capped at 1993-94 levels, but groundwater use was not capped. Since the imposition of the cap surface water use has stabilised, while groundwater use increased. Groundwater is expected to provide an increasing proportion of future water supply in the MDB in response to climate change (CSIRO 2008).

Until the late 1980s most of the emphasis in water management in the MDB was on building infrastructure and water supply capacity, with an emphasis on surface water delivered at low cost through large highly regulated delivery systems. Surface water centric management in the MDB has discouraged the development of integrated surface water and groundwater management. The absence of comprehensive basin wide sustainable use limits for groundwater allowed the depletion of some aquifers, rather than encouraging cyclical replenishment and drawdown.

National water policy now includes the principle of integrated surface water and groundwater resources managed as a single resource³. In Australia, state governments have constitutional responsibility for water planning and management in their jurisdictions, but the planning and management of surface and groundwater continues to be separated (NWC 2007).

The Murray-Darling Basin Authority has published a proposed basin plan that includes separately assessed sustainable development limits for surface water and groundwater catchments in the MDB (MDBA 2011). The proposed basin plan does not discuss cyclical use of surface water and groundwater over time. After a basin plan is adopted the MDB jurisdictions will prepare a set of catchment plans that are consistent with the basin plan. The scope and details of the integration of surface water and groundwater management in these plans has yet to be determined⁴.

³ National water initiative s 23 (x) - further details about Australian water policy provisions concerning integrated water management are included in chapter 4.

⁴ In September 2011 the National Water Commission released a report entitled "A National Framework for Integrated Management of Connected Surface Water and Groundwater Systems". Parts of this report will be referred to and discussed in later chapters <http://nwc.gov.au/publications/waterlines/national-framework-for-integrated-management-of-connected-groundwater-and-surface-water-systems>.

This history raises two questions that provide a starting point for the research in this thesis:

- What factors explain the limited development and implementation of integrated surface water and groundwater management in the MDB?
- What are the opportunities for improving the integration of surface water and groundwater management?

1.3. Theoretical perspectives on integrated water management

The literature on integrated water management examined during the scoping of this thesis can be broadly divided into three categories; physical properties and interactions of surface water and groundwater; optimal use of surface water and groundwater resources; and institutional and political issues. The following paragraphs introduce research in these categories by means of examples⁵. This introduction aims to provide some theoretical context for the research questions and methodology in this thesis.

1.3.1 Physical aspects of surface water groundwater interaction

Many variables affect surface water and groundwater interactions, leading to substantial variations in connectivity. Some streams gain water from connected aquifers, others lose water to connected aquifers. Often the relationship between a stream and a connected aquifer or aquifers varies from gaining to losing along a stream (Winter 1998).

The extensive literature on the interaction of surface water and groundwater in river valleys can be divided up into analytical, numerical, field and chemical methods and water management (Winter 1995)⁶. Until the advent of numerical modelling in the 1960s most of the literature was concerned with the flow of groundwater to fully penetrating streams⁷. Since the mid-1960s numerical modelling has been primary tool for analysing groundwater surface water interactions. There have also been many

⁵ This introduction does not attempt a thorough review of the literature on physical connections of surface water and groundwater or optimum use of surface water and groundwater. It provides a brief introduction to the literature on integrated surface water and groundwater governance, which is explored in more detail in the remainder of this thesis.

⁶ This article gives a good overview of the literature before 1995.

⁷ A stream that fully penetrates an aquifer without streambed resistance to groundwater flow.

studies of interactions by analysing chemical characteristics of surface water and groundwater, and by field investigations.

Groundwater and surface water interactions can be examined at a small scale (stream bed and underlying aquifer), or a larger landscape scale including streams, lakes, wetlands and estuaries. Much recent research on surface water and groundwater interaction has focused on the biogeochemical processes in the few centimeters of sediments beneath surface water bodies (hyporheic zone) which have a profound effect on the chemistry of water interchange and stream biota (Boulton 1998). It is important to understand interactions between surface water at landscape scales in order to advance the conceptual and other modelling of connected groundwater – surface water systems which is used to estimate the sustainable yields of various water resources.

There are many gaps in knowledge about surface water and groundwater connections and their impact (Sophocleous 2002). A flexible, adaptive approach to integrated water management enables water managers and users to incorporate new knowledge and information as it becomes available (Lee 1993, Pahl Wostl 2007).

1.3.2 Optimum use of surface water and groundwater resources

Surface water and groundwater differs in terms of inflows and storage. Surface water and groundwater storage differ in terms of storage capacity, recharge and depletion rates, and operational costs. Optimisation studies investigate the best use of surface water and groundwater resources and storage. Optimisation methods include economic analysis and hydroeconomic analysis, simulation and operations research.

Economic and hydroeconomic analysis has been used to investigate the optimal use and storage of surface water and groundwater. Groundwater stocks change in response to recharge and withdrawals. Optimal withdrawals depend on discounted net benefits (Burt 1964, Gisser and Sanchez 1980). As surface water scarcity and groundwater extraction increase, generally extraction costs and benefits of aquifer recharge also increase (Tsur 1993). This depends on aquifer characteristics, user demand for water and recharge costs (Brosovic et al 2006). Flexible management of additional conjunctive use facilities and groundwater storage capacity under flexible water allocation can generate substantial economic benefits (Pulido Valasquez 1997).

Simulation models have been used to study alternative management responses to impacts of groundwater on surface water resources and stream flow (Bredehoft and Young 1972, Daubert et al 1985), and optimum groundwater well capacity to buffer water supply in dry periods (Bredehoft and Young 1982). Examples of operations research and modelling include studies of reservoir management and optimal reservoir operating rules (Yeh 1985).

1.3.3 Institutional and political issues

Integrated surface water and groundwater management is a complex process that requires the coordinated governance of land and water resources and the environment at multiple spatial and time scales and administrative levels. The main factors that influence the design and implementation of integrated surface water and groundwater management are institutional issues including the assignment of rights, risks, and responsibilities; the distribution of costs and benefits; and inter-organisational cooperation and coordination of activities (Blomquist 1992, Foley-Gannon 1999, Blomquist et al 2004). Governments have insufficient authority, resources and knowledge to govern water resources by themselves. Collaborative governance by governments, water users and interested third parties is needed (Ostrom 2005, Emerson et al 2011).

There are few comprehensive studies of institutional issues related to integrated surface water and groundwater management. In 1996 the US Environment Protection Agency funded a comparative institutional analysis of conjunctive water management in Arizona, Colorado and California (Blomquist et al 2001, 2004)¹⁰. This study showed the substantial influence of water entitlements, operational rules and management organisations on integrated water management. The Managing Connected Waters Project funded by the Australian Research Council and the Natural Heritage Trust aimed to provide a coordinated approach to surface water and groundwater management

¹⁰ http://cfpub1.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/615/report/F accessed 28 January 2012.

including institutional and communication issues (Fullagar 2004, Brodie et al 2007)¹¹. These studies provided a starting point for the research in this thesis.

1.4 Theoretical framework, research questions and case studies

1.4.1 Summary of theoretical framework and research issues

Blomquist and Schlager (2008) propose that the physical and institutional aspects of river basins can be studied within the framework of complex adaptive social and ecological systems (SES). A SES is one or more ecological systems linked with and affected by one or more social systems (Holling 1978, Walters 1986). The framework used in this study for analysing integrated water management is adapted from the framework proposed by Ostrom to analyse social and ecological systems (Ostrom 2009).

Drawing from this framework 14 key properties of resources, users, governance systems and their interactions that affect integrated water management were selected for exploration in this research. These key properties were selected on the basis of academic and other studies, and interviews with academics, consultants, water user representatives and government officials¹².

Integrated cyclical water management, using more surface water in wet periods and more groundwater in dry periods, is feasible when there are significant supplies and storage of both surface water and groundwater, when they are substitutable in quality and price, and when infrastructure enables transfer and storage (Blomquist 1992, Blomquist et al 2004, Thomas 2001). Surface water and groundwater resources should be managed to optimise resource use while avoiding adverse impacts on other resources and the environment (Evans 2007).

Surface water users generally receive water from large collectively organised infrastructure, whereas groundwater users invest individually in wells. Consequently,

¹¹ http://www.connectedwater.gov.au/framework/institutional_arrangements.html accessed 28 January 2012.

¹² These variables are set out and discussed in section 3.3.4.

surface water and groundwater users have different interests and problem framing. This heterogeneity has multiple influences on the integration of surface water and groundwater management (Blomquist and Schlager 1998), but the overall effect is likely to be negative (Poteete et al 2009) unless surface water and groundwater users learn to collaborate.

Comprehensive, well defined, secure legal entitlements¹³ provide incentives for investment and collective water management (Ostrom 2005, Bruns et al 2005).

Schlager and Ostrom (1992) distinguish five elements of a bundle of entitlements for common pool resources: access, use, management, exclusion and transfer¹⁴.

Entitlements to store water in a surface water storage or an aquifer, and to extract it for use or transfer are also required to enable integrated water management. It is necessary to strike a balance between providing certainty and security of supply for water users, and enabling flexible responses to changing circumstances and knowledge (Blomquist et al 2004b).

Operational rules specify allowable use, carryover, storage, withdrawal from storage and exchange for specific surface water and groundwater resources. Rules for surface water use need to take account of impacts on groundwater and vice versa (NWC 2009). Rules and their administration need to provide clear direction and be transparent and predictable. At the same time rules and their administration need to be sufficiently flexible to respond to variations in water availability, socioeconomic conditions, political preferences and new knowledge (Pahl Wostl 2007).

Integrated water management requires effective coordination and communication between water users, governments and third parties with different values and interests. Coordination is needed across spatial, temporal and jurisdictional scales and across multiple policy sectors (Turrall and Fullagar 2007, Ross and Dovers 2008). Good, shared knowledge about surface water and groundwater resources and their value facilitates integrated water planning and rule making (Ross and Martinez-Santos 2010). Indiscriminate rather than integrated use, and free riding are likely to occur without effective monitoring and enforcement (Ostrom 2005).

¹³ In Australia the term water entitlement is preferred because water is owned by the state, and the right to use water is an entitlement granted by the state. In the US the term water right is used. In this thesis the term water entitlements is used, other than during specific discussion of US cases.

¹⁴ Transfer is used to encompass the right to sell or lease a water entitlement – Schlager and Ostrom (1992) refer to this as alienation.

1.4.2 Research questions and choice of case studies

In part II of the thesis (chapters 4-5) factors broadly affecting the development of integrated water management in the Murray-Darling Basin at jurisdictional scale are explored by means of a cross jurisdictional comparative study. The primary research question in this part of the thesis is “What factors have influenced the development and implementation of integrated surface water and groundwater management in the Murray-Darling Basin”. Secondary questions cover the opportunities for and barriers to integrated water management, and options for progressing integrated water management.

The Murray-Darling Basin was chosen for the study because it is a very important resource with well developed institutional and organisational arrangements for basin wide water management. These arrangements have received favourable international attention and assessment (Kemper et al 2005). However, the development of integrated water management has been relatively slow. One purpose of this thesis is to explore reasons for this slow development.

At the jurisdictional scale of analysis it is not possible to examine the interactions between specific water users and connected water resources at the level of water management units, which are sometimes no more than small areas of water catchments. Many collective choice and operational water governance choices and rules relate to these smaller areas.

Part III of the thesis (chapters 6-8) comprises an international comparative study of selected sub basin water management areas in New South Wales (Namoi region), Colorado and Idaho. In this study the influence of governance arrangements on the development and implementation of integrated water management are explored, with particular emphasis on the structure and implementation of water entitlements and operational rules, and the effects of different types of management organisation.

The areas in the Part III case studies were selected because they have similar biophysical and socioeconomic conditions including relatively dry climate, variable rainfall, water scarcity, and a high proportion of water use in irrigated agriculture (although there are some significant variations within the case study areas). Despite the

similarities between the NSW and US cases integrated water management has been developed to a greater extent in the US cases. The comparative analysis explores the effects of different governance arrangements; water entitlements, laws, rules and management organisation(s)¹⁵ on integrated water management.

The case studies primarily use qualitative methods relying on documentary analysis, supplemented by interviews. Although a set of factors thought to influence integrated water management is defined at the start of each phase of the case studies (parts II and III of the thesis), the analysis is essentially exploratory. This reflects the relatively small amount of existing theoretical and empirical work on the topic, in particular the limited amount of evidence and studies on social and institutional factors that influence integrated water management.

1.5. Contents of this thesis

This thesis contains four parts and nine chapters.

Part I contains an introduction to integrated surface water and groundwater management and the method and framework used in this thesis.

Chapter 2 provides an introduction to surface water and groundwater resources and the links between them. It includes a brief introduction to key concepts related to water resource connectivity. The chapter also introduces objectives and methods of integrated water management, and benefits including water saving, water quality enhancement and adaptation to variable water supplies and water scarcity.

Chapter 3 introduces the method and framework used in this thesis for analysing factors that affect integrated water management. The methodology involves a narrative synthesis approach which relies on qualitative integration of findings from existing studies, supplemented by interviews. Alternative frameworks for assessing factors that affect integrated water management, and related opportunities and barriers are discussed. A broad analytical framework and key variables are derived to guide comparative analysis of integrated water management.

¹⁵ Organisation(s) refers to (the impact of) both the collective organisation of many organisations as well as the impact of individual organisations.

The research questions, methodology and comparative case studies in this thesis are introduced at the end of the chapter. The analysis of empirical data and interviews to tackle research questions in the first comparative case study is used to develop further more focused research questions and the design of the second comparative case study. There is no single hypothesis tested throughout this thesis. Instead evolving set of research questions is explored in order to throw light on the factors that support and constrain integrated water management, and the policy and management implications of the analysis.

Part II includes a jurisdictional scale comparative analysis of integrated water management in the Murray-Darling Basin.

Chapter 4 begins with an overview of water availability and use in the MDB. The chapter continues with an analysis of the context for integrated water management and planning in the basin, including national and state laws, policies, water entitlements, water plans, markets and management organisation(s). This is followed by selected examples of integrated water management in the MDB jurisdictions.

Chapter 5 explores factors that have affected integrated water management in the MDB. These include resource and resource user characteristics, historical path dependency, and institutional factors. The chapter also includes a discussion of opportunities for improving integrated water management in the MDB.

Part III comprises an international comparative study of selected sub basin water management areas in New South Wales (Namoi region), Colorado and Idaho.

Chapter 6 examines integrated water management in the Namoi region in New South Wales. The chapter includes an outline of the historical development of integrated water management and use in the region, followed by an analysis of the impact of water entitlements, water sharing plans and rules, and water management organisation(s). The chapter ends with an assessment of opportunities for the further development of integrated water management.

Chapter 7 examines integrated water management in the South Platte region in Colorado and the Eastern Snake Plain in Idaho. The chapter is structured along the same lines as chapter 6.

Chapter 8 begins with a brief review of the impact of the different “core” water governance approaches in New South Wales, Colorado and Idaho; political choice and prior appropriation. This is followed by a comparison of integrated water management in the case studies, followed by a comparative analysis of the effects of historical development and governance arrangements and organisation(s). The chapter ends with an analysis of opportunities for improvements in the integration of water management in the case study jurisdictions.

Part IV, chapter 9 begins with a summary of the research findings in the thesis together with possible follow-up actions. The chapter continues with brief overview of the case studies, and a discussion of instruments and governance arrangements for implementing integrated water management. Opportunities for improving the integration of surface water and groundwater management are identified. The chapter also includes theoretical insights from the thesis and identifies opportunities for further research.

A journal article, based on chapter 5 (Ross 2012a) has been published, and a book chapter based on chapter 8 has been accepted for publication. A journal article based on chapters 5 and 8 is under review and a second book chapter is being prepared. The research is being developed further in a National Centre for Groundwater Research and Training sponsored project on managed aquifer recharge in rural areas. Results of the research have been presented at several international conferences and national workshops¹⁶, for example Ross 2012b.

¹⁶ These include Groundwater 2010 Canberra, Groundwater 2011 Orleans, Lund Conference on Earth System Governance 2012 and NCCARF workshops on water governance 2010 and 2011.

Chapter 2 Links between surface water and groundwater and benefits and techniques of integrated water management

This chapter is divided into two distinct parts. The first part provides an introduction to the physical interactions between surface water and groundwater, and the effects of stream and aquifer characteristics on surface water and groundwater connectivity. This part ends with a classification of surface water and groundwater connectivity. The second part of the chapter introduces the wide range of benefits and techniques of integrated water management. Integrated water management can enable better matching of water supply and demand and reduced evaporation from storage. It can also mitigate the impact of groundwater pumping on streamflow, and of surface water diversion on groundwater recharge.

Surface water management has traditionally received much more attention than groundwater management. This reflects the historical development of water resources. Human settlements have often been located close to rivers and lakes that have provided water for human consumption, and a medium for transport and waste disposal. Surface water is visible and relatively easy to locate without expensive equipment. Following precipitation relatively large quantities of surface water can move across the landscape and through channels. These flows are often highly variable over time. The quality of surface water is relatively uniform, although sometimes it is turbid or polluted (Spellman 2008). Groundwater is less visible or accessible, and its properties and peculiarities are less well understood (Fetter 1994). A lot more effort has gone into developing surface water management, science and engineering.

Groundwater has some beneficial features. It does not evaporate like surface water unless it is shallow and unconfined. Expensive structures are not required to store and transport it. It moves comparatively slowly, and can be tapped close to its place of use. Supply is more stable than surface water, and if used wisely remains available year-round, even during droughts. As a result, water suppliers and irrigators in many countries have turned to groundwater for water supply or storage when they have access to a suitable aquifer (Fornes et al 2005, Llamas and Custodio 2006). However,

groundwater is not always available in sufficient quantity and quality at the places where water is needed. The movements of groundwater are not visible, and are more difficult to map. There are many shortfalls in data on groundwater resources and their extraction. Typically there are significant uncertainties about the effects of individual use of groundwater on other users, the aquifer system, stream flows and water dependent ecosystems. Often these effects are only evident after many years (Moench 2004, 2007).

Integrated surface water and groundwater management can be defined as the joint or coordinated use and management of surface water and groundwater in connected or unconnected resources. The joint or coordinated use of surface water and groundwater can lead to better outcomes than the use of surface water or groundwater in isolation because of the different properties and availability of each resource. For example, groundwater can be used during dry periods when surface water is scarce, and replenished during wet periods.

In their natural state, surface and groundwater sources may be connected or unconnected, or have variable connectivity over time. In most cases surface water is connected to groundwater and vice versa, although the degree of interaction and the spatial and temporal impacts of the interaction vary widely. The development or contamination of one connected resource usually affects the other (Winter et al 1998, Woessner 2000, Sophocleous 2002, Evans 2006). Integrated water management is necessary to manage and mitigate the impacts of the exploitation of one resource on users of another. Moreover, the interactions between surface water and groundwater influence not only streamflow and recharge, but also water quality, riparian zone character and composition, and ecosystem structure and function (Sophocleous 2007, National Groundwater Committee 2004¹⁷). Surface water groundwater interactions can also affect energy use and greenhouse gas emissions. For example, in the Goulburn Broken catchment in Victoria irrigation leads to a rising water table that needs to be pumped away, using energy and increasing emissions (Proust et al 2007).

Integrated water management can contribute to the achievement of multiple policy objectives. This study will concentrate on a sub-set of the implications of surface water

¹⁷ National Groundwater Committee (NGC). 2004. Knowledge Gaps for Groundwater Reforms. Canberra.

groundwater interactions, especially increased efficiency of water use and conservation of the quantity and quality of water resources. For example, cyclical alternating use of surface and groundwater can provide efficient and flexible use of water in wet and dry periods, and undergroundwater storage offers less evaporative losses and environmental impact than surface water storage (Blomquist et al 2004, Fullagar 2004, Brown et al 2001, Purkey et al 1998).

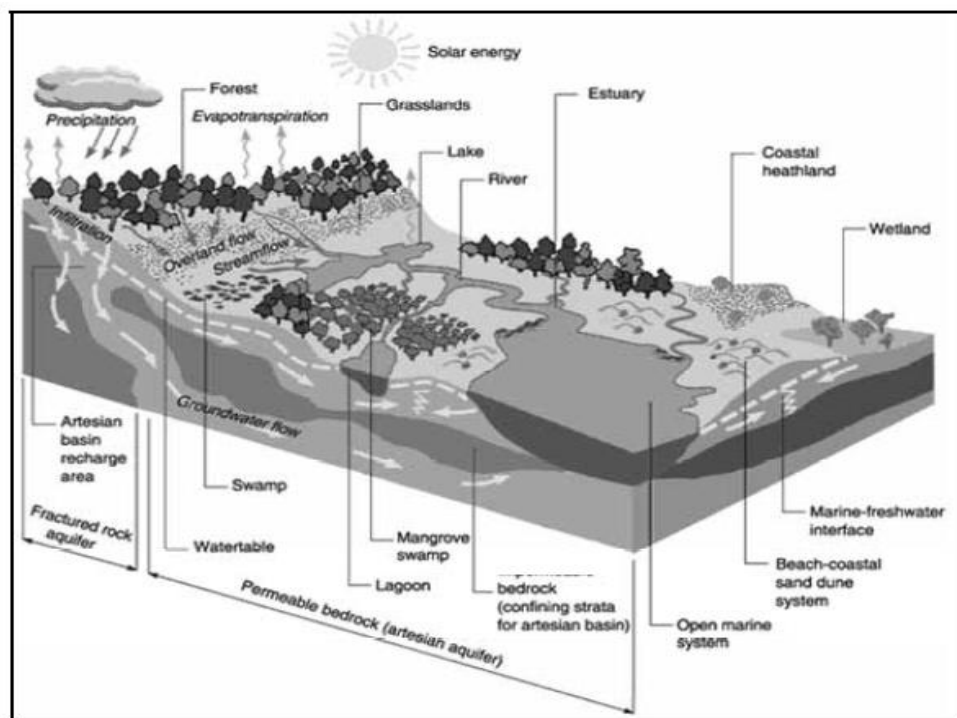
2.1 Physical factors affecting integrated water use and management

2.1.1 The water cycle

The interconnection between all sources of water within the global water cycle provides a context and rationale for integrated water use. The water cycle is a complex four dimensional system; with flows of water across geographical space, above and below the surface of the earth and through time. This cycle exists at various scales: planetary, continental, national, regional and local. The water cycle is illustrated in Figure 2.1 below.

It is estimated that 97% of the world's water is found in the oceans and is saline. Only 3% is fresh water, of which it is estimated that 68.7% is in ice caps and glaciers and 30.1% is in groundwater, and only 0.3% is present in surface waters (rivers and lakes) (Gleick 1996). In order to understand hydrological processes and to manage water resources, the hydrological cycle needs to be viewed at a wide range of scales because of its variability in time and space. Most precipitation never reaches the oceans as runoff, and there are large local variations in the relative magnitudes of the individual components of the hydrological cycle, such as evapotranspiration, recharge, runoff and storage. The distribution of rainfall, the extent of evaporation and transpiration of water and recharge to groundwater is highly variable according to climatic, geological and hydrological conditions.

Figure 2.1 The Water cycle



Source: Department of Land and Water Conservation 2000

Water moves along flow paths that directly depend on geology, topography and climate. The interactions of streams, lakes and wetlands with groundwater are governed by the position of water bodies with respect to groundwater flow systems, geological characteristics of aquifers and streams and their climatic settings (Winter 1999). A distinction can be made between local, intermediate and regional groundwater flow systems (Toth 1963). Water in a local flow system flows to a nearby discharge area such as a pond or stream. Water in a regional flow system flows a greater distance and discharges into major rivers, large lakes or oceans. An intermediate flow system is characterised by one or more topographic highs or lows between its recharge and its discharge area, but does not occupy the major high or low points at either end of a river basin. Undulating areas tend to have dominant local flow systems whereas flat areas tend to have a dominant intermediate and regional flow system (Sophocleous 2002).

Figure 2.1 also reveals factors in addition to geology, topography and climate that affect the way water flows through landscapes. Rainfall constitutes the basic water resource and is partitioned between “green” water, which is consumed by vegetation and soils, and “blue” water in rivers and aquifers, accessible for societal use (Falkenmark 2008).

Vegetation takes up water as it moves across the landscape, the amount depending on the nature and extent of vegetation. Much of this water returns to the atmosphere as evapotranspiration. A substantial amount of water is absorbed in soils before it reaches water tables/aquifers. These processes are critical for good ecosystem functioning and biodiversity. For example sub surface moisture together with vegetation growth cycles play a key role in maintaining soil stability and productivity, and the carbon cycle.

Integrated water use and management contributes to all of the above processes, and one vision for integrated water management would be as part of an integrated strategy for societies to live with and evolve in the landscape and the biosphere. A particular landscape is directly linked to neighboring landscapes through water flows above and below the ground surface. Therefore, it must be analysed as a component of the catchment or river basin of which it is a part (Falkenmark 2008).

This study adopts a more limited approach to integrated water management, exploring the water resources, water users, water governance systems and their interactions, while endeavouring to keep broader social, landscape, land use and ecological implications in mind.

2.1.2 Interactions between surface water and groundwater

Many variables affect surface water and groundwater interactions, leading to substantial variations in connectivity (Winter 1998, Evans 2007).

In connected water resources the magnitude and direction of water movement between a surface water body and an aquifer is called the seepage flux. Seepage relates to the flow of water through a porous medium (such as sediments), while the term flux relates to the flow rate of water through a given surface area. Groundwater seepage or discharge to streams, commonly referred to as baseflow, sustains stream flows over extended periods between rainfalls. Baseflow can be differentiated from quick flow. The latter is the direct, short term response to rainfall that includes flow over the land surface (runoff), rapid lateral movement in the unsaturated soil surface (interflow) and direct precipitation onto the stream surface. Baseflow may be sourced from snow melt,

wetlands and water stored in riverbanks (bankflow) as well as groundwater (Brodie et al 2007).

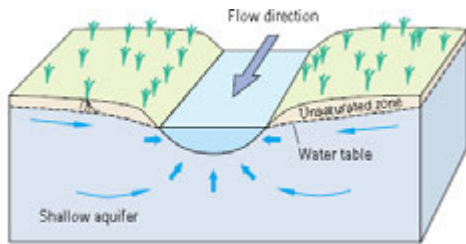
Local interactions between surface water and groundwater through seepage flux occur by subsurface lateral flow, and by vertical infiltration into or ex-filtration from the saturated zones (Sophocleous 2002). Larger scale exchange of groundwater and surface water in a landscape is controlled by the distribution and magnitude of hydraulic conductivities within the surface water channel and associated alluvial sediments, the relationship of the stream stage to the adjacent groundwater level and the position of the stream channel within the alluvial plain among other things. The flow of water between a surface water body and an underlying aquifer is directly influenced by the difference between the surface water and groundwater levels, the material separating the surface body from the aquifer and the hydraulic properties and features of the stream and the aquifer. The direction of the exchange processes varies with the hydraulic head, whereas the flow rate depends on the sediment's hydraulic conductivity (Woessner 2000).

Water moves down a gradient. If the stream surface is lower than the water table, the stream has the potential to receive water (baseflow) from the aquifer (gaining stream). If the stream level is higher than the water table, the stream has the potential to lose water to the aquifer (losing stream). The rate of stream leakage is affected by stream and aquifer characteristics (discussed in the next section), as well as the relative levels of the stream and the aquifer. This is illustrated in figures 2.2 a. and b. When the stream level is running high it also may be stored in stream banks (bank storage) rather than recharging the aquifer (figure 2.2 c.).

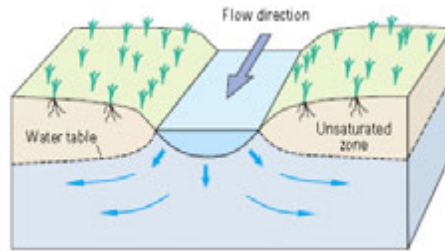
In the case of 'disconnected' losing streams (figure 2.2 d.), seepage occurs from the stream bed down to the aquifer (Winter et al 1998). The interactions between surface water and groundwater are complicated when several aquifers are layered beneath the surface (figure 2.2 e.). Groundwater recharge occurs through multiple layers in such cases. Pumping of deep unconfined aquifers can lead to recharge from overlaying shallow aquifers that in turn cause impacts on stream flow. These impacts can take many years, centuries or even millennia (Winter et al 1998).

Figure 2.2: Connections between surface water and groundwater

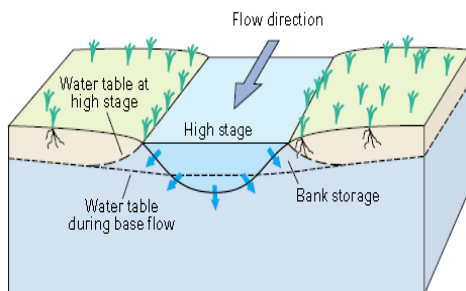
a. Gaining stream



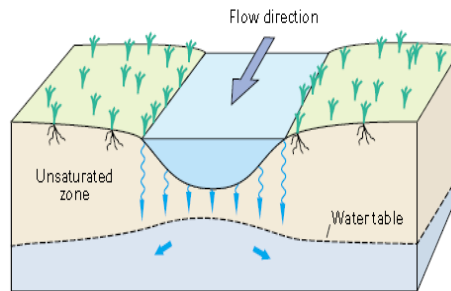
b. Losing stream



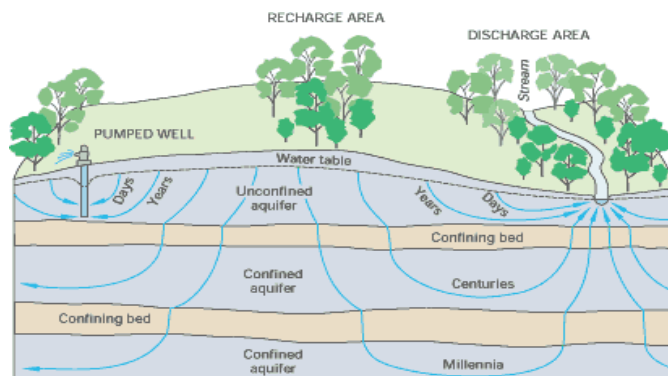
c. Bank storage



d. Disconnected losing stream



e. Multiple layered aquifers



Source: Winter et al 1998

2.1.3 Effects of characteristics of streams and aquifers on surface water and groundwater connectivity

Streams, groundwater basins and aquifers create a mosaic of resources that are connected to varying extents across space and through time. It is important to understand the different degrees of connection and their impact on surface and

groundwater connectivity in specific locations (Blomquist 1992). Some examples follow.

Surface water and groundwater connectivity is affected by several stream characteristics including the size and speed of flow, the permeability of the stream bed and the permanence of the stream. The size and speed of streamflow affects mixing between surface water and groundwater at their interface, and seepage from the stream bed. The permeability of the stream bed effects the rate of stream leakage and recharge of underlying aquifers. In perennial streams baseflow is more or less continuous and the stream gains from groundwater. In ephemeral streams the groundwater level is always beneath the channel so that they are losing streams when they are flowing. Intermittent streams receive water at certain times of year and may be either losing or gaining depending on the season (Gordon et al 1992).

Surface water and groundwater connectivity is also affected by several aquifer characteristics, including the size and slope, the aquifer material, and the confinement of the aquifer. Strong surface water and groundwater interactions are usually associated with shallow aquifers. These are generally unconfined - the surface of the groundwater body (water table) is contained within the aquifer. Aquifers may be semi-confined - they are overlain by a less permeable material (an aquitard). In this case vertical movement between the stream and the aquifer is limited compared with lateral movement, and the stream aquifer interaction is limited and/or delayed.

Some aquifers are completely confined by an impermeable layer of material that disconnects them from the stream (Evans 2007). If a stream is disconnected from the underlying aquifer, the rate of stream leakage is determined by the water level in the surface water body, the wetted surface area, the effective combined permeability of the bed of the water body and the saturated layer immediately below the bed, and the thickness of the saturated layer (Evans 2006).

The shape of groundwater basins must also be taken into account. In a flat basin pumping has an effect on nearby wells and streams. In a sloping basin pumping water in the higher part of the basin will affect users lower down, even if they are distant. Users in lower parts of the basin are also more likely to be susceptible to problems

related to rising water levels, such as salinity¹⁸ and waterlogging. In an aquifer with deeper parts separated by shallower parts users in deeper parts are in less danger of losing their water supply altogether than those in shallower parts.

Interconnections between aquifers can change the interrelationship between one aquifer and a surface water body. Pumping in a second aquifer connected to the first can lower the water table in the first aquifer, thus changing the relationship between the first aquifer and the stream, with consequent impact on streamflow and users. Multiple aquifers can improve the potential for and reduce the risk of temporary drawdowns. Such drawdowns can lead to adverse impacts if there is only one highly productive aquifer, or if overusing one or more aquifers leads to increased transmission of pollutants or poorer quality groundwater throughout the basin. Inflows of sea water can pose particular problems in the case of drawdowns in coastal aquifers (Blomquist 1992).

2.1.4 Other influences on surface water and groundwater connectivity

There are a number of broader influences on surface water and groundwater connectivity including land cover, land use, and climate.

Land cover change, such as land clearing, replacement of crop type and reforestation can significantly alter runoff, evapotranspiration rates and recharge. In Australia land clearing has resulted in rising water tables and increased influx of groundwater to streams. In many cases this has led to salination of water supplies and land degradation. Local revegetation coupled with slowing water flow through the landscape can increase plant water use and lead to increased water retention and soil fertility (Bruncke and Gosner 1997).

Land use also affects the potential for integrated water management. Urbanisation or irrigation development involves artificial drainage that can induce rapid runoff and reduce aquifer recharge. Irrigated agriculture uses greater volumes of water per unit area

¹⁸ Groundwater levels (water tables) may rise because of increased recharge owing to natural causes (rainfall), land clearing or irrigation. Rising water tables can bring relatively salty groundwater to the surface, or rising water can leach out salts in the soil and bring them to the surface. Increasing salinity owing to land management practices including land clearing is called dryland salinity while increasing salinity owing to irrigation recharge is called irrigation salinity.

of land than in urban areas, but the return flows from irrigation are greater than return flow from stormwater and sewage treatment in urban areas (Blomquist 1992).

Combinations of alteration to river flows, land cover and land use changes can combine to have a substantial influence on water resources and their interaction. For example in the Murray-Darling Basin, increases in plantation forestry and farm dams that interrupt rainfall and runoff, and increases in irrigation efficiency are combining to reduce groundwater recharge (Duggan et al 2008). This can be expected to lead to reduced baseflow to surface water resources (Australian Government 1996, 2001).

Climate also affects connectivity. When it is dry, baseflow typically discharges to streams. In contrast, when it is wet, surface run-off and inter-flow (near surface flow of water) increase leading to higher hydraulic pressures in the lower reaches of the stream, bank infiltration and aquifer recharge (Brunke and Gosner 1997). Global warming that changes the magnitude and variability of rainfall will have impacts on surface run-off, stream flow, groundwater recharge and seepage (IPCC 2007).

2.1.5 Classification of surface water and groundwater connectivity

Following from the preceding analysis, there are four key aspects to surface water and groundwater connectivity; contiguity, conductance, seepage and impact (Brodie et al 2007).

Contiguity describes whether or not a groundwater system is in direct hydraulic contact with a surface water feature. A stream is contiguous with an aquifer if the water saturation zone is continuous between the two. Figures 2.2 a-d show examples of contiguous resources. Disconnected losing streams are contiguous but not connected. Connected water resources can also be classified in terms of the direction of seepage. Gaining streams and losing streams are at two ends of the spectrum. Intermediate situations include streams that lose over part (s) of their reach and gain over other part(s), or gain during part(s) of the year and lose during other part(s).

Conductance refers to the ability of geological material to transmit water. Highly conductive streams are associated with highly permeable materials such as gravels and

coarse-grained sand. Weakly conductive streams have very low seepage flux associated with impermeable materials such as silt and clay. Table 2.1 shows further detail.

Connectivity can be classified in terms of the potential impact on the combined water resource and its management. This assessment needs to take account of impacts on quantity and quality of surface water and groundwater, and on all users of the resource over the long term i.e. more than 50 years.

Table 2.1 Typical features of conductance categories for stream-aquifer systems

Features	High Conductance	Mid conductance	Low conductance
Typical materials	Gravels, coarse sand, karst	Fine sand, silt, fractured rock, basalt	Clay, shale, fresh unfractured rock
Typical hydraulic conductivity	> 10m/d	10-0.1 m/d	< 0.1 m/d
Typical seepage flux	> 1000 m ³ /d/km	10-1000 m ³ /d/km	< 10 m ³ /d/km
Ratio of seepage to total flow	> 0.5	0.1-0.5	< 0.1
Typical near stream response time	Days-months	Years	Decades

Source: SKM 2003

Evans (2007) proposed a two dimensional assessment of surface water and groundwater connectivity that is a useful means for classifying the impacts of connectivity and identifying management and research priorities.

Table 2.2 Classification of impacts of surface water and groundwater connectivity²⁰

		Steady-State Impact			
		< 10%	10-50%	> 50-90%	> 90%
Time Delay	> 1 year	Low	Moderate, short term	High, short term	Very high, short-term
	1-10 years	Low	Moderate, medium term	High, medium term	Very high, medium term
	> 10 years	Very low	Moderate, delayed	High, delayed	Very high, delayed

²⁰This table is adapted from Evans 2007.

Qualitative influences such as climatic conditions (tropics to temperate) and level and style of water resource development add a third dimension to this classification (SKM 2011)²¹.

The highest priorities for management and research are resources which have a high short or medium term connectivity (the top two rows of the two right hand columns in Table 2.2) together with a high level of socioeconomic or environmental significance. This is indicated by the intensity of resource use and/or connections with important water related environmental assets or ecosystems. In the extreme case of a connected, rapidly responding (within weeks) and highly developed surface water and/or groundwater resource there may need to be daily allocations or cease to pump rules to ensure that allocation remains within sustainable or acceptable limits.

2.2 Objectives and benefits of integrated water management

There are two main reasons for integrating the management of surface water and groundwater. Firstly, both types of water have special advantages. Surface water is visible, moves quickly and is relatively easy to deliver. Secondly, the impact of the use of surface water on groundwater and vice versa needs to be managed.

2.2.1 Objectives and methods of integrated water use

Throughout history people have devised various ways to regulate the flow of surface water systems, for example by creating dams and reservoirs, and by releasing controlled amounts of water to regulate streamflow and meet human demands. In a typical basin groundwater is a renewable resource. Allowing for natural replenishment, losses and environmental requirements, a certain amount may be harvested without excessively depleting the amounts of water in storage in the basin. For example, water may be

²¹ The classification set out in Tables 2.1-2.2 gives sufficient detail to provide background for the following chapters in this thesis. An improved classification is given in SKM 2011. In the improved version the potential for surface water-groundwater connection depends on both aquifer material (conductance) and surface water environment (non-ephemeral/ephemeral) as well as contiguity. There are four categories of time delay ranging from very short (weeks) to very long (many years). <http://nwc.gov.au/publications/waterlines/national-framework-for-integrated-management-of-connected-groundwater-and-surface-water-systems> accessed 9 February 2012.

stored underground when surface water is plentiful and drawn down when surface water is scarce. Aquifers may be partially emptied during dry periods and recharged during wet periods.

The multiple benefits of surface water for human users and the environment have been widely recognized, but there has been less recognition of the multiple benefits of groundwater. Water managers have often concentrated on negative aspects of groundwater and its exploitation, such as salinity or reduced streamflow. The positive aspects of groundwater have received less attention especially the role of groundwater in maintaining landscape and ecosystem functions.

Experience in Australia and the USA indicates that integrated water management offers significant opportunities to increase the efficiency of water use and achieve multiple policy objectives (Dillon et al 2009, Blomquist et al 2004). The objectives and methods of integrated water management can be broadly divided into:

- maintaining stable water supplies for users and reducing exposure to droughts and floods;
- maintaining or replenishing surface and groundwater resources and water dependent ecosystems;
- water storage (temporary or long term);
- water quality control; and
- recycling stormwater and treated effluent

Individual integrated water management schemes often combine several of these objectives.

The most common methods applied in integrated water management are use restrictions, water transfers, underground storage, managed aquifer recharge, water carryover and banking, alternating cyclical use, water recycling, and diluting or filtering salt or other pollutants - see Table 2.3.

Individual water use limits consistent with aggregate annual and seasonal limits are the most widely used method for managing heavily exploited water resources. In connected resources aggregate and individual surface water and groundwater use limits need to be coordinated. When surface water and groundwater resources are connected impacts of the use of one resource on the other need to be considered when setting use limits for

each resource. The importance of these surface water and groundwater connections varies substantially along river reaches and across aquifers. The strongest and fastest connections occur in alluvial valleys and plains where shallow alluvial aquifers lie below the river. The case for joint management of surface water and groundwater is strongest in these resources.

Table 2.3 Integrated water management: objectives and methods

<i>Methods</i>	<i>Objectives</i>				
	Maintain water supply	Maintain or replenishing resources	Water storage	Water quality control	Recycle stormwater or treated effluent
Use restrictions	√	√		√	
Water transfers	√				
Underground storage	√	√	√		
Aquifer recharge		√	√	√	√
Water carryover and banking	√	√	√		
Alternating use	√	√	√		
Water recycling	√			√	√
Dilution and filtration				√	

Flows from groundwater to surface water and vice versa need to be omitted from estimates of groundwater and surface water availability and sustainable use limits in order to avoid double accounting. Cross connection impacts were not accounted for until the most recent round of water planning in the Murray-Darling Basin.

Surface water groundwater transfers are feasible in connected systems, although potential impacts must be addressed and time lags of impacts taken into account²². Surface water groundwater trading is easiest when surface water and groundwater resources are highly connected and where connections are rapid. Transfers from outside a connected surface water groundwater system can help relieve the pressure on highly exploited resources.

²² Further details are set out in Box 5.1.

Underground storage requires transfer of water from surface sources to underground storage(s). Direct recharge can be accomplished using natural stream or lake beds as recharge media. Alternatively water can be diverted from stream channels into adjacent storage areas sometimes called "spreading basins" where water can collect to percolate through the soil. Groundwater can also be recharged via bank filtration, by keeping water levels high in streams recharge connected aquifers through their banks. Aquifer storage and recovery programs use infiltration methods, or bores, to inject water into an aquifer. Treated wastewater (from sewage or stormwater) can also be used to recharge groundwater in this manner. Programs of managed underground storage require facilities for recovering stored groundwater either through existing wells or through newly installed pumping capacity (Blomquist et al 2004).

Managed underground storage is especially attractive as a means of saving water under dry climatic conditions. However, dry climatic conditions also reduce the amount of surplus water available for underground storage and long term programs of underground storage are required to ensure that stored water is available in dry periods when it is most needed. Users can forego a current water entitlement and "carry it over" to a future period. They can "bank" water underground when it is relatively plentiful and cheap, and then call on their banked reserve when supplies are restricted and/or more expensive.

Some of the facilities involved in engineered methods of surface water and groundwater integration are illustrated in Attachment 2.

In areas where water users have access to both groundwater wells and surface water connections alternating use of surface and groundwater is feasible. Alternating use may involve using more groundwater during the dry period and over exploiting the aquifer for short periods of time. It is important to ensure that the aquifer is replenished and sustainable exploitation levels are restored even if a drought persists. Fallowing - choosing not to plant a crop for a limited period of time - provides an additional de facto method of recharging groundwater (Dudley and Fulton 2005). Alternating use is attractive because it requires less physical effort and expenditure than direct recharge (Blomquist et al 2004).

2.2.2 Positive benefits from integrated water management

Integrated water management techniques, such as aquifer recharge and alternating use of surface water and groundwater can bolster water supply and buffer peak, seasonal and drought water demands by substituting a relatively plentiful resource for a scarcer or depleted resource. They can also allow some surface water supplies to remain in streams for environmental and recreational purposes without reducing the amount of water available for human consumptive use.

Underground storage (including bank storage) is less affected by evaporation and involves less ecological problems than surface storage (Tuinhof and Heederik 2002). Moreover, underground storage does not require large areas of land and the costs are relatively low. Integrated water management also offers opportunities for managing environmental flows (rarely considered), salinity and pollution management, and the use of saline or brackish water, stormwater or effluent by mixing and dilution. On the other hand groundwater withdrawal is often energy intensive, surface water reservoirs are suitable for multiple users and uses and are less vulnerable to mineral contamination (De Wrachien and Fasso 2007).

In countries with scarce or variable water supplies such as Australia, the western USA and Spain the management and allocation of water supplies based on long term averages of water in underground storage (stocks) might provide improved security, stability and flexibility. This option is explored further in Chapter 6 (6.4.1.1) and Chapter 8 (8.6.2).

2.2.3 Costs of not integrating surface water and groundwater management

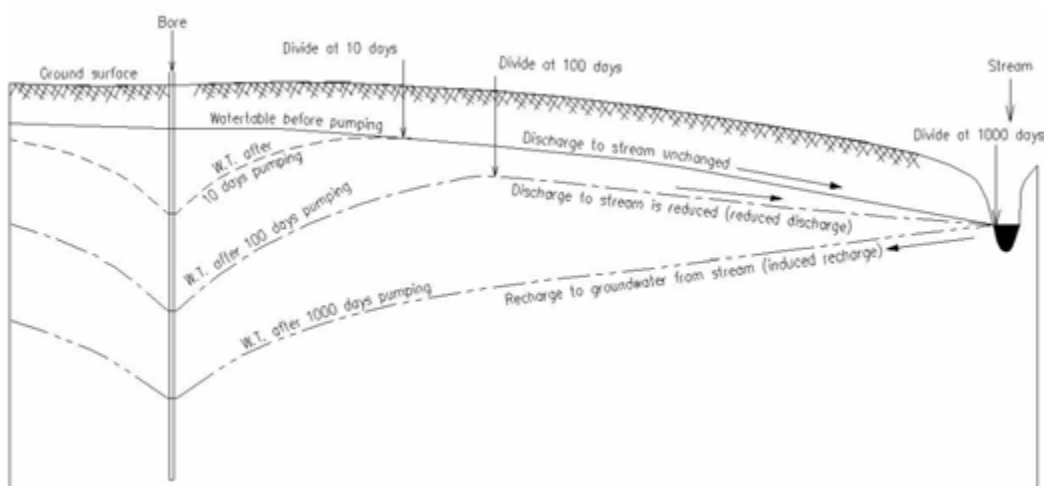
The diversion of surface water or extraction of groundwater for human consumptive use can have a range of adverse impacts on connected water resources including reduced inflows, reduced water quality, and harm to riparian ecosystems and wetlands. Integrated management is required to minimise or avoid these impacts and associated costs.

2.2.3.1 Impacts of pumping on streamflow and aquifer condition

Pumping temporally lowers the groundwater level in the immediate vicinity of the well. This creates a depression in the water table. Water from the surrounding area moves towards this depression. In a typical unconfined aquifer, the pumping rate, pumping duration, and the distance of the bore from the stream are the key factors that affect the impact of groundwater pumping on streams. The cross section size, conductivity, drainage capacity, and head of the aquifer are also significant factors. Groundwater pumping has a larger and more rapid impact on streamflow when the bore is close to the stream, because of the strong lateral transmission effect close to the bore. If the bore is close to the stream or the pumping continues for an extended period of time the slope of the water table can reverse and the stream can change from a gaining to a losing stream, leading to induced recharge - see Figure 2.3. When a bore is distant from a stream the impact of pumping is slower, and evapotranspiration, and discharge to other groundwater systems can have a greater impact on aquifer discharge to the stream (Evans 2006).

Aquifer materials also affect the impact of groundwater. Even temporary drawdowns in karst aquifers, and in relatively more fragile materials such as limestone or gypsum groundwater depletion can result in sudden subsidence. By contrast, the impact of drawdowns in large alluvial systems often takes a long time to manifest itself (Blomquist 1992).

Figure 2.3 Effects of groundwater pumping on streamflow



Source: Evans 2006

The degree of confinement of an aquifer also affects the impacts of drawdowns. Completely confined aquifers can only be replenished by subsurface flow, if at all. Although unconfined aquifers are more easily replenished, and it is easier to recover water from them there are greater risks of leakage of stored water and contamination during drawdowns. Semi-confined aquifers can also be replenished by percolation from the surface, but the impact of drawdowns differs from unconfined systems. For example, in an aquifer with a deeper high transmissivity layer separated by an aquitard from a shallow unconfined low transmissivity layer, the distance of a bore from the stream has much less effect on the timing of the impact. This is because of the rapid lateral transmission of the deeper layer. This effect is eventually transmitted vertically to the upper layer through the aquitard (Braaten and Gates 2004).

The timing of the change from groundwater depletion to induced recharge from surface water bodies is a key factor in developing sound water use policies (Balleau 1998). The rate of transition from groundwater depletion to surface water depletion is affected by the pumping rate, aquifer transmissivity and storativity, and the location and time of pumping. It is highly variable from case to case. The natural recharge rate is not related to the variables that affect the rate of transition from groundwater to surface water depletion, but it is often assumed that natural recharge can balance groundwater use (safe yield). This policy ignores natural groundwater discharge, and eventually leads to the drying of springs, wetlands and riverine riparian systems that constitute the natural discharge area of some groundwater systems (Sophocleous 2000). Pumping from a groundwater system will eventually lead to a new equilibrium of discharge and recharge (aquifer loss and stream loss) but this may take a very long time. During the adjustment period groundwater mining and related environmental degradation continues. An equilibrium steady-state is reached only when pumping is balanced by capturing discharge and, in some cases by a resulting increase in (induced) recharge (Bredehoft et al 1982).

While overexploiting groundwater in modest amounts for limited periods is unlikely to cause serious adverse consequences in most groundwater basins, persistent overexploitation can create a number of problems. Deeper wells may be required resulting in increased pumping costs. Some users, for example those near the edge of an aquifer may find that they can no longer obtain water at all. Sediments can become compacted leading to land subsidence and storage space in the aquifer may dwindle or

even disappear. Dropping water levels and compaction may also lead to greater groundwater contamination (Blomquist 1992). The loss of underground storage can result in high economic costs of replacement storages or loss of access to water. Finally, overexploitation and contamination can damage groundwater dependent ecosystems and environmental assets.

2.2.3.2 Impact of surface water diversion on groundwater recharge

The impacts of pumping on streamflow have been investigated more thoroughly than the impacts of surface water diversion on groundwater recharge. There are a number of explanations including the greater visibility of surface water resources and their connections with ecosystems, and the greater priority generally given to surface water development - representing a kind of "hydro-schizophrenia" (Llamas and Martinez-Santos 2004).

Streamflow may be modified by diversion from streams or the regulation of flows through water storages, channels, locks and weirs. In regulated systems releases from surface water storages can substantially change patterns of streamflow and recharge. For example, other things being equal the maintenance of high streamflows during dry periods can reduce stream inflows in gaining reaches and increase stream losses (groundwater recharge) in losing reaches. Releases from water treatment plants and industrial facilities and return flows from large scale irrigation and drainage facilities can have similar effects.

Straightening and lining streams, which is common in urban and industrial areas can drastically alter connectivity by isolating streams from aquifers or changing how and when seepage occurs (Brodie et al 2007).

2.3 Summary

Surface water and groundwater have distinct properties that strengthen the case for integrated water management. Streams, groundwater basins and aquifers vary substantially, creating a mosaic of resources that interact in four dimensions; across the surface of the earth, above and below ground and through time. Most surface water

resources are connected with groundwater and vice versa, but the degree and timing of connections and their impacts varies substantially.

Surface water and groundwater interactions are affected by a number of characteristics of streams and aquifers including size, shape, slope, boundaries, storage, the speed and variability of flows, and aquifer materials and confinement. There are also a number of broader influences on surface water and groundwater interactions such as land cover, land use and climate. Surface water and groundwater connectivity can be classified in terms of the size, extent and timing of its impact. A relatively long time lag before the impact of groundwater pumping poses a special challenge for management.

Integrated water management offers a range of opportunities to increase the efficiency of water use and achieve multiple policy objectives. These objectives include the maintaining water supplies, maintaining or replenishing resources, water storage, water quality, and recycling stormwater or treated effluent.

Methods of integrated water management include use restrictions, water transfers, underground storage, aquifer recharge, water banking, alternating use, water recycling, dilution and filtration. Managed underground storage and alternating surface and groundwater use are two prominent and contrasting methods of integrated water use. The feasibility, benefits and costs of integrated water management vary according to the characteristics of surface water and groundwater resources, their connections and uses. The development of integrated water management projects requires detailed site-specific knowledge.

Integrated water management can help to minimise or avoid adverse impacts of water resource exploitation on the quantity, quality and productivity of natural resources, ecosystems and wetlands. Groundwater is the major source of water storage in the landscape, and the contribution of groundwater to landscape and ecosystem health deserves greater recognition.

Chapter 3 Methodology and framework for studying integrated water management

3.1 Introduction

Integrated surface water and groundwater management is a highly complex process involving governments, water users and third parties at multiple scales. Integrated water management invites a large number and variety of research questions. Therefore it is important to clearly specify the scope of the research, questions and methodology. This research examines how institutional factors have influenced integrated water management at the broad river basin and sub basin scale.

This chapter begins by introducing a method and framework for analysing factors that have affected integrated water management, and theoretical perspectives underpinning the approach taken. The methodology involves a narrative synthesis approach which relies on qualitative integration of findings from existing studies. The chapter continues with the proposition that integrated water management may be considered as a policy and management process taking place in a complex social and ecological system. The main part of the chapter contains a discussion of alternative frameworks for assessing factors that affect integrated water management, and related opportunities and barriers at various scales of analysis. From this discussion a broad analytical framework and key variables are derived to guide comparative analysis of integrated water management. The chapter ends by introducing the case study comparisons of integrated water management that make up the main part of this thesis.

3.2. Methodology – an adaptive narrative synthesis approach

Integrated surface water and groundwater management can be examined at many different scales and from many different perspectives. Scale can be classified into spatial, temporal, jurisdictional, institutional, management, social network and knowledge dimensions. Levels are units of analysis that are located at different positions on a scale (Cash et al 2006, Gibson et al 2000). Spatial and temporal scales

have a very large number of different identifiable levels/units. The spatial scale for integrated water management can range from large river basins with many sub basins to sections of tributary streams. The temporal scale ranges from the management of resource connections with almost immediate impact, such as shallow alluvial aquifers, to connections with impacts over tens or even hundreds of years, such as fractured rock systems. The jurisdictional scale can range from inter-governmental to local government. The management scale can range from river basin organisations to water user groups in irrigation sub-districts. Focus on the institutional scale provides a relatively manageable and meaningful way to understand the very large range of actors, actions and activities that occur during integrated water management (Schlager 2007).

Integrated surface water and groundwater management can be analysed from several different theoretical perspectives. The physical connectivity between water resources is classified and assessed in water science (hydrology and hydrogeology). Water use, exchange and markets are analysed in economics. Water laws and water entitlements are covered in legal studies. Political and policy sciences throw light on water governance and water conflicts. Social sciences explore the importance of water to human communities. Literature drawing from each of these disciplines can be found in the digital library of the commons²³, one important source of references used in this research.

This research draws on a wide range of documentary evidence containing many different theoretical perspectives on integrated water management at different scales. Meta-analysis provides a methodology for synthesising results from a large number of studies (Wolf 1986). Meta-analysis is most usefully applied to the examination of domains with large groups of studies investigating the same question using roughly the same experimental or quasi-experimental design (Bangert-Drowns 1995). This is not feasible in the case of comparisons of integrated water management.

Firstly, the body of literature on integrated water management is relatively small and lacks consensus and/or empirical evidence on some key concepts such as resource connectivity, sustainable use limits and the efficacy of integrated water markets. Moreover, arrangements for important aspects of integrated water management such as aquifer storage and recovery are still in the developmental phase, even in areas such as

²³ <http://dlc.dlib.indiana.edu/dlc/> accessed 24 February 2012.

the western USA where integrated water management is relatively common. Secondly, while it would be desirable to compare a large set of case studies representing different physical and user characteristics in the MDB and other river basins, there are few examples of integrated water management in the MDB.

When the body of literature is relatively small, lacks consensus on key concepts and refers to cases with a variety of research designs because structured comparisons are not available, a narrative synthesis approach is appropriate. A narrative approach is better able to draw connections between distinct but related literature (Poteete et al 2010).

The range of different methods for synthesising quantitative and qualitative research has been growing in recent years (Barnett-Page and Thomas 2009)²⁴. Narrative synthesis only relies to a limited extent on the structured meta analysis of data from source materials. Whilst narrative synthesis can involve the manipulation of statistical data, the defining characteristic is that it adopts a textual approach to the process of synthesis to ‘tell the story’ of the findings from the included studies. Narrative synthesis can be used in systematic reviews of a large number of diverse studies (Bangert-Drowns 1995).

Systematic reviews are sometimes replacing narrative reviews as a way of summarising research and to translate the evidence from a large number of studies into a form that can be understood and used in decision-making (Hemingway and Brereton 2009)²⁵.

The methodology in this thesis draws on the methodology for systematic review identified by Popay et al (2006)²⁶:

1. Identifying the review focus, searching for and mapping the available evidence.
This includes studies from various disciplines using a range of research designs and interviews of participants in integrated water management;
2. Specifying the review questions and identifying scales to include in the review;
3. Data extraction in relation to the review question and scales of interest;

²⁴ Barnett-Page and Thomas classified 203 papers, and found nine distinct approaches to qualitative synthesis: meta-narrative synthesis, critical interpretive synthesis, meta-study, meta-ethnography, grounded formal theory, thematic synthesis, textual narrative synthesis, framework synthesis and ecological triangulation.

²⁵ Systematic reviews have been used largely to synthesise results from the large number of studies of interventions in health and education sectors. The methodology can also be used to synthesise analysis and results from studies of common property resources and natural resource management.

²⁶ While this study provides guidance on systematic reviews of the effectiveness of (interventions in) social programs, the general approach can be adapted for a review of integrated water management.

4. Synthesis: brings together findings from the included studies and interviews in order to draw conclusions based on the body of evidence. The synthesis includes three main elements;
 - a. developing a framework²⁷ to structure studies about factors that influence integrated water management and related opportunities and barriers;
 - b. preliminary synthesis of factors, opportunities and barriers from included studies;
 - c. exploration of relationships including differences between studies.

The methodology used in this thesis also draws on adaptive theory (Layder 1998). Layder proposes that the development of theory and the collection of evidence should be approached as a continuous interconnected process rather than a relatively fixed sequence of stages. Theory both adapts to, or is adapted by, incoming evidence while data is simultaneously filtered through, and adapted by, prior theoretical materials (frameworks, concepts, questions). Like narrative synthesis this approach is very useful when the body of literature is relatively small and lacks consensus on key concepts, because it allows, even invites the development of concepts and questions during the research process.

Layder distinguishes between three “typical” approaches to theorising; the collection of empirical information, application of concepts and ideas that constitute a theoretical framework for research and grounded theory. The second approach may involve application of some general theory or framework to contextualise discussion of empirical data, application and testing of specific concepts, or application of some tightly formulated hypothesis. All of these approaches tend to be concerned with confirming or refuting existing theories, concepts or hypotheses rather than generating new theory.

This thesis includes both the collection of information and the application of a framework to contextualise the analysis of empirical data, concepts and questions. The analysis of empirical data and interviews to tackle research questions in the first comparative case study is used to develop further more focused research questions and

²⁷ Popay et al talk about developing a theoretical model of how interventions work. This formulation is not appropriate for a study of factors that affect integrated water management. In view of the large number of variables that may affect integrated water management many theories are possible. In this case it is more realistic to propose a general framework to guide the exploratory study, as discussed in following sections of this chapter.

the design of the second comparative case study. There is no single hypothesis tested throughout this thesis. Instead evolving set of research questions is explored in order to throw light on the factors that support and constrain integrated water management, and the policy and management implications of the analysis.

3.3 Towards a framework for exploring factors that affect integrated water management

3.3.1 Study of integrated water management as a social and ecological system

There is cross disciplinary agreement that the optimal development of water resources depends on integrated use of surface water and groundwater resources and storage (Conkling 1946, Burt 1964, Freeze and Cherry 1979) while maintaining resources and related ecosystems and ecological assets (De Wrachien and Fasso 2007, Brodie et al 2007). Blomquist and Schlager (2008) propose that the biophysical and institutional aspects of river basin management can be studied within the framework of complex adaptive social and ecological systems (SES), building on the work of authors such as Holling (1978), Walters (1986), Lee (1993) and Berkes et al (2003). A SES is an ecological system intricately linked with and affected by one or more social systems. Both social and ecological systems contain units that interact interdependently and each may contain interactive subsystems as well. Interdependent surface water and groundwater systems and their user communities are examples of SESs (Anderies et al 2004).

Integrated water management framed as an SES can be examined from many perspectives depending on the nature of the enquiry. For example it can be analysed in terms of interactions between resource users, resources and the environment, or as a policy process linking governance systems with resources and users.

