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Further Closing the Integrated Total Water Cycle in the Lockyer Valley: A Catchment Scale Integrated Water Resource Management Conceptual Model

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Abstract

There is a need to facilitate decision making on integrated water resource management (IWRM) issues, minimise leakages from and further close the integrated total water cycle (ITWC). The complex social, economic and environmental dimensions and the scarcity of the resource make water management one of the truly “wicked” environmental management problems (cf. Rittel & Webber 1973). This study seeks to contribute to the resolution of this IWRM problem by adding a new definition of IWRM and providing analytical tools for the assessment of water catchments issues, conditions and improving management. A multidisciplinary integrated approach assisted in understanding and managing the complex dynamic multidimensional nature of water and its use. To advance this aim, a new conceptual model for catchment scale IWRM was developed then applied and refined, based on case studies.

A review of literature reveals inconsistencies and complexities in the application of IWRM and approaches to minimising leakages from the ITWC. This study has developed an ITWC conceptual sub-model that demonstrates the capacity to incorporate the principles and theory of other disciplines such as hydrogeology, ecological economics and political science into the IWRM conceptual model. The new IWRM conceptual model determined the key components of IWRM using a case study of the Lockyer Valley in South East Queensland, Australia. Further international cases challenged and provided additional insights into these key components using the complex and interconnected dimensions of an IWRM conceptual model – environment, economic, social and policy.

A mixed methodology combining quantitative and qualitative secondary data from the case study of the Lockyer Valley during the millennium drought (1997-2009) assisted development of a new catchment scale IWRM conceptual model and key IWRM components. The Lockyer Valley is a primary supplier of agricultural produce to eastern Australia, and contains the headwaters of the downstream Brisbane River catchment. The Lockyer Valley is primarily dependent on groundwater for irrigation, which it continues to draw upon in excess of its sustainable yield. Despite nearly 20 years of research and investigation into the Lockyer Valley and over 60 reports, research papers and consultancies, many of its IWRM issues

remain unresolved. This case study was enhanced by a comparison with international cases of IWRM, which assisted in the developing and refining of a contemporary IWRM conceptual model, approach, definition and principles for worldwide application.

This study advances water management using an IWRM conceptual approach that further closes the ITWC by focusing on urban-rural IWRM opportunities, going beyond using recycled water for irrigation. This model differs from previous models as it focuses on the ITWC rather than the natural water cycle. The limits of the environment are a feature of this approach, along with recognition of the role of social capital, policy input from government and non-government sectors, ecological economic theory and principles, and hydrogeological modelling for a catchment scale conceptual IWRM model, thus setting it apart from previous models in literature. These additions bring a wider perspective to IWRM decision making and assist in the management of ongoing issues of changes in climate, growing demand for irrigation water, population growth, environmental demand for water and excess wastewater. Such issues affect IWRM worldwide.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Publications during candidature

No publications.

Publications included in this study

No publications included.

Contributions by others to the study

No contributions by others.

Statement of parts of the study submitted to qualify for the award of another degree

None.

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Keywords

integrated, water, resource, management, conceptual, catchment, model, Lockyer, Valley, IWRM,

Australian and New Zealand Standard Research Classifications (ANZSRC)

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ANZSRC code: 160605, Environmental Politics, 20%
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Fields of Research (FoR) Classification

FoR code: 0502, Environmental Science and Management, 60%
FoR code: 1606, Political Science, 20%
FoR code: 1499, Other Economics, 20%

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Abbreviations

ABS	Australian Bureau of Statistics
AMLR NRMB	Adelaide Mount Lofty Ranges Natural Resources Management Board
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ANZECC	Australian and New Zealand Environment and Conservation Council
ANRA	Australian Natural Resources Atlas
ASCE	American Society of Civil Engineers
ATSE	Academy of Technological Sciences and Engineering
BCC	Brisbane City Council
C2S	City to Soil
COAG	Council of Australian Governments
DDV2000	Darling Downs Vision 2000
DEEDI	Department of Energy Environment and Innovation QLD
DEHP	Department of Environment & Heritage Protection QLD
DERM	Department of Environment and Resource Management QLD
DEWHA	Department of the Environment, Water, Heritage and the Arts Commonwealth
DEWS	Department of Energy and Water Supply QLD
DIP	Department of Infrastructure and Planning QLD.
DLGPSR	Department of Local Government, Planning, Sport and Recreation QLD
DNR	Department of Natural Resources QLD
DNRM	Department of Natural Resources and Mines QLD
DNRMED	Natural Resources Management and Environment Department
DNRMW	Department of Natural Resources, Mines and Water QLD
DNRW	Department of Natural Resources and Water QLD
DPI	Department of Primary Industries
DPIF	Department of Primary Industries and Fisheries
DSD	Department of State Development
DSDI	Department of State Development and Innovation QLD
DSDIP	Department of State Development, Infrastructure and Planning QLD

DPSIR	Driver-Pressure-State-Response Model
EC	European Commission
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
GWP	Global Water Partnership
ICWE	International Conference on Water and the Environment
ITWC	Integrated Total Water Cycle
IWRM	Integrated Water Resource Management
LWUF	Lockyer Water Users Forum
MAR	Managed aquifer recharge
MDB	Murray Darling Basin
NRMMC	National Resource Management Ministerial Council
NWC	National Water Commission
NWI	National Water Initiative
OGIA	Office of Groundwater Impact Assessment
PRW	Purified Recycled Water
QCA	Queensland Competition Authority
QGSO	Queensland Government Statistician's Office
QUU	Queensland Urban Utilities
QWC	Queensland Water Commission
ROP	Resource Operations Plan
RWUE	Rural Water Use Efficiency Initiative
SEQRP	South East Queensland Regional Plan
SEQRWSS	South East Queensland Regional Water Supply Strategy
SEQRWP	South East Queensland Recycled Water Project
SEQRWT	South East Queensland Recycled Water Taskforce
TEV	Total economic value
UNDESADSD	United Nations Department of Economic and Social Affairs Division for Sustainable Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNESCO	United Nations Organization for Education, Science and Cultural Organization
UNICEF	United Nations Children's Fund
UWSRA	Urban Water Security Research Alliance
VIA	Virginia Irrigation Association
VNAP	Virginia Northern Adelaide Plains
VTHA	Virginia Triangle Horticultural Area
VPS	Virginia Pipeline Scheme
WAE	Water Access Entitlements
WRSV	Water Reticulation Systems Virginia
WRP	Water Resource Plan
WSS	Water Supply Strategy
WCRWP	Western Corridor Recycling Pipeline
WCRWS	Western Corridor Recycled Water Scheme
WHO	World Health Organization
WMO	World Meteorological Organization

Chapter 1 Introduction

1.1. Background to research

The Lockyer Valley, 80 kms west of Brisbane in South East Queensland is a major supplier of agricultural production to national and international markets (The Stafford Group 2013). For decades the area has been exposed to the pressures of population growth, climate variability, agricultural intensification, overused groundwater, stream flow loss, water intensive lifestyles and urbanisation, reactive and inconsistent water policies and environmental demands on available water supplies (Sarker et al. 2009; Galletly 2007; Cox & Wilson 2005; DNRM 2005a). Despite nearly two decades of research studies and consultancies, the Lockyer Valley lacked an IWRM approach to further close the water cycle and effectively manage water as a common pool resource. A multidimensional approach was sought to recognise, understand and integrate these dimensions of integrated water resource management.

The Lockyer Valley has been affected by Australia's millennium drought (1997-2009) and the deluges of 2010-11 (DNRM 2005a; Thompson & Croke 2013). A review of IWRM for the Lockyer Valley was required if future impacts were to be managed effectively. Nearby urban Brisbane also produced vast quantities of wastewater, periodic stormwater and rainwater, available to relieve this water stress (NRMMC 2006). A new approach was needed that views these factors as part of the same IWRM issue – part of the same ITWC. These issues have not been resolved in the Lockyer Valley and many other rural areas internationally, highlighting the need for an IWRM approach that further closes the ITWC by reducing leakages from the water system in the urban-rural context. Leakages from the water cycle included water that becomes unusable in the water system due to contamination and waste (Keller et al. 1996). A water resource system is "closed" when no usable water leaves the system (Keller et al. 1996). A system that improves efficiency with minimal leakages in water and energy from the water cycle were goals also sought in a new IWRM conceptual model (NWC 2007a; DeSimone & Popoff 2000). Maintaining efficient energy use was desirable in closed systems such as these, but these technical and energy efficiency issues were beyond the scope of this thesis.

A new approach was needed to solve the continuing water problems of water catchments like the Lockyer Valley that integrated new and existing analytical tools for the assessment of water catchment conditions and issues. An IWRM framework was required to: understand and manage unsustainable rural and urban demand for 'single use' water; water requirements of the environment; highly variable rainfall and natural water flows; inadequate aboveground water storage; compromised underground water supplies; expensive underutilised recycled water supply and purification infrastructure and burgeoning wastewater supplies; under-priced clean water and water substitutes; and unclear rural water property rights (UN 2014, Tisdell et al. 2002; Keller et al. 1996). These issues represented failures in IWRM and lack of understanding total water cycle management principles. In developing this framework, an appropriate conceptual model for catchment scale IWRM was sought to address the research gaps, problems and questions in this study. Such a conceptual model was then applied to the case study of the Lockyer Valley, to enhance interdisciplinary research into IWRM and management of water as a common pool resource.

Irrigation water can be a common pool, public or privately owned resource. The foci of this study were the common pool and public groundwater water resources used for irrigation in the Lockyer Valley that were not subject to governance or market arrangements to manage access adequately. These resources brought with them complex issues of ownership and management responsibility. As a "wicked problem" full of dynamic complexities, IWRM required an equally complex and flexible management solution (Wester & Warner 2002). Water, as a common pool resource, is a necessary, but finite, natural resource with the characteristics of non-excludability and divisibility (Ostrom 2008). That is, as a common pool resource, it diminishes with successive use and its users cannot naturally be excluded (Hardin 1968; Demsetz 1967). As such, water exhibits characteristics of non-excludability as it is needed by all for survival, without restriction over its primary function – that of drinking (stock watering). Water as a common pool resource is also divisible, as more is consumed there is less available for other users. This situation may be altered with the careful use and reuse of water.

These issues, emerging from the case study of the Lockyer Valley, provided the background to the research into the international IWRM issues. They covered four dimensions of the IWRM problem including intergovernmental overlap and inconsistent application of IWRM, social complexities of the community's involvement in decision making, unresolved technical, economic and environmental issues. A new IWRM conceptual model was sought to analyse and understand the issues of further closing the ITWC and this water as a common pool resource. The search for a catchment scale integrated water resource management (IWRM) conceptual model was undertaken in this study to incorporate all water sources and users in a bid to further close (hereafter referred to as 'closing') the ITWC and better manage common pool resources such as groundwater.

Through this approach, the study demonstrated the components of IWRM required to attain the benefits of:

- restoration of catchment flows;
- responsible disposal of treated wastewater from urban, rural and industry water users;
- full utilisation of existing water infrastructure;
- sustainable management of all water sources in the water catchment;
- restoration of catchment ecosystems (and biodiversity);
- land use decisions impacting on economic gains from horticulture.

Other international IWRM case examples in Spain, Japan, China, Wichita U.S., Murray-Darling, the Virginia Northern Adelaide Plains area in South Australia and the Gnangara Mound in Western Australia were examined for the degree of success or failure to understand and incorporate these issues into their IWRM approaches. Before this could occur, the gaps in existing research in the area of IWRM frameworks and conceptual models were explored.

1.2. Research Gaps in Existing IWRM Conceptual Models

There were a variety of frameworks for IWRM in literature, many of which focus on river basin catchment scale management (Newson 2004; Postel & Richter 2003; Falkenmark 1997). Debate around these frameworks related to the focus on the scale of the river basin and the 'technocratic' emphasis on hydrological and technical boundaries and solutions (Newson 2004). Criticisms about the limitations of such frameworks from a social science perspective stemmed from the overemphasis on these geological and hydrological jurisdictional boundaries (Wester & Warner 2002; Rhoades 1998; Wouters 1997; Winpenny 1994). From this debate the issues of 'hydropolitics' - socio-political aspects of

IWRM emerged (Turton 2002; Ohlsson 1995). To address the IWRM issues of the Lockyer Valley a framework that encompasses the environmental, social, political, economic and technical dimensions of IWRM was required.

A conceptual model and definition of IWRM were needed to address the water cycle and encompass all water sources and users in the water catchment. A comprehensive definition and model was sought that included the ITWC - all water sources including natural and recycled water, upon which an integrated approach to IWRM at the catchment scale could be developed. (See Thomas & Durham 2003; Keller et al. 1996). These water sources included rainfall, surface water, natural overland flows, groundwater, wetlands, vegetation and soil moisture and wastewater. Wastewater included the used water from a system that was often treated to various purity levels for further use, including stormwater, rainwater, agricultural run-off and sewage. This ITWC sub-model was replicated in Figure 1-1.

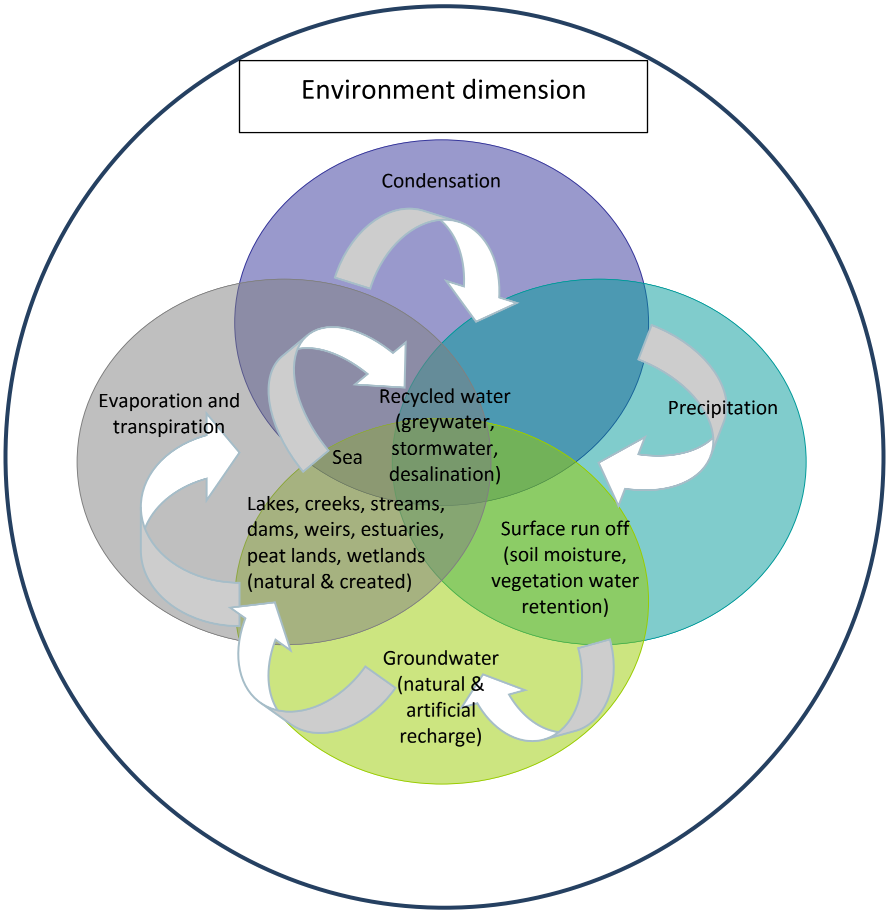

Figure 1-1 The Integrated Total Water Cycle Model as the Basis of the New IWRM

Conceptual Model.

A conceptual model was sought to close the ITWC at the water catchment scale by minimising leakages from the water cycle. Traditional IWRM focused initially on the natural total water cycle, which derives energy from gravity and the sun (Keller et al. 1996; Garbrecht 1987). Meanwhile the ITWC included created and recycled water often requiring large quantities of generated power from electricity, gas, solar or hydropower. Ideally a new catchment scale IWRM conceptual model would rely upon the ITWC, expend minimal energy and close leakages from the ITWC. Thus, the interconnectivity between water, energy, land and other resources was another element required of a new IWRM conceptual model (UN 2012; EC 2000). Even though such a model would be based upon the hydrological catchment boundaries, it needed to incorporate users from outside the catchment. It would do this through integration of social, political and economic dimensions of IWRM (e.g. trading of water rights with those outside the catchment hydrological boundaries such as those in the Murray Darling Basin where trading of water across states boundaries and valleys can occur as discussed further in section 5.3.4). Consequently, a research gap in existing IWRM conceptual models established the need for a catchment scale IWRM conceptual model to analyse and understand the issues of further closing the ITWC and managing public water (unmonitored groundwater use for irrigation in the upper and lower Lockyer Valley) as a common pool resource.

From literature, three conceptual approaches were examined for their ability to capture the dynamic and integrated nature of the dimensions of IWRM and its components:

1. The IWRM model (Koudstaal et al. 1992).
2. The Three Pillar framework of IWRM (GWP 2006) first presented at the conference in Dublin in preparation for the Earth Summit (UN 1992a).
3. The conceptual framework for catchment-scale integrated water resource management (Ross et al. 2006).

The existing models built upon the natural water cycle and then introduced recycled water. This study, however, built a model that centred on the ITWC sub-model – the integration of all water sources, urban and rural, natural and recycled flows, above and below water ground supplies (Keller et al. 1996). The environment was a dimension of these existing models, but a model constrained by the biophysical boundary of the environment was required, to reflect the absolute limits of water resources (Costanza & Daly 1992; WCED 1987). Different scales of IWRM were required for different water issues and communities and a new model that could easily be adapted for any scale was also sought. The environmental, policy, economic and social dimensions of the water issue also needed to be addressed in decisions of scale in IWRM. While a new model would be limited by the hydrological and geographical aspects of the study area, the users may extend beyond the boundaries of traditional river basin scale models – thus an extended catchment scale model was planned for this study. This was done to include water users and supply beyond the basin e.g. through water trading and imported recycled water. Together these aspects pointed towards the need for a new catchment scale IWRM conceptual model to address the following research gaps:

a) Reduction of leakages from, and options to close, the ITWC in catchments;
b) Understanding of the depth and complexity and connections between the dimensions of IWRM;
c) Integration of theory, principles and models from other disciplines;
d) Accommodation of total water cycle management principles;
e) Identification and incorporation of the key components of IWRM;
f) Reduction of pressure on overused single use water from common pool resources through urban-rural water integration;
g) Integration of treated urban and industrial wastewater as a source of recharge for nearby rural areas.

These research gaps provided focus for the research problem in this study. Separation of existing physical and economic models in practice failed to represent the links between the economy and environment (Giupponi et al. 2004). International organisations and forums mentioned IWRM but few had explicit definitions (UNEP-DHI 2009; GWP- TAC 2000; FAO 2000; World Bank 1993; WCED 1987). The GWP-TAC (2000) definition was selected for this study. More discussion on this appears in section 2.2. A multidisciplinary approach was required to assist with integrated natural resource management (Jeffrey 2003) and specifically to assist with agri-environment policy (Giupponi et al. 2004). Since the Millennium Ecosystem Assessment (2003), the ecosystem approach gained momentum as "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (Macleod et al. 2007 p. 593). Such an approach placed humans and their activities within the ecosystem and not the reverse. This trend signalled the move towards a multidisciplinary approach to IWRM, effectively combining natural and social sciences that has been adopted in this study (Haygarth et al. 2005).

Such an approach was used to develop a new conceptual IWRM model to promote understanding of international water management issues that were transferrable across disciplines including engineering, economics, policy, social and environmental science. Also, while research existed into IWRM in the urban and rural context separately, there was little research into urban-rural IWRM or management of public water as a common pool resource. A new IWRM conceptual model was needed to be flexible across scales and water issues as exemplified through the case study of the Lockyer Valley and other international case studies specifically focusing on gaps in the urban-rural context.

1.3. The Research Problem

Out of these research gaps, the research problem emerged from the need to develop a new catchment scale IWRM conceptual model to close the ITWC and reduce water leakages at the catchment level. The Lockyer Valley continued to demonstrate unresolved IWRM problems and issues that appeared in international literature and examples. These problems and issues were analysed using a new catchment scale IWRM conceptual model. Ongoing issues with unresolved economic, environmental, social and policy aspects of the water problem in the Lockyer Valley required a combined approach to understanding, developing and refining an appropriate IWRM conceptual model, its dimensions and key components.

The case study of the Lockyer Valley provided an example of a rapidly growing area of agricultural significance in South East Queensland. For the purposes of this study, the Lockyer Valley included the headwaters for the downstream urban area containing the capital city of Brisbane (Low Choy et al. 2007). The Lockyer Valley also offered a potential repository for large quantities of recycled water from and for surrounding local councils. As such, it exhibited all the drivers that put pressure on irrigation water and presented an opportunity to integrate available rural water supply with the vast quantities of wastewater, periodic stormwater and rainwater available for use (FSA 2006; ACIL Tasman 2005; Psi-Delta 2003; Higgins et al 2002). Some of these drivers included retail demand for agricultural produce regardless of growing cycles and rainfall (further discussion on these drivers for irrigation water continued in section 2.5.2. A conceptual model that recognised and included these drivers for demand for this water was therefore required. These dimensions of international IWRM issues were examined in the context of the Lockyer Valley and include intergovernmental and institutional overlap, inconsistent policy and application of IWRM, social complexities of the community involvement in decision making, and unresolved economic, technical and environmental issues.

As such, the Lockyer Valley offered theoretically sound, legislatively supported opportunities for a sustainable IWRM that closed the water cycle. After nearly 20 years of research studies and consultancies, the Lockyer Valley was still no closer to achieving an IWRM outcome that closed the ITWC and effectively managed public (groundwater) water as a common pool resource. This study revisited the Lockyer Valley IWRM situation during the millennium drought when groundwater was overdrawn, salinity in groundwater was rising and above ground water storage limited (Powell et al. 2002). The nature and extent of irrigated agriculture in the Lockyer Valley was threatened by the continuation of the existing irrigation practices (Powell et al. 2002). Meanwhile large quantities of expensive treated wastewater from nearby urban areas were (and still are) released unused into downstream ocean outfalls (Natural Resource Management Ministerial Council 2006; Catchion et al. 2001). Other rural recycled water options including stormwater remained unexplored and the problem of overdrawn groundwater persisted in the Lockyer Valley (Mainstream Economics & Policy MEP 2013). International case examples of these IWRM issues and approaches were sought and the more recent developments in the Lockyer Valley since the millennium drought were compared using the new IWRM conceptual model. These case studies offered an opportunity to advance contemporary IWRM where similar conditions exist. In the process, the key components of IWRM and dimensions of an IWRM conceptual model were identified and their explanatory strength harnessed to assist with worldwide IWRM issues.

A New Catchment Scale IWRM Conceptual Model

A review of IWRM literature provided details about the five dimensions to the research problem – unresolved environmental issues, technical issues, the intergovernmental overlap and inconsistent application of IWRM, social complexities of the community's involvement in IWRM decision making and unresolved economic issues. This literature was critiqued in more detail in Chapter 2, while the research problems were outlined here. Initial thoughts about the design of a new IWRM conceptual model stemmed from the realisation that the IWRM issues corresponded to the five dimensions of the IWRM issues in literature – environmental, technical, policy, social and economic. Each IWRM dimension interacted with the other dimensions and was dynamic and complex in its own right. A new catchment scale IWRM conceptual model that reflected this dynamism and complexity drove this study. These overlapping and interconnected dimensions conceptually fitted the 'egg of sustainability' model illustrated in Figure 1-2. (cf. Guijt & Moiseev 2001). This model depicted the trade-off between growth in human-made capital, social capital and human capital and the interactions between the dimensions (Keiner 2004; Stenberg 2001). For these reasons, the "egg model" was selected as the basis for a new IWRM conceptual model for this study.

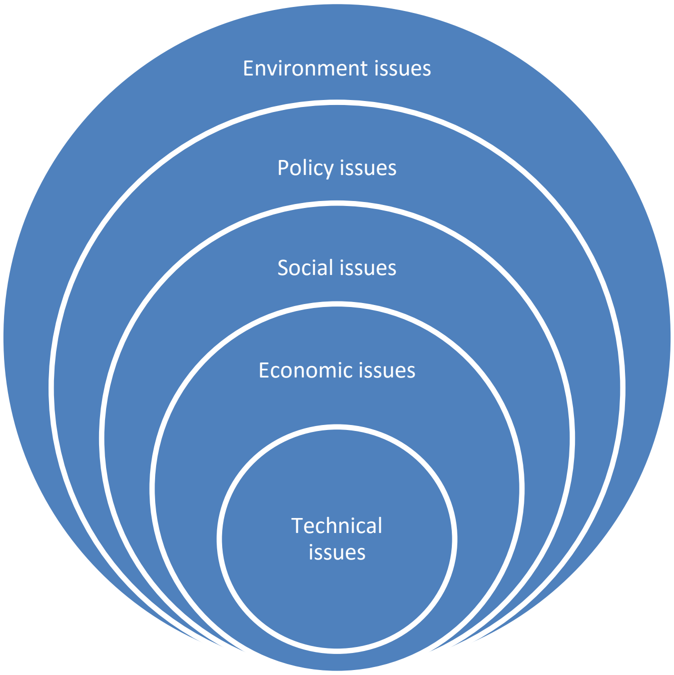

Figure 1-2 The "egg of sustainability" model approach to IWRM

The “egg model” depicted people within the environment who were completely dependent on it. The model was valuable to the development of the new IWRM model in that it showed that both people and the environment function in a sustainable way where society’s needs are met by the environment (cf. Guijt & Moiseev 2001). Both society and the environment had equal importance and were managed together. Where the environment provided the natural resources, the social economic and policy dimensions could operate within the limits of the environmental carrying capacity (Meadows et al. 1972). The complexity and interactions of society and the environment were recognised in the “egg model” and reflected the complexity of IWRM required in developing a new IWRM model for this study.

Improved information, research and understanding of these IWRM dimensions impacted on the development of a new IWRM conceptual model and assisted with understanding IWRM issues. Subsequent chapters of this dissertation investigated the IWRM issues in the Lockyer Valley and international case examples to assist understanding the:

- dimensions of IWRM problem
- components of each IWRM dimension
- links between dimensions and components
- role of each in the implementation of IWRM to close the ITWC.

The IWRM research problem was complex and dynamic and existed due to the unresolved issues, inconsistent application of IWRM and lack of understanding of the dimensions. These dimensions were outlined briefly and further explored in the literature review in Chapter 2.

The *environmental dimension* reflected the absolute limits of natural resources and comprise all natural capital - stocks of non-renewable, renewable and recycled resources. For this reason, it formed the limits of the proposed catchment scale IWRM model in this study. Literature was examined for a conceptual model that incorporated the ITWC within the environmental dimension as shown in Figure 1-3. The issues of the technical dimension were briefly addressed but this study was not intended to be a technical paper. There were a variety of research consultancies investigating these technical aspects and water supply scenarios (e.g. Gardner et al. 2007). For the purposes of this study, the technical and water supply aspects resided within the ITWC. Further discussion on how the integration of natural and recycled water in the ITWC conceptual sub-model restored some sustainability in water resource management continued in Chapter 2.

The *policy dimension* incorporated the decision-making aspects of government and non-government institutions. The *social dimension* encompassed human capital including views, knowledge and experience of water and its management (including perceptions and awareness of individuals). The *economic dimension* included the economic issues related to demand and supply of water. These four interconnected dimensions were depicted using an adapted version of the 'egg of sustainability' model (cf. Guijt & Moiseev 2001) as the basis for the new catchment scale IWRM conceptual model in Figure 1-3. This model firmly placed the actions and decisions of people within the boundaries of the finite environment.

To develop a new IWRM conceptual model that closed the ITWC in water catchments it was necessary to examine the principles of IWRM and incorporate the ITWC sub-model. As the largest user of water in Australia (65% in 2013) the agriculture sector offered a useful starting point for a new conceptual model of IWRM aimed at further closing the water cycle (ABS 2013a). This new approach was further developed and refined to assist with urban-rural water integration issues in the Lockyer Valley (Chapters 3 and 4) and international cases (Chapter 5).

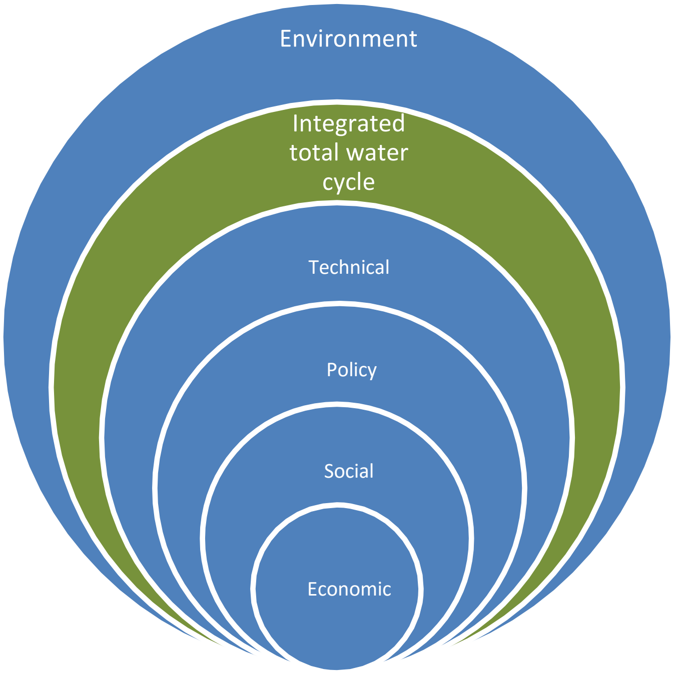

Figure 1-3 The 'egg of sustainability" model of IWRM incorporating the ITWC and technical dimension within the environment dimension

These IWRM issues were "wicked" problems with complex causes and solutions and therefore techniques used have wider application than purely technical and economic analyses. A critical review of IWRM literature provided the information upon which to build a catchment scale IWRM conceptual model based upon the ITWC. This literature further assisted in the formulation of an IWRM approach to address issues such as the measurement, allocation and pricing of all water sources using theory and principles from across disciplines, including ecological economics, hydrogeology and political science.

Techniques such as review of international literature (Chapter 2), the case study of the Lockyer Valley (Chapters 3 and 4) and other international IWRM cases (Chapter 5) replaced the process of gathering primary data from interviews where communities were found to be exhausted by over-consultation and research fatigue. The findings of this study will not verifiable until all water use is measured in catchments, all water sources are accounted for in water licensing, water prices reflect total economic value (TEV), the issue of subsidies is managed, and water infrastructure access and service provision issues are resolved. Meanwhile, the new conceptual models of catchment scale IWRM conceptual and total integrated water cycle were developed for wider application by policy makers.

An analysis of the case studies of the Lockyer Valley and other international cases provided the means to compare and contrast the implementation issues of a catchment scale IWRM approach that closes the ITWC. The urban-rural level IWRM was not well supported in international literature and cases and required the non-sectoral conceptual approach adopted in this study to address this.

IWRM is a complex ecological, economic, social and political problem that necessitated a multidisciplinary approach (Savenije & van der Zaag 2008; Macleod et al. 2007; Pahl-Wostl 2002). A conceptual model for IWRM that combined the sub-model for ITWC with a multidisciplinary approach to the management of common pool resources were not found in literature. The search began for a model that blended economic principles with those of ecology to recognise the natural limits of water resources, ecosystem demand for water and options for water reuse to investigate the dimensions of IWRM.

The multidisciplinarity was well captured in the school of thinking known as ecological economics - suited to managing complex worldwide, integrated water management issues (European Commission EC 2000; Daly 1996; World Meteorological Organization WMO 1992; Anderson & Leal 1991; Ehrlich & Holdren 1971). Management of common pool resources in literature had been developing with the aid of ecological studies (Bravo & Marelli 2008). For example, the social-ecological system emphasized links between humans living in natural systems. Studies on management practice from the perspective of their effects on ecosystem dynamics were useful for learning from and adapting to feedback from the natural environment. For example, concepts such as adaptability, resilience and robustness, first defined by the ecological science were central to the understanding of development of complex systems (Bravo & Marelli 2008; Berkes et al. 2003; Gunderson and Holling, 2001; Berkes and Folke, 1998). Inclusion of ecological economic theory and principles in a new IWRM conceptual model addressed issues involved in developing the framework for a multidisciplinary approach to a catchment scale IWRM conceptual model for general application. This research problem led to the development of the following thesis statement.

A new multidimensional and dynamic catchment scale IWRM conceptual model is required to explore the relevant dimensions and components of IWRM issues. Such a model would close the ITWC and resolve issues related to managing water as a common pool resource as demonstrated in the case study of the Lockyer Valley and other international cases. From this thesis statement, three research questions emerged.