Biophysical features interact with each other, and with social features. For example, groundwater affects river flows, and surface water affects groundwater recharge (Winter et al 1998). Trees contribute to riverine environments and river health, but they also use

up water. Land clearing affects evapotranspiration, run-off and recharge (CSIRO 2006). Climatic variability affects water system inflows (rainfall) and outflows (evaporation and evapotranspiration)(CSIRO 2008). The impacts of agriculture and human settlement on the landscape and natural resources depend on population size and growth, incomes and resource conservation practices. River basins often include large human populations who use the basin's natural resources for multiple purposes and affect the health of the physical system. Human exploitation of water resources affects water dependent ecosystems, ecosystem health affects the productivity of primary industries, and water supplies human settlements. When multiple uses and users are confronted by scarce resources and/or environmental impacts, there are often trade-offs between competing uses and users, and conflicts can ensue.

The development of integrated surface water and groundwater policy and management is a very complex process that can involve thousands of people from government agencies, businesses and other interest groups and dozens of programs and projects at multiple scales and levels²⁸. Moreover, like other policy processes, integrated water management involves long time periods (over a decade) to assess impacts on resources, and substantial policy debates involving deeply held values, substantial amounts of money and a degree of coercion. Given the highly complex policy process, analysts must find some way of structuring and simplifying the situation in order to develop propositions to explain phenomena (Sabatier 2007).

Ostrom (2007) distinguishes between three sets of propositions; frameworks, theories, and models. Frameworks provide a foundation for enquiry by specifying classes of variables and general relationships among them. Theories specify which elements of a framework are particularly relevant to certain kinds of questions, make general working assumptions about those elements and make specific assumptions that are necessary for an analyst to diagnose a phenomenon, explain its processes and predict outcomes. Several theories are usually compatible with any framework. Models make precise assumptions about limited set of parameters and variables. While it is not possible to have a one integrated model that captures all the potential interactions in an SES at all possible scales, it is important to have an analytical framework within which to

²⁸ There are a large number of integrated water projects in the western USA, but relatively few in the MDB, for reasons that will be explored in Chapters 6-8.

understand the broad structure of the elements and linkages, and how these linkages affect system performance and outcomes (Anderies et al 2004).

The above discussion suggests that a critical requirement for a comparative study of integrated water management is a framework to structure and guide the exploration of complex and diverse biophysical and social systems. More specifically the framework should be able to guide an exploration of characteristics of and relationships between surface water and groundwater resources, users and managers, and systems of governance at various scales. An interdisciplinary perspective is needed, taking account of a range of physical and social sciences. The boundaries of the framework need to be well defined, as do variables and relationships covered by the framework.

3.3.2 Selection of a framework

The following criteria were used to select candidate frameworks for structuring an analysis of factors that affect integrated water management;

1. Subject coverage: the framework should enable analysis of interactions between the biophysical, social and institutional variables that affect integrated water management including water resources (R), water users (U) and water governance systems (G) and their interaction;
2. Interdisciplinarity: the analysis of integrated water management requires the integration of thinking from the biophysical, social and political sciences. The framework should include at least two of the following disciplinary clusters; biophysical science (BS), hydrology and hydrogeology (HS), social science (SS), political and policy science (PPS).
3. Definition: the key concepts and relationships should be well defined. Ill defined concepts and relationships are likely to lead to ambiguity and possibly confusion in the interpretation of analysis.

4. Use: the framework should have been used in the analysis of many cases and/or problems. This provides a degree of confidence that the framework is relevant and applicable in practice.

Using these criteria six frameworks were shortlisted to guide an exploratory analysis and synthesis of integrated water management. These six frameworks are; integrated water resource management (IWRM), environment policy integration (EPI), the resilience perspective, hydroeconomic analysis, the advocacy coalition framework (ACF), and the framework for analysis of social and ecological systems.

The comprehensive subject coverage of IWRM (GWP TAC 2000, 2004) is appropriate for investigating integrated water management, but IWRM is intended for practical use rather than cross disciplinary scientific analysis. The treatment of options is descriptive and does not analyse choices or trade-offs between options (Biswas 2008).

The EPI literature (Jordan and Lenschow 2010) provides some interesting insights that can be applied to the development of integrated water policy and management. These include the distinction between hierarchy, market and network as governance instruments. However, the EPI framework does not include an analysis of resources, and has not been developed to analyse interactions between resource users and governance arrangements.

The resilience perspective (Walker et al 2004) provides a dynamic long term perspective on social and ecological systems. It has comprehensive coverage of natural resources, social systems and their interactions, with a growing number of case studies, but it does not include an analysis of political change, opportunities and constraints.

Hydroeconomic analysis (Harou and Lund 2008, Harou et al 2009) links physical and social sciences and includes many of the variables that drive integrated water management. Hydroeconomic models are generally well defined and have been extensively used to assess scenarios and policy choices. However, these models are calibrated to cover specific situations, simplify physical, economic and regulatory processes, and lack a sophisticated analysis of the interactions between governance arrangements and behaviour.

The ACF (Sabatier et al 2005, Sabatier 2007) enables broad subject and disciplinary coverage and is being used increasingly to analyse interactions between resource users, government organisations and third party interest groups. However, further work is needed to identify links between constitutional rules, social values and the policy subsystem, and to demonstrate the prevalence and advantages of coalitions.

The high-level framework for analysing complex social and ecological systems, (Ostrom 2007, 2009) is well suited to guide the analysis of complex social and ecological systems at multiple scales linking a variety of disciplines. It includes biophysical, social and institutional variables and their linkages. It draws material from a range of disciplines. The framework has been developed with reference to a large number of case studies of common pool resources, including many studies of water and irrigation management (Poteete et al 2010). The SES framework meets all of the selection criteria and is selected to provide the primary framework for structuring analysis of integrated water management. Table 3.1 summarises the above assessment of the six shortlisted frameworks, and Attachment 3 provides further details.

Table 3.1 Assessment of frameworks for analysing integrated water management

	<i>Subject coverage*</i>	<i>Interdisciplinarity**</i>	<i>Definition***</i>
<i>Integrated water resource management</i>	R U G	Mainly PPS	Many elements defined, interactions not well defined
<i>Environment policy integration</i>	U G	SS PPS	Definition of elements and interactions in the development stage
<i>Resilience perspective</i>	R U	BS SS	Elements and interactions clearly defined but very broadly specified
<i>Hydroeconomic analysis</i>	R U	HS SS	Elements and interactions well defined in specific studies
<i>Advocacy coalition framework</i>	U G	PPS	Elements well defined, interactions moderately well defined
<i>Framework for the analysis of social and ecological systems</i>	R U G	BS HS SS PPS	Elements comprehensively defined, interactions well defined in specific studies

Notes:

* R = resources, U = users; G = governance system

**BS = biophysical science, HS = hydrology and hydrogeology, SS = social science, PPS = political and policy science

***Definition refers to elements of the framework and interactions between them

3.3.3 Evolution of the framework for analysing social and ecological systems (SES framework)

The framework for the analysis of social and ecological systems evolved from studies of common pool resources. A common pool resource²⁹ is such that (a) "it is costly to exclude individuals from using the good either through physical barriers or legal instruments and (b) the benefits consumed by one individual subtract from the benefits available to others" (Ostrom 2000). Because of its two defining characteristics, a common pool resource is subject to problems of congestion, overuse and potential destruction.

Early frameworks and theories about management of the commons predicted that individuals would overexploit common pool resources (fisheries, forests, range lands) until they became unproductive, and in some cases beyond recovery (Scott Gordon 1954, Hardin 1968). Subsequent research brought attention to hundreds of examples of collective action to manage common pool resources, in contradiction of the "conventional theory" of the Commons. Successful collective action is not however the only possibility. Case studies have also documented numerous examples of collective arrangements that failed to survive market pressures, government interventions, or technological, demographic or ecological changes.

Research has shown that a large number of conditions influence the prospects for collective action in specific action situations (Agrawal 2001, Ostrom 2007). Research developments can be divided into three levels of analysis: individual human behaviour; the micro situation including the immediate variables impinging on individual decision-making in an action situation; and the broader social and ecological system within which individuals make decisions. Combinations of micro situational and broader contextual variables affect decisions made by individuals, and help to explain the substantial variation in behaviour observed across and within action situations (Poteete et al 2010).

²⁹ Common pool resources are sometimes called common property resources, but the term *common property* implies that there is some ownership structure, from which non-owners can be excluded. However one of the two defining characteristics of a common pool resource is that it is difficult to exclude anyone from using it. The term common pool avoids this contradiction.

This thesis focuses on the effects of broad contextual variables on integrated water management, and takes a long term perspective in which the micro situational variables are likely to evolve and change substantially. While micro situational variables are likely to strongly affect integrated water management at particular places and times, they are less likely to have strong systematic long term effects than laws, rules and the structures of management organisation(s).

Ontological frameworks are widely used in biology, medicine and informatics to set out the elements of complex systems. These frameworks generate sets of questions from which specialists can select questions most relevant to a particular problem. Ostrom has developed a multi tier framework for the analysis of social and ecological systems and common pool resources (Ostrom 2007, 2009). The first tier relates resource systems and their units, governance systems and users together with their interactions and consequent outcomes. This framework can be decomposed into further multiple tiers of variables. Further details are in Attachment 4. This framework is used as the basis for a framework to analyse integrated water management, as explained in the following section.

3.3.4 A Framework to analyse integrated water management

3.3.4.1 The basic framework

River basins usually include a range of different geological, hydrological, hydrogeological and social systems. Blomquist and Schlager (2008) propose that the biophysical and institutional aspects of river basins can be studied within the framework of complex adaptive social and ecological systems (SES). A SES is one or more ecological system linked with and affected by one or more social systems (Holling 1978, Walters 1986). Both social and ecological systems contain units that interact interdependently and each may contain interactive subsystems as well.

The framework for analyzing integrated water management is derived from the framework proposed by Ostrom to analyse social and ecological systems (Ostrom 2009), see figure 3.1. The framework diagram is similar to the diagram in Ostrom 2009, but the following description of variables in the diagram is more specific than

one given by Ostrom as it relates to the management of surface water and groundwater resources at both basin and sub basin scales.

Figure 3.1 A Framework for Analysing Integrated Water Management

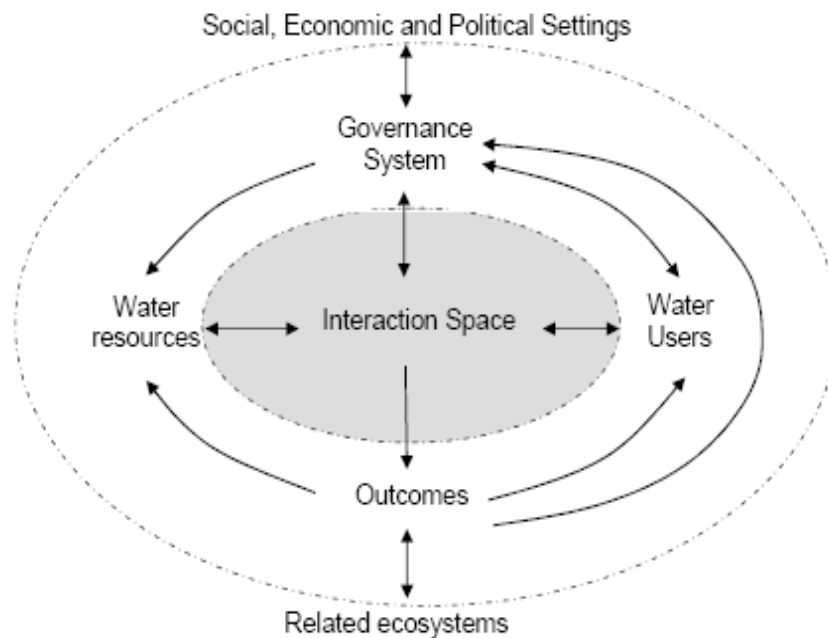


Figure 3.1 illustrates the highest level variables to be included in the analysis of water management in a river basin or sub basin. These first tier variables include water resources, water users and water governance systems and their interrelationships that together generate interactions and outcomes. Social processes and outcomes are situated within biophysical systems, and are framed and limited by them. At the planetary and continental scale integrated water management is situated within a larger biophysical (ecological) system conceptualised by the water cycle. At smaller scales such as sub basins (the typical scale of water management units), water resources and related ecosystems are situated within larger governance and social action units, as well as within larger planetary, continental and river basin biophysical systems.

The water resource system usually includes multiple surface water and groundwater resources and storages that are connected to a greater or lesser extent over various time scales. Water resources include and are linked with water dependent ecosystems³⁰. Water users include human settlements, indigenous, agricultural, industrial and

³⁰ Links between water resources and ecosystems are not examined in this thesis, but they are an important consideration in the establishment of sustainable use limits and other water policy objectives.

recreational users. The governance system includes laws, formal and informal rules, management organisation(s), instruments (regulations, markets, information, voluntary agreements), and their interactions.

The properties of the water resource system, surface water and groundwater resource units, users and the governance system affect and are affected by interactions between users, resources and the governance system and resulting outcomes. Interactions take place at multiple spatial and temporal scales. The basin SES is affected by the broader socioeconomic, political and ecological settings of the basin. For example, climate influences water resources, and major socioeconomic and political changes influence water users and the water governance system. The conceptual map in Figure 3.1 is highly simplified but it provides an important reference for the analysis in the remainder of this study.

The basic framework can be disaggregated into a larger number of "second tier" variables that affect integrated water management. Ostrom argues that scientific progress has been achieved in the past when complex systems have been decomposed into classes and subclasses of variables as proposed by Simon (1981). Within complex systems there are subsystems that are independent of each other in many functions but can affect each other's performance. Many variables affect the interactions and outcomes observed in empirical studies of common property resource management regimes. Ostrom identifies 33 variables related to resource systems, resource units, users and governance, and 8 related to interactions in the framework (details in Attachment 4). Drawing on Ostrom's framework and variables it is possible to identify variables that have a major influence on integrated water management. The level of analysis and choice of variables depends on the questions being asked.

3.3.4.2 Key variables that affect integrated water management

The selection of variables for examination in this study are based on three criteria;

1. Importance and scientific soundness of the relationship, as evidenced by citation and examination in scientific literature;
2. Clear specification of the relationship between the variable and integrated water management;

3. Feasibility of gathering information about the relationship from published documents, backed up by interviews.

Fourteen variables were selected, representing properties of resources, users the governance system and their interactions, and their effects on integrated water management. These variables are summarised in Table 3.2a (resources, users and their interactions) and 3.2b (governance system and users interactions with governing bodies).

Table 3.2a Properties of resources, users, their interactions (variables 1-7) and their expected effects on integrated water management

Property	Effect
<i>Resources</i>	
1. Significant and variable supplies of both SW and GW	Enables substitution between resources when supply is variable. Less incentive for IWM if one source dominates.
2. SW and GW storage capacity	Large inflows of SW coupled with SW and GW storage availability facilitate IWM.
3. Strong and/or rapid connection between SW and GW	Use of one resource likely to affect the other, IWM is required.
<i>Users</i>	
4. Values, interests and problem framing of SW and GW users	Different values and interests complicate collaboration between SW and GW users, and emphasis on SW may impede IWM.
<i>Interaction of users and resources</i>	
5. Users depend on SW or GW (or both), SW and GW resources intensively used	Scarcity and lack of reliable supply provide incentives for water saving including through IWM and management intervention.
6. SW and GW substitutability	If one resource has clear advantages in supply reliability, price or quality IWM is less likely.
7. Infrastructure availability and cost	Infrastructure is required for IWM - water storage, extraction and transfer.

Notes: SW = surface water, GW = groundwater, IWM = integrated water management.

These "properties" correspond to "lumped" variables, and are compatible with, and in most cases coincide with variables identified by Agrawal (2001) and Ostrom (2007, 2009), following extensive examination of scientific literature. These variables and their expected effects on integrated water management, based on previous research, are discussed below.

Surface and groundwater resources

Integrated use is more likely to occur when both surface water and groundwater provide important sources of supply. Integrated use is less likely when either surface water or groundwater is a small proportion of the total supply, because the focus will be on the dominant resource. Integrated use is also more likely when there are large seasonal or annual variations in rainfall and surface water supply, because this creates an incentive to use water supply cyclically with an emphasis on surface water use and storage in wet periods, and groundwater use in dry periods (Blomquist et al 2004, Fullagar et al 2006). When boundaries are well defined and aquifers are relatively immobile it is easier to manage aquifer storage and extraction. When boundaries are ill defined or aquifers highly mobile it becomes more complicated (Blomquist et al 1994). On the other hand mobile aquifers may have more transmissive materials that are easier to recharge.

Integrated water management requires surface and/or undergroundwater storage.

Underground storage is more attractive in relatively hot and arid climates (Dillon et al 2009) where surface water storages evaporate quickly or when the potential for additional surface water reservoirs is exhausted (Blomquist 1992).

Strong and/or rapid connections between surface water and groundwater increase the need for integrated water management, because groundwater use affects streamflow, and surface water use affects recharge (Evans 2007). Integrated management is needed to prevent the exploitation of either resource having adverse impacts on users of the other, or the environment. Resource connectivity is affected by the characteristics of surface water and groundwater resources and related geological features. The impact of pumping groundwater on streamflow depends on the distance of the bore from the stream³¹.

³¹ Further details about the relationship between surface water and groundwater connectivity and integrated water management are set out in chapter 2.

Water uses and users³²

Previous studies indicate that the heterogeneity of surface water and groundwater users can have multiple influences on the uptake and patterns of integrated water management (Blomquist and Schlager 1998). In aggregate these influences are likely to be negative (Poteete et al 2010). In this thesis the influence of heterogeneity is divided into several categories; values, interests and problem framing and group size.

User identification with surface water or groundwater groups, coupled with perceived differences in the values and interests of these groups complicates the achievement of understanding and trust required for collaboration in successful integrated water management. On the other hand differences may encourage collaboration to resolve problems (Emerson et al 2012).

Different problem framing helps determine the agenda for integrated water management. For example if surface water and groundwater are considered equally important, positive opportunities for integrated use are more likely to be emphasized. If surface water is considered more important than groundwater, integrated water management is more likely to emphasise protecting surface water resources from the negative effects of groundwater use.

Concerning group size it is often argued that collaborative action is more difficult in large user groups. This effect has been challenged by the argument that larger groups can gather more resources and monitoring and sanctioning capability (Agrawal 2001). Since most of the user groups covered in this study are relatively large, group size is not included in the list of variables for examination, although it is acknowledged that there may be size thresholds for integrated management projects (Thomas 2001).

Interactions of users and resources

Integrated water management is strongly affected by users' dependence on water use and intensity of use³³. Users who are highly dependent on water use (such as irrigators) are most likely to be interested in means to secure reliable supplies. Users of

³² Users include interested third parties and the environment and their representatives in IWM negotiations.

³³ Intensity of use is defined in terms of the ratio between water use and water resource availability.

intensively used and stressed water supplies are most likely to experience water scarcity and lack of reliable supplies. A combination of high dependency, high intensity of use and water scarcity provides a strong incentive to make the best use of available water supplies; integrated water management provides one option. Stored groundwater can be used as a buffer against variable surface water inflows (Brodie et al 2007). On the other hand there has been a historical emphasis on surface water supply in many regions of the world, together with a relative neglect of groundwater development to the detriment of integrated water management (Llamas and Martinez-Santos 2004).

Substitutability of surface water and groundwater in terms of price and quality encourages integrated water management. Cost and quality differentials may constrain integrated water management; groundwater pumping costs usually exceed charges for delivered surface water. High levels of salinity or pollutants limit the potential of some groundwater sources. Overusing aquifers can lead to increased transmission of pollutants or poorer quality groundwater throughout a basin. Inflows of salt water can pose particular problems in the case of drawdowns in coastal aquifers (Blomquist 1992).

Infrastructure to transfer surplus surface water, store it underground, and extract it play an important part in integrated water management (Thomas 2002). Groundwater users generally invest in their own infrastructure and organise their individual supply, but individual users may not be able to meet the infrastructure costs such as percolation ponds or injection well fields, and collective investments may be required.

Governance

While integrated water management has evident advantages, governance remains a major challenge to ensure long term sustainability (Shah 2005, Llamas and Martinez Santos 2005, Kretsinger and Narasimhan 2006). Governance refers both to setting objectives, principles and rules for managing the resource, and to implementation processes. Many of the variations in patterns and outcomes of integrated water management depend on governance arrangements. The exploratory research in this thesis is primarily focused on the effects of governance arrangements on the integration of surface water and groundwater management. Properties of governance systems and users interactions with governing bodies and their effects on integrated water management are summarised in Table 3.2 b and discussed in the following paragraphs.

Table 3.2b Properties of governance systems and users interactions with governing bodies and their effects on integrated water management

<i>Governance</i>	
8. Well defined, secure entitlements to use, store, extract and transfer SW and GW	Clear, specific water entitlements provide security and investor confidence – necessary conditions for IWM.
9. Well defined, flexible rules for use, carryover, storage, recovery and exchange of SW and GW	Carryover, storage and recovery, and exchange are necessary conditions for IWM. Flexibility (rules and/or implementation) to respond to unforeseen conditions or new knowledge is also important.
10. SW and GW management organisation(s)	Structure of management and coordination and leadership shape the nature and extent of integrated water management.
<i>Interaction of users & governing bodies</i>	
11. Coordination – instruments and administrative arrangements	Weak coordination – instrument mix and implementation – may constrain IWM.
12. Good, shared knowledge of SW & GW resources, their connections and condition	Good, shared knowledge facilitates IWM planning and rule-making. Lack of knowledge may lead to disputes or obstruction by vested interests.
13. Participation of SW and GW users in water management. Users can set management rules	Participation assists well informed IWM decision making. If users are given the autonomy to set management rules they are more likely to implement them.
14. Effective monitoring and enforcement	Indiscriminate rather than integrated use, and free riding likely without effective monitoring and enforcement.

Notes: SW = surface water, GW = groundwater, IWM = integrated water management.

Comprehensive, well defined, secure legal entitlements provide authority to use water and incentives to invest in collective water management (Ostrom 2005, Bruns et al 2005, Bruns and Meinzen-Dick 2005)³⁴. Schlager and Ostrom (1992) distinguish five elements of a bundle of entitlements for common pool resources; access, use, management, exclusion and transfer³⁵. Entitlements to store water in a surface water storage or an aquifer, and then to extract it for use or transfer are also required to enable integrated water management. There are two difficulties associated with entitlements

³⁴ The term water entitlement is preferred to water right because water is owned by the state, and the right to use water is an entitlement granted by the State.

³⁵ Transfer is used to encompass the right to sell or lease a water entitlement – Schlager and Ostrom refer to this as alienation.

for storage and extraction. Firstly, when water is scarce supplies for storage and extraction may be limited, especially when resources have been “overallocated” (Wilkinson 1997, Blomquist et al 2004). This means that the entitlements to store water and extract it later must be clearly established or disputes may arise. Secondly, individuals or groups wishing to establish an aquifer storage and recovery project have to mitigate any adverse impacts on the quantity or quality of existing water entitlements (Thomas 2001).

Clearly specified, transparent and predictable rules provide direction and confidence in relation to surface water and groundwater management. Collective choice and operational rules should cover allowable use, carryover³⁶, storage, withdrawal from storage and exchange for specific surface water and groundwater resources.

When surface water and groundwater are connected, the use of one resource will affect the use of the other. Rules for surface water use need to take account of impacts on groundwater and vice versa. Rules for the use of surface water resources should be combined with rules for connected groundwater resources or if rules are separate they should be closely coordinated (NWC 2009, SKM 2011).

At the same time rules and their administration need to be sufficiently flexible to respond to variations in water availability, socioeconomic conditions, political preferences and new knowledge (Pahl Wostl 2007). Rules and associated management mechanisms should enable cyclical surface water and groundwater management to allow for climatic variation such as the effects of the El Niño Southern oscillation, extreme events (droughts and floods) and changes in knowledge. Mechanisms that enable flexible responses while maintaining well defined rules include;

- rules for allocating variable water supplies among surface water and groundwater entitlement holders over time;
- rules enabling water entitlement holders to carryover, bank and exchange water entitlements, to store water and recover it from storage;
- practices that enable variable water use such as changes in agricultural crop mix and fallowing.

³⁶ Deferral of water use from one year to another.

Government and non-government management organisations are established to manage water and to give effect to systems of water entitlements and rules. These organisations and the people who manage them are assigned roles and responsibilities and legal and administrative powers. The structure of organisations and the distribution and coordination of responsibilities and powers affect the scope and delivery of integrated water management.

Historically water governance has been centralised and characterised by top-down decision-making. Most water supply and demand problems were addressed by additional infrastructure development, with regulation to address point source water pollution. Now water governance is seen as including a much broader range of issues including water for the environment, diffuse pollution from agriculture, and climate change. Given the complexity of water management and related uncertainties, multilevel integrated water governance is needed (Pahl-Wostl et al 2002, Sabatier 2005).

The dispersion of water governance across multiple jurisdictions can lead to a number of benefits. It can capture externalities, ranging from transnational to local impacts. More decentralized jurisdictions can enable greater flexibility and better reflect heterogeneity of preferences among citizens (Hoogue and Marks 2001). Multiple jurisdictions facilitate innovation and experimentation. However, fragmentation or duplication of authority can present problems in the management of large scale water resources. Effective coordination across functions, scales and levels presents a key governance challenge (Cash et al 2006).

Two broad models for coordination can be distinguished (Hoogue and Marks 2003). General purpose jurisdictions such as state and local governments and their agencies (Type I) cover a wide range of issues and have a limited number of levels whose membership doesn't intersect. Special purpose jurisdictions such as natural resource management organisations in New South Wales and water districts in Colorado (Type II) cover a more limited number of issues, but the number of levels is not limited and memberships often intersect. Research suggests that multilevel or polycentric governance (a mixture of Type I and Type II governance) is a more successful model for managing water resources than a hierarchical system (Ostrom 2005, Huitema et al 2009), even though it can sometimes seem relatively chaotic (Blomquist and Schlager

2008)³⁷. Groups that include effective leadership and previous experience in integrated water management are more likely to be successful (Schlager 2007).

Interactions between water users and the water governance system³⁸

Multilevel governance processes can be defined as systems of continuous negotiation at several territorial tiers including vertical and horizontal coordination between governments, non-governmental actors, markets and civil society (Marks 1993).

Integrated water management requires joint management of surface water and groundwater and/or effective coordination between agencies involved in surface water and groundwater policy, planning and management across multiple geographical and administrative scales. Coordination is also needed between water management and other related activities, notably land management and spatial planning (Turrall and Fullagar 2007, Ross and Martinez-Santos 2008). Effective cross-scale coordination presents several challenges including misfits between biophysical and administrative spatial units, interplay between organisations and the need to take account of long term biophysical effects and historical dependencies (Young 2002).

Government and non-government organisations use a range of instruments and administrative arrangements to coordinate interorganisational activities (Lenschow 2009). Government regulation is the traditional instrument for coordinating water management activities. This requires sustained leadership and political will coupled with enforcement capability and or a culture of compliance. Markets provide a means for interested parties such as water entitlement holders to optimise resource use through negotiation and exchange. However, markets need to be accompanied by regulation to ensure public good outcomes such as healthy rivers and sustainable aquifer drawdown. People and/or organisations can establish networks to pursue cross organisational interests through negotiation. Networks have difficulty resolving conflicts, either because they represent specific interests or because they have difficulty making

³⁷ The concept of multilevel governance originated in analyses of intergovernmental arrangements in the European Union (Bache and Flinders 2004). The concept of polycentric governance originated in American studies of city government service provision (E. Ostrom and V. Ostrom 1977). When multilevel governance is defined to include both vertical and horizontal integration, and both public and private sector organisations, as in this paper, these concepts overlap substantially.

³⁸ These factors apply within as well as between users and governance systems ie throughout polycentric systems

decisions. In large and complex river basins government interventions are often required to support the efforts of water users, and a package of instruments is needed.

Administrative arrangements include ministerial councils, lead agencies and liaison offices, administrative committees, advisory and consultative bodies (Schout and Jordan 2008, Ross 2008). The strength of coordination varies over a spectrum ranging from communication, consultation and avoiding policy divergence at the weaker end of the spectrum, to seeking consensus, arbitration of disputes and joint strategy and priorities at the stronger end (Metcalf 1994). Weak coordination and/or capacity may constrain integrated water management.

The successful implementation of integrated water management depends on the positive interaction and collaboration of users and governing bodies. There are several key building blocks of collaboration that are likely to have an important influence on integrated water management: good shared knowledge, effective participation, monitoring and sanctions.

Good, shared knowledge about water resources and their value facilitates integrated surface water and groundwater planning and rule-making. Groups with common understandings are more likely to be able to collaborate on water management projects (Sabatier et al 2007, Ross and Martinez-Santos 2010). Well informed planning and monitoring requires sharing of information by governments and water users. Great effort is needed to explain scientific outputs such as hydrogeological models, and to win acceptance of scientific uncertainty and iterative solutions (Letcher and Jakeman 2002). Gaps in knowledge about water resources and their connectivity create uncertainty about management targets and water use limits. Lack of knowledge may also result in disputes and increase the likelihood that vested interests will block the introduction of new arrangements.

Groups who are given autonomy and are able to set up their own management arrangements have more incentive to take collective action. Also such arrangements are more likely to be recognized as legitimate and gain support (Ostrom 2005).

In basins with difficult management issues such as overallocation and non point source pollution, participation of interested parties is required to ensure that water management plans are well informed and supported by water users (Sabatier et al 2007).

Participation by both surface and groundwater users and decision-makers is necessary to ensure that decisions take account of relevant information, especially in the face of uncertainty. Participation increases ownership of and support for decisions. Excluded parties may resist new integrated water management initiatives. Although there is evidence that participative processes lead to improved collaboration and more effective management and policy, collaboration is sometimes difficult to achieve (Ross and Martinez Santos 2010).

Effective monitoring and sanctions are important because free riding and/or cheating may result in the withdrawal of support for integrated water management. Sanctions in proportion to the repetition and severity of non compliance are required (Ostrom 1990, 2005). For example, if sanctions for breaches of groundwater laws and rules are weak, users are less likely to engage in integrated management practices such as aquifer storage and recovery. In regulated surface water systems it is relatively easy to monitor water use, charge fees for service and sanction rule violations. Groundwater monitoring requires individual groundwater meters, and it is more difficult for authorities to prevent breaches.

Several other variables are likely to influence integrated water management activities, but are difficult to research in broad comparative terms rather than specific cases. Collaboration between users and governments to implement water management rules is likely to be encouraged when individual benefits are proportional to costs and contributions, and free riders are excluded (Poteete et al 2010). Effective leadership of user groups and governing bodies can provide necessary energy to set directions and priorities, gain resources, overcome resistance by vested interests, discourage free riding and maintain sustained commitment to change (Ross and Dovers 2008). Champions and boundary spanners³⁹ play an important role in coordinating local efforts and providing momentum and energy. Facilitators can help to resolve conflicts (Loorbach 2006, Lufol and Bressers 2009). These variables have not been systematically included in the analysis, because that would require collection of information about individuals, and micro situation analysis which is beyond the scope of this research.

³⁹ Boundary spanning activities occur when individuals and groups make links between their activities and other previously independent sectors, scales and timeframes. For example catchment management organisations in Australia link local and statewide water management activities, although a few groundwater management areas cross catchment boundaries.

One important question in relation to the heterogeneity of surface water and groundwater resources and users is whether to manage groundwater and surface water separately, using individual property rights to allocate the resource, or to persuade or coerce users to work together in an integrated management regime under a single organisation (Blomquist and Schlager 1998). Alternatively resources can be allocated among users on the basis of common issues faced by specific groups (issue linkage). Separate surface water and groundwater management, with water allocated in accordance with politically determined priorities as in Australia, can be seen as a type of issue linkage approach.

3.3.5 Use of the framework and variables

The analysis in this chapter has identified a framework with 14 interconnected variables that can be expected to influence integrated water management. These 14 variables can be subdivided into four groups that relate to integrated water management in different ways:

Group 1: is there a problem that integrated water management can solve? (3,5);

Group 2: does integrated water management provide a feasible solution? (1,2,6,7);

Group 3: how do the characteristics of the governance system affect integrated water management? (8,9,10);

Group 4: how do interactions between users, governing bodies and third parties affect integrated water management? (4,11,12,13,14).

Agrawal (2001) warns about the difficulties of analysing complex common property systems with a large number of variables. These include multiple and contingent causation in single case studies, spurious correlation and non comparability of results from different studies. This study responds to these difficulties by using two different scales of analysis of integrated water management; beginning with identification of factors that may influence integrated water management at the river basin scale; followed by further analysis of a subset of the variables at a sub basin scale.

In Part II of this thesis the influence of a broad set of factors (variables) on integrated water management in the Murray-Darling Basin is examined, including variables in all four groupings. In part III of the thesis, comparisons between integrated water

management and New South Wales, Colorado and Idaho, variables in Group 3 were given particular emphasis in the research interviews and analysis. While the primary research topic in this thesis is the factors that affect integration of surface water and groundwater use and management, there is also some consideration of the benefits of integrated water management and the opportunities for realising the benefits.

3.4 The case studies

A case study approach to research can be defined as an intensive study of a single unit or a small number of units (the cases), for the purpose of understanding a larger class of similar units (population of cases). Research can involve one, several or many cases (Gerring 2007). Several cases are compared in part II and III of this thesis. These cases include both spatial and temporal variation.

Historical analysis and case studies can be used to investigate “how and why” integrated water management has occurred (Yin 2003). Case studies are used in this thesis because they are appropriate for investigating both current and past influences on integrated water management, and it is possible to interview current water users and managers to supplement historical documentary analysis.

3.4.1 Research design

The primary research question in this thesis is:

What factors influence the development and implementation of integrated water management?

Further questions cover:

- the opportunities for and barriers to integrated water management;
- options for progressing integrated water management; and
- the effects of the structure and implementation of water entitlements and operational rules, and different types of management organisation(s).

The unit of analysis is the incidence of integrated water management, assessed in terms of extent and strength. Integrated water management may be defined in terms of “output” indicators, or it can be studied as a process. In this research the primary interest is in the process of integrated water management and the factors that affect it..

The case studies primarily use qualitative methods relying on documentary analysis, supplemented by fieldwork. Information from the case studies is linked to propositions by structured comparisons of qualitative information about governance and policy settings. This is supplemented by some quantitative analysis such as time series of surface water and groundwater use and cross sectional information about biophysical and socioeconomic conditions, water availability and water use.

Although a set of factors thought to influence integrated water management is defined at the start of each phase of the case studies (parts II and III of the thesis), the analysis is essentially exploratory, with the expectation that the definition and understanding of the factors that affect integrated water management would evolve as the research progressed.

The case study research in this thesis touches on some broad concepts that are difficult to break down and define in a precise quantitative way, such as heterogeneity, participation, coordination and collaboration. Moreover, the meanings given to some biophysical and institutional variables shift over time as policies and knowledge evolve. Examples include boundaries of resource management units, definitions of water entitlements and sustainable use limits. This means that the case study research in this thesis relies substantially on a structured narrative, synthesising reports and studies, and contextual evidence to (re)construct causality within and between cases. This involves linking pieces of evidence that are not comparable, but collectively add up to a body of evidence from which it is possible infer conclusions. However, it is difficult to generalise conclusions across case studies (especially international comparisons) from this kind of evidence and analysis, because it is difficult to verify it (Gerring 2007)⁴⁰.

⁴⁰ Moreover because of the relatively detailed nature of the case studies in Part III it would be difficult to replicate them across a wide number of cases.

3.4.2 Number and choice of case studies

A multiple case study design has been chosen in this thesis because it has more potential to yield findings that can be generalised, with the potential for policy insights and identification of research priorities.

In part II of the thesis factors affecting the development of integrated water management in the Murray-Darling Basin at a jurisdictional scale were explored by means of a cross jurisdictional comparative study. The MDB was chosen for the study because it is a very important resource with well developed institutional and organisational arrangements for basin wide water management. These arrangements have received favourable international attention and assessment (Kemper et al 2005). However, the development of integrated water management has been relatively slow. One purpose of this thesis is to explore the factors that have affected the relative lack of integration of surface water and groundwater management in the MDB.

The MDB jurisdictional analysis enabled a broad assessment of factors that have affected integrated water management in the basin. That assessment was enriched by comparisons between the jurisdictions, which include different biophysical conditions, and institutional and policy settings.

At the jurisdictional scale of analysis it is not possible to examine the interactions between specific water users and connected water resources at the level of water management units, which are sometimes no more than small areas of water catchments. Many collective choice and operational water governance choices and rules relate to these smaller areas.

Governance arrangements developed for individual water management units have an important influence on integrated water management. Part III of the thesis comprises an international comparative study of selected sub basin water management areas in New South Wales (Namoi region), Colorado and Idaho. These areas were selected because they have similar biophysical and socioeconomic conditions including relatively dry climate, variable rainfall, water scarcity, and a high proportion of water use in irrigated agriculture (although there are some significant variations within the case study areas). Despite the similarities integrated water management has been developed to a much

greater extent in the US cases. The comparative analysis explores the effects of different governance arrangements; especially water entitlements, laws, rules and management organisation(s) on the integration of surface water and groundwater management.

Cross case variations between the selected jurisdictions have not been studied in depth in other studies. Indeed they are one of the main subjects for investigation in this study. These cross jurisdictional comparisons are not an ideal vehicle for a detailed analysis of the precise pathways by which different governance arrangements affect integrated water management. Also a broad scale study is not suited to undertake detailed examination of specific action situations. But it is possible to explore broad linkages between different governance arrangements and integrated water management. These could provide a starting point for more specific structured comparisons in future.

Part IV of the thesis includes a synthesis of the findings from all of the case studies.

The results of the analysis in phase II of the thesis were used to further develop the variables and analysis in part III of the thesis. The results of the analysis in part III were used to structure the synthesis in part IV.

3.4.3 Information and analysis

The information collected for the case studies was based on the variables derived from the SES framework and analysis of previous studies and information about integrated water management. The information and questions were modified as the work proceeded, based on results of the successive phases.

Information for the case studies was collected from documents and interviews. The documents largely comprised government and consultant reports, academic studies and magazine and newspaper articles, together with by a range of online material.

Analysis of documents and electronic material was supplemented and cross checked by interviews with government officials and experts and representatives of water user

groups. Copies of interview questions from phase 1 and an example of questions from phase 2⁴³ of the case studies are in Attachment 5⁴⁴.

Thematic analysis building on the framework and variables discussed in section 3.3.4 above, together with tabular summaries were used to organise and summarise the main findings from the large amount of material compiled during the case studies.

3.4 Summary

Water resource management systems can be analysed as a component of a complex and adaptive social and ecological system using a narrative synthesis approach. A basic analytical framework has been defined to guide comparative analysis of integrated water management. This framework has three interconnected nodes: water resources, water users and the water governance system.

The basic framework is disaggregated into 14 variables. Six of these indicate problems and feasible solutions related to integrated water management. Eight relate to the effect on integrated water management on institutional choices and relationships between users and governing bodies. The basic framework and the 14 variables provide a means of structuring the comparative analysis of integrated water management in the remaining chapters of this study.

The thesis proceeds with two separate case study analyses of factors affecting integrated water management: the first compares factors affecting integrated water management in the MDB jurisdictions (Chapters 4,5), the second compares institutional and organisational factors affecting integrated water management in selected sub basins in New South Wales, Colorado and Idaho (Chapters 6,7,8).

⁴³ The questions used in the New South Wales interviews were generally the same as those used in the US interviews but there were some differences reflecting different governance arrangements (water entitlements, water courts, water plans, water user organisations) and policy approaches in the Murray-Darling Basin, Colorado and Idaho.

⁴⁴ The analytical method is discussed further in 3.4.1 above.

Part II

Part II includes a comparative case study of factors affecting the integration of surface water and groundwater management in the Murray-Darling Basin.

Chapter 4 The context for integrated water management in the Murray-Darling Basin

Chapter 4 provides an introduction to the biophysical, socioeconomic, policy and institutional context for integrated water management in the Murray-Darling Basin. The chapter begins with a summary of surface water and groundwater availability and use in the MDB. The chapter continues with an overview of the governance of integrated water management and planning in the basin, including national and state laws, policies, water entitlements, water plans, markets and management organisations. This is followed by selected examples of integrated water management in Queensland, New South Wales, Victoria and South Australia.

4.1 Water availability and use in the MDB

The Murray-Darling Basin (MDB) occupies 1.04 million km² in southeastern Australia, and has a population of around 2.1 million people. About 40% of the gross value of Australian agricultural production is produced in the basin, and 84% of land in the MDB is owned by businesses engaged in agriculture. The main uses of irrigated land in 2004-05 were pasture (43%), cereals other than rice (20%), cotton (15%), rice (6%), grapes (6%), fruit and nuts (5%) and vegetables (2%). In 2004-05 agriculture consumed 83% of water used in the MDB, the water supply industry consumed 13% (predominantly irrigation water supply losses), households consumed 2%, and mining and other industry consumed the balance. In 2005-06 the commodities that produced the largest shares of the gross value of production in agriculture were fruit and nuts (18.4%), dairy (16.4%), cotton (14.5%) and grapes (13.1%). The agricultural commodities that consumed the most water in 2005-06 were cotton (20%), dairy (17%), pasture for other livestock (17%) and rice (16%)⁴⁵(MDBA 2010a, ABS 2008).

The recorded agricultural, mining, industrial and municipal consumption of water tends to be concentrated in specific areas, but there is also significant diffuse unrecorded consumptive use of water by crops in dryland agriculture, and by forestry. This diffuse

⁴⁵ Water consumption in cotton and rice production is highly variable depending on rainfall. The proportion consumed by these crops in 2005-06 was relatively high.

consumption is discussed in reports on risks to shared water resources prepared for the (former) Murray-Darling Basin Commission⁴⁶ (CSIRO 2006) and a report on water interception prepared for the National Water Commission (Duggan et al 2008). It is also reflected in regional water balances calculated for the 2005 stocktake of Australian water resources (NWC 2007a). However, it is not considered in detail in this report because of lack of comprehensive and consistent data, although it should be taken into account in assessing the impact of integrated water management schemes.

The MDB has a mainly dry but highly variable climate, with annual average rainfall varying from under 200mm in arid western regions to over 2000 mm in some eastern upland areas (MDBA 2010a). It is estimated that the entire basin receives an average annual rainfall of 531000 GL, of which about 94% evaporates or transpires, 2% drains into the ground and the other 4% becomes runoff (ABS 2008). Between 1997 and 2006 annual rainfall (440 mm) averaged at 225 locations across the basin was less than the 1895-2006 long term mean (457 mm), and much lower than the relatively wet 1950s and 1970s, when the largest increases in surface water irrigation occurred⁴⁷. Averaged over the entire MDB, the 1997 - 2006 mean annual runoff (21.7 mm) is estimated to be 21 % lower than the 1895 - 2006 long term mean (27.3 mm)⁴⁸ (Chiew et al 2008). Water availability in the MDB is much more variable and unpredictable than comparable large basins overseas (Craik and Cleaver 2008). Inflows from rainfall to rivers in the basin have ranged from 177,907 GL in 1956 to 6740 GL in 2006 (MDBA unpublished model data cited in MDBA 2010a).

The MDB uses 60% of the water used in Australia yet it generates only 6% of the nation's surface water resource, despite the fact that Australia's three longest rivers, the Darling (2740 km), Murray (2530 km) and Murrumbidgee (1690 km) are in the basin. The MDB also has significant groundwater resources which can be broadly divided into unconsolidated sediments, and sedimentary basins in the lowland plains and availability

⁴⁶ In December 2008, Murray-Darling Basin Authority (MDBA) assumed responsibility for all of the functions of the former Murray-Darling Basin Commission.

⁴⁷ Average annual rainfall was measured by averaging results from 225 rain stations across the MDB over the ten year period.

⁴⁸ The runoff data comes from the rainfall-runoff modelling over 5 x 5 km grid cells across the MDB carried out for the CSIRO Murray-Darling Sustainable Yields Project. This estimate of long term average runoff is about 6%, higher than the ABS estimate owing to different modelling assumptions.

across 18 regions in the MDB⁴⁹. Water availability in the basin can be considered in several different ways⁵⁰. One useful measure is the sum of water available across all regions in the MDB. This is estimated to average 23417 GL although water availability was substantially below this average during the the last decade, owing to prolonged dry climatic conditions. The north and east of the basin are wetter than the south and west. In the north it is wetter during the summer and in the south it is wetter during the winter.

Substantial water storage and regulating structures have been built across the MDB to cope with the inter-annual variability of streamflow and enable longer term storage and rerelease of water in drier years. The total public storage capacity in the basin's large storages is 22663 GL (MDBA 2010a). At 31 August 2008, there was 5840 GL in active storage or approximately 26% storage capacity. About 16% of this water is in the northern basin public storages (Darling River and its tributaries), and about 84% in the southern basin storages (Murray River including the lower Darling) (MDBC, 2008). The prolonged dry period during the last decade has resulted in volumes in large surface water storage falling well below long term averages - see Figure 4.1 below.

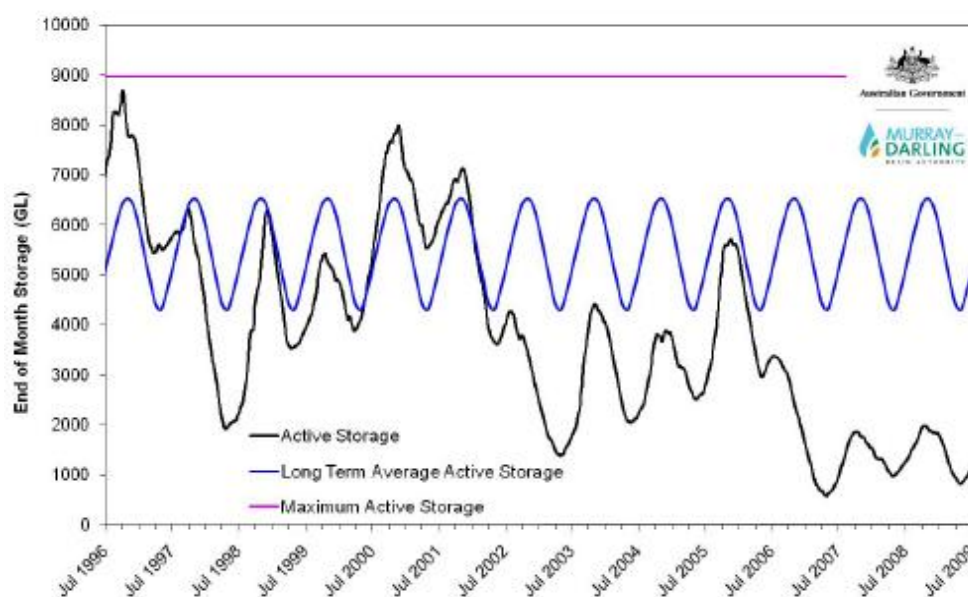
There is significant interception of inflows by floodplain harvesting storages and farm dams. Most of the floodplain harvesting storage in the MDB is in New South Wales (950 GL) and Queensland (1625 GL). It is estimated the impact of diversions to current floodplain harvesting storages averages about 900 GL. Floodplain harvesting is not likely to expand; there are moratoriums in place in the relevant river basins to restrict construction of new storages. Based on available farm dam datasets, the interception by farm dams in the MDB is about 1100 GL per year (in 2008)⁵². This impact is projected to increase by almost 20% by 2030 (SKM and BRS 2010).

⁴⁹ These regions were defined by CSIRO in their Murray-Darling Basin sustainable yields study. They are close to, but do not correspond precisely with the regions defined in the MDBA's Guide to the Basin Plan.

⁵⁰ These are sum of water available across all regions (23417 GL/year), surface run-off across the MDB (28900GL/year), water availability for the MDB assessed at Wentworth (near where the Murray and the Darling join – 14493 GL/year) and streamflow at the mouth of the Murray River (12233 GL/year) (CSIRO 2008).

⁵² About 70% of the estimated national volume of farm dams is in New South Wales, Queensland and Victoria, with small volumes in the ACT and the small South Australian section of the MDB. The national average impact of farm dams is estimated to be 1600 gigalitres.

Figure 4.1 Surface water storage in the Murray-Darling Basin 1996-2009

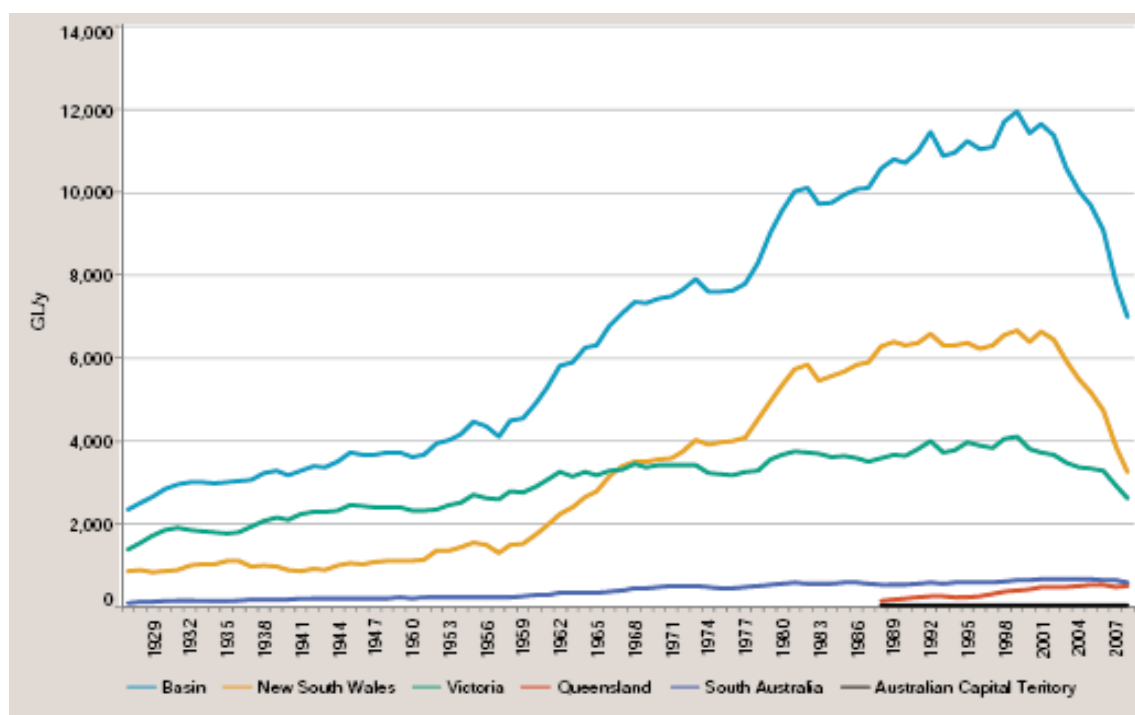


Source: Murray-Darling Basin Commission

There are no comparable figures for groundwater storage. Aquifer storage is thought to be relatively massive in the MDB in relation to annual inflows of water, but only New South Wales has attempted to estimate groundwater storage, and then only for selected catchments. Groundwater storage estimates for selected catchments include: Murrumbidgee 119000 GL, Lachlan 77000 GL, Namoi 20000 GL, Macquarie 9000 GL. These estimates suggest that aquifer storage is more than sufficient to support integrated water use (NWC 2007a). Although there are no estimates for Victoria, Queensland and South Australia storage in those States is likely to be many multiples of annual water inflows.

Water use in the basin has expanded substantially owing to growth in irrigated agriculture, from about 4000 GL a year in the mid-1950s to over 12,000 GL in the 1990s – see Figure 4.2. Severe droughts such as 1967 and 1982 have been a major driver for groundwater development. Many new bores were drilled in these (and other) periods.

**Figure 4.2 Growth in total and jurisdictional surface water use in the MDB
(5 year moving averages)**



Source MDBA 2010b

In 1995 the extraction of surface water in the MDB was capped at 1993-94 levels, but groundwater use was not capped. The cap was not based on objective considerations of sustainable yield or environmental impact, it was a “line in the sand” to prevent the negative effects of further growth in surface water extraction. Since the imposition of the cap surface water use has stabilized. In recent years it has fallen significantly owing to prolonged dry conditions. New South Wales typically accounts for more than half of surface water diversions in the basin, and Victoria accounts for more than one third although there are substantial year-to-year variations (see Table 4.1). Average surface water use in the MDB is 48% of water availability⁵³, but during the eight years to 2005 it exceeded 70%. There are significant variations across basin catchments in the intensity of water use⁵⁴, ranging from close to zero (Paroo) and 2% (Ovens) to over 50% (Goulburn-Broken, Murrumbidgee, Condamine-Balonne, Wimmera) (CSIRO 2008).

⁵³ CSIRO define average surface water availability as the sum of water availability across all 18 MDB regions including the internally generated portion of surface water availability for the Barwon-Darling and Murray regions (23417 GL/year). They define average surface water use as net irrigation diversions plus rural stock and domestic plus open channel and pipe loss plus stream flow loss induced by groundwater use (11327 GL/year).

⁵⁴ The intensity of surface water use is measured by surface water use as a proportion of surface water availability.

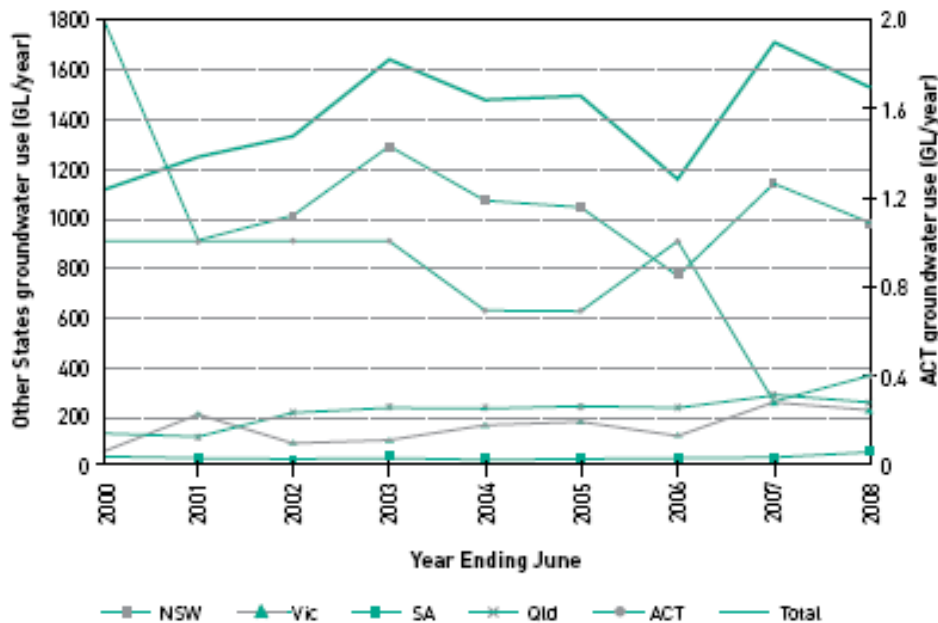
**Table 4.1 Surface water and groundwater diversions, Murray-Darling Basin
1994-95 to 2008-09 (GL)**

	1994-95	1996-97	1998-99	2000-01	2002-03	2004-05	2006-07	2008-09
<i>Surface water diversions</i>								
NSW	6462	7115	6350	7148	4131	3666	2352	1729
VIC	4823	4106	3730	3491	2957	3137	2081	1503
SA	638	580	669	662	737	624	627	485
QLD	176	467	608	688	214	392	149	383
ACT	32	30	23	34	40	27	25	19
MDB	12131	12298	11381	12023	8079	7846	5234	4119
<i>Groundwater diversions</i>								
NSW				900	1283	1047	1139	923
VIC				198	97	181	256	139
SA				25	27	31	34	48
QLD				116	225	230	275	162
ACT				1	1	1	0	1
MDB				1240	1632	1490	1703	1273
<i>Total diversions</i>				13263	9711	9336	6937	5392
% SW				90.7	83.2	84.0	75.5	76.4
% GW				9.3	16.8	16.0	24.5	23.6

Source: Murray-Darling Basin Commission Water Audit Monitoring Report (Various) (MDBC_a)

Groundwater use has trended upwards as a result of the surface water cap and dry climatic conditions. After the growth in the use of surface water was capped, the growth of groundwater use in the MDB accelerated. Between 1993-94 and 1996-97 groundwater use tripled in New South Wales and Victoria, the most populous MDB States (National Land and Water Resources Audit 2001). Groundwater entitlements were issued at well in excess of sustainable use limits, on the assumption that many entitlements would not be used except in exceptional circumstances such as prolonged droughts. As with surface water there have been large variations in groundwater use through time and across the MDB, reflecting the increased use of groundwater during dry periods. During the period from 1999-00 and 2008-09 annual basin wide groundwater use fluctuated between about 1200 and 1700 GL, and accounted for 9.3 – 24.5% of total water use in the MDB (Table 4.1). Trends in groundwater use in the MDB jurisdictions from 1999-00 to 2007-08 are shown in Figure 4.3.

**Figure 4.3 Groundwater use in the Murray-Darling Basin jurisdictions
1999-00 to 2007-08**



Source: MDBA 2009

In several MDB catchments groundwater averages more than 30% of total water supply, and this proportion increases to more than 50% in the year of lowest surface water use (CSIRO 2008). These developments have led to increasing concerns about the long term impacts on water availability for human use and the environment. This represents a shift from concerns during the wetter 1980s and 1990s, when salinity owing to rising groundwater tables was the major concern related to groundwater in the southern MDB.

There is substantial uncertainty about future water availability because of uncertainties about current water resources and their interconnections, and because of the effects of climate change and various forms of interception such as farm dams and forestry.

Forecasts of water availability in the MDB in 2030 (after climate change), compared to current conditions, range from an 11% increase to a 34% decrease with the median forecast giving a 12% reduction – see table 4.2 (CSIRO 2008). Under the median scenario consumptive use is projected to fall by 4% across the basin, but there are large variations between catchments. In the higher water use regions Murray, Murrumbidgee, and Goulburn-Broken, and some other regions consumptive users will be protected under current water sharing arrangements from reduced water availability, and the

environment will have to absorb most of the reduction⁵⁵. Average outflows from the mouth of the River Murray are forecast to fall by 24%.

Table 4.2 Surface water and groundwater availability and use in the Murray-Darling Basin (GL)

	Current development, historical climate ⁵⁷					Future development and climate ⁵⁸				
Catchment	SW	GW	GW % av SW	GW % low SW ⁵⁹	Total	SW	GW	GW % av SW	GW % low SW ⁶⁰	Total
Paroo	0	0	100	100	1	0	1	100	100	1
Warrego	52	0	-	-	52	50	0	-	-	53
Condamine-Balonne	723	244	26	61	956	692	225	25	69	906
Moonie	34	0	-	81	34	34	1	2	100	33
Border Rivers	412	34	8	26	446	441	124	24	67	516
Gwydir	317	46	13	55	363	308	164	35	85	467
Namoi	359	255	42	78	613	400	470	66	94	715
Macquarie	371	182	32	84	568	419	410	54	93	760
Darling	230	10	4	18	240	231	240	51	86	471
Lachlan	321	236	45	90	528	321	439	63	95	699
Murrumbidgee	2256	407	15	26	2658	2238	852	28	51	3023
Ovens	25	12	33	45	37	25	23	48	60	48
Goulburn-Broken	1071	92	8	16	1163	1021	154	13	41	1162
Campaspe	342	29	8	12	371	328	33	9	21	357
Loddon-Avoca	349	29	8	14	378	331	59	15	43	388
Wimmera	121	2	2	18	123	108	2	2	18	110
Eastern Mount Lofty Ranges	6	19	76	77	25	10	31	82	86	38
Murray	4288	233	5	8	4521	4190	727	15	24	4817
Total	11277	1830	14		13107	11147	3955	26		15102

Source: CSIRO 2008

⁵⁵ Current water sharing arrangements will be modified when the new MDB plan comes into force.

⁵⁷ Current developments represent current level of water resource development. Historical climate is represents the average of the period from mid 1895 to mid 2006.

⁵⁸ Future development includes “best guesses” of farm dam and commercial forestry plantation development given current policy and recent trends, and projections of future groundwater extractions based on maximum allowable use under current water sharing arrangements. Future climate represents the median of a range of possible future climates using three global warming levels and 15 global climate models included in the fourth assessment report of the IPCC..

⁵⁹ GW high is 2004/05 use as a percentage of total water use in the year of lowest SW use.

⁶⁰ GW high is projected 2030 use as a percentage of total water use in the year of lowest SW use.

By 2030 average groundwater use is expected to increase from 14 to 26% of the total water used in the MDB because of climate change. In years with average surface water (availability and) use years several catchments are projected to have groundwater exceeding 50% of total use by 2030, and in the years of lowest surface water use groundwater is projected to be the dominant source of supply in the northern basin.

Groundwater resources are less well understood than surface water. Groundwater surface water interactions are understood even less. Firstly, the physical interactions between surface and groundwater are affected by a complex set of geological and hydrological variables, and data is based on hydrological and hydrogeological models. Secondly, there are often long time lags between the observed impacts of groundwater pumping on stream flow (or surface water diversion on recharge) (Braaten and Gates 2004, Evans 2007).

The potential growth of groundwater use may impact on the reliability of supply to river users and, in unregulated rivers, on critical low flows and ecological assets. These impacts, and appropriate management responses depend on a number of variables including whether the aquifer is unconfined or semi-confined and wide or narrow, whether the river is regulated or unregulated, and whether it flows reliably or intermittently - see Attachment 6. (Braaten and Gates 2004, Evans 2007).