1.4. Research Questions

From the research problem outlined above, the three research questions were:

1. What are the key components of the new IWRM conceptual model required to close the ITWC and better manage water as a common pool resource? (Addressed in Chapter 2, 3, 4, 5 and 6).
2. Can the application of sound principles and theory of ecological economic and hydrogeology assist in the development of a new IWRM catchment scale conceptual model, which will achieve these aims? (Addressed in Chapters 2, 3, 4, 5 and 6).
3. Can the new IWRM catchment scale conceptual model aid management of the demands on water caused by climate variability, population growth and intensification of agriculture, in view of limited further viable above ground water storage options and unused wastewater? (Addressed in Chapters 3, 4, 5 and 6).

To answer these questions, it was necessary to build a catchment scale IWRM conceptual model from IWRM literature and then test and refine the model using the case study of the Lockyer Valley, South East Queensland (SEQ) (Chapters 3 and 4) and international cases in IWRM (Chapter 5). In recognition of these objectives and the ultimate goal of an IWRM, the closure of several research gaps was attempted and wider application of the new catchment scale IWRM conceptual model sought. These aims were further developed in the following chapters of this dissertation.

1.5. The Iterative Approach to the Study

The approach adopted in this study evolved throughout the chapters of the dissertation in response to the major environmental changes in the study area and as problems emerged with obtaining primary data and creating an appropriate conceptual model. The study originally attempted to investigate the case study of IWRM in the agricultural area of the Lockyer Valley, Queensland at the height of a 10-year drought in 2009. Solutions to its history of overuse of groundwater and surface water and its potential as a destination for excess treated waste water from nearby urban Brisbane water catchment had eluded policy makers and irrigators for decades. In the initial approach to the research for this thesis, no attempt was made to gather primary data through interviews as the community was exhausted from 20 years of consultations and at least as many surveys. The study instead investigated the socio-economic and hydrogeological alternatives for the excess wastewater available via the western corridor recycled water pipeline. When the drought broke during the Lockyer Valley deluges in late 2010 and early 2011, the impetus to use recycled water for irrigation water faded and available hydrological expertise focused on flood mitigation. A change in thesis methodological approach ensued.

The methodological approach evolved at various stages of this study. This iterative approach to managing data problems and facilitating the development of an appropriate conceptual model, was supported by five existing conceptual sub-models. The approach also combined deductive research (generalisations of IWRM theory applied to specific instances in Chapters 1 and 2) with inductive research (observations of specific instances in interviews and case studies to establish generalisations in Chapters 3, 4 and 5) (Hyde 2000; Parkhe 1993).

The seven chapters of this dissertation built the methodology, drew on IWRM literature and applied the conceptual model to the case study of the Lockyer Valley and other international cases as shown in extended dissertation outline in Figure 1-4.

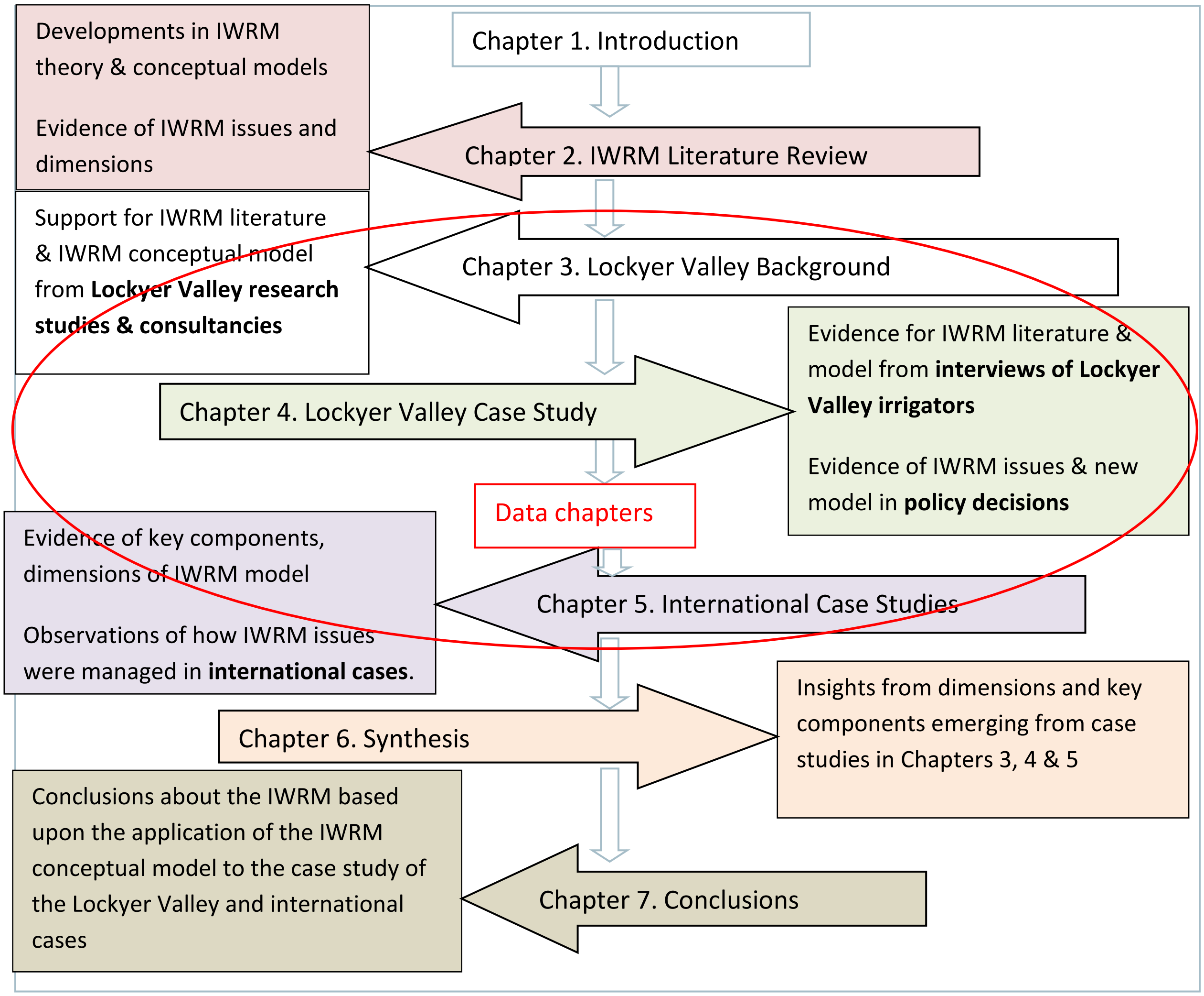

Figure 1-4 An extended dissertation outline highlighting the iterative approach combining deductive and inductive research

The background to the research into the international IWRM issues as demonstrated in the case study of the Lockyer Valley was provided in the introduction of the dissertation. These five dimensions of the IWRM problem, also apparent in the Lockyer Valley and outlined in the introduction, included intergovernmental overlap and inconsistent application of IWRM, social complexities of the community's involvement in decision making, unresolved economic and environmental problems. A research gap in existing IWRM conceptual models then established the need for a catchment scale IWRM conceptual model to analyse and understand the issues of further closing the ITWC and managing public water as a common pool resource. The chapter then explored the research problem and aims of the study in developing a new conceptual model. The research questions and the approach used in this study were described at the end of this chapter as it evolved and developed throughout the study chapters.

The literature critique in Chapter 2 provided qualitative information to assist understanding of the policy, economic, social, and environmental issues of IWRM. Literature on existing IWRM conceptual models was reviewed and used to further develop and refine a new IWRM catchment scale conceptual model, prefaced in Chapter 1. International literature on IWRM, the ITWC and its management and relevant theory and principles were provided to further understand the key components of the IWRM dimensions. A multidisciplinary approach was adopted, as it blended natural and social sciences in keeping with a positivist epistemology of one science, constructed from different scientific approaches. Such an approach included contributions from other disciplines using the most relevant observational data, scientific method, and economic assessment of alternatives of the proposed model or theory (see Carlin 2011). For this reason, the disciplines of ecological economics, hydrogeology and policy decision making were used in the case study chapters to demonstrate the capacity of the IWRM conceptual model to accommodate a range of disciplines. To begin the process of identifying research gaps in existing IWRM conceptual models, IWRM definitions and issues, a critique of literature aided the development of a new IWRM conceptual model in Chapter 2.

From the literature, five conceptual sub-models strengthened and supported the new IWRM conceptual model. These sub-models were:

- The ITWC model
- The DPSIR approach (OECD 1993)
- The five sector economic model (Mankiw 2006)
- Derived demand model (based on UN 1978)
- Hydrogeological model (The U.S. Geological Survey and the U.S Department of the Interior and the Kansas Water Office as per Hansen et al. 2014).

In Chapter 3 the case study approach was adopted to further develop and refine the new catchment scale IWRM conceptual model in the place of primary data collection from water users in these areas. The extensive secondary data from previous Lockyer Valley research studies and consultancies provided background data on the Lockyer Valley, data on water users, willingness to pay for water and water supply scenarios. This quantitative and qualitative data was employed to investigate the shortcomings and opportunities for improvement in IWRM (Robson 2002; Easterby-Smith et al. 1991). Essentially the case study research was a meta-synthesis of the qualitative data available on the irrigator's views on catchment boundaries, access to groundwater and its availability for irrigation Lockyer Valley water research studies and consultancies, mainly undertaken during the millennium drought. Some quantitative data on demand for and WTP for water was also reviewed from these sources using metadata analysis of published information on the case study area. This mixed methodology (Barnett-Page & Thomas 2009) was an appropriate multidisciplinary approach to the "wicked problem" of IWRM in the Lockyer Valley and to the lack of primary data on water supply and use at catchment scale. Chapter 3 provided the background to the IWRM issues in the Lockyer Valley and the case study of the Lockyer Valley.

Chapter 4 applied and further developed a new catchment scale IWRM conceptual model through interviews with eight Lockyer Valley irrigators and application to this case study. With ethical clearance, interviews were undertaken with Lockyer Valley irrigators to ascertain their willingness to use and pay for recycled water. The "snowballing technique" (Biernacki & Waldorf 1981) was used to contact irrigators recommended by other interviewees in the study area with similar experiences. Although 12 landholders were recommended for interview, the pool of respondents fell to eight. Many cited over-consultation and satisfactory water supply after the 2010-11 deluges in the area. After conducting eight interviews for this study, saturation was achieved (Beiten, in Gubrium et al. 2012) regarding irrigators' willingness to pay for and use recycled water. It was apparent that irrigators in this area were no longer interested in paying for recycled water for irrigation as groundwater and streamflow levels had returned to satisfactory levels. Water use data was also inadequate for a proposed hedonic regression analysis of the impact of water availability on rural property prices due to the extent of unregistered, unmonitored private groundwater bores and private dams.

This study then turned towards finding an appropriate IWRM conceptual model with which to investigate the IWRM decisions affecting the Lockyer Valley during the protracted drought and subsequent deluges. Post drought events, decisions and policy changes in the Lockyer Valley analysed with the IWRM conceptual model also served to highlight the developments in IWRM since then. Examples of policy decisions in the Lockyer Valley, pre and post drought supported and strengthened the IWRM conceptual model, and were provided in the data in Chapter 4. These data chapters, analysed through the IWRM conceptual model, revealed the key IWRM components required for IWRM policy decisions to close the ITWC and manage common pool water.

Chapter 5 examined and compared the case study of the Virginia horticultural area (VHA) in South Australia to that of the Lockyer Valley in South East Queensland (SEQ). The VHA catchment provided natural water flows to nearby urban Adelaide and surrounding rural areas. With the construction of the Virginia Pipeline Scheme (VPS) in South Australia, treated recycled water was returned for irrigation in the VHA. The success of the VPS was analysed using the new catchment scale IWRM conceptual model. Catchment scale IWRM schemes in Spain, US, Japan, China, the Murray-Darling in eastern Australia and the Gnangara Mound in Western Australia provided further examples of IWRM approaches that close the water cycle. The different components of the dimensions in this new model demonstrated the outcome of variations in policy, government involvement in wastewater infrastructure and services, third party water infrastructure access arrangements, water trading, pricing and cost recovery using the new catchment scale IWRM conceptual model. Further refinement of the IWRM conceptual model followed from collectively shared understandings from these international literature and cases (Kearney 1988; Barnett-Page & Thomas 1999) in this Chapter.

Chapter 6 drew together the insights emerging from the application of key components of new IWRM conceptual model. These insights from the component analysis followed common themes and issues emerging from the literature in Chapter 2, the background and case study of the Lockyer Valley in Chapters 3 and 4 and international cases in Chapter 5. The implications of these insights and analysis were used to formulate a legal framework and a set of IWRM principles for IWRM decision making. The implications of the synthesis for international IWRM emerged and conclusions were drawn in the remaining chapter.

Chapter 7 summarised the conclusions about the new catchment scale conceptual model of IWRM following its application to the Lockyer Valley (Chapters 3 and 4) and other international IWRM cases (Chapter 5). Dimensions of the model dealt with successfully in these case studies were acknowledged and aspects earmarked for further attention. Suggestions for future development of the new conceptual model, based upon component analysis of these case studies, were offered and insights from ecological economic theory and principles included. This chapter highlighted the role of the ITWC - from rainfall to water reuse and the need for water to be treated as a common pool resource for the entire water catchment by all users. The prospects for the model to provide insights for management of water when under pressure from increasing population, demand for irrigation driven by food security, climate variability and opportunities to utilise excess wastewater were provided and future IWRM applications outlined.

Chapter 2 Critique of Literature on Existing IWRM Conceptual Models and Unresolved IWRM Issues

2.1. Introduction to Literature on IWRM

A review of IWRM literature was undertaken to provide a definition of IWRM, information on the main issues and various IWRM conceptual frameworks and models. From this literature a definition of IWRM was adopted and a conceptual framework and model sought for use in the analysis of IWRM in the Lockyer Valley. The literature on existing IWRM frameworks and models explained the interactions between the IWRM dimensions and revealed the key components of an IWRM conceptual model. Various theories and approaches from other disciplines were examined in order to develop a deeper understanding of the IWRM issues, model dimensions and components.

2.2. Defining IWRM

IWRM has been developing in literature since the 1980s. Of the many definitions of IWRM in literature (GWP- TAC 2000; FAO 2000; World Bank 1993; WCED 1987), that which was provided by the GWP-TAC (2000 p. 22) was initially adopted for this study:

> *IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.*

Despite the criticisms and operational shortcomings of this definition (Biswas 2004), the GWP definition has been improved with IWRM principles developed at various forums since the United Nations Water Conference in Mar del Plata, 1977. These international IWRM events were examined for their contribution to the development of an IWRM definition and conceptual model. These major events were outlined in Table 2-1.

These successive attempts at developing IWRM principles in literature and these international IWRM events informed some the existing conceptual models for IWRM.

Table 2-1 Key International Developments in IWRM

Year	International Meetings and Developments
1977	UN Water Conference, Mar del Plata
1987	World Commission on Environment and Development: Brundtland report
1992	International Conference on Water and the Environment, Dublin
1992	UN Conference on Environment and Development, Rio de Janeiro
1994	UN Conference on Population and Development, Cairo
1996	Global Water Partnership
1996	World Water Council
1997	Commission on Sustainable Development
1997	Rio+5 Forum, Rio de Janeiro, Brazil
1997	5th Session of the UN Commission on Sustainable Development
1997	Earth Summit+5 - a Special Session of the UN General Assembly, New York
1997	UN Convention on the Law of the Nonnavigational Uses of International Watercourses
1997	First World Water Forum, Marrakech
2000	Second World Water Forum, The Hague
2000	United Nations Millennium Summit
2001	International Conference on Freshwater, Bonn
2002	World Summit on Sustainable Development, Johannesburg
2003	Third World Water Forum, Kyoto
2006	Task Force on IWRM was created by UN-Water
2007	UN Global Compact's CEO Water Mandate
2008	Task Force on IWRM
2009	IWRM guidelines at river basin level WWAP, UNESCO, International Hydrological Programme Network of Asian River Basin Organizations
2012	6th World Water Forum - Marseille 2012
2012	International Conference on Freshwater Governance for Sustainable Development, Drakensberg, South Africa
2015	7th World Water Forum - 2015 Daegu Gyeongbuk Korea

Sources: UNDESA 2013; Savenije & van der Zaag 2008 p.293; FAO 2000.

The first Action Plan referring to IWRM emerged at the first UNESCO International Conference at Mar del Plata in 1977. The concept was endorsed by all members of the United Nations at the time and IWRM was applied in an *ad hoc* project approach (Biswas

2008). The foundations for IWRM appeared in the Brundtland report on the World Commission on Environment and Development (WCED 1987). This report dealt with the issues of water supply and pollution rather than integrated resource management, but referred to a system that balanced the needs of society with limitations of natural resources (section IV, no. 74). International responses such as those of the Organisation for Economic Co-operation and Development (OECD), World Bank and FAO followed from the environmental, economic, social and political pressures associated with economic development. Among these policy responses were microeconomic reforms including deregulation, privatisation and competitive regulation designed to improve the efficiency of economies and management of public goods and services (Quiggin 1996). Various organisations such as the OECD promoted the use of economic policy instruments for environmental resource management. These unresolved policy and economic issues were discussed in more detail in sections 2.5.1 and 2.5.2.

Findings at the informal consultation, such as those in Copenhagen (1991), contributed to the development of IWRM (Savenije & van der Zaag 2008). As shown in Table 2-1, a range of international symposiums and conferences dealing with water ensue, including the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 and the International Conference on Water and the Environment (ICWE) in Dublin (WMO 1992), each contributing to the development of IWRM. The IWRM issues that emerged did not strictly fall into one dimension alone, but overlapped and interacted with the other dimensions, as represented by the four overlapping dimensions of the IWRM model.

The Dublin-Rio Principles presented and adopted at the UNCED (Earth Summit) Conference in Rio 1992 contribute to Agenda 21. Agenda 21 is a non-binding action plan of the United Nations for achieving sustainable development, to which Australia is a signatory (UN 1992b). By 1995 the World Bank and FAO guidelines were the measure of world best practice in water resource management policy making (FAO 2000). The dimensions of the IWRM model built upon these principles.

The Dublin-Rio Principles and issues of IWRM emerging at these international symposiums and conferences included:

1. Accurate assessment of water demand and supply available across users and sectors *(economic dimension)*

2. IWRM capacity building issues relating to lack of supportive policy and regulatory framework, public participation, inadequate managerial capabilities and systems for effective institutional operations, limited financial and technical capabilities, poor personnel management, and a general lack of communication between implementation and planning, horizontally or between subsectors *(policy dimension)*

3. Making capacity building operational through:
   - Coordination of water supply and demand agencies, sectors and governments at all levels *(policy dimension)*
   - Private sector involvement in water related supply management *(policy dimension)*
   - Engaging communities, particularly women in water management strategies[1]*(policy dimension)*
   - Including capacity building in undertaking technical, economic, social and water sector assessments *(policy and social dimension)*
   - Education and awareness of water as a finite resource and its management *(social, policy and environment dimension)*

4. Appropriate economic policy instruments (the ecological economic term encompassing water markets, taxes, subsidies etc.) including the valuing of water as an economic good had been an issue raised by many international organisations *(economic dimension)* (WMO 1992; UN 1992a).

Agenda 21 provides for 27 principles:

- based on the anthropocentric issues of sustainable development (Principle 1).
- a balance between environment and future development (Principles 3 and 4);
- poverty eradication (Principle 5);
- developing countries (Principle 6);
- common but differentiated responsibilities (Principle 7);
- the precautionary approach (Principle 15);
- the polluter pays principle (Principle 16);

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[1] Women were found to be involved in the majority of water management decisions internationally (UN 1992).

- participatory approach to solving issues in sustainable development (Principles 10, 20, 21, 22); and the use of legislative instruments to address environmental issues (UN 2000, 2002, p.15). These principles were recognized and included here in the development of a new conceptual model in IWRM after examining the literature on existing IWRM conceptual models.

2.3. Literature on Existing IWRM Conceptual Models

A conceptual IWRM model that captured the five dimensions of the IWRM issues internationally was sought in literature. Although not an exhaustive investigation of all IWRM models, four existing IWRM conceptual models and frameworks that balanced the various dimensions of IWRM were examined:

- The IWRM model (Koudstaal et al. 1992).
- The Three Pillar approach to IWRM (UN 1992a).
- The conceptual framework for catchment-scale integrated water resource management (Ross et al. 2006).
- The Urban IWRM model (Carden & Armitage 2012).

Koudstaal et al. (1992) offered a non-sectoral approach to IWRM that applies the principles of triple bottom line to satisfy the social, environmental and economic dimensions of IWRM. This model in Figure 2-1 depicted water resource management as integral to sustainable social and economic development rather than focusing on adequate supply of water to sustain increased economic growth. The Koudstaal et al. (1992) model was essentially an economic model driven by policy choices that affect demand and supply. Since the carrying capacity of the environment was a constraint in IWRM and a limiting factor in resource management decisions, a new IWRM conceptual model was sought in this study that instead endorsed the primacy of the natural environment over the economy, society and policy. The argument by Koudstaal et al. (1992) for a non-sectoral approach to IWRM was accepted in this study in order to facilitate better integration of urban and rural sectors.

The Koudstaal et al. (1992) IWRM model focused on the river basin scale and the issues surrounding internationally shared river basins. The traditional river basin scale has been adopted widely in literature (Savenije & van der Zaag 2008; Ravesteijn &

Kroesen 2007; Hooper 2005; GWP-TAC 2000). Yet the extended catchment scale for an IWRM conceptual model was regarded as more appropriate for this study given that the hydrogeology of rivers often includes complex connections to groundwater, overland flows and water infrastructure beyond the river basin, to be explained in detail in section 2.5.4.

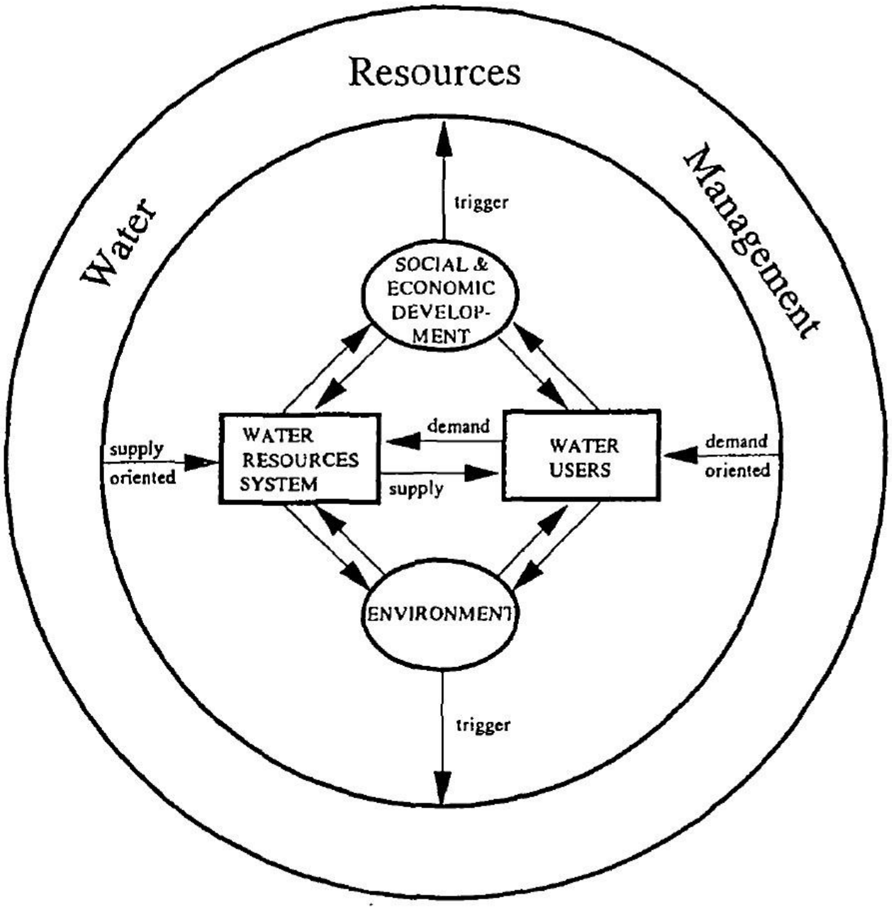

Figure 2-1 The IWRM conceptual model presented at the Earth Summit in 1992

Source: Koudstaal et al. 1992, p. 283

As with much of the IWRM literature at the time, the Koudstaal et al. (1992) IWRM conceptual model built upon the framework of the three pillars of sustainable development depicted in Figure 2-2. These three pillars of economic efficiency, ecological sustainability and social equity focused on resource management strategies, policies and legislation to achieve a less fragmented approach to water management (Ross et al. 2006; Jeffrey 2003; Scoccimarro et al. 1999). Early water resource management literature outlined three key policy principles in a similar approach to these sustainable development models - equity, ecological integrity and efficiency (Postel 1992). The *Three Pillar Basic Model* has been used for sustainable development by organisations such as the United Nations, European Commission, and the International Monetary Fund, Organisation for Economic Co-operation and Development, and World Bank. The three pillar approach supported the development of the Agenda 21 Action Plan and the 27 Principles of the Rio Declaration for sustainable development adopted in 1992 at the Earth Summit (FAO 2014, UN 1992b). The success of the three pillar approach to IWRM depended on an effective and transparent policy environment with governing institutions cutting across sectors (GWP 2006). The value of an IWRM conceptual model with a fourth policy "pillar" was explored further in literature of existing IWRM conceptual models.

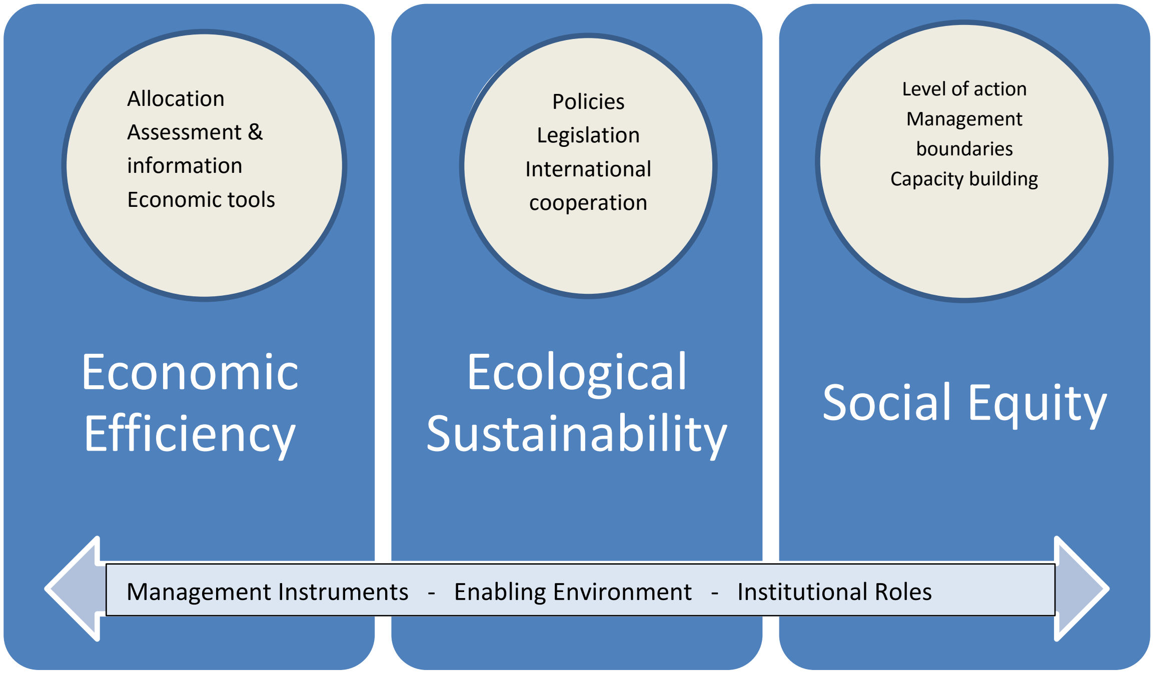

Figure 2-2 The Three Pillar Model of IWRM

Source: adapted from GWP (2006).

The dimensions of the three pillar model were useful in developing a contemporary approach to IWRM. Adapting from Figure 2-2, the dimensions of the new IWRM conceptual model included the *environmental dimension* (nature) which comprised of all natural capital - stocks of non-renewable and renewable resources (Fenichel & Abbott

2007). The *economic dimension* represented all human-made material assets such as dams, weirs and pipelines. The *social dimension* included perceptions and awareness of the individuals (human capital including views, knowledge, and experience). The three pillar framework, with a linking role for policies, provided justification for a fourth dimension (policy) for inclusion in existing IWRM conceptual models. Models such as the 'prism of sustainable development' contained this fourth dimension - institutions (Valentin & Spangenberg 1999; Spangenberg & Bonniot 1998). The fourth dimension of *policy* was adopted here in this study to represent private and public institutions, decision makers and policies associated with IWRM.

The conceptual framework for catchment-scale integrated water resource management designed by Ross et al. (2006) supported this view of the four dimensions of IWRM. This conceptual framework assisted IWRM by identifying the nature of a catchment system and linking the work of multidisciplinary team members or different numerical and spatial data (Ross et al. 2006). The framework was built on the natural water cycle (Figure 2-3) and, through a causal link model (Figure 2-4), connected this water cycle to economic activity, ecosystem response and waterway health. A new IWRM conceptual model built on the ITWC seemed more appropriate to close the water cycle. A conceptual model that does this by representing the dynamic overlapping and interconnected IWRM dimensions - the "egg of sustainability" model was adapted for IWRM in this study, in Figure 1-3.

The inclusion of water reuse through the ITWC complied with the sustainable perspective recommended by European Union policy and many leading environmental institutions and governments (e.g. the World Bank and FAO). The importance of water reuse also underscored the Dublin-Rio Principles (UN 1992a), upholding the view that fresh water is finite, precarious and essential to life, economic development and the environment.

Ross et al. (2006, p. 5) provided a framework featuring "a staged, multi-layered" approach including "basic understandings and systems analyses" of water uses. These basic understandings of the human and environmental need for water were explained in the supporting text for the model. The virtues of such an approach, combining all water sources and water users in the ITWC sub-model, drove the development of a new IWRM conceptual model for this study. The multi-user multi-supply aspects of this new IWRM conceptual model are explained in the literature reviewed in remaining sections of this chapter.

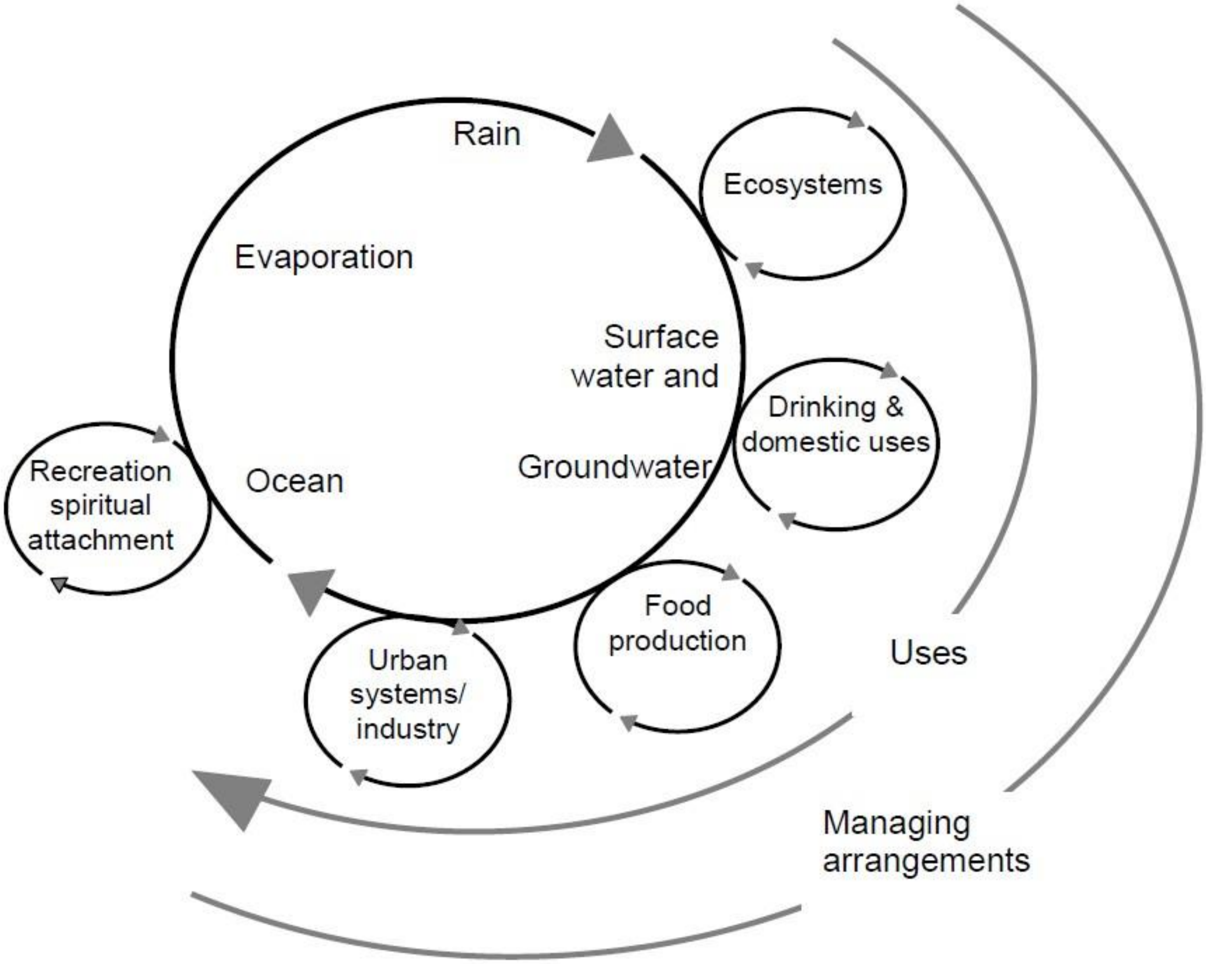

Figure 2-3 The water cycle used in IWRM conceptual models did not contain recycled water.