In some US analyses it has been assumed that 100% of groundwater pumping is derived from stream depletion, and that there is a one-to-one relationship between pumping and streamflow (Balleau 1988; Winter et al 1998). In Australia, arid conditions and deep layers of weathered subsurface material can cause low groundwater levels and long stretches of hydraulically disconnected river reaches. In these areas, particularly where groundwater extraction occurs distant to the stream, it is likely that a large proportion of the water pumped will be sourced from features other than the river and the impact on streamflow will be substantially lower than 100% of groundwater extraction (SKM 2001, Evans 2007).

In recent years there have been some substantial studies of groundwater systems in the MDB (Ife and Skelt 2004) and surface and groundwater connectivity. Priorities have been established for further research and modelling and a national groundwater action

program has been established to fill data shortfalls⁶¹. However, there are still critical gaps in knowledge of connectivity including studies of priority groundwater management units, development of robust conceptual or numerical groundwater models, historical groundwater extraction data (magnitude and timing) and information on the permeability of sediment at the stream – aquifer interface (REM 2006). A further prominent data shortfall is the impact of surface water diversion on groundwater recharge, and groundwater dependent ecosystems.

Table 4.3 Level of groundwater and surface water interaction in water management area water balances: Murray-Darling Basin

Water management area	Total GW-SW exchange volume⁶² (GL)	Total GW-SW exchange volume as % of GW recharge	Total GW-SW exchange volume as % of total inflows
Gwydir River - regulated	62	> 100	5
Namoi River - regulated	71	87	7
Macquarie River - regulated	60	> 100	15
Lachlan River - regulated	73	63	21
Murrumbidgee River - regulated	248	> 100	13
Goulburn River	115	49	4
Broken River	16	27	5
Ovens River	9	7	1
Wimmera River	4	2	2
Borders river	5	> 100	1
Murray-Darling Basin	600	11	3

Source: National Water Commission 2007b

Table 4.3, based on water balance studies, indicates that although groundwater – surface water exchanges are a relatively small proportion of total inflows they are highly significant in relation to groundwater recharge. The accuracy of these studies varies, and more research is needed⁶³.

⁶¹ <http://www.nwc.gov.au/www/html/350-groundwater-action-plan.asp> accessed 26 September 2009.

⁶² Exchange volumes represent surface water flows to groundwater plus groundwater flows to surface water calculated from water balances.

⁶³ The accuracy of these estimates varies from area to area.

4.2 Integrated water management and planning in the Murray-Darling Basin

4.2.1 The national policy context

In Australia's federal system water governance takes place at a number of levels at the jurisdictional and river basin scale. At the highest jurisdictional level the Council of Australian Governments (Commonwealth, State and Territory - COAG) has lead responsibility for national water policy. In 1994 COAG agreed on a national water reform framework including full cost recovery, separation of water from land titles, integrated catchment management and limited water trading (COAG 1994). Water entitlements are required to be well specified in the long term, exclusive, enforceable and enforced, transferable and divisible⁶⁴. The agreement did not say anything about integrated water management. However in 1996 a COAG working group released a policy paper containing principles to ensure that groundwater management activities were consistent with the 1994 Water Reforms (ARMCANZ 1996). These principles included "improved integration of surface water and groundwater management".

The 2004 National Water Initiative (NWI)(COAG 2004) requires preparation of plans for sustainable water use in each river basin, and the restoration of over allocated basins to sustainable levels. Section 23 of the NWI provides for "a nationally consistent market, regulatory and planning based system for managing surface water and groundwater resources for rural and urban use that optimizes economic, social and environmental outcomes". Section 23 (x) recognises the connectivity between surface and groundwater resources and systems managed as a single resource. Section 83 requires States and Territories to identify closely connected groundwater and surface water systems, and implement systems to integrate the accounting of use from such resources. Schedule E Clause 5 stipulates the inclusion in water management plans of an assessment of the level of connectivity between surface water (including overland flow) and groundwater systems. Other sections of the NWI recognise the importance of both surface water and groundwater in achieving key objectives. Section 25 (ii)

⁶⁴ <http://www.environment.gov.au/water/publications/action/pubs/policyframework.pdf> accessed 20 September 2011.

provides that water access entitlements and planning frameworks will provide a statutory basis for environmental and other public benefit outcomes in surface water and groundwater systems to protect water sources and their dependent ecosystems. Section 25 (iv) provides for adaptive management of surface water and groundwater systems in order to meet productive, environmental and other public benefit outcomes.⁶⁵

4.2.2 Integrated water management in the Murray-Darling Basin

Under the *Water Act 2007*, water management in the MDB is governed by the Australian Government, advised by the Murray-Darling Basin Ministerial Council, and supported by the Murray-Darling Basin Authority (MDBA)⁶⁶. The Council includes representatives of the governments of Australia, New South Wales, Victoria, Queensland, South Australia and the ACT. Functions of the former Murray-Darling Basin Commission (MDBC) have been absorbed into the MDBA.

Until the late 1980s most of the emphasis in water management in the MDB was on building infrastructure and water supply capacity, with an emphasis on surface water delivered at low cost through large highly regulated delivery systems. By the 1980s there were increasing concerns about pressures on water resources, water pollution and salinity (Smith 2001). In response a cap on surface water use in the MDB was established. Available surface water is allocated to the MDB jurisdictions on the basis of the formula set out in the 1992 Murray-Darling Basin agreement (MDBC 2006b). The 1992 agreement was amended by the 2008 Intergovernmental Agreement on the Murray-Darling Basin Reform (section 7.9)⁶⁷, which includes additional provisions to provide for critical human needs in dry periods and to cover extreme and unprecedented circumstances.

The importance of managing surface water and groundwater in the MDB as a single resource is being increasingly recognised. Flows from surface water to groundwater and vice versa need to be netted out of estimates of surface water and groundwater availability and sustainable diversion limits in order to avoid double accounting (Evans

⁶⁵ <http://www.nwc.gov.au/resources/documents/Intergovernmental-Agreement-on-a-national-water-initiative.pdf> accessed 26 September 2009.

⁶⁶ <http://www.mdba.gov.au/about/governance> accessed 25 February 2012.

⁶⁷ http://www.coag.gov.au/coag_meeting_outcomes/2008-07-03/docs/Murray_Darling_IGA.pdf accessed on 25 September 2009.

2007). Separate resource assessments of surface water and groundwater that do not allow for flows between the two resources overestimate the total water resource, because the same parcel of water is counted twice, once as surface water and a second time as groundwater⁶⁸. It is estimated that current groundwater extraction will eventually reduce streamflow across the MDB by 447 GL/year (CSIRO 2008).

The Australian Government's *Water Act 2007*⁶⁹ established the Murray-Darling Basin Authority as the body responsible for the management of the MDB's water resources in national interest (MDBA 2010b). The MDBA is responsible for the integrated management of water resources in the MDB, including developing and implementing a Basin Plan for the long term sustainability of diversions of surface and groundwater. The Authority is required to:

- give effect to relevant international agreements
- determine the environmental water requirement needed to protect, restore and provide for the MDB's ecological values and ecosystems services;
- promote the use and management of MDB water resources to optimise economic social and environmental outcomes
- establish long term average sustainable diversion limits for surface water and groundwater.

The *Water Act 2007*⁷⁰ requires that the new Murray-Darling Basin Authority prepare a plan for the management of the basin's water resources - surface water and groundwater. A draft plan has been published. The draft includes a description of the size, extent, connectivity, variability and condition of the basin water resources, uses to which the water resources are put, users of the resources and social and economic circumstances of basin communities. The plan proposes environmentally sustainable limits on quantities of surface water and groundwater that may be taken from basin water resources, and set basin wide environmental, water quality and salinity objectives. The plan also provides consistent water trading rules to be applied in basin water markets, and sets requirements that must be met by State water resource plans. It

⁶⁸ Suppose surface water inflows in one accounting period are 10000ML, groundwater recharge is 5000 ML, surface water baseflow (from groundwater) is 3000, and groundwater recharge from surface water is 1000 ML. In that case net inflow to surface water is 9000 ML, net inflow to groundwater is 2000 ML, and the sustainable use limit is 11000ML rather than 15000 ML.

⁶⁹ <http://www.environment.gov.au/water/policy-programs/water-act/index.html> accessed 24 July 2009.

⁷⁰ <http://www.environment.gov.au/water/policy-programs/water-act/index.html> accessed 24 July 2009.

includes strategies to manage risks including the effects of climate change and changes to land use and interception of water (e.g. by farm dams and plantations)(MDBA 2011). In relation to connected surface water and groundwater resources Section 9.25 of the Proposed Basin Plan States:

- (1) A water resource plan must be prepared having regard to whether it is necessary for it to include rules which ensure that, for groundwater that has a significant hydrological connection to surface water, environmental watering requirements (for example, base flows) are not compromised.
- (2) Without limiting subsection (1), regard must be had to whether it is necessary for the water resource plan to include rules that specify:
 - (a) the times, places and rates at which water is permitted to be taken from a groundwater SDL resource unit;
 - (b) resource condition limits, being limits beyond which the taking of groundwater will compromise the discharge of water into any surface water resource; and
 - (c) restrictions on the water permitted to be taken (including the times, places and rates at which water may be taken) in order to prevent a resource condition limit from being exceeded.
- (3) If the outcome of the requirement in subsection (1) is that such rules are necessary, the water resource plan must include those rules.

This marks a new policy emphasis on integrated management of groundwater and surface water resources, albeit with an emphasis on the former, and should encourage further development of integrated water management.

In 2011 the Australian government released a report on a "National Framework for Integrated Management of Connected Groundwater and Surface Water Systems" (SKM 2011)⁷¹. This framework contains 21 principles underpinning integrated water management, including the following. Managed surface water and groundwater systems should be identified and defined and their connections should be classified. Groundwater and surface water should be assumed to be connected, unless an assessment is carried out proving otherwise. Connected groundwater and surface water resources should be treated and managed in an integrated manner with linked limits on entitlements and/or abstraction. Cross connection impacts should be included in monitoring and accounting processes. Risks to integrated use outcomes and

⁷¹ This report was published by the National Water Commission - an Australian Government agency. The author is SKM, a leading projects and consulting firm.

environmental and other public benefit outcomes arising from cross connection impacts should be assessed. Decisions regarding new entitlements or transfer of entitlements should take account of cross connection impacts. Groundwater and surface water management plans should consider very short term impacts (within one week), short term impacts, in particular impacts on critical low flows (typically within months), and medium to long term cumulative impacts (1 to 50 years) associated with surface and groundwater connection.

The national framework represents an important step towards integrated water management, but it poses a number of challenges including the definition of sustainable levels of consumptive use and ecological objectives, processes for handling long term cross connection impacts and managing uncertainty, and the development of flexible water entitlements and rules, including storage entitlements, to enable cyclical surface water and groundwater management.

4.2.3 Integrated water management in the MDB jurisdictions⁷²

In Australia most responsibilities for natural resource management and environmental policy rest with State and Territory governments, while many day-to-day decisions are taken at a catchment, sub catchment (water management unit) or local level. From the 1980s the Australian government has taken on increasing leadership in natural resource management and environmental policy (Ross 2008). National initiatives include the National Landcare Program, Natural Heritage Trust, the COAG 1994 Water Reform, the National Water Initiative and the *Water Act 2007*. The Australian government has developed these initiatives in partnership with the States and Territories, who have primary responsibility for implementing them. Each of the MDB jurisdictions has enacted legislation and introduced new water planning and licensing arrangements in order to implement the COAG 1994 reforms and the National Water Initiative. As part of these reforms each jurisdiction has developed policy and management practices in relation to groundwater and surface water interaction. These arrangements are summarised below.

⁷² Section 4.2.3 draws from state legislation and from the following government and consultancy reports: NWC (2004), Hamstead et al. (2008), Dyson (2005), Tan (2008), REM 2006, and Appendix 4 by Kalaitzis in Fullagar 2004. References from the sources not cited individually because of the large number of duplicate references that occur if citations argument for each individual statement on the following text.

4.2.3.1 Legislation and policy

Under Australia's federal system of government, the primary right to own or to control and use water is vested with the States and Territories (Lucy 2008). Most of the jurisdictions have introduced new water legislation, and Victoria has amended existing legislation to give effect to the COAG 1994 reforms. South Australia has chosen to integrate water management into natural resource management legislation, the other jurisdictions have separate water legislation⁷³. Surface water and groundwater are defined in each of these pieces of legislation. The connectivity of surface water and groundwater is explicitly recognized in Queensland, Victorian and South Australian legislation but not in the New South Wales legislation (NWC 2011).

The jurisdictions have introduced further legislative amendments in order to implement the National Water Initiative (Gardner et al 2009). In each case the legislation includes broad principles for water management that apply to all sources of water, and the legislation is generally neutral towards the integration (or separation) of surface water and groundwater management. Legislation in the ACT requires surface water and groundwater resources to be considered a single resource and managed accordingly. Legislation in the other jurisdictions allows for integrated management of surface water and groundwater but does not require it. State legislation provides a good basis for integrated water management, albeit through separate surface water and groundwater planning and licensing processes. However, the state legislation does not allow for intervention to address land use impacts (e.g. forestry) on groundwater levels and surface water flows.

4.2.3.2 Sustainable yields and use limits

While jurisdictions may apply the same principles to the management of surface water and groundwater, the jurisdictions employ different legislative definitions of sustainable yields or sustainable diversion limits for surface water and groundwater. These differences increase the difficulty of integrating surface water and groundwater

⁷³<http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/W/WaterA00.pdf>
<http://www.legislation.nsw.gov.au/maintop/view/inforce/act+92+2000+cd+0+N> .
http://www.austlii.edu.au/au/legis/vic/consol_act/wa198983/
<http://www.legislation.act.gov.au/a/2007-19/default.asp>
<http://www.legislation.sa.gov.au/LZ/C/A/NATURAL%20RESOURCES%20MANAGEMENT%20ACT%202004.aspx> accessed 15212.

diversion limits within or between jurisdictions. New South Wales defines the sustainable yield for surface water as the current yield under the MDB cap, Victoria uses the average annual diversion under the cap, South Australia specifies the divertible yield taking account of environmental flow requirements, ACT uses long term (modelled) runoff. Queensland uses indicators and trigger levels to set limits on surface water use.

Each jurisdiction uses estimated recharge together with other factors to set groundwater diversion limits. New South Wales has developed a separate methodology for calculating surface water and groundwater “sustainable yields” for unregulated systems (Harris 2006).

New South Wales and Victoria have diversion limits on all of their (regulated) surface water resources, South Australia has diversion limits on most of its resources and Queensland has limited use of some resources, with further limits being developed. Victoria has diversion limits for all of its groundwater resources except three unincorporated (lightly used) areas. South Australia has groundwater diversion limits in most of its catchments, New South Wales has groundwater diversion limits in some catchments, while Queensland has no groundwater diversion limits, although there are moratoria on increasing use in most groundwater management units. The ACT has the most conservative diversion limits for both surface water (10% of flows above the 80th percentile) and groundwater (10% recharge) (NWC 2007b).

4.2.3.3 Water entitlements and use licenses

Historically a complex system of water use licensing was established in the MDB States and Territories. The COAG 1994 reforms and the National Water Initiative have required the introduction of tradable volumetric water entitlements and related water use licences that are separated from the land from which the water is taken. Following the COAG 1994 reform the MDB jurisdictions have converted licences for using surface water in regulated systems to government issued volumetric tradable water entitlements. These entitlements are: completely and transparently defined; separated from land wherever possible; specified in registers; monitored; and enforced (NWC 2009). The separation of water entitlements from land encourages the development of markets and

trade in water. Land ownership has largely been separated from water entitlements, although all jurisdictions control the place of use of water, which limits the transferability of entitlements. Victoria imposes a 10% limit on the ownership of access entitlements by non-water users.

Access entitlements have been given much greater certainty, clarity and security. Entitlements to access water, to take water in a particular season/year and to use water at a particular place and time for a specific purpose are being progressively unbundled. In New South Wales and Victoria entitlements in regulated rivers have been unbundled, and in New South Wales entitlements have also been unbundled in some unregulated systems. About 50% of Queensland water resources are now managed under unbundled water entitlements. South Australia is reviewing the feasibility of unbundling water in its unregulated systems. In the ACT, implementation of unbundled water access entitlements is limited, and is tied to requests from landholders to separate land and water assets (NWC 2011). Allocations are made against these entitlements for each season/year depending on the amount of water available, as defined in the relevant State water plan (see below) (Gardner et al 2009).

Exclusive state rights to groundwater were challenged in the High Court (ICM Agriculture Pty Ltd & Ors vs The Commonwealth of Australia & Ors) by farmers in the Lower Lachlan groundwater management area, whose water entitlements had been reduced under the Water Sharing Plan for the Lower Lachlan Groundwater Source 2003. The High Court found that the amount of water that the State could permit to be extracted was bounded only by the physical state and capacity of the aquifer, and such policy constraints as the State chose to apply. Neither the existence, nor the replacement or cancellation of particular licences altered what was under the control of the State or could be made the subject of a licence to extract⁷⁴.

Distinctions can be made between: entitlements to use water, allocations of water (or restrictions on the use of water) from particular water source, access to water from distribution (or collection) infrastructure, and conditions about the use of water at

⁷⁴ The High Court also found that the replacement of the plaintiffs previous bore licences did not constitute an acquisition of property within the meaning of s 51(xxxi) of the Constitution, and was not invalid in that sense. Although sub surface water has been vested in the State since 1966, it is not right to describe the consequence of that vesting as giving the State ownership of, or property in groundwater because the difficulties and incongruities of treating water in the ground as a subject of property are insuperable.

particular sites. In the case of regulated surface water, flows are controlled by water supply organisations and delivered to users, and state entitlement systems separate and distinguish between entitlements to use water, and rights to a share of available water in a particular season or year. In the case of unregulated surface water and groundwater, which is extracted directly by users, water use entitlements generally allow a specific volume to be extracted, subject to conditions. In the case of groundwater, use restrictions are the only way to ensure that environmental requirements are met. Water entitlements, or a further separate licence may specify conditions of use such as purpose, area, time and duration of use. For example, annual volumetric limit and/or cease to pump rules apply in some unregulated surface water and groundwater management areas (SKM 2008, Department of the Prime Minister and Cabinet 2006)⁷⁵. Stock and domestic use does not require a licence in any of the MDB States.

Some MDB jurisdictions have different classes of water entitlements, with different priorities for allocation when water is scarce. In New South Wales a distinction is made between high security entitlements which may be supplied at close to 100% in average conditions and general security entitlements which may only be supplied at about 50% or less in average conditions⁷⁶. In Victoria there are two classes of entitlement: high security which historically has had over 95% probability of delivery, and sales water which has had 45-75% probability of delivery. Sales water is being converted to a volumetric entitlement. Queensland make a distinction between high security and other licences. South Australia and the ACT treat all licences as having the same (high) security (Productivity Commission 2003, 2006).

The transition to volumetric water entitlements and use licences has been completed or is nearing completion in all of the jurisdictions for regulated surface water resources, and many stressed or overallocated groundwater resources (NWC 2009, 2011). This sometimes requires a reduction in entitlements and leading to difficult negotiation and adjustment processes.

⁷⁵ There is a wide variety of entitlement models and license conditions in specific water management areas, reflecting the diversity of biophysical conditions and historical development in the MDB jurisdictions.

⁷⁶ These shares are much lower in drought years.

4.2.3.4 Surface water and groundwater planning

Surface water and groundwater planning is the main mechanism for integrated water management. There are significant and interesting variations in the water planning systems in the MDB jurisdictions.

- In Queensland there is a two tier planning process: water resource plans (WRP) set broad catchment wide standards and outcomes, while resource operating plans include operational rules. There can only be one WRP in each part of the State. In drafting a WRP consideration must be given to the potential effects on other water resources including sub-artesian or artesian water. The management of non-Great Artesian Basin groundwater is being progressively introduced in water resource plans.
- In New South Wales the State Water Management Outcomes Plan (SWMOP) includes overarching water management strategy and targets. Water sharing plans (WSPs) set targets and rules for water management areas consistent with the SWMOP and the Murray-Darling Basin agreement (NSW Government 2002). WSPs cover over 80% of the area of the state's water resources. The rest of the state will be covered by macro plans that cover broader regional areas than the WSPs, but are subdivided into smaller management units. NSW has developed a policy for the management of highly connected, unregulated river aquifer systems.
- In Victoria there are two types of statutory water plan: regional sustainable water strategies (SWSs), and management plans for declared water supply protection areas (WSPs). SWSs cover large areas and include comprehensive forward-looking assessments. WSPs cover water management unit areas. Declared WSPAs are generally stressed or particularly sensitive (socially or environmentally).
- In South Australia water allocation plans (WAPs) lie within a hierarchy headed by the State Natural Resource Management Plan followed by regional NRM plans and WAPs.
- In the ACT surface water and groundwater resources are considered to be a single resource and managed in one integrated plan.

Table 4.4 shows the number of surface water and groundwater plans that had been finalised or released in draft form in the MDB jurisdictions in 2005, and the extent to which consideration of surface water and groundwater was integrated in these plans. These are figures for the whole jurisdiction rather than the MDB parts of the

jurisdiction, and they generally cover higher priority planning and water using areas. However, since many of the high priority water using areas lie in the MDB, these figures gave a good indicator of the situation in the basin in 2005. At that time only a minority of surface water plans had considered connections with or impacts on groundwater, in South Australia⁷⁷, the ACT and some areas in Queensland. A majority of groundwater plans had considered of connections with and impacts on surface water, but the methodology varied widely, and the analysis was often rudimentary. Even though there are significant groundwater surface water interactions in many catchments, only four groundwater plans in NSW and three in Queensland were reported to have required more than a minor reduction in groundwater usage owing to impacts on surface water (NWC 2007b).

**Table 4.4 Consideration in water plans of impacts on other water resources:
Queensland, New South Wales, Victoria, South Australia, ACT**

	Total plans⁷⁸	SW plans⁷⁹	SW plan considers GW	GW plans⁸⁰	GW plan considers SW
QLD	25	16	6	9	8
NSW	63	10	0	53	32
VIC	49	27	0	22	22
SA	20	4	4	16	12
ACT	2	1	1	1	1

Source National Water Commission 2007a

The 2011 biennial assessment of the National Water Initiative (NWC 2011) provides an update on recognition of connectivity between surface water and groundwater resources and management of connected systems as a single resource.

- Queensland has completed a statewide risk assessment of the impacts of groundwater extraction on surface water flows. Individual catchments and groundwater management areas are assessed for connectivity, which is quantified through modelling. Groundwater allocation and management strategies are defined

⁷⁷ The number of completed plans in SA is relatively small because new plans are being prepared under the 2004 NRM Act.

⁷⁸ In 2011 the revised total plans (completed plans) figures were QLD 23 (22), NSW 84 (62), SA 23 (20) ACT 1 (1), VIC 4 (2). The VIC plans are sustainable water management strategies, there are also streamflow management plans and groundwater management plans at smaller scales.

⁷⁹ SW plans complete or in draft, others are in progress, some water management areas are not covered.

⁸⁰ GW plans complete or in draft, others are in progress, some water management areas are not covered.

taking connectivity into account. Moratoria on pumping have been introduced in high-risk priority areas. In Queensland groundwater is now included in ten water resource plans and work is progressing on inclusion of groundwater in another six WRPs. An enhanced level of groundwater management has been developed in three areas where connectivity is determined to be especially high.

- In New South Wales a standard set of rules for water access has been provided for highly connected systems (NSW Government 2011). Integrated plans have been or are being developed where connectivity is high. 10 out of 51 water sharing plans have been developed as combined surface water groundwater plans. In other cases surface water and groundwater plans are separate with provision made in each plan to address connectivity issues. For macro water sharing plans water systems are classified as gaining, losing or highly connected and a suite of rules has been developed to cover different cases.
- In Victoria sustainable water strategies recognise the importance of managing groundwater surface water interaction. Connectivity must be taken into account in the assessment of individual licence applications. But with the exception of the (draft) Upper Ovens Water Supply Plan there are no integrated surface water groundwater plans.
- In South Australia most water allocation plans are for groundwater resources. More recent WAPs address both surface water and groundwater. Three WAPs include an integrated management approach and three further integrated plans are being prepared.

4.2.3.5 Surface water and groundwater trading

The MDB is Australia's main water market making up over 90% the volume traded across Australia. There are two main types of water trade; trade of a water allocation (retaining the entitlement to receive future allocations) and trade of water entitlement (losing the entitlement to future allocations). 2300 GL of water allocations were traded across the entire MDB in 2009-10 mainly in the southern basin - especially along the Murray River. As the volume of water allocation fell between 1998-99 to 2006-07 the percentage of the total allocation that was traded tripled going from approximately 5% to 15%. Entitlement trade exceeded 1800 GL in 2009-10 (NWC 2010).

The scale of groundwater trading is relatively minor compared to trading of surface water in regulated river sources. The total volume of groundwater allocation traded has been about 210 GL per year and entitlement traded has historically been about 100 GL per year. Groundwater trade makes up less than 10% of all allocation trade and 5% of all water entitlement trade, with New South Wales having by far the greatest volume (NWC 2011).

So far there have been no recorded trades between surface water and groundwater in the MDB. Surface water groundwater trading is constrained by the different properties and availability of surface water and groundwater, uncertainty about the impacts of trading on other water resources, restrictions on carryover and the lack of development of surface water groundwater trading rules.

4.2.3.6 Metering, monitoring and compliance

Historically metering of surface water use in unregulated systems, and of groundwater use has been patchy across the basin, with each state having different priorities and arrangements. Metering technologies, the quality of metering and the frequency with which meters are read vary widely across the basin. Some systems provide for regular meter reading and self reporting (with independent checking), in some areas meters are read only once a year. There are a few trials of real-time remote read metering technology, but this is expensive (Department of Prime Minister and Cabinet 2006).

COAG has developed the National Framework for Non-Urban Water Metering to establish a national standard for non-urban water meters. This framework came into effect on 1 July 2010 (NWC 2011):

- Queensland is progressively introducing metering. 2900 water meters are being installed on non-urban properties – over 10000 may be required
- In New South Wales most of the regulated river systems and about 50% of groundwater extraction are metered, but very few unregulated river systems are metered. New South Wales has started installing government water meters in the upper Murray Valley, which is a pilot scheme for meter installation in the NSW's part of the MDB.

- Victoria has 49700 metered extraction sites. Extensive modernization programs are under way; an estimated 18924 meters will be upgraded and a further 7523 will be installed.
- South Australia is taking a risk based approach to implementing the new national standards. A condition attached to a licence may require that water take must be metered to an accuracy of + or – 2%.
- In the ACT 100% of licensed extraction is metered, but stock and domestic use of surface water is not metered.

The National Framework for Compliance and Enforcement Systems for Water Resource Management is seeking to combat unlawful water use on a national scale. The framework includes an analysis of offences and sections, risk analysis of water resources, improvements to compliance capability and increasing monitoring and public awareness.

4.2.3.7 Water management organisations

In the MDB jurisdictions, the primary regulatory authority for water resource management is vested in the Minister responsible for the administration of water resources legislation. In Victoria important administrative functions are conferred on regional bodies called “authorities” which are defined to be either a water corporation or a catchment management authority (Gardner 2009).

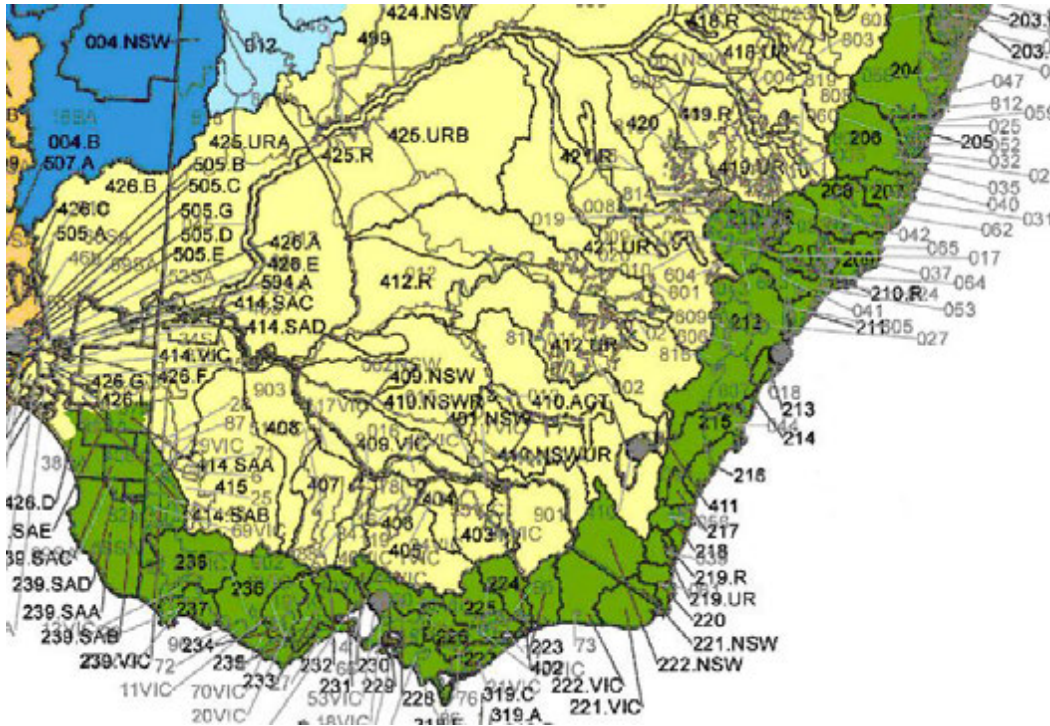
Each jurisdiction has one lead department responsible for water management⁸¹, but surface water and groundwater are managed by separate units within these agencies, or by separate agencies, except in the ACT. This separation has been driven by several factors including the historical emphasis on surface water management, the different uses and users of groundwater and different scientific disciplines related to surface water and groundwater. The reasons for this separation will be elaborated in the following chapter.

There are a substantial number of surface water and groundwater management units in the MDB; over 50 surface water, and over 100 groundwater. Superimposed on these

⁸¹ Further details of management arrangements in the MDB jurisdictions are given by the National Water Commission at <http://www.nwc.gov.au/www/html/1112-water-governance.asp?intLocationID=1112> accessed 10 July 2009 and in Attachment 4.2.

are the 18 catchments for which integrated water plans will be prepared under the MDB plan. This creates a highly complex (and visually overwhelming!) network of overlapping management units, as illustrated in Figure 4.4.

Figure 4.4 Surface Water and Groundwater Management Units: southern Murray-Darling Basin⁸²



4.3 Examples of integrated water management in the MDB jurisdictions

While national and state governments set the framework for integrated surface water and groundwater use and management in Australia, the action of integrated water management is carried out at smaller scales of activity; water management units and their subdivisions. It is at this level of activity that specific water access, allocation and use rules are established by state authorities in consultation with water users and interested third parties. The potential for using "unconventional sources" such as recycled wastewater and treated saline groundwater has been recognised (Department of Resources and Energy 1987), but this potential has not been widely exploited. There have been some pilot projects in urban areas, especially South Australia. Where

⁸² Notes: map shows surface water zones superimposed on groundwater management units in the southern MDB. Black numbers and boundaries represent surface water management areas. Grey numbers and units represent groundwater management units.

integrated water management has been pursued in rural areas in the MDB it has been owing to groundwater management problems especially overexploitation and negative impacts on streamflow, rather than to capture strategic benefits. Those integrated water management arrangements that have been and are being introduced in the MDB jurisdictions have served a range of purposes. These include stabilisation and/or conservation of water supplies to meet human consumptive and environmental requirements, maintaining water quality including minimising salinity and saltwater intrusion and augmentation of supply with recycled water. Table 4.5 provides some examples of the variety of integrated water management schemes in MDB jurisdictions.

Table 4.5 Examples of Integrated Water Management in Australia (examples from the Murray-Darling Basin marked*)

<i>Integrated water mangement scheme</i>	<i>Key elements</i>
Conjunctive water licences NSW*	GW to smooth irrigation and town supply. Licences withdrawn after evidence of GW depletion in some catchments.
Macro Water Plans NSW*	Integrated management of connected unregulated SW and alluvial GW resources.
Burdekin basin QLD	Integrated water management and farm practices to recharge aquifers and minimise saltwater intrusion.
Pioneer Valley QLD	Introduction of volumetric licences requires complex SW GW use rules to minimise saltwater intrusion in coastal areas and to avoid overutilisation of water resources and environmental degradation in inland areas.
Sustainable water strategies VIC*	Comprehensive framework for strategic integrated planning of the use of water resources at a regional (cross catchment) level.
Marne Saunders region SA*	Integrated SW and GW management plan including rules for sharing SW with linked under groundwater resources.
Angas Bremer catchment SA*	Exchange of GW licences for SW allocations. Voluntary environmental stewardship (re)vegetation.
Suburban Adelaide SA	Injection of treated stormwater into aquifer and later recovery for consumptive use.

Note: GW = groundwater SW = surface water

4.3.1 Conjunctive water licensing in New South Wales

The largest and most widespread example of integrated water management in the MDB was conjunctive water licensing in New South Wales. This licensing no longer exists. Conjunctive licences were introduced in NSW in the mid 1970s to provide more stable water supplies in regulated systems. These were essentially groundwater licences for which the groundwater allocation was inversely proportional to surface water availability i.e. it was increased in dry years. Under a conjunctive licence, a surface water allocation which was unmet in dry years became a (supplementary) groundwater allocation. It was assumed that groundwater would recharge when groundwater use fell in wet periods. Conjunctive licences were first issued in the Lachlan catchment in 1976 and were subsequently extended, first to the Namoi, Gwydir, and Border rivers, and later to the Macquarie, the Murrumbidgee and the Lower Murray. About 1000 conjunctive licences were issued (Fullagar et al 2005).

Following the establishment of the MDB cap, groundwater use entitlements were issued in excess of sustainable extraction limits in several catchments and groundwater extraction increased. Conjunctive water licences contributed to unsustainable levels of groundwater use because they allowed extraction above long term average annual recharge during dry periods, but did not provide for offsetting aquifer replenishment at other times⁸³. Also they did not consider environmental water requirements. In 1997 conjunctive use licences were replaced with separate surface water and groundwater licences (and entitlements). Users kept their surface water allocation, and received groundwater entitlements equivalent to 70% of the long term average annual recharge, allowing for an environmental provision of 30% of recharge (Gates and O’Keefe 1999)⁸⁴.

4.3.2 Macro water plans in New South Wales

Macro water plans cover unregulated surface water and groundwater sources in relatively large regional areas of NSW including many sub catchments. NSW has

⁸³ Aquifer replenishment could come from surface water or groundwater entitlements. Replenishment from groundwater entitlements would reduce the security and stability of groundwater supply. Replenishment from surface water entitlements during "high inflow" years would smooth surface water supplies and results in more equitable "burden sharing" between groundwater and surface water entitlement holders - but this option was never contemplated, and neither option was implemented.

⁸⁴ Further details of conjunctive water licences in the Namoi region are given in chapter 6.

developed an innovative approach to integrated and sustainable water planning for unregulated surface water and groundwater sources (Bish et al 2006, Harris et al 2006, NSW Government 2011). This is based on an assessment of the quantity of water being extracted relative to natural flow (daily and annually), the social and economic benefits that this extraction provides, and the risk of harm as a result of the extraction. The Draft Water Sharing Plan for the Lower North Coast unregulated and alluvial water source (DWE 2007) provides an example of how the approach may be applied to integrated water management. Aquifers are classified according to their level and speed of connection with surface water. In the Lower North Coast region up-river alluvial aquifers have high levels and speeds of interaction with connected streams.

The principles underlying water sharing rules for these highly connected systems include:

- a joint long term annual extraction limit for surface water and alluvial groundwater;
- a common set of available water determinations for surface and groundwater users; restrictions on new bores within 40 metres (m) of the stream;
- management of surface water and groundwater bores within 40 m of the stream by the same access rules;
- permits to convert surface to alluvial entitlements (but not the reverse); and
- the same rules for trading alluvial groundwater and surface water, including restrictions on trading into areas with high in stream water values or high hydrological stress⁸⁵.

4.3.3 Integrated water management in Queensland

In Queensland the examples of integrated water management are mostly in coastal catchments where integrated management has been primarily driven by concerns about salt water intrusion. The Burdekin Basin (outside the MDB) provides the most prominent long term and sustained example of aquifer recharge and storage among the MDB jurisdictions. Excess withdrawals from the delta groundwater systems led to establishment of the North and South Burdekin Water Boards in the mid 1960's to manage groundwater replenishment. The Boards use a number of strategies to achieve this, including the use of sand dams in the Burdekin River, distribution channels and

⁸⁵ The integrated surface water and groundwater plan for the Peel Valley is discussed in chapter 6.

natural waterways, and recharge pits. The sand dams are used to help maintain practical operating levels at river pump stations by containing releases from upstream storages.

Farm water practices such as recycling (excess irrigation water recharges the groundwater); water spreading (water too turbid for the recharge pits is made available as surface water for irrigation); and direct pumping from recharge channels to farms in zones with deeper buried aquifer have played an important role in the groundwater management (Bristow et al. 2000). Further assessment of the interactions between current scheme and farm activities and groundwater quantity and quality and other potential off site impacts is required to ensure sustainable groundwater use (Bristow et al 2003).

The Pioneer Valley water resource plan 2008 illustrates the impact of national water reform on integrated water planning for specific water management units. Implementation of the COAG 1994 water reform requires the conversion of existing water use licences to tradable volumetric water entitlements. In some areas like the Pioneer Valley, existing surface water and groundwater use licences cannot be simply converted to volumetric licences because water resources are under pressure, and over used in dry periods. License conversions in the coastal strip have to be limited to minimise the risk of further seawater intrusion owing to excessive pumping of groundwater causing reduced reliability for existing human users and environmental flows.

In inland areas there are minimum requirements for seasonal and inter-annual baseflow to maintain environmental assets such as water hole refugia. In some highly developed inland parts of the catchment there is a risk that both water security and environmental objectives could be undermined unless groundwater and surface water pumping is controlled. A complex set of licence conversion, and water use rules (including cease to pump rules) is proposed to achieve sustainable water management. The complexity can be partly explained by the variety of existing licenses, and the desire to minimise negative impact on existing users (agriculture, stock and domestic, and towns) (DERM 2009⁸⁶).

⁸⁶ http://www.nrw.qld.gov.au/wrp/pioneer_draft_wrp_amend.html#info accessed 23 July 2009.

4.3.4 Integrated water planning in Victoria

Victoria has a highly regulated water supply system very largely dependent on surface water. During the 1980s and 90s the primary objective for groundwater management was to minimize salinity (rising water tables, saline groundwater intrusion). In the last decade there has been more attention to groundwater as a source of supply and the effects of groundwater use on streamflow. Following the publication of the Victorian state water strategy *Our Water Our Future* (Victorian Government 2004), regional sustainable water strategies (SWSs) have been introduced to provide a comprehensive framework for strategic integrated planning of the use of water resources at a regional multi-catchment level. They integrate urban and rural water supply planning with river and aquifer sustainability planning. They include consideration of water delivery efficiency, water reuse and recycling (recycled waste water, stormwater), and land use changes that impacts on water resources (farm dams, plantations).

The northern region SWS includes principles to guide consideration of both surface and groundwater caps in the MDB, for setting permissive consumptive volumes for surface water and groundwater, and for integrating environmental water requirements, farm dams and stock and domestic use in the water management regime. The strategy proposes that rural water corporations formally document, adopt and publish local management rules for surface water and groundwater including flow requirements, trigger levels and annual restriction rules, trading zones and rules, and monitoring requirements. The strategy also proposes that combined surface water and groundwater management plans may be prepared where appropriate for systems with high groundwater and surface water interaction (DSE 2008)⁸⁷.

A draft integrated surface water groundwater management plan for the Upper Ovens catchment was released in March 2011 - the first in Victoria (Goulburn Murray Water 2011⁸⁸). Management arrangements recognise that groundwater in the unconsolidated sedimentary aquifer and surface water resources are highly connected. The draft plan proposes an integrated water sharing regime, with a focus on low flow periods when there are increased risks to the environment and water users. The water sharing regime comes into operation when flows in the Ovens River at Myrtleford fall to 100 ML/day.

⁸⁷ <http://www.ourwater.vic.gov.au/programs/sws/northern> accessed 23 July 2009.

⁸⁸ <http://www.g-mwater.com.au/upperovensriver> accessed 22 September 2011.

If flows continue to decline water extractions are restricted, and when flows fall to 1ML/day water extractions cease. Although there is no legal impediment to integrated water management, the political and bureaucratic process is long and cumbersome. It took several years before a draft plan was released by the Victorian Minister for Water.

Victoria is working on policy relating to managed aquifer recharge (MAR) to clarify the approvals process and licensing framework under the Water Act 1989. Policies are being developed to link approvals to add water to an aquifer (section 76 approvals) and subsequent taking of the groundwater (section 51 take and use licence). The policies will link the entitlement to take water with the volume of water recharged to an aquifer and provide for carryover of the water to facilitate water banking⁸⁹. These policies align with work being conducted on managed aquifer recharge (MAR) at a national level, in particular with the Victorian EPA's guidance on MAR health and environmental risk management⁹⁰.

4.3.5 Integrated water management in South Australia

There are a number of examples of integrated water management in South Australia in both rural and urban areas. In the Marne Saunders region an integrated water surface and groundwater management plan has been proposed by the South Australian Murray-Darling Basin Natural Resources Management Board (SAMDBNRMB). This plan includes rules for sharing surface water between management zones (higher and lower catchments) with linked underground water resources, and further rules for management at sub-zone scale to ensure adequate flows to support water dependent ecosystems. These rules apply to all surface water diversions from streams and storages including farm dams. There are a number of aquifers in the Marne Saunders system. Use limits are proposed for each aquifer with the objective of balancing inflows and outflows in management zones and sub-zones. Resource capacity is further managed at a local scale through allocation limits, buffer zones, dam capacity limits, and extraction rules such as returning or not capturing low flows and maximum diversion or extraction rates.

⁸⁹ http://www.ourwater.vic.gov.au/_data/assets/pdf_file/0019/80443/Groundwater-Newsletter-October-2010.pdf accessed 1 March 2011.

⁹⁰ <http://epanote2.epa.vic.gov.au/EPA/publications.nsf/PubDocsLU/1290?OpenDocument> accessed 1 March 2011.

A relatively complex set of rules has been proposed to govern trading and transfers of water entitlements, including aquifer entitlement rollovers (SAMDBNRMB 2010)⁹¹.

In the Angas Bremer irrigation district, unsustainable groundwater use has been managed by the widespread exchange of groundwater for River Murray water licenses facilitated by the installation of locally funded pipelines that carried water up to 14 km from Lake Alexandrina (Muller 2002), and recharge of groundwater resources. Irrigators are required to monitor water table heights, drainage and salinity and to plant deep-rooted vegetation. A number of groundwater licensees in the Angas Bremer also use River Murray licences on their land. Separate water allocation plans have been prepared for the Angas Bremer groundwater district and the River Murray watercourse water district⁹².

The River Murray WAP includes an assessment of the impacts of the use of River Murray water on the Angas Bremer - predominantly water-logging from rising water tables. The WAP requires licensees of River Murray water who use the water within the Angas Bremer area to report regularly on water use and management (Dyson 2005). In 2007-08 salinity increased in Lake Alexandrina and local aquifers. Irrigators are investigating alternative sources of water such as reclaimed water and desalinated brackish groundwater, and the increased use of aquifer storage and recovery (Thomson 2008).

Aquifer recharge and underground storage are expected to make an important contribution to Adelaide's future water supply (South Australian Government 2005). For example, at Salisbury, a suburb of Adelaide, an aquifer storage transfer recovery demonstration project uses urban stormwater harvested from a residential and industrial catchment, which is treated in a reed bed wetland before injecting into a limestone aquifer 160 to 180 m below the ground. After flushing out the formerly brackish storage zone by injecting stormwater into a number of wells, the system will be operated to produce drinking quality water (Dillon et al 2009).

⁹¹ <http://www.samdbnrm.sa.gov.au/Portals/9/PDF%27s/Water/MS%20Water%20allocation%20plan.pdf> accessed 22 September 2011.

⁹² The surface water, watercourse water and underground water of the Eastern Mount Lofty Ranges (EMLR) was prescribed on 8 September 2005, and the SAMDBNRMB is now preparing a water allocation plan for the area. As the Angas Bremer prescribed Wells area falls within the boundaries of the EMLR prescribed area a single WAP is being prepared to cover both areas.

4.4 Summary

Integrated water use offers significant opportunities to increase the efficiency of water use and achieve multiple policy objectives in the MDB. Yet there has been relatively little development of integrated water management in the MDB.

The National Water Initiative recognises the connectivity between surface and groundwater resources and systems managed as a single resource. In the MDB jurisdictions progress towards managing connected surface water and groundwater resources as a single resource has been mixed.

- State legislation is generally neutral towards the integration (or separation) of surface water and groundwater management
- Different definitions of sustainable diversion limits for surface water and groundwater, and different structures of water entitlements and water planning within and between the States complicate the integration of surface water and groundwater management
- In most regions of the MDB surface water and groundwater plans are separate. Progress towards integrated planning for connected water resources is mixed. Recent water plans include better assessments of connectivity, and methods of dealing with it. In many older water plans, especially surface water plans, impacts on the other resource have not been assessed.
- Groundwater trading is much smaller than surface water trading, and there is no recorded surface water groundwater trading.

Recently there have been a number of developments that have increased the potential benefits of integrated water management. Drought and the prospect of a drier climate in future, and increasing concern about the continued viability of rural communities and environmental degradation are leading to even greater efforts to make the best use of available water resources. The development of the new Murray-Darling Basin plan provides an opportunity for the further development of integrated water management in the MDB.

In response there are a few emerging examples of integrated water planning in specific water management units in the MDB jurisdictions, but these only cover a very small proportion of the basin's water resources. The question remains whether these examples

are early signs of the widespread adoption of integrated water management, or whether integration will continue to be held back by biophysical, economic, political and institutional factors. The factors that have affected and will affect the integration of surface water and groundwater use and management in the MDB are explored in the following chapter.

Chapter 5: Factors that have affected integrated water management in the Murray-Darling Basin

5.1 Introduction

In this chapter factors that have affected the development of integrated water management in the MDB and at the jurisdictional scale are identified and examined. Factors affecting integrated water management can be divided into two broad groups; water resources availability and use, and water governance. Water resources availability and use includes; characteristics of surface water and groundwater resources, surface water and groundwater uses, user characteristics and infrastructure. Governance arrangements include; social, economic and political settings, water plans, operational rules, groundwater trading, water management organisations and their interrelationships. In this study particular attention is given to governance arrangements.

Integrated water management has considerable potential to deliver economic, social and environmental benefits, as discussed in chapter 2. Moreover many catchments in the MDB have substantial surface and groundwater resources in which integrated water management can be practiced. Yet integrated water management has been developed less in the MDB than in other dry regions with large agricultural sectors such as the western USA and Spain. Surface water and groundwater management and planning has generally proceeded on separate tracks in all of the MDB jurisdictions except the ACT.

Analysis of integrated water management in Australia (Braaten and Gates 2003, Brodie et al 2007, Evans 2007) and overseas (Bredehoft 2007, Sophocleous 2000, 2002, Winter et al 1998) has generally concentrated on its implications for water availability and sustainable water use. There has been relatively little study of the governance and implementation of integrated water management, and its social and environmental implications. Most studies examine particular cases, there have been few attempts at broader syntheses.

The following sections of this chapter explore why integrated water management has not been further developed in the MDB. Factors affecting integrated water management in the MDB and opportunities for better integration of surface water and groundwater management are summarised in the concluding section. The analysis draws on academic and other studies, and interviews with 23 academics, consultants, user representatives and senior government officials⁹³. Interviews were undertaken to cross check and supplement documents and other media.

5.2 Resources and their connections

5.2.1 Connections, complementarity, opportunities

Surface water and groundwater can be used cyclically to optimise the use of available water supplies in the MDB. For example relatively stable groundwater supplies can be used at above the long term average sustainable diversion limit during dry periods, and can be recharged in wet periods. Statistics indicate that farmers and rural towns exploit cyclical alternating use possibilities in many catchments in the MDB (MDBC Various⁹⁴), especially in the alluvial plains down the central part of New South Wales. The greatest opportunities for integrated water management are interannual but in northern NSW and Queensland heavy summer rainfall creates seasonal opportunities.

Adequate groundwater storage and means of extraction are required to enable integrated water management, especially in the case of managed underground storage (Blomquist et al 2004). Aquifer storage is thought to be relatively massive in the MDB in relation to annual inflows of water, and is likely to be more than sufficient in aggregate to support integrated water management, although there are substantial variations (NWC

⁹³ Government interviewees were selected on the basis of their policy and operational responsibilities for groundwater and integrated water management. User representatives were selected on the basis of their cross jurisdictional representational responsibilities. Academics and consultants were selected on the basis of their expertise and publication record in groundwater and integrated water management. Interviews took place between January and March 2009. The names and other details of interviewees are confidential under the research ethics protocol for these interviews. Comments by individual interviewees are not quoted, but aggregate responses by groups of interviewees are quoted in several sections of this chapter to supplement other evidence.

⁹⁴ MDBC Water Audit Monitoring Reports 1996-2009.

2007a, Hostetler 2007)⁹⁵. Saline or artesian aquifers increase the cost of storing water underground, although they do not preclude it. Putting fresh water into a saline aquifer causes a freshwater lens to form on top of the salty groundwater. Care then needs to be taken, when withdrawing freshwater, to minimise the chance of mixing fresh and salty water. This can reduce the proportion of stored water that can be recovered (Roeder 2005). In order to store water in an aquifer under artesian pressure users must overcome the artesian pressure head. That increases the cost of the storage operation.

In some areas in the MDB limited surface water and groundwater connectivity reduces opportunities for integrated water management. Estimated aggregate surface water groundwater exchange only exceeds 5% of total inflows in six of the 18 MDB catchments; the Gwydir, Namoi, Lachlan, Murrumbidgee and Goulburn (NWC 2007b), although the aggregate surface water and groundwater exchanges underestimate the local importance of connectivity, especially in the long term. In the highland areas in the eastern part of the basin fractured rock aquifers are common, and surface water groundwater connections are slower and more uncertain. In some areas of the basin groundwater resources are not adjacent to human settlements and irrigation districts (see Attachment 6)

During the last decade the most important constraint on integrated water use has been the lack of surplus surface water in most areas of the basin. Some aquifers are already fully exploited or near full exploitation. Water management authorities have been understandably reluctant to encourage increased pumping as part of a cyclical integrated water management strategy because of uncertainty about the capacity of future rainfall to recharge overdrawn aquifers.

5.2.2 Boundary issues, knowledge gaps and their impact on integrated water management

In Australia surface water is managed on a catchment scale, but aquifers sometimes overlap more than one catchment. Within catchments surface water and groundwater boundaries often do not coincide, and there are substantial variations in the connection between surface water and groundwater. For example many streams gain base flows

⁹⁵ Groundwater storage estimates include: Murrumbidgee 119000 GL, Lachlan 77000 GL, Namoi 20000 GL, Macquarie 9000 GL.

from groundwater in upland regions, but when they reach the alluvial plains streams can change from losing to gaining and back again. Also, there are intertemporal mismatches between surface water and groundwater management because of the relatively slow movement of water in aquifers compared to rivers and streams. The lags between the impact of groundwater recharge and extraction on surface waters and environmental assets is highly variable, ranging from weeks or months in highly connected alluvial resources to tens or even hundreds of years. Surface water groundwater interactions and their lags are complicated by the presence of multilayered aquifers in some regions of the MDB. Consequently aquifers are sometimes divided into a number of management zones on the basis of hydrogeological types and or flow characteristics (GHD and AGT 2011). These physical features complicate integrated surface water and groundwater planning (see below).

Incomplete knowledge about water resources, uses and the impacts of uses on resources or other uses (including the environment) also constrain integrated water management. Surface water resources are comparatively well categorised and understood compared to groundwater systems. There are still major shortfalls in information about groundwater quantity, quality, dynamics and extractions, and the connections between groundwater and surface water in Australia (Evans 2007 NWC 2009). Large-scale models of water resources are a relatively recent phenomenon. Surface water and groundwater models are usually separate, there are few integrated models (Rassam et al 2008). Monitoring and measurement is incomplete leading to gaps in data required to develop and run models (Kelly et al 2007). Some phenomena are not usually accounted for in detail or at all in models or water balances, such as the effects surface water - groundwater interactions, and the impacts of farm dams, afforestation and irrigation recharge on groundwater recharge. Moreover, the impact of groundwater use is often only evident in the long term (see Chapter 2 for further details).

Knowledge gaps and uncertainty have had mixed effects on the development of groundwater resources and integrated water use. On the one hand groundwater licences have been overallocated and the use of groundwater has grown relatively rapidly since the 1980s. Also groundwater use has been substantially higher in the driest years (MDBC various⁹⁶), for example the estimated proportion of groundwater use in the MDB ranged from 9.3% in 2000-01 to 24.5% in 2005-06 – see Table 4.1. This

⁹⁶ Surface water and groundwater use statistics are published in MDBC Water Audit Monitoring Reports.

variation on groundwater use indicates that a form of integrated water management is practised extensively by individual users in the MDB.

On the other hand lack of knowledge has led to conservative groundwater management practices by water management agencies which may have held back the development of integrated water use. Long term impacts of groundwater pumping are uncertain, but cannot be discounted away. For example conservative water level thresholds have been set for some groundwater resources in northern Victoria. These have been disputed by some scientists as well as users (Macumber 2001). Groundwater users and other vested interests have challenged groundwater use limits imposed in some groundwater management areas in New South Wales, such as the Namoi and NSW Murray catchments (Kuehne and Bjornlund 2006). Knowledge shortfalls have been used to dispute scientific evidence, for example in various court cases initiated by groundwater users (Millar 1999).

The National Groundwater Action Plan⁹⁷, the National Centre for Groundwater Research and Training⁹⁸, CSIRO's study Water Availability in the MDB (CSIRO 2008), the Australian Bureau of Metereology's Australian National Water Account 2010⁹⁹, and the National Water Commission's biennial assessments of progress in implementing the National Water Initiative (NWC 2009, 2011) are helping to reduce knowledge and information deficits. However, there is much work still to be done to communicate the results of the above research and studies to decision makers and the public.

5.2.2.1 Training, skills, capacity to use knowledge

Management of surface water and groundwater as a single resource at the regional sub basin scale to meet multiple economic, social and environmental goals is a much more complex task than historical supply and engineering based approaches. Regional water management requires an array of skills including hydrology and hydrogeology, engineering, agricultural science, law, economics, environmental management, and skills and policy coordination, communication and mediation (Connell et al 2007). Integrated water planning and management requires the ability to use tools such as

⁹⁷ <http://www.nwc.gov.au/www/html/350-groundwater-action-plan.asp> accessed 27 September 2009.

⁹⁸ <http://www.groundwater.com.au/> accessed 6 July 2012.

⁹⁹ <http://www.bom.gov.au/water/> accessed 6 July 2012.

integrated water models, water balances, scenarios and risk analysis (Pahl-Wostl et al., 2007). A comparative study of water allocation planning in Australia found that improved skills and training are needed for water managers and planners (Hamstead et al 2008)¹⁰¹.

5.2.2.2 Dealing with uncertainty

Integrated water management presents a paradox - it offers a more flexible response to uncertainty arising from variable water supplies, but it also introduces additional uncertainty compared with a surface water based supply system. On the one hand integrated water management can help to improve the adaptive capacity of the water management regime by diversifying sources of water supply and storage, and better tailoring supply to the seasonal demands of water users (Fullagar et al 2006). On the other hand the outcomes of integrated water management are themselves uncertain, because of knowledge and information gaps and uncertainties such as climate change.

Although knowledge about surface water groundwater interactions is developing rapidly, there remains much to do to complete the identification and integrated management of connecting to surface water and groundwater resources (NWC 2009). The full benefits of integrated water management will only be realised by adaptive water management - increasing and sustaining the capacity to learn during ongoing management and planning processes (Pahl-Wostl et al 2002). A major international project on adaptive water management found that learning is sustained by an iterative process of testing and improving analysis and planning by monitoring outcomes and feedback¹⁰². Plans and strategies should perform well under a range of future developments which implies increased use of scenario planning and modelling¹⁰³. Effective risk management is required, that takes account of the risks of not realising the potential gains from integrated water use, as well as the impact of the exploitation of surface water and groundwater on other resources and related ecosystem services.

¹⁰¹ Interviewees broadly split into two camps; those who thought that lack of scientific understanding of groundwater resources and their connection with surface water prevented the development of integrated water management, and those who thought that lack of understanding of existing science among the policy and user communities is the main barrier to the implementation of integrated water management.

¹⁰² <http://www.newwater.info/> accessed 25 September 2009.

¹⁰³ <http://www.newwater.info/intern/sendfile.php?id=317> accessed 25 September 2009.

5.2.3 Infrastructure

Integrated water management requires good storage and delivery infrastructure for both sources of water as well as the legal and institutional framework to allow water to be borrowed and banked. Water infrastructure in the MDB has emphasised surface water capture, storage and delivery. There has been little consideration of aquifers as water storage "reservoirs". Preliminary estimates for aquifer storage in New South Wales suggests that aquifer storage has great potential, but further studies are required (NWC 2007b).

Some forms of integrated water management do not require infrastructure investments, but some techniques require new infrastructure. For example, managed transfers between surface water and groundwater, and managed underground storage require facilities such as percolation basins or injection wells. US experience suggests that the most effective investments are made by partnerships between authorities and water users (Blomquist 1992, Thomas 2001 and Schlager 2007)

5.3 Characteristics of surface water and groundwater users and their use of resources

Water users in the MDB have ample incentive to optimise the use of water for private and commercial purposes when and where it is available, although this optimisation does not usually take account environmental and social impacts. Water is often scarce, many resources are intensively exploited and many users are highly dependent on regular or periodic water supplies.

Surface water and groundwater users experience very different conditions. Most surface water users such as towns and irrigation areas are relatively concentrated. They generally rely on water supply organisations which deliver water through large scale infrastructure in regulated river systems, although some rural users in unregulated systems pump their water from local streams or lakes. The historical availability of cheap surface water through large highly engineered systems, especially in the southern

MDB, and the expectation that surface water supply would continue at historical levels may have discouraged more active consideration of integrated water use (Smith 2001).

In contrast, groundwater users, both individuals and corporate and municipal entities, have generally invested their own capital and developed their own infrastructure. Individual pumpers often believe that the water that they pump belongs to them, although that is not legally correct. They have a strong sense of individual ownership and independence. Remoteness from other users, independence, and conviction about their "rights" to pump weaken their inclination to cooperate with each other or state authorities.

Individual groundwater users are more likely to organise themselves to manage issues with an immediate impact on their production and the resource such as new wells, well depth and seasonal timing. They are unlikely to take action to manage impacts of pumping that emerge in distant locations or in the longer term such as remote impacts on streamflow, declining water tables and drying wetlands (Schlager 2007).

Water providers and users have common interests in the maintenance of long term supplies in both regulated and unregulated systems. This provides surface water and groundwater users with some incentive to collaborate, although they may also perceive opportunities to free ride, and even to cheat or steal water if they can do so without jeopardising their long term supply (Ostrom 2005).

External impacts and enforcement problems mean that government interventions, and effective partnerships between users and governments are necessary to achieve basin wide water management goals including the maintenance of environmental condition and services.

5.4 Governance

5.4.1 History of water management and policy in the MDB

The history of water management in the MDB has created a dependency on surface water delivered at low cost through large highly regulated delivery systems. In Australia, until the late 1980s most of the emphasis in water management was on building infrastructure and water supply capacity (Smith 2001). State governments supported the development of agriculture in the MDB and built infrastructure to ensure that water was available for irrigated agriculture and other consumptive uses. Farmers invested in irrigation systems assuming that cheap water would always be available. Investments in groundwater have provided a secondary source of supply, for use when surface water is scarce. Collective surface water development and management has been historically separated from groundwater development and management.

The surface water centric water management regime in the MDB has exhibited a hydroschizophrenia and bias familiar in many parts of the world (Llamas and Martinez Santos 2004). Groundwater is the invisible resource and groundwater management has received less attention than surface water management.

By the 1980s there were increasing concerns about pressures on water resources, water pollution and salinity (Smith 2001). In response a cap on surface water use in the MDB was established. Available surface water was allocated to the MDB jurisdictions on the basis of the formula set out in the 1992 Murray-Darling Basin agreement¹⁰⁴. While the MDB cap has been implemented over most of the basin¹⁰⁵ (MDBA 2010), the cap is not a long term sustainable use limit¹⁰⁶, and does not apply to groundwater. The 1992 MDB agreement only recognized surface water and groundwater links to the extent that the MDB Commission is required to monitor the effect of groundwater on surface water resources, or if a special river valley audit is required (MDBC 2006).

¹⁰⁴ The 1992 agreement was amended by the 2008 Intergovernmental Agreement on the Murray-Darling Basin Reform (section 7.9)¹⁰⁴, which includes additional provisions to provide for critical human needs in dry periods and to cover extreme and unprecedented circumstances.

¹⁰⁵ In 2009 the cap had been implemented in 21 out of 24 river valleys.