Source: Ross et al. 2006, p. 9.

The framework provided by Ross et al. (2006) was the basis for a systems analysis of the main influences between natural and human elements using “causal loop modelling.” The drivers of change and potential impact on environment and society were then identified by examining the use, management and other processes in the system (Ross et al. 2006). This process was known as, “unpacking the key elements of social-ecological systems” (Chapin et. al. 2009; Pahl-Wostl 2007, n.p.) and assisted understanding of the interdependencies within these key elements.

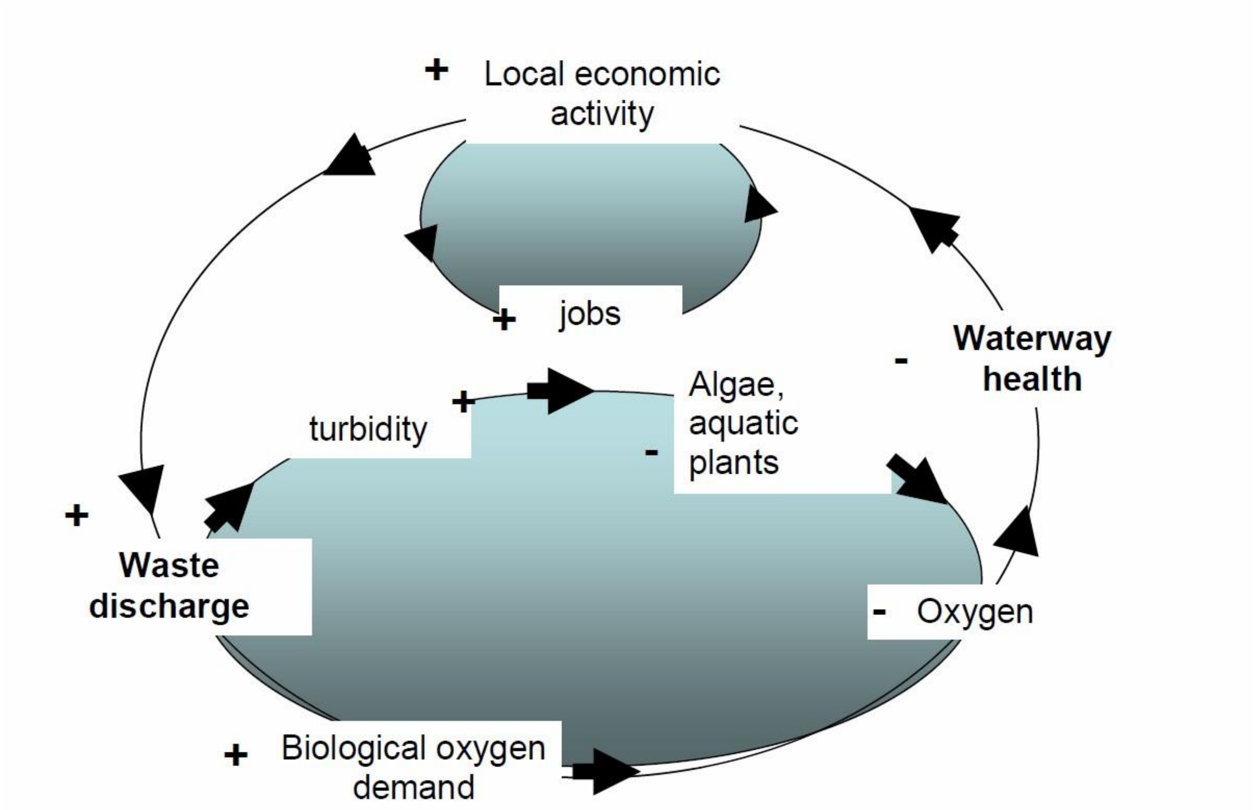

Figure 2-4 The causal loop model included recycled water and economic drivers

Source: Ross et al. 2006, p. 11.

The limitations of the existing IWRM conceptual models were recognised in the work of Carden and Armitage (2012) and Khatri et al. (2011). These models focused on the design of performance indicators to rank the four dimensions of urban IWRM infrastructure systems. The Carden and Armitage (2012) model depicted in Figure 2-5 labelled the four dimensions of urban IWRM accordingly - social/technical, institutional/political, environmental and economic. This model recognised that IWRM was constrained by environmental limits in the same way as the “egg of sustainability” IWRM model outlined in Figure 1-3. Yet as with the Koudstaal et al. (1992) model and the three pillar approach, the Carden and Armitage (2012) model favoured an overarching institutional governance system to manage IWRM. This model was based on the natural water cycle in the environmental dimension to which total water cycle management was added through the social/technical dimension.

Although the Carden and Armitage (2012) conceptual model adopted a sectoral approach to urban IWRM, it could be used holistically to combine the urban, industrial and rural sectors. Such a non-sectoral approach can facilitate the extension of an IWRM model to other natural resources such as land and energy (Falkenmark 1997). The issue of land integration was raised in the water chapter of Agenda 21 (Chapter 18 section 18.9), but water did not feature strongly in the chapter on land (FAO 2014; Falkenmark 1997). Criticisms of Agenda 21 included its sectoral focus and neglect of interlinkages between sectors (UN 2012).

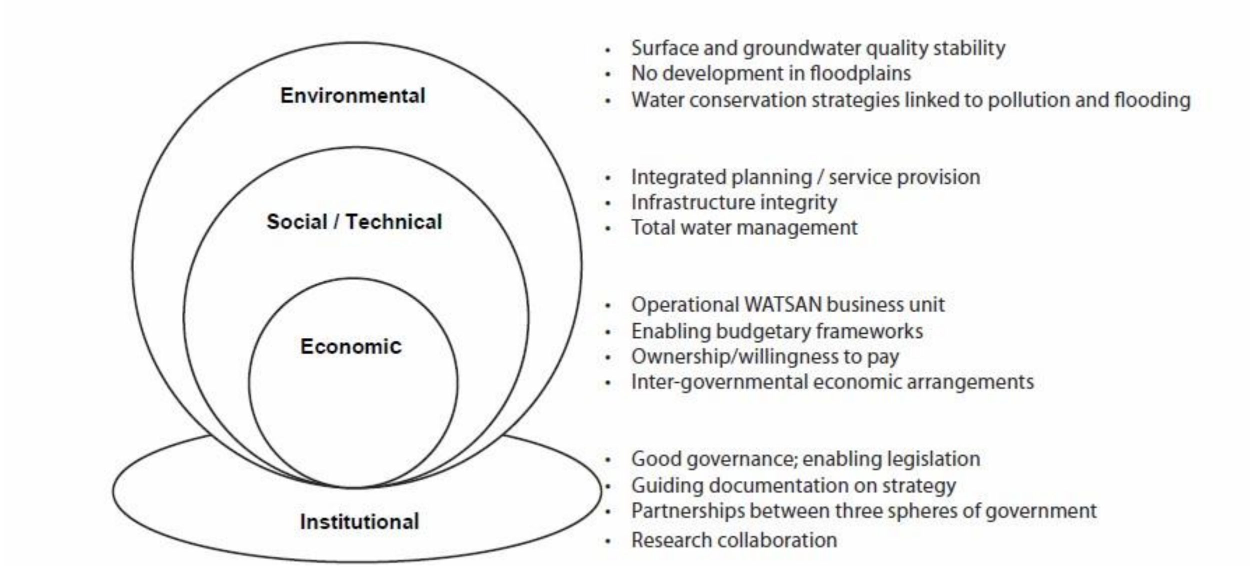

Figure 2-5 An urban IWRM conceptual model

Source: Carden & Armitage 2012 p. 347

Rather than focus on the integration of green (water in soils) and blue (river and aquifers) water supply (FAO 1996; Postel et al. 1996), early inclusion of the ITWC was the intention of the new IWRM approach and model sought for this study.

The Carden and Armitage (2012) IWRM conceptual model appeared to blur the distinction between the equity and feasibility aspects of service reliability and service quality by combining the social and technical dimensions. Whereas the Khatri et al. (2011) conceptual model divided the technical dimension, to reflect service effectiveness and service reliability separately. Although these are interconnected IWRM issues, the separation of the social and technical dimensions better fitted the four IWRM dimensions outlined in the research problem in Chapter 1. Another difference in the Khatri et al. (2011) model was the way this model further subdivided the economic dimension into costs and prices. Both costs and prices were dealt with under the economic dimension of the new IWRM conceptual model in this study. Other major influences on the existing IWRM conceptual models include international IWRM principles that are outlined next.

Since the early 1990s, IWRM Principles presented at the World Summit in Rio de Janeiro in 1992 (UN 1992a; WMO 1992) have influenced IWRM conceptual models, strategies and policies. The four original Dublin Principles recognised that water is finite, and required a participatory planning and management approach involving all stakeholders (WMO 1992). It also recognised the important role of women in managing and safeguarding water, and viewed water as an economic good with economic value in all its forms and uses (WMO 1992). The Dublin-Rio Principles of IWRM (UN 1992a) represented World best practice in IWRM and were examined for their contribution to developing an appropriate IWRM conceptual model for this study.

The Rio Declaration established 27 principles for sustainable development (UN 1992a). In the interests of attaining World best practice in IWRM, these Principles were reflected in the dimensions of the new IWRM conceptual model. For example, the social and economic dimensions of the “egg of sustainability” IWRM model represented those anthropocentric issues of sustainable IWRM (Principle 1) and poverty eradication (Principle 5). The environment and economic dimensions addressed the current and future balance between environment and development (Principles 3 and 4). The Principle of common but differentiated responsibilities or equity (Principle 7)[2] was covered within the policy and social dimensions. The ‘polluter pays’ principle (Principle 16) was addressed in the economic dimension and the precautionary approach (Principle 15) in the environmental dimension. The participatory approach to solving issues in sustainable development (Principles 10, 20, 21, 22) and the use of legislative instruments to address environmental issues (UN 2000, 2002, p.15) were dealt with under the policy and environmental dimensions of the

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[2] This equity principle referred to developed countries acknowledgment of the international responsibility they hold pursuing sustainable development.

developing IWRM conceptual model.

The implementation of these IWRM principles was slow and developed countries had not noticeably altered water consumption patterns by 2012 (UN 2012). Incorporating these principles in IWRM in a new IWRM conceptual model was expected to overcome some of the inadequacies in funding arrangements and technology changes were blamed for the slow progress in implementing Agenda 21 (UN 2012; UN 1992b). In other words, the interconnectedness of the dimensions and application of the principles emerging from international forums required further investigation in the search for an appropriate IWRM conceptual model for this study.

These principles were applied to the developing IWRM conceptual model to improve understanding about derived demand for water. Water demand traditionally is derived from all water uses and can be estimated according to its end use. Other principles applied to the range of water supply options available can establish rigorous social cost benefit analysis at a common scale to ensure affordable equitable access to water for all. A participatory process to natural resource development and urban development involving all stakeholders was advocated using adaptive management practices in decision making over time (Turner et al. 2007). These IWRM principles were included with the GWP-TAC (2000) IWRM definition in order to create a new definition of IWRM for this study.

The new definition, synthesised from IWRM literature and principles, recognised that IWRM is an adaptive and participatory process that promoted the coordinated development and management of water, land and related resources as common pool resources, in order to maximize the resultant economic, social and ecological welfare. It can do this through the principles of common but differentiated responsibilities or equity, polluter pays, precautionary approaches and the use of triple bottom line accounting and legislative instruments to address environmental issues (adapted from Turner et al. 2007; UN 2002, 2000; GWP-TAC 2000; Postel 1992; WMO 1992; Koudstaal et al. 1992; Ehrlich & Holdren 1971). Using this new definition of IWRM and literature on existing models of IWRM, the dimensions of the new IWRM conceptual model were developed.

2.4. The Implications of IWRM Literature for the Development of a Catchment Scale IWRM Conceptual Model

Thus the information on existing IWRM conceptual models, the IWRM principles in literature and the new definition of IWRM, reinforced the concept of a four dimensional conceptual model with which to examine catchment scale IWRM issues. The environment, policy, social and economic dimensions of the new catchment scale IWRM conceptual model (hereafter labelled the IWRM model) were enhanced using literature on IWRM issues. Support for the IWRM model was also sought from general literature in other disciplines, such as ecological economics, hydrology and geology, given these common themes in IWRM literature.

The environment dimension of the IWRM model represented the natural limits of resources while being vital to the survival of all species. This view of water was supported by the Dublin Principle – "fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment" (WMO 1992). Managing this water cycle and minimising leakages from it, was a major goal of IWRM in theory (Keller et al. 1996). The aim of the IWRM model was to include recycled water as part of the ITWC in developing the environment dimension of the IWRM model.

Postel's (1992) principle of ecological integrity was applied in the environment dimension of the new model through the inclusion of the ITWC conceptual sub-model (Figure 1-1). Including this conceptual sub-model of the ITWC within the environmental dimension of the IWRM model was the first stage of the "nesting" process of imbedding other theory, principles and approaches advocated by Ross et al. 2006. Thus the IWRM model had the potential to conceptually manage all water sources in the catchment to close the ITWC (research question 1).

The policy dimension in the IWRM model adhered to the 2nd Dublin Principle that, "water development and management be based on a participatory approach, involving users, planners and policymakers at all levels" (WMO 1992, p.3). The policy dimension of the IWRM model was further expanded to include non-government institutions and policies that foster an adaptive management approach to IWRM decision making, as suggested in additional IWRM principles by Turner et al. (2007). Organisations such as the OECD focused on water catchment management governance within natural boundaries to manage water in a holistic, equitable, efficient and sustainable manner (OECD 2010). Yet adequate quantities of quality water depend on healthy ecosystems and are an important ecosystem service to be conserved for environmental, social, economic and political reasons (UN 2011). This interdependency of IWRM dimensions is an important development in any contemporary approach to IWRM and one that is adopted in the development of the IWRM model here.

Water catchment management literature viewed the interdependency of users and uses as a technical function of the diversion, storage, usage, quality and allocation of a basin's water resources. In IWRM there was "an increasing tendency to resort to *technical solutions"* (US Army Corps of Engineers 2014, p.1). This study shifted towards a more holistic management of water within its ecological and social limits. More than a technical function, IWRM in the new model also represented a shift away from politically determined administrative boundaries with no link to natural ecosystem processes involved, or available data. Such administrative catchment boundaries traditionally were based upon the foundations of economic and administrative need (MDBC 1999; Blackmore 1995). Understanding these multidisciplinary interconnected aspects of the catchment was central to the development of the policy dimension in the IWRM model in this study.

The issue of management of water in literature ranges from social, economic, environmental and policy approaches. One example is the use of economic policy instruments (GWP, 2006). The timing of implementation of policy instruments and setting and achieving IWRM objectives were other issues factored into the IWRM model. The selection of policy instruments was dynamic and subject to changing conditions, community input, economic and policy factors. As with the GWP (2006), the IWRM model made allowances for these dynamic elements of the economic, social and policy dimensions. The social dimension of the IWRM model recognised the 3rd Dublin Principle that, "women play a central part in the provision, management and safeguarding of water" (WMO 1992, p.1) particularly in developing countries. In Turner et al. (2007) the additional IWRM principle of a participatory process recommended incorporating all stakeholder preferences in decision making. This aspect of decision making directly linked the social and policy dimensions in the IWRM to the scale of the model and the types of water in the ITWC sub-model.

The additional principle suggested by Turner et al. (2007) related to the recognition of the importance of derived demand. To do this effectively, the contemporary IWRM approach in this study incorporated all water users in the catchment - urban, rural and industrial sectors. This inclusion was expected to correct the focus in the literature on land use based IWRM which dealt with either urban or rural IWRM but rarely both (Crase et al. 2007; NWC 2006; Young et al. 2006; FAO 2000; Pigram 1973). Further, the principles of Turner et al. (2007) justifed the inclusion of sound social cost benefit analysis, detailed demand forecasting and use of economic policy instruments for demand and supply water management in the economic dimension of the IWRM model. The economic dimension of the IWRM model went further than the 4th Dublin Principle, which recognised "water had an economic value in all its competing uses and should be recognized as an economic good" (WMO 1992, p.1). The IWRM model recognised some water (particularly public water) as a common pool resource could be effectively managed in the ITWC.

In a further stage of the "nesting" process of imbedding other theory, principles and approaches into the IWRM model, ecological economics theory and principles were applied to the economic dimension. Ecological economics blends economic, ecological and social theory and principles and guides economic activity towards a "steady-state" within the Earth's limited natural resources (Daly 1991). This approach was well suited to managing the "wicked problem" of water within sustainable limits and other economic, ecological, social and political constraints. The ecological economic approach is grounded in the principle of thermodynamics - that the Earth is a closed system containing finite quantities of natural resources and energy (Malthus 1798). Ecological economics offers a unique approach to the analysis and management of natural resources such as water, and the flow of ecosystem goods and services from it (Hackett 2010). Utilising a combination of economic and ecological principles, the impacts of economic activity on natural resources such as water were incorporated in the economic dimension of the IWRM model. The overarching view of ecological economics was that these finite resources must be managed sustainably for future generations for all users (Daly 1996; WMO 1992; Anderson & Leal 1991; Ehrlich & Holdren 1971).

The technical dimension of the IWRM approach related to the availability and appropriateness of water quality and reliability measures. Issues such as technical efficiency, geographical and hydrological appropriateness were important considerations in any IWRM decisions in literature. For example, the technical aspects of IWRM impact on the physical efficiency of IWRM by reducing leakages from and depletion of total available water in the water cycle (Keller et al. 1996). As mentioned earlier these technical aspects were related to yet separate from the social issues of equitable and secure access to water. The technical aspects of IWRM were dealt with by incorporating the ITWC, using a sub-model into the environment dimension of the IWRM model. The ways in which these dimensions of the IWRM model were useful in understanding and analysing IWRM issues in literature were analysed.

2.5. Literature on the Issues of the IWRM Model

Literature on international IWRM issues was reviewed to add depth and understanding to the four dimensions of IWRM by focusing on the:

- components of each of the IWRM dimensions
- links between dimensions of the water problem and model components
- role of each dimension in the implementation of IWRM to close the ITWC and treat public water as a common pool resource with focus on the urban-rural IWRM.

The institutional and policy overlap and inconsistency in the application of IWRM emerged in literature because water had been managed as an economic good. These unresolved policy issues were examined next. The theory, principles and approaches from literature were then used to better understand the dimensions for the IWRM model. First the contributions from forums and conferences held by international organisations were reviewed. The new definition of IWRM developed for this study was added and then the literature on the unresolved policy, economic, social and environment IWRM issues helped build the IWRM model dimensions.

These international principles can be viewed as the foundations for determining the key components of each dimension of the IWRM model. The literature and IWRM principles in practice viewed water as an economic good valued for its market characteristics. Literature and practice failed to treat water as a common pool resource to be managed sustainably for future generations. Thus it should be treated as a resource that diminishes with successive use and from which users cannot naturally be excluded (Hardin 1968; Demsetz 1967).

The social and non-market valuation aspects of water resources and their management were also not often addressed in literature or IWRM practice (Munasinghe 1993). Recycled water and its use were not explicitly included in the Dublin-Rio principles and Turner et al. (2007) additional principles. Instead these were addressed through environmental economic policies affecting demand. In the IWRM model, recycled water and other natural water sources were considered part of the ITWC to be managed, utilised and valued according to ecological economic principles that included the non-market characteristics and non-use benefits of water (explained in section 2.5.4).

Some of these considerations were addressed with the development of Postel's (1992) three key policy principles in water resource management - equity, ecological integrity and efficiency including:
(a) **Equity** - Water as a basic human need and a public good providing sustenance, security, but also involving floods, droughts and other (Gleick 1999) *(social policy dimension);*
(b) **Ecological integrity** - Water resources can only persist where the natural environment remains capable of regenerating fresh water of sufficient quality and quantity for current and future generations *(environment dimension);*
(c) **Efficiency** - Water as a scarce resource needs to be used efficiently according to institutional arrangements that recover costs of the water services whilst maintaining the equity principle through economic valuation and pricing (Savenije & Van der Zaag 2008 p. 292) (*economic policy dimension).*

Again Postel's (1992) principles focused on water as an economic good without reference to its common pool characteristics. Further there was mention of ecological integrity in terms of capability of the natural environment to regenerate fresh, water but no specific mention of water reuse and recycling options. Also the institutional arrangements in the third principle related only to efficiency rather than to other economic aspects such as sustainability, the environment and society. Finally, the links to other resources such as land and energy were not raised. These aspects of coordination with other resource management approaches were addressed in the IWRM model developed in the following sections of this Chapter.

2.5.1. Intergovernmental Overlap and Inconsistent Application of IWRM

In literature the institutions responsible for IWRM were many - including government, finance, education, water businesses and related service providers. There were also community based water management institutions such as cooperatives and other collective management systems (Ostrom 2005). With the plethora of institutions came inconsistency in IWRM policies and overlapping institutions (Savenije & van der Zaag 2008; UN 1992a; WMO 1992). A consistent approach was required within a water catchment to resolve the lack of coordination in planning and management of all resources, users and institutions involved in IWRM.

IWRM literature also highlighted the importance of involvement of water users in decisions about using, monitoring and managing water through cooperative management and collective decision making in developing successful resource management outcomes (Schneider & Homewood 2013; Olsson et al. 2006; van Vugt 2002; EC 2000; Ostrom 1992). A policy issue that impacts on the water problem and its management related to scale and degree of coordination of IWRM (Savenije & Van der Zaag 2008). Often in literature IWRM followed a national approach with central water planning and state/local operational management. Generally, a centralised approach with a single designated agency with responsibility at the national level fostered a level of institutional coordination that can deliver uniform water resource management of various sectors in the economy. Such an approach is capable of achieving multiple planning objectives (Lane & Robinson 2009). Centralised coordination of IWRM was often seen to reduce the likelihood of duplication and conflict between sectors.

Given water issues crossed state/regional boundaries and legislative powers, IWRM frameworks and governance arrangements had been traditionally the responsibility of national governments. State/regional governments generally undertook the operational aspects under these national arrangements. Yet operational aspects of water catchments often crossed state and even national boundaries (GWP 2006). The river basin was the commonly accepted unit for water resources management (Savenije & van der Zaag 2008; Ravesteijn & Kroesen 2007; Hooper 2005; GWP-TAC 2000). A river basin included contributing watersheds within the basin that drain within and through their basins and tributaries (Ffolliott & Brooks 2014, p. 62).

Managing connecting wetlands and underground water systems with boundaries beyond above ground water systems and even nearby wastewater re-use opportunities was an issue regularly raised in IWRM literature (Selfa & Becerra 2011; Scoccimarro et al. 1999; Pries 1994; Bastian 1993; Boyden 1992). It appeared that a catchment scale IWRM model was required to reflect water sources and users beyond the river basin. Thorough hydrological studies of the catchment were required in order for such catchment boundaries to be established. Yet political-economic considerations such as regulatory authority and revenue raising powers had traditionally determined the scale of IWRM (OECD 2010; Biswas 2004). These inconsistencies in IWRM needed to be resolved in an IWRM approach and conceptual model. In the IWRM model these issues were dealt with under the policy dimension in Figure 2-6.

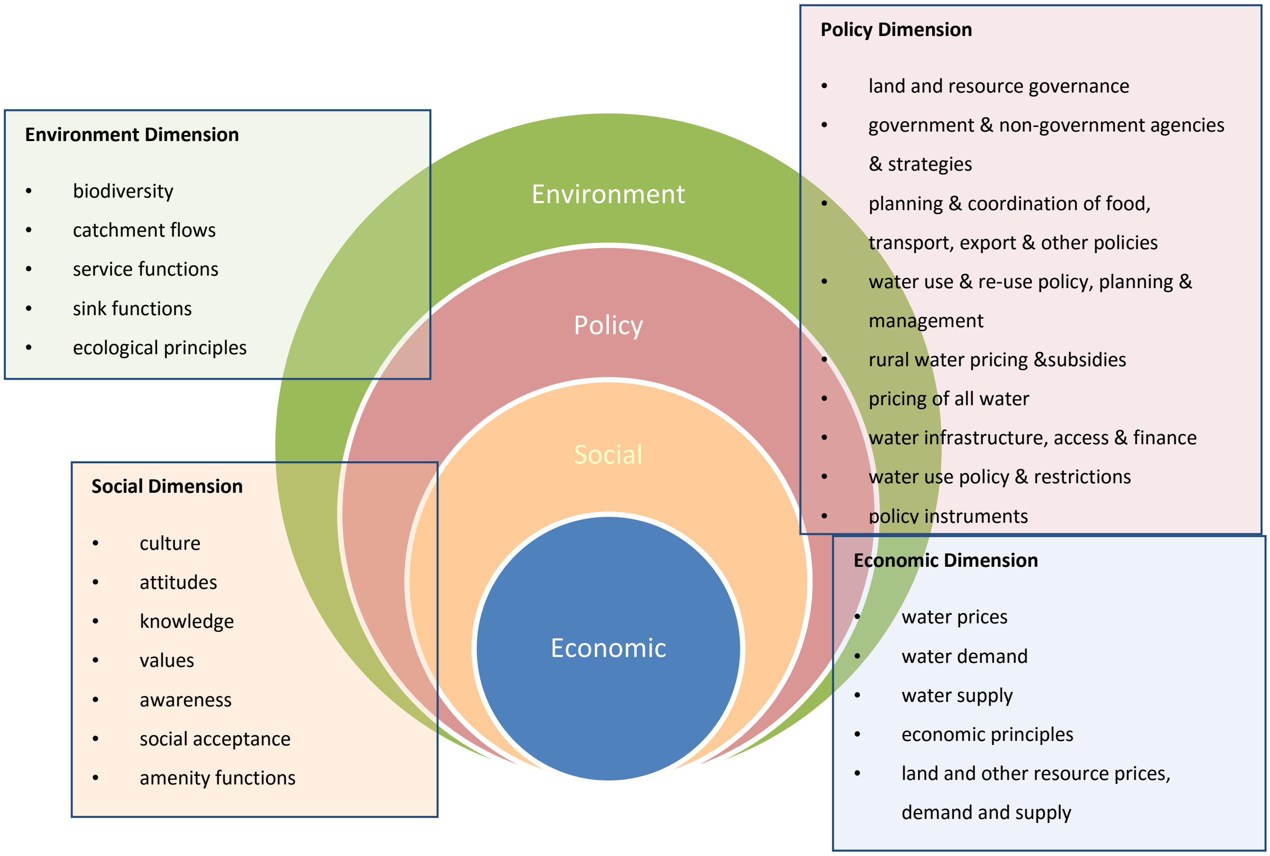

Figure 2-6 Building the dimensions of the new conceptual model to guide management of catchment scale IWRM

Poor coordination of other natural resources also remained a problem in IWRM literature. For example, land, air and energy resources require an integrated management approach along with water in IWRM (Biswas 2004). In reality, water resource management impacts on other resources such as energy, agriculture and ecosystems, and vice versa. These complex factors affecting water required the same consideration as water in policy making (Biswas 2008).

Literature that concerned the urban-rural water imbalance in western developed countries generally centred on inadequate water supply for growing urban (including industrial) users (Pumphrey et al. 2008). This approach needed to be reviewed as the focus shifts to food security issues such as poverty, lack of investment in agriculture, natural disasters, soil degradation and food waste (Department of Foreign Affairs & Trade 2014; FAO 2000; Postel et al. 1996; Molden et al. 2007). These gaps, with regard to the urban-rural context of IWRM, were the first stage in developing the IWRM model in this study.

Fragmentation in the approach to water resource management occurred when other such resources were managed separately, often resulting in misappropriation and inefficiency in allocation of resources (Biswas 2004). When sector water users were managed separately, conflict emerged (Tisdell et al. 2002). For example, in the water industry it was standard practice to separate users according to sectors – the urban (generally included industry) and rural sectors according to a land use approach in policy making (Crase et al. 2007; Young et al. 2006; NWC 2006; Pigram 1973). There were few examples of urban-rural integration in IWRM (Foster & Ait-Kadi 2012; Tian et al. 2011; Shen & Liu 2008; Zeng et al. 2006; FSA 2006; ACIL Tasman 2005; Dwyer et al 2005). While the "rural urban interface" was recognised in water management literature (Zeng et al. 2006; Smith 1937), more research was required into rural aspects of IWRM. More than a spatial scale of water sources and users in IWRM, the urban-rural interface was seen as the transition zone between urban and rural areas with characteristics of both (Tian et al. 2011). This literature justified an approach that coordinated IWRM across sectors in the IWRM model.

IWRM faced challenges because water policy was often subordinated to policies of other sectors and because of the unique attributes of water (Grigg 2014). Other sectors were evolving integrated management paradigms to deal with complex situations, but water had unique attributes requiring mobility of an essential resource. The challenge remained to develop adequate governance and management tools for the multifaceted nature (including equity and sustainability) of water management (Biswas 2004). Each water-dependent sector treated water as one input among many in its policy issues. This has led to the view of water as a "system of systems", requiring management of all of these systems in an integrated way (Grigg 2014).

The unique and essential characteristics of water also created the need for governance through non-coercive collective action rather than government mandates and inclusion diverse cultural and social values. The GWP (2014) view of IWRM was one of an enabling environment, institutional roles and management instrument - integrated water resources governance, or a collection of management practices, rather than a process (Grigg 2014). Grigg (2014) suggested IWRM provide guidelines and clarify the role of tools in promoting "the coordinated

development and management of water, land and related resources” (GWP 2014).
This would assist water planning to occur in conjunction with integrated land use and energy planning and explains some of the complexity involved in the IWRM model.

The area of socio-politics was relevant to discussions about timing and resources of IWRM policy decisions. Programmes designed to reduce water scarcity relied on the allocation of limited resources. This involved political decisions about the availability, affordability and political importance of these scarce resources. In the past, such decisions have reflected and caused institutional weaknesses that result in strong bureaucracies and economic inefficiencies (Dovers in Troy ed. 2008).

Policy attention cycles often dictated the decisions. Politicians and decision-makers influenced the allocation of limited budgets and the adoption of policy. The timelines of politics often do not coincide with the timelines of prudent water resource management. The result was that, IWRM decision-making was based on short term political expediency rather than social, environment or even economic grounds. With privatization of water providers, the attention cycle became more aligned with the business cycle and motivations of profit and healthy economic returns. The consequences can be similar for complex and expensive infrastructure such as water that requires long term planning and investment in a supportive policy environment (Gray & Gardner in Troy ed. 2008).

Of particular note was the lack of literature on urban-rural integration that closed the ITWC by including the return of water back to the original source (e.g. urban-rural-urban) for continuous reuse. The IWRM model addressed this deficiency in recognising all water sources in the ITWC sub-model and all sectoral users in the urban-rural IWRM conceptual sub-model. Figure 2-7 depicted the urban-rural conceptual model representing the future of IWRM using a non- sectoral approach. For example, the centre of this model represented a combination of urban and rural sectors rather than the traditionally separated urban and rural sectors. The urban-rural example model was the first stage in the progress towards the non-sectoral IWRM model. All the dimensions of the catchment scale IWRM model remained relevant to the urban-rural IWRM model. The inclusion of agricultural and urban models was a way to introduce issues connected to “land” without focusing on the sector. Rather this approach combined the various uses of land traditionally separated in rural and urban models respectively. These intersectoral aspects of the model were further enhanced with existing agro-economic-hydrologic rural water models and economic-hydrologic urban water models (see Blanco et al. 2012; NWC 2007b for further explanation). Examples of these models included supply and demand modelling as found in the Agricultural Sector Model (Chang et al. 1992), and agriculture soil and water modelling as found in the Soil and Water Assessment Tool (Arnold et al. 1998). The urban-rural model was applied to close the ITWC, and achieve urban-rural integration.

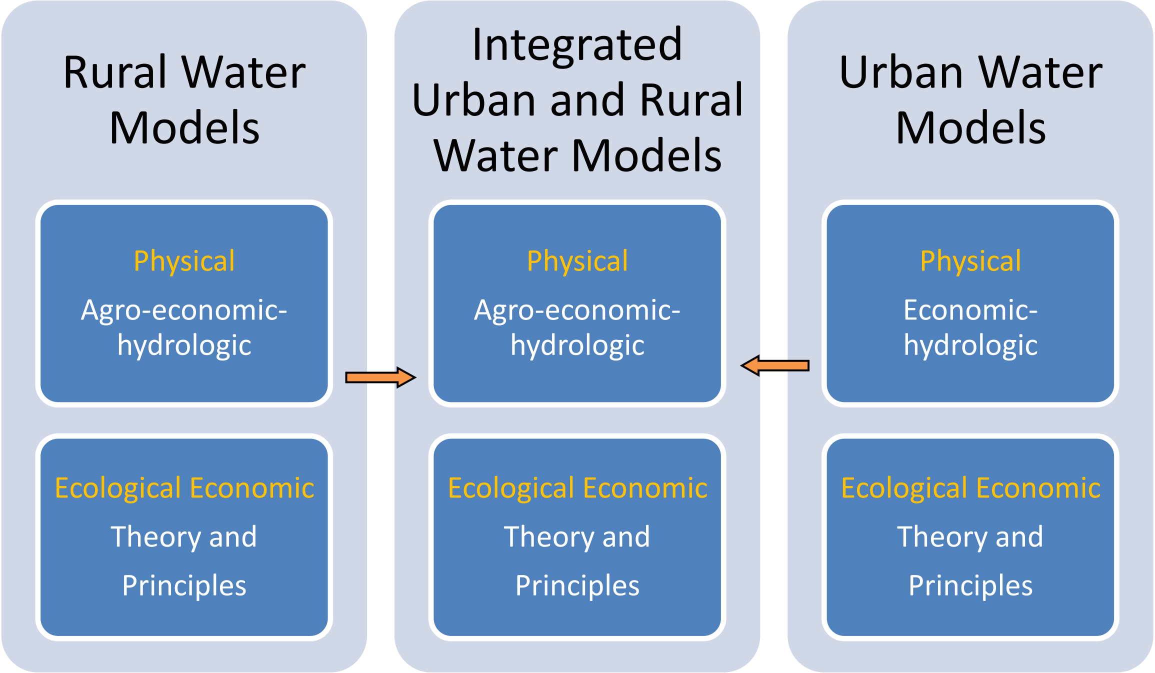

Figure 2-7 The urban-rural conceptual model representing the future of IWRM using a non-sectoral approach.

The traditional sectoral approach to IWRM in literature focused on separated management of water uses and users. This separated management style, delivered plans and designed water resources management for separate sectors or districts (Zeng et al. 2006). This resulted in poor coordination of planning, management and administration across regions and departments, and conflict amongst sectors (World Bank 2010; Zeng et al. 2006). Instead, inter-sectoral water allocation, planning and management were recommended

(World Bank 2010). Through uniform management of the entire water catchment, higher level comprehensive management solved sector conflicts and integrated strategies from fragmented planning in different sectors or districts (Zeng et al. 2006). IWRM that involved central coordination of laws, acts and standards, yet was fully integrated with various state and local agencies management of water resources, would be useful in any new approach to IWRM.

The scale of water issues did not appear to be directly related to the degree of centralisation adopted (Lane & Robinson 2009). Whether utilising a top-down approach or a bottom up approach, the level of integration between institutions and policymakers appeared critical. Clearer delineation of responsibility for water at an appropriate spatial scale was needed to recognise the complexity of factors affecting IWRM (Savenije & van der Zaag 2008). Experience has shown that both vertical and horizontal collaboration is possible. There was no ‘hard wired’ structural solution to IWRM as policy and institutional fragmentation existed at and within national and lower levels of government (Lane & Robinson 2009). Such fragmentation perpetuated the ‘wickedness’ of environmental management problems (Lane & Robinson 2009). Factors including institutional transaction cost and the impact of the political economy on the water sector on the institutional change process were relevant to the debate on fragmentation of water institutions. See literature on institutional economics for further perspectives on the water crisis, and its institutional foundations in terms of all its dimensions (e.g. Saleth & Dinar, 2004, Hodgson, 2000). An integrated approach, utilising community based co-management in the IWRM model, was sought to accommodate water issues with other resource management issues whether at national, regional or local levels.

In literature the issue of water reuse stood out in terms of inconsistency of planning and management. Often IWRM was a local or state policy issue and lacked coordination with other water supply strategies (Thomas & Durham 2003; GWP-TAC 2000). Other areas of water use which emerged as important in terms of managing leakages from the ITWC included evaporation and the environment as a water user (Smakhtina et al. 2004). These aspects were investigated further in the next section of this chapter.

The World Bank (2010) recognised the tensions over water, and emphasized that this spatial dimension required appropriate and effective water management. The problem with this approach was that water for rural and urban use was managed according to sectoral use and not alternative water sources (World Bank 2010). This sectoral approach reinforced by the separation of sectoral water disputes and water supply in both the centralised and separated approaches to IWRM was discussed below (Zeng et al. 2006). Concern about the urban-rural water imbalance in western developed countries has centred on the adequacy of water supply for growing urban (including industrial) users (Pumphrey et al. 2008). This situation may be reversed, as concerns about food security issues highlight the urgent need to secure rural water supply (Molden et al. 2007; American University International Law Review 2001; Postel et al. 1996). This agricultural water situation was exacerbated by the highly regulated urban water sector and tendency to subsidise agricultural water systems (Crase et al. 2008).

Worldwide, agriculture is the dominant consumer of freshwater, consuming around 70 per cent of all water lost from the water cycle (FAO 2014). Although industry and urban water withdrawals were also significant, the majority of urban water was recycled (FAO 2012). The second highest water consumption levels were due to reservoir losses from evaporation and leakage (FAO 2012). Water required for World food production has been estimated at 40 percent (FAO 2012). This overuse of scarce water explains why urban-rural integration is the focus of further closing the water cycle with the IWRM model in this study.

To examine this issue properly, literature on the interconnections between groundwater, agricultural policy, urban land use and infrastructure decisions and energy requirements (Foster & Ait-Kadi 2012) was provided. For example, cross-sectoral issues such as subsidies for rural groundwater and bulk electricity tariffs, urban land use and sanitation were major impediments to water sustainability and water cycle management (Foster et al. 2013a, b; Garduno & Foster 2010). IWRM practices have been adopted in countries such as Australia, the U.K, U.S., Singapore, Spain, Japan and China and were examined in more detail in Chapter 5.

In literature, models or principles of IWRM generally did not include operational aspects that interfere with the successful implementation of IWRM (UN 2012; Muller 2010; Biswas 2008; Brown 2008; Stenekes 2008). In literature, resource scarcity, the distribution of the resource and efficiency of water use depended on the institutional and property rights structure (Demsetz 1967). Literature on IWRM implementation through such economic policy instruments was extensive (Jackson 2009; Griffin 2008; Freebairn & Quiggin 2006; UN 2002, 2000; Stavins 2001, 2000) but the focus in this study remained, not on the type of policy instrument employed, but more on the coordination of an appropriate range and mix of policy instruments for IWRM. While IWRM was often a regional or state issue, the policies and instruments for management of IWRM were delivered in an inconsistent and uncoordinated fashion (Biswas 2004). The roles for the government and non-government sector were included in the policy dimension of the IWRM model. These unresolved policy issues exacerbated the environmental, economic and social aspects of water issues as discussed in the remainder section 2.5.

A management plan was needed for integration of these policies, legal requirements and guidelines for non-government involvement in IWRM – particularly with regard to rural integration. An implementation strategy was also required to link these policy related issues to those in the social, economic and environmental areas of the IWRM model. These social complexities and community involvement aspects of the water problem were also addressed in this section 2.5.3.

Coordination of policy in other sectors and on related issues remained other unresolved issues in IWRM. Other policies such as regional development and general economic development, including production of food, housing, health, education and other goods and services required improved coordination with water policy (Schneider & Rist 2014). The contributions from international developments and principles of IWRM to these unresolved policy issues raised above were reviewed.

Internationally, the water resources management phase appeared during the decade from 1980 to 1990 (Savenije & Van der Zaag 2008). This period was marked by the national coordination of the water sector and rapid construction of dams, and other supporting water infrastructure (FAO 2003). Since the 1980s development and implementation of IWRM research has been aided by various international organisations through symposiums, conferences and commissions.

Whilst IWRM development continued, implementation of IWRM was plagued by inconsistent and overlapping intergovernmental institutions and responses (Savenije & van der Zaag 2008; UN 1992a; WMO 1992). "IWRM reforms and implementation have been costly and time-consuming while the benefits are yet to be seen" (Butterworth et al. 2010, p. 70). In Australia, institutional failure to manage water was found to be the primary cause of water usage associated problems (Brown 2008; Biswas 2008; Stenekes 2008; Pigram 1999; Musgrave 1996; Ostrom 1990; Paterson 1987; Davidson 1969).

Conference and symposium findings at the time generally supported the idea that existing nation specific institutional frameworks work best in the planning and management of water resources (Savenije & van der Zaag 2008). An alternative view was that water management functions were best allocated across institutions from the bottom up, involving communities, water users and service providers (UN 1991). Specific details on how to achieve co-ordination, balance and integration in practice were not suggested in the early IWRM principles of Postel (Savenije & van der Zaag 2008, Gooch & Stålnacke 2006). Duplication and conflict inefficiencies were the result of poor coordination of planning in a separated water management system where different state, regional or local level agencies were responsible for water planning, management, regulation and policies (Zeng et al. 2006; GWP-TAC 2000). For example, markets and quotas for water often required both local and central agency involvement (FAO 2000). The new catchment scale IWRM model provided for a system involving a central institution to coordinate laws, acts and standards, with various state or local agencies to manage water resources use.

The integrated aspects of water with other resources such as energy, irrigated agriculture, the environment, mining and their users, planners and policy makers for example, were not well defined in Postel's principles. The principles did not offer guidelines on how these principles should be implemented and consequently IWRM has been slow to put them in place (Muller 2010; UN 2012). For example, these principles treat water purely as an economic good, ignoring its common pool resource characteristics and social aspects of equitable access to a resource necessary to life. The importance of treating water as a common pool resource was an important insight emerging from the analysis of IWRM principles that informed the developing IWRM model.

Although IWRM was not specifically defined or referred to in the Rio-Dublin Principles, international examples of water policy began to link water resources management with water use through water supply, rural development, sanitation, irrigation, drainage, energy and environment (World Bank 2003). Conflicting and inconsistent legislation (e.g. environment and conservation) constrained IWRM outcomes and required further investigation and coordination. The management of water in the natural environment may require assistance to regenerate sufficient quantity and quality of resources. Common pool resources need assistance to overcome market failure and avoid overexploitation, remaining available to all for basic consumption and security against the elements. These overlapping environmental issues were reviewed in section 2.5.4.

Prior to 2005 specific details on how to achieve co-ordination, balance and integration in practice were unavailable (Gooch & Stålnacke 2006). Since 2005, the United Nations-Water Decade Programme on Advocacy and Communication UNW-DPAC) has produced manuals and guidelines for the implementation of IWRM (UN 2014). An example was the 2007 UN Global Compact's CEO Water Mandate. As a result of this public-private initiative the Guide to Water-Related Collective Action was released (CEO Water Mandate & Pacific Institute 2012). This guide assisted company CEOs to manage their water sustainability policies and practices by working with government, non-government and community.

River basin management for water management was established in the European Union's Water Framework Directive (EC 2000). Since the 1980s this directive and subsequent literature recommended that water and other resources be managed on an integrated basis – not as separate sectors using water (Biswas 2008). The implicit assumption was that such integration of water-related institutions contributed to integrated water resources management, yet centralised consolidation of various institutions related to IWRM had not been successful historically (Biswas 2008, pp.19-20). Thus while IWRM became a popular concept in recent years, its success in terms of application to more efficiently managed large scale water policies, programs and projects was poor (Butterworth et al. 2010; Biswas 2008; Blomquist & Schlager 2005). Local input was seen as a necessary part of the participatory framework often where the local experience existed and the knowledge, concerns and priorities were held by community (Miller & Hirsch 2002). Although the IWRM model proposed here was at the catchment scale, the main underlying principles and key components were expected to remain the same whether at the river basin or more local scale.

The slow progress in water resource sector coordination emerged at the 1992 Earth Summit and the fragmentation of the sectoral agencies within the water sector was flagged as a major impediment (Agenda 21, chapter 18, paragraph 18.6). These frustrations were again raised at the Rio+5 Forum 1997, subsequent water conferences in Harare and Paris, 1998 and the UN Commission on Sustainable Development at its “Rio +5” follow-up meeting in 1998 (GWP-TAC 2000, p.13).[3] Outcomes from these conferences and meetings culminated in the Dublin-Rio principles (UN 1992) underlying IWRM today. In 1998, the European Commission (EU) published a series of Guidelines for Water Resource Development Cooperation (UN 2000). This approach promoted international consensus on integrated water resources management (IWRM) and led to development of cooperation activities amongst agencies like EU and UN. Subsequently it became apparent that successful IWRM required more than just agency cooperation (UN 2000, 2002).

A report on the success of the Rio Principles and Agenda 21 found that “market” outcomes required more regulation in order to achieve the Millennium goals of freedom, equality, solidarity, tolerance, and respect for nature and shared responsibility (UN 2000, 2002). After the ICWE in Dublin, a more coordinated integrated approach to water resource management was sought. The literature revealed that a UN organisation was required with

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[3] Rio+5 Forum - 13-19 March 1997; Rio de Janeiro, Brazil and the 5th Session of the UN Commission on Sustainable Development (CSD) - 7-25 April 1997; New York, USA; lead to the Earth Summit+5 - a Special Session of the United Nations General Assembly in New York, 23-27 June 1997.

specific responsibility for water resources, instead of a shared responsibility amongst organizations such as WMO, WHO, FAO, UNESCO, UNDP, UNEP and UNICEF (Savenije & van der Zaag 2008).

Some of the Rio Principles became international laws and national policy instruments, but were not translated into IWRM action (UN 2012). In a comparative review of the success in IWRM following the implementation of both the Dublin and the Rio Principles, water infrastructure investments in developing countries were found to more constrained by the way water was managed under the Dublin Principles (Muller 2010). IWRM principles such as those in Agenda 21 neglected the nature of derived demand for water, the competing uses for water and the role of water as a common pool resource. The Rio-Dublin principles also continued to neglect advice on IWRM policy implementation. These concerns were addressed by additional principles produced by Turner et al. (2007).

Turner et al. (2007, pp. 2-3) developed IWRM principles further emphasising the importance of understanding the derived demand for all water service, detailed demand forecasting based upon end use, the broad range of water efficiency, substitution, reuse and supply options, social cost benefit analysis of these options, the participatory process towards provision of water service and adaptive management in IWRM decision making. These refined IWRM principles formed the basis of the key components of the four dimensions of the IWRM model.

A more coordinated approach to IWRM followed with the establishment of the Global Water Partnership (GWP) and the World Water Council (WWC). The latter raised political awareness of IWRM whilst the former assisted with implementation of IWRM concept. The two cooperated in bringing about the second and third World Water Forums in The Hague, The Netherlands 2000 and in Kyoto, Japan 2003. The "From Vision to Action" Forum in 2000 led to debate on the World Water Vision and a Framework for Action. Issues raised included the state and ownership of water resources, development potential, management and financing models, and their impact on poverty, social, cultural and economic development, and the environment. The multidimensional approach to the water problem that emerged there was adopted in this study in the development of a new conceptual

IWRM model. Meanwhile the Ministerial Declaration of the 2nd World *Water* Forum in The Hague, 2000 identified the key challenges in meeting basic water needs, securing food supply, protecting ecosystems, sharing water resources, managing risks, valuing water and governing water appropriately (GDRC 2000). The Global Water Partnership too developed a “toolbox” for integrated water resources management (GWP-TAC 2000) that was extensive, but remained largely unused (Biswas 2008). These and other implementation problems continued to plague IWRM.

Whilst many of those countries were represented at the Johannesburg World Summit on Sustainable Development (WSSD) in 2002, inability to incorporate IWRM into policy making instruments, and operational issues such as legislative and monitoring requirements, effectively prevented full implementation of IWRM in practice (McDonnell 2008). Other issues of implementation focused on a technocratic approach to IWRM implementation in areas of water purification and infrastructure requirements (Wolf et al. 2010; Dore et al. 2004). The problem world-wide remained one of “institutional inertia” – inflexible, contradictory and overlapping institutions and procedures governing infrastructure, resources, knowledge, rules, habits etc. (Biswas 2008; Brown 2008; Stenekes 2008). Real institutional reform remained limited (Mollinga et al. 2007). These issues pointed towards a need for a multidisciplinary approach to understanding the policy dimension of the water problem.

It was apparent that involvement of water users in water management tasks was more effective when combined with both the development *and* the implementation of clear rules and regulations and the creation of institutions and frameworks in society (FAO 2000). There was a need to involve both local and central agencies to connect water users with these institutions and regulation (Ostrom 2008). There were roles for a variety of institutions for water management issues including:

- *national governments and line ministries,*
- *civil society organizations,*
- *community groups,*
- *the private sector,*

- *bilateral aid agencies and multilateral development banks,*
- *export credit agencies,*
- *inter-governmental organizations,*
- *professional associations, and*
- *academic and research bodies.*

(American University International Law Review 2001, p.1451). The IWRM model here in this study recognised the roles and importance of all of these institutions in the policy dimension.

In reality rigid functional divisions within governments and international development agencies interfered with this inter-sector approach to development planning and resource management that IWRM required (GWP 2006). Building capacity for IWRM was difficult when agencies were organized along sectoral lines and where social and environmental issues were managed separately (GWP 2006). An iterative dynamic process with long-term changing goals was required to manage these issues together in an integrated way (GWP 2006).

An appropriate institutional structure in terms of legal and other regulatory instruments, monitoring arrangements was necessary, for example managing water withdrawals through water markets (Marino & Kemper 1999). Local management and central agency involvement were often both required (FAO 2000). There was also a need to promote an understanding of the values of water in its various functions (FAO 2000). This can be achieved using economic theory and principles of total economic value and appropriate economic policy instruments. Administratively the outcomes of either model can be achieved in a variety of ways and success appears to rely upon a combination of economic policy instruments. These instruments were further explained in section 2.5.2 on unresolved economic issues in IWRM.

Spatial Scale of IWRM

Some level of institutional coordination was required such that decision making was appropriate for these diverse water scales (Savenije 2000; Savenije & van der Zaag

2008). Spatially water resources and uses are traditionally quite diverse, ranging from water abundant watersheds upstream to water depleted plains downstream. Water has been managed at the level of the watershed, catchment or basin scale. There was also an emerging need for global IWRM (Savenije et al. 2014; van der Zaag et al. 2002). The degree of hydrological connectivity of these water areas sometimes impacted on the scale selected to manage such water resources although usually these boundaries were administratively determined, as previously mentioned. The approach taken in the IWRM model developed in this study, was that the environment was the limiting factor and therefore the environment (hydrogeology) determined the spatial scale of IWRM – that is, catchment scale determined by connectivity to all water sources and users. In order to overcome such issues, the policy of total water cycle management in IWRM required further investigation in managing unresolved issues.

Total Water Cycle Management

The policy approach to IWRM shifted focus towards a combination of water demand- and supply-side management approaches (Gleick 2000). This approach has become known as total water cycle management (TWCM) (Chanan & Simmons 2002). This holistic approach aimed to balance water resource management by combining water demand and supply management, as indicated in the Koudstaal et al. model (1992) in Figure 2-1. Managing water demand through improvements in water use efficiency was sometimes assisted through augmentation of water supply.

The temporal scale in IWRM can be adjusted to match availability of and demand for water resources and its relationship to the market. Traditionally the emphasis was on physical structures built to coordinate water supply and demand (Savenije & van der Zaag 2008; Savenije 2000). Coordination of water supply and demand assisted in managing fluctuations in demand and climatic or hydrogeological patterns (Savenije & van der Zaag 2008; Savenije 2000). Water supply management has also relied upon augmentation and water transfers – either physically via infrastructure or legally through water rights), wastewater reclamation, recycling and reuse in the water cycle (Asano 1998).

Management of the hydrological cycle and anthropogenic influences became the subject of research highlighting the issues of aquifer mining, surface water diversion and changes in internally draining lake volumes, desertification, wetland drainage, soil erosion in agricultural regions, deforestation and dam building. TWCM was mostly used in integrated urban water management that targets the total urban water cycle - including water supply, stormwater and wastewater (Mitchell et al. 2003). Literature around the limits on renewable freshwater resources often linked it to the acceleration rate of the water cycle and ways to reduce leakage (Oki & Kanae 2006). For this reason, the ITWC management approach was adopted in the IWRM model via the ITWC sub-model. Evidence of TWCM was sought in the case study of the Lockyer Valley (Chapters 3 and 4) and international case examples to understand what was required of the IWRM model to close the water cycle. These issues around urban-rural integration in IWRM were used to focus the development and refinement of the IWRM.

The IWRM model incorporated elements of water demand management into all the model's dimensions. Although derived demand remained an economic issue, the management and impacts of demand for water have policy, social and environmental dimensions. As mentioned in Chapter 1 the IWRM model incorporated all water users and sectors. Growing populations and economies demand more water as groundwater, surface water and water quality decline, straining all dimensions of IWRM. Water demand can be managed using water use efficiency and reuse incentives. Pressure of demand and supply of water provided incentives for new forms of cooperation and innovation (American University International Law Review 2001). Literature and international developments showed that inconsistent and overlapping intergovernmental institutions and responses interfered with the development and implementation of IWRM. The ways in which the IWRM model assisted to resolve economic issues associated with water problem were then examined. To address these aspects, the IWRM model allowed that all users and uses be accounted for, valued, priced and managed collectively at the catchment scale in the economic dimension of the IWRM model.

2.5.2. Unresolved Economic Issues

Unresolved economic issues in literature on IWRM was used to focus attention on these in the forthcoming case studies in Chapters 3, 4 and 5. Water traditionally had both public good and common good characteristics, and irrigation water had some characteristics of both where it was not properly metered, capped or regulated. Economic literature on irrigation provided useful input into the development of the IWRM model including how to manage unresolved economic issues. These included market failure, third party access to water services and infrastructure, water quality, price and cost recovery. A brief review of literature on these unresolved economic issues followed with a view to managing them in the economic dimension of the IWRM model.

The function of water that lead to its classification as a public good, was its non-rivalry. For example, the consumption of benefits arising from its ability to act as a filter for the ecosystem (sink function) did not reduce benefits from its other uses (Samuelson 1954). Public water can be a common pool resource that diminishes with successive use and from which users cannot naturally be excluded (Hardin 1968; Demsetz 1967). Where these characteristics occurred, the “tragedy of commons” (overexploitation) resulted from under-pricing of such resources (Hardin 1968). The nature of public water (i.e. groundwater that is not fully monitored and licensed) should determine how it is managed and this has remained a major unresolved economic issue around the world.

Since the 1990s, regional and national IWRM planning was followed and water demand-side measures became the focus of policy makers (Savenije & Van der Zaag 2008; UN 1992, WMO 1992). In many parts of the world, water property rights resided with government due to the complexity of social, economic and environmental aspects of water. Water supply and use generally remained the responsibility of States and Territories. Water users paid to have access to water through “entitlements” - particularly in the rural water sector. These entitlements to fresh water (above and below ground), wastewater, recycled water, water infrastructure and trading, vary internationally and even across water catchments. Property rights for recycled water have been slower to emerge (ACIL Tasman 2005). Without clear property rights, inefficiencies in water use, pricing, investment in recycled water infrastructure and security of supply emerged (OECD 2010; Radcliffe 2004; Hatton MacDonald & Dyack 2004). The degree of efficiency of the water markets is determined by the buyers, sellers and rules that govern water trading (Syme et al. 1999) with support from other policy instruments mentioned in section 2.5.2). The inconsistencies of water property rights were further explored using the IWRM model - including concerns about their ability to manage environmental flows in section 2.5.4.

Derived Demand for Water

The demand for water is derived, that is, demand is dependent on its various uses, substitutes and other factors (Agthe & Billings 2003). Before pricing can be established, demand for water has to be thoroughly explored. Consequently, IWRM involved addressing the drivers for demand for water that arise out of its uses – for drinking, cleaning, agriculture, industry and the environment. As water is essential to life it has been described in economics as demand inelastic – with demand for water responding very little to changes in water prices. This is especially the case when water supply is high, available at low prices, or when water substitutes are available (Bjornlund et al. 2008; Moore et al. 1994; Kelso 1967). Water demand management relies upon estimates of water use and demand forecasts and one of the most difficult issues has been data availability (UN 1978). This had been especially the case with rural irrigation demand data as many rural water systems were unregulated and operated as private irrigation systems (Kelmelis & Snow, 1991).

In practice there were major problems with measuring, estimating and forecasting water demand. This has been attributed to uncertainty regarding:

- historic actual water use data
- water use efficiency levels
- economic, social and demographic assumptions

(OECD 2010; WBCSD 2009; UN 1992; UN 2002).

Demand for water is often estimated through water consumption data obtained from water supply utilities. For accuracy, demand for water should also include all components of the ITWC (rainwater, recycled water, private dams, unmetered creek, river, overland flows and groundwater extraction etc.). There is often no official data on demand and use of these water sources and so estimating demand and water use is not always accurate (UN 2009). This problem emerged in literature with regard to rural water use (Kelmelis & Snow, 1991). Demand for rural water has been estimated in a variety of ways using productive land estimates multiplied by crop type and average crop irrigation rates, actual water usage data (dam and groundwater allocations) and estimates of quantities based upon WTP data. The use of water for irrigation from private dams, unmetered water extractions from natural waterways and overland flows was often large (Frenken & Gillet 2012) and sometimes not recorded. Where demand was difficult to estimate, pricing became problematic.

Inelasticity of demand is relatively high amongst public water consumers, as consumers do not respond to some price changes unless water and its substitutes are priced competitively (Worthington & Hoffman 2006). Economic policy instruments including price and non-price mechanisms can be used to manage demand where water use is excessive or price inadequate. These options were explored further in the following parts of this section of this chapter. It was sufficient to note that non-price demand control mechanisms were preferred options where price elasticity of demand were low – as it was for irrigation water (Worthington & Hoffman 2006). These IWRM economic policy instruments have economic, social, policy, environment and technical dimensions. As mentioned in section 2.5.1, management of the water catchment sector conflicts have been resolved in the past where planning and strategies are better integrated, rather than using approaches to individual sectors or districts (Zeng et al. 2006). Urban domestic users use water for drinking, washing (potable) and recreation. Urban industrial users require water for cooling, heating, cleaning or as product inputs (potable or non-potable, recycled or fresh water). In agriculture, traditionally the largest sector user of water, demand consists of potable water for drinking and other domestic uses, some crop and livestock watering, and non-potable for washing down equipment and some crop irrigation, where permissible.

The Five Sector Model

The standard five sector economic model of income flows in the economy highlights the integration of the household, business, financial, government and foreign sectors through income flows between the sectors (Mankiw 2006). It can also be used to represent flows of expenditure and production in the five sectors. This five sector sub-model depicted in Figure 2-8 can reside within the environment dimension of the IWRM model. This can help policy makers conceptualise the way in which the five sectors can be dealt with in managing demand of all water users in the economy. This economic sub-model was subject to the environmental constraints of the water catchment. This was very much an ecological economic view of the economy where economic activity resides within the environment’s biophysical limits (Costanza & Daly 1992).

Thus the economic dimension of the IWRM model incorporated the economic decisions of all sectors - government, firms, household, overseas and finance sectors (just as the policy dimension incorporated the institutions and policy decisions of each of the five sectors). There were roles in IWRM for each of these sectors, but these sectors were not singled out for decision-making. Instead the roles of sectors were dealt with in an integrated way across the four dimensions of the IWRM model. In this way the IWRM model differed from existing IWRM models as it relied upon the overlapping complexity of the “egg of sustainability” model approach to manage cross sectoral water demand, supply and decisions.

Management of the ITWC sub-model, also within the environment dimension of the IWRM, model benefitted from collective oversight. Collective management by users can ensure comparative pricing, and quantity allocations are implemented regardless of the sector (Ostrom 2010; Bromley & Paavola 2002). The collective management approach reflected the common pool nature of water rather than the treatment of water as an economic good as suggested in Dublin-Rio IWRM principles (Bromley & Paavola 2002; Quiggin 1986). In the Dublin Principles, water was seen as a “natural resource... social and economic good” rather than a common pool or public good to be managed (UN 1992, Agenda 21, Chapter 18). A central problem with demand for and management of common pool resources was recognition of its total value to all users. Unresolved issues in literature associated with water valuation and pricing in the IWRM model were then addressed.

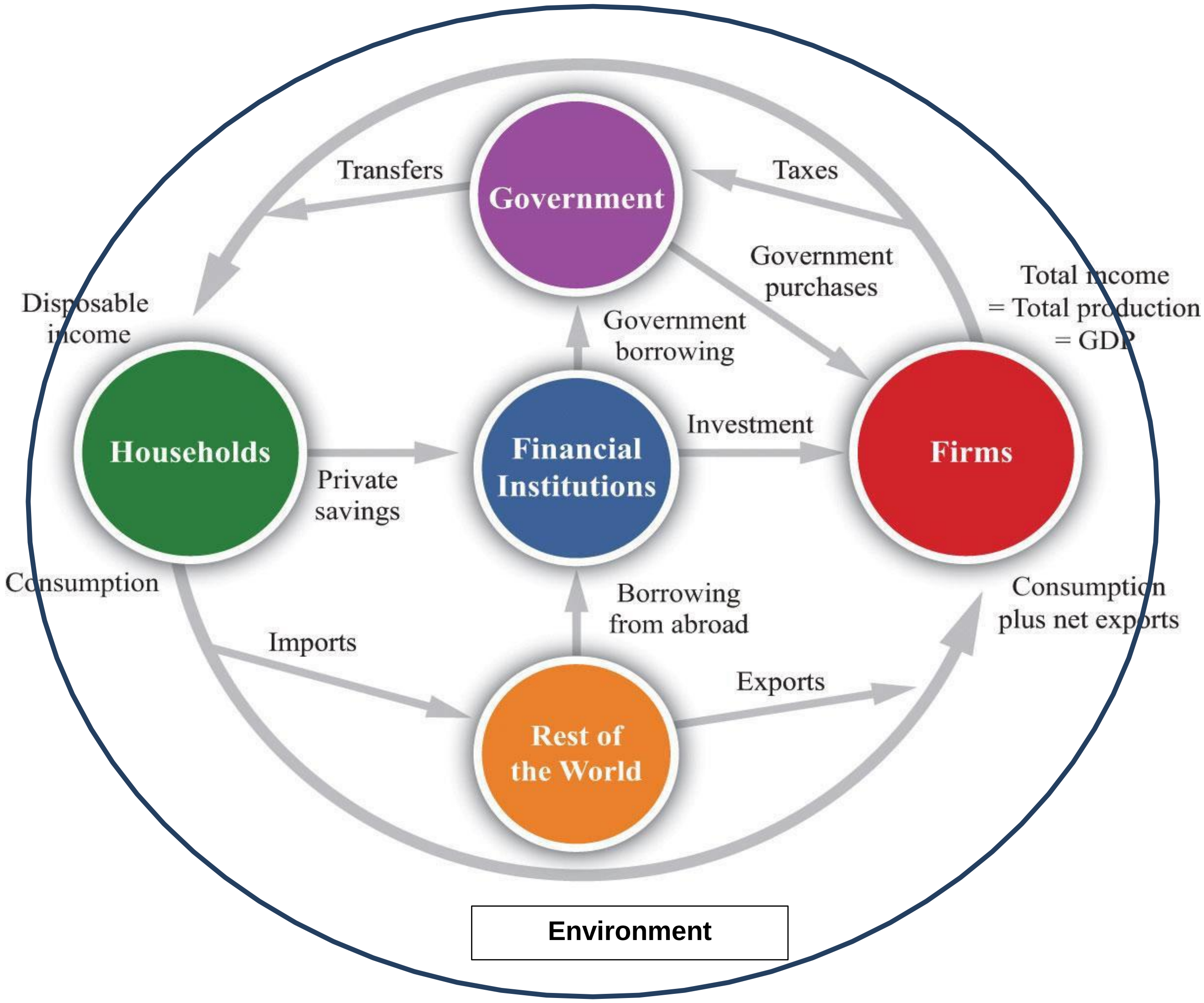

Figure 2-8 An ecological economic view of the economic dimension of the IWRM model.

Source: adapted from Cooper & John (2015).