¹⁰⁶ It is an arbitrary limit to prevent further increases in water use entitlements above sustainable levels.

The surface water centric settings for water management in the MDB have discouraged the development of integrated water management. The absence of comprehensive basin wide sustainable use limits for groundwater has allowed the long term depletion of some aquifers, rather than encouraging cyclical depletion and replenishment. After the growth in the use of surface water was capped, the growth of groundwater use in the MDB accelerated. Between 1993-94 and 1996-97 groundwater use tripled in New South Wales and Victoria (NLWRA 2001). Groundwater entitlements were issued at well in excess of sustainable use limits, on the assumption that many entitlements would not be used except in exceptional circumstances such as prolonged droughts.

Interviewees commented that in many parts of the MDB salinity management has been the primary concern for groundwater managers. Until the last decade the main emphasis of groundwater policy has been to reduce water logging and salinity by preventing rising water tables. There has been relatively little interest in how to "get water into the ground".

Connectivity between surface water and groundwater has not been considered in policy development until the previous decade, when the problems of groundwater overexploitation, including impact on streamflow have been recognised. Recently concerns about salinity have abated somewhat owing to dry conditions, and more attention has been given to avoiding overexploitation of groundwater. However this effort is biased towards the impact of groundwater pumping on streamflow (Evans 2004, 2007), rather than the effect of surface water diversion or irrigation on recharge.

Some initial national policy considerations of surface water and groundwater connectivity and integrated water management were published in 2004 (Fullagar 2004). As discussed in more detail in chapter 4, sections of the 2004 National Water Initiative and the Proposed Basin Plan recognise the connectivity between surface and groundwater resources and encourage further development of integrated water management.

5.4.2 Water Law

Water legislation in the MDB jurisdictions following the COAG 1994 reforms and the National Water Initiative is generally neutral towards the integration (or separation) of

surface water and groundwater management. State and territory legislation allows jurisdictions to set total surface water and groundwater diversion limits¹⁰⁷, and to introduce a means to implement the initiatives. The legislation allows the relationship between groundwater and surface water to be taken into account when determining environmental flow requirements, the consumptive pool and sustainable diversion limits for related resources. Jurisdictions have the necessary power to gather relevant information and the duty to undertake monitoring necessary to underpin resource management (Dyson 2005).

Integrated water management requires modifications of water laws and entitlements such that that water users can recover water when they arrange to have it stored underground, or that if they forgo supply they will receive water in a specified future period. There are significant gaps in legislation and rules in MDB jurisdictions in relation to water carryover, underground storage and recovery of stored water. Specific legislation (or legislative amendments) need to be developed to allow for storage, recovery after storage and losses during storage and recovery, and related rules to enable integrated water management. These requirements are discussed further in section 5.4.4.1 below.

5.4.3 Water entitlements

Owners of clearly defined water resource use entitlements have a powerful incentive to optimise the use of water for private and commercial purposes because they will benefit financially. Ownership of clearly defined water entitlements also provides security and an incentive to invest (Tietenberg 2000).

The evolving system of surface water entitlements in the MDB provides surface water users with a volumetric share of the available water resource. Users are guaranteed delivery of that share with various levels of security. Although the MDB jurisdictions have legislated to introduce NWI compliant water entitlement systems, implementation is incomplete. Priority has been given to implementation in high priority regulated surface water systems with significant use (NWC 2009). Water use in these systems is controlled, consistent with the MDB cap.

¹⁰⁷ The term sustainable diversion limits is used in the Proposed Basin Plan, rather than sustainable yields or sustainable use limits.

The management regime for groundwater resources is different from surface water. It has not been possible to give users a share of total available groundwater because this total has not been defined and there has not been a cap on use. The use of groundwater has been restricted in a limited number of management areas on the basis of exploitation of, or stress in surface and/or groundwater resources, but there is no systematic basin-wide approach.

The lack of a basin-wide aggregate sustainable diversion limit for surface water and groundwater (both or combined) has reduced the incentives for cyclical integrated water management to make the best use of scarce and variable surface water supplies. Instead the cap on surface water use has created an incentive for increased groundwater use, which has resulted in groundwater use growing faster than surface water use since the cap was imposed (NLWRA 2001, MDBC various). This regime has encouraged the long term depletion of groundwater, rather than cyclical depletion and replenishment. The Proposed Basin Plan includes an aggregate sustainable diversion limit (cap) for groundwater but this will not be translated into a consistent and comprehensive set of basin wide groundwater plans until 2019, see below.

Exceptions and gaps in the water entitlement system also reduce incentives to save water and to invest in water saving methods such as underground storage and water banking. Special treatment or exemptions are applied to various kinds of surface water use.

Water can be taken for domestic purposes, watering stock or emergency purposes without a licence. There are de facto limits to stock and domestic use but these are not monitored closely and a few interviewees reported anecdotal evidence of "stock and domestic water" being used for irrigation purposes. In the northern part of the MDB much of the rainfall comes from a small number of high rainfall events. Following these events farmers are given access to supplementary water in addition to their regular licensed water allocations. In South Australia and Victoria water entitlement or licences are only required in declared or prescribed areas (Gardner et al 2009). There are also special licensing provisions for mining, oil and gas, and special circumstances provisions that can be exercised by ministers (Lucy 2008).

Exceptions and gaps in the surface water entitlement system coupled with the lack of legislated entitlements to store or extract water in aquifers except in South Australia (see below) reduce incentives to save water and to invest in water saving methods such as underground storage and water banking. Potentially this reduces the efficiency of water use.

5.4.4 Surface water and groundwater management rules

In the MDB surface water and groundwater management rules are determined through jurisdictional water planning processes led by government authorities with participation from water users and interested third parties (Productivity Commission 2003). The NWI requires that the share of the consumptive pool of a specified water resource granted by a water entitlement should be determined by the relevant water plan, and that the allocation of water to the entitlement must be consistent with the plan. Legislation in the MDB jurisdictions generally requires that converted entitlements, and any new entitlements must conform to allocation rules in the water plan (Gardner et al 2009)¹⁰⁸. In all MDB jurisdictions regulated surface water entitlement holders are entitled to a share of water available in the season or year. These shares come with various levels of security. For example, in NSW holders of high security entitlements receive a higher proportion of the face value of their entitlement than general security entitlement holders. Unregulated surface water and groundwater entitlement holders get a volumetric entitlement to which various conditions may be applied.

5.4.4.1 Surface water and groundwater management plans

Following the National Water Initiative separate surface water and groundwater plans have been prepared for priority catchments and water management units. There are few integrated surface water and groundwater plans, and in most cases surface water and groundwater is still managed separately. Only a minority of surface water plans consider impacts on groundwater. Most groundwater plans consider impact on surface water, but the analysis is often rudimentary (NWC 2007). No state has yet developed a water management plan that specifies and quantifies the degree of relationship between connected resources, and explicitly provides for that relationship in all relevant

¹⁰⁸ The same requirement is imposed on licences and water shares in Victoria, but is absent from bulk entitlements.

components of the plan (Dyson 2005). The next generation of these water plans are scheduled to be produced (consistent with the MDB plan) in 2019. There are no management plans for unincorporated water management areas, outside defined groundwater management units¹⁰⁹.

There are only a small number of integrated surface water and groundwater plans in the MDB and these are relatively recent. These plans are in water management areas that include highly connected systems. The diversity of surface water and groundwater systems in these catchments can result in complicated sets of operational rules. For example the integrated water management plan for the Peel River region contains eight sub regions with tailored management rules for each region. The degree of integration varies across the eight regions; for example, shallow alluvial groundwater below a river channel is managed by the same rules as surface water, whereas groundwater remote from the river channel is managed as a separate resource.

The New South Wales conjunctive water licence scheme which was abandoned in 1997 provides the only long term Australian experience of integrated cyclical water management (Fullagar et al 2006)¹¹⁰.

The policy and planning frameworks for the latest generation of water plans in Victoria (sustainable water strategies) and NSW (macro plans) provide a relatively well developed template (albeit higher-level and fairly generalised) for integrated surface and groundwater plans. These include common principles for managing surface water and groundwater in connected systems¹¹¹. These frameworks allow for further consideration of cyclical surface and groundwater use in future water plans, although there are a number of challenges such as establishing surface and groundwater connectivity at various spatial and timescales and identifying groundwater dependent ecosystems.

Integrated water storage and management is hindered by significant gaps in legislation and rules in relation to water carryover, underground storage and recovery of stored water.

¹⁰⁹ In New South Wales unincorporated areas are lumped together in macro plans.

¹¹⁰ Further details are in sections 4.3.1 and 6.3.2.

¹¹¹ <http://www.ourwater.vic.gov.au/programs/sws>.
http://www.dwe.nsw.gov.au/water/plans_macro.shtml accessed 27 September 2009.

Carryover is subject to a range of limits in different jurisdictions, and further limitations have been introduced in recent water seasons because of drought¹¹². Rules for groundwater recharge and recovery have been established in South Australia, and on a trial basis in Victoria, but not in other MDB jurisdictions (GHD and AGT 2011)¹¹³. Legislated rules need to be developed to allow for storage, recovery after storage and losses during storage and recovery to enable integrated water management. Under current arrangements most users have no guarantee that they can recover water that they store underground – it becomes part of the common pool.

In some cases the development of rules will be complicated by water quality issues that will trigger environmental and other assessments. These rules need to be backed by effective accounting, metering and monitoring. For example, recharge into saline groundwater will create a freshwater lens, but extraction rules and monitoring will be required to guard against saltwater intrusion (Roeder 2005). Rules may also need to be developed for dealing with irrigation recharge; for example will it be allowed as an offset against groundwater pumping?

These are significant complications, and further questions are likely to emerge during the implementation phase of water planning when detailed operational rules are worked out taking account of local biophysical and socio-political conditions.

The combination of surface water and groundwater plans in a single instrument allows optimal integration of surface water and groundwater management. The 2010 Guide to the Basin Plan notes that some groundwater systems that are highly connected to surface water systems may be able to sustain greater exploitation if there is a corresponding reduction in surface water use to offset the resulting impact on stream flow.

¹¹² http://www.nrw.qld.gov.au/about/policy/documents/3832/page_3_16.html
http://www.dnr.nsw.gov.au/mediarelnr/mm20090701_4027.html
<http://www.premier.vic.gov.au/minister-for-water/changes-to-carryover-rules-give-irrigators-greater-choice.html> <http://www.ministers.sa.gov.au/news.php?id=2734> all accessed 18 September 2009.

¹¹³ Victoria is trialling a managed aquifer recharge policy that allows aquifer storage and recovery.

Strategies and rules that can be used to optimize cross system water management include:

- linked water entitlements or extraction; linked seasonal allocation determinations;
- linked restrictions on rates of extraction tied to water levels or flow triggers;
- provision for surface water groundwater trade or exchange;
- constraining the location of groundwater extraction to alter the timing or extent of cross connection impacts; and
- provision for measures such as works, purchase of water entitlements and structural adjustments to offset cross connection impacts (Hamstead 2011).

However, integrated water planning can lead to complex multipart water plans even in relatively small water resources, and effective coordination between surface water and groundwater plans may be preferable to a joint plan unless the connections between surface water and groundwater resources are large and rapid. The case for joint or separate plans needs to be examined on a case-by-case basis taking account of the benefits and costs including the transaction costs (Challen 2000). In any event integrated water planning and management is likely to involve significant transaction and financial costs. One senior state official commented that the reason why there has not been a more rapid implementation of integrated water management is that it is "bloody hard" to do. The implementation of integrated water management is discussed further in section 5.4.6.

5.4.4.2 Compliance and enforcement

Effective integrated water management requires monitoring and enforcement of surface water and groundwater use. Surface water monitoring is generally centralised and carried out by the large irrigation agencies or companies. Monitoring groundwater use presents more problems because, unlike a surface water irrigation scheme where water is supplied to users through a regulated system, there are large numbers of wells, mostly on private farms. Metering and monitoring of groundwater use has been uneven with each state having different priorities and arrangements. Groundwater use has not been monitored so systematically as surface water. Compliance procedures have been weak; interviewees commented on low fines for significant breaches of water entitlement conditions, as low as \$100.

The implementation of a metering, monitoring and compliance system presents some dilemmas concerning the system design and choice of implementing agents (Ross and Martinez-Santos 2010). Government authorities do not have enough information or resources to meter and monitor the use of thousands of wells, and have substantial difficulties in enforcing use limits without active collaboration from users.

Groundwater users have the potential to organise themselves to meter and monitor water use, and to identify illegal users, but user associations may face difficulties such as conflict between users, distrust of authorities and reluctance to denounce illegal users. Also, metering imposes a significant additional cost for some users.

Incentives may be needed to make it worthwhile for users to engage in monitoring and compliance. Thus the transition to effective groundwater use monitoring and compliance is likely to require collective action by authorities and users. This will in turn require improved relationships and trust between various water users and authorities.

5.4.5 Surface water and groundwater exchange and trading

Water markets create the potential for increases in the efficiency with which water is used by enabling water entitlements to be exchanged and effectively transferred to locations and uses which give optimum value for use. Markets also help users to get the best value for money, and water supplies that meet their needs (Productivity Commission 2006).

In theory exchanging surface water entitlements for groundwater entitlements across surface water groundwater connections¹¹⁴ can lead to increased efficiency in the same way as trading between different sources of surface water or groundwater. Trading across connections can occur spatially or through time. In theory surface water entitlements could be traded for groundwater entitlements in dry periods, and the reverse exchange could occur during wet periods so that groundwater can be recharged.

¹¹⁴ This may involve trading a surface water use entitlement for a groundwater use entitlement, or vice versa.

The Proposed Basin Plan s11.25 states that:

The trade of a water access right between a groundwater SDL resource unit and a surface water SDL resource unit is prohibited, unless all the following conditions are met:

- a. There is sufficient hydraulic connectivity between the 2 units;
- b. Any resource condition limits in the groundwater SDL resource unit specified in a water resource plan will not be exceeded as a result of the trade;
- c. Measures are in place to account for the trade;
- d. Either:
 - i. water access rights in the 2 units have substantially similar characteristics of timing, reliability and volume; or
 - ii. measures are in place to ensure that the water access right to be traded will maintain its characteristics of timing, reliability and volume; and
- e. Measures are in place to address the impact, as a result of trade, on water availability in relation to a water access right held by a third party.

Trading surface water and groundwater entitlements is relatively uncomplicated when surface water and groundwater resources are highly connected and where connections are rapid, such as in valleys where there is shallow alluvial aquifer with many bores fairly close to a river (DWE 2007). In this instance surface water and groundwater can be managed as a joint resource within a single sustainable use limit. When resources are less highly connected and/or the connections are slow the impact of trading is more complicated and/or more uncertain as indicated in Box 5.1 below. In these circumstances trading is less likely to be a problem when both resources are underexploited or large, and therefore insensitive to additional use, but becomes more problematic when either resource is over exploited and /or small and sensitive to additional use.

There are some biophysical and institutional prerequisites for successful trading of surface water and groundwater. Trading requires significant supplies of both resources and sufficient storage facilities to enable integrated water management. For example the strategy of using groundwater in dry periods and replenishing it in wet periods is only possible if there are periodic surpluses of surface water and sufficient and accessible aquifer storage is available and cost effective.

Box 5.1 Possible rules for surface water groundwater trading¹¹⁵

Surface water groundwater trading offers opportunities to improve spatial and temporal access to water. For example, abstraction can be transferred from a riverine location to a place where the aquifer is the only source of supply or vice versa. Abstraction can also be transferred from one season or year to another¹¹⁶, for example a surface water entitlement can be exchanged for a later groundwater entitlement or vice versa.

Two way surface water groundwater trading is feasible in connected systems, although potential impacts must be addressed. These impacts depend on the unit volumetric impact (UVI) of a surface water groundwater transfer and the consequent effect on river flows and groundwater dependent ecosystems (GDEs). The time lags of impacts also have to be taken into account.

If the UVI is 1.0 surface water-groundwater trade will have no net impact on river flows or non-riverine GDEs. If the UVI is less than 1.0 the impacts of surface water groundwater trade depend on the direction of the trade. For example, if water is traded from the river to the aquifer this will result in an increase in downstream river flows with the reduction in water to non riverine GDEs. If water is traded from the aquifer to the river there is an increase in water available for non riverine GDEs and a reduction in downstream flows to the river.

The acceptability of these impacts on river flows and non riverine GDE's depends on the situation. For example if depletion in downstream river flows is unacceptable because of the impacts on downstream water entitlement holders a conversion factor equal to the UVI can be applied. If the UVI were 0.5 a trade from groundwater to surface water would receive 0.5 units of surface water per unit of groundwater. A trade from surface water to groundwater would receive 2.0 units of groundwater per unit of surface water¹¹⁷.

Alternatively trade may be restricted in one direction to avoid adverse impacts. This is reflected in the current practice of only allowing trade out of highly exploited water management areas in New South Wales, for example the lower Murrumbidgee groundwater management area (Kumar 2008).

In reality UVIs cannot be determined with precision, and water entitlements cannot be accurately represented by a single number because of variations through time. Time lags in cross connection flows further complicate the picture, giving rise to the possibility that delayed impacts may occur at a time which imposes a greater risk.

Also trade from an aquifer to a river when there is a multiyear time lag in impact could pose a risk to the river in the intervening years. One way of addressing this would be to allow the trade, but not allow the surface water entitlement to be used until sufficient time has elapsed for the reduction in groundwater use to be translated into increased river flows. However such delays might make trading relatively unattractive.

¹¹⁵ Box 5.1 adopts the analysis of UVIs in SKM 2011 p55-60.

¹¹⁶ This might be desirable if an entitlements holder wishes to increase production or to ensure supply at a future point in time.

¹¹⁷ Using the same formula a trade from surface water to groundwater would receive 2.0 units of groundwater per unit of surface water. This would be acceptable providing the aquifer could absorb greater abstraction without putting important values at risk.

Surface water groundwater trading requires a regulatory regime including clearly specified sustainable use limits and tradable water entitlements. It also requires rules that permit water carryover, banking and borrowing and storage and recovery of underground water. As discussed in section 5.3.4.1, these requirements are not currently met in most areas within the MDB, other than in South Australia (Dillon et al 2009), and on a trial basis in Victoria¹¹⁸. Sustainable use limits and tradable water entitlements for groundwater are still in the process of being established, and rules for carryover, banking, borrowing and storage and recovery of undergroundwater are not in place in most jurisdictions.

There are a number of difficulties in establishing a regime and rules to enable surface water groundwater trading. Firstly there are substantial gaps in knowledge about surface water groundwater connections and the impacts of surface and groundwater use in connected systems including their environmental impacts (especially across different sub basins and aquifers). Secondly, it is particularly difficult to account for intertemporal impacts, especially long term impacts of groundwater pumping on surface water flows and ecosystems. Thirdly trading may become problematic when resources have different properties e.g. freshness and pollution. This has led water managers in the MDB to take a generally conservative approach towards surface water groundwater trading.

Government water managers interviewed in this study generally considered that trade would be limited to highly connected resources with rapid connections; otherwise the risks and uncertainties arising from trade would be too great, at least at current levels of knowledge.

5.4.6 Management organisations

Government and non government management organisations are established to manage water and to give effect to systems of water entitlements and rules. These organisations

¹¹⁸ http://www.ourwater.vic.gov.au/_data/assets/pdf_file/0019/80443/Groundwater-Newsletter-October-2010.pdf accessed 17 February 2012.
<http://epanote2.epa.vic.gov.au/EPA/publications.nsf/PubDocsLU/1290?OpenDocument> accessed 17 February 2012.

and the people who manage them are assigned roles and responsibilities, and legal and administrative powers.

Historically water management in the MDB was largely concerned with ensuring water supply, and related infrastructure development, with regulation to address point source water pollution. In recent years a broader range of issues have been included in water management, such as water for the environment, diffuse pollution from agriculture, and climate change.

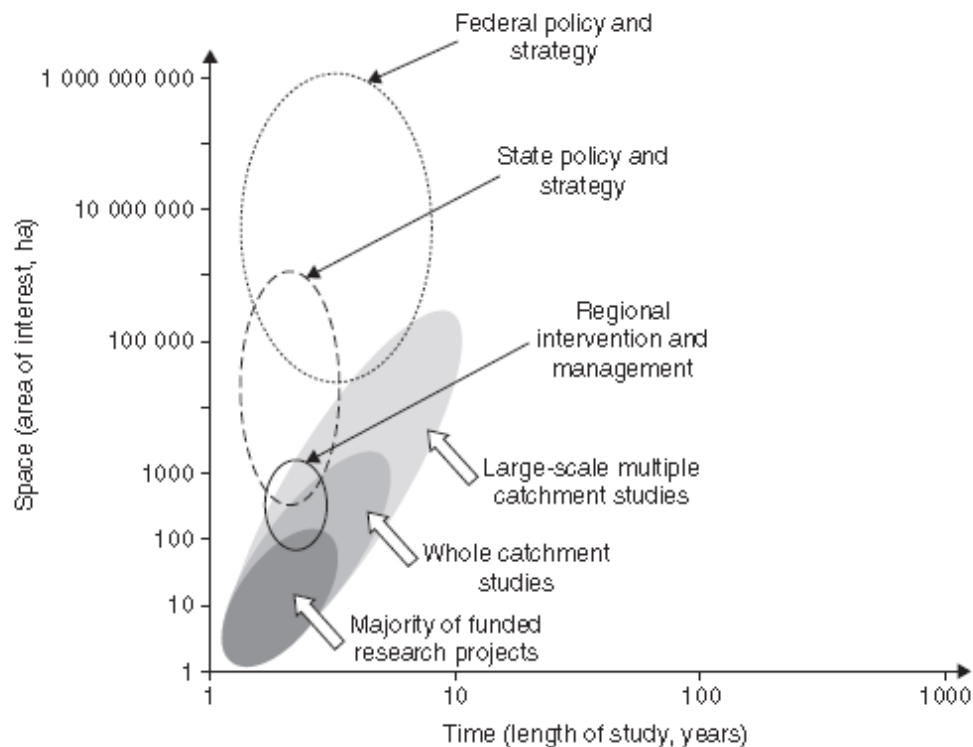
Integrated water planning and management requires action at multiple geographical scales and administrative levels. Neither governments nor water users have all the legal competencies, funds, information and other resources necessary to manage these issues to their own satisfaction. Consequently, stakeholders need to cooperate and pool resources. Multilevel integrated water governance has become the norm.

Much of the detailed work has to be done at a catchment and water management unit scale. In the MDB there are significant challenges in bridging the boundaries between high level policy interventions such as the National Water Initiative, the Water Act 2007, the Proposed Basin Plan, and State water planning processes and implementation "on the ground" (Connell et al 2007).

Participants working at smaller scales such as sub basins and water management units, often produce work that is disconnected from others in time and space. Work at larger spatial and temporal scales such as catchments in the MDB, or the whole of the basin is more complex, addresses multiple questions and is relatively new to applied science and management communities in Australia.

There has been a major mismatch between the large scale environmental problems faced in Australia and the small scale, fragmented scientific knowledge and management strategies available to address them - see Figure 5.1. (Likens 2009)

Figure 5.1 Scales of water management and research in the Murray-Darling Basin



Source: Likens 2009

Integrated water management raises some difficult cross scale management problems. Connections between surface water and groundwater are imperfectly understood, and the impacts of each resource on other resources and the environment are uncertain (Evans 2007). Integrated water management often involves contested water allocation which can only be resolved through extended processes of stakeholder negotiation (Blomquist and Schlager 2008). The success of such processes depends on broad stakeholder participation, the development of trust and mutual understanding, effective coordination and leadership and adequate financial resources (Emerson 2011).

Historically surface water and groundwater planning, rule development and administration have been separated in the MDB jurisdictions. Interviewees commented that surface water and groundwater management organisations have often been separate as well¹¹⁹, with different objectives, values and cultures.

¹¹⁹ Separate units within agencies, separate agencies or separate specialised consultancies.

Water management and allocation in the MDB States is highly centralised in the hands of responsible Ministers and their Departments. Surface water and groundwater policy and planning are coordinated at the highest levels of decision making, but separate at lower levels. This separation has been accompanied by an inadequate analysis of the impact of surface water use on groundwater, and of groundwater use on surface water – especially the longer term impacts. This weakness is exacerbated by the gaps in knowledge about surface water groundwater connections.

The historical separation of surface water and groundwater science (hydrology and hydrogeology) has reinforced the administrative separation. Hydrology and hydrogeology are separate disciplines with their own traditions, teaching and literature. The two disciplines have different perspectives on water systems. Surface water and groundwater models have been developed separately - there are few integrated models in the MDB or elsewhere in the world.

The development of the new Murray-Darling Basin plan provides a substantial opportunity to improve the integration of surface water and groundwater management. The Murray-Darling Basin Authority has the legislative authority, and the agreement of MDB jurisdictions to develop sustainable diversion limits, water quality requirements and risk sharing arrangements and to harmonise sub basin planning with the Basin Plan. The collection of information on water resources and availability has also been centralised under the Bureau of Meteorology, and this promises to improve the content and timeliness of information available to water users and decision-makers¹²⁰.

However, there are limits to how far surface water and groundwater planning and decision-making on water management can be centralised. There are substantial variations between surface water and groundwater connections within some catchments. This suggests that integrated surface water and groundwater planning areas should be relatively small, with decentralised planning and decision-making processes. Catchment based water plans developed by MDB jurisdictions consistent with the Basin Plan, can integrate surface and groundwater planning at the catchment scale. They can provide a bridge between high level policy frameworks and the Basin Plan, developed by the Commonwealth and State governments, and water management and supply units at the local scale.

¹²⁰ <http://www.bom.gov.au/hydro/> accessed 27 September 2009.

Catchment-based water plans require substantial regional and local capacity. Higher-level authorities (Commonwealth and State governments) have delegated natural resources management and planning to regional bodies but the results have been mixed because of lack of delegation of decision making powers, uneven and, in some cases, inadequate resourcing, and frequent failure to provide scientific information in a form that is useful to regional decision makers (Connell et al 2007, Ross 2008).

Similar issues have arisen in sub basin water management and planning in the MDB. State water legislation includes provision for consultation in relation to water plans but consultation often appears more symbolic than real. It often takes place after policy changes have been made and/or does not take sufficient account of stakeholder views (Bowmer, 2003).

Interviewees advised that water governance in New South Wales has been improved by centralising the preparation of macro plans, and putting out a draft for a standardised communication and consultation process, but it will be some time before the outcomes of the management plans and rules produced by the streamlined process can be fully evaluated.

In Victoria groundwater planning was outsourced in the 1990s. Many water supply protection areas were declared, but the planning process remained very slow and some groundwater targets and plans were challenged by users. Although departmental groundwater expertise is being rebuilt the management planning framework requires interaction between different administrative levels, government agencies and stakeholders. Interviewees reported that the process is onerous and time consuming.

In South Australia NRM boards, government departments, SA Water, private water supply companies and agricultural industries are involved in integrated water planning. The first plans under the new South Australian legislation are just being prepared, and, as in other jurisdictions it will be some time before outcomes can be fully evaluated.

5.6 Conclusions and issues for further study

5.6.1 Factors affecting integrated water management in the MDB

Several factors have influenced the limited development and implementation of integrated water management and use in the MDB. These are:

- The overhang of attitudes, practices and infrastructure arising from historical priority given to surface water development and the relative neglect of groundwater management and monitoring;
- Shortfalls in information about groundwater, the connections between groundwater and surface water and their impacts;
- Gaps and exemptions in water use entitlements and rules including light regulation of water harvesting and interception, limits on carryover and lack of entitlements and rules for aquifer storage and recovery;
- Limited opportunity for surface water and groundwater trading; and
- Separate management of surface water and groundwater except at the highest levels of administration.

Several other factors have had mixed impacts on the development of integrated water management in the MDB:

- Access to both surface water and groundwater supplies and storage is available in many regions of the MDB, although surplus surface water for banking and storage is often limited in quantity, frequency and/or duration;
- Surface water and groundwater users have different objectives and practices. Users in towns and large irrigation schemes rely on water supply organisations using large-scale collectively owned infrastructure. Groundwater is usually developed by individual users who supply their own infrastructure. But these differences are

moderated by the fact that many users live in communities which have a history of use of both surface water and groundwater;

- Although in the past the availability of cheap surface water may have discouraged integrated water management, now many resources are intensively exploited, and prices are higher, especially for traded water; and
- National and State government laws do not impede integrated water management, but differences between surface water and groundwater use entitlements and limitations increase the difficulty of integrated water management.

Integrated water use projects also face a range of economic, health and social concerns. Managed underground storage projects can involve expensive land acquisition and infrastructure. Concerns about the health and other implications of mixing groundwater and surface water also have to be overcome in some cases.

Integrated water planning and management is complex and difficult, with coordination and collaboration at multiple geographical scales and administrative levels. Planning and coordination needs to be sustained over long periods of time to allow for the delayed impacts of groundwater recharge and use.

5.6.2 Incorporation of integrated water management in water policies and programs

The move towards managing surface water and groundwater as one interconnected resource is part of a larger transition towards managing water as part of a larger social and ecological system. This transition involves strategic changes in issue framing and action at multiple levels. Key elements in this transition are represented in Table 5.1. This is a stylised representation; in reality most water management systems, including systems at the basin and sub basin scale in the MDB, lie between the two cases described in the table. These transitions are already occurring in the MDB, and high level policy is broadly consistent with them. The transition to integrated water planning and management for surface water and groundwater involves major changes compared

to current conditions. It is relatively easy to get in principle agreement to such changes in general terms, it is much more difficult to implement them in particular instances.

Table 5.1 Transition to integrated water management

	<i>Fragmented water management</i>	<i>Integrated water management</i>
<i>Context</i>	Surface water and groundwater managed as separate resources disconnected from the natural environment and society	Surface water and groundwater managed as part of a connected social and ecological system at multiple scales (local, regional, national, international)
<i>Management Goal</i>	Supply water for human consumption	Multiple goals including economic productivity, social fairness and environmental sustainability
<i>Producer Action</i>	Producers act individually to produce economic goods and services	Producers act individually to produce economic goods and services and collectively and with governments to achieve multiple water management objectives including sustainable landscapes and communities
<i>Government Action</i>	Governments pursue interests of their jurisdiction.	Governments pursue interests of their jurisdiction but also collaborate with each other and water users to achieve multiple objectives including sustainable landscapes and communities
<i>Water storage and infrastructure</i>	Large scale centralised surface water storage, delivery and financing	Mixed centralised and decentralised systems of surface water and groundwater storage, delivery and financing
<i>Planning and analysis</i>	Separate planning and analysis of water sources and sectors	Integrated surface water and groundwater planning and cross sectoral analysis taking account of emerging issues
<i>Governance</i>	Hierarchical centralised jurisdiction based governance, with fragmented proprietary information and limited stakeholder participation	Polycentric, multilevel governance combining river basin and jurisdictional governance, with open shared information and broad stakeholder participation
<i>Instruments</i>	Heavy reliance on regulations	Mixed system of regulations, market mechanisms and voluntary agreements

Integrated surface water and groundwater management raises a number of controversial and/or difficult questions. Most of these are shared with the broader water reform agenda. These questions include; how to make operational contested concepts such as environmental sustainability and social fairness, how to get producers and governments to take responsibility for multiple non traditional objectives including aquifer storage and recovery, and to collaborate to achieve them, and how to handle the transaction and other costs that may be associated with multilevel, participatory governance, and what is the best instrument mix to provide incentives for these changes. These are at least in part normative questions that can only be resolved through the political process. This emphasises the importance of effective and fair process (Syme 2003), taking account of and managing the transaction costs (Challen 2000).

Integrated water management has multiple policy objectives and is evolving rapidly along with new knowledge and technology. This suggests that a diverse and flexible set of instruments and governance arrangements is desirable.

Laws and legally binding regulations are necessary to establish framework conditions for integrated water management such as entitlements and sustainable use limits but they are relatively cumbersome and inflexible instruments for other purposes.

Water markets are good at allocating scarce water among human users, but they are not so good at guiding choices about environmental water allocation or investment in sustainable rural landscapes, or dealing with concerns about fair distribution. Also groundwater and surface water groundwater trading is complicated by uncertainty about the impacts on other resources and the environment.

Partnerships between water users and governments can bring about collaboration to achieve integrated water management outcomes at a regional and local scale.

Clear policy objectives, comprehensive well defined water entitlements and allocation rules are needed to give incentives for collaborative agreements and action.

5.6.3 Opportunities for better integration of water management

What can be done to help realize the benefits of integrated water management? The development of the new MDB plan provides a context in which current arrangements for integrated water management can be assessed, and new rules can be built into the Basin and sub basin plans. This provides the opportunity for the further development of integrated water management.

While the integration of surface water and groundwater planning and management needs to be assessed on a case-by-case basis, there are opportunities for more integrated water management over time. Authorities have been reluctant to encourage increased groundwater use as part of a cyclical water management strategy because some aquifers are already fully exploited, or near to full exploitation. Also, it is often argued that there is no surplus surface water for underground storage because surface water is fully allocated. However, there are seasonal high flows in some catchments. Moreover, under Australia's system of separate and tradable water entitlements, entitlement holders receive an annually assessed share of available surface water. This opens the door for state authorities and water users to store shares of available surface water underground in wet years for use in dry years.

Some modifications would be needed in governance arrangements; water entitlements, laws, rules and management organisation(s) in order to develop surface and groundwater plans that are integrated through time as well across resource boundaries, and to implement water banking and trading. Water entitlements need to be well defined to provide security and confidence to water users, and flexible to adjust to changing conditions and new knowledge. Longer term carryover provisions and entitlements to store and extract water would need to be integrated with current carryover provisions and water use entitlements. The ownership of, and management responsibilities for, stored water and its recovery will need to be clarified and resolved. The management regime would need to be robust enough to withstand legal challenges.

Integrated water planning is complicated by boundary problems and knowledge gaps, and can involve significant transaction and financial costs. Aquifer storage and recovery projects can involve expensive land acquisition and infrastructure. Concerns about the

health and other implications of mixing groundwater and surface water also have to be overcome in some cases.

Regional organisations¹²¹ could play a greater role in integrated water planning management and monitoring, and encourage greater innovation by users and authorities, but there are significant challenges. These include:

- gaining common understandings, approaches and collaboration between different users and jurisdictions;
- achieving broad representative participation in decision-making;
- overcoming the reluctance of state governments to give up traditional roles and responsibilities and delegate decision-making powers;
- making available scientific information in a form that is useful to regional decision makers; and
- building the capacity of regional organisations to use new methods and tools such as integrated water models, water balances, scenarios and risk analysis.

5.7 Concluding comments

In summary the analysis in Part II of this thesis suggests that a combination of biophysical, historical, social, political, financial and institutional factors explain why integrated water management has developed relatively slowly in the MDB.

Integrated water management in the MDB has been constrained by the historical priority given to surface water development and management, the relative neglect of groundwater management, gaps in knowledge about groundwater resources and groundwater surface water interactions, and gaps in the structure of water entitlements and rules. The development of the new Murray-Darling Basin plan provides an opportunity for the further development of integrated water management in the MDB.

Integrated water management could be advanced by the establishment of more comprehensive water entitlements and use rules, including rules for extended carryover, water banking, aquifer storage and extraction. There is scope for greater

¹²¹ Water user organisations, as established in Colorado and Idaho, could provide supplementary or alternative coordination services.

decentralisation of integrated water planning and implementation, and more effective engagement of regional and local stakeholders.

Research comparing governance arrangements in the MDB and overseas jurisdictions with greater experience of integrated water management would help to identify requirements and prospects for integrated water management in the MDB. Governance arrangements in the Namoi region of New South Wales, the South Platte region in Colorado and the Eastern Snake Plain in Idaho are explored in the following part of this thesis.

Part III

Part III includes a comparative case study of governance arrangements affecting integrated surface water and groundwater management in the Namoi River Basin in New South Wales, the South Platte River Basin in Colorado and the Eastern Snake Plain Aquifer in Idaho.

Chapter 6 Integrated water management in the Namoi region

6.1 Introduction

This chapter examines integrated surface water and groundwater management in the Namoi region in New South Wales. The chapter proceeds in four parts. The chapter begins with a brief description of the biophysical, socioeconomic, legal and historical context for water management in the region. The second part includes an outline of the historical development of integrated water management and use in the region. This is followed by a brief analysis of the impact on integrated water use and management of some specific governance arrangements; conjunctive water licensing, water sharing plans, and water management organisation. The chapter ends with an assessment of opportunities for integrated water management.

6.2 The Namoi region

6.2.1 Physical, climatic and socioeconomic features

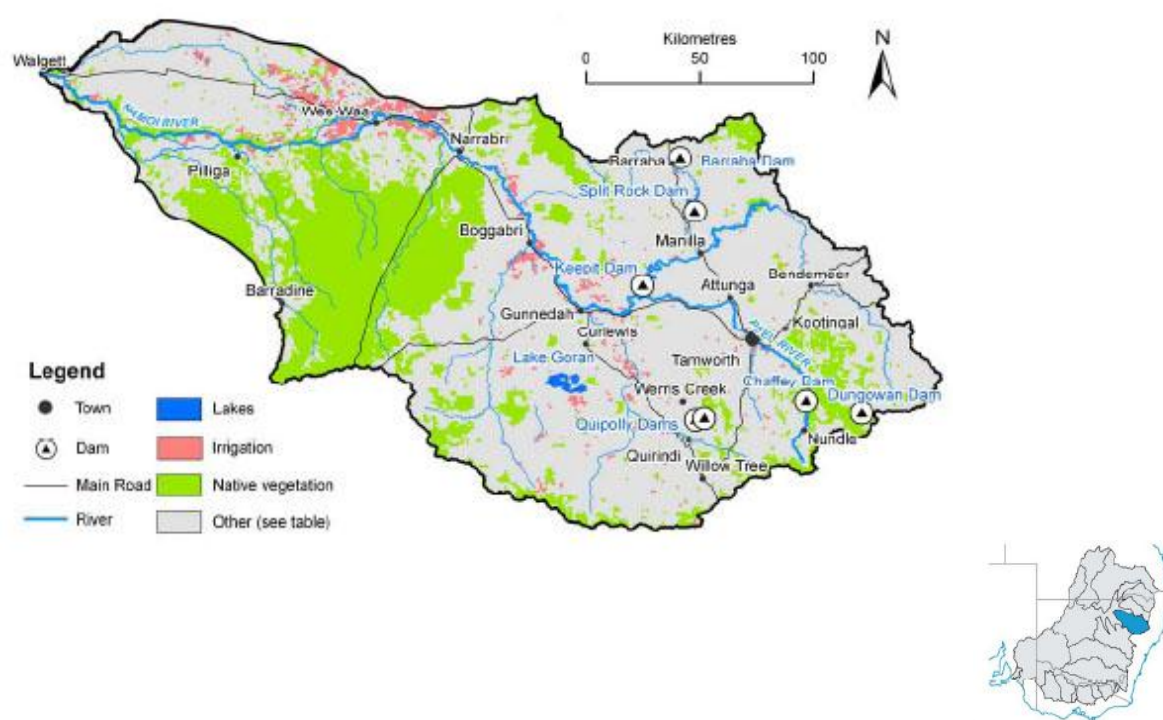
The Namoi region in northern NSW covers approximately 42000 km². The mean annual rainfall within the region is 633 mm varying from 1300 mm in the east to 400 mm in the West. Rain falls predominantly in the summer, and much of it occurs in short duration heavy falls. Rainfall varies considerably from year to year, for example rainfall at Wee Waa varied from about 240 mm to almost 1000 mm between 1965 and 2008 (DWE 2009). At lower elevations from Tamworth to Walgett average daytime temperatures range from 19-34°C in January and 4-17°C in July. At higher elevations (above 900 m) the temperature range is about 5° lower.

About 88000 people live in the region, 4.5% of the MDB's population. The major towns are Tamworth, Gunnedah, Boggabri, Narrabri and Wee Waa. Agriculture is the

main land use in the region. The majority of the catchment is used for cattle and sheep grazing. Cropping dominates the flatter country, including the alluvial floodplains. The region, especially the central part, is highly dependent on irrigation. The mining/coal seam gas industry is growing in importance in the Upper Namoi and Narrabri areas.

Figure 6.1 shows a map of the Namoi region.

Fig 6.1 The Namoi Region



There is a substantial irrigated cotton industry in the catchment, along with pasture and hay, cereals, dairy and other broadacre crops. The gross value of irrigated agricultural production (GVIAP) in the Namoi region totaled \$322.5 million in 2005-06. Cotton is the region's main irrigated crop - in 2005-06 it accounted for 79% of the GVIAP, 60% of the irrigated area and 76% of the water used. The area of irrigated cotton varies from about 20000 to 65000 according to water availability. Usually 70 to 80% of irrigation water is used to grow cotton, but in drought years this proportion drops to around 40% (MDBA 2010 a MDBA 2011). Forests cover approximately 25% of the catchment, including the Pilliga scrub and some plantation forest (Letcher 2002).

6.2.2 Surface water resources and storages

The main surface water resources in the region are the Namoi River and its main tributary the Peel River, which rise in the Great Dividing Range at elevations over 1000 m, falling to 250 m where the two rivers meet near Gunnedah. Major tributaries include Cox's Creek and the Mooki river which join the Namoi upstream of Boggabri. The average yearly flows in gegalitres (GL) of the Namoi River are about 390 at the Keepit Dam, and 790 at Narrabri. The average yearly flow of the Peel River at the Chaffey Dam is about 55 GL, and 300 GL at the junction with the Namoi River. River flows are highly variable. For example the recorded annual flow of the Namoi River at Gunnedah has ranged from a low of only 4% of the average to a high of 5.2 times the average. (DWR 1992).

The main surface water storages, are the Keepit Dam (423 GL) on the Namoi River, the Split Rock Dam (397 GL) on the Manilla river and the Chaffey Dam (62 GL capacity) on the Peel River which provides water to Tamworth and to downstream users (CSIRO 2007). Irrigators also use on farm water storages that they have constructed themselves. It is estimated that around 1990, private on-farm storages for irrigation had a capacity of about 30 GL (DWR 1992). Capacity is estimated to have grown to 171 GL (SKM et al 2010). There are also a large number of farm dams to supply stock and domestic needs, with an estimated capacity of 145GL (Jordan et al 2008).

6.2.3 Groundwater resources

The most significant groundwater resources are found in unconsolidated sediments of clay, sand and gravel in the lower and upper Namoi Valley. The total area of the lower Namoi alluvium west of Narrabri is about 5100 km² with a maximum depth of 130 m. The estimated storage volume is 20000 GL. In the main body of the alluvial fan, groundwater salinity is less than 1000 mg/litre. The total area of the upper Namoi alluvium is about 3000 km² with an estimated storage volume of 11500 GL (DLWC 1997). This zone includes the Mooki River valley, Cox's Creek and the deep, narrow paleochannel along the Namoi River. The Namoi River paleochannel is about 115 m deep increasing to a maximum of 150 m between Carroll and Gunnedah. In general,

since the late 1960s and early 1970s, groundwater levels throughout the aquifer have been declining. During the relatively wet years 1996–2001 there was a period of reduced extraction, and water levels in most parts of the aquifer stabilised or recovered. However, since 2001, when dry conditions returned water levels have continued to decline, and in the 2006-07 water year many areas experienced their lowest water levels since monitoring commenced (DWE 2009).

6.2.4 Water use

Irrigation grew rapidly after the completion of the Keepit Dam in 1960. The area authorised for irrigation increased from around 2000 ha in 1944 and 4000 ha in 1960 to more than 41000 ha in 1983 and 112000 ha in 2000 (Pigram 2006, CSIRO 2007). The annual surface water use is strongly influenced by seasonal rainfall patterns which cause inflows into the Keepit and Split Rock dams, and accessions by irrigators to supplementary water¹²² during periods of high river flow. Surface water diversions for the combined Namoi and Peel River systems ranged from 142 to 363 GL during the period from 1997-98 to 2008-09 (190 GL in 2004-05) including unregulated stream diversions (MDBA 2010b). Stock and domestic water use accounts for less than 1% of the annual use.

Groundwater resources in the Namoi region are the most intensively developed in New South Wales. Total groundwater extraction increased from about 130 GL in the late 1980s to a peak of 324 GL in 1994-95, well above the average annual recharge of around 200 GL. Groundwater extraction within the Namoi region totalled 254.8 GL in 2004-05, about 15.2% of total annual groundwater use in the MDB. On average the Namoi groundwater resource accounts for about 40% of NSW's total groundwater use (Turrall and Fullagar 2007) and averages over 40% of total water use in the Namoi region (DWR 1992). However, this proportion varies substantially, for example surface water diversions were around two-thirds of the total irrigation water use in 2000-01 and around one-third of total water use in 2003-04 (CSIRO 2007).

¹²² Supplementary water, previously called off allocation water, and sometimes called uncontrolled flows, is water in excess of user and environmental requirements entering the regulated river from tributaries downstream of dams or from dam spills.

6.2.5 Water trading

Water trading is not so highly developed in the Namoi region as in the southern part of the MDB. The water allocation trading intensity, defined as the total volume of trades divided by the total nominal volume of water entitlements, is relatively low (2-5%) compared to 10-20% in the Murray and Murrumbidgee regions, and as high as 40% in some parts of the Murrumbidgee (NWC 2009). Table 6.1 shows the sum of surface water trading in the Namoi and Peel catchments and groundwater trading in the upper and lower Namoi groundwater areas during the 10 years between 1999-00 and 2008-09¹²³. There was significant groundwater trade between 2005-06 and 2008-09 – since 2006 there has been 1GL of permanent trade and 18.4 GL of temporary trade in the lower Namoi region (DWE 2009).

Table 6.1 Water trading in the Namoi region 1999-00 to 2008-09 in ML

	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
SW	22.4	27.6	34.2	34.1	49.1	8.1	24.3	31.3	8.4	13.2
GW	0	0.3	0	1.8	5.1	9.4	na	na	na	10.2

Sources: MDBC various, ABS (2006) Singh et al 2008¹²⁴

6.3 Historical development of surface water and groundwater use and management

6.3.1 Political and policy context

In Australia's federal system, water governance takes place at a number of levels at the jurisdictional and river basin scale. Water management in the MDB is governed by the Murray-Darling Basin Ministerial Council, supported by the Murray-Darling Basin

¹²³ These figures refer to trade in allocations (temporary trade).

¹²⁴ There are significant variations between the different sources of trading statistics, partly owing to different definitions and methods. Statistics on groundwater trading between 2005-06 and 2007-08 were not available from the above sources.

Authority. Historically surface water and groundwater have been managed separately in the MDB. The MDB cap is not a long term sustainable use limit¹²⁵, and does not apply to groundwater. The importance of managing surface water and groundwater in the MDB as a single resource is being increasingly recognised. The Proposed Basin Planning includes an integrated surface and groundwater plan for the basin. Further details of these national and MDB initiatives are given in chapter 4.

The *Water Management Act 2000* (WMA) gives effect to the NWI (and the earlier COAG 1994 reforms¹²⁶) by establishing a framework of water management based on clearly defined water access entitlements/licences (WALs). These entitlements are separate from land ownership and have two components; a share component and an extraction component. The share component entitles its holder to a specified share of available water from a water management area or water source. Available water determinations (AWDs) are made on an annual basis. The extraction component entitles its holder to take water at specified times and rates, or in specified circumstances, in specified areas or locations. WALs can be traded. There are three types of WAL transactions; assignments of a share component or a fraction of a share component; permanent sale; or term transfer (lease agreement). The rules for allocation of water are specified in water sharing plans for specified water management areas. Water sharing plans are required to make provision for the identification, establishment and maintenance of environmental water, to identify requirements for water to satisfy basic landholder rights and for extraction under access licences, and the establishment of access licence dealing (transfer) rules and bulk access regimes¹²⁸ (Montoya 2010).

The WMA establishes two classes of environmental water. Planned environmental water is committed by management plans for fundamental ecosystem health or for specified environmental purposes. Adaptive environmental water is committed by the conditions of access licenses for specified environmental purposes (WMA s 8).

Human consumptive use of water is constrained within long term average annual extraction limits (LTAAEL) established in water sharing plans (DWE 2009). Basic rights (native title, domestic and stock) and access licences for domestic and stock use

¹²⁵ It is an arbitrary limit to prevent further increases in water use entitlements above sustainable levels.

¹²⁶ Amendments to the Act enable implementation of the National Water Initiative in NSW.

¹²⁸ This means a bulk access regime established by a management plan, as referred to in section 20 (1) (e) of the Water Management Act 2000, or by a Minister's plan. This regime includes environmental water, basic landholder rights and water for extraction under access licenses.

and local water utilities are volumetric and are granted highest access priority. Water access licenses entitle the holder to a share (usually expressed in 1 ML units) of the water that can be sustainably abstracted from a particular water source. The seasonal or annual share is adjusted according to the availability of water¹²⁹. Surface water shares in regulated rivers are determined in AWDs based on the amount of water in dam storage. This procedure enables water managers to respond flexibly to variable water inflows and storage. Groundwater shares are linked to annual average recharge levels and are more stable than surface water¹³⁰.

There have been two phases of preparation of water sharing plans under the *Water Management Act 2000*. The first phase included the most highly developed and intensely exploited water resources. Plans for surface water and groundwater resources were prepared separately during this phase. During the second phase since 2004, “macro” water sharing plans have been prepared for unregulated rivers¹³¹ and groundwater systems, at the catchment (or aquifer) scale. A small number of these plans have included integrated water arrangements for highly connected water resources within the macro planning area. Water access rules in macro plans vary according to community dependence on extraction and risks to in stream values. Trading rules vary according to hydrological and in stream risks (Office of Water 2010).

6.3.2 Historical development and management of water resources in the Namoi region

Until the 1980s governments saw opportunities to create employment and incomes in rural New South Wales by providing water for irrigation developments (Wilkinson 1997). Substantial investment was made in water infrastructure projects and infrastructure in order to improve the reliability of water supply. One distinction between the Namoi region and the southern MDB is that surface water and groundwater are equally important sources of supply in the Namoi, while surface water is the primary source in the southern basin. Nevertheless, until the 1990s water resource development

¹²⁹ <http://www.water.nsw.gov.au/Water-Licensing/About-licences/New-access-licences/default.aspx> accessed 27 February 2011.

¹³⁰ These shares might be adjusted in some circumstances to take account of other information such as declining groundwater levels.

¹³¹ Unregulated rivers are dependent on rainfall and natural river flows rather than water released from dams.

and policy in the Namoi was surface water centric, with an emphasis on the development of regulated surface water supplies. The development of groundwater resources has been more autonomous and decentralized.

6.3.2.1 Surface water

In the Namoi irrigators were encouraged and allowed to expand beyond the capacity of available water resources. By 1965 cotton irrigators were using about 80% of the water from the Keepit Dam. They were using concentrated numbers of much larger pumps than other primary producers (Wilkinson 1997). In 1966 Namoi Valley Water User Association expressed concern at the expansion of irrigation licences and the danger of over-commitment of the Keepit Dam. But it was not until 1976 that an embargo was placed on the issue of further licences. Over commitment of resources coupled with a succession of dry years resulted in drastic curtailment of surface water allocations. This in turn lead to rapid development of groundwater.

Irrigators in the valley initiated the introduction of volumetric surface water allocations which were given effect in the *Water (Amendment) Act* 1980. Volumetric allocations were introduced in the Namoi region in 1983. These allocations were expressed in megalitres (ML) per hectare of irrigation, and % allocations were set with reference to the total volume of water for irrigation available in storage. Further amendments provided for the transfer of volumetric allocations of water attached to licences. In mid-1997 some irrigation licences were selling for as much as \$650000 (Wilkinson 1997).

The growth of irrigation raised some environmental issues, including increasing salinity, declining fish populations and a major outbreak of blue green algae. The New South Wales government moved to provide for environmental flows of water to maintain and restore surface water and groundwater systems (Smith 2000). A Namoi River Management Committee was formed in 1997 to make recommendations on environmental flow rules. The committee included representatives of irrigators, environmental groups, indigenous communities, local government politicians and government agencies (Pigram 2006).

6.3.2.2 Groundwater

As irrigation grew and demands on surface water supplies increased irrigators turned to groundwater as an important source of supply. The first production bores for cotton were developed in 1965. During the 1970s private development of irrigation bores was encouraged. A licence was required for each bore, but the licence was for the life of the bore, no volume or area limitations applied, and no water use figures had to be supplied or meters installed.

During the 1980-83 drought groundwater use increased sharply, exceeding 100 GL for the first time in 1982-83. In 1983 a total groundwater embargo was introduced for all irrigation and other high yield bores in the lower Namoi valley. Compulsory metering for bores and monitoring of allocation and use was introduced in 1984. An embargo was placed on the approval of new groundwater allocations in the more stressed zones in the upper Namoi Valley in 1985 (Williams et al 1998).

In the early 1980s New South Wales authorities allowed up to one third of aquifer storage to be depleted for a specified timeframe so that water users had time to recoup their large establishment costs. "Controlled depletion" allowed annual allocations and extractions in excess of groundwater recharge, anticipating that annual usage would not reach the allocation ceiling, and that wet years would recharge the groundwater system. It was not anticipated that groundwater use in some zones would surpass the average recharge on a regular basis (NGERP 1999)¹³².

Although average irrigation use was less than annual aquifer recharge, in drought years such as 1994-95, 2003-04 and 2006-07 average use was substantially above annual recharge. This prompted embargoes on new groundwater allocations in most of the upper Namoi. In 1997 the first groundwater management plan for the upper and lower Namoi valleys was released. This plan included a 10 to 35% allocation reduction to be phased in over three years.

In 1998 a study was undertaken on developing fair processes for the reallocation of groundwater for long term sustainability in the Namoi Valley (Nancarrow et al 1998).

¹³² The Namoi Groundwater Expert Reference Panel was appointed by the Minister in 1998 to advise the government on a process to move groundwater entitlements in the Namoi valley to within sustainable limits and on an appropriate structural adjustment package.

In late 1998 a Namoi Groundwater Management Committee was established to prepare further groundwater management proposals. Key developments in water management in the Namoi region from 1960 to 2000 are summarised in Table 6.2.

Table 6.2 Key developments in water management Namoi region 1960-2000

1960	Keepit Dam completed
1976	Embargo on surface water irrigation licences
1976	Linkages between surface water and groundwater availability and licences established under an informal conjunctive use policy
1980	Volumetric allocations for water introduced in the <i>Water (Amendment) Act 1980</i> ¹³³
1980	Moratorium on the issue of new groundwater licences
1983	Introduction of volumetric surface water licences
1983	Embargo on new irrigation and other high yield bores in the lower Namoi
1983	Volumetric groundwater policy introduced for groundwater management areas
1984	Groundwater meters made compulsory
1985	Formal conjunctive use policy introduced
1986	Temporary groundwater transfers introduced
1988	Split Rock Dam completed
1997	Conjunctive water licences withdrawn, replaced by separate groundwater licence allocations
1997	Establishment of Namoi River Management Committee
1997	First groundwater management plan for the upper and lower Namoi valleys
1998	Establishment of Namoi Groundwater Management Committee

6.4 Integrated water use and management in the Namoi region

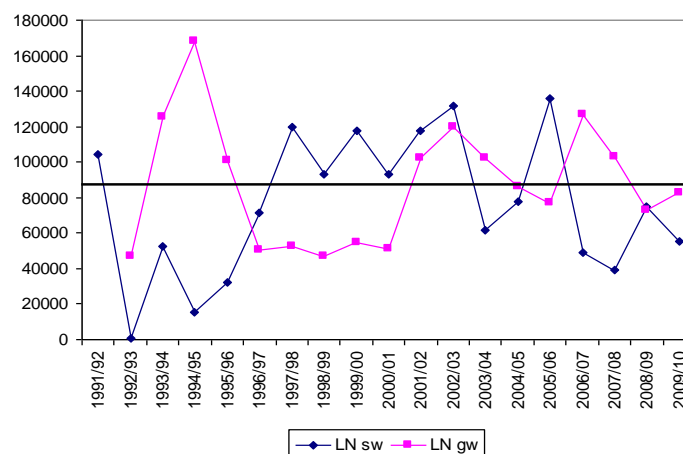
This section documents integrated water use in the Lower Namoi region and water trading in the Namoi and Peel catchments. The section continues with an investigation of two broad phases of integrated water management; conjunctive water use licensing from around 1980 - 1997, and water sharing plans implemented following the *Water Management Act 2000*.

¹³³ The *Water (Amendment) Act* was passed in 1977 but was not initially proclaimed. The legislation was passed again in 1980.

6.4.1 Integrated water use

Individual water users and organisations in the MDB make use of both surface water and groundwater over time in response to variations in water supply. The share of groundwater in total water use increases in dry periods and falls in wetter periods. Groundwater's share of total water consumption in the MDB varied between 9.3% in 2000-01 and 24.5% in 2006-07. In the Namoi region the periods of highest groundwater consumption have coincided with the lowest periods of surface water consumption.

**Figure 6.2 Surface water and groundwater use in the lower Namoi region
1991-92 to 2009-10**



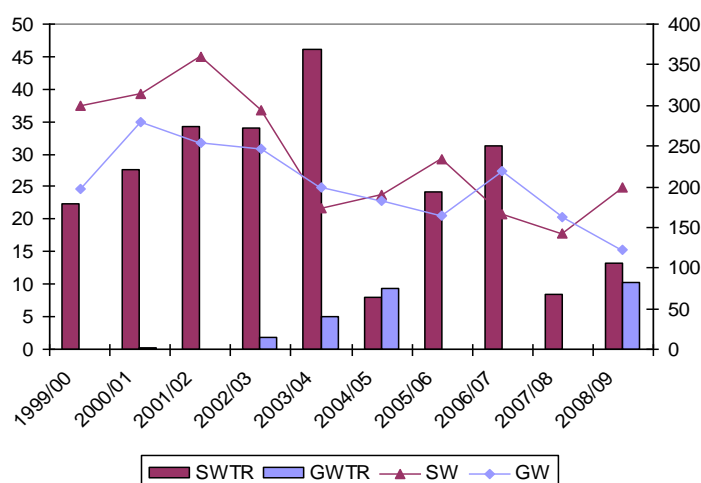
Source: NSW Office of Water.

Figure 6.2 shows surface water and groundwater use in the lower Namoi water management area (LN sw and LN gw) over the last 20 years with reference to the long term average groundwater recharge - the horizontal black line in the figure. Cyclical surface water and groundwater use is clearly evident, the periods of highest groundwater consumption generally coinciding with the lowest periods of surface water consumption. The imposition of the MDB cap on surface water diversions may have had some effect on relative preferences for surface water and groundwater, but the peaks in groundwater use in 1994-95, 2002-03 and 2006-07 were largely due to the unavailability of surface water.

6.4.1.1 Water trading

Figure 6.3 shows aggregate surface water and groundwater use (SW, GW) in the Namoi and Peel Catchments, plotted against water trading (SWTR, GWTR) during the period from 1999-00 to 2008-09 (in GL).

Figure 6.3 Surface water and groundwater trade: Namoi and Peel catchments



Sources: MDBC various, ABS (2006) Singh et al 2008 NWC (2010)¹³⁴.

The data series in Figure 6.3 shows that surface water trade tends to move in the same direction as surface water use (with a variable lag). The groundwater trading data is insufficient to be able to gauge the relationship between groundwater trade and use. There has been no recorded surface water groundwater trading in the Namoi region.

6.4.2 Conjunctive use licences and their impact

As the growth of the irrigated cotton industry led to increasing pressure on water resources during dry periods, surface water users were given access to groundwater in an ad hoc way until 1984 when a formal conjunctive use policy was adopted. A new class of conjunctive licences was introduced in NSW to provide more stable water supplies in regulated systems. These were essentially groundwater licences for which

¹³⁴ There are significant variations between the different sources of trading statistics, partly owing to different definitions and methods. Statistics on groundwater trading between 2005-06 and 2007-08 were not available from the above sources.

the groundwater allocation was inversely proportional to surface water availability i.e. it was increased in dry years.

Under a conjunctive licence, a surface water allocation which was not available in dry years became a (supplementary) groundwater allocation. Conjunctive licences were first issued in the Lachlan catchment in 1976 and were subsequently extended, first to the Namoi, Gwydir, and Border rivers, and later to the Macquarie, the Murrumbidgee and the Lower Murray (Fullagar et al 2006). About 1000 conjunctive licences were issued in New South Wales. It is estimated that there were about 60 conjunctive water users in the lower Namoi (about 40% of all irrigators) and about 30 in the upper Namoi (7% of irrigators) (Nancarrow et al 1998)¹³⁵.

In the lower Namoi valley conjunctive irrigators were allocated 6 ML per hectare of surface water from the Keepit Dam per irrigation year. This surface water allocation reduced in increments of 0.6 ML/ha for every 10% reduction in announced allocations (based on water in storage in the dam). The regulated surface water could be augmented by volume of groundwater according to a fixed scale of access. When the surface water allocation dropped below 100% users could access groundwater in increasing increments of 0.4 ML/ha for every 10% reduction in announced surface water to a maximum of 4.0 ML/ha at zero surface water allocation. This proved to be a useful drought mitigation strategy. Historically conjunctive users had close to 100% surface water reliability for 8 out of 10 years, and they could achieve high reliability in the remaining two years by using their groundwater component.

Following the establishment of the Murray-Darling Basin Cap, groundwater use entitlements were issued in excess of sustainable extraction limits in several major aquifers including those in the Namoi. Conjunctive water licences contributed to unsustainable levels of groundwater use in these aquifers, because they allowed extraction above long term average annual recharge during dry periods, but did not provide for offsetting aquifer replenishment at other times¹³⁶. Also they did not take account of environmental water requirements.

¹³⁵ These estimates are based on inflating the numbers included in the survey conducted by Nancarrow et al by the inverse of the percentage of properties included in the survey.

¹³⁶ Aquifer replenishment could come from surface water or groundwater entitlements. Replenishment from groundwater entitlements would reduce the security and stability of groundwater supply. Replenishment from surface water entitlements during "high inflow" years would smooth surface water

The conjunctive use strategy in the lower Namoi was not based on matching surface water and groundwater supply with demand, but on improving reliability of water supply when dam storages were lowered. It was assumed that groundwater would recharge during the (majority of) years when 100% surface water allocations were available. However, in practice sometimes there was not enough time between irrigation periods to allow reasonable groundwater level recovery to take place. This resulted in rates of decline in water levels in excess of 1 m/year in some zones, further exacerbated by continuous pumping by some landholders to irrigate winter crops.

Although the long term average use was not exceeding the estimated long term average recharge of 95 GL/year, use was much higher in drought years, for example in excess of 160 GL in 1994-95. Some areas of the region were experiencing dewatering of shallow aquifers due to large irrigation drawdowns; negligible water level recovery resulting in minor subsidence; changed groundwater flow characteristics; water quality changes; reduced yields in some bores; and access problems for shallow stock and domestic bores. The longer-term effects on groundwater availability and quality and on connected water resources and ecosystems were unclear (Kalaitzis et al 1998).

In 1997 conjunctive use licences were replaced by separate surface water and groundwater licences (and entitlements). Users kept their surface water allocation, and received groundwater entitlements equivalent to 2.11 ML/ha of authorised surface water area that they held (NSW Office of Water personal comm). This was equivalent to 70% of the long term average annual recharge, allowing for an environmental provision of 30% of recharge (Gates and O'Keefe 1999).

Individual integrated water use and management continued after the removal of conjunctive use licences, and conjunctive users were actively involved in negotiations of surface water and groundwater sharing plans under the New South Wales *Water Management Act 2000* (WMA). Conjunctive users have higher allocations and use than surface water or groundwater only users. In the negotiations of new water sharing plans they have favoured solutions giving preference to users with a strong history of use (Nancarrow et al 1998).

supplies and result in more equitable "burden sharing" between groundwater and surface water entitlement holders. Neither option was implemented.

6.4.4 Surface water and groundwater plans

The guidelines for water plans and planning processes in schedule E of the National Water Initiative provide that water plans should include “an assessment of the level of connectivity between surface water (including overland flow) and groundwater systems”. The New South Wales WMA includes a number of provisions relevant to the integrated management of surface water and groundwater resources - see Box 6.1. below.

Box 6.1 Extracts from the Water Management Act 2000 relevant to integrated management of surface water and groundwater

Division 1 Water management principles s5

(2) (d) the cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised

(3) (a) sharing of water from a water source must protect the water source and its dependent ecosystems (recharge is defined as one of the activities for maintaining dependent ecosystems)

(4) (c) the impacts of water use on other water users should be avoided or minimised

Division 3 Water use

23 (b) the identification of those uses and activities which have adverse impacts, including cumulative impact, on water sources or their dependent ecosystems or on other water users

24 (b) prevention of off-site impacts of water use

Division 6 Controlled Aquifer Activities

32 (a) identification of the nature of any controlled activities or aquifer interference causing impacts, including cumulative impacts, on water sources or their dependent ecosystems, and the extent of those impacts

33 (d) the preservation and enhancement of the quality of water in the water sources in the area affected by controlled activities or aquifer interference

34 (a) a) provisions identifying zones in which development should be controlled in order to minimise any harm to water sources in the area or to minimise any threat to the floodplain management provisions of the plan

In short, the above provisions require that the impacts of the use of each water resource on other water resources, users and ecosystems should be avoided or minimised.

Neither the NWI or the WMA explicitly provide for integrated management of surface water and groundwater to optimise the use of both resources collectively, for example by means of cyclical water storage and use¹³⁷.

New South Wales mirrors the basin wide situation concerning the integration of surface water and groundwater plans. Separate surface water and groundwater plans have been prepared for priority catchments and water management units. There are very few integrated plans - the Peel Valley Plan is one of them (see below).

The following sub sections briefly examine key elements of three water sharing plans; one surface water plan and one groundwater plan covering the upper and lower Namoi regions, from the first phase of WSPs, and one integrated macro plan for the Peel Valley from the second phase. These plans include water use limits and rules that mitigate the impacts of water uses on the other water resources and users. The plans rely on long term use limits to address the impact of cumulative use and indirect impacts. They include more specific use limits and rules (e.g. shares of available water, volumetric limits, cease to pump rules) to address the direct impacts of use on the resource (eg river flow, aquifer levels) and the environment. However they do not include provisions to improve water storage or water quality¹³⁸.

6.4.4.1 Upper Namoi and Lower Namoi Regulated River Water Sources

The Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources was gazetted in 2003 (New South Wales Government 2004)¹³⁹. The plan was based on 1999-2000 development conditions, infrastructure and management rules¹⁴⁰. The long term annual average extraction limit (LTAAEL) set in the Namoi Water Sharing Plan is based on the average diversion limit, currently estimated to be 238 GL/year¹⁴¹. The 238 GL/year limit to the LTAAEL ensures that approximately 73% of

¹³⁷ Additional details about integrated water planning in New South Wales can be found on chapter 4, section 4.2.3.

¹³⁸ Water quality issues are addressed in catchment management plans such as the Namoi Region Catchment Action Plan <http://www.namoi.cma.nsw.gov.au/931351.html?5> accessed 17 February 2012.

¹³⁹ <http://www.legislation.nsw.gov.au/viewtop/inforce/subordleg+179+2003+FIRST+0+N/> accessed 10 September 2011.

¹⁴⁰ Surface water licences under the Water Act 1912 were converted into a water access licence (with the same volumetric allocation as the old licence) and a combined water supply work and water use approval. Annual allocations under both the old licences and the new licences depend on water in storage before the irrigation season (Office of Water 2010).

¹⁴¹ The long term average annual extraction figure is calculated by using the NSW government's IQQM model, assuming the long term average annual extraction that would occur with the water storages and

the long term average annual inflow in these water sources will be preserved and will contribute to the maintenance of basic ecosystem health¹⁴².

Most irrigators hold general security access entitlements and supplementary water access entitlements. General security access entitlements are supplied from releases from Split Rock and Keepit dams. The majority of the remaining surface water resource flows are provided for environmental flows.

Supplementary water is made available for consumptive use when heavy rainfall events lead to dam spills and high channel flows. Supplementary water provides a large proportion of irrigation water during dry years. Prescribed rules include:

- thresholds for extraction of uncontrolled flows; and
- limits on the amount of supplementary flows that can be extracted, namely either 10 or 50% of the volume of each uncontrolled flow event (percentage limit depends on the time of year).

Landholders are allowed to harvest flows on floodplains originating from run-off that has not reached a river or water that has overflowed the banks of the river¹⁴³. They are allowed to harvest and store up to 10% of average regional run-off on their property. Landholders have constructed a variety of banks, channels and storages to retain these overland flows. The New South Wales government has proposed a new floodplain harvesting extraction policy including the management of floodplain harvesting within the LTAAELs of existing water sharing plans, and the proposed Murray-Darling Basin plan. Floodplain harvesting will require a works approval and water extraction licence¹⁴⁴.

Groundwater recharge and groundwater dependent ecosystems receive some de facto protection from the plan provisions to protect environmental flows, because some of these flows recharge groundwater. However the plan does not contain explicit

water use development that existed in 1999/2000, the share components existing at the commencement of the plan and application of the water management rules defined in this plan.

¹⁴² Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources 2003 Part 3 s 14 and Part 8 s 30. The IQQM model includes inflows, storage, consumptive and wetland uses, water sharing rules (including the MDB Cap) and outflows.

¹⁴³ http://www.ruralresidentialliving.com.au/water/resource_downloads/farms_dams/What%20are%20rural%20landholders%27%20basic%20rights%20to%20water_print.pdf accessed 19 December 2011.

¹⁴⁴ <http://www.water.nsw.gov.au/Water-management/Law-and-policy/Key-policies/Floodplain-harvesting/Floodplain-harvesting/default.aspx> accessed 19 December 2011.

provisions to protect groundwater resources or groundwater dependent ecosystems from the impact of surface water use.

A water allocation account is kept for each access licence. Water is credited to the account when an available water determination is made, or when water allocation is transferred into the account from another access licence. The account is debited when water is released from storage, extracted or assigned to another access licence. Any water that remains in an account at the end of each water year is forfeited. The account receives a new allocation of water in the next water year. The limit to available water determinations for these access licences is 100% or 1 ML per unit share.

The water allocation accounts for general security access licences provide some flexibility for water users to reduce year-to-year variations in water availability. In the Upper Namoi, extraction of uncontrolled flows without debit to the account is permitted when the sum of available water determinations is equal to or less than 0.6 ML per unit share (further restrictions also apply – see below). In the Lower Namoi, “carry over” is allowed of any water remaining in the account from one water year to the next. The maximum volume that may be held in the water account of a general security access licence is 2 ML per unit share. The maximum volume that may be extracted under a general security access licence or assigned from it in any water year is limited to 1.25 ML per unit share, or 3 ML per unit share over any consecutive 3 years. These limits can be increased by water allocations assigned from another access licence.

6.4.4.2 Upper and Lower Namoi groundwater resources

A Namoi Groundwater Sharing Plan was developed during the period 2001-2003, taking into account economic impacts of reduced groundwater use (Wolfenden and Van der Lee 2002). The 2003 water use reduction proposals were based on a 100% long term annual average recharge less an allowance for environmental health (approximately 30%)¹⁴⁵ The Water Sharing Plan for the Upper Namoi and Lower Namoi Groundwater Sources 2003 was issued in 2006 (NSW Government 2006).

¹⁴⁵ The estimate of the long term rate recharge for the lower Namoi is based on a relatively sophisticated multilayer model of the underlying aquifers. Overlying rivers and streams provide the largest component of aquifer recharge, almost double direct recharge from floods and rainfall combined. The share of

Irrigators were issued with a new groundwater licence that entitles them to a share in the groundwater resource. Separate licences were issued for stock and domestic, local water utilities, and irrigation (aquifer access and supplementary access). These licences provide increased security by means of a perpetual right to access groundwater and are fully tradeable. Aquifer access licences generally receive an annual allocation of 1 ML per unit share. However, owing to previous overallocation of groundwater, the entitlement attached to the old (irrigation) aquifer access licences received a one-off reduction of 51% in the Lower Namoi and by 61% in the Upper Namoi.

Supplementary access licences were provided to the high use irrigators to help them make the transition to lower levels of entitlements. These supplementary access entitlements are being phased out over 10 years. An Achieving Sustainable Groundwater Entitlements Program (ASGEP), jointly funded by federal and NSW governments and water users, is providing financial assistance to help irrigators make the transition during which supplementary entitlements in excess of the LTAAEL are to be phased down to zero.

Each aquifer access license has an account. Some carry over of unused allocations is allowed in these accounts. There is an account limit of 3 ML per unit share so that any water carried over into the account in excess of this limit is forfeited. There is also a limit of 2 ML per unit share that can be debited from this account in one water year. This includes water that is traded out¹⁴⁶. There is no carryover of allocation for stock and domestic, local water utility and supplementary water access licence accounts.

Water licence holders were strongly critical of the process for developing the Namoi Groundwater Sharing Plan. The main argument was about whether entitlement reductions should be equalised "across the board", or adjusted in favour of irrigators who had developed their enterprise and were regularly using more than their reduced entitlement (active users) compared to those who used little or none of their entitlement (inactive users). There were also questions raised about the definition of sustainable

rainfall is relatively insignificant. Returns from irrigation are not included in the model (Kelly et al 2007).

¹⁴⁶ For example, an Aquifer Access Licence with a share component of 100 units may hold up to 300 ML in the account but can only pump and trade to a combined total of 200 ML in one water year. A volume greater than 2 ML per unit share may be taken from the account if additional allocation is assigned to the account by a temporary transfer.

extraction (based on estimated annual average recharge), and the allowance for environmental purposes. Some stakeholders criticised the procedural fairness of the process, and a number of users took legal action against the government (Kuehne and Bjornlund 2006).

In May 2006, following prolonged consultation, the Namoi Catchment Management Authority representing discussions by regional stakeholders recommended that entitlement reductions should take account of historical use, with a 75%-25% weighting between active and inactive users (Department of Natural Resources, 2005). This WSP commenced in 2006¹⁴⁷ and specifies a long term average annual extraction limit of 208.1 GL/year for the Lower and Upper Namoi aquifers (DIPNR, 2006). The volume of the Supplementary Licences¹⁴⁸ was set at a total of 59.08 GL/year at the commencement of the plan and reduces annually to zero by 2014. The plan indicates that environmental provisions will be met from aquifer storage minus supplementary groundwater water access licences (see below).

The physical water contained in the storage component of the groundwater in the lower Namoi groundwater source and zones 1 to 12 of the upper Namoi groundwater source, minus the amounts required for supplementary water access are reserved for the environment. This is called planned environmental water. Water may also be committed for environmental purposes by the holder of an access license. This is called adaptive environmental water¹⁴⁹.

The water sharing plan for the upper and lower Namoi groundwater resources contains a number of provisions to limit any adverse impacts of groundwater pumping. These include restrictions on constructing new bores near wetlands or rivers, and measures to protect groundwater dependent ecosystems and groundwater quality. These restrictions and measures offer some incidental protection to surface water flows, although the plan does not include explicit provisions to systematically protect surface water resources or ecosystems from the impacts of groundwater pumping. The plan includes performance target 10; to assess the degree of connectivity between aquifers and rivers, and to map

¹⁴⁷ <http://www.legislation.nsw.gov.au/viewtop/inforce/subordleg+1035+2002+FIRST+0+N/> accessed 10 September 2011.

¹⁴⁸ These supplementary groundwater licences under the AGSE should not be confused with the supplementary surface water licences that allow supplementary water to be taken following dam spills and high channel flows.

¹⁴⁹ Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources Part 4, s 18 and 20.

zones of high connectivity to enable baseflows to the river to be maintained or improved. A review of groundwater dependent ecosystems is being undertaken in the first five years of the plan and there are mechanisms in the plan to change the environmental rules as a result of that review.

6.4.4.3 Peel Valley Water Sharing Plan

The water sharing plan for the the Peel Valley Regulated, Unregulated, Alluvial and Fractured Rock Water Sources was gazetted in 2010 (NSW Government 2010)¹⁵⁰. The Peel Valley WSP includes different sets of rules to manage to manage water resources with varying degrees of connectivity¹⁵¹. This makes the plan quite complicated. Table 6.3 shows the highly connected water resources in the Peel Valley.

Table 6.3 Highly connected water resources in the Peel valley

<i>Connected Water Sources</i>	<i>River flow and gains/losses</i>
Peel regulated river and Peel regulated river alluvium	Flows 100% of the time. Regulated losing stream over most of its length
Cockburn river and Cockburn river alluvium	Flows more than 90% of the time. Unregulated stream with gaining and losing sections
Dungowan Creek and Goonoo Goonoo Creeks and Dungowan and Goonoo Goonoo Creek alluvia	Flow 85 to 90% of the time Unregulated stream with gaining and losing sections

The plan makes provision for environmental water based on long term average annual rainfall recharge. For the Peel alluvium the environmental share is 54%. For the Peel fractured rock resource it is 50%. The plan sets a long term annual average extraction limit (LTAAEL) for each water source as long term management indicator against which total extractions can be monitored and managed. All other water in the water source is set aside for environmental needs. Response to growth in use is based on the LTAAEL. For the Peel regulated river source the LTAAEL is based on computer

¹⁵⁰ <http://www.legislation.nsw.gov.au/sessionalview/sessional/subordleg/2010-134.pdf> accessed 10 September 2011.

¹⁵¹ There are 15 water sources in the Peel Valley, 7 surface water and 8 groundwater. Of those 4 surface water sources are highly connected to 4 groundwater resources. These resources are shown in table 6.3.

modelling. For the Peel fractured rock water source the LTAAEL is based on a groundwater risk assessments and classification process. For the other water sources the LTAAEL is based on historical average annual extraction over a selected seven-year period. A growth restriction is applied if the LTAAEL is exceeded by 15%. The available water determination (AWDs) are linked to the LTAAEL¹⁵². Available water determinations combined with carryover enable licence holders to use up to twice their water allocation in a year provided that over a consecutive three year period they do not exceed the sum of their water allocations for those three years..

In addition to long term management rules, environmental flow protection rules known as “cease to pump rules” are established to control licence pumping in unregulated surface water sources when stream flows drop below a specified level at either the pumping site or a relevant flow reference point. Daily access rules govern when licence holders can extract water. Generally licence holders cannot pump when there is no visible flow at their pump site. Flow classes are applied in response to in stream values and hydrologic stress. Buffer distances for new and replacement bores have been established to protect groundwater dependent ecosystems from the impact of groundwater extraction. Licensed water can be committed for adaptive environmental water purposes (NSW Government 2010 b).

6.4.5 Surface water and groundwater management organisation

The policy framework for water management in the Namoi region is established by the Council of Australian Governments and the Murray-Darling Basin Council. But there are only a small number of staff in Australian Government agencies who have any knowledge of or responsibility for groundwater management, which is largely left to the States. The Murray-Darling Basin Authority includes a small groundwater unit, but policy development is primarily oriented to surface water. The New South Wales State government has the primary responsibility for managing water in New South Wales.

¹⁵² Generally the AWD for unregulated river access licences and aquifer access licences will be one ML per unit share except in the first year of the plan when an AWD of 200% of the share component (or 2 ML/share) will be made. This allows 3 year accounting rules to operate from year 1 of the plan. The AWD for aquifer access licences in the Peel regulated river alluvium is 0.51 per unit share plus 49% of the AWD for the regulated river, to reflect the fact that on average 49% of water taken from the alluvium originates as recharge from the regulated river.

Water management in New South Wales is highly centralised in the hands of the Minister for Regional Infrastructure and Services and the Office of Water in the Department of Primary Industries DPI. The Office of Water carries out policy advisory and planning functions. Surface water and groundwater policy and planning functions are joined at the highest level of decision making. Otherwise they are separate but coordinated. Technical and implementation functions are often carried out separately. Regional staff at Tamworth and Narrabri are responsible for analysis, liaison, monitoring, metering, inspection and compliance.

The Water Management Act (s14,15) provides for a consultative and participative process of policy and plan development. Plans are prepared by management committees that include statutory representation for various interest groups¹⁵³. Management committees are advisory, they have no statutory powers. In NSW the government makes the draft plan, which is then put out for a standardised communication and consultation process. There is no special provision for comments by users, although users are represented on management committees. Extensive consultation can be very slow and expensive, and does not guarantee representation of every point of view or agreement between stakeholders. Consultation often appears more symbolic than real, because it takes place after policy changes have been made and/or does not take sufficient account of stakeholder views (Bowmer 2003).

In practice the Minister often intervenes, and makes a Minister's plan when management committees cannot agree on water allocations. The NSW Court of Appeal has upheld the statutory application of Minister's plans, but in the case of the Upper and Lower Groundwater Management Plan 2003 the Minister's intervention was challenged on the grounds of procedural fairness (Gardner et al 2009). While the Minister's intervention was necessary to break the negotiation deadlock, active participation of water users was needed to come up with an acceptable formula for reducing groundwater entitlements. A wide range of management organisations and representative bodies are involved in water management in New South Wales. These include New South Wales government departments and agencies, water management committees, the Water Advisory Council, catchment management authorities, the State Water Corporation,

¹⁵³ Representation includes at least 2 environmental protection; 2 water user groups; 2 local council; 1 catchment management authority; 2 aboriginal representatives; 1 Departmental staff representative; and 1 person nominated by the Minister.

irrigation corporations, private irrigation districts and industry and environmental representative groups. Further details are provided in Box 6.2.

Box 6.2 Water Management Organisations in NSW

The Minister for Primary Industries has the primary responsibility for the management of NSW water resources. The Minister's functions and duties include implementing national agreements and policies, developing and implementing water plans, administering and enforcing access licenses and water use approvals and distributing water.

The Office of Water in the Department of Primary Industries carries out many of the Minister's functions including the development of water policy and plans and the administration, monitoring and enforcement of access licenses and water use approvals.

Water management committees (WMCs) are established by the Minister to prepare and/or provide advice about water management plans. These committees include between 12 and 20 members appointed by the Minister. They include representatives of environment protection groups, water users including irrigators, local councils, aboriginal groups, catchment management boards, departmental representatives and a nominee of the Minister.

Community Advisory Committees (CACs) are similarly constituted to WMCs but have a purely advisory role. Most committees established to develop draft management plans have been constituted as CAC's.

The Water Advisory Council is the peak advisory group that advises the Minister on water resource management, water management reform and the development of water resource policy. It has similar membership to WMCs.

Catchment management authorities are established under the Catchment Management Act 1989 or the Catchment Management Regulation 1999. They are established to promote a healthy and productive catchment by identifying critical opportunities, problems and threats associated with the use of natural resources, and identifying objectives, targets, options strategies and actions to manage natural resources including water.

State Water Corporation is New South Wales' rural bulk water delivery business. State Water owns, maintains, manages and operates major infrastructure to deliver bulk water to approximately 6300 licensed water users on the state's regulated rivers along with associated environmental flows.

Irrigation corporations are privately owned organisations that own and operate water supply infrastructure for the provision of water to shareholders in irrigation districts. Irrigation corporations receive water under a bulk entitlement licence from the Office of Water.

Private irrigation districts and private drainage districts are legal entities established under the WMA 2000. They are constituted by landholders for the construction, maintenance and operation of water supply works and water drainage infrastructure. Namoi Water is the peak industry group for irrigated agriculture in the Peel, Upper Namoi and Lower Namoi Valleys. Namoi water covers 60-70% of all water users.

Source: Productivity Commission 2003

Regional catchment based management bodies have been created to provide an institutional mechanism linking state and local activities, using a consultative approach and supporting the activities of local groups (Curtis and Lockwood 2000). Catchment management organisations represent an interesting innovation to integrate policy at the regional scale. They have responsibilities for land and environmental conservation and water quality but not for water allocation.

The effectiveness and resourcing of these bodies, including the Namoi CMA, is constrained by limited personnel and budgets (Robins et al 2007). Experience in the Namoi and elsewhere illustrates the importance of clearly defining roles and responsibilities for organisations at all levels, and following this through with leadership that ensures diverse stakeholder participation, and builds capacity within regional bodies (Bellamy *et al.* 2002).

Government representatives generally consider that policy and implementation functions are coordinated effectively. The Office of Water endeavours to consult stakeholders, and take account of their views. They also endeavour to coordinate water planning processes with CMA plans to achieve public benefits. However, according to interviewees some functions are poorly integrated with water management. Examples include lack of clarity about rules for environmental water, difficulties in integrating management of overland flows and stock and domestic bores, and separate management of irrigation and mining water. Concerns were raised about State Water's unilateral decision making about water releases, and lack of consultation on how releases may be made to achieve public benefits¹⁵⁴.

6.4.5.1 Information

Although the Namoi region benefits from good historical data on water inflows and groundwater levels, there are substantial gaps in data about groundwater surface water connectivity, groundwater inflows, recharge and discharge, evapotranspiration, and surface water storage losses (Kelly et al 2007). These information deficiencies suggest that the water use limits established under water allocation plans need to be flexible

¹⁵⁴ State Water Corporation (State Water) is New South Wales' rural bulk water delivery business (further details Box 6.2).

with scope for periodic adjustment during the life of the plan. Moreover the NWC found in its 2005 assessment of water reform progress that the ecological information in water sharing plans was often too generic and not sufficiently detailed about specific catchments to enable planning committees to determine flow requirements needed to maintain ecosystem health (NWC 2005).

The Department of Primary Industries has lead responsibility for ensuring that water plans reflect the best available scientific knowledge as required by the National Water Initiative. However, there is no clear statutory duty imposed on the person preparing a water plan to undertake scientific research to ascertain ecological requirements of the water system (Gardner et al 2009 314). Some users complain that data is not easily accessible to users. For example, state agencies do not systematically share data with other stakeholders on groundwater conditions such as quality or availability in areas regulated under Water Sharing Plans, largely because of limited staff and budgets.

Management of local hotspots of resource overuse or degradation is a major problem. Authorities intervene to resolve issues, but interviewees mentioned that criteria are often unclear and users cannot anticipate interventions. Moreover, engagement of users (farmers) does not persist beyond the planned development stage, and farmer participation groups become dormant (Holley and Sinclair 2011). Finally, the measurement of water extraction is not straightforward and there are insufficient staff for inspection and a meter reading despite assistance from a national metering program. Most large irrigation bores in regulated systems are metered, users know each other and check on each other, but metering is less effective in unregulated systems.

6.5 Factors affecting integrated water management in the Namoi region and opportunities for improvements

6.5.1 Opportunities for more adaptive, integrated water management

Water users and managers in the Namoi region face significant challenges in managing water supply variability and uncertainty. In the upper and lower Namoi regulated rivers area and the lower Namoi groundwater area supply variability is reduced by Keepit and

Split Rock Dams, and by the integrated use of surface water and groundwater.

Supplementary flows from high rainfall events provide an additional source of supply.

In the unregulated river valleys surface water flows are much more variable.

Groundwater provides the only stable source of supply.

Rural producers and communities can adopt many strategies to manage water supply variability and uncertainty (Halstead and O'Shea 1998, Agrawal 2009). These include:

- a) diversification of sources of water, products or sources of income;
- b) improvement of water storage;
- c) using markets, insurance and trading to mitigate the impact of variability;
- d) sharing investments in infrastructure, skills and training or droughts and flood preparation; and
- e) moving to a place not threatened by water shortages.

The first four of the above strategies overlap with and can be pursued through options for integrated water management:

- cyclical or alternating use of surface water and groundwater;
- water carryover and banking;
- use of non traditional sources of supply;
- aquifer storage and recovery;
- surface water and groundwater trading; and
- better management of infrastructure.

These options are discussed in the following section.

6.5.1.1 Cyclical water management and carryover

Cyclical integrated water management offers the possibility of using a higher proportion of surface water and recharging aquifers during wet periods, and using a higher proportion of groundwater and drawing down aquifers during dry periods.

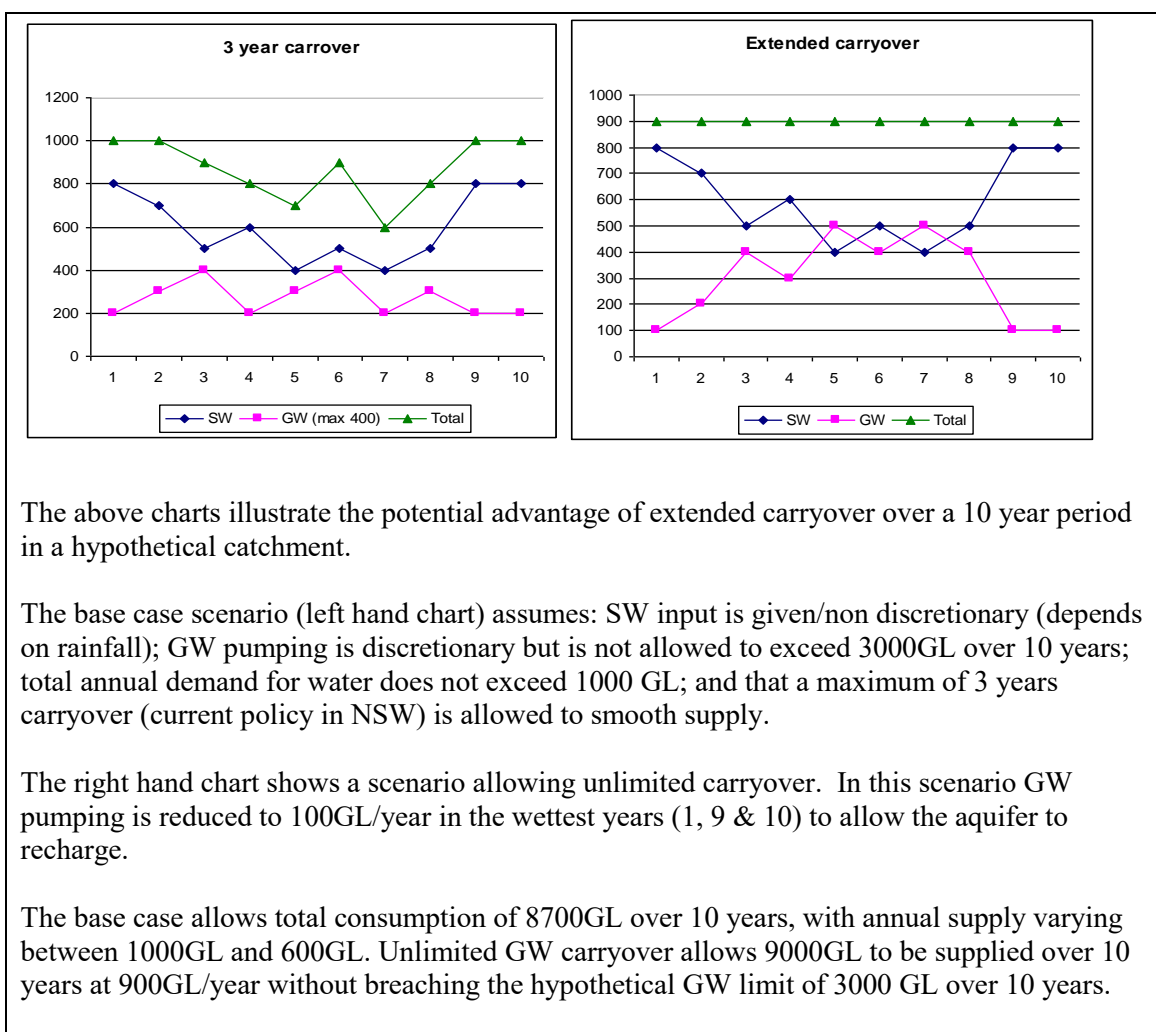
Carryover allows water users to delay the delivery of water allocations to manage supply variability. Extended carryover enables water supply variability to be smoothed,

with slightly greater aggregate water supply over time by utilising larger peaks and troughs in groundwater use without breaching long term groundwater use limits.

Carryover is restricted in the MDB jurisdiction. For example in New South Wales cyclical management of surface water and groundwater is limited by surface water and groundwater carryover rules. Carryover is limited within three year accounting periods and the maximum carryover is three years.

This limits the scope to conjunctively manage surface water and groundwater over the wet dry climatic cycle that often lasts for over five years. Extension of carryover periods would allow water users to use surface water and groundwater more flexibly over the typical 5-7 year wet and dry climate cycle¹⁵⁵ – see Box 6.3.

Box 6.3 Illustrative example of extended carryover

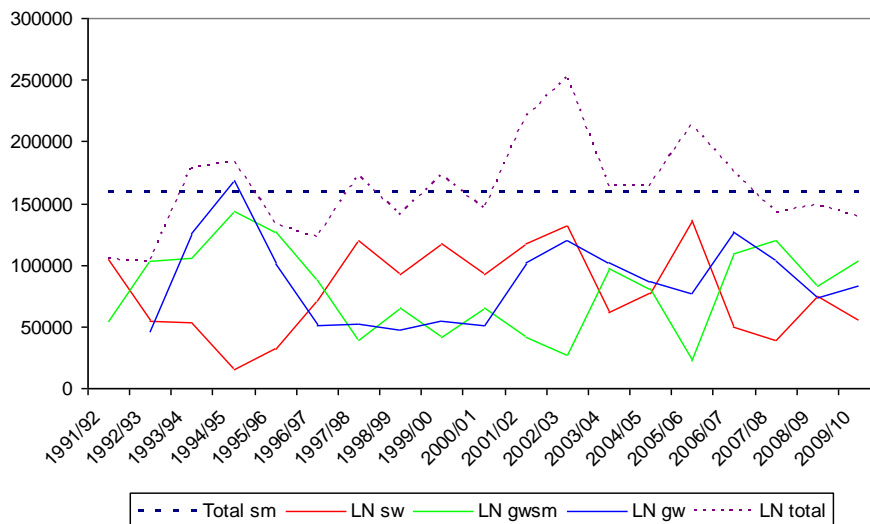


¹⁵⁵ In the MDB the wet dry cycles typically coincides with the El Niño La Nina cycle, 5-7 years (REF).

Figure 6.4 shows how fairly modest changes in the phasing of groundwater use through time could smooth out irregularities in overall water use. Surface water plus groundwater use in the Lower Namoi region during the period 1991-92 to 2009-10 is shown by the purple dashed line, the hypothetical smoothed amount is shown by the horizontal black dashed line. A hypothetical groundwater use (green line), which acts to smooth total water use, fluctuates somewhat more than the actual groundwater use (blue line). Surface water use is shown by the red line. This degree of flexibility in the hypothetical groundwater use could not be achieved without more flexible carryover for periods longer than three years.

Extended carryover is worth further examination but care needs to be taken to ensure that adequate supplies are available to service regular users as well as meeting demands for carryover water. Consideration also has to be given to environmental watering requirements for pulsed flows over seasonal and multi-year periods. River and floodplain connection may best be achieved by saving environmental water for several years. Dam capacity, spill management and aquifer storage may be needed as part of an integrated strategy (Thomas 2001).

Figure 6.4 Surface water and groundwater use in the lower Namoi with and without extended carryover



The availability of supplementary water coupled with unregulated floodplain harvesting and large on-farm surface water storages provides some flexibility for irrigators to adapt

to water scarcity. This approach is less than ideal for two reasons. Firstly floodplain diversions reduce the amount of natural flow, leading to degradation of floodplains and the environment. Secondly there is a great deal of evaporative loss from surface water storages.

Studies indicate that around 4000 GL evaporated from surface water storages in the MDB in 2009-10, 1000 from on-farm storages and 3000 from large storages, see Box 6.4. Evaporation from water storages is one of the biggest barriers to increasing water use efficiency especially in the northern basin. Current arrangements encourage surface water storages rather than underground storage. Aquifer storage and recovery has been contemplated but has not been developed¹⁵⁶.

Box 6.4 Evaporation from water storages in the Murray-Darling Basin

Water storages in the MDB can be divided into two categories farm storages and large storages (reservoirs).

The evaporative loss from farm storages is calculated by estimating the storage volume and then multiplying that by the number of storages with water in them and an evaporative loss fraction. The storage volume is estimated to be 3400 GL, 2600 GL in floodplain storages, mainly in NSW and Queensland (SKM 2010) and 800 GL in farm dams. The volume of farm dams is estimated by combining information from an estimate of farm dams in Australia (SKM 2010) and an estimate of farm dams in the MDB (CSIRO 2008)¹⁵⁷.

Annual evaporation loss from farm storages is estimated to be 1020 GL. This is calculated by multiplying the storage volume (3400 GL) by an evaporative loss fraction (30%) and the number of storages with water in them.

The evaporative loss fraction is estimated at between as 20-40% (Baillie 2008), an average of 30% has been assumed. It is also assumed that 100% of storages have water in them. This is optimistic, and the average for farm dams may be 50% or less, especially in dry years. On the other hand the number and volume of farm dams is likely to be a substantial underestimate.

The evaporation from large surface water storages¹⁵⁸ in the MDB was estimated using monthly open water evaporation data produced by the Bureau of Meteorology, in conjunction with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), as part of the Australian Water Availability Project (AWAP). Further details are given in Bureau of Meteorology pilot water account¹⁵⁹.

¹⁵⁶ NSW Office of water – personal communication.

¹⁵⁷ SKM 2010 estimate 1460 GL in Australia. CSIRO 2008 estimate 2164 in MDB. CSIRO estimates include on-farm storages >5ML, SKM exclude farm dams > 5 ML. SKM compare their estimates with CSIRO in several catchments in Victoria and one in New South Wales. This enables CSIRO MDB estimate to be adjusted pro rata – $207/547 \times 2164$ = about 800.

¹⁵⁸ Storage volumes in 2009-10 ranged from 29 ML at Pine Lake to 872,388 ML at Lake Alexandrina.

¹⁵⁹ <http://www.bom.gov.au/water/nwa/2010/mdb/notes/fullNotes/was/14.1> accessed 22 February 2012

6.5.1.2 Aquifer storage and recovery

Underground storage could substantially reduce evaporative losses. Aquifer storage and recovery could also be used to provide holding storage for dam spills, conveyance water and floods.

The key requirements for aquifer storage and recovery are availability of surplus surface water and means to convey it, aquifer storage space, and proximate sources of demand. Other conditions which support aquifer storage and recovery include proximity of rivers, irrigation areas and urban areas, aquifer size and permeability, and acceptable water quality. Hostetler (2007) includes an initial assessment of the suitability of areas across Australia for "water banking" (undergroundwater storage). According to this assessment, the Namoi region is highly suitable for undergroundwater storage.

There are a number of opportunities for using managed underground storage (managed aquifer recharge) to benefit agriculture. At a meeting with regional managers and water users, it was suggested that underground storage of high flows and locally captured runoff, and (re)regulation of river flows may be worth further investigation in the Namoi catchment.

High flows sometimes occur during winter months in the Namoi owing to high precipitation events leading to high flows from tributaries or reservoirs to the Namoi or Peel Rivers. Managed underground storage may reduce evaporation, and provide an alternative relatively low cost storage option. Managed underground storage also provides a means of reregulating water supplies to better align water delivery with demand¹⁶⁰. Currently water delivery orders cannot be varied easily owing to the lack of en route storage and reregulating capacity. Managed underground storage may cater for some or all of en route storage needs.

Underground storage in Angus Bremer and Barossa Valleys in South Australia, and the Burdekin Delta and Pioneer Valley demonstrates the potential of aquifer storage and recovery. There have been a number of studies of potential for aquifer storage and recovery in the Namoi region. Williams (1984) recommended four sites for a pilot

¹⁶⁰ Reregulation of reservoir supplies in conjunction with underground storage is being trialled in Northern California (Thomas 2002, 2008).

artificial recharge trial. Ross et al (1991) suggested the construction of floodways and levies in irrigation districts had increased the potential for artificial recharge during flood events. In the mid 1990s artificial recharge trials were conducted in the Namoi Valley by the Department of Water Resources (Jiwan et al 1995) but were not continued due to lack of shallow aquifers suitable for surface infiltration¹⁶¹, and the infrequency and unpredictability of high flows.

It would be useful to conduct further trials of aquifer storage and recovery. Three barriers need to be overcome. Firstly, there is no legal and administrative regime to enable underground storage of water and subsequent recovery. Groundwater enters the “common pool” once it is underground, and can be accessed by anyone with a use licence. Current NSW policy does not recognise any ownership of artificially recharged volumes. Clear ownership and accurate measurement and accounting of stored volumes would be required – taking account of experience with managed aquifer recharge in South Australia (see section 4.3.5), and the guidelines now being trialled in Victoria (see section 4.3.4). Secondly, water releases are not planned to optimise water supply phasing and delivery using intermediate storages, including aquifer storage. Thirdly, underground storage requires infrastructure such as percolation areas or injection wells. While the costs of underground storage vary from case to case, these projects are likely to require some collaboration between farmers and governments.

6.5.1.3 Surface water groundwater trading

In theory surface water groundwater trading could provide a smoothing (or drought adjustment) mechanism. Surface water entitlements could be exchanged for groundwater entitlements in dry periods, and the reverse exchange could occur during wet periods so that groundwater can be recharged. Trading surface water and groundwater entitlements is relatively less complicated when surface water and groundwater resources are highly connected and where connections are rapid. When resources are less highly connected and/or the connections are slow the impact of trading is more complicated and/or more uncertain. Moreover surface water groundwater trading is constrained by the different properties and availability of surface water and groundwater, restrictions on carryover and the lack of development of surface water groundwater trading rules. It may be worth examining opportunities for surface

¹⁶¹ Infiltration into shallow aquifers is a relatively simple method of aquifer recharge, but in highly connected surface water and groundwater systems much of the recharge may return to connected streams.

water groundwater trading when both resources are underexploited or large, and therefore insensitive to additional use, providing that the risks of damage to key environmental assets and ecosystems are small.

6.5.1.4 Use of non traditional sources of supply

Recycled water is already being used in the Namoi region. In the Peel Valley it is reported that 30% of sewerage is recycled. Tamworth City Council is open to water recycling but state regulations prevent treated effluent being put in the river. There are two cases of using treated effluent for recharge: Gunnedah and Narrabri. There may be further opportunities to use sewage effluent and stormwater runoff from towns for irrigation. Also it might be possible to exchange such resources on a seasonal or longer-term basis for surface water and groundwater entitlements held by agricultural producers¹⁶³.

6.6 Conclusions

Water users, notably irrigators in the Namoi region have used surface water and groundwater conjunctively to improve water use efficiency and smooth supply in response to climatic variation.

Apart from an unsuccessful experiment with conjunctive water licensing, the New South Wales government has generally pursued a policy of separate surface water and groundwater planning and management.

There are several opportunities for improving integrated water management that are worth investigating. These include cyclical integrated water management with extended carryover arrangements, trials of aquifer storage and recovery – possibly in conjunction with recycled water supplies – and further investigation of surface water and groundwater trading.

¹⁶³ Rural to urban leases and exchanges are widely practised in Colorado and California.

Chapter 7 Integrated Water Management: Case Studies from Colorado and Idaho

7.1 Introduction

This chapter examines integrated surface water and groundwater management in the South Platte Basin in Colorado and the Eastern Snake Plain in Idaho. The chapter begins with a description of the biophysical, socioeconomic, legal and institutional context of integrated water management in the South Platte Basin and Eastern Snake Plain. This is followed by an analysis of integrated water management and management organisation in each of the two regions. The chapter ends with a comparative assessment of governance arrangements that have influenced integrated water management in the two regions, together with opportunities for integrated water management.

7.2 South Platte Basin, Colorado

7.2.1 Context

7.2.1.1 Biophysical and socioeconomic context

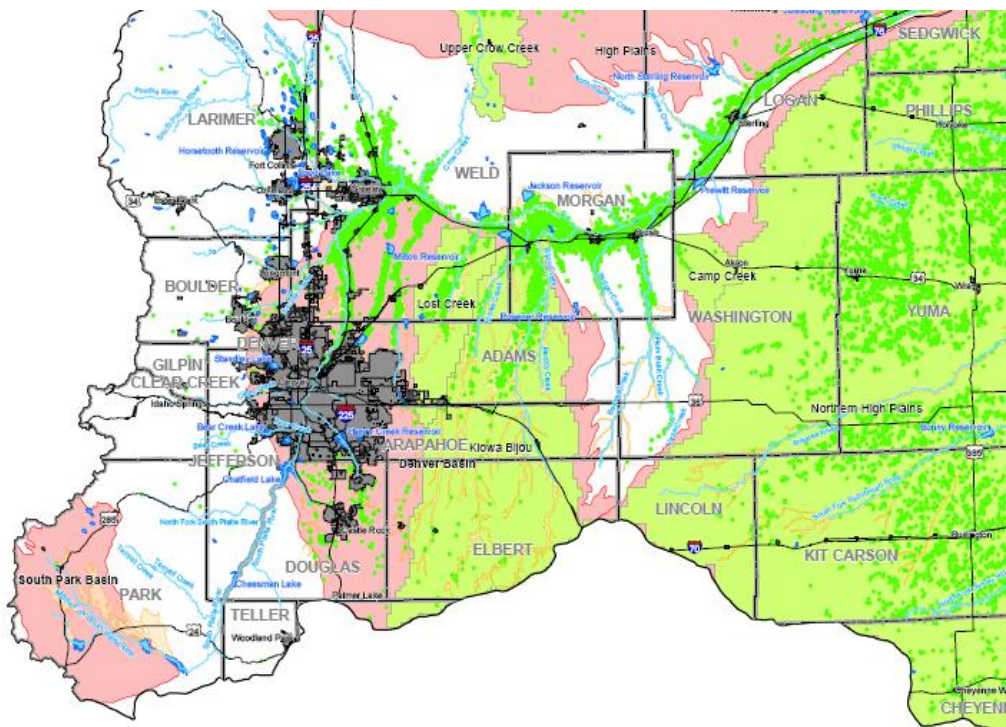
The South Platte River flows north east through Denver to Nebraska. Its altitude varies from 3400 to over 14000 feet (1054 to 4340 metres). The climate is highly variable with a temperature range of -30 to 100°F (-35 to 38 °C) and average rainfall varying from 10-17 inches (25-43 cm). Annual precipitation on the plains is less than 15 inches (38cm)(CWCB 2004). The long term average annual flow in the South Platte at Julesberg, near the Arkansas border, is about 395000 acre-feet (AF) (483GL), but within the last 50 years there has been a huge variation in average flow between 55000 and 2.1 million AF¹⁶⁴ (70-2590GL).

¹⁶⁴ One acre foot (AF) = one acre covered to a depth of 1 foot. 1 AF = approximately 1.23 megalitres .
1 inch = approximately 2.5 cm.
1 gallon = approximately 3.8 litres.

Flows are bolstered by transfers of more than 400000 AF (490GL) from the western slopes, mostly from the Colorado River. Return flows from irrigation may make an even larger contribution to stabilising river flows (Best CFWE 2009). The South Platte alluvial aquifer which is hydraulically connected to the South Platte River is estimated to hold 8 million AF (9867 GL) of groundwater. In the lower South Platte River there are approximately 10880 permitted wells with yields averaging 430 gallons per minute (gpm)¹⁶⁵ (CWCB 2004).

South Platte is one of eight major river systems in Colorado with a basin drainage area of 23238 square miles (60186 square km). The South Platte River Basin includes 14 counties and comprises about 20% of the state's land area.

Figure 7.1 South Platte Basin, main rivers, aquifers and wells



Source: Colorado State Water Supply Initiative, CWCB 2004.

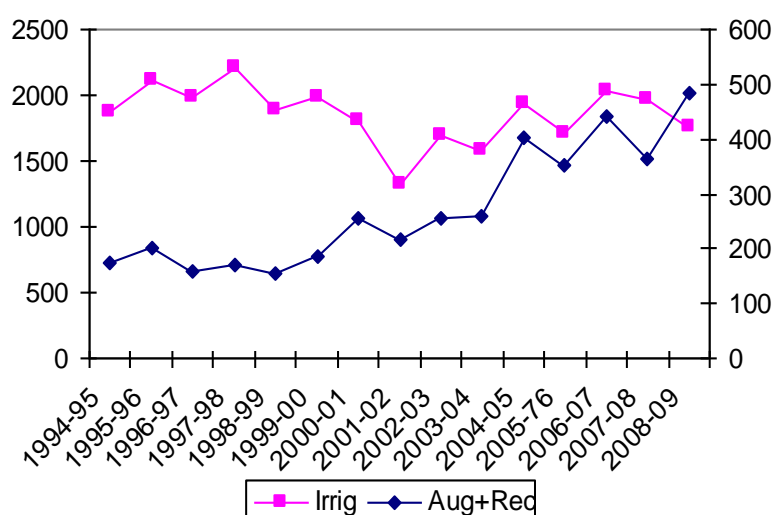
The population is about 3.0 million and 70% of the State's employment is in the South Platte Basin. In 2002 annual value of sales and services in the South Platte equalled \$US 251 billion of which agriculture accounted for \$2.2 billion. Although agriculture's share is less than 1%, the percentage exceeds 2% in the eastern half of the basin, and

¹⁶⁵ 50% of wells, many of them domestic wells, have a yield of 30gpm or less

any reduction of irrigated crop land in these areas has a large impact on the economy in agricultural counties. 40% of Colorado's agricultural production occurs in the South Platte (Thorvaldsen and Pritchett 2005).

In 2005 irrigated agriculture accounted for over two thirds of water use in the South Platte Basin, 2.2m AF out of 3.1m AF (Ivanenko and Flynn 2010). Rapid growth of population and urban water demand is leading to increasing competition and conflict over water use. Figure 7.2 shows surface water use (left axis), and augmentation and replacement (right axis) from 1994-95 to 2008-09. Augmentation and replacement are amounts supplied by groundwater users to mitigate impacts of their pumping on senior surface water users.

Figure 7.2 South Platte Basin: surface water use, augmentation and replacement
(000 acre feet)



Source: Colorado DWR. Irrig = irrigation, Aug = augmentation, Rec = replacement

7.2.1.2 Water management in Colorado - legal and institutional context

In the United States federal system of governance each state has “plenary control” over the waters within its boundaries, and is free to develop whatever system of water entitlements administration it chooses (Hobbs 1997). State law provides the basic system for the allocation of water resources.

In Colorado rights to access and use water are based on the doctrine of prior appropriation (Kenney 2005). The State of Colorado recognised the doctrine of prior appropriation by writing it into the Colorado State Constitution Article XVI, Sections 5 and 6¹⁶⁶. Appropriation refers to the act of diverting (extracting) water from a natural surface stream or ground, from a specified, surveyed location and for a specified beneficial use. The doctrine of prior appropriation includes four guiding principles (Jones and Cech 2009):

1. A claimant needs to divert water, and apply it to beneficial use in order to establish a water right. This right is usufructory – it depends on continued beneficial use. Beneficial use is defined flexibly to include a wide range of productive, consumptive, recreational and environmental uses. The intention to make beneficial use of water through an investment project is recognised by means of a conditional water right which must be exercised within a specified period of time.
2. The earliest user of a water source gained the rights to use it, to the exclusion of others, during times of shortage, regardless of their location on the water source. The Adjudication Acts of 1879 and 1881 required all persons who claim a water right to file a claim in court to establish the validity of their right¹⁶⁷. From 1881 to 1969 Colorado legislature passed a number of acts calling for general adjudications, and clarifying the process by which water rights were determined and administered.
3. Water can be removed from a stream and used in locations distant from the stream. Ownership of riparian land is not a condition of use.
4. Once established a right can be sold to third parties.

Many surface diversions allocated for irrigation use date back to the mid 19th century. If low stream flows prevent senior rights holders from diverting the water to which they are entitled, the seniors put a "call" on the river, requiring all upstream rights "junior" to the caller (including rights to pump tributary groundwater) to stop diverting water until adequate streamflow is restored (Howe 2008).

There are four types of groundwater rights. In this comparative case study the emphasis is on tributary groundwater which is hydrologically connected to a surface water stream. Groundwater pumping affects stream flow and/or surface water diversion affects

¹⁶⁶ <http://www.michie.com/colorado/lpext.dll?f=templates&fn=main-h.htm&cp=> accessed 11 January 2011.

¹⁶⁷ The Colorado Supreme Court recognized and confirmed the appropriation doctrine as the legal method of water allocation in the state, and superior to riparian claims in *Coffin v Left-Hand Ditch Co.*, 6 Colo 443 (1882).

recharge. Tributary groundwater is subject to the prior appropriation system, but before 1969 tributary groundwater was not adjudicated (MacDonnell 1988).

The Federal government has had a strong historical involvement in water development and distribution, through major water projects. During the Reclamation Era from the 1890s to the mid 1970s the Federal government supported irrigated agriculture, and constructed dams to provide margins of safety for recurring periods of drought and highly variable rainfall. These storages made it increasingly unnecessary to enforce water rights rigorously and helped produce culture of non enforcement of the beneficial use doctrine (Tarlock 2001).

Under the McCarran Amendment the United States Government can claim the adjudication and administration of certain rights to use water within state's water allocation systems. State courts can adjudicate Federal water rights claims under state law with certain exceptions. Implementation of the prior appropriation doctrine in Colorado (and elsewhere) is complicated by the influence of Federal law, especially the US government's "reserved water rights" on Federal lands (Indian reservations, forests, national parks, Bureau of Land Management Lands), and under certain Federal laws notably the *Endangered Species Act* 1973 and the *Clean Water Act* 1977 (Sax et al 2000, Kenney et al 2001).

Many water resources in the US overlap state boundaries. These resources are regulated by interstate compacts; self governing arrangements that states enter into, which prescribe the quantity of water each state can legally appropriate from a shared river basin (Schlager and Heikkila 2007). Colorado is party to nine interstate compacts, including the South Platte River Compact.

7.2.2 Historical development of integrated water management in the South Platte Basin

Socioeconomic development in eastern Colorado from the mid 1800s to the 1950s was almost entirely achieved through "native"¹⁶⁸ surface water supplemented by trans-mountain diversions. In the early 1950s reductions in surface water supplies led to the

¹⁶⁸ Surface water resources flowing through specific river basins and tributaries in the state of Colorado.

construction of thousands of wells in Colorado, notably in the South Platte and Arkansas River Basins. In 1969 the Colorado legislature enacted the *Water Right Determination and Administration Act*. This Act required all owners of tributary wells to file for adjudication in the Water Court by 1972, and required owners to administer the wells within the priority system. Since July 1972 tributary groundwater rights have been adjudicated and dated in the same manner as surface water rights¹⁶⁹ (Blomquist et al 2004). This made most wells very junior in priority in their respective basins. The 1969 Act also introduced the concept of “plans for augmentation”(see below). The 1969 Act placed administration of the water rights of the States completely within the control of state and divisional engineers. In 1970 the State Engineer introduced rules to curtail wells on a graduated basis. Following court challenges amended rules covering well curtailment were issued in 1974 (Radosevich 1974)¹⁷⁰. These rules allow wells covered by an approved plan of augmentation (see below) to continue to operate.

Under the prior appropriation system the management and use of surface water and groundwater is closely integrated. In practice, the primary purpose of integrated surface water and groundwater management is to maintain stream flows to protect senior surface water rights holders. This ensures certainty of supply for senior rights holders and also enables Colorado to comply with interstate river compacts, such as the South Platte Compact. In addition, Colorado courts have held that water should be allocated and administered in a way that promotes the maximum utilisation of the resources through statutory means allowing flexible administration and efficient methods of diversion. These flexibility mechanisms include augmentation plans and exchanges, and the "futile call doctrine", which are discussed below.

An augmentation plan allows a water user to divert water out of priority¹⁷¹ from its decreed point of diversion, so long as replacement water is provided to the stream from another source in time, location and amount sufficient to prevent any injury to senior

¹⁶⁹ Four different types of groundwater are statutorily defined in Colorado. Tributary groundwater is groundwater which is hydrologically connected to a surface water stream. Non-tributary groundwater is defined as "a groundwater outside the boundaries of a designated basin the withdrawal of which will not within 100 years deplete the flow of a natural system at annual rates greater than 0.1% of the annual rate of withdrawal". Not non tributary groundwater is that when withdrawn from specified basin aquifers does influence stream flow, but is allocated differently from tributary waters because of unique hydrological characteristics and importance to the economy. Designated groundwater is groundwater that would not be available to fill surface rights or groundwater, that has been the principal water supply for the area for at least 15 years and is not adjacent to a naturally flowing stream.

¹⁷⁰ <http://water.state.co.us/DWRIPub/Documents/south.pdf> accessed February 26 2011.

¹⁷¹ If there is insufficient water to supply a (junior) groundwater right it is said to be out of priority.

water rights users. There are three types of augmentation plan. Court decreed augmentation plans fully cover out of priority pumping depletions. Decreed recharge plans do not fully cover out of priority depletions, and the organisation holding the decree has to agree to enhance its recharge efforts and eventually seek a decreed plan of augmentation. Temporary substitute supply plans¹⁷⁴, administered by the State engineer, and renewed annually allow well owners to continue to pump while they seek court decreed plans (Blomquist et al 2004).

Augmentation plans use various water sources to get credits to offset groundwater pumping. Recharge credits must be used to cover out of priority depletions, they cannot be leased or sold.

Most augmentation plans include a proportion of secure water supply obtained by purchasing water rights within a ditch or reservoir company. Not using these water rights serves to offset pumping.

Seasonal surpluses of water can be put into leaky ditches, shallow ponds or natural depressions from which the water is allowed to seep to the underlying aquifer and flow back to the river. The time that water takes to return to the river depends several factors including well distance from the river and aquifer transmissivity. Some water returns to the river within months, some water takes several years to return. Water that has historically returned to rivers through irrigation recharge or surface return flow cannot be claimed as augmentation.

Alternatively seasonal surplus water can be held in temporary storages such as gravel pits lined with bentonite to prevent water seeping away. This stored water can be delivered to the river to answer priority calls. Groundwater associations can also obtain supplies of treated effluent to store and/or carry out river recharge activities.

Groundwater users can also employ augmentation wells. These wells are located some distance from the river. Pumping augmentation wells causes depletion that must be replaced, but this depletion and the consequent replacement obligation is delayed.

¹⁷⁴ Since 2002 the State Engineer's authority to approve temporary substitute supply plans has been withdrawn. TSSPs have been replaced by substitute water supply plans which have more restrictive conditions.

Within a basin, water rights may be exchanged to a new type, place and manner of use. Municipalities and other water users can satisfy their water needs by appropriating new water rights, and/or by purchasing senior water rights (typically from agricultural users) and changing them to municipal, commercial or industrial uses. Applicants must ensure that historical return flows (amount, timing, and location) from the use of water are maintained and that there is no expansion of historical use. These conditions do not apply to “foreign water” brought into the watershed from a source unconnected with the receiving system. Foreign water includes non tributary groundwater introduced into a surface stream, as well as water imported from an unconnected stream system (trans mountain water). Adjudicating a change of water rights can be time consuming and costly even if there is no dispute. When there are disputes it can take years to resolve them.

In 2003 legislative amendments were introduced in Colorado to authorise the State Engineer to create water banks within each water division¹⁷⁵ and to adopt rules allowing for the "lease, exchange, or loan of stored water within a water division" including transfers to the CWCB for stream flow purposes.

If curtailing an upstream junior water right does not materially improve the downstream senior’s condition then a call is deemed to be futile and will not be recognised as valid by state and division engineers. When there is a substantial time lag between shutting down wells and increase in surface water flows the curtailment of a junior groundwater right may not materially improve the condition of a senior rights holder (Jones and Cech 2009). The futile call rule helps to ensure that the prior appropriation system is administered consistent with efficient water use.

Finally, under the 1969 Act the CWCB is authorised to appropriate water for minimum streamflows or natural surface water levels or volumes for natural lakes to preserve the natural environment to a reasonable degree. Appropriations for in stream flows may only be made by the CWCB, not by private individuals. In 2003 legislation was amended to allow the CWCB to receive loaned water for in stream flow purposes on a temporary basis, not to exceed 120 days. By early 2009 CWCB had developed in stream rights on 8678 miles of Colorado rivers and streams (Sibley CFWE 2009).

¹⁷⁵ An attempt by the State to initiate a water banking program in 2002 in the Arkansas basin was not successful. The bank was based on individual applications; but the process did not include the irrigator associations, who did not support it (Lepper 2006).

7.2.3 Integrated water management instruments in the South Platte Basin

7.2.3.1 Augmentation and substitute supply plans

In March 1974 water appropriators in the South Platte Basin agreed on a set of rules for regulating wells. These rules defined a timetable for phasing out well pumping, but allowed wells covered by an approved augmentation plan to continue to pump during the summer provided that they did not injure downstream senior appropriators.

Augmentation plans and substitute water supply plans (see below) have ensured that senior water rights are met, while providing flexibility for groundwater use to continue.

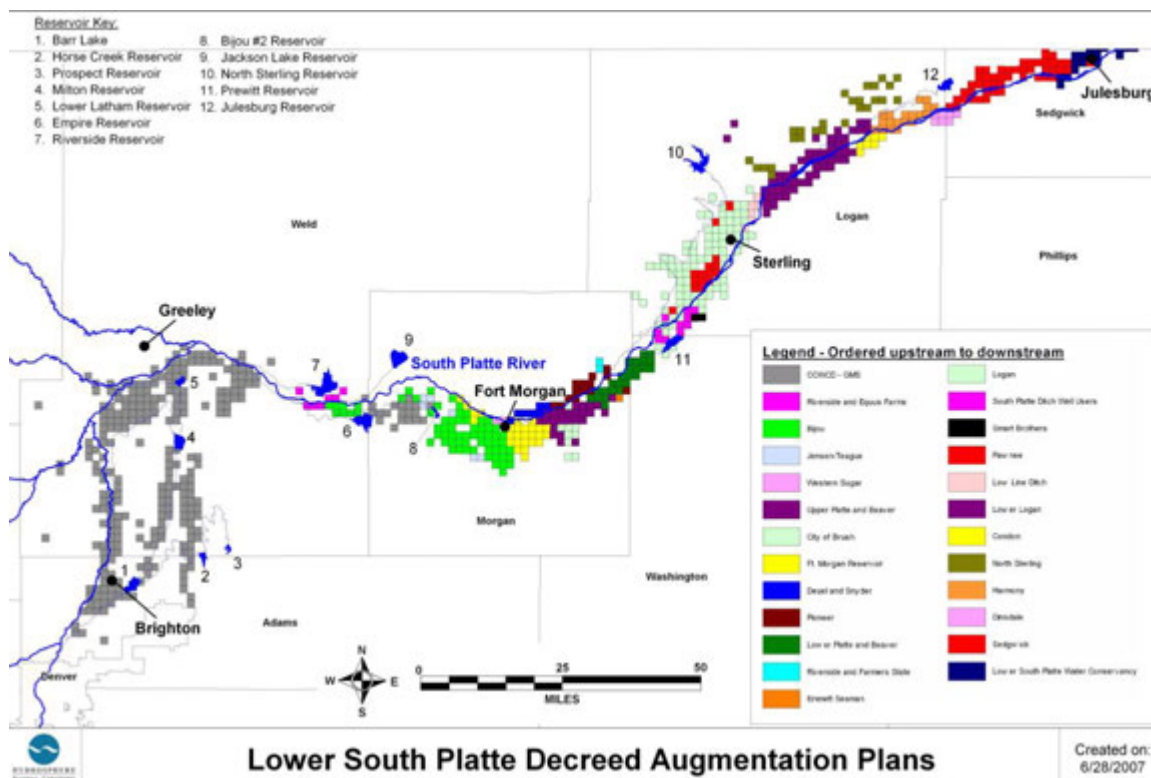
Well owners that pump from alluvial aquifers are required by law to belong to an augmentation plan such as to Groundwater Appropriators of South Platte (GASP), the Central Colorado Water Conservancy District (CCWCD), or an individual augmentation plan. GASP and CCWCD have developed groundwater recharge projects where the South Platte River is diverted into recharge basins or dry creek beds during the irrigation off season (October-March). CCWCD also rents reusable municipal effluent from cities along the Front Range and has developed numerous lined¹⁷⁶ gravel pits to hold augmentation water from various sources (Cech 2005). In general CCWCD worked towards approved augmentation plans in order to secure long term water supplies, while GASP relied on temporary leases with shorter term supplies (Jones 2010).