Valuation of Water

Where the threat of the "tragedy of the commons" existed, valuation of a common pool resource required understanding and willingness to pay for the benefits and costs beyond its market value (Muradiana et al. 2010). Efficient allocation of scarce water resources required recognition of the role of common marginal value to society of water in all uses, and recognition of positive and negative externalities in water use (Freebairn 2003). Unpriced externalities accrue to those other than the direct water users making a marginal price or average price inadequate, with relatively little connection to consumption and demand for rural water (Chicoine & Ramamurthy 1986). According to ecological economic principles, total economic value should be applied to resources such as water (Landell-Mills & Porras 2002; Munasinghe 1993). This is the full social cost of supply and use of water and includes the market costs and cost of externalities associated with the supply and use of water (see Hackett 2010). Externalities include the costs and benefits to those not directly using water but were still affected. In this way, the use and non-use values of such resources were recognised and included in price decisions (Landell-Mills & Porras 2002).

Public water, (such as groundwater) is a common pool resource - a resource that diminishes with successive use and from which users cannot naturally be excluded (Hardin 1968; Demsetz 1967). The cost of such water often failed to recover the full social cost from users (Tisdell 1996). Externalities, if not taken into account can cause a gap between the social and market marginal benefits and social and market marginal costs of resource use, and lead to over or under estimation of social benefits and costs of water use.

Water in all its uses therefore required appropriate environmental economic valuation before rigorous economic analysis of supply and pricing options could occur. An ecological economic approach to the valuation of common pool resources necessitated the total economic valuation (TEV) of full social costs and benefits of water. TEV recognised the use and non-use values (human and non-human uses) of natural resources (Young & Loomis 2014; Munasinghe 1993). In this way the non-uses of such resources including the amenity, bequest, intrinsic and vicarious value of water could be ascertained (Munasinghe 1993). Specifically, these values are associated with:

- preservation of biodiversity, management of catchment flows,
- service functions such as erosion control,
- salinity management,
- flood and drought management,
- ecological principles of sustainability
- geological and hydrological characteristics.

This approach to valuation enables policy makers to attach appropriate prices to these scarce resources and establish equilibrium quantity at the price where social demand and social supply are equal (where externalities are paid). This background to TEV provided insights into how the IWRM can be applied to the case study of water in the Lockyer Valley (Chapters 3 and 4) and internationally (Chapter 5).

Some of these use and non-use values for natural resources are difficult to quantify in literature and practice. Using the TEV approach depicted in Figure 2-9 below, all use and non-use values of a water resource management project can be assessed, and given an approximate monetary value (Young & Loomis 2014; Landell-Mills & Porras 2002). TEV includes use values (direct use values, indirect use values and option values directly related to personal use of the resource) and non-use values (effects not directly related to personal use, but potentially affecting both users and non-users alike). TEV of the source, sink, life support, amenity values of natural resources to society were included in the IWRM model to assist with resource allocation and pricing decisions (Young & Loomis 2014; Pearce & Turner 1990). A useful investigation into the economics of non-potable recycled water projects exploring the principles of TEV was provided in Marsden Jacob Associates (MJA) (2013). The cost and time involved in conducting the TEV approach meant that these principles were not used even in the MJA (2013) example.

Methods used to value the use and non-use value of resources such as water can include revealed and stated preference methods (see Hackett 2010 for further discussion). There are disadvantages with such methods including the level of expertise and cost involved in TEV assessment, but the idea is sound for the valuation of water as it assists in determining the wider benefits of water and IWRM projects and aids selection of appropriate economic policy instruments and pricing (see Rigby et al. 2010).

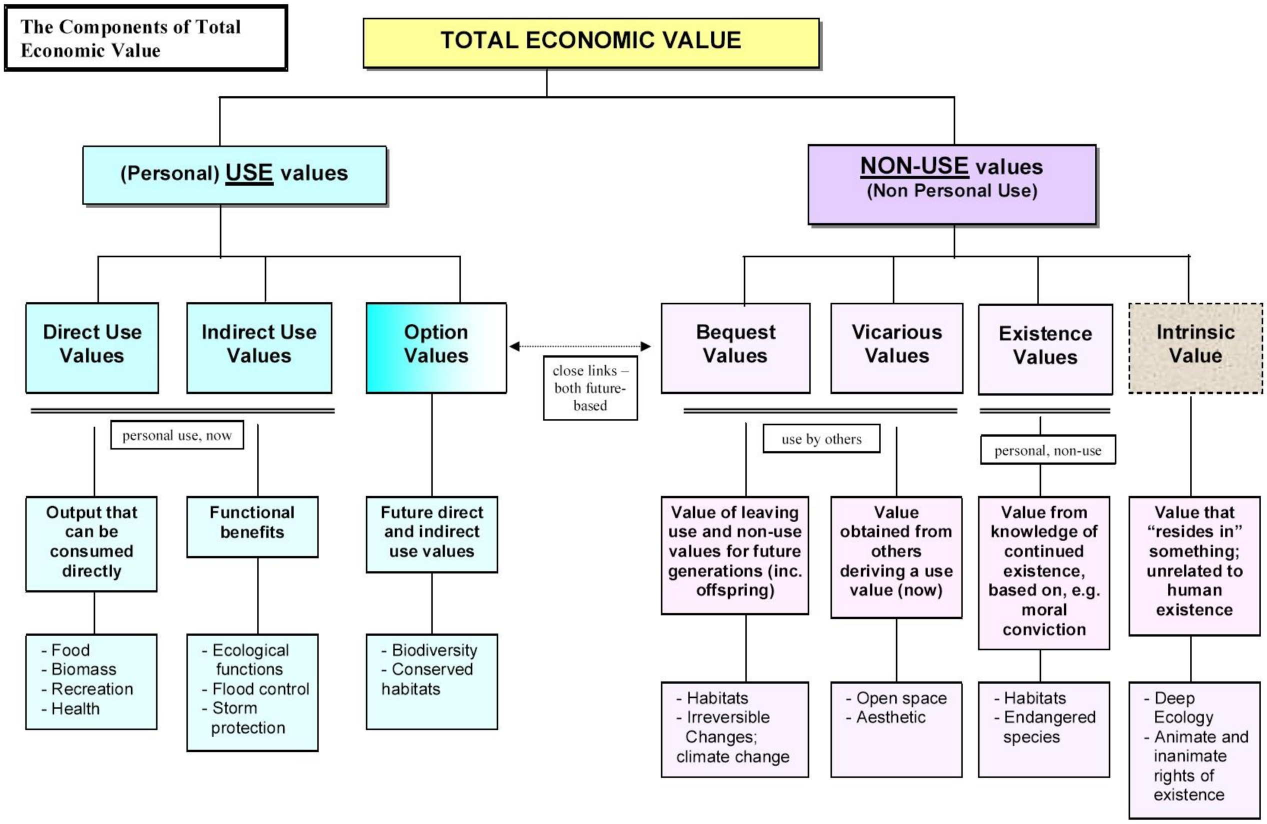

Figure 2-9 Using the total economic value approach to value both the use and non-use value of water

Source: Daniels 2012 derived from Munasinghe 1993

Correctly valuing water for its TEV leads to the creation of water markets and provides estimates of demand and willingness to pay (WTP) for water (Tisdell & Ward 2003; Randall 1981). WTP is the highest price a buyer indicates that they are prepared to pay (Ciriacy-Wantrup 1947). This knowledge of correctly valuing and pricing water according to ecological economic principles may assist IWRM policy decision making. It facilitates the internalisation of externalities - making users pay even for non-use values (Howe 1986) and potentially resolves the "tragedy of the commons." The economic concept of user pays, when applied to water resources, results in water pricing such that the full benefits derived from water equals the full cost (Waelti 1985). The nature of derived demand for water sees a range of unpredictable factors (weather, crop values and water policy changes) disrupting the market price signal to water users and investors in the agricultural industry (Tisdell 1996).

In both Keynesian (Keynes 1936) and Neoclassical economic theory it is common to invoke limits on monopoly pricing, rents, profits and access to infrastructure. Market failure (Stiglitz 1989; Arrow 1969) due to natural monopoly (Baumol 1977), characteristics of water infrastructure and economies of scale (Ferguson 1969) are justifications for such intervention. The logic is that markets do not reflect non market values placed on public goods and alone are insufficient economic policy instruments for water (Griffin 2008, p. 4). Ecological economic theory supports government involvement to back market based or voluntary economic policy instruments, at least until society evolves or becomes aware enough of the TEV of environmental resources to implement the required changes itself (Jackson 2009). Once the TEV of water is established, appropriate water pricing and allocating decisions can be implemented in IWRM as follows.

Water Pricing

Classical economic theory is based on the concept that the market establishes prices determined by free market forces of supply and demand (Smith 1937). At the market price, the marginal cost of providing the resource is equal to the marginal revenue earnt from purchasing it (Tirole 1988). So too, the OECD (1999) and the Water Framework Directive (2000) require full cost recovery of large scale IWRM projects with hard infrastructure for example dams and desalination plants. Yet many such projects worldwide struggle to recover capital costs and few have implemented alternative uses for this infrastructure (AATSE 1999; Paterson 1987). Full cost recovery in water pricing has been recommended so that marginal cost pricing of water includes all externalities (Savenije & van der Zaag 2002). Yet most policy makers advocate traditional full cost pricing (recovery of capital and operating costs only, but not externalities).

Traditional full cost pricing of water was recommended at the Ministerial Conference (2nd World Water Forum in The Hague) and the World Water Vision Water Commission on Water in 2000. The latter also recommended privatization of water supplies and emphasized the user pays principle of traditional full cost for water. At the Bonn International Conference on Freshwater (2000), agricultural users were recommended to pay both the full cost of operations and financial costs of water supply (World Water Council 2013). Yet common pool resources such as water did not often have private markets. Ostom (1990) suggested rules to allocate benefits be proportional to inputs (which can include payments for water) to create a market for common pool resources (Hardin 1994).

Often the levels of marginal revenue and cost for such goods do not incorporate values not recognised in the market (aesthetic and future use values) as proposed in the TEV approach, and intervention by government or similar independent authority is required (Tisdell 1996; Hardin 1994; Ostrom 1990). Water management required more than efficient pricing and optimal allocation. Instead, economic efficiency, when applied to decision making on allocation of water between all users in all sectors, involved sound principles of TEV, full social cost pricing and property rights (Agudelo 2001; Winpenny 1994). In reality application of such principles was costly and time consuming. New water policies or water projects were required to meet the goal of economic efficiency (Postel & Thompson 2005; FAO 1995; Winpenny 1994). With the inclusion of social costs and benefits (including externalities) many water projects do provide a net social benefit but water may become too expensive for all to access (Ward & Michelsen 2002; FAO 1995).

The next best solution was to estimate a price based upon “what the market will bear” by pricing water using shadow pricing (Stiglitz 2000). This technique involved using the cost of a similar existing product in use elsewhere. Traditionally both shadow prices and WTP for irrigation water are used to determine water demand and assess supply scenarios. These scenarios with shadow prices enable irrigators to indicate preferred water demand and make land-use decisions with recycled water availability. Both techniques are designed to ascertain the opportunity cost of water or the value of its next best use (Yound & Loomis 2014; Buchanan 2008). In this way policy makers ascertain the price users would pay for proposed IWRM projects and determine whether costs could be met prior to construction. WTP varies across cultures and other non-market characteristics including community resource management and heritage factors (Birckhead et al. 2011; UNESCO 2002). These were explored briefly in section 2.5.3 on social issues.

In pricing for different users, neoclassical economists apply principles that facilitate the shift of water use to its higher value (generally urban use). This is often based on the higher willingness to pay (WTP) for water by urban users. This WTP represented the opportunity cost of water used elsewhere. It has been argued that with many industries dependent on agriculture, for example food processing, the real value of this agricultural water is multiplied, yet often underestimated, if based on farm gate prices (Rogers et al. 1998). As urban water users pay much more for their water, decisions about the “best economic use of water” or allocation of water resources to their “highest economic return” often centre on prioritising urban water supply (Tsur 2005; Briscoe 1996).

Where individual WTP is difficult to assess or inappropriate, related methods of analysis such as risk assessment and cost-effectiveness are used. Shadow pricing or WTP estimates provide an indicator demand for that resource or service where the market is misunderstood, undervalued, or lacked a market or price (externalities existed). See Tsur 2005; Griffin et al. 1995; Whittington et al. 1987. In the interests of achieving an optimal and social acceptable outcome, any policy changes can be evaluated on the basis of a cost benefit test; the benefits must demonstrably exceed the costs. A thorough cost benefit analysis (CBA) is recommended in literature using both use and non-use values associated with the proposed policy change. This has been dealt with in literature elsewhere (see Munasinghe 1993). A full social CBA that incorporates both use and non-use values, by way of contingent valuation, provides the framework to analyse water pricing and valuation decisions, in accordance with international recommendations for World Best Practice as established by the World Water Council, World Water Forum and FAO. The CBA is dealt with in the economic dimension of the IWRM model.

As shown above, water and its management involve an understanding of the complexities of demand for and supply of water. Related water pricing, quantity allocations, reuse and infrastructure are also important ongoing economic issues. The common pool characteristics of water are managed using a variety of economic policy instruments to reduce over-reliance on both the quantities of water used and recycled - rainwater, stormwater and wastewater (Common & Stagl 2005). According to economic theory, water priced as a common good or a public good can be provided with appropriate access (Baumol 1982). In some cases, users may not be aware of, nor be prepared to pay, the full cost of water. Others may be prepared to pay more for this resource to secure its supply. This behaviour gives rise to resource rents – the extra profit over and above production or extraction costs earned from the sale of such resources (Stoneham et al. 2005; Sharp 2003). These rents provide incentives to pay more for scarce water supplies and are an important insight for all IWRM projects.

Different cultures have different relationships with water, land and its resources and therefore there are strong links between these resources to cultural vitality and resilience (Altman & Jackson 2008). Historically the lack of awareness of these cultural ties and values is compounded by a lack of awareness of water institutions, technical information and regulation (Jackson, 2007, pp. 65-6). Consequently, Indigenous people have not been engaged and involved in consultation and the development of water policy. Alternative processes and approaches to valuing, participating in, planning for and using water are needed. These socio-cultural aspects of IWRM are dealt with in the social dimension of the IWRM model in section 2.5.3.

With contestability, even the credible threat of new water sources becoming available, encourages water prices to remain competitive (Baumol 1982). Where alternative water sources are made available through the ITWC there is often a requirement for governments to induce water suppliers to factor in all the costs and benefits of water supply and use. Historically water use has been subsidised or priced below its full cost to provide basic access (Ward & Pulido-Velazquezet 2008). A justification for water subsidies in irrigation is the ‘multiplier effects’ from positive externalities from society’s recreational use of dams and creeks, and the drought and flood mitigation benefits to wider society including food security (see Tisdell 1996). These were important factors to consider in social and economic dimensions of the IWRM model.

A comparative advantage is afforded on this basis and essential services such as water, sewerage treatment and water using sectors (energy and food production) can be provided at lowest marginal cost (Crase 2007). Traditionally in Australia, the agricultural sector has been the highest water user (ABS 2013a) and the object of such water subsidies (Lin et al. 2008; Crase 2007). Low density land use areas require large amounts of water for irrigation and energy for transporting water and sewage over long distances (UN ESCAP 2014). This expensive service is generally subsidised by government in Australia (Lin et al. 2008; Crase 2007). According to the basic economic laws of demand and supply, resources flow to where the price is lowest, albeit via subsidies (Ward & Pulido-Velazquezet 2008; Hargerger 1954).

Regardless whether these subsidies are artificial or real, they affect the users' choice of water types and water developments (Ward & Pulido-Velazquezet 2008; Dinar & Subramanian 1997). Artificial subsidies are created when alternative water from dams and other sources is available at prices lower than the full social costs (Dinar & Subramanian 1997). Actual subsidies may also be paid by government to improve the affordability of water for social reasons. The application of economic theory and principles in the IWRM model assists in understanding these issues and managing them appropriately. This knowledge enhances understanding of the economic dimension and provides insights into the overlapping policy, environment and social dimensions of the IWRM model.

Underlying this, is an understanding of water demand and supply functions, as well as management and application of economic incentives to the use and supply of water. This need is emphasised as water economies mature and exhibit increasing incremental water supply costs (Ward & Pulido-Velazquezet 2008; Tisdell & Ward 2003). The result is both increased competition between alternative users and interdependencies amongst water uses (Tisdell & Ward 2003; Randall 1981). These socio-economic aspects of supply were considered in the economic dimension of the IWRM model.

In economic literature, water as an economic good, can be managed using market principles of supply and demand to guide price and quantity decisions, supported by limited government involvement (Savenije & Van Der Zaag 2002; Coase 1937). Co-management of common pool resources, like water, has also proved to be successful (Pahl-Wostl et al. 2007; Ostrom 1992). Although, co-management can sit within the policy dimension, co-management is very much constructed of social aspects such as community values, traditions and historical practice. This overlap is discussed in more detail in section 2.5.3. The long history of community management of common pool resources is also demonstrated in international case examples in Chapter 5. Where co-management was not possible initially, economic policy instruments such as subsidies encouraged private water resource management in the short term. Until voluntary policy instruments stemming from education and awareness of water scarcity are adopted, economic policy involvement will often be required. These economic issues were then explored.

Economic Policy Instruments

Internationally, the trend in water resource management has been towards greater efficiency and ecological sustainability (ASCE & UNESCO 1999; WCED 1987). This economic approach, favouring a mixture of market based and non-market based economic policy instruments, is ideally suited to achieving these goals e.g. water property rights, water trading, education about and implementation of full social cost pricing of water (see Pigou 1920 on taxes; Keynes 1936 on government policy intervention; Samuelson 1954; Coase 1960; Dales 1968 on property rights). An understanding of these instruments and how they may be useful in the new approach to IWRM was dealt with in the economic dimension of the IWRM model.

There are a range of alternative policy instruments - command and control, voluntary non-market based policy instruments and market based policy instruments reported in literature (see WHO 2016). Market based policy instruments for water management include creation of markets (water markets), market pricing for water, and friction reducing market based instruments (improved information and communication in existing water markets). Non-market based instruments include voluntary instruments such as education, information and moral suasion of community values to motivate individuals and businesses to manage water more efficiently themselves. Compulsory policies include non-market based policy instruments that control agents in the water market, such as regulations and rules backed by legal or court action (fines for water pollution). Generally, governments use a range of these economic policy instruments in combinations of market and non-market based policy instruments (mixed market based policy instruments) (Hackett 2010).

Thus a mixed approach in economic policy making encourages the freedom of choice and efficiency associated with market forces of supply and demand. For example, water users are encouraged to use water saving devices to lower water usage. Some degree of regulation is still required to facilitate basic water access (e.g. block tariffs with higher water charges on excess water use). Over time there has been a shift away from compulsory policies that involve high costs of enforcement and government involvement (Stavins 2000). The market is generally more efficient in affecting the demand and supply for goods and services, and delivers a higher degree of choice (Kotchen 2006; Covery 1998).

Integration of water resource markets can also be achieved using these policy instruments. For example, water trading based on clear water property rights (a market based policy instrument) integrates a variety of water sources and users (Freebairn & Quiggin 2006). Markets are used to ensure water is treated as a common pool resource when it reflects the values society and the environment place on it, due to its amenity and heritage services (Freebairn 2003). These water markets provide alternatives to engineered solutions that rely on expensive pipeline water infrastructure. The latter is a common response in IWRM as discussed earlier in Chapter 2. Supply and demand for water is facilitated by new or existing water markets. Yet these markets required physical access to the water supply - naturally or via constructed water transport network.

In order for markets to function in a socially efficient manner - maximise their net value to society (Kotchen 2006; Field 2001 p. 111), buyers, sellers and rules to govern trading are required (Freebairn & Quiggin 2006; Syme et al. 1999). The degree of public control over these rules had been a contentious issue in IWRM over past decades (WHO 2016; Saliba & Bush 1987). Many countries around the world operate large water supply networks to transfer water to users. The international trend in developed nations is away from administered water rights transfers, toward water rights markets (WHO 2016; Field 2001). The IWRM model opened up discussion of water markets for fresh and recycled water as another avenue for further closing the ITWC.

Where physical means exist to transfer water between users, developments in infrastructure ownership and access required further investigation in the IWRM model. To limit the opportunity for monopoly infrastructure providers to charge (excessive) monopoly rents (WHO 2016; Krueger 1974), governments use legislative instruments to control charging and supply arrangements for them. Contestability through third party access to water supply infrastructure and property rights are other economic policy options available to manage these IWRM issues (Bromley & Paavola 2002).

Common pool resources require incentives for users of such resources to act in a socially efficient manner and internalise all externalities associated with the resource (Tsur 2005; Demsetz 1967). Approaches to appropriate management of common pool resources range from regulated private property rights, appropriate supporting institutional arrangements for property rights to collective management of common pool resources at community level (Tsur 2005; Ostrom 1990). Successful management of common pool resources through property rights requires careful alignment of ecosystem and governance goals, interests, costs and management (Ostrom 1990). One can charge for access to common pool resources. The role of property rights in water catchment management was integral to this study, but decisions about the type of and timing of these rights varied across nations, states and regions and alternative sources of water (i.e. stormwater is the responsibility of Australian local governments and is still under development in some areas). The application of the theory of property rights was an unresolved issue in economic dimension of the IWRM model.

Market Failure in Water Management

As with any IWRM approach or model, understanding and management of water market failure is important. Market failure occurs when the price does not reflect costs and or the allocation of goods and services is inefficient. Non-market mechanisms (eg. taxes levied by government) may require subsidise or compensation to other users (e.g. the environment). Market failure in water markets results from the presence of monopoly power, large sunk costs, externalities, inadequate markets or information (Stiglitz 1989). Such market failure limits competition in water infrastructure provision, consumer choice of water providers and competitive pricing. As a result of these market failures, governments operate water monopolies, subsidising large sunk costs and absorbing externalities to deliver subsidised water to some water users. Externalities refer to the under-priced or unpriced impacts on those other than the direct users of the resource or those affected by the market transaction (Tsur 2005; Coase 1937). As a result, governments generally bear the bulk of the infrastructure costs involved in collection, storage and diversion of water, by virtue of the nature of water as a public good (Aschauer 1989; Samuelson 1954). These factors were considered in the economic dimensions of the IWRM model.

Public goods often require exploitation of economies of scale to promote regional economic and social development in addition to achieving lowest long-run average total costs (Coase 1960). Water supply is subject to many costs, including treatment, planning and management, transport and storage infrastructure, and negative externalities (pollution and use impacts on third parties). These factors restrict the provision and uses of water (Devi 2009) and often necessitate government involvement in water management on economic, social, equity and political grounds. Other factors leading to the government monopoly provision of water services include health and safety risks, uncertainty of sales, income and potential losses and large sunk costs for water infrastructure (Joskow 2005; Agthe 2002).

Public irrigation water infrastructure includes the expensive connections from dams to agricultural users and is generally of large scale and expense, representing significant sunk costs with long asset life times. These large capital or sunk costs result in entry barriers to competition and often require government regulation for social equity reasons (Aschauer 1989). Yet diseconomies (costs increase with size) with and constant economies of scale appear to be more common in publicly owned water providers, than for privately owned providers (Saal & Parker 2000). This is partially due to these expensive connections from dams to agricultural users. Water is often classified as a natural monopoly based upon the cost advantages in being the largest or first supplier in an industry and economies of scale (costs fall as size increases) (Baumol et al. 1977). These sunk costs form a barrier to competitors and foster monopoly control.

Water supplied for Australian rural use is typically provided “below cost” (Tisdell et al. 2002). Rural water infrastructure costs have been written off by government as sunk costs and subsidised for a variety of reasons including regional and national development (Tisdell et al. 2002; AATSE 1999). Urban users generally pay for operating costs and contributed to infrastructure costs of highly treated water piped directly to the door. Irrigation water is sometimes gravity fed, utilising nearby channels, streams and creeks and involves relatively low levels of treatment before and after use (AATSE 1999). Although these factors lower delivery costs, delivery of irrigation water is substantially subsidised (Higgins et al. 2002; Pigram 1999; Greig 1998; Alaouze & Whelan 1996; Pigram 1993; Paterson 1987; Randall 1981). Subsidies were provided for public irrigation water infrastructure such as large dams, where non-agricultural users enjoy recreation (e.g. fishing and boating).

Justifications for the removal of cross subsidisation of rural water infrastructure include; the high cost of this infrastructure and service, the negative environmental consequences of its development, regional impacts of location, public reforms in this area that favour full cost pricing of water and infrastructure, benefits accruing to a few and better environmental and regional management of these scarce resources (Hatton MacDonald & Dyack 2004; Higgins et al. 2002; Greig 1998; Randall 1981). Where open competition cannot achieve cost efficiencies equal to those of a monopoly, some alternative measures of competition were investigated (Smith 1937). There are many options for private and mixed private-public arrangements for managing public water access and other unresolved economic issues dealt with in the economic dimension of the IWRM model.

Market failures often make unregulated privatisation of natural resource markets unfeasible (Tisdell 1996; Anderson & Leal 1991). Market failures necessitate government involvement in markets, as mentioned earlier, via direct regulation, market instruments (water trading) or voluntary methods, such as education of water users or supplier provided incentives (Hackett 2010). Some stability in these variables (e.g. water policy) is required before the ‘user pays’ principle can be applied to the irrigated agriculture industry (Tisdell 1996). There is sometimes a role for government in economic decisions on natural resources (Bromley & Paavola 2002).

Managing Water Access

There are ways to introduce competition including third party access to water infrastructure, competition in water (or wastewater treatment) suppliers and entitlements. Privatisation is one option but where natural water monopolies exist, there is always potential for private monopolies to develop, with high prices and abnormal profits (Spulber & Sabbaghi 1994). In the absence of property rights and adequate resource management, open access to these resources often leads to overexploitation and degradation – “tragedy of the commons” (Hardin 1968). Temporal factors such as seasonal changes affecting water supply and demand often require private investment and or access to seasonal water storages for irrigation (ACIL Tasman 2005). Given such economies of scale, the integration of all water sources and users in IWRM is very expensive. Where economies of scale dictate that there be one supplier of a service (i.e. water), contestability theory contends that the threat of open competition may be sufficient to achieve the same efficiencies as government owned water providers (Joskow 2005; Baumol 1982). The possibility of alternative water suppliers and sources (e.g. recycled water) has the potential to transform the water market from a possible monopoly into a contestable market.

Contestable markets have few or no real impediments to market operations (Baumol 1982). Markets are contestable even when the threat of entry keeps up the pressure for the incumbent to remain competitive (Baumol 1982). With contestability, there is little need for legislative instruments to control charging and supply arrangements of monopoly infrastructure providers (Baumol 1977). The level of contestability in the water market determines the level of intervention by government. For example, more contestable water markets require less government involvement in the form of subsidies. These associated economic issues were examined in the context of water supply within the economic dimension of the IWRM model.

The natural monopoly characteristics of water and a small private sector often result in government intervention to provide competition for common pool or public water in rivers, creeks and aquifers for example (Common & Stagl 2005; Coase 1960; Samuelson 1954). There is abundant literature about the economic implications and treatment of water through property rights (Ostrom 1997; Schlager & Ostrom 1992). Issues such as provision of and access to water infrastructure, water services and operations are dealt with using various organisations including government management, non-government organisations, privatisation and varying degrees of access. Community management has often been overlooked by developed countries in public irrigation management scenarios (Ostrom 2010; Common & Stagl 2005; Sarker & Itoh 2001, 2003; Ostrom 1992). As a common pool resource, any unmonitored groundwater requires an understanding of demand for water and its management. The IWRM model offered the economic dimension with which to explore these issues of derived demand for water.

Any community service obligations on infrastructure owners to provide wider access, or lower charges for community resources are generally subsidised according to GATT and WTO protocols (Australian Government 2010 Water Charge (Infrastructure); AATSE 1999). Perverse taxes and subsidies can harm the environment by encouraging extra demand for these subsidised goods and services - water (OECD 2002). The dilemma was often solved with increasing block tariffs (Savenije & van de Zaag 2002). The increasing block tariff system offers a balance between efficiency and equity for domestic water supply by pricing water for essential use (drinking, cooking and bathing) at the lowest value use whilst charging for non-essential use (external cleaning and industrial use) as the highest value. Water pricing to cover variable costs may be appropriate for essential water use and water pricing at marginal cost. The block tariff works best when based on quantity and non-essential use, with the intention of recovering the full costs of these uses (Savenije & van de Zaag 2002). The problem emerges when too much water use shifts from high volume low value water sector (agricultural) users to lower volume high value water sector (urban) users (Savenije & van de Zaag 2002).

Different sectors often require different water qualities and reliabilities of supply that affect the opportunity cost and prices of water in those sectors (Tisdell et al. 2002). Appropriate policy instruments are available to solve this dilemma. Different sectors require different water qualities and reliabilities of supply that affect the opportunity cost and prices of water in those sectors (Tisdell et al. 2002). Therefore, regulators try to ensure that the marginal cost pricing of water includes all externalities to satisfy equity and efficiency criteria (Savenije & van der Zaag 2002). The environment, as an important water user, may need to be protected as flora and fauna depend upon it. “Environmental watering” ensures that water catchment quality and health are maintained. Appropriate water pricing and allocation for the environment was an unresolved IWRM issue dealt with in the IWRM model in the section 2.5.4.

High water usage for irrigation is exacerbated by the high evaporation rate of water from open channels, creek and streams and various methods of irrigation. Water efficiency improvements (e.g. drip and sub-surface irrigation practices), encouraged by government and embraced by irrigators, are one method of achieving decreased water use per hectare. Further improvements to water use efficiency could be achieved through the use of recycled water for irrigation. These “improvements” must be balanced against potential economic and social losses associated with the collection, treatment, diversion and storage of such water (Pareto 1927). Economic theory of “Pareto efficiency” states that actions be undertaken where the benefits of the action outweigh or are at least equal to the costs of that action – even if compensation is required (Kaldor-Hicks efficiency criterion named for Hicks 1939 and Kaldor 1939).

Where clear rights to water are established, water trading can occur. Yet water and its users overlap and increase the complexities of identification and definition of water property rights (Tisdell et al. 2002, p. 2). For water markets to operate efficiently they must be defined, complete, secure and transferable in order to secure water property rights (Tisdell et al. 2002). With clearly defined property rights, economically efficient allocation can be achieved in the presence of externalities (Coase 1937). Other policy instruments facilitate water exchange, but each has varying degrees of social efficiency. This is dealt with in section 2.5.3.

A comparison of total social costs to benefits of a project provides policy makers with a decision making tool. The cost-benefit approach reduces conflict in collective action problems by proceeding with projects where net benefits exceed net costs (U.S. Army Corps Engineers 2014). The welfare criterion (Pareto 1896) is then introduced to ascertain whether the resulting project makes at least one person better off without making someone else worse off. Costs and benefits across time then need to be discounted to their present values to factor in inflation. This has been dealt with elsewhere (Al-Sabbry et al. 2002). A cost benefit analysis of catchment recharge using treated wastewater includes a variety of costs and benefits requiring further investigation.

As knowledge of the economic aspects of IWRM was applied to the IWRM model in this study, a range of economic principles, theory and policy instruments emerged to assist policy makers in implementing it. The mix of such policy instruments varies with the individual water catchment, but the IWRM model had the capacity to incorporate and promote understanding of these economic, policy and social aspects of the water problem and the instruments to correct it. The literature on these unresolved social issues and how the IWRM model dealt with them was examined next. The links between the economic, social and political development issues in IWRM were important (Beveridge & Monsees 2012) inclusions in any future development in IWRM.

2.5.3. Social Issues

The literature on the social issues in IWRM, were investigated briefly to highlight the issues for review in the forthcoming case study chapters. The first of these social issues in IWRM related to the social complexities of the water problem and the second issue was the community's involvement in IWRM decision making.

The Social Complexity of the Water Problem

A basic requirement of water is for equity in its management. For example, water is a basic human need and a public good providing sustenance, security, cultural value but also negatives such as floods, droughts, famine and other hazards (McDermott et al.

2013; FAO 2000; Gleick 1999). Equitable treatment of water involves understanding of culture, attitudes, knowledge, values, awareness, social acceptance, amenity functions, historical practice, and the economic principle of user pays balance against the need for equity in making water available to all (including securing water for the environment and other public benefits) now and in the future (Schneider et al. 2014; Bjornlund 2013; Young 2010; Sarker et al. 2009, 2008; Baldwin 2008; FAO 2000). Although water is publicly owned in order to provide equitable access to all, literature showed that demand management and society acceptance of water reuse are important factors in the success of IWRM strategies (Dolnicar et al. 2011; Ostrom 2010).