Blomquist et al (2004) documented six irrigation districts in the South Platte region. These organisations owned or leased 39 separate recharge or augmentation sites covering the out of priority pumping of approximately 600 wells. Between 1980 and 1997 these six organisations diverted 409000 AF (505 GL) of water into various recharge sites. Decreed plans of augmentation include lists of wells to be covered, lists of augmentation/structures, measurement and monitoring methods and decreed rights of augmentation water. Buchanan documented 25 irrigation and municipal districts, and other organisations with augmentation plans (shown in Figure 7.3) with 22 more in preparation. The CCWCD augmentation plan, discussed below, largely applies to the

¹⁷⁶ These pits are lined with bentonite slurry that forms an underground curtain around the perimeter of the gravel pits from the land surface down to the bedrock, and prevents water from escaping.

area south of Greeley. Trends of augmentation and recharge in the Lower South Platte region are shown in Figure 7.3.

Figure 7.3 Lower South Platte decreed augmentation plans 2007



Source: Buchanan 2007¹⁷⁷

Temporary (non decreed) substitute supply plans were coordinated by a group of well owners, the Groundwater Appropriators of the South Platte. These temporary, annual plans¹⁷⁸ were approved by the State Engineer between 1972 and 2001. Under these arrangements, Water Court Division One permanently approved 2800 South Platte wells that continued to operate; Division One also permitted several hundred wells to operate temporarily while applications to the Water Court for permanent plans were pending (Howe 2008).

Temporary supply plans violated the prior appropriation doctrine because they did not fully replace “out of priority” stream depletions. In 2001 the Colorado Supreme Court

¹⁷⁷ <http://www.colorado.gov/cs/Satellite/Agriculture-Main/CDAG/1184748122275> accessed 26 February 2011.

¹⁷⁸ These plans include a list of members and wells, estimates of the amount of water to be pumped in the coming and previous irrigation season, and an amount of water to replace as a priority depletion is and offset injuries to senior rights (MacDonnell(1998).

ruled (*Empire Lodge Homeowners Association vs Moyer*) that the legislature did not give the State Engineer authority to approve temporary water supply plans. In May 2002 State Engineer Simpson proposed revised rules, but more than 30 water user entities and individuals opposed the revised rules and the Water Court and the Supreme Court ruled that the State Engineer lacked authority to approve replacement plans (*Simpson vs Bijou Irrigation 2002*).

In 2003 the Governor of Colorado signed a bill allowing annual approvals of substitute water supply plans for three more years. However, negotiation of SWSPs for 2002-2004 was complicated by the severe drought. Calls by senior water rights holders to stop junior rights holders from diverting water began in June and continued for the rest of the year. Consequently well owner associations could not obtain replenishment water. GASP eventually went out of business in 2006. The Central Colorado Water Conservancy District (CCWCD) established a Well Augmentation Subdistrict (Central WAS) covering some former members of GASP. After lengthy negotiation the GMS obtained the agreement of senior water users to a new augmentation plan based on limiting pumping to ensure that depletions would not exceed replacement supply. This plan is based on a seven year projection tool that forecasts the amount and timing of depletions from past and projected future pumping, and projects deliveries from surface storage and groundwater recharge (Jones 2010). The plan does not assess regional aquifer conditions or impacts on biota. In stream flow requirements are dealt with separately (see below).

Central WAS proposed a program of groundwater recharge designed to capture free water and retine flows to replace well depletion. During 2006 Central WAS was not able to come to an agreement with senior rights owners, and the Division Engineer ordered 449 Central WAS member wells to cease pumping. This had the effect of drying up 30000 acres of cropland with immediate, severe impacts on the farms and associated rural communities. In 2007 Central WAS was awarded an augmentation plan decree, but it was unable to issue quotas to members because all of its supplies were dedicated to replacing previous pumping. Central WAS is continuing to build its water portfolio including senior water rights, municipal effluent and other consumable supplies.

In 2010 4500 wells are enrolled and augmentation plans and continue to pump although most of these are partly curtailed. 3700 wells are not enrolled in any court approved augmentation plan and have been completely curtailed (Jones 2010). The direct economic costs of the well shut down has been conservatively estimated at \$28 million through 2007 (Thorvaldsen and Prichett 2007).

Augmentation plans have to take account of provisions of the South Platte River Compact as well as Colorado priority users¹⁷⁹. This requires that between April 1 and October 15 Colorado cannot permit diversions with an appropriation date after June 14, 1897 when the flow of the river is less than 120cfs¹⁸⁰, unless the diversions are augmented. Colorado has the right to full uninterrupted use of waters in the South Platte River from October 16 to March 31¹⁸¹. In 1997 Colorado, Nebraska and the US Department of the Interior made a cooperative agreement to develop and implement a recovery program for four endangered species: the whooping crane, the least tern, the piping plover and the pallid sturgeon. Colorado has committed to making 10000 AF of water available between April and September of each year by adjusting the timing of water flows (Freeman 2011).

7.2.3.2 Other water management mechanisms

Water trading, water leasing, storage and in stream flow management provide further mechanisms for flexible integrated water management in the South Platte Basin.

There is a significant amount of water trading within the South Platte, mainly transfers from agricultural to municipal users (Howe and Goemans 2003). These transfers have helped to reallocate water to meet growing urban demand. Water leasing enables farmers to lease part of their water portfolio to municipalities and to reduce their acreage temporarily through crop rotation or fallowing (Pritchett et al 2008, McMahon and Griffin Smith 2011). This practice has helped to reallocate water during dry periods, but has not led to cyclical integrated water management using aquifer storage and recovery.

¹⁷⁹ <http://ssl.csg.org/compactlaws/southplatteriver.html> accessed 12 January 2011.

¹⁸⁰ 100 cubic feet per second equals 2.82 cubic metres per second.

¹⁸¹ <http://ssl.csg.org/compactlaws/southplatteriver.html> accessed 25 February 2011.

Storage is vital for optimising surface water and groundwater use. Recharge in alluvial aquifers will continue to play an important role in the South Platte region (Wolfe 2008).

In stream flow requirements under the South Platte River Compact and Federal endangered species legislation have been managed separately from municipal, industry and irrigation water. Municipal water users have met their endangered species obligations by assisting well owners in the lower South Platte region to obtain augmentation supplies and carry out river recharge operations to ensure that in streamflow targets and critical habitats in Nebraska are met.

7.2.4. Water management administration¹⁸²

7.2.4.1 Water management organisations

Water management in Colorado involves a partnership between national bodies, the state assembly, water courts, the Department of Water Resources/state engineer (DWR), and municipalities and water user associations at local level. In Colorado water courts rather than state officials define (adjudicate) and enforce appropriation of rights, including the amount, priority, location and beneficial use of water rights, the approval of exchanges and plans for augmentation. The earliest water right decrees in Colorado were adjudicated by the district court system – there are 80 water districts in Colorado. Most administration is still done at the level of water districts. A Water Commissioner serves each water district. Adjudicating industry water rights across districts is unwieldy. The seniority of appropriators reflects the date of adjudication as well as the date of appropriation. Some districts completed adjudication at an earlier date than others.

The *Water Right Determination and Administration Act 1969* authorised to the establishment of seven water courts and water divisions, based on the seven major river drainage basins in Colorado. These larger divisions have greater capacity to deal with strategic and cross tributary issues. The judge in each water court is designated by the Supreme Court to review water right applications within the relevant water division. The judge may appoint a water referee to assist in the investigation. Water referees

¹⁸² The Colorado Revised Statutes, Title 37, Water and Irrigation provides a primary source for the following section.

consider applications, gather evidence from applicants and make initial determinations concerning water rights (Vranesh 1987). If the ruling of a referee is appealed hearings are held before a water judge. The Colorado Supreme Court has exclusive appellate jurisdiction over water cases.

The state and division engineers provide information and technical resources to appropriators, the courts and the state legislature assisting them to implement the water rights system. Appropriators, the state engineer, the engineer's seven divisional offices, and water commissioners employed by the state engineer participate in monitoring and enforcing water rights (Blomquist et al 2004).

DWR administers water rights, assesses who has priority, issues water well permits and licences, represents Colorado in interstate water compact proceedings, approves dams and maintains dam safety, monitors streamflow and water use and maintains Colorado's water information system (Knox 2008). Seven divisional engineers who report to the State Engineer coordinate water rights across districts. On average DWR personnel record 30000 diversion and storage measurements, and process permits for 5000 new wells and 1200 new water right filings each year (Best CFWE 2009). The State Groundwater Commission establishes rules for designated groundwater basins.

DWR faces a number of administrative challenges. Although proponents are obliged to provide detailed augmentation plans, DWR divisional staff develop terms and conditions for the operation of wells as well as administering replacement plans. South Platte divisional staff have developed protocols for recharge, accounting for augmentation plans, delivery of replacement water, dry up of irrigated lands, and exchanges of excess credits. They have also provided leadership and resources in automating data collection, internet communication, and training in the installation of measurement devices (Wolfe 2008).

The Colorado Water Conservation Board is appointed by the Governor. It formulates policy for water development programs, provides funds for water projects, acquires and manages in stream rights and assists in interstate compact administration. The Water Quality Control Commission in the Colorado Department of Public Health and the Environment establishes policy and set standards for surface and groundwater quality.

Many Federal departments and agencies play a role in state water management. Key departments include the US Fish and Wildlife Service which administers the Endangered Species Act and fisheries management, US Environmental Protection Agency which administers national water standards, and the US Army Corps of Engineers which designs, builds and operates water resources and other civil works projects.

The Federal Government also has a strong presence in water issues in relation to Native American and international treaty obligations and public lands management. Federal and State laws and programs do not always fit together easily. Federal laws and programs that encourage leaving water in streams can conflict with state water laws and programs that encourage maximum diversion and consumptive use (Kenney et al 2001).

Water supply and distribution is managed by regional and local water entities, notably mutual water user companies and cooperatives, irrigation districts, conservancy and conservation districts. These organisations are non profit and raise revenue by assessments on shares (mutual companies), on acreage allotments (irrigation districts), or taxes on land or water sharing assessments (conservancy districts) (Freeman 2000).

Under the Water Conservancy Act 1937 Colorado's legislature has authorised the creation of water conservancy districts at the sub basin scale. There are 50 of these public entities, some divided into sub districts, which engage in a wide range of water issues including; development and management of water projects, water conservation, distribution water quality protection, flood control, legislation and education. Many districts were formed to contract with the Federal government to develop large water projects. Further details about the Central Colorado Water Conservancy District (CCWCD) are in Box 7.1.

Water conservancy districts provide a crucial link between state laws and policies and individual water users. They mobilise people, enable community participation and provide arenas for discourse. The districts' taxing ability allows them to borrow money for projects and repay it with tax revenue. These districts do not own water, but they may acquire and develop water rights. Some districts such as the Northern Colorado Water Conservancy District deliver water directly. Others, like the CCWCD develop an augmentation plan.

Box 7.1 Central Colorado Water Conservancy District (CCWCD)

CCWCD was formed in 1965 to develop, manage and protect water resources in northeast Colorado. It currently provides water augmentation and decree administration for over 1100 irrigation wells from Brighton north to Greeley, and east to Fort Morgan, including parts of three different counties. CCWCD has a court appointed board of directors, currently 12 members. Board of director meetings are held on the third Tuesday of every month and are open to the public.

Constituents owning property within the main district boundaries pay a levy assessment. Services provided to these taxpayers include an extensive water quality testing program, water education outreach and active legislative efforts to protect water sources and water rights. Irrigation allotment contract holders pay an annual assessment for the services provided by the two well sub districts; the Groundwater Management Subdistrict created in 1973, and the Well Augmentation Subdistrict created in 2004.

The main district and two sub districts own an extensive portfolio of water rights, including ditch, river and reservoir shares. They administer dozens of water management sites, for example, reservoirs and recharge ponds.

CCWCD operates two augmentation plans the Groundwater Management Subdistrict (GMS) and the Well Augmentation Subdistrict (WAS), using multiple water sources. These augmentation plans include surface water rights, water storage facilities and recharge sites. CCWCD began aggressively purchasing senior water rights shortly after the formation of GMS in 1973. This water is used to fill reservoirs and recharge ponds, covering depletions to the South Platte River caused by well pumping. CCWCD has rights in twenty-eight different ditch and reservoir companies. This diversification allows for greater flexibility in providing replacement to senior water rights holders.

CCWCD also uses diverse storages. CCWCD's Siebring Reservoir is a former gravel pit, now lined with bentonite clay that allows minimal groundwater interaction – an innovation that is being used around the world. The Nissen Reservoir consists of unlined infiltration ponds which effectively recharge an area within a slurry wall liner, which prevents discharge. CCWCD's storage ponds have a range of capacities. There are now approximately 27 smaller recharge ponds constructed along the South Platte River. These smaller ponds have been built in partnership with landowners. Expenses and water credits are negotiated in contracts with CCWCD.

CCWCD also undertakes water conservation and education projects. CCWCD and the Natural Resource Conservation Service have joined efforts to fund water users' recharge ponds, meter telemetry and other agricultural water conservation initiatives. Currently, CCWCD is establishing a system that will collect project requests from water users, and provide assistance for proposal development.

Source CCWCD¹⁸³ Cech 2010.

Water districts play an important role in encouraging regional coordination and innovation. In most cases organisation members democratically establish policy and elect management Boards. CCWCD exemplifies the way that diversification of water

¹⁸³ <http://www.ccwcd.org/> accessed 26 February 2011.

supplies and storage can encourage innovation leading to increased adaptive capacity and resilience.

In addition to water conservancy districts, four water conservation districts have been authorised by Colorado General Assembly to manage water resources across large geographic areas of the State, broadly corresponding to the river basin scale.

Corporate water entities have always played an important role in Colorado in organising and constructing diversion works, including irrigation, and delivering water (Jones and Cech 2009). Private associations were created across Colorado in the 1800s to develop, maintain and deliver irrigation water. A Title 32 Special District can be created, usually on a scale between counties and municipalities to supply domestic and other uses with services such as reservoirs, and water treatment facilities. There are over 700 metropolitan districts and more than 100 water and sanitation districts in Colorado. These entities commonly raise money for infrastructure. The Colorado Water Congress consists of water resources stakeholders representing industry, agriculture, government, recreation and others. Key non government environmental groups are also actively involved in the state water management (CWCB 2004).

7.2.4.2 Cross policy coordination

A coordinated cross policy approach is required to address the challenges of sustainable land and water management in Colorado. It is important to coordinate land use planning and water use planning, transportation and energy (Smith 2009). Moreover, water quality issues and recreation and environmental considerations are becoming increasingly important. Colorado's Statewide Water Supply Initiative and the Colorado for the 21st Century Act are important steps towards an coordinated approach.

The Interbasin Compact Committee (IBCC) was established by the legislature¹⁸⁴ to facilitate conversations among Colorado's river basins and to address statewide water issues. A 27 member committee, the IBCC encourages dialogue on water and broadens the range of stakeholders actively participating in the state's water decisions. Separate basin roundtables also were established by the Act for each of the state's major river basins and the Denver metropolitan area¹⁸⁵. These basin roundtables facilitate

¹⁸⁴ Colorado Water for the 21st Century Act.

¹⁸⁵ <http://cwcb.state.co.us/about-us/about-the-ibcc-brts/Pages/main.aspx> accessed 31 December 2010.

discussions on water issues and encourage locally driven collaborative solutions. The Roundtables have broad membership; for example, the South Platte Basin Roundtable has 51 voting members. An Interbasin Compact Committee, with representatives from each basin, is intended to provide a statewide perspective; negotiate interbasin agreements; and address issues between Roundtables.

7.3 *The Eastern Snake Plain: Idaho*

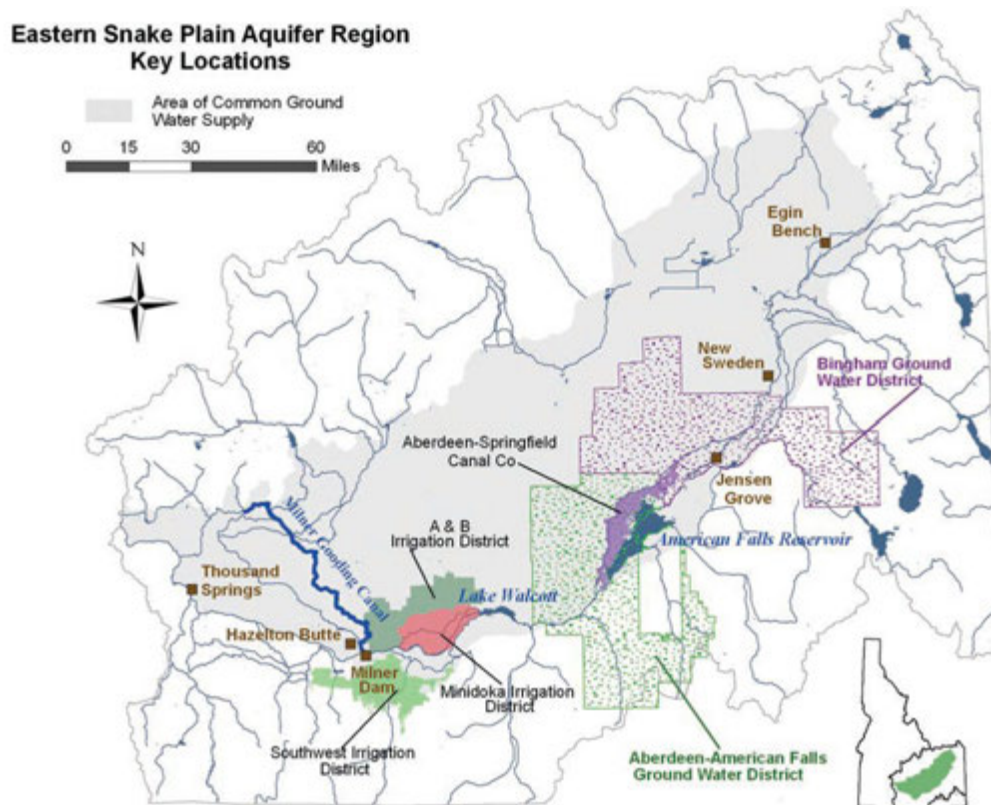
7.3.1 Biophysical and socioeconomic characteristics

The Eastern Snake Plain covers about 10800 square miles (27970 square km) in southeastern Idaho. Its altitude averages about 6000 feet (1830 metres) in the eastern part falling to 2700 feet in the west (IWRB 1998). The region has a relatively dry continental climate, with an average rainfall of less than 10 inches (25 cm) per year, ranging from 8 inches a year in the West to 14 inches a year in the north-east (Johnson et al 1999)

The Eastern Snake Plain aquifer (ESPA) underlies the plain (Figure 7.4). It consists of thousands of cubic miles of porous, fractured basalt. The aquifer is estimated to contain 1 billion acre feet of water (1.2 m GL), although only 100 to 220 million AF stored in the top a few hundred feet of the aquifer can be easily pumped and used. An estimated 24 million AF (29600 GL) of water was added to the aquifer by irrigation recharge from the 1880s to the 1950s.

On average the aquifer level rose by 50 feet (15.5 metres) between 1907 and 1959, in some areas it rose by 200 feet. From the 1950s to 2002 16 million AF were lost from the aquifer, leading to aquifer level declines of up to 60 feet in some areas.

Figure 7.4 Eastern Snake Plain Aquifer Region



Source: IDWR 2010

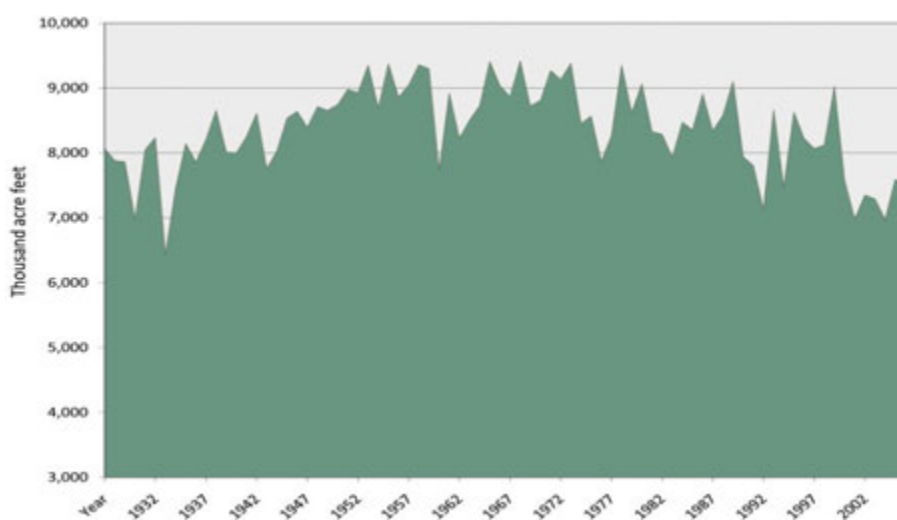
The Eastern Snake Plain is a key element of southern Idaho's economy and covers approximately 10,800 square miles of Idaho (27970 square km). About one third of Idaho's population resides on the Eastern Snake Plain. Agriculture is the largest segment of the local economy and the largest consumptive user of water. There are roughly 2.1 million irrigated acres (850000 ha) on the ESPA (about 60% of Idaho's total). In addition to irrigated agriculture, food processing and aquaculture facilities depend on an ample supply of groundwater. Springs discharging from the ESPA also sustain fish and wildlife habitat and provide water quality benefits.

Irrigation accounts for 85% of the total water used in the Snake River Basin. Surface water supplies 75% of water (Olenichak, 2008). Groundwater supplies the remaining 25% (IWRB 2010)¹⁸⁶. Hydroelectric power generation, recreation, and fisheries are also dependent on river flows. About 30% of Idaho's hydroelectric power generating capacity is located in the Upper Snake Basin. Hydroelectric projects in the area use

¹⁸⁶ It is difficult to identify surface water and groundwater use in the ESPA. USGS estimates apply to the state as a whole. Around 1995 total surface water use in the ESPA was estimated at 8.9 m AF and total groundwater use was estimated at 1.7 m AF (IWRB 1998).

approximately 400 million acre feet of water (489000GL) annually to produce about 3 million MWh (IDWR 2010)¹⁸⁷. Aquaculture is an important industry and uses roughly 2.75 million AF of water (3360 GL) per year (Maupin, 2008). It is estimated that 50 percent of the spring flow along the Snake River between Milner Dam and Bliss Reservoir is used for fish production. Though small relative to agricultural uses, domestic, commercial, municipal, industrial (DCMI) water use is also increasing in proportion to total use. Figure 7.5 shows estimates of water diverted from the ESPA from 1932 to 2007.

Figure 7.5 ESPA water diverted from 1932 through 2007 (000 AF).



Source IDWR 2010

7.3.2 Legal and historical development of integrated water management

The Idaho Constitution states that priority of water rights in time shall be subject to “such reasonable limitations as to the quantity of water used and the times of use as the legislature, having due regard both to such priority of rights and the necessities of those subsequent in time of settlement or improvement, made by law prescribe”¹⁸⁸.

Beneficial use is one limit on the right of priority. This constitutional provision gives the legislature and government agencies some room to move in implementing the prior appropriation doctrine.

¹⁸⁷ <http://www.idwr.idaho.gov/WaterBoard/WaterPlanning/CAMP/ESPA/default.htm> accessed 4 January 2011.

¹⁸⁸ <http://www.legislature.idaho.gov/idstat/IC/ArtXVsect5.htm> accessed 11 January 2011.

The passage of the 1951 Groundwater Act affirmed that groundwater is covered by the prior appropriation doctrine. This requires that all water uses within a single source be managed in order of priority, and that hydraulically interconnected water is be managed under a single priority system. However, in most cases groundwater and surface water rights in Idaho have been managed independently, including surface water in the Upper Snake River and groundwater in the ESPA. Integrated water management has been constrained by the difficulty of estimating the interconnections (fluxes) between resources, the desire to maximize the use of both surface water and groundwater, sufficiency of water supplies and the lack of clear legal authority for integrated management, especially in the absence of an adjudication of groundwater rights.

Several factors caused increasing conflicts between the holders of relatively senior priority surface water rights from the Snake River and tributary springs, and holders of relatively junior groundwater rights from the ESPA, leading to the development of integrated management from the mid 1980s on. These include over appropriation of water rights, the impacts of increased irrigation efficiency and groundwater pumping on surface water flows, and most importantly, increasing competition for resources during water scarcities (Sehlke 2000).

The criterion for issuing water rights is based on whether unappropriated water is available part of the time rather than whether a sustainable amount of water is available. Also loss of water rights not put to a beneficial use is rarely enforced in Idaho. The effect of issuing water rights of infinite duration that are rarely revoked is that there has been a continual increase in the number of water rights holders competing for a finite supply (Sehlke 2000).

By about 1950 the use of irrigation sprinkler systems had increased. The construction of deep groundwater wells for applying groundwater using sprinkler systems also became generally feasible. Consequently since 1950 the incidental recharge to the ESPA has declined by as much as 1 million AF annually. Moreover many of the surface water rights diverting from springs in the Thousand Springs area are partially or totally unfilled - there is not enough water to supply them - underlining the over appropriation of rights. During recent years shortages have occurred in supply available to holders of surface water rights. The prior appropriation doctrine provides a harsh but orderly means of allocating a reduced water supply (Dreher 2006).

7.3.2.1 The Swan Falls and Musser Cases

Two court cases precipitated integrated water management in the ESP; the Swan Falls case and the Musser case. By the early 1970s reduced recharge and groundwater pumping were diminishing power producing flows in the Snake River. In 1983 Idaho Power filed a lawsuit against the State and several thousand water rights holders upstream. In 1984, the Swan Falls agreement provided that Idaho Power's water rights at its hydroelectric facilities between Milner Dam and Swan Falls entitled the company to a minimum flow at Swan Falls of 3900 cubic feet per second (cfs) during the irrigation season and 5600 cfs during the non-irrigation season (IDWR 2010). From the point of view of the further development of integrated water management in the Snake River Basin, the most important result of the Swan Falls dispute was the commencement of a basin wide adjudication of Snake River Basin water rights as part of the statutory implementation of the Swan Falls Agreement¹⁸⁹ (Fereday 1992).

Following the Swan Falls agreement, several policies relevant to integrated water management were introduced, including the minimum flow requirements in the Swan Falls Agreement (Policy 1F and 5G), and a related Policy (5J) that reservoir storage be required to ensure minimum flows taking account of the impact of groundwater use. Development of a new consumptive use of water in the Snake River Basin can be authorized if the applicant provides mitigation to offset injury to other rights. Small domestic and stock water appropriations are exempted from this regulation.

In 1994 Idaho promulgated a set of "conjunctive use" administrative rules for managing interconnected surface and groundwater. The adoption of these rules was spurred by an Idaho Supreme Court case *Musser vs Higginson*. The Mussers and other plaintiffs did not receive their full water right between 1990 and 1992. In 1993 they made a number of calls for distribution of their decreed water rights. The Snake River Basin Adjudication (SRBA) Court and the Idaho Supreme Court found that the Director had a clear duty to distribute the water under the prior appropriation doctrine. This decision implied that junior rights could be shut off even if this resulted in an underutilization of the aquifer. In response, following public meetings IDWR adopted a set of conjunctive management rules in October 1994 (Raines 2006). The rules govern the distribution of

¹⁸⁹ As of July 2008, there were over 170,000 claims including federal reserved right claims and Indian claims on over one million cubic feet per second in the Snake River Basin.

water from groundwater sources and areas having a common groundwater supply, including the ESPA¹⁹⁰. Domestic and stock watering groundwater rights are exempt from delivery calls (Rassier 2008).

The stated purposes of the rules include reasonable use of surface water and groundwater and denial of futile calls, although delayed injury to senior rights holders may require mitigation or curtailment of junior rights. The rules apply where the diversion and use of water under junior groundwater rights either individually or collectively causes material injury to senior water rights holders. Factors that the Director may consider in determining material injury include the availability of water from a source, the cost of diversion, the quantity and timing of depletions owing to the exercise of junior priority rights, the reasonableness (efficiency) of irrigation practices, the amount of water diverted and used compared with the water right, senior rights to maintain reasonable carryover storage, and the availability to seniors of alternative means of diversion.

The Director may allow out of priority diversion of water by junior priority groundwater users subject to a mitigation plan that has been approved by the Director. The rules have now been tested and upheld in several court actions taken by senior rights holders, including several actions by canal companies, and an important case by two aquaculture companies, Blue Lakes Trout Farm Inc and Clear Springs Foods Inc.

In response to the actions from the canal companies the Idaho Supreme Court upheld the constitutionality of the conjunctive use rules (Fereday 2007). The Blue Lakes and Clear Springs case illustrated that the time delay between groundwater pumping and impacts on spring flows complicates integrated water management, and also makes groundwater recharge an attractive tool for drought management (Dreher 2006). At the same time the hearing in 2007 decided some important issues about the interpretation of the conjunctive use rules. Firstly, it needs to be demonstrated that the curtailment of groundwater pumping would have a significant effect on the rate of spring discharge. The Idaho Groundwater Users Association presented statistics to show that pumping

¹⁹⁰ The rules provide for the full economic development of undergroundwater resources for beneficial use in the public interest at a rate not exceeding the reasonably anticipated average natural recharge rate, and in a manner that doesn't injure senior priority surface or groundwater rights and furthers the principle of reasonable use of surface water and groundwater.

would have in impact of 3% or less on the rate of pumping. Secondly the economic impact of curtailing pumping should also be taken into account (Carlquist 2009).

Some of the information constraints on integrated water management are being addressed. IDWR is now able to electronically measure flows at a large number of head gates and other flow points to estimate natural flows and flows from storages. In addition University of Idaho hydrologists have developed a model that IDWR uses to manage water transfers.

7.3.3 The Eastern Snake Plain Aquifer Plan

In April 2006, in response to declining aquifer levels and spring discharges, changing Snake River flows and increasing water conflicts, the Idaho State Legislature asked the Idaho Water Resource Board (IWRB) to develop an Eastern Snake Plain Aquifer Comprehensive Aquifer Management Plan (IWRB 2009)¹⁹¹. The goal of the plan is to “sustain the economic viability and social and environmental health on the Eastern Snake Plain by adaptively managing a balance between water use and supplies”. Objectives for aquifer management include increased predictability of supply, creation of alternatives to administrative curtailment, improved demand management, increased recharge to the aquifer and reduced withdrawals from the aquifer.

In collaboration with the Governor of Idaho, the IWRB appointed an ESPA Advisory Committee. Beginning in May 2007, the Advisory Committee held 18 meetings¹⁹² across the ESPA led by an external expert facilitator.¹⁹³ The Eastern Snake Plain Comprehensive Aquifer Management Plan (CAMP) was adopted by the IWRB on January 29, 2009 and passed into law by the Governor of Idaho on April 23, 2009.

The long term objective of the Plan is to incrementally achieve a net water budget change in the ESPA of 600000 acre-feet (600 KAF) annually. It is projected that this

¹⁹¹ Idaho Senate Concurrent Resolution Number 136. Further details about the ESPA Planning process are at <http://www.idwr.idaho.gov/WaterBoard/WaterPlanning/CAMP/ESPA/espa-process.htm> accessed on 6 January 2010.

¹⁹² There were also numerous meetings of the management alternatives, fish and wildlife, economic analysis and funding subcommittees.

¹⁹³ The expert facilitator from Colorado played an important role in bringing the large number of stakeholders together and reconciling their diverse views.

hydrologic goal can be achieved by the year 2030 at a total cost of \$600 million through implementation of a mix of management actions including:

- Groundwater to surface water conversions – 100 KAF/year by acquiring water below Milner dam to replace water required for salmon flow augmentation;
- Managed aquifer recharge – 150-250 KAF/year using the Board's natural flow water permits and storage water when available;
- Demand reduction – 250-350 KAF/year through voluntary mechanisms including; fallowing and crop mix changes; surface water conservation and dry year leasing; buyouts; subordination agreements and CREP¹⁹⁴ enhancements;

The Plan approaches the 600 KAF target in phases. Phase I (1-10 years) provides for a water budget change between 200-300 KAF. Between \$70-100 million are required to implement phase 1 of which ESPA water users contribute 60% and the State of Idaho contributes 40%.

Although the ESPA plan is a very promising initiative, an interdisciplinary evaluation study has identified significant barriers. These include lack of availability of unappropriated water, and security and adequacy of funding. Power imbalances among affected parties are a further complication (Darrington et al 2009).

Two of the three major CAMP goals require significant volumes of additional water. Water for conversion must be found from existing upstream users, whether through purchase, lease, demand reduction or conservation. Conversion of 20% of flood irrigated lands in Water District 1 could deliver sufficient water, but the senior users in Water District 1 are unlikely to accept irrigation system conversion or canal lining without compensation. Water could be obtained for groundwater to surface water conversions, but the stated funding requirements for the CAMP seem to substantially underestimate the costs¹⁹⁵. Demand reduction is unlikely to be achieved without financial or other incentives. If government incentives are not available, market approaches could be adopted but these approaches are complicated by the high transaction costs of water transfers, and market creation.

¹⁹⁴ The Conservation Reserve Enhancement Program (CREP) is a voluntary land retirement program that helps agricultural producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water. The program is a partnership among producers, governments and, in some cases, private groups.

¹⁹⁵ The estimated cost of groundwater to surface water conversion in the A&B Irrigation District is \$360 million, or 3.5 to 5 times more than the entire CAMP Budget for Phase 1 of the plan.

Water users are slated to provide 60% of the funding for the CAMP but their interests are widely divergent and public comments suggest that water assessments may not be easily collected (Darrington et al 2009). One interviewee commented that the Governor has already withdrawn some money from the monitoring and modelling budget, raising questions about the State's commitment to meeting their share of the funding.

On a more positive note water banking and managed aquifer recharge might contribute positively to water efficiency and adaptive capacity on the Eastern Snake Plain. Water banks might provide one option for facilitating water transfers and reducing their costs. Water banking has a well established tradition in Idaho. In the 1930s water users in Idaho established rental pools to allow entities with surplus stored water to make it available to others. Many Canal companies hold natural flow rights that provide surplus water in years with average to good runoff. The company then weighs the benefit from renting the storage to another user against the risk that the storage space may not refill during the following season¹⁹⁶. The first known annual rental pool transfers occurred during the drought period of the 1930s. In 1932 14700 AF of water were rented for 17 cents per AF (Slaughter 2004)¹⁹⁷. In 1978 the rental price was 75 cents per AF, currently it is \$14 per AF¹⁹⁸.

The 1976 State water plan recommended that a self financing water supply bank should be established to acquire water rights from willing sellers for reallocation by sale or lease. In 1979 the Idaho legislature formalized the program of annual leases of storage water entitlements. Water rights may be proposed to be placed in the state water resource bank or in rental pools operated by local committees appointed by the Board. Proposals are submitted for approval by the Director of the IDWR (IDWR 2001).

There is increasing interest in managed aquifer recharge to improve water use efficiency and storage. Since the 1970s, as incidental recharge from irrigation has declined and groundwater pumping has increased, intentional recharge was implemented at convenient sites to help sustain declining spring flows and water levels. For example, between 1995 and 1997 irrigation companies recharged 579 KAF of surplus water

¹⁹⁶ http://www.idwr.idaho.gov/WaterManagement/WaterRights/waterSupply/history_of_bank.htm
accessed 19 February 2012.

¹⁹⁷ http://cses.washington.edu/db/pdf/Slaughter_InstitutionalHistorySnake241.pdf.

¹⁹⁸ http://www.idwr.idaho.gov/WaterManagement/WaterRights/waterSupply/ws_default.htm
accessed 19 February 2012.

through irrigation canals to man made recharge sites such as gravel pits. This was encouraged by state compensation of \$0.25 per AF for conveyance. More recently the State has embarked on a managed aquifer recharge program using specific sites for specific purposes (Johnson et al 1999, Contor 2007).

7.3.4 Water management administration

The Idaho Department of Water Resources (IDWR) leads water management in the state. The department administers water rights and distributes water in accordance with the prior appropriation doctrine. The IDWR acts as an independent expert and technical assistant to the court in the water right adjudication process. The IDWR is responsible for administering water rights and enforcing state water laws. The Department also has responsibility for monitoring and planning the state's water resources. The Idaho Water Resource Board (appointed by the Governor) (IWRB) is responsible for developing the state water plan, and plans for individual basins or other geographic areas. The Idaho Department of Environmental Quality is responsible for water quality in the state (IDWR 2001).

Since 1971 new water rights must be established by filing an application with the IDWR. Idaho district courts (backed by the Idaho Supreme Court) are responsible for the adjudication of Idaho's watersheds, but the IDWR administers the adjudication system, including filing claims, investigating them and reporting to the court. The court is responsible for decreeing water rights.

When surface water rights holders make delivery calls against groundwater users, the parties must meet the requirements of the conjunctive management rules. The IDWR Director is responsible for administering the rules. If the parties can negotiate an agreement (stipulated agreement) this provides the basis for the Director's order. If the parties cannot agree formal hearings are held, and the Director evaluates the evidence and issues a decision (Sehlke 2000).

The IDWR has established more than 100 water districts (70 of which are active) to implement water rights and coordinate the management of the state's water (IWRB 2010). Water users in each water district meet annually to elect a water master who is responsible for the delivery of stored water. The Groundwater District Act 1995

enables groundwater users to organise their own groundwater districts to perform measurement and monitoring functions, develop and operate mitigation and recharge plans and represent their members. Nine separate groundwater districts have been organised.

Water users have formed mutual Canal companies or irrigation districts to deliver water to users. There are over 600 irrigation organisations in Idaho.

7.4 Assessment

7.4.1 Factors influencing integrated water management in the South Platte and Eastern Snake Plain regions

In both Colorado and Idaho, prior appropriation has encouraged the integration of surface water and groundwater management. Surface water users have senior rights, and as groundwater use expanded after World War II, surface water users became increasingly concerned about the impact of groundwater pumping on their surface water rights. “Calls” by senior surface water rights holders on groundwater pumpers have prompted initiatives by users and state authorities, and legal and policy innovations to enable groundwater use to continue. The nature and timing of these initiatives have been influenced by differences in groundwater resources, configurations of water users and governance arrangements.

In the South Platte region in Colorado shallow alluvial groundwater resources are closely connected with rivers, and pumping groundwater has a rapid impact on surface water stream flow. This impact is noticeable to senior surface water rights holders within a single irrigation season. The relatively early adjudication of groundwater by 1972 has provided a strong driver towards integrated water management. Since groundwater adjudication senior surface water calls have prompted groundwater users, working with state authorities, to develop decreed or temporary augmentation plans to offset their impacts on senior users.

In the Eastern Snake Plain the groundwater resource is larger and deeper, the material is less porous, and the connection is less immediate. The connection is also complicated by the impact of surface water irrigation in the upper part of the basin, which until the 1950s led to increasing volumes of water in the aquifer, and increasing spring flows to the river downstream. In Idaho the most high profile surface water and groundwater conflicts did not occur until the 1980s and groundwater adjudication did not begin until then. In 1994 the State of Idaho promulgated conjunctive management policy and rules that promote integrated management, but the rules are relatively recent and are still being tested in the courts.

The key policy problem facing Colorado and Idaho authorities is how to make beneficial use of available surface water and groundwater resources, while at the same time upholding the legal rights of senior water users. In Colorado augmentation plans and replacement plans have provided a flexible solution, but the long term future of these plans is unclear owing to water scarcity and legal action following a prolonged drought. Mitigation plans in Idaho are a more recent innovation but they face similar challenges. It is evident that a more multifaceted approach is required in order to achieve optimal use of water resources.

Water administration in Colorado and Idaho provides an interesting contrast. In Colorado the water courts have primary responsibility for administering water rights and determining claims. The State Engineer has played a key role in developing and administering integrated water management, but in recent years the authority of the engineer has been challenged, and the balance of influence has swung back towards the courts and the legislature. In Idaho the IDWR has the primary responsibility for administering the prior appropriation system after water rights have been adjudicated by the courts. The Eastern Snake Plain planning process was initiated by government, and followed through by the IWRB supported by the IDWR. The planning process bears some similarities with processes in New South Wales, but without integrated consideration of water for the environment. In Idaho groundwater users rather than the state are responsible for developing plans to mitigate the impact of their pumping.

A report prepared for the Western States Water Council concludes that States should not take over local planning but should establish policies that facilitate the flow of information from water resource agencies to local planning agencies, and that require

local governments to create and adopt comprehensive plans that include water resource elements. States should offer technical and financial support for watershed organisations, and should work with stakeholders to find innovative ways of allowing transfers of water from agriculture to urban uses while avoiding or mitigating damage to agricultural economies or environmental values (Bell and Taylor 2008).

7.4.2 Opportunities for and barriers to integrated water management

Recent attempts in both Colorado and Idaho to make the best use of surface water and groundwater resources and reconcile the interests of surface water and groundwater users involve multifaceted approaches including new sources of water, water transfers, agricultural demand management, water banking and managed aquifer recharge.

In Colorado and Idaho water supply and demand are balanced by means of the prior appropriation system. When water is scarce senior water right holders have priority and junior water right holders may not receive water. The total of both surface water and groundwater rights held by users is substantially in excess of sustainable use levels. It remains to be seen whether augmentation and replacement can continue to be successfully adapted in the face of growing pressures on water resources, and whether vested interests (senior surface water rights holders) will block innovative initiatives by groundwater rights holders.

In Colorado inter basin water transfers from west to east of Front Range have played an important part in supplying growing demand in the South Platte region. Water transfers can continue to contribute to the solution, subject to compliance with interbasin compacts, energy costs and impacts on existing water users including the environment. However, there are few options for new inter basin transfers, and costs would be very substantial (CWCB 2004). This means that it is (increasingly) difficult for groundwater users to find surplus surface water for augmentation or substitute water supply plans in dry years. Users are increasingly turning to “new” sources of water including recycled stormwater and waste water.

Discussions during the development of the Colorado Statewide Supply Initiative and the subsequent interbasin roundtables have highlighted a number of approaches to address future water supply challenges.

Transfers from agriculture to urban areas are likely to increase substantially. For example the SWSI study concluded that the number of acres of irrigated land in the South Platte River Basin will be reduced by one third, 133000 acres, to 226000 acres by the year 2030. There are opportunities to reduce the amount of permanent transfer of irrigated farming in Colorado, and mitigate adverse socioeconomic impacts through the use of interruptible water supply agreements and rotational crop management contracts. Interruptible supply agreements provide another form of lease whereby agricultural users rotate or fallow crops in certain years allowing temporary transfers to municipal uses. However, these opportunities are limited to the extent that they do not provide for stable and more predictable supply to municipalities.

One of the attractive features of the Eastern Snake Plain Aquifer Plan in Idaho is that it includes a package of different measures with complementary effects; conversion of some groundwater rights to surface water, and a set of voluntary demand reduction measures including fallowing, crop mix changes, surface water conservation, dry year leasing, buyouts, subordination agreements and CREP enhancements.

Storage is vital for optimising surface water and groundwater use. Aquifer storage and recovery and water banking provide further opportunities for integrated water management. Recharge in alluvial aquifers will continue to play an important role in the South Platte region (Wolfe 2008). In Colorado a CWCB study has identified a large potential for aquifer recharge in a number of regions. Although water availability is a problem, aquifer recharge can certainly play a role in retiming supplies and facilitating temporary rural-urban exchanges (CWCB 2007).

Many of the augmentation and substitute water supply plans have been based on managed aquifer recharge and recovery within individual years or irrigation seasons. There may be opportunities for longer term aquifer storage and recovery, and water banking to provide increased security and adaptability in response to variable water availability. There are only a limited number of areas in the shallow alluvial aquifers in the South Platte for longer term water storage and recovery, and the prospects in the

Denver Basin aquifers may be greater. The legal regime for recovering stored water needs to be confirmed and consolidated, and partnerships between authorities and users for the management, financing and implementation of aquifer recharge and recovery need to be strengthened (DNR 2008).

In Idaho the ESPA includes aquifer storage and recovery initiatives. The prospects for accessing surplus surface water for managed aquifer recharge in the Eastern Snake Plain depend on cooperation from senior surface water rights holders such as the upper basin surface water irrigators and Idaho Power. There may also be scope for improving integrated water management in Idaho by building on the long established water banking institutions. These could also provide a model for other jurisdictions.

7.5 Conclusion

The prior appropriation system has driven integrated water management in both Colorado and more recently in Idaho.

The major feature of integrated water management is the use of augmentation or replacement plans that allow out of priority groundwater users to continue to pump groundwater. In Colorado these plans are under review owing to legal action prompted by water scarcity, and a significant amount of groundwater pumping has been curtailed.

A range of options are being examined in both jurisdictions to overcome water shortages and conflicts including improved water use efficiency and crop mix changes; water banking; aquifer storage and recovery; and demand reduction strategies such as fallowing, leasing and buy outs. There is scope to further develop integrated cyclical water management as an important strategy to adapt to variable water supply, water scarcity and climate change.

Chapter 8 Integrated water management: comparisons between New South Wales, Colorado and Idaho

8.1 Introduction

At the jurisdictional scale of analysis it is not possible to examine the interactions between specific water user groups, connected water resources and governing bodies. Moreover, it is not clear which institutional features are the most influential, or how they exert their influence. Many key collective choice and operational water governance decisions can only sensibly be made in relation to smaller water management units. At the smaller scale it is easier to examine the effects of specific governance arrangements.

Chapter 6 and 7 included a description and analysis of integrated water use and management in the Namoi region of New South Wales, the South Platte River Basin in Colorado, and the Eastern Snake Plain in Idaho. These areas were selected because they have similar biophysical and socioeconomic conditions including relatively dry climate, variable rainfall, water scarcity, and a high proportion of water use in irrigated agriculture (although there are some significant variations within the case study areas). The relative similarity of biophysical and socioeconomic conditions facilitates cross jurisdictional comparison of the impact of different policy and institutional settings on integrated water management. The effect of water entitlements, rules in use and management organisations received special attention.

Historically the three case study areas have shared a common spatial and jurisdictional scale; sub basins under state government jurisdiction, although the Namoi region will come under intergovernmental jurisdiction when the new MDB Plan is adopted. The temporal and management scales vary markedly. The temporal scale ranges from impacts within months in the alluvial aquifers in the Namoi and South Platte regions, to impacts over tens or even hundreds of years in the basalt of the Eastern Snake Plain aquifer. These impact lags help to explain the relatively late adjudication of groundwater on the Eastern Snake Plain. The management scale ranges from state based authorities and water courts, to water user associations in irrigation sub districts.

Experience from the three case study areas confirms that there are a number of difficulties in pursuing integrated water management. The biophysical system in large river basins and sub basins is very complex and the connections between surface water and groundwater are not well understood. Surface water and groundwater users have different traditions and practices, which make it more difficult to achieve integrated collaborative management. The design and implementation of comprehensive bundles of water entitlements, integrated surface water and groundwater plans and management rules present considerable challenges. These tasks involve multilevel polycentric governance which raises problems of coordination and transaction costs. In short integrated water management is attractive in theory but hard to do in practice.

Integrated water management has been actively pursued in Colorado and Idaho and other States in the western USA, but not in the Namoi region (or most other regions in the MDB). What explains this difference, and what lessons can be learned from the different experiences in New South Wales, Colorado and Idaho? What are the opportunities for the further development of integrated water management in these regions?

This chapter proceeds as follows. The next section examines the impact of the different “core” water governance approaches in New South Wales, Colorado and Idaho; political choice and prior appropriation. The following section summarises patterns of integrated water use and management in the case study areas. The following two sections examine the effects of water entitlements¹⁹⁹, water plans, water management rules and organisation. The final sections summarise the comparative analysis of factors affecting integrated water management and discuss opportunities for improving integrated water management.

¹⁹⁹ In Australia the term water entitlement is preferred because water is owned by the state, and the right to use water is an entitlement granted by the State. In the US the term water right is used. In this chapter the term water entitlements is used in separate discussion of the Australian cases and in joint discussion of the Australian and US cases. Water rights is used in separate discussion of the US cases.

8.2 “Core” water governance principles and path dependency

The choices of water users and managers in specific water management areas are shaped and constrained by “core” principles of water governance, and by previous decisions about governance arrangements (laws, rules, and management organisations) and instruments. The prior appropriation system in Colorado and Idaho establishes legal priority for senior surface water entitlements that drives integrated water management in tributary water resources. Water allocation plans are the primary instrument for integrated water management in New South Wales, and the separation of surface water and groundwater planning and allocation does not encourage integrated water management.

8.2.1 New South Wales

In Australia’s federal system, water governance takes place at a number of levels at the jurisdictional and river basin scale. Essentially it is a relatively centralised and hierarchical governance system. The Council of Australian Governments²⁰⁰ (COAG) has led responsibility for national water policy. In 2004 COAG established an Intergovernmental Agreement on a National Water Initiative (NWI)(NWC 2004). Key NWI provisions include comprehensive planning for surface water and groundwater and secure tradeable water access entitlements. The NWI requires assessment of connectivity between surface water and groundwater systems, and integrated accounting of the use of closely connected surface water and groundwater resources.

The 1992 Murray-Darling Basin agreement covers water allocation between MDB jurisdictions²⁰¹. The agreement only recognises surface water and groundwater links to the extent that the Murray-Darling Basin Authority (MDBA) is required to monitor the effect of groundwater on surface water resources, or if a special river valley audit is required (MDBC 2006). In the MDB water plans and water markets are the main instruments for managing water resources and allocating water. Water use limits for each water resource are established by State water plans. Tradeable water use

²⁰⁰ The Council of Australian governments includes the Australian government, and the governments of Queensland, New South Wales, Victoria, South Australia, Tasmania, Western Australia, the Northern Territory and the Australian Capital Territory.

²⁰¹ http://www2.mdbc.gov.au/_data/page/44/Murray-Darling_Basin_Agreement_full.pdf accessed 24 February 2011.

entitlements are allocated according to the histories of use, usually over periods in the relatively recent past. There is little surface water groundwater trading. The Australian Government's *Water Act 2007*²⁰² requires that the new Murray-Darling Basin Authority prepares an integrated surface water and groundwater plan for the basin together with a plan for each water resource area within the basin, but these new plans will not come into effect until 2019.

The New South Wales *Water Management Act 2000* gives effect to the COAG 1994 reforms²⁰³ and the NWI by establishing a framework of water management based on clearly defined tradeable water access entitlements/licences in water. The rules for allocation of water are specified in water sharing plans for specified water management areas (Montoya 2009). Plans for the most highly developed and intensely exploited water resources were prepared first. Plans are prepared by the New South Wales Office of Water with advice from management committees including regional stakeholders.

Surface water and groundwater plans have generally been made separately. A very small number of water sharing plans for unregulated rivers²⁰⁴ and groundwater systems, including the water sharing plan for the Peel River²⁰⁵, have included integrated surface water and groundwater plans for highly connected water resources.

8.2.2 Colorado and Idaho

Under the United States federal system of governance each state has "plenary control" over the waters within its boundaries, and is free to develop whatever system of water rights administration it chooses (Hobbs 1997). In Colorado and Idaho, State law underpins the doctrine of prior appropriation, which provides the basic system for the allocation of water resources (Kenney 2005), and drives integrated water management. Many surface diversions allocated for irrigation use date back to the mid 19th century. If low stream flows prevent senior rights from diverting the water to which they are entitled, the seniors put a "call" on the river, requiring all upstream rights "junior" to the caller to stop diverting water until adequate streamflow is restored (Howe 2008).

²⁰² <http://www.environment.gov.au/water/policy-programs/water-act/index.html> accessed 24 July 2009.

²⁰³ http://www.austlii.edu.au/au/legis/nsw/consol_act/wma2000166/ accessed 16 February 2011.

Amendments to the Act enable implementation of the National Water Initiative in NSW.

²⁰⁴ Rivers fed by rainfall and groundwater, and not regulated by dams or fed by water released from dams.

²⁰⁵ http://www.austlii.edu.au/au/legis/nsw/consol_reg/wspftpvrwafrws2010946/ accessed 16th February 2011.

The doctrine of prior appropriation includes four principles (Jones and Cech 2009): a claimant needs to divert water, and apply it to beneficial use; the earliest user of a water source has the right to use it, and to exclude others; water can be removed from a stream and used in locations distant from the stream – ownership of riparian land is not required; and a right can be sold to third parties. The doctrine of prior appropriation sets priorities and solves shortages by a queuing principle – first in time, first in (priority of) right.

In Colorado there are four types of groundwater rights²⁰⁶. In this comparative case study the emphasis is on tributary groundwater which is hydrologically connected to a surface water stream. Tributary groundwater is subject to the prior appropriation system (MacDonnell 1988), and surface water and groundwater are managed as a single connected resource. Tributary groundwater wells can be “shut down” unless they can offset or make good the impacts of pumping on senior surface water rights holders. Water courts enforce the priority of water rights, supported by the Colorado Department of Water Resources (DWR) headed by the State Engineer.

Idaho also operates under the doctrine of prior appropriation, but the balance of authority between the courts, the legislature and the administration is somewhat different from Colorado. The Idaho Constitution gives the state legislature powers to limit water rights taking account of “priority of rights and the necessities of those subsequent in time of settlement or improvement”²⁰⁷. In Idaho, water courts are responsible for adjudicating water rights, but thereafter water rights are administered by the Idaho Department of Water Resources (IDWR). Surface water and groundwater were managed separately in the Eastern Snake Plain until the introduction of integrated use rules in 1994. These rules require groundwater users to replace water taken out of priority.

The US Federal government has had a strong historical involvement in water development and distribution, through major water projects. Under the McCarran

²⁰⁶ Tributary, non tributary, not non tributary and designated groundwater. Non tributary groundwater is almost totally disconnected from surface water. Not non-tributary groundwater is connected but only over a long period of time. The definition for non tributary groundwater is rigorous. A proposed diversion cannot deplete surface streams more than 0.1% of the proposed diversion volume in any single year for up to 100 years. <http://www.blm.gov/nstc/WaterLaws/colorado.html> accessed 15 February 2011.

²⁰⁷ <http://www.legislature.idaho.gov/idstat/IC/ArtXV/Sect5.htm> accessed 11 January 2011

Amendment the United States government can claim the adjudication and administration of certain rights to use water within States' water allocation systems (Kenney 2005). In addition, many water resources in the US overlap state boundaries. These resources are regulated by interstate compacts; self governing arrangements, which prescribe the quantity of water each state can legally appropriate from a shared river basin (Heikkila and Schlager 2008). Colorado is party to nine interstate compacts, including the South Platte River Compact. These compacts have had an important influence on integrated water management arrangements in the state.

8.3 Patterns of integrated water use and management

Integrated water use in New South Wales, Colorado and Idaho is similar in many respects, but the management regime and the balance of high level and lower level authority is very different reflecting the governance principles in the three jurisdictions.

Water users in each region choose between diverse water supplies on the basis of water availability, cost and quality. Interviews with user associations in all three regions indicate that when water users have a choice they usually prefer surface water, because the cost of delivered surface water is usually less than groundwater that they have to extract themselves. Some users depend on groundwater because delivered surface water is unavailable. Many users turn to groundwater during dry periods when less surface water is available. This leads to a cyclical pattern of surface water and groundwater use, with groundwater use peaks coinciding with surface water troughs and vice versa.

Surface water and groundwater management has gone through similar phases in the three regions (Pigram 2006, Heikkila 2000, Sehlke 2000). Initially surface water and groundwater use was not restricted. Then as surface water demand exceeded availability groundwater use increased. Eventually this led to increasing concerns from users and authorities about the impact of groundwater pumping on surface water flows and aquifers. Finally groundwater pumping was restricted and/or groundwater users were required to make good their impacts on surface water users. The three jurisdictions have taken different approaches to groundwater restriction, reflecting the different character of their water governance arrangements.

The New South Wales government placed embargoes on new surface water and groundwater licences in the Namoi region in 1976 and 1984 respectively. Volumetric limits were introduced for surface water licences in 1984 to restrict the growth of water use (Wilkinson 1997). An embargo on stressed groundwater systems was imposed in 1985 (Williams et al 1998). However, both groundwater and surface water licences were overallocated, beyond the availability of the resources. Separate surface water and groundwater plans were introduced in the Namoi region in 2003²⁰⁸. The upper and lower Namoi groundwater plan included large reductions in the volumetric entitlements attached to groundwater licences. The plan was disputed by water users for a number of years, but eventually came into force in 2006 with a 10 year transition period and compensation to the most affected users²⁰⁹.

Colorado's 1969 legislation required tributary groundwater rights to be adjudicated and included in the prior appropriation system. From that time management of tributary surface water and groundwater has been integrated. In Colorado, and more recently in Idaho the claims of senior water rights holders, coupled with the availability of seasonal surpluses of surface water, have driven integrated water management activity. In order to allow continued use and development of groundwater without jeopardising senior surface water rights groundwater users have been required to bring forward long term or temporary plans to supply water to mitigate the impact of pumping on senior surface water rights holders (Blomquist et al 2004). Water is obtained during seasonal periods of high flow (eg during the snow melt) and often returned to the river via the aquifer within months²¹⁰. This arrangement worked well until 2001 when the Colorado Supreme Court ruled that legislation does not give the state engineer authority to approve temporary water supply plans²¹¹ (Blomquist et al 2004). Since then temporary arrangements have been put in force to allow most groundwater pumping to continue, often at a reduced rate, but long term legal agreements have not been established.

In Idaho the 1951 Groundwater Act confirmed that groundwater is covered by the prior appropriation, but until 1994 groundwater and surface water rights were generally

²⁰⁸ Four water sharing plans are now in place covering various water resources in the Namoi region. http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/Plans-commenced/plans_commenced/default.aspx accessed 16 February 2011.

²⁰⁹ Further details in case study 2.

²¹⁰ Usually river returns via aquifers are accomplished through seepage from irrigation ditches or ponds, but sometimes wells are used.

²¹¹ Empire Lodge Homeowners Association vs Moyer 2001.

managed independently. There is a long tradition of surface water users banking seasonal surpluses of water for later use (Clifford et al 2004). Now there is increasing interest in water banking linked with short and long term integrated water management (Contor 2010). In 1994 Idaho promulgated a set of integrated use administrative rules for managing connected surface water and groundwater²¹². These rules require junior groundwater pumpers to mitigate injury caused by their pumping to senior surface water users (Sehlke 2000). Subsequently senior surface water rights holders launched several court actions against groundwater users. In 2006 the Idaho State legislature asked the Idaho Water Resources Board to prepare an Eastern Snake Plain Aquifer Management Plan²¹³. This integrated water management plan is discussed further in following sections.

8.4 The influence of water entitlements and rules on integrated water management

Analysis in the case studies in this thesis and in academic literature (Schlager and Ostrom 1992, Bruns et al 2005) suggests that water entitlements and rules should be:

- Comprehensive: covering access, use, storage, withdrawal from storage, exclusion and transfer;
- Well defined to provide security and confidence to water users and to encourage investment in integrated water management activities;
- Flexible to adjust to variable and unpredictable conditions and to take account of new knowledge;
- Balanced: taking advantage of properties of different water resources and taking account of impacts of the use of each resource on other resources and the environment.

The general characteristics of water entitlements and rules in New South Wales, Colorado and Idaho are summarised in Table 8.1 and discussed in the following sections.

²¹² These were initiated by an Idaho Supreme Court Case Musser vs Higginson.

²¹³ http://www.idwr.idaho.gov/waterboard/WaterPlanning/CAMP/ESPA/PDFs/ESPA_CAMP_lowres.pdf accessed 14th February 2011.

Table 8.1 Water Entitlements and Rules in New South Wales, Colorado and Idaho

	<i>New South Wales</i>	<i>Colorado and Idaho</i>
<i>Coverage & Definition</i>	<ul style="list-style-type: none"> – Comprehensive well defined entitlements for consumptive and non consumptive use – Weakened by exemptions and gaps – No legislated provision for aquifer storage and recovery 	<ul style="list-style-type: none"> – Comprehensive well defined entitlements for consumptive use – Environmental water entitlements managed separately from consumptive use
<i>Flexibility</i>	<ul style="list-style-type: none"> – SW allocation based on shares of available annual resource 	<ul style="list-style-type: none"> – Flexible administration of plans to offset impacts of GW pumping on senior rights holders
<i>Balance</i>	<ul style="list-style-type: none"> – Management rules encourage SW harvesting and storage 	<ul style="list-style-type: none"> – Consumptive SW use has priority

Note: SW = surface water GW = groundwater

8.4.1 Comprehensiveness and definition of water entitlements²¹⁴ and related rules

Schlager and Ostrom (1992, 1996) distinguish five elements of a bundle of rights for common pool resources: access; withdrawal; management; exclusion; and alienation. Access refers to access to a defined physical area, withdrawal refers to the right to appropriate water, management refers to the right to regulate internal use patterns and make improvements to the resource, exclusion refers to the determination of access rights and how they can be transferred, and alienation refers to the right to sell or lease rights.

In principle these categories could cover a complete bundle of resource use rights, but Schlager and Ostrom's discussion centres around rights to appropriate and transfer resources, and to exclude others from their use. The establishment of entitlements to store water in a surface water storage or an aquifer, and then to extract it for use or transfer are also crucial for integrated surface water and groundwater management. These rights are not specifically discussed by Schlager and Ostrom.

²¹⁴ As explained earlier the term water entitlement is generally used in the following discussion rather than the term water right.

Generally surface water and groundwater entitlements and rules are well defined in all of the jurisdictions under consideration. New South Wales has introduced secure, well specified water entitlements for surface water and groundwater that are separate from land and tradable. However, aquifer storage and extraction entitlements have not been established in New South Wales. In Colorado many surface water entitlements were established in the 19th century, and tributary groundwater entitlements were adjudicated in the 1970s. In Idaho groundwater entitlements have not been adjudicated, but conjunctive use rules have been promulgated.

The definition of entitlements for storage and extraction presents some difficulties. Firstly, when water is scarce supplies to users may be limited. In both the Murray-Darling Basin and in the western USA, water supplies have been overallocated (Wilkinson 1997, Blomquist et al 2004, Sehlke 2000). In New South Wales, even in years of average rainfall, some users only receive a proportion of their volumetric “entitlement”, and there are continuing pressures to use any available water. This means that the rights to store water and extract it later must be clearly established and guaranteed or disputes may arise. Secondly, in the case of aquifer storage it is difficult to establish clear and exclusive storage boundaries and use entitlements. Individuals or groups wishing to establish an aquifer storage and recovery project have to share the resource with existing users (Thomas 2001). They also have to mitigate any adverse quantity or quality impacts on existing water entitlements.

In New South Wales water sharing plans include water for both consumptive use and the environment. For example the 238 GL/year limit to annual allowed extractions from the Namoi regulated river ensures that approximately 73% of the long term average annual inflow in these water sources will be preserved and will contribute to the maintenance of basic ecosystem health. The extraction limits in the water sharing plan for the upper and lower Namoi groundwater area are based on a 100% long term annual average recharge less an allowance of approximately 30% for environmental health.

In Colorado, consumptive and environmental water is managed separately. The Colorado Water Conservation Board is authorised to appropriate water for minimum streamflows or natural surface water levels or volumes for natural lakes to preserve the natural environment to a reasonable degree. Appropriations for in stream flows may

only be made by the CWCB, not by private individuals. Augmentation and substitute supply plans have to take account of provisions of interstate river compacts. For example the South Platte Compact requires that between April 1 and October 15 Colorado must ensure river flows do not fall below 120cfs²¹⁵. Colorado has also committed to making 10,000 acre feet of water available between April and September of each year to assist recovery programs for three endangered birds and one endangered fish (Freeman 2011).

8.4.2 Flexibility and balance of water entitlements and related rules

New South Wales, Colorado and Idaho employ a range of methods to enable flexible responses to variable water supplies, and to allow “wriggle room” for regional implementation of laws and policies - see Table 8.2.

Table 8.2 Methods for improving flexibility of responses to variable water supplies

Methods	New South Wales	Colorado, Idaho
Shares of available water	✓	
Supplementary water provision	✓	
Water harvesting	✓	✓
Integrated water use	✓	✓
Integrated water management		✓
Offsets		✓
Carryover	✓	✓
Surface storage	✓	✓
Aquifer storage and recovery		✓
Trading water	✓	✓
Leasing water		✓
Change in land use, crop mix	✓	✓
Buy out	✓	✓
Administrative discretion	✓	✓

²¹⁵ 100 cubic feet per second equals 2.82 cubic metres per second.

In the Namoi and other regions in New South Wales flexibility methods are based on surface water. Firstly, surface water users are entitled to a share of available water in accordance with the class/priority of their right. Secondly, in northern areas of New South Wales, such as the Namoi basin, supplementary water is made available for consumptive use when heavy rainfall events lead to dam spills and high channel flows²¹⁶. Supplementary water provides a large proportion of irrigation water during dry years. Thirdly, individual producers are allowed to harvest up to 10% of inflows on their properties. Individual landholders build high capacity on-farm surface water storages that can store large volumes of supplementary and/or high flow water. This approach may come under challenge for two reasons. Firstly, individual capture of water high flow events can reduce the amount of natural flow, leading to degradation of floodplains and the environment²¹⁷. Secondly, there is a great deal of evaporative loss from surface water storages. Studies indicate that up to 1000 GL evaporates from on-farm surface water storages in the MDB (see Chapter 6 (6.4.1.1))

Rural landholders vary surface and groundwater use during wet and dry periods, but there is no systematic cyclical management of surface water and groundwater in the water planning process. Rural landholders do not make use of aquifer storage and recovery. There are limited carryover allowances/periods²¹⁸. Interannual carryover in New South Wales is limited to three year accounting periods. Groundwater users have more flexibility than surface water users to vary carryover within each accounting period, but the relatively short length of the accounting period limits the scope of water banking and integrated use. The reason for these carryover limits include making sure that users have some access to available supplies each year, and the potential for orders for “carryover” water to severely curtail supplies to some users in dry years. There are also concerns about the impacts of high levels of pumping on groundwater quality and/or groundwater dependent ecosystems (Kalaitzis et al 1998). Groundwater trading is highly regulated to prevent adverse impacts on third parties and the environment. There is only a limited amount of groundwater trade, and no groundwater surface water trade.

²¹⁶ Subject to certain rules and restrictions – see Chapter 6 (6.3.4.1).

²¹⁷ Australian Senate enquiry into the sustainable management by the Commonwealth of water resources http://www.aph.gov.au/senate/committee/ec_ctte/water_licences/report/c02.htm.

²¹⁸ Irrigators in New South Wales have a water access licence with a unit share component (and a works component). Irrigators have 3 year rolling water accounts. Surface water users can use 125% of the share component of their access licence in any one year, groundwater users can use 200% of share component of their access licence in any one year. Surface and groundwater users cannot exceed 300% of share component of their access licence over any three year period.

In New South Wales the Minister and the Office of Water have a high degree of discretion in making water plans. The Minister also has authority to vary water plans in response to extreme conditions and emergencies.

In Colorado and Idaho, augmentation, replacement or substitute water supply plans enable flexible operation of prior appropriation rules. They promote integrated water management by enabling groundwater users to continue to pump water during the irrigation season while mitigating the impact on senior rights holders. In Colorado groundwater users have collaborated to obtain surface water when it is plentiful, for example during the snow melt season. They use various techniques to return water to the river including infiltration from irrigation ditches and ponds, delivery from special purpose surface water storages or simply not using their purchased entitlement.

In Idaho water rights holders have profited from the creation of water banks. In both Colorado and Idaho water transfers have assisted adjustment to water scarcity. Water transfers have helped to reallocate water from rural areas to meet growing urban demand, but have not promoted cyclical integrated water management (Howe and Goemans 2003, Brewer et al 2007). Water leasing does enable cyclical water management by enabling farmers to lease part of their water portfolio to municipalities and to reduce their acreage temporarily through crop rotation or fallowing (Pritchett et al 2008, McMahon and Griffin Smith 2011). In some cases these adjustments have been assisted by the Conservation Reserve Enhancement Program²²⁰.

In all three jurisdictions flexibility methods have been challenged by recent severe droughts, coupled with the over allocation of use entitlements. In New South Wales, in the Namoi and other regions, there was insufficient water to enable 100% supply for high security water users. Groundwater entitlements were subject to severe cuts. In Colorado temporary replacement plans were challenged by senior surface water rights holders. The State Engineer's powers to allow temporary replacement plans were

²²⁰ The Conservation Reserve Enhancement Program (CREP) is a voluntary land retirement program that helps agricultural producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard groundwater and surface water. The program is a partnership among producers, governments and, in some cases, private groups.

curtailed, together with a reduction in administrative discretion, swinging the balance of power back towards the water courts. In Idaho the Eastern Snake Plan Aquifer Plan is an example of a strategic approach to managing variability and uncertainty by means of improved water use efficiency, and reduced irrigation coupled with integrated water management, subject to funds being made available for plan implementation.

8.5 The organisation and implementation of integrated water management

The organisation of surface water and groundwater management affects how users interact and their capacity to coordinate and collaborate in integrated water management.

In New South Wales, Colorado and Idaho multiple jurisdictions and organisations, with different interests are involved in water management. Neither governments nor water users have all the legal competencies, funds, information and other resources necessary for integrated water management. Consequently, stakeholders need to cooperate and pool resources. Government interventions are required to support the efforts of water users.

The balance between higher level direction and local initiative is markedly different in New South Wales and the two US cases as summarised in Table 8.3. The successful implementation of integrated water management depends on striking an effective balance between broad direction and coordination and local initiative in order to get the best possible use of water resources in multiple uses such as agriculture, other industries and municipalities. There are several key building blocks that contribute towards positive interactions between water users, governments and interested third parties: coordination, participation and knowledge.

**Table 8.3 Water Management Organisation(s) in New South Wales,
Colorado and Idaho**

	<i>New South Wales</i>	<i>Colorado and Idaho</i>
<i>Key characteristics</i>	<ul style="list-style-type: none"> – Centralised management led by Minister and the state water agency 	<ul style="list-style-type: none"> – Multilevel governance: water courts, users, water districts, and the state water agency each play an important role
<i>Coordination</i>	<ul style="list-style-type: none"> – Separate planning and management of surface water and groundwater – Some weaknesses in coordination 	<ul style="list-style-type: none"> – Integrated management of consumptive surface water and groundwater – Water for the environment is managed separately
<i>Participation</i>	<ul style="list-style-type: none"> – Consultation with stakeholders often appears more symbolic than real 	<ul style="list-style-type: none"> – Local organisations play a major role in water management – Significant local innovations

Integrated water management requires effective coordination between agencies involved in surface water and groundwater policy, and planning and management across multiple geographical, administrative and time scales. Coordination is also needed between water management and other related activities, notably agriculture, energy, the environment and spatial planning (Turrall and Fullagar 2007, Ross and Dovers 2008, Kenney et al 2001).

Broad stakeholder participation is required to ensure that water management plans are well informed and reflect the views and interests of stakeholders, especially in basins with difficult water allocation and management issues such as overallocation of water entitlements, and diffuse environmental impacts (Sabatier et al 2005, Daniell et al 2010)²²¹. Excluded parties may resist water management initiatives, including integrated water management.

²²¹ It is also desirable that individual benefits are proportional to costs and contributions, and that there is effective monitoring and sanctions to avoid free riding or cheating (Ostrom 2005). In addition effective leadership of user groups and governing bodies can attract resources, overcome resistance and maintain sustained commitment to change (Ross and Dovers 2008). These variables have not been systematically included in the analysis, because that would require collection of information about individuals, and micro situation analysis which is beyond the scope of this study.

Good, shared knowledge and information about surface water and groundwater resources and their value facilitates integrated water planning and rule making. Groups with shared knowledge and common understandings are more likely to collaborate on water management projects (Sabatier et al 2005, Ross and Martinez-Santos 2010). Gaps in knowledge may lead to uncertainty about the viability of integrated water projects.

8.5.1 Coordination and participation

Two models for coordination have been distinguished in the governance literature (Hooghe and Marks 2003). General purpose jurisdictions such as state and local governments in New South Wales, Colorado and Idaho (Type I) cover a wide range of issues and have a limited number of levels whose membership doesn't intersect. Special purpose jurisdictions such as natural resource management organisations in New South Wales and water districts in Colorado and Idaho (Type II) cover a more limited number of issues, but the number of levels is not limited and memberships often intersect. The roles and interactions of these bodies are relatively dynamic. Multilevel or polycentric organisation (a mixture of type I and type II governance) is a more successful model for managing water resources than a hierarchical system, although it can seem relatively chaotic (Ostrom 2005, Blomquist and Schlager 2008).

The strength of coordination and engagement varies from communication, consultation and avoiding policy divergence at the weaker end of the spectrum, to seeking consensus, arbitration of disputes and joint strategy and priorities at the strongest end (Metcalf 1994).

New South Wales has a relatively centralised and hierarchical system of water management and planning, with relatively weak coordination in terms of the Metcalfe scale. Water management and allocation in New South Wales is highly centralised in the hands of the Minister and the Office of Water, who are responsible for determining and issuing water entitlements. State Water, a state owned corporation, is responsible for water distribution and delivery in rural areas, in partnership with private irrigation

organisations²²². Surface water and groundwater policy and planning are broadly coordinated at the highest levels of decision making, but separate at lower levels.

Office of Water staff draft water sharing plans in consultation with management committees which include catchment management organisations, farmers, industry, municipal and indigenous representatives. However, consultation often appears more symbolic than real, because it takes place after policy changes have been made and/or does not take sufficient account of stakeholder views (Bowmer 2003). Also, the Minister may overrule the consultative document and make a separate plan. This can provoke conflicts and legal action, as in the case of the upper and lower Namoi groundwater plan (Gardner 2009)²²³, but so far there is no case of a plan being stopped by court action.

Catchment management organisations represent an interesting innovation to integrate policy at the regional scale. They are appointed by the state government, and have responsibilities for land and environmental conservation and water quality but not for water allocation. However, the effectiveness of these organisations, including the Namoi Catchment Management Authority, is constrained by the limits to their delegated functions, and limited personnel and budgets (Ross 2008, Robins and Dovers 2007).

New South Wales Government representatives who were interviewed generally consider that policy and implementation functions are integrated effectively. The Office of Water endeavours to consult stakeholders, take account of their views. The Office also endeavours to coordinate water planning processes with catchment natural resource management plans to achieve public benefits. However, water users and other stakeholders who were interviewed consider that some functions are poorly integrated. Examples include lack of clarity about rules for environmental water, and the separation of management of overland flows, stock and domestic bores, and issues related to water in the mining sector from other water planning and allocation processes.

Colorado has relatively decentralised polycentric water management which involves a partnership between national bodies, the State assembly, water courts, the Department

²²² A range of public and private water businesses are responsible for water delivery in urban and rural areas <http://nwc.gov.au/home/water-governancearrangements-in-australia/new-south-wales/water-supply-and-services> accessed 21 February 2012.

²²³ As in the case of the upper and lower Namoi groundwater plan (Gardner 2009).

of Water Resources (DWR)²²⁴, and municipalites and water user associations. Water courts rather than state officials define (adjudicate) and enforce appropriation of rights, including the amount, priority, location and beneficial use of water rights, the approval of exchanges and plans for augmentation. Fifty water conservancy districts at the sub basin scale perform an important range of activities including development and management of water projects, augmentation plans, water conservation, distribution, water quality protection, flood control, legislation and education.

Coordination of water management is generally weak in Colorado, but there is strong coordination between surface water and groundwater users, authorities, and water courts in relation to augmentation and replacement plans. Plans by junior groundwater users to meet senior surface water rights have driven development of integrated water management projects. State authorities have a facilitating rather than a leadership role. There have been a number of occasions when the State or a divisional engineer has tried to promulgate rules and these have been stopped or amended in the water court. The relative power of senior water rights holders was illustrated in 2002, when senior surface water users challenged temporary supply plans by groundwater users (Moyer case) (SPTF 2007).

Idaho represents a middle ground between New South Wales and Colorado, where there is a degree of central management and planning led by the Idaho Department of Water Resources (IDWR), but water courts, water districts and water user associations also play important roles in management. The Idaho Department of Water Resources leads water management in the state, administers water rights and distributes water. The Department promulgates rules and makes decisions to give effect to the prior appropriation system – including conjunctive use rules. Like its Colorado counterpart, the IDWR is responsible for assisting the courts and the adjudication of water rights, and enforcing the state’s water laws. The IDWR has established more than 100 water districts (70 of which are active) to implement water rights and coordinate the management of the state’s water (IWRB 2010). The preparation of the Eastern Snake Aquifer Plan represents a notable effort to prepare an integrated regional plan with a number of integrated water management initiatives, even though there are a number of implementation challenges to be overcome (see case study 3).

²²⁴ DWR is headed by the State Engineer. There are divisional engineers in each of the seven major water divisions.

8.5.2 Knowledge and information

The three water management areas covered in this chapter have each been extensively studied. Surface water and groundwater models have been established and there is extensive monitoring and metering of use. A strong information base with shared understanding among stakeholders about resource conditions has played an important part in the management of stressed water supplies in all three regions.

For example in Idaho technical aspects of the Eastern Snake Plain aquifer hydrogeological system have a substantial effect on water users and management. The definition of aquifer boundaries determines which groundwater users may be held accountable for depletion of surface water supplies. The identification of hydraulically connected river reaches partly determines which surface water users may legitimately claim adverse impacts from groundwater pumping. The distribution of aquifer transmissivity and storativity largely controls the direction and rates of propagation of groundwater pumping and recharge effects (Johnson et al 1999).

The Namoi Catchment is one of the better studied regions with respect to groundwater in NSW and numerous data sets have been collected over the past 50 years. Hydrological and hydrogeological models have been developed and used in water planning in New South Wales (Williams et al 1998). However, data is not easily accessible to users. For example, state agencies do not systematically share data with other stakeholders on groundwater conditions, quality or availability in areas regulated under Water Sharing Plans, largely because of limited staff and budgets. Moreover, engagement of users (farmers) does not persist beyond the planned development stage, and farmer participation groups become dormant (Holley and Sinclair 2010).

Changing knowledge means that the success of water management initiatives including integrated water management requires knowledge sharing, and the timely supply of knowledge to users and decision-makers. For example, water sharing plans in the Namoi and augmentation plans in Colorado could not succeed without a shared understanding between users and authorities about water resources and the aims of water management (Kuehne and Bjornlund 2004, Lepper 2006).

Nonetheless many knowledge gaps remain about the effects of surface water groundwater interaction and its impacts on water quality and the environment. Estimates of recharge, discharge, evapotranspiration and storage losses, irrigation returns to aquifers, interactions between groundwater and vegetation, and the effects of irrigation on salinity and water quality are imperfect. More work is needed on catchment water balances and integrated surface water and groundwater models (Kelly et al 2007, Gates et al 2006).

Estimates of sustainable groundwater use are often disputed for a variety of reasons, both by scientists (Sophocleous 2000, 2002, Moench 2007), and also by users (Turrall and Fullagar 2007). When there are uncertainties and data gaps, iterative policy development is needed with an emphasis on learning from experience and adaptive management. This places a premium on effective monitoring and review to provide feedback that enables learning and guides future policy development. Therefore it is important to prepare the ground and gain acceptance for adaptive strategies, even if these are difficult to implement in a world of short term political cycles (Allan and Curtis 2005). Experience indicates that great effort is needed to explain scientific outputs, and to get affected parties to accept scientific uncertainty and iterative solutions (Martinez-Santos et al 2007). Gaining feedback through public seminars and discussions is insufficient, and ongoing engagement of and effective collaboration between policy makers, scientists and practitioners is required (Letcher and Jakeman 2002).

8.6 Discussion

8.6.1 General assessment of integrated water management in New South Wales, Colorado and Idaho

Integrated water management depends on the properties of surface water and groundwater resources, the characteristics of water users and the governance system and interactions between resources, users and the governance system. Integrated water management is complicated by shortfalls in information about groundwater, the connections between groundwater and surface water and their impacts; gaps and imbalances in water use entitlements and rules; and problems of coordinating action

across spatial, temporal and administrative scales. Integrated water management is easy to say but hard to do. Integrated management needs to be tailored to regional and local circumstances using an adaptive approach to respond to emerging conditions and knowledge.

The Namoi region in New South Wales, South Platte region in Colorado and Eastern Snake Plain in Idaho have some similar biophysical and socioeconomic features. The three regions share a similar surface water centric pattern of development of their water resources, but the institutional development has been different. Surface water was developed first, followed by surface water management arrangements. Groundwater development came later, and groundwater management arrangements were strongly influenced and shaped by impacts of groundwater pumping on surface water.

Experience in New South Wales, Colorado and Idaho (and elsewhere) suggests that effective integrated and adaptive water management requires water entitlements and management rules that are comprehensive, well-defined, flexible and balanced.

In New South Wales the management of water for consumption uses and the environment is integrated in water law and planning, but surface water and groundwater planning and management have developed separately. Comprehensive separate and tradable water entitlements have been introduced more recently than in Colorado. Some elements of a comprehensive system of water entitlements, such as entitlements for storing water in aquifers and extracting it, and entitlements for using dam spills and overland flows have not been established. The management system encourages individual surface water harvesting and storage, but does not encourage carryover or aquifer storage and recovery.

The prior appropriation system of water allocation in Colorado and Idaho has driven the development of a comprehensive system of water use entitlements. The management of surface water and groundwater for consumptive use is integrated, while water for the environment, for example in stream flows, is managed separately. The prior appropriation system provides very well defined priorities and entitlements for consumptive water use. The system has encouraged local management and innovation; for example, augmentation and temporary supply plans by groundwater users. However, the system has not proved flexible or robust during severe drought in the

South Basin. Calls by senior surface water users led to a reduction rather than an increase in groundwater pumping during periods of severe surface water scarcity. In this case prior appropriation reduced the potential of cyclical surface water and groundwater use as an adjustment mechanism for variable water supply. This led to wells shut down with adverse economic and social consequences in the medium term.

The successful implementation of integrated water management depends on striking an effective balance between broad direction and coordination and local initiative in order to get the best possible use of surface water and groundwater in multiple uses: agriculture, industries, domestic consumers and the environment (Ross and Dovers 2008, Turrall and Fullagar 2007).

Water management in New South Wales is relatively hierarchical and centralised. This system provides strong strategic direction, integrating the full range of consumptive and non consumptive uses of water. The system is relatively low cost, and can respond quickly and flexibly when water use crises or conflicts occur. The weakness is lack of responsiveness to local circumstances and inadequate community engagement, as illustrated by the 2003 Namoi groundwater plan. Centralised management does not give much incentive for local innovation. There is also a risk that a water governance system and plans developed over a long period of time at substantial cost may be undermined or abandoned because of short term political considerations.

The relatively decentralised multilevel governance system in Colorado provides a secure and stable system of water allocation with integrated surface water and groundwater management. It encourages community participation and innovation. The disadvantages are that there is no overall integrated river basin planning and the management of water for the environment is not systematic. Also management lacks flexibility to cope with abnormal situations. This can lead to perverse well closures when senior water rights holders insist on their rights regardless of the social and political costs, as occurred in the South Platte after 2002. In addition, management can be relatively costly for participants, and parties without adjudicated rights are excluded from negotiations. Informal agreements reduce costs but may not be robust during water scarcities.

Idaho represents a “hybrid” case where the water courts adjudicate water rights, but the Idaho Department of Water Resources manages the conjunctive use rules and determines the validity of replacement plans. The Eastern Snake Plain Aquifer Plan represents a particularly interesting example of an integrated surface water and groundwater management plan. This includes conversion of some groundwater rights to surface water, managed aquifer recharge and a suite of voluntary demand reduction measures. The achievement of this plan depends on continuing cooperation and financing by water users and governments.

8.6.2 Opportunities for improving integrated water management

8.6.2.1 Cyclical integrated water management, storage and trading

Integrated cyclical management of surface water and groundwater can provide efficient and flexible use of water, address the impacts of water use on other users and the environment and help adaptation to climate variation and uncertainty. Effective and efficient storage is vital for optimising surface water and groundwater use. The development of water storage in the Murray-Darling Basin, Colorado and Idaho has emphasised the capture of water flows in surface water reservoirs. The capacity of reservoirs and on-farm surface water storages in the MDB substantially exceed annual surface water use, but they have not provided sufficient reserves in prolonged severe droughts. High rates of evaporation, especially during summer, are a major disadvantage of surface water storage.

In countries with scarce or variable water supplies the management and allocation of water supplies based on long term averages of water in storage (stocks) rather than flows might provide relatively greater security, stability and flexibility than allocations based on volumetric shares (see Box 8.1). Whether the management and allocation of water is based on flows or stocks, aquifer storage and recovery enables surplus water to be stored in wet seasons or years for use in dry seasons or years and has the potential to provide a buffer against the most severe droughts.

Box 8.1 A sustainable water use regime based on stock management

In countries with a dry climate and variable water supply it is difficult to determine sustainable use of water resources. The management of highly variable inflows involves difficult tradeoffs between providing security of supply and flexible responses to changing climatic conditions and knowledge. In these countries the management and allocation of water supplies based on long term averages of water in storage (stocks) rather than inflows may provide relatively greater security, stability and flexibility than allocations based on volumetric shares.

A stocks based allocation regime would actively manage underground water storage to maintain aquifer condition and to ensure that short term overdrafts do not turn into chronic resource depletion.

Surface water resources are highly variable and communities that depend upon them are subject to boom and bust cycles²²⁵. Some animals and plants are well adapted to highly variable water supplies, with long breaks between watering. Humans have adapted to variable water supply by creating surface water storages and transmission infrastructure to smooth supply fluctuations. However, in dry periods surface water storages are drawn down, and human users turn to groundwater, where it is available, to supply human consumptive needs and keep industries going.

Aquifers provide most of the planetary storage of fresh water. In dry countries with a highly variable water supply such as Australia, the western USA and Mediterranean region, groundwater resources are relatively stable. Where they are available they provide a relatively stable and secure basis for meeting top priority human requirements such as drinking water, livestock, industry, and perennial crops, including vineyards, orchards and forestry²²⁶.

It could be advantageous to take the further step of basing water management in dry regions with highly variable rainfall on groundwater storage and extraction, and managing surface water as a supplementary resource with a critical stock replenishment function during wet periods. What would be the elements of such a management regime? What would be the implications?

Groundwater could be used as the primary resource for meeting top priority human consumptive needs where there are sufficient stocks of appropriate quality groundwater proximate or connected through transmission infrastructure to major sources of demand. These conditions exist in some catchments in the MDB, the western USA and Spain. In the MDB, under a dry climate scenario (similar to conditions that prevailed during most of the previous decade) all of the catchments in New South Wales, Queensland and the Eastern Mount Lofty catchment in South Australia are forecast to be more than 50% dependent on groundwater by 2030²²⁷.

Conventional methods of managing and allocating available water supplies based on inflows raise questions such as the time periods used for estimating availability, means of allowing for interseasonal and interannual variations and priorities for allocating water when supplies are scarce.

²²⁵ This applies to animal and plant populations and human activity such as agricultural production.

²²⁶ These uses are equivalent to "critical human needs" and high security water entitlements in the current MDB water management regime

²²⁷ Historically Victoria has relied less on groundwater than other MDB states, and has experienced substantial problems from saline groundwater, but groundwater use is likely to rise substantially if a drier climate persists.

If groundwater were treated as the primary resource, groundwater recharge would become a (if not the) primary policy goal and the basis for establishing sustainable consumptive use. In the case of large aquifers, recharge could be averaged over many years to determine sustainable extraction levels. This would allow considerable smoothing of supply through time, and alleviate some of the problems of allocating highly variable surface water flows.

The first priority for surface water use would be to satisfy environmental water requirements. This would allow environmental water supply to be aligned with natural inflow, and enable natural systems to adjust over time to changing inflows e.g. drying. The second priority for surface water use would be to supplement groundwater in providing for town water supplies, stock and domestic and other high security water entitlements. The third priority would be to ensure, and if necessary augment groundwater recharge/storage. A fourth priority for surface water use would be industries and enterprises that could operate opportunistically using intermittent and unpredictable water supplies²²⁸.

The groundwater management regime would need to become more uniform and comprehensive, with municipal, agricultural, mining and industrial users treated equally and subject to the same regulatory requirements. Groundwater trading would play an increasing role in water management, including trading between towns, mining industries and irrigation districts.

There would be resistance from vested interests to any such fundamental change, and there would be winners and losers. US experience suggests that there could be trading of groundwater entitlements away from agriculture (both irrigation and stock and domestic) to municipalities and mining industries with deep pockets. But agricultural industries would have opportunities to lease groundwater entitlements to towns or industries during dry periods or on a longer term basis. Agriculture could also share the net benefits (revenues) from water storage in rural aquifers.

There are a number of issues that require further examination/research, including:

- What is the physical feasibility for aquifer storage and groundwater extraction to provide drinking water supplies for towns, and water for industries and perennial agriculture?
- Is there sufficient water and aquifer storage space to enable a management regime based on underground storage and extraction²²⁹?
- How does the physical feasibility of aquifer storage and extraction improve when natural recharge is augmented by managed recharge using high rainfall events, dam spills and recycled water (irrigation recharge, stormwater, wastewater and mine water)?
- What are the benefits and costs of aquifer storage and extraction compared to current methods of capturing overland and ephemeral streamflows including impacts on evaporation, conveyance losses, supply reliability, water quality, delivery costs and third party (including environmental) impacts?
- Is private diversion and harvesting of overland flows inconsistent with reliance on groundwater stocks to meet critical human needs? Would additional regulation of private diversion and harvesting be needed?
- What institutional changes would be required to implement a stock/groundwater based management regime, for example, legal entitlements for groundwater access, use, storage, recharge and groundwater trading, and regulation of interception including channel and overland flow harvesting (farm dams and other), stock and domestic use and forestry?

²²⁸ Rice farming is one example

²²⁹ This question can only be answered at a catchment or sub catchment scale. The first step would be to do a pilot study

In Colorado groundwater irrigators use a mixture of aquifer and surface water storage. Many of the augmentation and substitute water supply plans have been based on managed aquifer recharge and recovery within individual years or irrigation seasons. Recharge in alluvial aquifers will continue to play an important role in the South Platte region (Wolfe 2008). A Colorado Water Conservation Board (CWCB) study identified a large potential for aquifer recharge in a number of regions (CWCB 2007). There may be opportunities for longer-term aquifer storage and recovery, and water banking to provide increased security and adaptability in response to variable water availability.

Water banks have been established in some States in the US (Clifford et al 2004). The functions of these banks vary, but they usually include holding water entitlements, releasing them for later use, setting prices and intermediary/clearinghouse/broking functions. There is scope to further develop water banks when water storage and recovery is feasible, when the ownership of stored water and the entitlements to withdraw it are clear, including any allowance for losses.

In New South Wales irrigators do not use aquifer storage. Aquifer storage and recovery (ASR) offers opportunities for both water saving, and smoothing water supply. Studies indicate that around 4000 GL evaporated from surface water storages in the MDB in 2009-10, about 1000 GL from on farm storages and 3000 GL from large storages (see chapter 6.4.1.1). Evaporation from water storages is one of the biggest barriers to increasing water use efficiency especially in the northern part of the MDB, which receives much of its rain in large isolated rainfall events. ASR could be used to provide holding storage for dam spills, occasional high river flows and floods. It could also be used to re-regulate water supplies to better align water delivery with demand. Clearly specified individual entitlements and management authorities for storage and extraction would be required in order provide certainty and security for investors, and to reduce transaction costs. Extension of these carryover periods would allow water users to use surface water and groundwater more flexibly over the typical 5-7 year wet and dry climate cycle (see Attachment 7).

Surface water groundwater trading offers opportunities to improve spatial and temporal access to water (Purkey et al 1998). Two way surface water groundwater trading is feasible in connected systems, although potential impacts must be addressed. These impacts depend on the unit volumetric impact of a surface water groundwater transfer

and the consequent effect on river flows and groundwater dependent ecosystems. The time lags of impacts also have to be taken into account. Surface water groundwater trading is easiest when surface and groundwater resources are highly connected and where connections are rapid. When resources are less highly connected and/or the connections are slow the impact of trading is more complicated and/or more uncertain (SKM 2011). Trading requires significant supplies of both resources and sufficient storage facilities to enable integrated water management. Surface water groundwater trading is facilitated by rules that permit water carryover, banking and borrowing and storage and recovery of undergroundwater. These requirements are not currently met in most areas within the MDB, other than in South Australia²³⁰.

In Colorado, transfers from agriculture to urban areas are likely to increase substantially. For example the State Water Supply Initiative study (CWCB 2004) concluded that the number of acres of irrigated land in the South Platte River Basin will be reduced by one third, 133000 acres, to 226000 acres by the year 2030). In Colorado agricultural water entitlements are leased to cities to augment supplies during dry periods. The payments for leases compensate farmers for reduced production during dry periods, and enable them to survive through drought. Some trading of surface water entitlements along the River Murray has achieved similar benefits (NWC 2010).

8.6.2.2 Management organisation and integrated water planning

The New South Wales government is responsible for setting goals for integrated water management. It is debatable whether the State government should prescribe the means for achieving those goals at the regional scale, especially when this involves cuts in water entitlements. Catchment management organisations, such as the Namoi Catchment Management Authority have achieved some promising results. They have the potential to play a larger role in integrated water management at the regional scale, subject to the further development of processes to ensure their accountability and a well balanced representation of interests (Ross 2008). Local and regional bodies could play a larger role in water planning and management if there were increased delegation of responsibility to these bodies, increased funding or fund raising capacity and support from high level leadership.

²³⁰ Victoria is developing a policy relating to managed aquifer recharge (MAR) to clarify the approvals process and licensing framework - further details are in section 4.3.4.

Integrated water management in Colorado could be improved by strategic watershed planning that integrates consumptive and environmental requirements and gives governments and users an opportunity to adjust the prior appropriation doctrine in order to achieve improved water management outcomes. One option is for the State to set performance goals for the protection of water resources, water user communities and water dependent habitats, and to allow local governments the first opportunity to develop action plans to meet the goals (Thompson 2010).

The Eastern Snake Plain Aquifer Plan in Idaho provides an example of an integrated surface water and groundwater management plan, including conversion of some groundwater rights to surface water, managed aquifer recharge and a suite of voluntary demand reduction measures (IWRB 2009)²³¹. Drought planning and management for the Jucar basin in Spain provides a further example of flexible integrated surface water and groundwater management planning, albeit in a different institutional context (Andreu et al 2009).

Regional water management requires an array of knowledge and skills including hydrology and hydrogeology, engineering, agricultural science, law, economics, environmental management, and skills and policy coordination communication and mediation (Connell et al 2007). Substantial benefits can be gained from linking hydrology, hydrogeology and social science training for water professionals. Also information on surface water and groundwater resources is often fragmented and difficult to access. Consolidation of national water information responsibilities in the Bureau of Meteorology is a promising initiative to resolve this problem²³².

Groundwater management units in national State government agencies are often very small and separated from other water management functions or even placed within different organisations. The delivery of an integrated Murray-Darling Basin plan requires increased profile, staffing and integration of groundwater specialists into general water management functions.

²³¹ Idaho Senate Concurrent Resolution Number 136. Further details about the ESPA Planning process are at <http://www.idwr.idaho.gov/WaterBoard/WaterPlanning/CAMP/ESPA/espa-process.htm> accessed on 6 January 2010.

²³² <http://www.bom.gov.au/water/> accessed 2 March 2011.

8.7 Conclusions

Integrated water management depends on the properties of surface water and groundwater resources, the characteristics of water users and the governance system and interactions between resources, users and the governance system.

Effective integrated water governance requires a comprehensive, flexible and balanced system of water entitlements and rules including provisions that allow extended water carryover/banking, aquifer storage and recovery and water trading. The successful implementation of integrated water management requires broad direction by high level governments and more detailed local planning and initiatives tailored to local resources and user communities.

The case studies illustrate that both the New South Wales and Colorado system have particular strengths. The New South Wales system enables comprehensive planning, taking account of environmental impacts. The Colorado system gives more autonomy to local water districts and water users, which encourages innovations that support integrated water management.

There is no simple formula for integrating surface water and groundwater management and use. In particular it is difficult to craft long lasting water governance arrangements that will be robust during severe unexpected water scarcities.

Part IV

Part IV summarises the findings of this research, and includes a discussion of opportunities for advancing integrated water management and for further research

Chapter 9: Integrated water management: governance, instruments and opportunities

9.1 Introduction

Surface water and groundwater are two parts of one connected global water resource. Most surface water resources are connected to groundwater and vice versa, but the use, storage and exchange of these resources are usually managed separately. The research in this thesis has explored factors affecting the integration of surface water and groundwater management by means of comparative case studies of integrated water management in the Murray-Darling Basin, Colorado and Idaho. The research has also looked at opportunities for and barriers to integrated water management and options for progressing integrated water management. The main findings of the research and suggested follow up actions are summarised in Table 9.1 (a and b).

The research in this thesis confirms the findings of previous studies (Blomquist 1992, Blomquist et al 2004) that water entitlements, operational rules and management organisation(s) have a powerful influence on integrated water management. More specifically, integrated water management depends on the implementation of a comprehensive clearly defined set of entitlements and rules to use, store and exchange surface water and groundwater, and the development of well coordinated, well informed, participative management organisation(s). The lack of entitlements and rules for aquifer storage and recovery are a constraint to integrated water management in New South Wales.

The research also found that rules and/or their implementation also need to allow flexibility to respond to variable water availability and changing knowledge and priorities. Examples of flexibility mechanisms include the provision of annually determined shares of available water in New South Wales and temporary supply plans that have allowed out of priority groundwater pumping in Colorado.

Table 9.1a Main findings: factors affecting integrated water management (IWM) in the Murray-Darling Basin, Colorado and Idaho

Question	Findings	Action required ²³³	Chapter
Factors that affect IWM	Water entitlements operational rules and management organisations play a key role <ul style="list-style-type: none"> – Resource properties and connectivity affect the scope for IWM – Institutional path dependency can be a barrier to IWM 	Research on path dependency and effects. Develop strategies to overcome "institutional stickiness"	2, 5 and 8
Importance of comprehensive, clearly defined water entitlements	Confirmed - comprehensive, clearly defined secure water entitlements play a key role <ul style="list-style-type: none"> – mechanisms that allow a flexible response to changing conditions and knowledge are also very important 	Clarify water entitlements and fill the gaps (NSW) Further theoretical and practical development of flexibility mechanisms (MDB, western USA)	5 and 8
Importance of well coordinated, well informed participative management organisation(s)	Confirmed - gap between high level strategies and plans and action on the ground can be a barrier to IWM	Further development of coordination mechanisms and local and regional organisations	5 and 8

Integrated water management is also influenced by resource properties and their connectivity, and policy and institutional path dependency. Integrated water management is both more important and more straightforward when surface water and groundwater resources are highly connected and the connections are rapid.

The case studies show the persistent influence of different policies and governance arrangements. In Colorado prior appropriation has encouraged integrated water management; in New South Wales the water management system has encouraged dependence on surface water (see 9.4.1).

²³³ Further research opportunities are discussed later in this chapter and summarised in 9.4.5.

Table 9.1b Main findings: opportunities and options for improving integrated water management (IWM)

Findings	Action required	Chapter
Cyclical, intertemporal, management of surface water and groundwater resources, stocks and storage would lead to better adaptation to water variability and scarcity	Further development of policies and plans for cyclical intertemporal management of water use and storage in the MDB and western USA Establishment of entitlements and rules for aquifer storage and recovery in the MDB	2, 5 and 8
Aquifer storage and recovery (ASR) and water banking are important strategies for IWM	Further ASR research and pilot projects in the MDB Further development of institutional arrangements for water banking, including carryover in MDB and western USA	5 and 8
Implementation of IWM can be improved by mixture of high-level strategic integrated planning and lower-level operational management	Further development of comprehensive cyclical integrated water management plans in the MDB and western USA Further development of regional water management organisations in the MDB	5 and 8

The most important findings in the research are about the advantages of integrated cyclical water management, and the potential for aquifer storage and recovery and water banking. Integrated surface water and groundwater storage is the missing link in Australia's otherwise comprehensive water reform. In Colorado and other States in the western USA surface water priority has driven innovation by groundwater users in water storage and recovery, and there is scope for further developments in this field.

Integrated cyclical management of water resources and storage can help communities and the environment to adapt to increasing water variability and scarcity. There are substantial opportunities for integrated cyclical surface water and groundwater management with aquifer storage and water banking in the Murray-Darling Basin, elsewhere in Australia and in other countries.

The remainder of this chapter proceeds as follows. The chapter begins with a summary of the findings of the basin and sub-basin case studies in chapters 4-8. This is followed by a discussion of the implications of the case studies for the future design and

implementation of integrated water management in the case study areas and elsewhere. The chapter continues with a discussion of some theoretical issues arising from the case studies, and issues for further research.

9.2.1 Factors affecting the integration of surface water and groundwater use and management in the Murray-Darling Basin

The first case study (chapters 4-5) examines factors affecting integrated surface water and groundwater use and management across the Murray-Darling Basin as well as specific examples of integrated management in the Basin States. Integrated surface water and groundwater management is an objective of the Australian National Water Initiative and legislation in the MDB jurisdictions. Many individuals and organisations in the MDB use both surface water and groundwater, but many aspects of the management of and research on surface water and groundwater remain separate; such as sustainable development limits, water entitlements, water resource plans and water transfers. Integrated water management is only found in a few very highly connected resources. This reflects the separate evolution of surface water and groundwater policy and priorities, with groundwater management being the junior partner.

There are a number of reasons for slow progress towards integrated surface water and groundwater management in the MDB:

- Mismatches between surface water and groundwater boundaries;
- Shortfalls in information about groundwater, the connections between groundwater and surface water and their impacts;
- The persistence of attitudes, practices and infrastructure arising from the historical priority given to surface water development and the relative neglect of groundwater management and monitoring;
- Gaps and exemptions in water use entitlements and rules;
- Limits on carryover, and a lack of rules to enable underground storage of water and subsequent recovery;
- Separate management of surface water and groundwater, except at the highest levels of administration;
- Shortfalls in coordination of surface water and groundwater management and research; and

- Limited engagement of stakeholders in water planning and management.

Authorities have been reluctant to encourage increased groundwater use as part of a cyclical water management strategy because some aquifers are already fully exploited or near full exploitation. Although it is often argued that there is no surplus surface water for underground storage because surface water is fully allocated, there are seasonal high flows in some catchments. Moreover, entitlement holders receive an annually assessed share of available surface water. This opens the door for water supply organisations and water users to store shares of available surface water underground in wet years, and create water banks to smooth water supplies through time and act as a dry year resource.

9.2.2 Comparative analysis of integrated water management in New South Wales and Colorado

The second case study (chapters 6-8) looks at the effects of different systems of water entitlements, management rules and management organisation on the integration of water management in New South Wales (NSW) and Colorado. Theory and experience²³⁴ suggest that integrated management will be promoted by water entitlements and rules that are:

- Comprehensive, well defined and secure - covering access, use, storage, withdrawal from storage, exclusion and transfer;
- Flexible to adjust to variable and unpredictable conditions - for example, by using more groundwater in dry periods and replenishing aquifers during wet periods;
- Balanced - taking advantage of properties of different water resources, and taking account of impacts of the use of each resource on other resources and the environment.

The two jurisdictions have taken different approaches to providing definition, security, flexibility and balance, reflecting the different character of their water governance arrangements.

²³⁴ See section 8.4.

In Colorado integrated water management is clearly defined and driven by the seniority of water use entitlements, enforced by the courts, and administered by government organisations, water districts and water users. Flexibility has been introduced into the water allocation system by allowing junior groundwater users to bring forward long term and temporary plans to offset the impact of their pumping on senior surface water users. Water trading and leasing have provided further flexibility mechanisms. In the South Platte Basin this system proved robust for 30 years until the 2002-04 drought, when groundwater pumpers could not obtain surplus surface water and several hundred wells had to be shut down with significant socioeconomic losses. Water for environmental purposes is managed separately from water for consumptive purposes, and environmental allocations are often driven by federal environmental law.

In NSW water plans, developed by state administrations specify allocations of water for consumptive and environmental purposes. Generally plans and rules for surface water and groundwater use and exchange are developed separately. The main flexibility mechanism is surface water entitlement “shares”, that vary according to volumes of water in reservoirs, and water accounts with limited carryover provisions. These arrangements enable only limited flexibility in response to medium term cycles in water availability. Groundwater trading is highly regulated to prevent adverse impacts on third parties and the environment. There is only a limited amount of groundwater trade, and no groundwater surface water trade.

The polycentric governance system in Colorado enables water allocation by means of clearly defined legal processes, and encourages community ownership and participation. This has encouraged technical innovation by groundwater users and government agencies. The risk of this approach is a lack of comprehensiveness and consistency. The groundwater user plans in Colorado do not take account of environmental water needs. Also the system can be costly for users, and parties without adjudicated rights are excluded from negotiations.

The relatively hierarchical government led system in NSW enables a comprehensive and flexible approach to allocating water and resolving (or deflecting) conflicts. The risk of this approach is lack of broad community engagement and support, and relative lack of incentive for innovation by water users or regional and local governments.

9.3 Instruments and implementation

In chapter 3 several properties of a water governance system and interactions were identified that encourage integrated surface water and groundwater use and management. These are:

- Secure, well defined entitlements to use, store, extract and transfer surface water and groundwater;
- Well defined, flexible rules for use, carryover, storage, recovery and exchange of surface water and groundwater;
- Coordination and capacity of surface water and groundwater management;
- Good shared knowledge of surface water and groundwater resources, their connections and condition;
- Participation of surface water and groundwater users in planning and implementation;
- Effective monitoring and enforcement.

The following discussion of instruments and implementation reflects and elaborates on these properties, drawing on the findings of the case studies. Water entitlements and rules are the primary instruments for integrating surface water and groundwater management. Knowledge management, coordination and participation are key elements in the management organisation required to implement integrated water management.

9.3.1 Instruments for integrated water management: entitlements and rules

Entitlements and rules for integrated water management can be broadly divided into three categories; surface water and groundwater use, storage and exchange. Each source of water requires clearly defined entitlements and rules to enable sustainable and efficient operation. Gaps in the structure of entitlements and rules increase transaction costs and the difficulty of integrated water management. At the same time flexible implementation of water entitlements and rules is needed to allow for unforeseen conditions, including droughts and floods, and changes in knowledge.

When surface water and groundwater resources are connected impacts of the use of one resource on the other need to be considered when establishing sustainable use limits and entitlements for each resource. This is complicated by the fact that the impact of groundwater pumping on stream flow, or of surface water diversion on recharge, varies substantially along river reaches and across aquifers.

9.3.1.1 Entitlements for using connected surface water and groundwater

Well defined, secure entitlements to use water within the sustainable yield of a water resource provide incentives for investment in resource management, and support collective management efforts to maintain water resources.

When either surface water or groundwater in a connected resource is fully or overexploited the issue of entitlements to use one or both resources should be limited to avoid adverse impact on connected resources and water dependent ecosystems.

Surface water is usually developed to full exploitation or overallocated before sustainable use limits are introduced. Generally the development of groundwater to full exploitation and the introduction of limits takes place after surface water use limitations are already in place. Groundwater limitation may be further delayed by lags in use impacts, but embargoes on the issue of further entitlements have been placed on many groundwater resources in the Murray-Darling Basin.

In practice water entitlements are often issued and held in excess of the sustainable yield of water resources. This assists adaptation to changing conditions. When it results in an excess of actual use over sustainable use²³⁵ strategies such as issuing entitlement “shares” (see 9.3.1.2) are needed to allocate water between entitlement holders or the number of entitlements may have to be reduced. Reduction of legal entitlements can lead to legal claims for compensation, as in the case of Namoi region groundwater resources.

²³⁵ Excess water entitlements do not necessarily lead to excess use. Many entitlements are not fully exercised all the time; for example, some entitlements are held as a precaution against water shortages, some because of changing demand by households over wet and dry periods, and some because of cyclical changes in demand for agricultural products.

Entitlement buyback can directly address overallocation of surface water or groundwater entitlements coupled with excess use. Entitlement buyback is costly for governments and only used as a strategy of last resort, although it can sometimes be cheaper than other strategies such as irrigation efficiency improvement (Grafton et al 2010).

In some cases locational constraints on the issue of new surface water or groundwater entitlements can be used to reduce the cross connection impacts of water use. In groundwater systems this is commonly done by establishing zones around rivers and only allowing new pumping entitlements outside those zones.

The provision of supplementary sources of water such as water transfers or recycled water may avoid the need for entitlement reductions or use limits. Additional water supplies may be provided from floodwater following high rainfall events, transfers from other resources or recycled water.

9.3.1.2 Rules for using connected surface water and groundwater

Rules for managing connected surface water and groundwater resources need to be coordinated to achieve the best possible use of both surface water and groundwater while maintaining the condition of surface water and groundwater resources, water dependent ecosystems and assets. Clearly specified and flexible rules provide direction and confidence in relation to integrated water management activity.

Individual use limits consistent with annual and seasonal limits on the use of a water resource are the most widely used strategy for managing heavily exploited resources. In connected resources overall and individual surface water and groundwater use limits need to be coordinated. This is relatively simple when surface water and groundwater resources have strong and rapid connections. It becomes progressively more difficult as connections become weaker and impacts are more delayed. The strongest and fastest connections and impacts occur in alluvial valleys and plains where shallow alluvial aquifers lie below the river. The case for joint management of surface water and groundwater is strongest for these resources.

In New South Wales and other Murray-Darling Basin jurisdictions the provision of entitlement shares based on water availability provides clearly defined water allocation priorities as well as flexible allocation based on water available in storages. This is the main flexibility mechanism for surface water allocation in the MDB. In the northern part of the MDB on-farm water harvesting provides an additional source of water. On-farm water harvesting has impacts on stream flows and aquifer recharge, and rules to limit water harvesting are under consideration in New South Wales.

The impacts of groundwater use on surface water users and vice versa can be neutralized by the provision of offsetting, replacement supplies of surface water or groundwater when they are available. In Colorado and Idaho junior groundwater entitlement holders are allowed to continue to operate if they offset the impacts on senior surface water entitlement holders by augmenting stream flow in the irrigation season. This is the main flexibility mechanism for integrated water management in these States.

9.3.1.3 Entitlements and rules for storing surface water and groundwater

Storage plays a very important part in integrated water management in both connected and unconnected systems. Storage entitlements and rules are less well developed than use entitlements and rules.

The development of water storage in the Murray-Darling Basin and the western USA has been based on surface water reservoirs. Most water users are supplied from large reservoirs owned by public or private organisations. Generally there are no individual storage rights, although a system of capacity sharing for surface water storages has been trialled in Queensland²³⁶.

Aquifer storage and recovery is not feasible without an entitlement to store water in an aquifer and recover it. Rules that allow carryover or banking of water entitlements are

²³⁶ Capacity sharing is a system of property rights to water from shared storages proposed by Dudley (Dudley and Musgrave 1988). Rather than allocating users a share of total releases, each user is allocated a share of total storage capacity, as well as a share of inflows into and losses from the storage. Capacity sharing has been adopted successfully by SunWater in the St George irrigation region in southern Queensland and more recently in the nearby MacIntyre-Brook region. Capacity sharing has a number of potential advantages over standard carryover rights systems; however it remains largely untried outside Queensland (Hughes 2009).

also required. Aquifer recovery rules need to allow for losses owing to lateral movement and evaporation²³⁷.

In Colorado and Idaho aquifer storage has been developed to hold surplus surface water, primarily driven by groundwater entitlement holders. They have used both surface and groundwater storages to hold seasonal surpluses of water that they use to offset their impacts on senior surface water entitlement holders. This has led to the development of rules for aquifer storage and recovery. In most MDB jurisdictions, other than South Australia, aquifer storage entitlements and rules have not been established.

9.3.1.4 Rules for trading surface water and groundwater

Surface water groundwater trading offers opportunities to improve spatial and temporal access to water. Two way surface water groundwater trading is feasible in connected systems, although potential impacts must be addressed. These impacts depend on the unit volumetric impact (UVI) of a surface water-groundwater transfer and the consequent effect on river flows and groundwater dependent ecosystems. The time lags of impacts also have to be taken into account (SKM 2011)²³⁸. Surface water groundwater trading is easiest when surface and groundwater resources are highly connected and where connections are rapid. Surface water groundwater trading is facilitated by rules that permit water carryover, banking and borrowing and storage and recovery of underground water.

There are two difficulties in establishing rules for surface water groundwater trading. These are gaps in knowledge about surface water groundwater connections and long term impacts of surface and groundwater use on rivers and GDEs, and differences in the properties of surface water and groundwater e.g. freshness and pollution. These difficulties have led water managers in the Murray-Darling Basin to take a generally cautious and conservative approach towards surface water groundwater trading.

²³⁷ The amount of water that can be recovered from aquifer storage is slightly less than the stored amount because of lateral movements of water in the aquifer coupled with a relatively small amount of surficial evaporation.

²³⁸ Further details are set out in Box 5.1.

9.3.2 Implementation of integrated water management - knowledge, coordination and participation

Implementation of integrated water management presents several challenges related to knowledge, skills, coordination and participation²³⁹.

Decision makers need to get the best available information about water resources, their connections and their use in a timely way. There are many gaps in knowledge about connections between surface water and groundwater. Connected surface water and groundwater resources have different boundaries although the resources overlap to some extent. The nature of the connection (gaining or losing) often varies along river reaches. There are often several underlying aquifers with varying degrees of connection.

Gaps in knowledge create uncertainty about management targets and water use limits. Lack of knowledge may also result in disputes and increase the likelihood that vested interests will block the introduction of integrated water management arrangements. Monitoring of surface water flows and groundwater levels together with further research and analysis of surface water groundwater connectivity is required, especially for surface water and groundwater resources that are strongly connected and fully allocated.

Integrated water management also requires an array of knowledge and skills, including hydrology and hydrogeology, engineering, law, economics, environmental management, policy coordination and communication. Integrated cross disciplinary programs are required to train water managers.

Integrated water management requires effective coordination between governments, water users and interested third parties at multiple scales and levels. Lack of coordination and/or capacity may constrain integrated water use and management.

Successful implementation of integrated water management depends on the positive interaction and collaboration of users and governing bodies. Participation by both surface water and groundwater users in decision making is necessary to ensure that users understand each other and have the opportunity to craft mutually acceptable

²³⁹ For further discussion see section 8.5

management arrangements taking account of relevant information and uncertainties (Emerson et al 2011, Ross 2012). Effective monitoring and enforcement is important because free riding and/or cheating may result in the withdrawal of support for integrated water management (Ostrom 2005).

Some aspects of implementation like research, training and coordination require high level direction but many aspects of operational management are best addressed locally. A balance needs to be struck between comprehensive implementation of entitlements and rules, and flexibility to bend the rules to achieve broader policy goals (for example – temporary surface water replacement plans in Colorado).

9.3.3 Opportunities for improving integrated water management in the Murray-Darling Basin, Colorado and Idaho

9.3.3.1 How much integration of surface water and groundwater use and management is desirable and possible?

In some respects integrated water management makes good sense. Surface water and groundwater are part of the same unified water cycle, and making the best use of all available water resources is a key policy goal. Surface water, groundwater and land uses needs to be planned and managed as a whole, because surface water use affects groundwater availability and groundwater use affects surface water availability. Farm dams and water diversions, forestry and vegetation management all affect river inflows and groundwater recharge, sometimes at times and locations far removed from the original impacts. Coherent multilevel state policies, plans and regulations are needed to address these impacts. In Australia, integrated surface water and groundwater management is a principle of the National Water Initiative and State and Territory legislation in the MDB jurisdictions.

There are also reasons for treating surface water and groundwater separately. Surface water and groundwater have different properties and life cycles. From the point of view of human users they have different advantages and disadvantages. In a commercial sense they are different products. Surface water and groundwater science is represented by two distinct disciplines.

In practice the optimum integration of water plans and project has to be evaluated on a case-by-case basis, taking account of variations in surface water and groundwater resources and their connections, water uses and legal, social, economic and political conditions.

9.3.3.2 How could integrated cyclical water management be improved?

Cyclical water use, underground water storage and water banking are key strategies for integrated water management. Subject to the availability of suitable water supplies and storage they enable water users and managers to allow for variable and uncertain water supplies by using water entitlements flexibly through time to meet environmental and consumptive requirements. In some circumstances the gains from water banking might be increased by water trading.

Cyclical use of surface water and groundwater is already practiced in the MDB but management of surface water and groundwater is generally separate. Further study is needed of the potential for other types of integrated water management schemes in the MDB. These include cyclical surface water and groundwater management, with increased use of underground water storage and water banking. Effective and efficient water storage and banking regulation and markets are a missing link in Australian water reform.

9.3.3.3 Institutional requirements

Some modifications would be needed in laws, rules and management organisation in order to develop surface and groundwater plans that are integrated through time as well across resource boundaries, and to implement water banking and trading. Longer term carryover provisions and entitlements to store and extract water would need to be integrated with current carryover provisions and water use entitlements. The ownership of, and management responsibilities for, stored water and its recovery will need to be clarified.

While the integration of surface water and groundwater plans is desirable, integrated plans can be complex, even in relatively small catchments. Effective coordination of surface water and groundwater plans taking account of the impacts on other resources

and the environment may be preferable to fully integrated plans, except in cases where the connections between surface water and groundwater are relatively large and rapid.

9.3.3.4 Implementation issues

Integrated surface water and groundwater management is a complex process across multiple jurisdictional, geographical and time scales. There are substantial uncertainties about surface water and groundwater connections and their impacts. Water allocation and use is often contested. National and state policy principles are not always easy to translate into implementation "on the ground" resulting in a mismatch between higher and lower levels of water policy and planning.

Integrated water planning and management is complicated by boundary problems and knowledge gaps, and can involve significant transaction and financial costs. Managed underground storage projects can involve expensive land acquisition and infrastructure. Concerns about the health and other implications of mixing groundwater and surface water also have to be overcome in some cases. The management regime will need to be robust enough to withstand legal challenges.

Collective cyclical water management can offer greater economic and environmental benefits, and better risk management than uncoordinated individual action. US experience suggests that the most effective investments in underground water storage and recovery are made by partnerships between authorities and water users (Thomas 2001, Blomquist et al 2004). There may be a case for transitional government incentives for pilot projects or for governments to share the costs with users.

In Australia, catchment based organisations²⁴⁰ could play a greater role in integrated water planning management and monitoring, and encourage greater innovation by users and authorities, but there are significant challenges (Chapter 5 (5.6.3)). In Colorado integrated water management could be improved by strategic watershed planning that integrates consumptive and environmental requirements and gives governments and users an opportunity to adjust the prior appropriation doctrine in order to achieve improved water management outcomes.

²⁴⁰ Water user organisations, as established in Colorado and Idaho, could provide supplementary/alternative coordination services.

9.4 Theoretical insights

The framework proposed by Ostrom for analysing social ecological systems²⁴¹ is a useful starting point for investigating issues related to integrated surface water and groundwater management. The framework requires further development when analysis focuses on particular variables such as water entitlements²⁴², operational rules and management organisations which are explored in Part III of this thesis.

Water entitlements can be divided into different categories such as use, storage, exchange or consumptive or environmental water. They can be allocated according to different principles; seniority or public choice; and by different mechanisms, user cooperation, agency regulation and/or market transactions. They can also be limited in different ways such as shares of available water, annual/seasonal use limits or cease to pump rules. Management organisations can be divided into public and private; general and special-purpose; global, national and local.

Some aspects of Ostrom's framework including water resource and user characteristics were not explored in any depth in this research. However, case studies with similar water resource and user characteristics were selected in order to facilitate comparison of the effects of different institutional settings.

9.4.1 Path dependency

The case studies in this research suggest that integrated water management is strongly influenced by the historical development of water management and the method of allocating water. Political choice in the MDB and prior appropriation in the western USA led to different priorities for allocation. Different governance arrangements have been developed to handle water allocation, but in both cases there has been a "surface water centric" development path. Groundwater management has developed at least in part to protect surface water entitlements, rather than to optimise integrated surface water and groundwater use over time.

²⁴¹ See section 3.3.4.

²⁴² The term water entitlements is used rather than property rights – see footnote 10 Chapter 1.

In the MDB the development path was reliance on surface water delivered at low cost through large highly regulated delivery systems. The surface water centric settings for water management in the MDB discouraged the development of integrated surface water and ground water management. The absence of comprehensive basin wide sustainable use limits for groundwater allowed the long term depletion of some aquifers, rather than encouraging cyclical replenishment and depletion.

In Colorado and Idaho the prior appropriation system of allocating water coupled with the seniority of surface water entitlements has driven the development of plans by groundwater users to offset their impacts on senior rights. Users have developed innovative methods of storing and recovering water in order to deliver these plans. But the seniority of surface water rights has been upheld regardless of changing circumstances or social impacts, and some groundwater pumping has been shut down or limited, even in dry periods when groundwater is most reliable source of supply.