Application of the equity principle to the water problem involves appropriate economic valuation and pricing (Savenije & Van der Zaag 2008). These are all factors recognised in the ecological economic approach to valuing natural resources using TEV. The TEV approach recognises the cultural, heritage, bequest and existence value of resources to non-human users such as the environment. Full social cost of pricing is a way to efficiently allocate water and avoids the tragedy of the commons. Yet public water providers traditionally had a social responsibility to supply water and generally did not earn profits – often charging below marginal cost at average cost pricing point (Purcell & Currey 2003). The new conceptual model for IWRM included these aspects under the social dimension of IWRM, as was the recommendation to use the TEV approach to water valuation.

Where quality water is to be provided in a socially efficient manner, government traditionally becomes involved in water markets (Livingston et al. 2004). This enables government to maximise the net value of the water to society even where a participatory approach (stakeholder participation) to IWRM is sought (Savenije & van der Zaag 2008). In literature this was achieved with a mix of such market and non-market policy instruments by government and non-government agencies dealing with the unresolved social dimensions of the water problem (see Hackett 2010).

International organisations reinforce the importance of equity in the provision of water as it is essential to life (UN 1992; WMO 1992). These are social issues of global importance which require global efforts to ensure access to quality drinking water is available to all (WWC 2007; UN 2002; WCED 1987). Equal access to water for survival regardless of ability to pay for it, is imperative to the success of IWRM. The needs of the environment as a water user are also one of the IWRM principles. Economic principles of full cost pricing may seem at odds with the equity principle as water prices rise to cover costs (FAO 2010). In traditional water management this has meant subsidised water use for some users (the poor and rural users) and sometimes for expensive community water infrastructure (dams). Arguments for basic access and subsidisation of water for low income earners, were justified on equity grounds (Pigou 1920), intervention for negative externalities (Stigler 1971), benefits of regulatory controls and cross subsidisation, and ecological tax reform aimed to shift from destructive activities to beneficial activities (see Roodman 1998 on making the polluter pay and the removal of harmful subsidies to shift economies toward better alternatives).

Public goods, such as water, have characteristics that the market alone may not be able to ensure their efficient provision. Collective action to achieve a desirable result for all, is often required to ensure the supply of public goods. This requires coordination, cooperation or coercion by the community (UN 2008). Community involvement to communicate their preferences and goals is essential and TEV is one approach to incorporating a wider set of values from communities.

Acceptance by society is a large hurdle in the implementation process of recycled water use and recharge of natural catchments in IWRM (Higgins et al. 2002). Key factors identified in research as influencing public perception of wastewater reuse that need to be considered amongst the social issues in IWRM include:

- The disgust or “yuck” factor,
- Perceptions of risk,
- Specific uses of recycled wastewater,
- Sources of recycled wastewater,
- Ability to have choice to reuse,
- Trust and knowledge,
- Existing environmental attitudes,

- Environmental justice issues,
- Cost of wastewater reuse,
- Socio-demographic factors.

(McGuinness & Van Buynder 2005

There are successful examples of recycled water use and its social acceptance elsewhere in the World, especially for irrigation and urban use, (see Angelakis et al. 2003 on Sweden and the Netherlands). Untreated and treated wastewater is used on a variety of crops around the world. Crops grown with recycled wastewater depend on the water quality level and standards in that country or region as well as the community's acceptance levels (Winpenny et al. 2010; Jiménez & Asano 2008; Lazarova 2005; California State Water Resources Control Board 1990).

Concerns about the impact of recycled water on human and environmental health exist worldwide. Examples include concerns about the existence of purification contaminants (EPA 2001), energy requirements, concentration of non-recyclable water from desalination and disruption to aquifer, river, stream or marine ecosystems (Pavelic et al. 2005; Toze 1997), the presence of endocrine disruptors, pharmaceuticals, hormones and more (Lee et al. 2002) contaminated agricultural run-off (Gilliom et al. 2006), spread of disease, salinity or other contaminants in farming (Toze 1997). Recharge using soil purification can remove some of these impurities and even overcome some religious restrictions against direct uses of recycled water in Islamic countries (Warner 2000).

There is little evidence to support any contamination concerns about recycled water projects, yet there are risks of treatment malfunction, temperature changes and pulses at injection points and lack of nutrients in highly purified recycled water used in irrigated agriculture (Hussain et al. 2002). These were some examples of overlapping issues of the environmental and social dimensions of IWRM. There are the ecological benefits of water catchment recharge and other advantages, including security of water supply and reduced reliance on variable rainfall, planning and development applications, greater wastewater usage and balance in water usage between current and future generations (Higgins et al. 2002). Many of these benefits are unrecognized and undervalued by the water market but were accounted for by including TEV in the IWRM model.

In ecological economics, the decline in capital includes the decline in social capital (Danchev 2005). Sustainable development requires a degree of social capital that builds on social organisation, coordination and cooperation for mutual benefit (Putnam 1993). IWRM that encourages high levels of natural and social capital offers long term solutions to water scarcity issues. One of the essential elements of social capital is that of trust. This trust can be enhanced by cooperative management in natural resource management projects involving the various stakeholders (Hutchinson & Vidal 2004).

Community Involvement in IWRM Decision Making

The dilemma of how IWRM can utilise social capital in policy making was addressed in Postel's (1992) third (social equity) principle. Management of common pool water resources was traditionally achieved through government imposed water property rights or community co-management. Ostrom (1990) cited three models that generally apply to the issue of common pool resource management including the "tragedy of the commons", the "prisoner's dilemma game" and the logic of collective action. She used several case studies to show how collective action to engage stakeholders and manage common pool resources could lead to local self-governance rather than government involvement. The question of ownership of and access to groundwater resources and recycled water from stormwater and greywater sources) remains unresolved around the world. Yet these resources have been successfully managed in common for and by the community (Ostrom 1990).

The realisation that there has been "no place in modern river management systems for the protection of Indigenous spiritual values" (McAvoy 2008) has encouraged the inclusion of cultural and spiritual values when water is used for non-Indigenous economic, development, recreational or domestic purposes. Adaptive governance mechanisms have the potential to overcome resistance to the recognition of Indigenous and other cultural water claims (Bark et al. 2012). This overlap between social and political aspects of water management was dealt with using the overlapping social and political dimensions of the IWRM model.

The prisoner's dilemma game explained that in the pursuit of self-interest, collusive action may prevail but the incentive to "cheat" on others predominated (see discussion in Stanford Encyclopaedia of Philosophy). Ostrom used several case studies to show how collective action to manage common pool resources could lead to local self-governance and community benefits without government involvement. It is apparent in literature that an integrated approach needs to consider a wider range of social and environmental interconnections in a catchment (Hooper 2005). This research provided important social input into the new approach to IWRM.

During discussions at Copenhagen (1991) the concept of a demand driven approach to water management and the subsidiarity principle emerged, as did the importance of the community in decision making. The principle of subsidiarity is established in Article 5 of the Treaty on European Union and outlines occasions for legislation (Europa 2013). These principles reinforce the view that those affected by water policy decisions should be included for successful resource management projects (Sarker et al. 2009, 2008; Baldwin 2008). For example, concerns about water quality, psychology of resistance to change and trust require careful consideration and inclusion in successful IWRM policy making (Pahl-Wostl et al. 2007).

Literature suggests a collective decision on a common pool problem could lead to a better solution than various independent individual decisions (Negri 1989). Evidence also suggests that greater involvement of water users in decisions about using, monitoring and managing water through cooperative management and collective decision making delivers successful resource management outcomes (van Vugt 2002; EC 2000; Ostrom 1992). It is commonly asserted in literature and international principles that implementing participatory management processes engages stakeholders with water management and fosters resource stewardship in keeping with the findings on management of common pool resources (Ostrom 2010; van der Lee 2002; Bruns & Meinsen-Dick 1997; Maaren & Dent 1995). As multidisciplinary issues, IWRM is suited to a participatory approach, involving users, planners and policy makers from across the board (Savenije & van der Zaag 2008). For example, the soil salinity problem is a basic economic issue solved with collective management of common pool resources (Kinzelbach et al. 2003).

Water allocation decisions may deliver just consequences for some, while being unjust for others. Reframing a water management issue as a dynamic social dilemma across multiple scales and levels can assist in understanding stakeholders' perceptions of justice and injustice (Patrick et al. 2014). As a result, IWRM would need to regularly engage the community, water providers and policy makers in water allocation decisions. The overlapping social, environment, policy and economic dimensions of the new IWRM model assisted in taking a more holistic view of scale and levels in water allocations. Literature on justice has focused on "cross-sectional studies at one level and for one problem as seen by the key stakeholders at that level" (e.g. Syme et al., 1999). In these situations, conflict emerged between those at different levels and scales due to lack of understanding of the issues of others at these levels and scales. Rather than shifting blame, open communication and forward planning can assist in overcoming injustices linked to level and scale. The IWRM model offered an opportunity to link the dimensions of IWRM and lessen conflict in water allocations (Patrick et al. 2014).

The range of social issues that remain unresolved in literature and practice included appropriate pricing of all water in the ITWC, appropriate property rights for all water users (equity) and the correct mix of policy instruments to involve the community in managing water (and other resources) as a common pool resource. In economics, social cost pricing ensures that the socially optimum price and quantity of water supplied is also economically efficient (i.e. includes external costs and benefits). The way in which the IWRM model assisted in understanding and managing unresolved environmental issues was investigated discussed next.

2.5.4. Unresolved Environmental Issues

The literature on unresolved environmental issues became the focus of attention in the case study chapters of this thesis. The United Nations had announced that water usage rates were so high that the natural environment was no longer capable of regenerating fresh water of sufficient quality and quantity for current and future generations (FAO 2014; Hackett 2010). In ecological economic terms, the goal of strong sustainability involves an environment that provides sufficient water to balance the current and future generational needs for water (Williams & Millington 2004). Short term options for reducing water leakages from and supplementing the natural water cycle are possible (Pearce et al. 1990) but are a weak sustainability approach. This term refers to the use of technical and engineered water storage and transport infrastructure to ameliorate the problems of inadequate water supply and quality, leakages from the natural water cycle and growing demand for water (UN 2014; Pearce & Atkinson 1993; Pearce et al. 1990). Issues emerging from literature on weak sustainability approaches to environmental issues were reviewed within the environmental dimension of the IWRM model using the ITWC sub-model.

The strong sustainability approach relies more upon demand management whilst operating within the finite limits of natural resources like water (Pearce & Atkinson 1993). As such, an IWRM model was required that offered a framework to analyse the environmental issues associated with water demand and supply management approaches. It needed to address some unresolved environmental issues raised in the literature, including:

- overuse and quality deterioration of water,
- high use of energy, land and other resources in engineered water management solutions,
- excess and underutilised wastewater,
- water use inefficiencies,
- reduced environmental flows and ecosystem services including prevention of erosion, drought and flood mitigation (UN 2014).
- the role of technology in reduction of water use, the treatment and reuse, transport and storage of water and catchment recharge (ITWC and supply modeling).

As recognition of the environment as both a source of water, and a user itself grew, an ecosystem approach gained momentum in IWRM. Since the Millennium Ecosystem Assessment (2003), this approach has sought, “a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way” i.e. humans and their activities are part of the ecosystem and not the reverse (Macleod et al. 2007 p. 593). This trend towards a multidisciplinary approach to IWRM, combining natural and social science (Haygarth et al. 2005), was continued in the IWRM model and approach developed here.

Overuse and Quality Deterioration of Water

With the environment as the confining boundary of the problem and of the IWRM model, finite water resources are to be managed and used sustainably to ensure sufficient resources exist for all users, both human and other species of animals and plants, and the environment now and in the future (Ostrom 1997; Daly & Townsend 1993; Ostrom 1990). This strong sustainability approach relies on the careful consumption of natural water resources rather than on human made technological solutions (Pearce et al. 1990). Until wider acceptance of the strong sustainability approach is achieved, the current IWRM approach will involve human made technological solutions (ITWC). These technical solutions can be introduced slowly and in a coordinated manner to ensure the social, economic and policy considerations of IWRM are respected. Ecological aspects such as aquatic ecosystems, wetlands, rare or endangered species and vegetation, biodiversity, service functions such as management of erosion, salinity, flood and drought, ecological principles of sustainability, geological and hydrological (hydrogeological) were IWRM facets incorporated into the environmental dimension of the IWRM model.

Technology in the reduction of water use, the treatment and reuse, transport and storage of water and catchment recharge (ITWC and supply modeling)

The hydrology and geology of the water catchment area play a large role in type and availability of water sources, storage and uses (Fetter 1994; Bear 1979; Johnstone & Cross 1949). Connectivity of streams, creeks, aquifers, oceans and other natural water sources largely determine leakages and options for closing the water cycle. Mapping and supply modelling of the connectivity between lakes, wetlands, streams, creeks and other water storages and the surrounding aquifer systems are needed to understand these water sources and the impact of demand on them (Turner & Townley 2006; Winter 1983, 1976). This information also provides more details on aquifer chemistry, connectivity and draw down (Khan et al. 2008; Braticevic & Karanjac 1997).

Reduced Environmental Flows and Ecosystem Services

This approach was adopted in understanding of the ecosystem needs for water and other resources by organisations such as the UN, UNEP and WHO. This recognition of environmental need for water is also legislated for in Australia and overseas. See *A Framework for Determining Commonwealth Environmental Water Use* (Commonwealth Environmental Water Office 2013).

In respecting the ecological limits of the environment the 'precautionary principle' is sometimes adopted with regard to any environmental resource projects. This principle involves taking preventive action in the face of uncertainty, shifting the burden of proof to the proponents of an activity, exploring a wide range of alternatives to possibly harmful actions and increasing public participation in decision making (Kriebel et al. 2001, p. 871). In the absence of scientific proof about irreversible environmental damage, projects with unknown impacts on the environment should proceed with caution (see Hackett 2010).

The DPSIR Framework

An ecological economic framework useful in managing the various components of the dimensions of an IWRM model is the driving force–pressure–state–impact–response (DPSIR) framework (OECD 1993). DPSIR describes the two way flows linking socio economic drivers to environmental management issues (Gabrielson & Bosch 2003). The *driving* forces in the DPSIR approach refers to human activities or drivers of the environmental impacts similar to the economic and social dimensions of IWRM. The *pressure* refers to those that are placed on the environment due to these drivers (environmental IWRM dimension). The *state* of the environment is then measured by key indicators and *impacts* on the environment determined (environment, social and economic IWRM dimensions). The DPSIR framework facilitates decision-making, by identifying opportunities for *policy* responses (policy IWRM dimension) in this two-way causal chain (OECD 1993). In this way, inclusion of the DPSIR framework in a sub-model strengthened the multidimensional approach adopted in the IWRM model. The DPSIR sub-model was placed within the economic dimension along with the five sector economic sub-model.

Negri (1989) and others argued that water catchment recharge must at least equal the usage rate, if the water supply was to remain sustainable. The ITWC was used to introduce the element of recharge into the IWRM model. Climate events such as high and low periods of rainfall, seasons, varying temperatures, levels of evaporation, transpiration, soil moisture, creek, river, wetland, ice, snow, groundwater, dam and recycled water levels all require careful monitoring and management. The consequence of too little or too much of any of these components of the water cycle is devastating to both human and natural environments.

An environmental watering plan would assist with managing the environmental water needs of a catchment. Examples of such were provided (Chapter 5). Such a plan can coordinate environmental flows with water released for irrigation, community use and industry. Collaboration with holders of environmental water, state government and local communities, and indigenous people, is also necessary to protect environmental watering. The variety of water sources in ITWC gave rise to a number of unresolved environmental issues for the IWRM model to tackle.

Market based policy instruments such as water rights and trading can improve the allocative efficiency of extractive water use but their effectiveness in ensuring environmentally sustainable resource use is guaranteed (Bell & Quiggin 2008). In order to increase environmental flow aggregate water use must be decreased (strong sustainability). Water rights and trading would therefore need to include the environment as a water user and protect environmental flows (Bjornlund 2013; Young 2010; Bell & Quiggin 2008).

Excess and Underutilised Wastewater

Recycled water use in agriculture has a long history (Winpenny et al. 2010; Jiménez & Asano 2008; Lazarova 2005; Blair & Turner, 2004; Koutsoyiannis & Angelakis et al. 2003; Viollet 2003; California State Water Resources Control Board, 1990). The link back from agriculture to recharge of the urban catchment is often dismissed primarily because of contamination concerns from agricultural run-off (nitrogen, pesticides etc.) and soil disturbance (Stevens et al. 2003a). A non-sectoral approach to IWRM was an important development in the IWRM model. The inclusion of the principle of TWCM assisted with the conceptual integration of all water sources and users in the IWRM model. Unresolved environmental issues involving recycled water were also part of the water problem in the environmental dimension of the IWRM model. The technical aspects of managing the unresolved issues in IWRM were important, but were not the main focus of this study. Literature on these various water sources in the ITWC and supply modelling became the focus of the IWRM model's development discussed in the next section.

Above ground water systems

In the ITWC, above ground water storage and transport systems include natural and constructed dams, creeks, streams, ponds, some wetlands, pipelines, aqueducts, channels, siphons and weirs. Groundwater can also be stored in above ground storages. Research has found that above ground water storage such as dams often does not fully deliver the intended level of catchment benefits and services (World Commission on Dams 2000). In addition, there have been many underestimated negative environmental and social impacts of large dams caused by storing or diverting water, evaporation, altering the natural flow of streams and creeks (World Commission on Dams 2000). Reduced peak flow downstream from dams compromises wetland and floodplain saturation and particularly affects related ecosystems (Bergkamp et al. 2000; Duvail & Hamerlynck 2003; McCartney et al. 2000; State of the Environment Advisory Council 1996). Literature examined in section 2.5.1 and 2.5.3 outlined how legislation and community management can manage inflows of water, wastes, storage and users in connected waterways. Environmental factors to be addressed in the IWRM model included the quantity and quality of water discharges, water storage, use and transport impacts on the environment and optimal catchment flows (Higgins et al. 2002).

Along with constructed water systems, natural systems (streams, wetlands and aquifers) assist in further purifying recycled water by removing human and other pathogens (Dillon et al. 2005). The natural environment increases the biodegradation of slow degrading matter (Dillon et al. 2005). Natural systems have capacity for inter-seasonal and inter-year storage of water, often when surface water storage is inadequate. Also, issues with infestation by algal blooms and mosquitoes, evaporation and consequent rising salinity problems are better managed in these natural systems. These water sources contribute to the ITWC and provide IWRM options to unresolved environmental issues. The degree of connectivity with other water sources is also an important aspect highlighted in literature (Turner & Townley 2006; Winter 1983). Integration of both above ground and underground water transport and storage options, assisting with drought and flood management, seasonal water variability, future growth in water demand and connection to various water supply options wer issues flagged for investigation with the IWRM model in case studies in Chapters 3, 4 and 5.

Wetlands and Land Spreading Treatment and Storage of Wastewater

Wastewater discharge onto land has a long history in Greece, Rome, China, and India, but in past centuries this sewage contained little industrial waste, harmful chemicals or heavy metal contaminants (Angelakis & Durham 2008). Yet even then, two issues emerge around recycled water - the need to dispose of wastewater and the huge demand on water that necessitates its reuse. Aqueducts, viaducts, channels, underground cisterns, tunnels and siphons, used for centuries by ancient civilizations such as Greece and Rome assisted in the management of water and waste (Hughes 2010; Bruun 1991; Ozis 1996; Hansen n.d.). Since then the role of infrastructure in assisting with the management of the ITWC has become a key issue in IWRM. Understanding regional hydrogeology becomes critical in IWRM as these water sources often connect lakes, wetlands, streams, creeks and other water storages to each other and the surrounding unconfined aquifer systems (Turner & Townley 2006; Winter 1983, 1976). Where these water sources are not connected naturally, engineering options are often employed in IWRM. These constructed options were included in the ITWC sub-model (environment) dimension of the IWRM model.

Agriculture remains a heavy water user and during water scarcity farmers have historically turned to wastewater to augment natural water sources. Yet historical data on water sources and demand for crop irrigation is often unavailable. Many countries do not differentiate between natural rainfall and managed irrigation methods (Dourte & Fraisse 2012). Wetlands too offer an underutilised storage facility for wastewater in addition to their crop watering and ecosystem functions (dispersing runoff and filtering sediments).

The type, function and connectivity of wetlands to other waterways determines the potential role that wetlands play in closing the water cycle. Wetlands can be permanent or temporary (McEwan et al. 2006; Williams 1998), natural or constructed (Wentz, 1987; Kadlec & Tilton 1979; Hammer & Bastian 1989; Breen & Chick 1989).

International examples were explored and outlined in Chapter 5. The variable characteristics of wetlands make it difficult to predict responses to wastewater and apply results from one wetland to another (Brix 1993). Control and management strategies for wastewater treatment and water quality in wetlands were central to the hypothesis in the IWRM model that natural or created wetlands could assist in closing the water cycle (Stainbridge 1976; Cooper & Boon 1987; Wentz 1987). Pre-treatment of wastewater prior to discharge into aquifers, wetlands and soils is based on the precautionary principle that considers that the burden of an unknown risk rests with those pursuing action or policy (Jiménez 2003; Raffensperger & Tickner 1999). Industrial discharge may contain compounds difficult to detect and remove, therefore the World Health Organisation recommends the regulation of discharge of toxic compounds (Jiménez 2003, p. 92). Research by the San Diego Water Research Study (2006) recommends soil or aquifer retention for recycled water prior to discharge into aquifers, wetlands and other water systems. The IWRM model was designed with the capacity to manage these overlapping environmental, social, economic and policy considerations of wastewater in closing the ITWC.

Aquifer Treatment and Storage of Wastewater

Aquifers are sometimes used to store and purify wastewater in their saturated permeable geological layers and sometimes transmit water elsewhere depending on hydraulic conductivities (Bear 1979). Variables include surrounding soils, possible discharge paths (groundwater or baseflow) and recharge paths (rainfall infiltration, infiltration from overflow flooding, streamflow and or baseflow) and the lifetime of an aquifer (whether recharge water replaces extracted water) (Galletly 2007; Cox & Wilson 2005; DNRM 2005a; Fetter 1994).

The inclusion of aquifers in the ITWC was an important consideration in IWRM model.

Aquifers can be recharged naturally through slow seepage via surrounding area or outcrops in the aquifer, or artificially with wastewater. The hydrogeological characteristics of the aquifers are important in determining the nature of recharge and connectivity to other water systems (see Timms et al. 2007; Zhang 2002; Koltermann & Gorelick 1996; Fetter 1994). Data on this connectivity is vital to any IWRM decision involving aquifers. The soil properties of the aquifers naturally filter contaminants from water flows, even purifying untreated wastewater (Timms et al. 2007; DNRMED 2009; Vengosh & Keren 1996).

Sometimes clogging and groundwater mounds occur with aquifer injection. Regular monitoring and backwashing of pumps in injection areas is required to prevent this build up and improve water quality (Bouwer 2002). Other environmental considerations in using recycled water to recharge aquifers include balancing the ecosystem within the aquifers, the temperature and flow of pulses (Watts et al. 2009) and potential for over recharge and pressure build-up (Adelaide & Mount Lofty Ranges Natural Resources Management Board AMLR NRMB 2008). Although various guidelines govern water quality, several variables determine the final use of recovered recharge water from aquifers. These water quality variables include original water quality, time spent in aquifer, the level of contaminants and pathogens and effectiveness of waste water treatment (Ward & Dillon 2009, p. 116). These important issues were considered within the environment dimension of the IWRM model.

Agricultural irrigation improvements harking back to ancient Greece are used to capture and store water using aqueducts, sewer systems, hydraulics, lake draining for agriculture, canal systems, and polder construction for improved drainage of natural sinkholes (Koutsoyiannis & Angelakis 2003). Developments in ancient Greece and Rome enable rainwater to be captured using sand filters, sedimentation tanks and water cisterns to be used in irrigation, thereby further closing the ITWC (Sklivaniotis & Angelakis 2006; Koutsoyiannis & Angelakis 2003; Viollet 2003). Later, the water can be transported via aqueduct for urban, agricultural irrigation and industry use. These features appear in urban water systems of Europe and North America late in the 19th century A.D. (Koutsoyiannis & Angelakis 2003; Antoniou et al. 2006). These were important considerations in the IWRM model.

Most aquifer recharge schemes around the world restrict treated wastewater reuse to irrigation, industrial or recreational purposes (Israel in Blair & Turner 2004). Wastewater for drinking is generally treated and discharged into groundwater, reservoirs or settling basins for further purification (California on indirect potable reuse, in Pescod 1992). Aquifer recharge is also useful in preventing saltwater intrusion caused by over use of groundwater. Further examples were provided in Chapter 5. The social equity and acceptance, economic viability, environmental feasibility and policy aspects of water reuse required further consideration in the approach adopted in the IWRM model both prior to and when investigating impacts of related decisions.

Most countries permit treated effluent to enter rivers and ecosystems rather than direct potable reuse for drinking. Untreated and treated wastewater is used on a variety of crops around the world depending on the water quality level and standards in that area and the community's acceptance levels (Winpenny et al. 2010; Jiménez & Asano 2008; Lazarova 2005; California State Water Resources Control Board 1990).

Whether natural or artificial recharge of aquifers is used as an adjunct to other water sources in the ITWC, remains an unresolved environmental issue in literature. The need for comprehensive monitoring and modelling of all water sources in the ITWC – including recycled water recharge were recurrent themes in this literature. Environmental issues overlap with social issues about community understanding and acceptance of IWRM practices. With the support of consistent policy and coordination of infrastructure the appropriate mix of economic policy instruments can be ascertained for each IWRM situation.

Policy instruments that can promote efficient water use by shifting water usage to higher value-added users (e.g. water markets) may not achieve environmental goals and instead reduce environmental flows (Bell & Quiggin 2008). Shared decision-making about water allocations between the private and public sectors and provisions for environmental and other public benefits in a statutory based water planning processes may better promote the joint goals of environmental, social, political and economic balance sought in a new IWRM approach here (Bjornlund et al. 2013; Bell & Quiggin 2008). The conclusions from this critique of literature on IWRM issues demonstrated the value of an IWRM approach, assisted by five sub-models (the ITWC model, the five sector economy model and DPSIR approach model, demand and hydrogeological modelling).

2.6. Conclusions about Quality and Relevance of Literature to the IWRM Model

The literature reviewed here in Chapter 2 supported the need for an IWRM approach, definition and conceptual model to manage the various dimensions of IWRM issues. It was apparent in literature that successful IWRM requires hydrogeological, supply and demand modelling to determine the context-specific conditions in the catchment. This necessitates sound knowledge of all the dimensions of the water management issue and area (Berveridge & Monsees 2015; Butterworth et al. 2010; Warner et al. 2008). The plethora of unresolved policy, economic, technical, social and environmental issues and options in IWRM, explored in literature in this chapter, reflected the truly “wicked” nature of IWRM and the need for a multidimensional approach to these issues.

Despite varying definitions of IWRM in literature and lack of solid evidence of the effectiveness of IWRM, it has become a growing area of research in the international water policy arena (Biswas 2008, 2004; Mollinga et al. 2006). However, very few studies attempted to explain the IWRM approach worldwide with a systematic and theoretically grounded framework (e.g., Biswas 2004). Using the new definition of IWRM adapted for this study, the new IWRM model reflected an adaptive and participatory process which promotes the co-ordinated development and management of water, land and related resources as common pool resources, in order to maximize the resultant economic, social and ecological welfare. It did this through the inclusion of principles of equity, polluter pays, precautionary approaches and the use of triple bottom line accounting and legislative instruments to address environmental issues (economic and environment dimensions). The model took a triple bottom line accounting approach by adopting more than just an economic view of IWRM, including the social, environmental and policy benefits and costs of aspects for example in the use of recycled water.

Using the case study of the Lockyer Valley, the policies, institutions, environmental, social, economic and technical dimensions were then examined using a mixed method approach of case studies and the IWRM model. The data in Chapter 3 provided the background and context of the Lockyer Valley case study and Chapter 4 provided the detailed analysis of the case study using the IWRM model to answer the three research questions.

Chapter 3 The Background and Data for the Case Study of the Lockyer Valley Water Catchment, South East Queensland

3.1. Introduction to the Background of the Lockyer Valley

The case study of the Lockyer Valley was then used to demonstrate the complexity and contradictions of the dimensions of IWRM, and to test the relevance and appropriateness of the IWRM model. The implications and consequences of this approach were then used to assist in refining the IWRM model and understanding IWRM in the Lockyer Valley. The urban-rural IWRM conceptual example model was applied in this case study to develop and test the new catchment scale IWRM model derived from literature and close the research gap in urban-rural IWRM.

The Lockyer Valley was selected for its role as a major agricultural production area in SEQ. It also contains the headwaters for the nearby capital city of Brisbane. The Lockyer Valley was examined for examples of the IWRM issues emerging from literature in Chapter 2. After nearly 20 years of research, lobbying and investigation of its IWRM issues, the Lockyer Valley provides a rich source of secondary data to which the IWRM model was applied. This data was of sound quality but had not been synthesised before or analysed using the multidimensional approach adopted in this study. A brief background of the case study area was first compiled from the extensive research studies and consultancies on the Lockyer Valley in Chapter 3, before the various dimensions of the IWRM model were applied in more detail in Chapter 4.

The data used in Chapter 3 was divided into two sections – that which pertained to the period preceding the work of the SEQ Recycled Water Taskforce (SEQRWT) and construction of the western corridor recycled water pipeline (WCRWP), and that which followed the breaking of the drought and shutdown of the WCRWP infrastructure.

3.1.1. The Case Study Approach

The case study approach used the accepted practice of multiple data collection methods and analysis techniques (Aaltio et al. 2009). The methods included a review of literature, case study analysis, analysis of themes from interviews and development of a conceptual model. Multiple sources of data were synthesised to facilitate a case study of the Lockyer Valley during the millennium drought. The methods included case study analysis, analysis of themes from interviews and development of a conceptual model. Literature, secondary data from existing research consultancies, ‘snowballing’ to generate eight interviews, two other Australian case studies and international case examples provided data for this research in lieu of insufficient interview data. Journals, books, business and government websites, government reports, ministerial press releases, research studies and consultancies including previous surveys on IWRM issues in the case of the Lockyer Valley, were then analysed and synthesised.

Internet and literature searches were conducted using key words including IWRM, Lockyer Valley, groundwater, aquifers, agriculture, irrigation, water management, recycled water, western corridor recycled water pipeline and combinations of these keywords. Both quantitative and qualitative secondary data were collected, analysed and interpreted through the application of the IWRM model. Interviews provided some primary data in the form of themes for analysis of secondary data. Conclusions about the issues, data and relevance of the IWRM model in this case study were then drawn.

The case study of the Lockyer Valley was later used in cross-case analysis comparing international case examples of IWRM in Chapter 5. Similar types of data were compared across the cases investigated. Patterns in one case supported by evidence from other international cases provided stronger findings to assist understanding of how IWRM decisions were made in these case studies. Further investigation supported by international literature and cases were used where conflicts or inconsistencies emerged in the cross-case analysis thus establishing an iterative approach throughout the study.

Essentially this case study was a meta-synthesis (Barnett-Page & Thomas 2009) of the qualitative publicly data available on the Lockyer Valley, enhanced with interviews carried out in the study area of the Lockyer Valley as described in section 1.5. The mixed methodology reflected the need for a multidisciplinary approach to IWRM and approaches for dealing with lack of primary data on water supply and use at catchment scale. The methodology for this study continued to develop throughout the remaining chapters of the dissertation as shown in the extended dissertation outline in Figure 1-5. The remainder of this chapter provided the background to the Lockyer Valley IWRM issues. In so doing, rich detail on the components required for an IWRM model emerged. Then publicly available data from research studies and consultancies was analysed and synthesised to understand problems with available data and how lack of an appropriate approach to IWRM can result in unresolved IWRM issues in the case of the Lockyer Valley. This demonstrated the relevance of the multidimensional approach to analysing and synthesising the decisions and options available, for the purpose of providing a context necessary to apply the IWRM model to a real life case study of the Lockyer Valley in Chapter 4.

3.2. The Historical Background of IWRM in the Lockyer Valley

The Lockyer Valley is located 80 km west of Brisbane in SEQ and is a supplier of water and salad vegetables to the region. The Lockyer Valley (circled in red) contains headwaters and tributaries that recharge the Brisbane River, associated catchments and eventually Moreton Bay (The Stafford Group 2013) as shown in larger shaded area in Figure 3-1. The underlying Lockyer Valley aquifers are the largest water storage system in the Brisbane Valley at 49 638 ha (LVSC 2011). The local government area of Lockyer Valley Regional Council in this map is bounded west by 'The Escarpment' of the Great Dividing Range, south by the Little Liverpool Range, north by Mount Hallen and east by land separating the Lockyer Creek and Bremer River catchments (ICA 2011). Lockyer Creek covers an area of 2,600 km2 and joins the Brisbane River at Lowood (ICA 2011). Its tributaries include Flagstone, Ma Ma, Tenthill, Laidley, Murphys, Fifteen Mile, and Alice and Buaraba Creeks.