The effect of the surface water centric development on integrated water management deserves more attention. Effecting change towards fully integrated surface water and groundwater management would involve significant technological and transaction costs. These include the “transition” costs of changing from one system to another, and the “lock in” costs of overcoming resistance to change (Challen 2000, Marshall 2005). Further long-term comparative studies are needed to examine the benefits of integrated water management in relation to these costs.

9.4.2 Definition and flexibility of water entitlements and operational rules

The importance of well defined entitlements and rules for governing water use, storage and exchange is well established in theory and practice and has been reinforced and further explored in this study. The importance of related mechanisms to enable flexible responses to variability and uncertainty is less well established and researched, but is strongly supported by this study. Mechanisms that allow the flexible use, storage and exchange of surface water and groundwater over time are required to optimise the use of both sources of water during wet and dry cycles.

In New South Wales comprehensive separate and tradable water use entitlements have been introduced, but entitlements for storing water in aquifers and extracting it have not been established. The main flexibility mechanisms in use – allocation of shares of available water, water accounts with limited carryover, on-farm surface water harvesting and storage and “temporary” water trading are relatively short term in duration.

In Colorado the prior appropriation system provides well defined priorities and entitlements for water use. Surface water replacement plans provide flexibility for groundwater pumping to continue when surplus surface water is available, but the court based prior appropriation system can be inflexible during severe water shortages when senior entitlement holders insist on their entitlements regardless of the broader social costs.

Neither the New South Wales nor the Colorado systems of water entitlements and related flexibility mechanisms exploit opportunities for cyclical management of surface water and groundwater or aquifer storage and recovery over wet dry climate cycles. Water trading and leasing are growing, but temporary transfers and leases generally cover short time periods. More attention needs to be given to the management of water stocks as well as water flows, and water storage as well as water use. Opportunities for extended carryover, aquifer storage and recovery and surface water groundwater exchange over time merit further consideration, taking account of third party impacts on other users and water quality.

9.4.3 Intertemporal water management

Cyclical management of surface water and groundwater raises a number of issues relating to intertemporal management. These include time lags between groundwater pumping and its impacts on other uses and the environment, assumptions about “discount rates” among water users, government agencies and third parties, maintenance and management of stocks of water for the long term, and the appropriateness of different instruments to handle long term impacts.

Surface water use usually has a fairly rapid impact on downstream surface water users and the environment. The impact of groundwater use varies markedly. Pumping of shallow alluvial resources has a rapid impact, but the impact of pumping of groundwater resources that are confined, have low transmissivity or are a long distance from rivers can be delayed for tens or even hundreds of years. If these delayed impacts are discounted using a “market” discount rate, such as a government bond yield, impacts in a hundred years time will have negligible value. This implies that long-term impacts of groundwater overuse will be considered relatively unimportant compared to short-term impacts of surface water overuse, and maintenance of long term stocks of groundwater will be considered much less important than preserving jobs and environmental icon sites.

If discount rates were to be chosen by means of a deliberative process that allows discount rates (and their components) to be negotiated by stakeholders ranging from commercial developers to environmental organisations, and also took account of local impacts, the chosen discount rate could be much lower than the average market rate. This would provide an arena for long term impacts of groundwater overdraft and associated long term impacts on rivers and wetlands to be fully considered at a local or regional scale and weighed together with shorter term impacts. Community negotiated discounting is not current practice and would be expensive, but it could better reflect the range of community views and aspirations for the future²⁴³. A literature review and further examination of the pros and cons of community discounting would be required to establish the theoretical merits and practicality of this option.

Water management has generally concentrated on the management of inflows and short-term storages. Further attention needs to be given to maintaining and managing stocks of water to ensure relatively stable water supplies during wet - dry climate cycles. The management and allocation of water supplies based on long-term averages of water in storage (stocks) may provide relatively greater security, stability and flexibility that allocations based on volumetric shares of annually available water. This would entail

²⁴³ Discount rates reflect assumed rates of return on capital ie net yield on investments in capital, education, and technology. Rates of return on corporate capital have averaged 7% in recent years. The long run equilibrium real return on capital is determined by $r = \rho + \eta g$, where g is the average growth in consumption per capita, ρ is the time discount rate, and η is the consumption elasticity. The discount rate is highly sensitive to assumptions about these parameters. For example the Stern Review assumed $\rho = 0.001 \text{ yr}^{-1}$ and $\eta = 1$. Together with an assumed growth rate ($g^* = 0.013 \text{ yr}^{-1}$) and stable population, this gave a real interest rate of 1.4% per year, far below the returns to standard investments (Nordhaus 2007).

actively managing underground water storage, allowing aquifer drawdown in dry periods, and recharging aquifers during wet periods.

Water markets have proved a very useful instrument for allocating surface water on an annual or seasonal basis in the MDB, Colorado and Idaho. Cyclical water management requires a longer term approach, with a greater emphasis on holding reserves of water, like savings accounts. Water banking can play an important role – as indicated by experience in the western USA (Clifford et al 2004, Contor 2010). The ownership of stored water and entitlements for “drawing on the bank” must be clearly defined and secure, including allowances for losses and third party impacts. Analysis and approval processes need to be streamlined to minimise transaction costs and time. Underground water bank accounts can be built in two ways; directly, by holding water (entitlements) in aquifer storage; or indirectly by using less than the full entitlement of groundwater. The latter may be achieved in various ways such as using surplus surface water instead of groundwater or reducing groundwater use by changing cropping area or mix.

9.4.4 Multilevel integrated water governance

Integrated surface water and groundwater management does not meet the boundary and information conditions proposed by Ostrom for self organised common pool management (Ostrom 1990, 2005). The boundaries of connected surface water and groundwater do not usually coincide, and the impacts of surface water use are often much faster than groundwater. There are many gaps in knowledge about the connection between surface water and groundwater. Sustainable use limits and entitlements for surface water and groundwater are usually defined separately and in different ways.

Under the prior appropriation system in the US groundwater users have successfully organised themselves to offset their impacts on senior water entitlement holders. However, this cannot be simply interpreted as a violation of Ostrom’s conditions. Their success does not merely reflect the capacity of irrigators to organise themselves. There are a number of other explanations. These include the historical development of water resources and infrastructure through Federal projects, the establishment of water courts and the adjudication of water rights, and periodic water supply crises which have propelled collaborative action by both government agencies and water users.

Integrated water management requires effective cross scale coordination, broad stakeholder participation, good shared knowledge and effective monitoring and feedback. Coordination may be carried out by governments, special purpose organisations (often working across jurisdictions) or a mixture of the two (Hoogue and Marks 2003). High level governments can provide greater control, broad level coordination and accountability, and can act flexibly to solve crises. At the same time hierarchical integrated water planning and management can become very complicated at the river basin or sub basin scale. Also high level government intervention may displace stakeholder and community action and reduce the motivation of water users to engage in collective water management. Special purpose organisations, such as catchment management organisations in Australia and water districts in the USA provide local coordination, and encourage engagement and innovation (Marshall 2005, Cech 2010). However, local organisations lack capacity to manage intertemporal impacts of resource use at a river basin scale (Schlager 2007), and sometimes lack public accountability.

In practice integrated water management is typically polycentric, involving a network of governments and their agencies, and special purpose organisations. The successful implementation of integrated water management depends on collaborative governance striking an effective balance between broad direction and coordination, and local initiative.

Research indicates that collaborative governance requires engagement of stakeholders, development of trust and mutual understanding, and a commitment to common goals and direction. The capacity for collaborative action is influenced by institutional arrangements, leadership, knowledge and resources (Emerson 2011, Ross and Dovers 2008).

The case studies in this research suggest that integrated water management needs to include both jurisdictional and/or basin wide overviews of water resources and uses and detailed management arrangements for individual connected resources. This multilevel approach can avoid the difficulties involved in drafting and communicating a fully detailed management plan at the river basin or jurisdictional scale, but at the same time ensure a coordinated approach to water management and consistency with broader social and policy goals. Integrated water management would include:

1. A coordinated jurisdictional scale approach including sustainable use limits, projections of surface water and groundwater availability and demand, together with integrated water management strategies. Examples include the State Water Supply Initiative in Colorado and Regional Sustainable Water Strategies in the state of Victoria in Australia.
2. Locally developed integrated surface water and groundwater management arrangements, including water allocation, operational rules and monitoring. The capacity for local management depends on local financial, human and social capital and expectations about the value of participation, which in turn depends on local authority and autonomy, and willingness of stakeholders to engage constructively in deliberative processes. Higher level governments will need to overcome their reluctance to give control to decentralized organisations (Marshall 2005, Ross 2008). Augmentation plans in Colorado and some catchment management plans in Australia provide positive examples.

9.4.5 Further research

Research carried out in this thesis, and in other studies in the US and Australia²⁴⁴ suggests a range of research opportunities to support the further development of cyclical integrated water management, aquifer storage and recovery in the Murray-Darling Basin.

While the general geological and hydrological characteristics of the major aquifers in the basin are known, there is a lack of precise estimates of the boundaries and holding capacity of basin aquifers. Better estimates of the availability and quality of water for underground storage are also needed, including from overland flows and floods, and recycled stormwater, waste water and mine water. Further investigation of the quality of water available for aquifer storage and processes for removing sediment, contaminants, microbes and pathogens would assist the further development of aquifer storage. Methods of measuring and monitoring the mobility and quality of stored water require further development. This is an important input to the development of recovery rules (see below).

²⁴⁴ For example Dillon 2009, NRC 2008.

The requirements for further work on institutional requirements for integrated cyclical water management have been discussed in earlier chapters of this thesis. These include the design and establishment of water entitlements and operational rules and inclusion of cyclical management in water plans. Comparative studies of the transaction costs of moving towards more integrated water management were suggested in 9.4.1. Further research on the integrated management of surface water and groundwater storage through time, community negotiated discount rates and water banking arrangements was discussed in 9.4.3.

Further development of decision support systems for the development of aquifer storage and recovery projects would assist both regulators and project managers. Studies of community attitudes to aquifer storage and recovery drawing on the experience with recycled water projects²⁴⁵ would help to improve community understanding and acceptance of the technology. Cost benefit analysis of aquifer storage and recovery in comparison with alternative means of improving water storage and supply will be required for specific project proposals²⁴⁶.

Research carried out in this thesis has identified three additional specific topics for further research; carryover periods, aquifer recovery fractions, and the use of cyclical water management to achieve environmental goals.

One reason why carryover periods in the Murray-Darling Basin have been restricted to three years or less have been concerns about scenarios that could occur if carryover were allowed to accrue in a water bank. For example, large calls could be made on the system during a dry period, crowding out regular water allocations. Further work is needed on options that would enable essential and high priority uses to continue to receive water at the same time that water was being withdrawn from the bank²⁴⁷.

It is appropriate to reduce deliveries of carried over water held in a surface water storage by a percentage that allows for annual evaporation from the storage. In the case

²⁴⁵ See for example Alexander, K. et al. (2010). 'Community management of onsite wastewater treatment systems – what they want in Mount Gambier'. *Water Practice and Technology* 5(1): 1-10.

²⁴⁶ Cost benefit studies would take account of external and remote impacts on other water users and the environment.

²⁴⁷ These options include reduced percentage delivery of carryover water during years when regular supplies are heavily restricted, or an annual fractional reduction in banked water holdings as a risk management tool.

of aquifer storage an allowance should be made for losses owing to lateral movements of water in the aquifer as well as any evaporative losses²⁴⁸. These fractions can be estimated roughly from water balances, but further research is needed to generate improved estimates that would be sufficiently robust for use in specifying management rules.

Groundwater and aquifer storage has some potential to maintain environmental water requirements during dry periods. Generally the most effective way to get environmental benefits from groundwater is to reduce the rate of consumptive use. Aquifer storage and recovery is a relatively expensive way to obtain water for the environment compared to the purchase of consumptive water entitlements. Nonetheless cyclical surface water and groundwater management offers opportunities to use additional groundwater during dry periods. This could take the pressure off surface water resources and related ecosystems and environmental assets. This possibility merits further examination.

9.5 Concluding comments

Integrated surface water and groundwater management can provide opportunities for more efficient water use and improved adaptation to wet and dry periods by means of carryover, water banking and aquifer storage and recovery. These opportunities could be exploited more vigorously in the Murray-Darling Basin, and in Colorado and Idaho in ways described in this thesis.

The development of integrated surface water and groundwater management, especially in the Murray-Darling Basin has been constrained by the surface water centric development of water resources and governance arrangements, gaps in knowledge about surface water and groundwater connectivity, the lack of a comprehensive, flexible and balanced system of water entitlements and rules and implementation difficulties. These include coordination and stakeholder participation.

²⁴⁸ There can be some evaporative loss from shallow aquifers but it is relatively small compared to surface water storage.

Integrated water management is no panacea. The impacts of moving to more integrated water use, storage and exchange need to be assessed on a case by case basis. These impacts include health and water quality, and need to take account of transaction costs.

Further development of integrated water management requires better knowledge, more flexible governance and improved management capacity. Further research and development needs to be devoted to the integrated management of water stocks and storages. Further research is required to understand surface water groundwater connectivity and to develop strategies for managing long term impacts. Ongoing development of flexible systems of water entitlements and rules is needed to enable cyclical surface water and groundwater management. Finally the capacity for the implementation of integrated water management at local and regional scales needs to be improved together with collaboration between higher level governments and local organisations and stakeholders.

Attachment 1: Notes on some keywords used in this thesis

Integrated water management.

Integrated water management is the integrated management of one or more surface water and one or more groundwater resources. These resources may or may not be hydraulically connected. This contrasts with conjunctive water management which is the coordinated management of hydraulically connected surface water and groundwater resources. Most surface water resources are connected to groundwater and vice versa. But some surface water and groundwater resources are either not connected, or connected so remotely in space or time that effects of their interaction negligible over realistic water planning periods. In practice most river basins or sub-basins include multiple surface water and groundwater resources with a wide range of connectivity.

Integrated water management has been defined more broadly as “a process that promotes coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (GWP TAC 2000). In these terms integrated water management is highly complex and represents an aspiration that has not been achieved and will be difficult to achieve (Biswas 2008). This study adopts a more limited approach to integrated water management, exploring surface water and groundwater resources, water users, water governance systems and their interactions, while endeavouring to keep broader social, landscape, land use and ecological implications in mind.

Governance

Governance means the manner of governing human action in a defined sociopolitical sphere. For example integrated water governance is about how the use of surface water and groundwater resources is governed in a river basin or subbasin. Governance includes sociopolitical choices about the nature of water use entitlements and rules, the

structure and management of organisations, and their roles, responsibilities and powers.

There are three broad ideas behind this concept of governance:

- steering society or making policy that requires the active participation of a range of actors in addition to government;
- governance is not an alternative to government - government is one of its constituent parts; and
- governance involves steering society by means of networks, markets, partnerships, negotiated collaboration between governments, businesses and civil society associations (Pollitt and Bouckaert 2011).

The term governance is used in a wide variety of ways in the literature including the minimal state; corporate governance; new public management; socio-cybernetic system; self organising network and public governance (Rhodes 1996).

In this thesis a distinction is made between the “core” governance system, and elements of governance including water use entitlements, rules and management organisations.

In this context, the “core” governance system refers to the overall system of water allocation, such as prior appropriation in the western USA and political choice in the Murray-Darling Basin.

Institutions

Institutions have been defined as “the rules of the game of a society or, more formally, the humanly devised constraints that shape human interaction” (North 1990). They are made up of formal constraints (for example, rules, laws and constitutions), informal constraints (norms of behaviour, conventions, self imposed codes of conduct), and their enforcement characteristics. Together they define the incentive structure of societies and economies. Institutions can be distinguished from organisations. Institutions provide the regulatory framework for social behaviour, organisations implement the rules. Organisations and their activities have an important impact on the implementation of integrated water management.

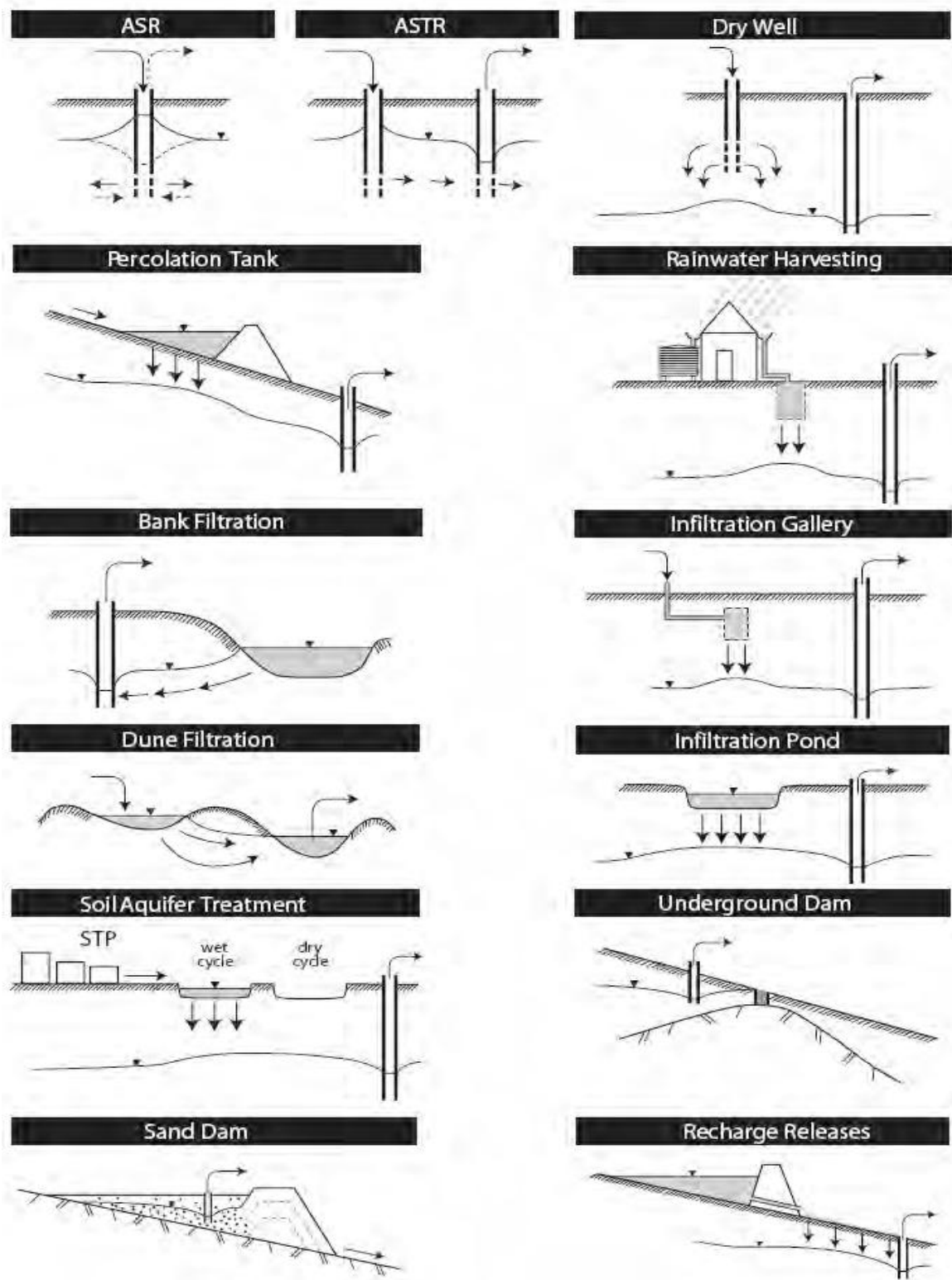
Management organisation and management organisations

Water management organisation refers to the way that multiple water management activities across multiple geographical, temporal and jurisdictional scales are coordinated. For example coordination may be achieved by democratically elected governments and their agencies (organisations) or by special purpose governments and non government organisations such as river basin organisations, catchment management bodies, or irrigator and environmental representative bodies. Water management usually involves government and special purpose organisations working together in various groupings to achieve various purposes.

Water management organisations are established by governments or other representative bodies to exercise responsibilities for matters such as water law and policy, water planning, water storage and delivery, water quality, water markets and prices, research, monitoring and enforcement.

In this thesis management organisation and management organisations are often referred to collectively as management organisation(s).

Attachment 2: Types of managed aquifer recharge (MAR)²⁴⁹



²⁴⁹ This note includes diagrams and extracts from explanatory notes taken from Dillon et al 2009.

Notes:

Aquifer storage and recovery (ASR): injection of water into a well for storage and recovery from the same well.

Aquifer storage: transfer and recovery (ASTR): injection of water into a well for storage, and recovery from a different well.

Infiltration ponds: diverting surface water into off stream basins and channels that allow water to soak through an unsaturated zone to an underlying unconfined aquifer.

Infiltration galleries: buried trenches (containing polythene cells or slotted pipes) in permeable soils that allow infiltration through the unsaturated zone to an unconfined aquifer.

Soil aquifer treatments (SAT): treated sewage effluent is passed through infiltration ponds. Nutrients and pathogens are removed in passage through the unsaturated zone. Treated water is stored in the aquifer for later recovery by wells.

Percolation tanks or recharge weirs: dams built in the ephemeral streams detain water which infiltrates through the bed to enhance storage in an aquifer for later extraction.

Rainwater harvesting for aquifer storage: roof runoff is diverted into a well, sump or caisson filled with sand or gravel and allowed to percolate to the water table where it is collected by pumping from a well.

Recharge releases: dams on ephemeral streams are used to detain floodwater. Uses may include slow release of water into the stream bed downstream to match the capacity for infiltration into underlying aquifers.

Dry Wells: typically shallow wells where water tables are very deep, allowing infiltration of very high quality water to the unconfined aquifer at depth.

Bank filtration: extraction of groundwater from a well or caisson near or under a river or lake to induce infiltration from the surface water

Underground dams: in ephemeral streams where a high impermeable base (basement) constricts flows, a trench is constructed across a stream bed, keyed to the basement and backfilled with low permeability material to help retain flood flows.

Sand dams: built in ephemeral streambeds in arid areas on low permeability lithology, these trap sediments when flow occurs, and following successive floods the sand dam is raised to create an aquifer which can be trapped by wells in dry seasons.

Selection of suitable sites for MAR and choice of method will depend on the hydrogeology, topography, hydrology and land use of the area. It is common to find similar types of MAR projects clustered in the same area due to shared physical attributes. In another area the methods may be quite different.

Source: Dillon et al 2009

Attachment 3: Frameworks for the analysis of integrated water management

Introduction and selection criteria

A framework to structure and guide the exploration of complex and diverse biophysical and social systems is a critical requirement for a comparative study of integrated water management. This framework needs to cover characteristics of and relationships between surface water and groundwater resources, users and managers, and outcomes in a range of spatial, temporal, jurisdictional, institutional, management, social network and knowledge dimensions (scales). An interdisciplinary perspective is needed, taking account of a range of biophysical, hydrological, social, political and policy sciences. The boundaries of the framework need to be well defined, as do variables and relationships covered by the framework. Frameworks which have been tested on particular cases or used to address specific problems are preferable.

The following criteria were used to select candidate frameworks for analysing integrated water management:

1. Subject coverage: the framework should be able to include analysis of characteristics of two of the following three subject clusters - resources (R), users (U) and governance systems(G);
2. Interdisciplinarity: the framework should include at least two of the following disciplinary clusters biophysical science (BS), hydrology and hydrogeology (HS), social science (SS), political and policy science (PPS);
3. Definition: the boundaries and content of the framework should be well defined; and
4. Use: the framework should have been used in the analysis of many cases and/or problems

Candidate Frameworks

Six frameworks were shortlisted for an assessment of their suitability to guide the exploratory analysis and synthesis of integrated water management. These six frameworks are; integrated water resource management, environment policy integration,

the resilience perspective, hydro-economic analysis, the advocacy coalition framework, and the framework for analysis of social ecological systems that has been developed from the institutional analysis and development framework. Integrated water resource management and environmental policy integration are not well defined and the environmental policy integration framework has not been widely used, but both of these frameworks were assessed because it is anticipated that they can provide useful perspectives when used in conjunction with other frameworks.

Integrated Water Resource Management

The most prominent definition of integrated water resource management (IWRM) was formulated by the Global Water Partnership (GWP). Integrated river basin management is "a process that promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP-TAC 2000). IWRM involves striking a balance between the use of water resources as a basis for human livelihoods and the protection and conservation of resources to sustain their functions and characteristics. This requires an enabling environment of appropriate policies, legislation, regulations and information for sustainable water resources management, an institutional framework that defines the roles and responsibilities of administrative levels and stakeholders, and instruments for implementation based on agreed policies, available resources, environmental impacts and the social and economic consequences (GWP-TAC 2004).

The IWRM framework provides a good overview of broad management principles and implementation options. The comprehensive subject coverage is appropriate for investigating integrated water management. IWRM is intended for practical use rather than cross disciplinary scientific analysis. In that sense it is biased towards policy sciences, but the treatment of options is descriptive and does not analyse choices or trade-offs between options.

While the IWRM concept is widely known in water management practice, its implementation is not as widespread. Common barriers to the implementation of IWRM include ambiguous objectives, complexity of the issues and diversity of interested parties, differences between stakeholders, institutional stickiness (resistance to change), and difficulties in measuring outcomes and success (Young 2002). The

establishment of viable political institutions, workable financing arrangements, self governing and self supporting local systems, and a variety of other institutional arrangements is not easy to achieve (Grigg 1999). Biswas (2008) argues the key components of IWRM are ill defined, with no clear indicators of whether they are being achieved.

Environmental policy integration

Environmental policy integration (EPI) involves ensuring that development is environmentally as well as economically sustainable. This concept is relevant to integrated water management in the sense that water is managed to meet both human consumptive and environmental requirements. EPI can be viewed as a process of governing or as a policy outcome (Jordan and Lenchow 2010).

EPI as a process of governing can be viewed from a political system or policy analysis perspective. EPI represents a major coordination challenge. Jurisdictions with a greater degree of ministerial independence and/or federal systems experienced greater institutional obstacles in coordinating EPI. Jurisdictions with a consensual style such as the Scandinavian countries tend to have more commitment to EPI than countries such as Germany and the US with a very legalistic approach. But there have been substantial cycles in support for EPI even in the most supportive countries. The literature points to widespread political commitment to EPI, but substantial variations in practice - a disconnect between policy and practice.

From a policy analysis point of view there are a very wide range of instruments and organisational structures in use, often with limited persistence. There has been a general preference for soft, voluntary or discretionary approaches rather than harder, measured and tightly monitored approaches. As far as policy outcomes are concerned there is often limited evaluation of processes and instruments because it is difficult and/or expensive to get information and because of a lack of commitment. Indeed many policy integration initiatives appear to be largely symbolic politics.

The EPI literature provides some interesting insights that can be applied to the development of integrated water policy and management, such as the concept of symbolic political action. However, the EPI framework does not include an analysis of resources, and it has not been developed or tested sufficiently to provide a framework

for systematic analysis of interactions between water users and governance arrangements.

Resilience perspective

Social ecological resilience can be interpreted as having three aspects:

1. The amount of disturbance the system can absorb and still remain in the same state with essentially the same function, structure, identity and feedbacks (Walker et al 2004);
2. The degree to which the system is capable of self organisation (as opposed to lack of organisation, or organisation forced by external factors); and
3. the degree to which the system can build and increase the capacity for learning and adaptation (Carpenter et al 2001) self organise and transform itself.

Coupled social and ecological systems share a common dynamic with the cycle of four stages; exponential change and exploitation; growing rigidity and conservation; collapse; and reorganisation followed by renewal. Much of the work on ecosystem resilience has emphasised capacity to absorb disturbance, or buffer capacity. The capacity of groundwater storage to act as a buffer against surface water scarcity is an example. This has also been used in relation to social change where social resilience has been defined as the ability of communities to withstand external shocks to the social infrastructure (Adger 2000). The capacity of irrigation communities to withstand reduced water supplies is an example. Resilience is not only about being persistent. It is also about the opportunities that disturbance opens up in terms of recombination of the old structures and processes, renewal of the system and the emergence of new trajectories. In this sense resilience is related to adaptive capacity (Smit and Wandel 2006) with a dynamic interplay between conservation and change.

The resilience perspective provides a dynamic long term perspective on social and ecological systems. It has comprehensive coverage of natural resources, social systems and their interactions, with a growing number of case studies. It does not include an analysis of political change, opportunities and constraints. Also there are many outstanding research issues including the identification of thresholds for the four phases of SES dynamics and clarification of feedbacks of interlinked SESs (Folke 2006).

Hydroeconomic analysis

Hydroeconomic models represent regional scale hydrologic, engineering, environmental and economic aspects of water resource systems within a coherent framework. Hydroeconomic models are solution oriented tools for discussing new strategies to advance efficiency and transparency in water use (Harou et al 2009). Applications include in stream and off stream uses including environmental flows and irrigation, infrastructure evaluation and integrated water management. When surface water and groundwater management is integrated, hydroeconomic models can show the potential for groundwater banking (Pulido-Velasquez et al 2004, Harou and Lund 2008). Hydroeconomic models can also be used to investigate water markets, conflict resolution, land use management and managing for climate change, floods and drought.

Hydroeconomic analysis links physical and social sciences and includes many of the variables that drive integrated water management. Hydroeconomic models are generally well defined and have been extensively used, for example to provide insights about scenarios and policy choices. However, there are several difficulties with a direct use of hydro economic models in practical settings. Simplification and aggregation of physical, economic and regulatory processes and data may lead modelled results to be too theoretical or insufficiently detailed to support local decision making. Simplification may also contribute to a lack of robustness at the local scale. Another difficulty is that hydro-economic models do not include a sophisticated analysis of the interactions between governance arrangements and behaviour. The models necessarily impose market solutions, whereas these models can be poor tools to simulate actual water markets since individual agent behaviour and transaction costs cannot be represented easily. Moreover it is difficult to represent indigenous and environmental values of water that are difficult to quantify.

The advocacy coalition framework

The advocacy coalition framework (ACF) developed by Sabatier and Jenkins-Smith (1993) focuses on interactions between participants in multilevel policy processes. In the ACF it is proposed that resource users, government representatives and interested third parties may be grouped into advocacy coalitions whose members share a set of normative beliefs and perceptions of the world and act together to some degree in pursuit of their common policy objectives. Policy making occurs primarily among

specialists who seek to influence policy within the policy subsystem. Specialists can be grouped into two or more coalitions based on similar beliefs and some degree of coordinated behaviour. Their behaviour is affected by two sets of exogenous factors: natural resource properties, sociocultural values and constitutional rules, all of which are relatively stable; and more dynamic changes in socioeconomic conditions, government and public opinion. The ACF assumes that normative beliefs cannot be assumed and must be ascertained empirically. The ACF does not preclude altruistic behaviour.

There have been calls for further work to identify links between system parameters such as constitutional rules and social values and the policy subsystem, and also to demonstrate the prevalence of coalitions and the advantages that bind them (Schlager 2007b). In addition the ACF has been criticised for having over-restrictive assumptions about individual motivation, and that there are many more opportunities for collaboration than those lying within the common belief systems of advocacy coalitions (Ingram and Schneider 2007).

Despite these reservations, there are a growing number of studies that have used the ACF framework. The ACF could provide a useful tool for analysing interactions between surface water and groundwater users and their organisations, government authorities and third party interest groups at multiple scales of analysis.

Framework for analysing social and ecological systems

Research has shown that a large number of conditions influence the prospects for collective action in specific action situations (Agrawal 2001, Ostrom 2005). Research developments can be divided into three levels of analysis: individual human behaviour; the microsituation including the immediate variables impinging on individual decision-making in an action situation; and the broader social and ecological system within which individuals make decisions. Combinations of microsituational and broader contextual variables affect decisions made by individuals, and help to explain the substantial variation in behaviour observed across and within action situations (Poteete et al 2010).

A very large number of broad contextual variables can impact on collective action at different scales. Ontological frameworks are widely used in biology, medicine and

informatics to set out the elements of complex systems. These frameworks generate sets of questions from which specialists can select questions most relevant to a particular problem. Ostrom has developed a multitier framework for the analysis of social and ecological systems (and common pool resources).

The first tier relates resource systems and their units, governance systems and users together with their interactions and consequent outcomes. The first tier may be unpacked into further tiers, depending on the question being asked, and whether different subtypes of a variable tend to generate different outcomes in particular types of processes. The framework can act as a starting point to organise an analysis of how attributes of a resource system (e.g. rivers, lakes and aquifers), resource units generated by the system (surface and groundwater), the users of the system (e.g. towns and irrigators) and the governance system interact and what outcomes are achieved at a particular time and place (Ostrom et al 2007).

Ostrom suggests that further use and development of this framework could be used to answer three broad classes of questions (Ostrom 2009):

- patterns of interactions and outcomes likely to result from using a particular set of rules for a specific resource/user/governance configuration in specific technological and sociopolitical conditions;
- likely endogenous development of different governance arrangements, use patterns and outcomes given different patterns of incentives and rules; and
- the robustness and sustainability of particular configurations of resources, users and governance systems to external and internal disturbances.

Assessment of the six frameworks

The following table A3.1 summarises the above assessment of the six shortlisted frameworks in terms of their subject coverage, interdisciplinarity, definition and use. The framework for the analysis of social and ecological systems is the most comprehensive of the six frameworks. It integrates biophysical, social and institutional factors and draws on very wide range of disciplines and case studies. This framework meets all the selection criteria and is selected to provide the primary framework for analysing integrated water management at multiple scales.

Table A3.1 Assessment of frameworks for analysing integrated water management

	<i>Subject coverage*</i>	<i>Interdisciplinarity**</i>	<i>Definition***</i>
<i>Integrated water resource management</i>	R U G	Mainly PPS	Many elements defined, interactions not well defined
<i>Environment policy integration</i>	U G	SS PPS	Definition of elements and interactions in the development stage
<i>Resilience perspective</i>	R U	BS SS	Elements and interactions clearly defined but very broadly specified
<i>Hydroeconomic analysis</i>	R U	HS SS	Elements and interactions well defined in specific studies
<i>Advocacy coalition framework</i>	U G	PPS	Elements well defined, interactions moderately well defined
<i>Framework for the analysis of social and ecological systems</i>	R U G	BS HS SS PPS	Elements comprehensively defined, interactions well defined in specific studies

Notes:

* R = resources, U = users; G = governance system

**BS = biophysical science, HS = hydrology and hydrogeology, SS = social science, PPS = political and policy science

***Definition refers to elements of the framework and interactions between them

The other frameworks have strengths that could be used to supplement the primary framework. The environment policy integration framework gives additional insights on political processes and instrument choice. The resilience perspective provides a framework for understanding dynamic change in SESs. Hydroeconomic analysis enables quantitative assessment of specific scenarios and policy options. The advocacy coalition framework can provide insights into the collective behaviour of water users, governments and third parties.

Attachment 4: Further background on the framework for analysing social and ecological systems.

Introduction

The framework for the analysis of social and ecological systems evolved from studies of common pool resources. A common pool resource²⁵⁰ is such that (a) "it is costly to exclude individuals from using the good either through physical barriers or legal instruments and (b) the benefits consumed by one individual subtract from the benefits available to others" (Ostrom 2000). Because of its two defining characteristics, a common-pool resource is subject to problems of congestion, overuse and potential destruction. It is costly to devise physical and institutional means of excluding potential beneficiaries from the resource, and when one user withdraws units from the resource they cannot be used by others. Under these conditions resource users have incentives to overexploit the resource, free ride on infrastructure and shirk on maintenance, unless rules are developed, monitored and enforced to counteract these incentives (Ostrom et al 1994).

Early frameworks and theories about management of the commons predicted that individuals would overexploit common pool resources (fisheries, forests, rangelands) until they became unproductive, and in some cases beyond recovery (Scott Gordon 1954, Hardin 1968). During the 1980s some scholars engaged in field based research on common pool resources questioned the conventional theory. In response a Panel on Common Property Resource Management was set up under the US National Research Council. The Panel brought attention to the existence of hundreds of examples of collective action to manage common pool resources, in contradiction of the "conventional theory" of the Commons. Successful collective action is not however the only possibility. Case studies have also documented numerous examples of collective arrangements that failed to survive market pressures, government interventions, or technological, demographic or ecological changes.

²⁵⁰ Common pool resources are sometimes called common property resources, but the term *common property* implies that there is some ownership structure, from which non owners can be excluded. However one of the two defining characteristics of a common pool resource is that it is difficult to exclude anyone from using it. The term common pool avoids this contradiction.

The institutional analysis and development framework (IAD) was developed drawing on the observations from these case studies (Kiser and Ostrom 1982, Ostrom 1990). The IAD framework was initially developed to explain collective action and field settings of diverse structures especially complex services in US metropolitan areas. It has been primarily used for studies of small scale common pool resources, but the findings are also relevant to larger scale resources. The IAD has proved quite robust in the face of empirical testing and allowed a wide range of theoretical development including design principles for the management of common pool resources (Ostrom 2005).

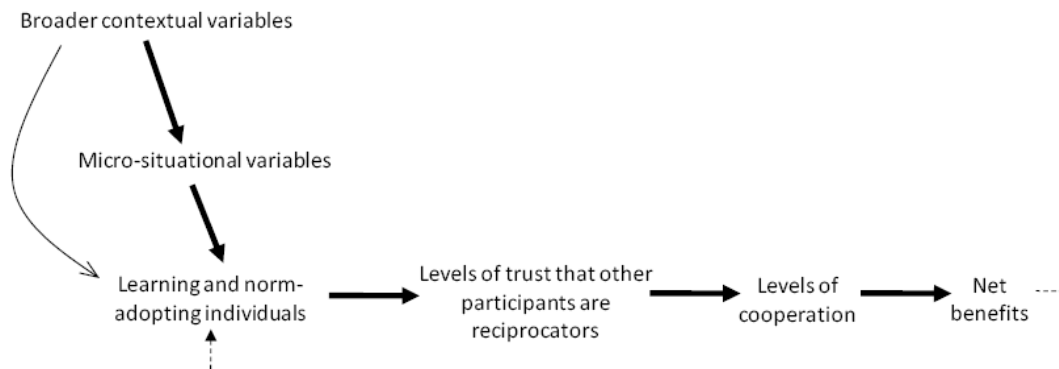
However, the IAD and the design principles derived from it have limitations when dealing with large scale common pool resource management systems with multiple and diverse action arenas where water users can generate large scale externalities and large scale political processes and conflicts. Resource users such as irrigators are more likely to organise themselves to manage “appropriation” issues that have an immediate impact on the resource, such as new wells, well depth and seasonal timing of extractions, than “provision” problems such as those that emerge in distant locations, or in the longer term as water tables decline (Schlager 2007a). Design principles derived from the analysis of small scale common pool resources cannot necessarily be scaled up to large scale systems such as river basins. When aquifers connect with other water resources and/or cross a number of jurisdictions, and when users and government agencies have heterogeneous values and interests, management occurs at multiple scales and levels with broad stakeholder participation (Young 2002).

Recent developments in the theory of collective action and the Commons

Research has shown that a large number of conditions influence the prospects for collective action in specific action situations (Agrawal 2001, Ostrom 2007). Research developments can be divided into three levels of analysis: individual human behaviour; the microsituation including the immediate variables impinging on individual decision making in an action situation; and the broader social and ecological system within which individuals make decisions. Combinations of microsituational and broader contextual variables affect decisions made by individuals, and help to explain the

substantial variation in behaviour observed across and within action situations, as shown in figure A4.1 (Poteete et al 2010).

Figure A4.1. Effect on behaviour of microsituational and broader contextual variables



Source Poteete et al 2010

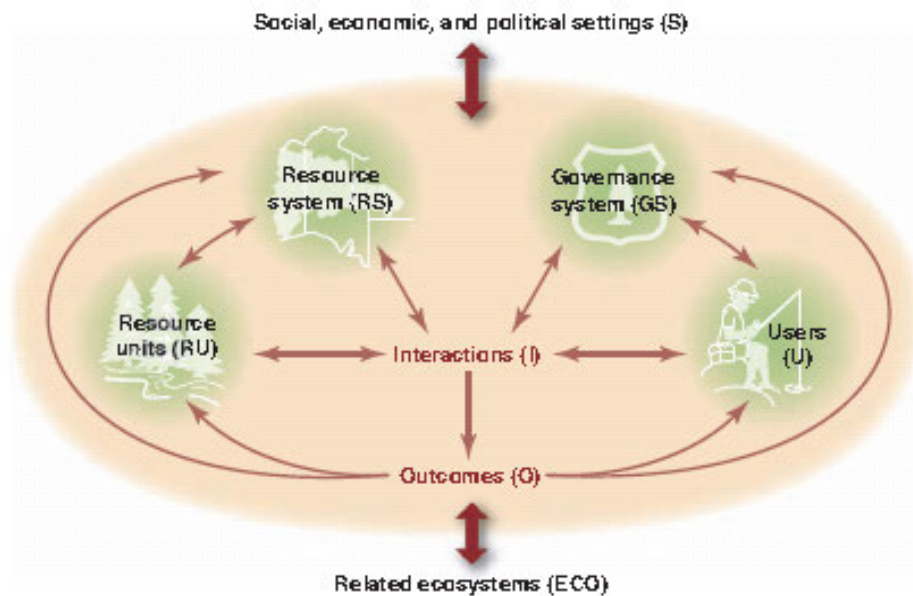
Individual human behaviour and decision making in the face of common pool dilemmas reflects a much more complicated picture than individuals simply seeking to maximise their personal self interest:

- individuals have incomplete information about the situation in which they are interacting with others, and learn or adapt as they acquire more complete and reliable information;
- individuals have preferences related to achieving net benefits for themselves, but these are combined with “other regarding” preferences, and norms of appropriate action and outcomes that affect their decisions;
- individuals use of a variety of decision rules (heuristics) that may approximate maximisation of net benefits in some situations but are cooperative in other situations; and
- trust plays a central role in influencing prospects for collective action.

It is a substantial challenge to move towards theories of collective action and common pool resources that acknowledge complexity and multiple levels of analysis, offer analytical leverage and can be tested and improved over time. The challenge arises from the very large number of variables that can impact on collective action at different scales. Ontological frameworks are widely used in biology, medicine and informatics to set out the elements of complex system. These frameworks generate sets of questions

from which specialists can select questions most relevant to a particular problem. Ostrom has developed a multitier framework for the analysis of social and ecological systems (and common pool resources)(Figure A4.2) (Ostrom 2007, 2009).

Figure A4.2 Framework for analysis of social and ecological systems



Source: Ostrom 2009

The first tier relates resource systems and their units, governance systems and users together with their interactions and consequent outcomes. This framework can be decomposed into further multiple tiers of variables. The second tier is shown in (Appendix 1). This takes account of variables identified by Ostrom (1990), Agrawal (2001) and others – see Appendix 2.

In this framework the multilevel structure of action arenas and decision making is recognised by including a separate governance node, and the impact of external social, economic and political factors is also included. This recognises that in large SESs such as river basins the interactions between resource users and separate and independent governing bodies is the main determinant of resource management outcomes. The framework can act as a starting point to organise an analysis of how attributes of a resource system (e.g. rivers, lakes and aquifers), resource units generated by the system (surface and groundwater), the users of the system (e.g. towns and irrigators) and the governance system interact and what outcomes are achieved at a particular time and place (Ostrom 2007).

The first tier may be unpacked into further tiers, depending on the question being asked, and whether different sub types of a variable tend to generate different outcomes in particular types of processes. Ostrom suggests that further use and development of this framework could be used to answer three broad classes of questions (Ostrom 2009):

- patterns of interactions and outcomes likely to result from using a particular set of rules for a specific resource/user/governance configuration in specific technological and sociopolitical conditions;
- likely endogenous development of different governance arrangements, use patterns and outcomes given different patterns of incentives and rules; and
- the robustness and sustainability of particular configurations of resources, users and governance systems to external and internal disturbances.

Second Tier Variables for Analysing a Social Ecological System

<i>Social, economic, and political settings (S)</i>	
S1 Economic development. S2 Demographic trends. S3 Political stability. S4 Government resource policies. S5 Market incentives. S6 Media organization.	
<i>Resource systems (RS)</i>	<i>Governance systems (GS)</i>
RS1 Sector (e.g., water, forests, pasture, fish)	GS1 Government organizations
RS2 Clarity of system boundaries	GS2 Nongovernment organizations
RS3 Size of resource system*	GS3 Network structure
RS4 Human-constructed facilities	GS4 Property-rights systems
RS5 Productivity of system*	GS5 Operational rules
RS6 Equilibrium properties	GS6 Collective-choice rules*
RS7 Predictability of system dynamics*	GS7 Constitutional rules
RS8 Storage characteristics	GS8 Monitoring and sanctioning processes
RS9 Location	
<i>Resource units (RU)</i>	<i>Users (U)</i>
RU1 Resource unit mobility*	U1 Number of users*
RU2 Growth or replacement rate	U2 Socioeconomic attributes of users
RU3 Interaction among resource units	U3 History of use
RU4 Economic value	U4 Location
RU5 Number of units	U5 Leadership/entrepreneurship*
RU6 Distinctive markings	U6 Norms/social capital*
RU7 Spatial and temporal distribution	U7 Knowledge of SES/mental models*
	U8 Importance of resource*
	U9 Technology used
<i>Interactions (I) → outcomes (O)</i>	
I1 Harvesting levels of diverse users	O1 Social performance measures (e.g., efficiency, equity, accountability, sustainability)
I2 Information sharing among users	O2 Ecological performance measures (e.g., overharvested, resilience, bio-diversity, sustainability)
I3 Deliberation processes	O3 Externalities to other SESs
I4 Conflicts among users	
I5 Investment activities	
I6 Lobbying activities	
I7 Self-organizing activities	
I8 Networking activities	
<i>Related ecosystems (EO)</i>	
EO01 Climate patterns. EO02 Pollution patterns. EO03 Flows into and out of focal SES.	
*Subset of variables found to be associated with self-organization.	

Source: Ostrom 2009

Critical enabling factors for sustainability of the commons

1. *Resource system characteristics*

- (i) Small size (RW)
- (ii) Well-defined boundaries (RW, EO)
- (iii) Low levels of mobility
- (iv) Possibilities of storage of benefits from the resource
- (v) Predictability

2. *Group characteristics*

- (i) Small size (RW, B&P)
- (ii) Clearly defined boundaries (RW, EO)
- (iii) Shared norms (B&P)
- (iv) Past successful experiences social capital (RW, B&P)
- (v) Appropriate leadership young, familiar with changing external environments, connected to local traditional elite (B&P)
- (vi) Interdependence among group members (RW, B&P)
- (vii) Heterogeneity of endowments, homogeneity of identities and interests (B&P)
- (viii) Low levels of poverty

1. and 2. *Relationship between resource system characteristics and group characteristics*

- (i) Overlap between user group residential location and resource location (RW, B&P)
- (ii) High levels of dependence by group members on resource system (RW)
- (iii) Fairness in allocation of benefits from common resources (B&P)
- (iv) Low levels of user demand
- (v) Gradual change in levels of demand

3. *Institutional arrangements*

- (i) Rules are simple and easy to understand (B&P)
- (ii) Locally devised access and management rules (RW, EO, B&P)
- (iii) Ease in enforcement of rules (RW, EO, B&P)
- (iv) Graduated sanctions (RW, EO)
- (v) Availability of low cost adjudication (EO)
- (vi) Accountability of monitors and other officials to users (EO, B&P)

1. and 3. *Relationship between resource system and institutional arrangements*

- (i) Match restrictions on harvests to regeneration of resources (RW, EO)

4. *External environment*

- (i) Technology:
 - (a) Low cost exclusion technology (RW)
 - (b) Time for adaptation to new technologies related to the commons
- (ii) Low levels of articulation with external markets
- (iii) Gradual change in articulation with external markets
- (iv) State:
 - (a) Central governments should not undermine local authority (RW, EO)
 - (b) Supportive external sanctioning institutions (B&P)
 - (c) Appropriate levels of external aid to compensate local users for conservation activities (B&P)
 - (d) Nested levels of appropriation, provision, enforcement, governance (EO)

RW = Wade (1988)

EO = Ostrom (1990)

B&P = Balland and Plateau (1996)

(Source Agrawal 2001)

Attachment 5: Interview Questions

Interview Questions: Case study 1 - Murray-Darling Basin

1. Please describe your understanding of integrated water use and management
2. How have you seen the evolution of policies and practices relevant to integrated water use and management in the Murray- Darling Basin over the past 20 years. What have been the most significant policy changes affecting integrated water use and management in the Murray-Darling Basin during this period?
3. What have been the main purposes of integrated water use and management in your State/Territory?
4. What have been the main benefits and risks of integrated water use and management in your State/Territory?
5. How have the physical characteristics of land and water resources in your State/Territory affected integrated water use?
6. How have the different temporal and spatial scales of surface water and groundwater management affected integrated water management?
7. How do uncertainty and shortfalls in knowledge and information about surface water and groundwater resources, their connectivity, and their availability and use affect integrated water use and management?
8. How have developments and modifications in water law affected integrated water use and management?
9. How have rules about access to water, entitlements to use water (qualitative and quantitative) and their enforcement (or lack of enforcement) affected integrated water use and management?
10. How have water markets and trading affected integrated water use and management?
11. How have administrative structures and processes, and the coordination between them affected integrated water use and management?

12. Which stakeholders (governments, users, third parties) have had the most influence on integrated water management, and how have they exerted this influence?
13. What opportunities exist in your State/Territory for a) managed aquifer recharge and b) alternate use of groundwater and surface water?
14. What infrastructure, knowledge and skills are needed to implement integrated water management?
15. What are the most significant examples of integrated water use or management that you are aware of in the Murray-Darling Basin in the last ten years?
16. Are there any other issues that haven't been covered yet or observations you would like to make?

Interview Questions²⁵¹: Case Study 2 - NSW, Colorado and Idaho

PART 1

1. What have been the most significant changes in policies and management practices relevant to integrated surface water and groundwater management over the past 20 years?
2. Does state policy and legislation require integrated surface water and groundwater management
 - a. As a general rule
 - b. Under specified conditions eg connected surface and groundwater resources?
3. What are the primary purposes of integrated surface water and groundwater use and management?
4. What are the main benefits and risks of integrated surface water and groundwater use and management?
5. What methods are used for integrated surface water and groundwater management (eg joint use, cyclical use, aquifer storage and recovery, other)?

PART II

6. How does the clarity and specificity of surface water and groundwater entitlements affect the integration of surface water and groundwater use and management?
7. How do differences between entitlements to use surface water (HS, GS) and groundwater affect the integration of surface water and groundwater use and management?
8. Which surface and groundwater management authorities are clearly specified and which are not:
 - a. Manage a water resource (eg determine available water, shares of entitlements that can be met, pumping limits, ceased to pump rules?
 - b. Exclude people from using a water resource?
 - c. Transfer ownership of an entitlement to use, store or withdraw water:
 - i. from one surface water user to another?
 - ii. from one groundwater user to another?
 - iii. from a surface water user to a groundwater user or vice versa?

²⁵¹ Most interviews only covered a sub-set of these questions. The number and detail of questions varied depending on the time available for the interview. Some of the above questions were covered in all interviews: 1, 3-6, 10, 14 and 17.

- d. Monitor water extraction and use
 - e. Enforce surface water and groundwater laws, rules and sanctions
9. How do the clarity and specificity of surface water and groundwater management authorities affect the integration of surface water and groundwater management?
10. How are the impacts of surface water use and transfer on groundwater, and vice versa, taken into account in;
- a. Approval and issue of water entitlements?
 - b. Water management regulations and plans?
 - c. Negotiation between affected parties?
 - d. Other? (please specify)
11. How effective is measurement, metering and monitoring of surface water and groundwater use?

PART III

12. If surface water and groundwater management functions are carried out in separate organisations what are the reasons for this separation:
- a. Different policy objectives and priorities? (please specify)
 - b. Different resource and user characteristics? (please specify)
 - c. Different knowledge bases and disciplines? (please specify)
 - d. Separate stakeholder groups (with different membership, values and interests) eg government water administrations, surface water user groups, groundwater user groups, water supply organisations, other interest groups? (please specify)
 - e. Other? (please specify)
13. If surface water and groundwater management functions are carried out by separate organisations what means are used to coordinate their activity:
- a. Communication - organisations inform each other about their activities?
 - b. Consultation - organisations consult before making decisions?
 - c. Consistency - organisations actively seek to ensure that their policies are consistent?

- d. Consensus - organisations seek a common approach (e.g. through joint committees and teams)?
 - e. Conciliation and arbitration - external arbiters or higher authorities are used to resolve differences and inconsistencies?
14. How does coordination of surface water and groundwater management between different organisations at different scales affect the integration of surface water and groundwater management?
 15. How does collaboration between surface water and groundwater management organisations affect the integration of surface water and groundwater management?
 16. How does coordination and collaboration between water management organisations and other organisations (eg public health, land management, environment, economics, energy) affect the integration of surface water and groundwater management?

PART IV

17. Are there any factors not covered above that have had a strong influence on the integration of surface water and groundwater management such as:
 - a. Characteristics of land, surface water and groundwater resources and climate?
 - b. Information (or lack of information) about surface water and groundwater resources and their connectivity over space and time?
 - c. Substitutability of surface water and groundwater (price, quality)?
 - d. Relative availability of surface water and groundwater infrastructure?
 - e. Relative capacity of surface water and groundwater management organisations eg availability of people, skills and finance?
18. Are there any other issues relevant to this study that haven't been covered, or observations you would like to make?

Attachment 6: Classification of surface water groundwater connections across New South Wales

Introduction

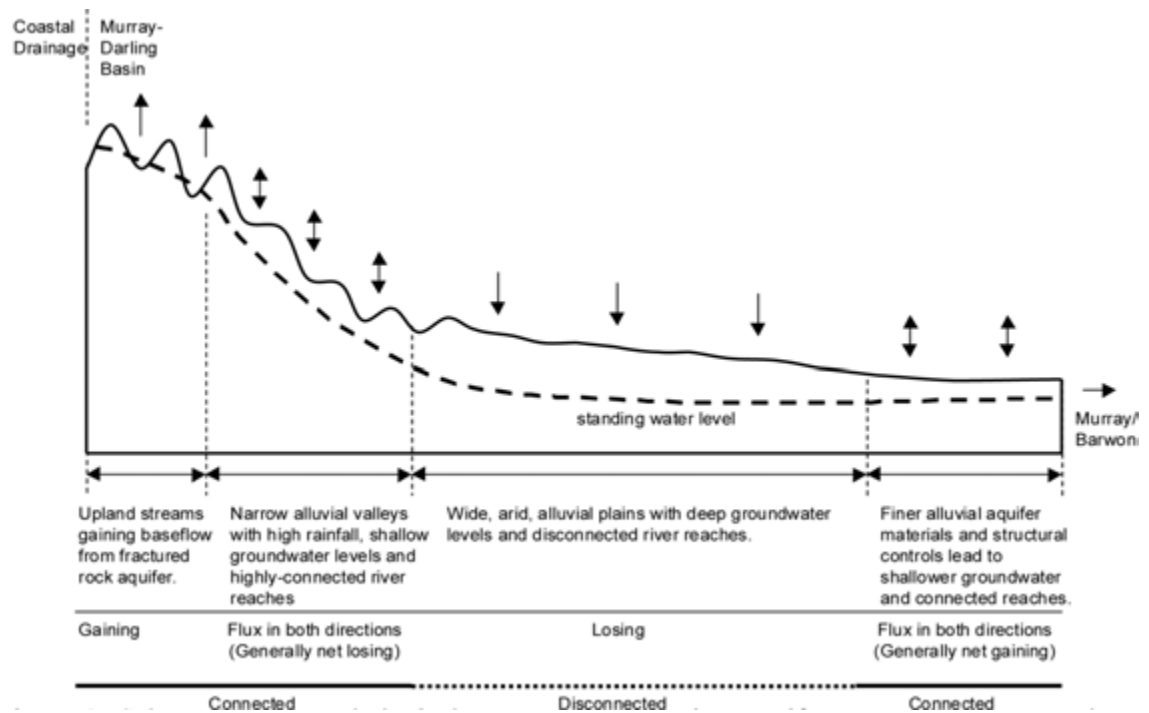
Research from the United States often assumes that 100% of groundwater pumping is derived from stream depletion i.e. that there is a one-to-one relationship between pumping and streamflow (Balleau, 1988; Sophocleous, 2000; Winter *et al.*, 1998). However, in Australia, arid conditions and deep layers of weathered subsurface material can cause deep groundwater levels and long stretches of hydraulically disconnected river reaches. In these areas, particularly where groundwater extraction occurs distant to the stream, it is likely that a large proportion of the water pumped will be sourced from features other than the river and the impact on streamflow will be substantially lower than 100% of groundwater extraction (SKM, 2001).

Classification

River aquifer connections can be divided into the following categories moving from the highlands to the lowland plains as shown in the transect in figure A6.1 (Braaten and Gates 2003). Connected systems can be spatially classified. Classification of systems for management purposes must take into account whether the aquifer is unconfined or semi confined, wide or narrow, whether the river is regulated or unregulated, and whether it flows reliably or intermittently (Braaten and Gates 2004).

Small streams draining upland areas are generally hydraulically connected. These streams have high gradients and small or absent alluvial systems. Discharge from fractured rock aquifers provides a significant proportion of streamflow. Aquifer transmissivity is low. Bore yields are low and lag times between groundwater pumping and stream depletion are long.

Figure A6.1 River - Aquifer Connections: Murray-Darling Basin



Source: Braaten and Gates 2003

In the middle sections of larger Murray-Darling Basin rivers, alluvial systems are more developed, but still narrow and restricted by bedrock. High rainfall and the narrow floodplain produce shallow alluvial water tables and strong hydraulic connection between rivers and aquifers. The direction of river aquifer links can vary over time. After major floods the aquifer may drain back to the river for several years, followed by a period of the river recharging the aquifer. Changes in flux direction may also be seasonal with the river recharging the aquifer during the irrigation season.

Large scale irrigation bore development is common across the floodplains. About one third of total groundwater extraction in New South Wales is in these areas, most of it within a few hundred metres of the river. Groundwater pumping can be expected to impact streamflow to a high degree within a relatively short period of time. In these cases it makes sense to manage groundwater with the same rules as surface water. Such river systems include the upper Murray, Billabong Creek, mid-Murrumbidgee, portions of the upper Lachlan, upper Namoi and Peel, and several tributaries of the Macquarie.

Further across the wide semi arid plains, hydraulic connection is broken. Extensive alluvium has enabled widespread development of bores, but these are usually located many kilometres from the nearest connected river reach reducing the impact of pumping

on streams. Discharges to lakes and wetlands, and recharge from irrigation areas further reduces pumping impact. However, in semi confined systems relatively rapid lateral transmission may have some impact on streamflow even when bores are a long distance from the stream (Braaten and Gates 2004). River systems with these characteristics include the lower Murray, lower Murrumbidgee, lower Lachlan, lower Namoi, and lower Gwydir.

Near the confluence of major inland rivers with the Darling-Barwon and Murray Rivers reduced aquifer transmissivity caused by finer materials forces groundwater near the surface, re-establishing connectivity with the river. Groundwater has generally of high salinity and groundwater discharge is known to degrade river water quality. Because of the high salinity, there are few irrigation bores and little groundwater extraction.

In many small connected systems river flows are ephemeral. Groundwater is often been developed to provide a reliable source of supply. While groundwater extraction cannot impact on river flow during no flow periods, it may lead to delayed restart of flows, impacting remnant pools and other environmental assets.

The above classifications are conceived at the regional or catchment scale. At the local scale many hydrological and hydrogeological variables can influence the outcomes including local properties of streamflow, streambeds, aquifer slope and materials, and the height of the water table in relation to the stream surface and stream bed. It is important to understand local processes in order to interpret broader scale analyses (Evans 2007).

Management and policy implications

The above analysis shows that different types of aquifers, and different aquifer stream connections lead to a wide variety of pumping impacts on streamflow. The growth of groundwater use in some highly connected river aquifer systems has the potential to overtake the aquifer's sustainable diversion limit. The potential growth may also impact on the reliability of supply to river users and, in unregulated rivers on ecological and critical low flows. In unconfined systems, pumping location can be arranged to take advantage of time lags, and rules can be established to reduce adverse environmental

impacts, but these lags and effects are less significant (or even absent) in semi confined systems (Braaten and Gates 2003, 2004).

Priorities for managing connected surface water and groundwater resources need to take account of

- a) the level of connectivity, that is the impact of pumping on streamflow (or diversions on recharge); and
- b) the time delay before the impact occurs.

Evans (2007) proposed a two dimensional assessment of surface and groundwater connectivity that is a useful means for classifying the impacts of connectivity and identifying management and research priorities.

Table 2.3 Classification of impacts of surface water and groundwater connectivity²⁵²

		Steady-State Impact			
		< 10%	10-50%	> 50-90%	> 90%
Time Delay	> 1 year	Low	Moderate, short term	High, short term	Very high, short-term
	1-10 years	Low	Moderate, medium term	High, medium term	Very high, medium term
	> 10 years	Very low	Moderate, delayed	High, delayed	Very high, delayed

²⁵²This table is adapted from Evans 2007 and SKM 2011

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