The Lockyer Valley receives most of its average annual rainfall (775 mm) during the warmer months September to March (Bureau of Meteorology (BOM) 2013). This summer-dominant rain limits crop choice in the absence of a reliable supplemented water source for irrigation. Irrigation for these crops relying on deeper pumping from underlying bedrock aquifers raised saline levels in the water (NRMSC 2002). The Lockyer Valley has been up to 80 per cent dependent on groundwater for irrigation and this has had significant impacts on the ability of the aquifers to recharge naturally where permanent damage to depleted aquifers occurred (Sarker et al. 2009; DNRW 2006, p. 30; Powell et al. 2002).

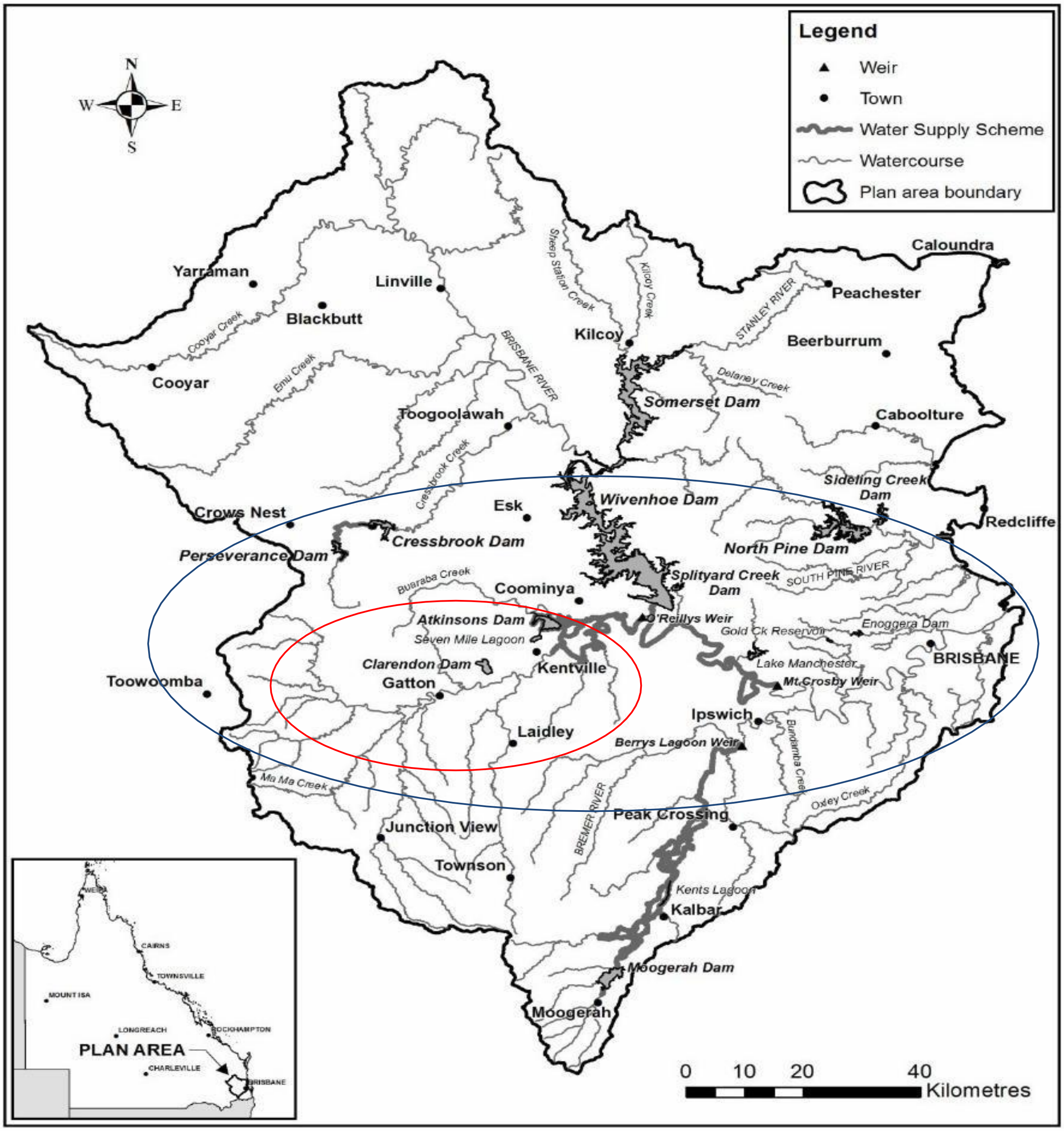

Figure 3-1 The Lockyer Valley within the Extended Catchment Containing the Brisbane Valley Headwaters and Connecting Downstream Water Catchments

Source: DNRM 2014a, p.3

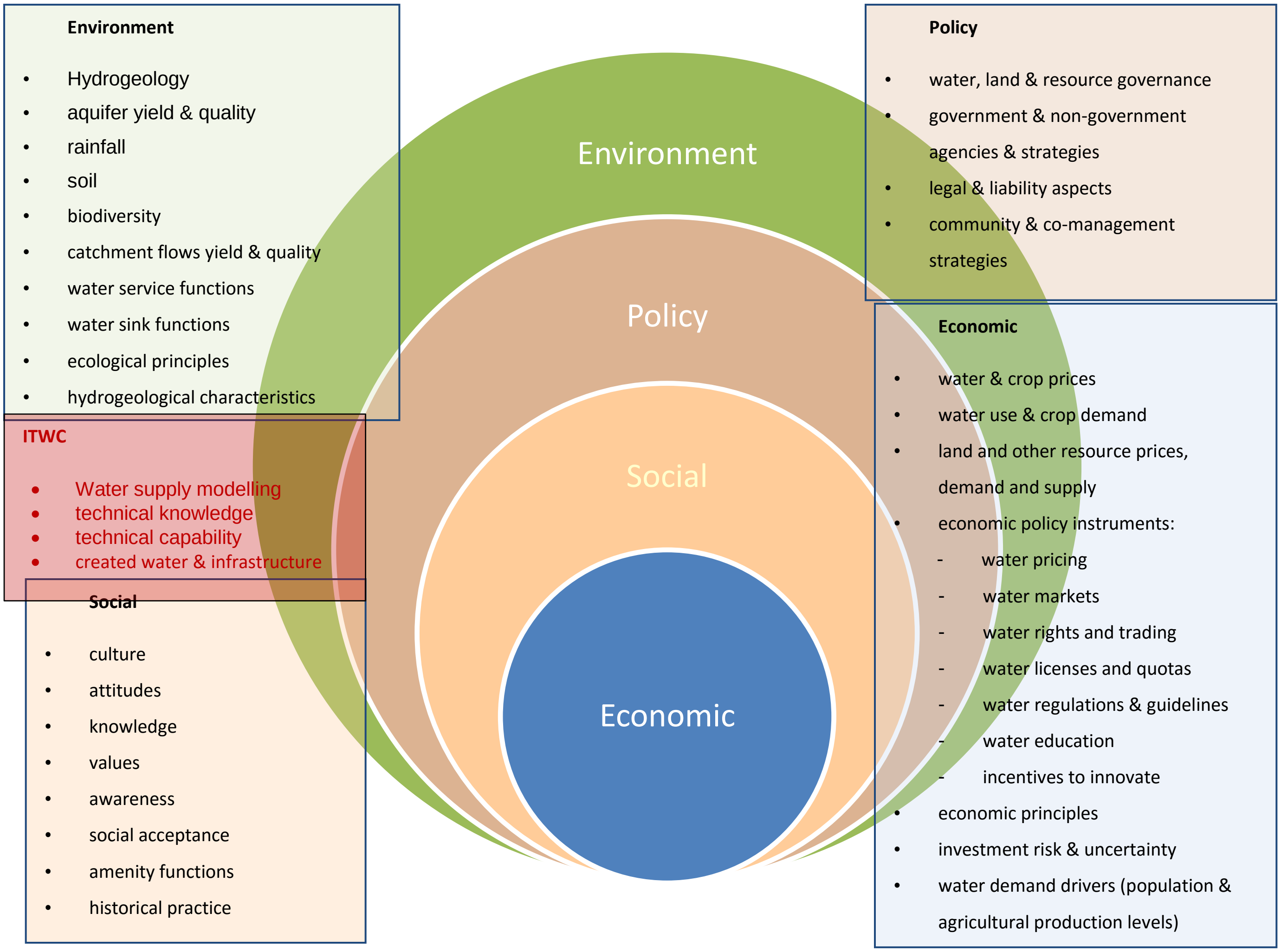

Figure 3-2 Refinement of the new conceptual model using research studies and consultancies to guide management of catchment scale IWRM

By 2005 Lockyer Valley groundwater for irrigation was being extracted at a rate of 74,000 mega litres (ML) per annum (p.a.). This rate exceeded the estimated sustainable yield for these aquifers of 27,000 ML p.a. (DNRM 2005a). Groundwater in the area has been accessed via over 5,000 registered bores and quite a few unregistered bores (MEP 2013, p. 23). These are still the most recent statistics quoted in research and are considered an underestimation of groundwater withdrawal rate (MEP 2013). There are 17 water storage facilities (dams and weirs) in the Lockyer Valley that supply approximately 64,676 ML via an irrigation distribution network of channels and aquifers to approximately 530 irrigators (MEP 2013 p. 20). The partial implementation of groundwater monitoring in the Lockyer Valley means that estimates of central groundwater usage and yields have been used to estimate those for the entire Lockyer Valley area.

Further, around 50 per cent of QLD agricultural water use was supplied from the farmer's own infrastructure with the capital and operational costs paid by the farmer (OCED 2010). The incidence of this was higher in the Lockyer as each landholder owned their own pumps, pipes and storages (Baldwin 2008). The usage and yield estimates were therefore understated. Traditionally, few records of private irrigation water volumes or usage were kept (OECD 2010). Such records were only required if water allocation was licensed. These economic drivers put pressure on the environmental, economic, policy and social dimensions of IWRM according to the DPSIR sub-model. These environmental components of hydrogeology, aquifer yield and quality, rainfall and soil characteristics are interrelated to the economic dimensions of water demand and extraction rates, crop demand, land and other resource demand.

Over-extraction of groundwater has exacerbated salinity in some aquifers during extended dry periods, as either saline water seeped in from adjacent sandstone areas to replace the higher quality water taken from alluvial aquifers, or more salt was washed down from the unsaturated zone due to irrigation and dryland clearing (Wolf 2013 p. 6). Mid way through the millennium drought, approximately 7.5 per cent of the Lockyer Valley was under dryland cultivation (Shaw 2008; Powell et al. 2002). Dryland salinity was aggravated by the clearing of natural vegetation for agriculture and housing (Rick Galbraith Aquila 2008) and was present in 2.9 per cent of this land in the Lockyer Valley (Kunde 2001). A study of the salinity of surface water and its suitability for irrigation purposes was conducted in the late 1960s (DLGPSR 2005; Talbot & Dickson 1969). Following this, several artificial recharge weirs were constructed throughout the Lockyer Valley in the 1970's to slow the flow of surface water and increase the amount of recharge seeping through to the alluvial aquifers below the stream channels (Wilson 2005, p. 20; Haigh 1970). Information about supplementary water and infrastructure of the area was included in the environment dimension of Figure 3-2 as it contributed to the knowledge about the ITWC sub-model.

Three types of aquifers house the groundwater of the Lockyer Valley region - the basalt aquifers higher up the range, the alluvial aquifers underlying the Lockyer Creek itself and the basalt aquifers underneath this again. The alluvium extends beneath the Lockyer, Laidley, Sandy, Tenthill, Ma Ma and Flagstone Creeks (EHA 2006a). Groundwater in the Lockyer Valley generally occurs within fractured zones, old gravel beds and bedding planes. In some places this groundwater forms within the sedimentary formations or appears as springs on the sides of the Valley. There is also a highly variable relationship between the hydrochemistry of saline groundwater in alluvial aquifers and that of the underlying rock formations (Wilson 2005). Groundwater chemical analyses linked water quality to climate events, farming and irrigation practices (Wilson, 2005; Willis et al. 1996). These findings informed landholders and water policy makers on water quality changes following rainfall events and other external changes (pumping rates, allocations). This knowledge of the hydrological and demand characteristics is vital to IWRM decision making regarding groundwater allocation and use for irrigation and the potential for water catchment recharge. These theories and principles of hydrogeology were critical inclusions in the IWRM model.

As demand for groundwater increased, the Central Lockyer Valley was declared the Clarendon Sub-artesian area in 1988 in order to introduce licensing, metering and management of groundwater supplies for irrigation within that area. The groundwater in the areas outside the central Lockyer Valley is still not monitored, and water usage and allocations remain uncertain. A smaller area within this declared area known as the “benefitted groundwater area” represents areas that are expected to benefit from the nearby created water infrastructure such as dams, weirs, irrigation channels and barrages (Baldwin 2008). A decade later, research on aquifer connectivity, soils, salinity and sustainable aquifer yield highlighted the need for extended groundwater monitoring beyond the central Lockyer Valley (Ellis 1999; Ellis & Dharmasiri 1998; Cox et al 1997; McMahon & Cox 1996; Willis et al. 1996; McNeil et al. 1993; Dixon & Chiswell 1992; Smith et al. 1990; Wells et al. 1990; Brown & Root 1998). The area outside the central Lockyer Valley remained outside the groundwater monitoring area, even at the time of this study here. This research highlighted the importance of the interrelationships between the components in the environmental dimension (groundwater yield, water storage and soils) and economic dimension (groundwater demand, monitoring and extraction rates) of the IWRM model in Figure 3-2.

The soils of the Lockyer Valley are renowned for their exceptional crop growing properties (Powell et al. 2002; James et al. 1974). Although most of the high quality arable land in the Lockyer Valley is covered by heavy black cracking clays that retain water, the underlying brown calcareous loams are highly permeable, rapidly draining water away (Galletly 2007). The seven different soil types and the geological associations of the Lockyer Valley are dealt with in the works of Cox and Wilson (2005), Wilson (2005) and Smith et al. (1990). Research establishes the links between these soils and underlying geology in understanding the interconnectivity of water sources in the Lockyer Valley and rural land use (McHugh 2003; Tullberg 1998; Ly et al. 1998). These environmental interconnections between water, soil and land use were important considerations in any new approach to IWRM.

Although the state of water supply had been deemed satisfactory by government until at least the year 2010, SEQ water had been a concern as far back as the 1990s (Casey 1990). The impact of a prolonged drought had not been foreseen in these assessments. The security of water supplies in the Lockyer Valley for irrigation was raised for the first time in State Parliament in 1998 (Wivenhoe Dam to Atkinson Dam Pipeline Reference Group 1998). The State Water Infrastructure Taskforce was then established to investigate prospective new water infrastructure for QLD. A submission on a potential recycled water project from Ipswich and Brisbane to the Lockyer Valley was assessed by Kinhill Engineers in 1998 (GHD-Kinhill 1999) and further investigations recommended. In 1999 a Ministerial Taskforce was established to consider “new water opportunities" for the Lockyer Valley and Darling Downs including:

- desalination of seawater
- access to the Brisbane Valley dams
- transferring water from Sunshine Coast and northern NSW rivers, and
- recycling Brisbane wastewater (FSA 2006).

It was estimated at the time that shortfall of surface and groundwater water for this region ranged between 10-40,000 ML p.a. (Barraclough & Co. 1999). Based on this report the medium to long-term regional water availability was revised and deemed adequate until at least 2003 (The State of Queensland Submission 2007). These estimates took no account of other drivers such as the risk of prolonged drought or periodic flood or the pressures of rising demand for agricultural or population in these parts of the State. The DPSIR sub-model and IWRM model explained the relevance of this information. The components of the environmental dimension (yield) needed to be examined in conjunction with components of the economic dimension (irrigation water and agricultural demand and its drivers such as population growth). How these components of the economic dimension add depth to the IWRM concept model in Figure 3-2 was then investigated.

At the time of the millennium drought the Lockyer and Fassifern region further south[4] consisted of larger than average sized vegetable holdings (Hajkowicz et al. 2006; Henderson 2006). Along with the South Coast of Queensland, the Lockyer–Fassifern area was the most diverse production region in 2004. These two areas each produced 20-21 vegetable crops each, estimated to be worth more than $500,000 p.a. (Henderson 2006, p. 27). Opportunities for capitalising on this high rate of return were identified in demand management strategies including water savings, yield improvements and moving from average to best practice (Barraclough & Company 1999). The Lockyer–Fassifern region as one of the ‘Big 3’ vegetable production regions in QLD at the time, contributed over 60 percent of the total value of Queensland’s vegetables (Henderson 2004; ABS 2004; CDI Pinnacle Management & Street Ryan & Associates 2004). As such, the Lockyer Valley offered potential financial gains from improved IWRM in SEQ (Hajkowicz et al. 2006; DLGPSR 2005; CDI Pinnacle Management & Street Ryan & Associates 2004; ABS 2004). The Lockyer Valley remains central to the current plans of the Queensland Government to increase State food production by 50 percent by 2040 (QLD Government 2012). These economic components provided rich data for the IWRM model in Figure 3-2.

Another economic driver of IWRM is population growth in the region (DPSIR sub-model). The population of the Lockyer Valley Regional local government area is rapidly expanding at a rate of 1.7 per cent per year to 2036 and was projected to reach 54,238 by 2036 (QLD Government Statisticians Office 2014). This is important since the headwaters of the Lockyer Valley feed downstream Brisbane city in the fastest growing region in SEQ (ABS 2013a).

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[4] ABS Census data for the region includes statistical local areas of Boonah, Gatton, Ipswich West, Laidley and Esk.

Research showed how the complex variable nature and extent of surface water to groundwater connectivity impacted on water pricing, property rights, markets and trading (Fisher 2000). Due to unmonitored use of groundwater in the upper and lower Lockyer Valley, groundwater was overused (Natural Resource Management Standing Committee 2002). This was a direct result of a lack of understanding about common pool resources as discussed in Chapter 2. Many private water bores at the time were unlicensed, free flowing and produced groundwater for which there was no charge (CSIRO 2009a). During the millennium drought, the water table fell dramatically and downstream irrigators experienced failing bores and poor quality groundwater (Galletly 2007; Psi-Delta 2003; Harper et al. 1999).

3.2.1. The History of Water Planning Involving the Lockyer Valley

The COAG principles (1994 and amendments in 1996) provide for the use of ecological values and impacts, sustainable yields in determining water allocations, and full cost recovery for all water withdrawals, including private arrangements. The National Framework for Improved Groundwater Management delivered in 1997 responded to the dwindling groundwater levels and quality issues, covering topics such as the transferability of groundwater entitlements and the improved integration of groundwater and surface water management.

The Intergovernmental Agreement on the National Water Initiative (NWI) was signed by COAG[5] in 2004 to facilitate water security (NWI 2009). This agreement had significant implications for the provision of reliable water supply, water recycling, water trading, and an integrated catchment management approach to water resources (Radcliffe 2004). One of the objectives of the NWI was to restore overused groundwater levels to sustainable levels (DNRM 2005a). Research found that inconsistent guidelines and regulations were amongst the most important impediments to the Australian recycled water industry as a whole (ACIL Tasman 2005). Yet these changes, designed to improved security of water supply, were slow to emerge (NWI, 2009). Evidence of policy overlap, inconsistencies and “institutional inertia” described in literature in Chapter 2, were present and restructuring of the water

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[5] Signed by Australian States and Territories in 2004, Tasmania in 2005 and Western Australia in 2006.

sector was required (Brown 2008; Stenekes 2008; Tisdell et al. 2002). These aspects of IWRM were included in the components of the policy dimension in Figure 3-2.

The *Water Act 2000* (Qld) brought the regulation of recycled water and drinking water in line with the regulation of other water service providers in the State (Allens 2008). The processes in the Act gave the State Government a higher level of control over recycled water not previously seen in QLD (Allens 2008). The Government controls access to water through licences under the Act.

Under the *Water Act 2000*, water resource plans (WRP) were created for “priority catchments” (Tan et al, 2012). Such plans were consistent with the principles and goals of the NWI (2004) and water resource plans pursued efficiency goals (Hilmer et al. 1993). WRP in South East Queensland covered four water areas including Moreton and provided water entitlement security for rural communities. These plans,

> *convert existing water entitlements to tradable water allocations, separate from land, provides irrigators with opportunities to buy and sell entitlements, capitalise on efficiency improvements, and better match water availability to their business needs*. (DNRM 2006, p. 67).

WRPs include monitoring requirements, ecological outcomes and strategies proposed to achieve outcomes and environmental flow objectives, and water security objectives if water trade proceeds. These WRPs also outline strategies to balance both environmental flows and water security, through allocation and management of overland and groundwater flows. The release of unallocated water is also controlled though the use of WRPs (Claydon 2008 p.15).

The State Government introduced regulation on state water resources, including those of the Lockyer Valley, using a two-stage water planning process. This included a Water Resource Plan (WRP) followed by a more detailed Resource Operation Plan (ROP) (Sarker et al 2009, p. 6). The Water Resource (Moreton) Plan was released in 2007 and an amended plan released in October 2008. Under this Plan, water allocations for the following water supply schemes are managed under the resource operations licence for the:

(a) Central Lockyer Valley water supply scheme;

(b) Lower Lockyer Valley water supply scheme;
(c) Lower Lockyer Valley water supply scheme;
(c) Warrill Valley water supply scheme (DNRM 2014a, p.25).

A water allocation to take supplemented water or groundwater in the Central Lockyer Valley can occur via an interim resource operations licence (DNRM 2014a, p.28). The WRP granted an interim water allocation to the owners of land who have a contract with SunWater for taking water from the Morton Vale Pipeline (DNRM 2014a, p.26).

Under the Moreton Plan 2007, existing bores continue to take groundwater (*Water Act 2000* s.72 Water Resource (Moreton) Plan 2007). In parts of the upper and lower Lockyer Valley, landholders' supplementary water licences are still calculated for historical volumetric water licence calculations. There were no groundwater licences in the Lockyer Valley outside the central area at the time the SEQRWT was investigating the recycled water options for the Lockyer Valley (Sarker et al. 2009). This indicated a lack of recognition of common pool resource characteristics of the groundwater resource and contributed to its over-appropriation in the Lockyer Valley (Sarker et al. 2009, p.15).

The Resource Operations Plan (ROP) for Moreton was released in 2009 to implement the Water Resource (Moreton) Plan 2007. This ROP applied to water in a watercourse or lake, and water in springs not connected to groundwater in the plan area. It did not apply to groundwater (DERM 2009, p.1). The original ROP (2009) did not extend to the nearby Warrill and lower Lockyer Valleys (DNRM 2014a). The Moreton ROP amendment to include the Warrill Valley and Lower Lockyer water supply schemes was approved in 2014, following extensive community consultation. Although the remaining Lockyer Valley groundwater was divided into implementation areas, the amended ROP still does not extend to groundwater. These implementation areas can be viewed on the Lockyer Valley groundwater area implementation areas map (Figure 3-1). During community consultation, some irrigators indicated that it would be easier for farmers to accept additional regulation, metering and monitoring in the midst of drought, if PRW was made available. These regulatory changes for the groundwater throughout the Lockyer Valley commenced but were not implemented when the drought broke in 2010-11 (Baldwin 2008).

The Lockyer Water Users Forum (LWUF) proposed self-organised water management within this regulatory framework (Baldwin 2008). Although the LWUF had been working with the State Government since 2003 on this proposal and continues to have input into the management process, this co-management model has not been accepted by the Queensland Government (DNRM 2013). The monitoring bore network throughout the entire Lockyer Valley, is still to be implemented. Groundwater management in the Moreton catchment was facilitated by the release of the Great Artesian Basin water resource plan (GAB WRP) in 2006 and the ROP in 2007. For example, licensing of the take of groundwater from sandstone aquifers in the Gatton Esk Road Implementation Area was completed by 2010 (DNRM 2015, 2013). The groundwater in the Lockyer Valley can now be managed under a WRP groundwater management area. The WRP outlines the Government's plans for managing a catchment's social, economic and environmental needs (DNRM 2013).

Prior to the *Water Act 2000*, groundwater throughout Australia, other than for stock and domestic use (e.g. for irrigation), did not require a water licence. It was not until 2005, when the whole of the Lockyer Valley was declared as a sub artesian area, that the water planning process began in earnest (DNRM 2005a). This was required prior to the water planning process. The QLD State Government is yet to extend groundwater monitoring to these areas. The many unlicensed private bores throughout the Valley and SEQ (CSIRO 2009a, p. 30) disguised the fact that the real groundwater extraction rate was much higher. Research highlighted the need for more monitoring bores, surface water stations and further spatial distribution of sampling points (CSIRO 2009a). Another factor contributing to groundwater depletion in the Valley was the failure of water infrastructure to recharge the aquifer. This research combined the components of the environmental dimension (ITWC) and economic dimension (water demand and extraction rates) of Figure 3-2.

Recharge in the area is through a combination of natural flows (rainfall, baseflow and overland flows), and releases from water storage areas (ANRA 2001). Surface water supplies are subject to State government licensing. Three off-stream storages supplement and recharge the stream, surface and groundwater supplies through a system of weirs and meters (CSIRO 2009 p. 4). Atkinson, Clarendon and Bill Gunn Dams struggled to reach capacity throughout the millennium drought (Atkinson Dam was periodically empty in 1998, 1999 & 2006). These issues about water scarcity, failure of water infrastructure (insufficient dam storage and poor weir placement), and inadequate policy on monitoring and allocations were raised by irrigator lobby groups from the 1980s (Baldwin 2008). These components respectively correlated to the environmental and economic policy dimensions of the IWRM model in Figure 3-2. Since the early 1980s, various irrigation lobby groups have sought access to Wivenhoe Dam for agricultural water supply to the Lockyer Valley. The Lockyer Watershed Management Association (LWMA) formed in 1982, and the DDV2000 interest groups for the Darling Downs formed in 1995. By 2001, irrigator and community groups comprised of the DDV2000 and C2S and focused on a recycling scheme with Ipswich and Brisbane, because of low Wivenhoe dam levels. Pressure to secure water supplies for irrigation peaked during the millennium drought.

As the drought continued, an Interagency Committee formed under the QLD Department of State Development (DSD), to focus on recycled water options. The technical and environmental consequences of using Class A recycled water on Lockyer Valley soils, salinity and groundwater were deemed to be sustainable, further groundwater management and monitoring were recommended to facilitate recycled water projects (Heiner et al. 1999; Kinhill 1998). This project had joint agreement and funding from the Brisbane City Council (BCC), DSD, DDV2000 and C2S. Involvement of community and irrigator lobby groups signaled the importance of these components of the social dimension in the IWRM model in Figure 3-2.

The QLD Government embarked on a strategy of consolidation of water entities, rationalisation of water pricing and allocations, mostly with urban water security as the priority. This combination of changes in policy and economic policy instruments was dealt with in the policy and economic dimensions of the IWRM model. In 2001, the Federal Government agreed to fund the SEQ Regional Water Taskforce (SEQRWT) investigation into the feasibility of using recycled water to secure water for industry, and irrigation in the Lockyer Valley and surrounding areas. The Taskforce[6] engaged consultants to commence

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[6] The Task Force included representatives from six Local Government members of SEQROC (Ipswich, Logan and Brisbane Councils (water supplier Councils) and Gatton, Laidley and Toowoomba Councils (water user Councils) and representatives from State Government Departments of the Premier and Cabinet, State Development and Treasury. A Brisbane City

the SEQRWP to investigate the feasibility of using recycled effluent from Brisbane, Ipswich and Logan City Councils' Waste Water Treatment Plants (WWTPs) for industry and agricultural use in the region. This pivotal research delivered in 2003 (Psi-Delta), signaled the beginning of over a decade of investigation into solving IWRM issues in the Lockyer Valley. The verdict was that while technically feasible, none of the scenarios were economically viable due to the large capital and operating costs. It appeared that few irrigators were prepared to pay enough for or benefit from the various scenarios. Technical aspects of the ITWC were dealt with under the environment dimension of the IWRM model. This research and its implications for the Lockyer Valley were further discussed in section 3.3.

The Lockyer Catchment Association (LCA) was formed in 2002 to focus on natural resource management issues including water. Since 2004, the LWUF represented irrigators in the Lockyer Valley (Baldwin 2008). Subsequent irrigator groups lobbied for and funded research consultancies into other resource management options. The findings of these consultancies were explored, analysed and synthesised further in section 3.4.

Although in 2014 it was deemed that there was sufficient water supply available to meet projected demand for rural water until 2025 (DNRM 2004), the demands of high productivity continued to put agricultural land under substantial pressure. These findings conflicted with the earlier predictions of Government (Casey 1990), the 1999 (Barraclough & Co.) study, findings of The State of Queensland Submission (2007) and the reality of the prolonged drought in the area. The average annual groundwater withdrawal rate in the Lockyer Valley in 2007, was growing and had reached approximately 45,000 ML p.a. (ANRA 2007a, p. 1). Groundwater storage in the alluvial aquifers had been estimated to have a safe annual yield of approximately 25,000 ML p.a. (Baldwin 2008, p.111). Changing farm practices by 2006-07 (including switching from irrigated to dryland agriculture and high efficiency irrigation), relieved some of the pressure on water supply

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Council representative chaired the Task Force and representatives from SEQWater, DDV2000 and C2S were observers for the community and irrigators (SEQRWT 2003). C2S and Darling Downs Vision 2000 then form NUWater to co-fund the project.

(Baldwin 2008, p.111). Yet these efficiencies had a limited impact on overall groundwater levels as alluvial aquifers continued to be over-exploited and some bores ran dry. Continued unregulated extraction of groundwater from unlicensed bores was depleting the alluvial aquifers, and lowering the water quality and altering the chemistry of the water (Low Choy 2013; CSIRO report 2009, p. 30; EHA, 2006; Harper et al. 1999). Higher levels of salinity were found above lower catchment sandstones (Wilson 2005).

High water usage for irrigation were exacerbated by the high evaporation rate of water from open channels, creek and streams and various spray methods of irrigation. In 2004-5 the Lockyer Valley average irrigation rates for crops and pastures were 3.8 ML/ha (ABS 2005, p. 13). Although this was below the national average of 4.2 ML/ha (ABS 2005, p. 13), demand management strategies helped to lower this rate to 3.6 ML/ha by 2009–2010 (ABS 2010, p. 10). A variety of strategies and incentives were used to reduce irrigation water demand including water efficiency improvements (e.g. drip and sub-surface irrigation practices and low or no till planting). These improvements were encouraged by government and embraced by irrigators to noticeably decrease water use per hectare (DNRM 2013; Henderson 2006; Clark 2003). These water efficiencies were briefly investigated.

The QLD State Government commenced work in 2005, on a water grid to connect water infrastructure in SEQ to various wastewater treatment plants, a planned desalination plant for Tugun and expanded existing and newly constructed dams. The SEQ Water Grid and seven stage water purification scheme provided the technical means to transfer purified recycled water (PRW) to the gateway of the Lockyer Valley (Lowood). Research by Psi-Delta (2003) dismissed the connection of this grid to the Lockyer Valley on economic grounds. The importance of this policy decision to build the SEQ water grid and provide recycled water to the gateway of the Lockyer Valley, should be analysed in conjunction with the social, economic and environmental dimensions of Lockyer Valley IWRM at that time. The WCRWS (2006-2008) provided for PRW to be added to the Wivenhoe dam, if levels fell below 40 per cent (QWC 2010, p.7). The WCRWS was also designed to provide power stations with an alternative to potable water from the SEQ water grid. Although the WCRWS was not designed for the irrigation of the Lockyer Valley, it could provide benefits of this water to agriculture and revenue from the sales of PRW.

In January 2007, the QLD Government announced plans to deliver the PRW scheme to SEQ without conducting a referendum (Nancarrow et al. 2007). A referendum and negative publicity had already led to the rejection of a reclaimed water project for drinking water in Toowoomba at the peak of the millennium drought (Fielding & Russell, 2008). While it appeared that public opinion remained firmly against mixing recycled water with drinking water in Wivenhoe dam, it remained acceptable for irrigation purposes (Nancarrow et al. 2007). After rainwater and stormwater, PRW for irrigation was the preferred option to more dams, desalination and bore water (Nancarrow et al. 2007). The existence of alternative sources or smaller scale schemes, poor government planning and continued neglect of the social acceptance of the project caused some resistance to PRW for drinking purposes (Nancarrow et al. 2007). These and other complex social issues and impacts needed to be analysed more thoroughly in terms of the multiple dimensions of the IWRM model prior to undertaking such policy decisions.

Although the social acceptability of using PRW for drinking was largely ignored by policy makers, Lockyer Valley interest groups keep campaigning for alternative water supplies for irrigation. Since the early 1980s interest groups, including the Lockyer Watershed Management Association (LWMA); the DDV 2000; C2S and the then Gatton Shire Council, lobby intensively to access Wivenhoe Dam for agricultural water supply to the Lockyer Valley. In 2002, the Lockyer Catchment Association (LCA) formed to focus on other natural resource management issues, including water. It was later replaced by government-funded Natural Resource Management (NRM) bodies to manage natural resources on a regional basis (Baldwin 2008). Later natural resource management groups were incorporated into the Southeast Queensland Catchments (SEQC) and provided staff and support to the Lockyer Valley Water Users Forum. Since 2003, the Lockyer Valley Water Users Forum (LWUF) has represented irrigators in the Lockyer Valley lobbying for Government funding for research and solutions to the dwindling groundwater problem (Baldwin 2008). As Wivenhoe dam levels fell throughout the millennium drought, the LWUF focused on a smaller recycling scheme with Ipswich (Connell Wagner 2005a). As negotiations for recycled water in the Lockyer Valley continued, the community and those affected by these water policy decisions desired greater input into such resource management projects

(Baldwin 2008; Sarker et al. 2009, 2008).

Research outlined in Chapter 2, emphasised the importance of including stakeholders in such decisions relating to the co-management of common pool resources (Ostrom 2010, 1990). In keeping with this theory, monthly meetings of irrigators are held to assess the impact of irrigation on the area, encouraging input from stakeholders such as the Department of Natural Resource and Mines, local governments, South East Queensland Catchments (SEQC), the University of Queensland, Queensland University of Technology (QUT), and industry associations such as Growcom (Baldwin 2008).

The LWUF's proposal for co-management was based on improved understanding of the water resource, establishing sub-catchment limits to groundwater, and implementing on-farm management approaches (LWUF, SEQC & QUT 2006 cited in Baldwin 2008, p. 357). The proposal relied heavily upon cooperation from government in terms of monitoring of groundwater through installation of metres and formalisation of the co-management concept and ‘rules’ through the Moreton WRP and ROP, among other requirements (for further details see Baldwin 2008). The State Government did not support the proposal for co-management of groundwater, leaving these important social aspects of community involvement outside the IWRM process.

This research and discussion focused attention of the components of the social dimension of the IWRM model shown in Figure 3-2. Research into issues such as the destination of recycled water (dams, farm gate or pipeline), method of recycled water delivery to farms, and water allocations, price and access to recycled water pipelines were investigated further in section 3.3 of this study.

Food industries expressed confidence in purchasing crops irrigated with reclaimed water (Fielding & Russell 2008). Further, recycled water that met Australian quality standards and guidelines was acceptable to growers and buyers of vegetables (GHD 2004; Fielding & Russell 2008). Bulk buyers of vegetables such as Coles and Woolworths[7] with HACCP-based[8] systems for food safety and quality assurance, require QLD Government Class A

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[7] Bought 70 % of vegetables in Australia at the time of the GHD (2004) survey (Psi-Delta 2003, Appendix p. 7)

[8] Hazard Analysis Critical Control Point (HACCP) is a methodology for risk management used by the Australian food and related industries to control food safety hazards risk levels (HACCP 2012).

standard water be used for vegetable crop irrigation (DEWS 2008). The social and political requirements for the use of PRW for vegetable irrigation appeared to be satisfied (Uhlmann & Head 2011). These economic policy instruments were dealt with under the economic dimension of the IWRM model.

The Western Corridor Recycled Water Pipeline (WCRWP) was constructed in 2009, to connect this water grid with other water infrastructure in SEQ. The WCRWP is the largest reclaimed water scheme in Australia and consists of over 200 km of pipeline and is capable of providing up to 66 ML/day of recycled water (Rowe 2009, p. 22; DIP 2008b). Purified recycled water was made available to SEQ via the WCRWP from 2009 to 2013. This option requires an extension of the WCRWP to the Lockyer Valley if irrigator access is to be organized. The WCRWP is intended to supply Wivenhoe Dam with additional water during the continuing drought and provide industry and irrigators with a recycled water option. The SEQ water grid infrastructure remains unconnected to the Lockyer Valley and has been on stand-by since the millennium drought broke in 2010. The consequences of considering dimensions of the IWRM model in isolation of all components, their interactions and other research at the time culminated in the fate of the WCRWP. Further analysis of the WCRWP was undertaken in Chapter 4.

Since the millennium drought broke, another pipeline has been constructed, connecting the Wivenhoe dam to Cressbrook Dam, near Toowoomba. The availability of recycled water via the existing WCRWP, the Toowoomba treated wastewater pipelines, and other SEQ water grid infrastructure and supporting policy, provided the Lockyer Valley with more IWRM options. However, since the flood events of 2010–2011 in SEQ, the imperative to replace diminishing groundwater in the Lockyer Valley has all but disappeared. Creek, stream, aquifer and dam levels in the Lockyer Valley returned to comfortable levels (Wolf 2013; Bleakley 2011).

As a result of the floods in 2010-11 and 2013, that affected the Lockyer Valley and surrounding catchment, various flood investigations ensued. Flood mapping has been updated (SEQ Catchments Limited 2013). Areas of major concern highlighted in the process included:

- Banks of major streams and rivers contributing to downstream sediment pollution of water treatment plants, coastal estuaries and Moreton Bay.

- Debris and contaminated waste washed into creeks and the impact on bridges and roads
- Loss of agricultural topsoil
- Mobilization of salt
- Bank erosion and riparian damage
- Infrastructure loss (bridges, irrigation works, electricity etc.).

These issues may be exacerbated by increased storages of recycled water in the Lockyer Valley (Wolf 2013). Issues, such as optimal top up volumes for water catchments, required further investigation and became a necessary component of the environment dimension of the IWRM model.

These issues and decisions were further investigated using the IWRM model in Chapter 4. The research studies and consultancies in the ensuing period, were first reviewed to provide an understanding of how and why these decisions about IWRM issues and the option of recycled water in the Lockyer Valley were made. The data emerging from these research studies and consultancies then provided data for use in the case study of the Lockyer Valley in Chapter 4.

3.3. Research Investigations - the Lockyer Valley Water Problem 1998 to 2013

There were at least 35 investigations into the water situation and various water supply options in the Lockyer Valley, by various government and industry directed consultancies from 1998 to 2013 as shown in Table 3-1. There was a noticeable overreliance on economic and technical solutions to IWRM in many of these research studies and consultancies. A further 20 research studies on the Lockyer Valley water situation were conducted by research institutions such as the University of Queensland, QUT and CSIRO through partnerships such as UWSRA,[9] ATSE[10] and Institute of Sustainable Futures (Deloitte Access Economics (DAE) 2013; Wolf 2013; Ellis & Wolf 2012; MJA 2012b; Wolf et al. 2010; Cresswell 2008; Fielding & Russell 2008; Alexander et al. 2008; Turner et al. 2007;

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[9] 9 A research partnership between the Queensland Government, CSIRO, University of Queensland and Griffith University.

[10] Academy of Technological Sciences and Engineering

Radcliffe 2003) or by independent researchers (van Opstal 2012, 2010; Sarker et al. 2009, 2008; Baldwin 2008; Galletly 2007; Hamilton et al. 2005; Wilson 2005; Cox & Wilson 2005; Hamlyn-Harris 2003; Apan et al. 2000). At least 20 surveys and consultations with landholders were conducted in the course of these studies demonstrating the strength of components within the social dimension of the IWRM model. Together these research studies cover a variety of technical, environmental, policy, social and economic aspects of water in the Lockyer Valley.

Research at the time focused on single sector water use – urban, agriculture or environment. This is confirmed by the sectoral focus of many of these research studies and consultancies (FSA 2006; Hajkowicz et al. 2006; Psi-Delta 2003; Halliburton KBR 2002; Brown & Root1998). Some of this research investigates the environmental and social impacts of rural water demand, but few take this further and review the inter-connectedness of urban-rural demand or rural-environment demand (as Hamlyn-Harris 2003 did briefly). The limitations, assumptions and strengths of these works were reviewed in order to further expand on the components of the dimensions of the IWRM model and establish the validity of the secondary data to be used in the case study of the Lockyer Valley in Chapter 4. The assumptions, decisions, strengths and shortcomings of these studies were then considered, such that the data could be understood prior its use in the case study of the Lockyer Valley in Chapter 4.

3.3.1. Summary of Findings from Research Studies and Consultancies

Many of these research consultancies assessed the possibility of using recycled water for irrigation to offset depleted groundwater levels in the Lockyer Valley (Brown & Root, 1998; Heiner et al. 1999; GHD & Kinhill 1999; GHD, 1992; Psi-Delta 2001 & 2003; Halliburton KBR 2002; Brennan et al. 2003; Clark 2003; Hamlyn - Harris 2003; Radcliffe 2003; Horticulture Australia Limited (HAL) 2003; GHD 2004; RidgePartners 2004; ACIL Tasman 2005; Hamilton et al. 2005; Connell Wagner 2005a,b; Moreton Rural Service 2005; Enhance Management 2005; Hajkowicz et al. 2006; FSA 2006; Turner et al. 2007; Fielding & Russell 2008; SGS Economics & Policy 2006; CH2M Hill, 2008; Helm et al. 2009; Ward & Dillon 2009; Saxton 2009; Wolf et al. 2010; van Opstal 2010, 2012; MJA

2012b; Ellis & Wolf 2012; Wolf 2012; Wolf 2013; QUU 2013; AEC 2013 cited in MEP 2013). During this time several independent research studies on the Lockyer Valley water situation were also undertaken (van Opstal 2012, 2010; Sarker et al. 2009, 2008; Baldwin 2008; Hamilton et al. 2005; Wilson 2005; Cox & Wilson 2005). Despite the range and depth of these studies, a full technical, policy, economic and social analysis of the complex components involved in managing Lockyer Valley IWRM, has not been undertaken. A review of these existing studies and data was undertaken.

The SEQ Recycled Water Task Force (SEQRWT) project (Psi-Delta 2003) was pivotal in the investigations into recycled water supply and use in the Lockyer Valley. The water demand and use data from this research was used repeatedly in subsequent research and consultancies, and the findings from it determined policy decisions on the recycled water infrastructure and planning in SEQ for the next decade. These contributions represented the components of the dimensions of the IWRM model. These research studies and consultancies were divided into pre- and post SEQRWT.

Table 3-1 Lockyer Valley Water Studies

Year	Author and Title	Type and Agency	Scope	Data used
1998	Brown & Root, *Use of Renewed Water for Irrigation in the Lockyer Valley*	Summary document prepared for QLD Department of Natural Resources (DNR)	Report on potential use of renewed water for irrigation in the Lockyer Valley	
1999	Heiner, et al. *Sustainability of Agricultural Systems using Recycled Water in the Lockyer Valley and Darling Downs Area*	Prepared for Department of Natural Resources (DNRM)	To determine the sustainability of agricultural systems in the Lockyer Valley and Darling Downs if they were to use recycled water.	Calculations of irrigation with Class A recycled water in varying proportions on soils of the Lockyer Valley
1999	Barraclough & Co, *Audit of Water & Irrigation Use Efficiencies on Farms within the Queensland Horticultural Industry*	Prepared for Queensland Fruit and Vegetable Growers and Department of Natural Resources to assist implementation of the Rural Water Use Efficiency Initiative	Technical and economic audit of water and irrigation efficiency on farms including the Lockyer Valley.	Desktop research (ABS census database 1993-1996 averaged & 1997) & DNR databases; growers survey.
1999 April	GHD & Kinhill, *SEQ Water and Wastewater Management and Infrastructure Study*	Report for SEQ Water and Wastewater Management and Infrastructure Study	Study of SEQ water and wastewater management and infrastructure augmentation requirements based on the then existing demands and existing yield assessments	Estimated the rural water demand and usage
2000	Apan et al. *Quantifying Landscape Fragmentation in the Lockyer Valley Catchment, Queensland*	Presented at Conference of Australasian Urban & Regional Information Systems Association	Assessment of land fragmentation due to development	Research on developing mapping and assessment techniques for quantifying and analysing landscape fragmentation and gaining insights on landscape change in SEQ from technical and environmental perspectives
2001 Nov	Psi-Delta, *City to Soil: Recycling Water to Feed our Future: Market Assessment for Recycled Water* (later incorporated into Psi-Delta 2003)	Report commissioned by Queensland Department of State Development (QDSD) later incorporated into SEQ Recycled Water Taskforce (Psi-Delta 2003)	Economic market Assessment for Recycled Water in the Lockyer Valley	Average operating and capital cost estimates (Brown & Root 2001 unavailable)

Year	Author and Title	Type and Agency	Scope	Data used
2002 Sept	Halliburton KBR, *Lockyer Valley Hydrological Consultancy Final Report* prepared for Brisbane City Council	Prepared for the Brisbane City Council and later included in SEQ Recycled Water Taskforce (Psi-Delta 2003)	Hydrological study to develop predictive tools based on sound hydrological modelling techniques to assess the sustainability of water resources in the study areas with, and without the irrigation of the imported recycled water in the Lockyer Valley	Tested five scenarios using data from Queensland Department of Primary Industries (1994); Department of Natural Resources (1994a); Water Studies (2002); Powell et al. (2002) (2002); Psi-Delta 2002; NR&M irrigation water use data; KBR groundwater flow estimates
2002 April	ABN Amro, *SEQ Recycled Water Taskforce*	SEQ Recycled Water Taskforce (Psi-Delta 2003)	Financial evaluation - SEQ recycled water options	capital and operating costs estimates developed by GHD 2003
2003 March	Psi-Delta, *Socio Economic and Financial Feasibility of the SEQ Recycled Water Project*	SEQ Recycled Water Taskforce (2003)	Combined report on social, policy, economic and environmental aspects of recycled water for irrigation in the Lockyer, Bremer Warrill Valleys & Darling Downs	Data from Psi-Delta 2001
2003 Feb	GHD, *South East Queensland Recycled Water Project - Infrastructure Costs Study* - Final Report,	Report for Brisbane City Council for *SEQ Recycled Water Taskforce* (Psi-Delta 2003)	Study of infrastructure costs of recycled water projects including the Lockyer Valley	Estimated infrastructure requirements
2003 April	ABN Amro, *SEQ Recycled Water Taskforce*	SEQ Recycled Water Taskforce (Psi-Delta 2003)	Financial evaluation - SEQ recycled water options	capital and operating costs estimates developed by GHD 2003
2003 April	Psi-Delta, *SEQ Recycled Water Taskforce*	SEQ Recycled Water Taskforce (Psi-Delta 2003	Socio-economic impacts of recycled water use in the Lockyer Valley and surrounding region	Conducted price sensitivity for recycled water from a demand survey of 400 recycled in Warrill, Bremer & Lockyer Valleys. Data from Psi-Delta 2001; Halliburton KBR 2002; GHD 2003; ABN Amro 2002
2003	Clark, *Rural Water Use Efficiency Initiative, Water for Profit and Queensland Fruit and*	Milestone Report for DNRM	Research options for improved	DNRM data, ABS special request

Year	Author and Title	Type and Agency	Scope	Data used
	Vegetable Growers		water efficiency	data (2000/01)
2003	Hamlyn-Harris, *Integrated urban water management and water recycling in South-East Queensland: Recent developments*	Research for the Institute of Public Works Engineering Australia, Qld Division Inc.	Review of demand for recycled water in Lockyer, Warrill and Bremer Valleys	Demand and prices (GHD 2003), 2003)
2003 Sept	Radcliffe, An overview of water recycling in Australia	Results from ATSE study presented at 2nd National Conference, Australian Water Association	A review of policy, technical, economic aspects of recycled water use in the agricultural sector including the Lockyer Valley.	GHD Kinhill 1999; Hamlyn-Harris 2003 estimates for demand for recycled water; Halliburton KBR 2002
2003	Horticulture Australia Limited, *Water Initiative: Ensuring Ongoing Access to Water for Horticulture*	Report for Centre for International Economics on behalf of Horticulture Australia	Draft business plan to improve water access	Economic, policy and environmental requirements to improve horticultural industry performance
2003	Henderson, *Quantifying high priority reasons for vegetable producers to adopt improved irrigation management strategies.*	QLD DPI report on RWUE Project 18	Report quantifying high priority reasons for vegetable producers to adopt improved irrigation management strategies.	DNRM data, ABS special request data (2000/01)
2004 July	GHD *Lockyer Valley water reliability study*,	Prepared for QLD Department of State Development and Innovation (DSDI)	Assessment of water reliability in the Lockyer Valley	KBR (2002); GHD (2002) demand estimates & DNRM&E discussions (2004)** on demand estimates for Lockyer Valley
2004 Nov	CDI Pinnacle Management, Street Ryan and Associates, *Economic Contribution of the Horticulture Industries to the Queensland and Australian Economies*.	Prepared for Growcom and Horticulture Australia Limited (HAL)	Assessment of economic contribution of the horticulture industries to the Queensland and Australian economies.	ABS value of agricultural commodities produced 2001, 1993; ABS unpublished data; Agricultural census data 2001, 1991; HAL and DPIF data; OESR data
2004	RidgePartners, *Rural water trends and issues in the SEQROC region*	Report for stage 1 of the SEQ Regional Water Supply Strategy Regional (SEQRWSS) for QLD Department of Natural Resources and Mines and	Study of rural water demand and usage in SEQ	Summarised estimates of rural water demand and usage from irrigators' representatives, allocations & modelling. Provided production & employment increases from proposed Lockyer

Year	Author and Title	Type and Agency	Scope	Data used
		Brisbane City Council		Valley recycled water schemes
2004	Henderson, *Producing vegetables for a market (or are vegetables an appropriate enterprise?)*	Prepared by QLD DPI&F	Study of producing vegetables for a market (or are vegetables an appropriate enterprise	ABS 2000/01, 2004, 2005; CDI Pinnacle Management & Street Ryan & Associates 2004
2005 June	ACIL Tasman, *Research into access to recycled water and impediments to recycled water investment*	Report prepared for DAFF on behalf of the Natural Resource Policy and Programs Committee	Investigation into the environmental, economic, policy, social and technical barriers to investment in recycled water projects including the Lockyer Valley.	Literature review and stakeholder survey and consultations with government, industry, community and water users; Psi-Delta 2003
2005a	Connell Wagner, *Scoping Study into supplying recycled water to Ipswich region and then extending the supply to rural Bremer, Warrill and Lockyer Valleys*	Scoping study into using Ipswich recycled water	Scoping Study into supplying recycled water to Ipswich region and then extending the supply to rural Bremer, Warrill and Lockyer Valleys	An environmental, technical and economic investigation including Psi-Delta data (2003); CH2MHill 2004 & GHD 2003 & 2004; stakeholder consultation
2005b May	Connell Wagner, *Background Documents to the Scoping Study, Ipswich Regional Recycled Water and Economic Structural Adjustment Strategy*	Scoping study into using Ipswich recycled water	Scoping the Ipswich regional recycled water and economic structural adjustment strategy	KBR 2002; Psi-Delta 2003; GHD 2003, 2004; CH2MHILL 2004
2005	Wilson, Hydrogeology, *Conceptual Model and Groundwater Flow Within Alluvial Aquifers of the Tenthill and Ma Ma Catchments, Lockyer Valley*	Academic research (PhD)	Developing a groundwater flow conceptual model for parts of the Lockyer Valley	Hydrographs and NRM&E geological bore logs are used to estimate the chemistry and interconnectivity and recharge in the Lockyer Valley aquifers and some extraction scenarios
2005	Cox & Wilson, *Use of geochemical and isotope plots to determine recharge to alluvial aquifers: Lockyer Valley*	QUT research presented at ISMAR 2005, International Conference of Recharge, Berlin, 12-17 June.	Determining recharge methods and interconnectivity in Lockyer Valley aquifers	Analysis of chemistry from 100 bores in the Lockyer Valley
2005	Hamilton et al., *Position of the Australian horticultural industry with respect to the use of reclaimed water*	Published in Agricultural Water Management Journal	Investigation of the policy, economics, market access, policy, environmental impact, agronomic sustainability and public health aspects of the	ABS (2000–2001) Radcliffe (2001–2002) including a review of policy and literature.

Year	Author and Title	Type and Agency	Scope	Data used
			Australian horticultural industry's preparedness to use reclaimed water for irrigation including the example of the Lockyer.	
2005 un-avail	Moreton Rural Services		Lockyer Valley water use intensity by broad crop type	
2005 Oct un-avail	Enhance Management, *Part B. Lockyer Valley water reliability study*	Prepared for the Coordinator-General report.	Part B of the Study of the Lockyer Valley water reliability	Conducted surveys of willingness to pay for recycled water & 50 capacity to pay interviews of growers in Lockyer, Bremer and Warrill Valleys (15% response using farm profitability data from 1996-97)
2006 May	EHA, *Groundwater Review of South East Queensland On-Shore Aquifer Systems, Draft Preliminary Scoping Report*	Report for Queensland Department of Natural Resources, Mines and Water	Hydrological review of major on-shore groundwater resources in SEQ including the Lockyer Valley	Provided groundwater yield data
2006 May	Hajkowicz et al., *Irrigated Agriculture in South East Queensland A review of economic data and policy issues*	A consultancy report to the Rural Water Task Group of the South East Queensland Regional Water Supply Strategy, CSIRO Sustainable Ecosystems.	Economic & policy analysis of irrigated agriculture in SEQ including Lockyer Valley. Recommended policy changes and future research options.	CSIRO reviewed economic data and policy issues in their assessment of the marginal economic value of incremental increases in water for irrigation.
2006 June	Henderson, *Maximising Returns from Water in the Australian Vegetable Industry: Queensland.*	Report produced by QLD DPIF and is one in a series on vegetable industry water use at state and national levels and has been funded by Horticulture Australia Ltd (HAL) and AUSVEG. Funded by the National Vegetable levy	An assessment of the irrigation practices, water efficiencies and economics of the QLD vegetable industry including Lockyer Valley. Recommends further economic modelling and more frequent analysis of water use, yield, efficiencies, value added and prices and improved data collection.	ABS, DPI, CDI Pinnacle Management, Street Ryan & Associates 2004, personal communications,

Year	Author and Title	Type and Agency	Scope	Data used
2006	Cardno (QLD) *SEQRWSS Bulk Water Supply Network Model: Draft Final Report*	Prepared for DNRM for SEQRWSS review of bulk water supply network	Report on SEQ bulk water supply network	DNRM data
2006 Aug	FSA Consulting, *South-East Queensland Regional Water Supply Strategy Rural Water Supply Strategy*	Prepared for QLD DNRM and Council of Mayors SEQP	An economic and policy assessment of SEQ water supply options including Lockyer Valley.	Australian Bureau of ABS (1996); the audit of water & irrigation use efficiencies in the horticulture industry (Barraclough 1999); Water use (ML/ha) for each commodity (Growcom 2004); NR&M 2001; *NR&M (2005a); DNRM&W 2006a,b;* GHD (2004)
2006	SGS Economics & Planning, Lockyer and Brisbane Valleys Social Infrastructure Plan 2006–2026	Undertaken for the Office of Urban Management to report to the Department of Infrastructure and Planning	Study into the social infrastructure needs and delivery mechanisms for long-term growth to 2026. Focus on facilities and the services using these. Study to inform development of Social Infrastructure Planning Guidelines for SEQ	
2007 un-avail	MJA, Western Corridor Recycled Water Scheme business case, vol. 1 – report.			
2007 Feb	Turner et al. *Review of Water Supply-Demand Options for SEQ*	Review by Institute for Sustainable Futures and Cardno	An independent Review aims to assess the Queensland Government's proposed strategy for meeting the long-term water supply-demand balance for SEQ including Traveston & Lockyer Valley	water demand & use data (DNRM 2004-2006) & supply data (QWC 2006)
2007	Galletly, *Baseflow in the Lockyer Creek*	Academic Research (study)	Hydrological study of the Lockyer Valley	Hydrological data from DNRM & test results
2008	Alexander, et al. *Community Perceptions of Risk, Trust and Fairness in Relation to the Indirect Potable Use of Purified Recycled*	CSIRO report for UWSRA	Report on the detailed understanding of the SEQ community's perceptions in	nine community workshops & previous behavioural (Nancarrow

Year	Author and Title	Type and Agency	Scope	Data used
	Water in South East Queensland: A Scoping Report		relation to the key behavioural predictive variables using Nancarrow et al (2007) baseline measurement and modelling	et al. 2007) survey respondents
2008	Fielding & Russell, *Industry Perspectives on the Introduction of Purified Recycled Water into SEQ: A Report of Scoping Interviews*	Report for UWSRA	Investigates environmental, technical, policy, economic and social perspectives of SEQ industry on purified recycled water	Interviews with 15 SEQ industry representatives
2008 Un-avail	Cresswell, *Recycled water use in the Lockyer Valley: Summary of past activities and proposal for new research,*	Water for a Healthy Country Flagship Draft Report. Brisbane: CSIRO.		Literature review
2008 March Un-avail	CH2M Hill, *Reuse of Purified Recycled Water in South East Queensland*	prepared for the Queensland Water Commission		
2008 June	Baldwin, *Integrating Values and Interests in Water Planning Using a Consensus Building Approach*	Academic Research (study)	Social, policy and economic aspects of decision making in water planning in the Lockyer Valley	interviews
2008	Sarker et al. *Interdependence of common-pool resources: lessons from a set of nested catchments in Australia.*	Academic research published in journal of *Human Ecology*	Investigates the socio-ecological interdependence of common pool resources with a case study of a set of nested common pool resources in the Lockyer, Brisbane River & Moreton Bay catchments	Relevant literature, conceptual analysis & six years' observation
2009 April	CSIROa (Helm et al) *South East Queensland Opportunity Assessment for Aquifer Storage and Recovery*	Milestone Report to National Water Commission	A regional assessment of potential aquifer storage and recovery for SEQ identifying the potential of the WCRWP	EHA, 2006 (aquifer yield); Parsons & Brinckerhoff 2005 & DNRW 1997 (bore yields).
2009	CSIROb (Ward & Dillon) *Robust design of*	Milestone Report to National	Assessment of the policy requirements for secure market	Literature review & interstate

Year	Author and Title	Type and Agency	Scope	Data used
April	*Managed Aquifer Recharge policy in Australia*	Water Commission	based approach to manage the water quantity elements of MAR	comparison of MAR policy
2009	Sarker et al., *Managing groundwater as a common-pool resource: an Australian case study*	Academic research published in *Water Policy* journal	Co-management of Lockyer Valley groundwater	DNRW & LWUF
2009 Aug	Saxton, *Implications of supply of purified recycled water to the Lockyer and Warrill Valleys and mid-Brisbane River for groundwater recharge and irrigation purposes*	Report by SEQ Healthy Waterways Partnership for the QWC	Technical report on impact of PRW in groundwater recharge	Technical review and expert opinion
2010	Wolf et al. *Supplying high purity recycled water for groundwater banking in rural areas: Approaches for the integrated management of common pool resources.*	Presentation to Integrated Water Resources Management, International Conference Karlsruhe	Quantification of benefits, minimisation of impacts of variable quality injection water, minimisation of mobilisation of salts & potential for direct aquifer recharge	Field investigations, lab trials & modelling techniques
2010	van Opstal, *Irrigation with reclaimed water Down Under: A bottom-up Approach*	Academic research in Irrigation and Water Engineering journal	simulating the farm systems with changes to reclaimed water	Literature review and farming-system modelling tool quantifying biophysical and crop productivity changes.
2011	Bleakley, *Changing Groundwater Storage in the Central Lockyer*.	QLD Department of Natural Resources and Mines.		
2012 Mar	Ellis & Wolf, *Impacts of Applying Purified Recycled Water (PRW) in the Lockyer Valley, Qld*	UWSRA report	Investigated the possible technical & environmental effects on soil structure of the use of PRW for irrigation in Lockyer Valley.	Technical & environ-mental tests on soil and water quality & characteristics using lab tests
2012	Wolf, *Enabling the Use of the Lockyer Valley Groundwater System as a Buffer in the SEQ Regional Water Grid – An Assessment Framework.*	Presentation at Science Forum	Suggested framework for assessing biophysical impact of PRW use in Lockyer Valley	Water sampling, groundwater modelling and remote sensing of crops
2012	van Opstal et al. *A participatory modelling approach to define farm-scale effects of*	Academic research. *Water*	A participatory modelling	Six farm irrigation case studies from the Lockyer Valley are

Year	Author and Title	Type and Agency	Scope	Data used
	reclaimed wastewater irrigation in the Lockyer Valley, Australia	*International* journal	approach was used to analyse the consequences recycled water availability at the farm scale focus on non-technical issues like perception and acceptance	modelled providing estimates of demand for recycled water
2012a Sept	Marsden Jacob Associates, *Assessing the value of groundwater*	Waterlines report for National Water Commission	Assessing the value of consumptive and non-consumptive use of groundwater	Cost benefit analysis of case studies including the Lockyer Valley. Uses irrigated crop area data from Hajkowicz et al. (2006); Moreton Rural Services 2006; NSW DPI gross margins; DERM 2011 (unpublished)
2012b Nov	Marsden Jacob Associates, *Governance, Decision Processes and Pricing: Implications for Potable Water Recycling*	Report prepared for the Australian Water Recycling Centre of Excellence.	Policy, pricing and technical issues involving a case study of recycled water in the Lockyer Valley WCRWP.	Case Study 1 of 3 – SEQRWT involving 11 face-to-face semi-structured interviews with government & industry
2013	Wolf (ed.) *Implications of using Purified Recycled Water as an Adjunct to Groundwater Resources for Irrigation in the Lockyer Valley*.	CSIRO Report prepared for UWSRA.	Technical study of the PRW for irrigation in the Lockyer Valley.	Estimated demand using deep soil coring, geophysical investigations, groundwater quality monitoring & numerical modelling, hydrogeological modelling (HowLeaky) & surface water simulating with IQQM* & water quality testing
2013	Queensland Urban Utilities (QUU), *Lockyer Valley Recycled Water Scheme: consultation & stage 1 report.*	Consultation and report for QUU options for upgrading the Gatton sewerage treatment plant	Investigation into options to augment irrigation water provided with recycled water from upgrading the Gatton sewerage treatment	Consultation undertaken for QUU to determine likely demand for recycled water at various prices
2013 (un-avail)	AEC, *Economic Analysis and Social Impact Assessment of the Lockyer Valley Recycled Water Scheme Final Report*	Socio-economic research into Lockyer Valley recycled water scheme used in (MEP 2013) report	Economic value of regional production if Lockyer Valley recycled water scheme eventuated	

Year	Author and Title	Type and Agency	Scope	Data used
2013 Dec	Mainstream Economics & Policy, *Growing Opportunities: A strategy for sustainable growth of the South East Queensland Food Bowl Information Report*	A report for Regional Development Australia – Ipswich and West Moreton Inc. to provide background and information relevant to the Food Bowl Strategy	Summary of key information to assist with the Strategy for Foodbowl	ABS, AEC 2013,
2013 Oct	Deloitte Access Economics, *Economic Value of Groundwater in Australia*	Research conducted by the National Centre for Groundwater Research and Training	Economic analysis of groundwater value using case studies including the Lockyer Valley.	Case study data on groundwater values (MJAa)

*DNRM&W Integrated Quantity-Quality Modelling (IQQM)

**DNRM&E discussions (2004) publicly unavailable data quoted in GHD (2004)

3.3.2. Research Studies and Consultancies Preceding and Including the SEQRWT Project

For over 20 years, the Lockyer Valley water system has been targeted for many research studies and consultancies. Policy makers, irrigator lobby groups and researchers were concerned about the sustainability of Lockyer Valley groundwater use and the economic importance of the agricultural producing area to SEQ. A technical and economic audit of water and irrigation efficiency on farms (Barraclough & Company 1999) established more support and education was required to manage the increasing demand for irrigation water in the Lockyer Valley. GHD Kinhill (1999) then investigated the SEQ water and wastewater management and infrastructure augmentation requirements based on the then existing demands and existing yield assessments. This research established the important components of the environment (rainfall, hydrogeology, soil) and economic (irrigation water and crop demands) dimensions of the IWRM model.

As Australia's millennium drought (1997-2009) continued an "Interagency Committee" was formed under the DSD to focus on recycled water options. The technical and environmental consequences of using Class A recycled water on Lockyer Valley soils, salinity and groundwater was deemed to be sustainable, and further groundwater management and monitoring were recommended to facilitate recycled water projects (Heiner et al. 1999; GHD Kinhill 1999). This project had joint agreement and funding from the BCC, DSD, DDV2000 and C2S. The Committee investigated private sector investment in and health considerations regarding the use of recycled water in nearby rural areas including the Lockyer Valley (Heiner et al. 1999).

No analysis was done at the time regarding the social acceptability of recycled water, although this was a large determinant in the success of recycled water projects (Hurlimann 2010).[11] Although scenarios testing the impact of irrigation with Class A recycled water on Lockyer Valley soils, salinity and groundwater were found to be environmentally and technically feasible, further environmental analysis and understanding were still required for

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[11] Negative public opinion regarding acceptability of drinking PRW ld to the loss of a referendum to introduce it in Toowoomba in 2010.

long-term irrigation management using saline water (Powell et al. 2000). This research provided important components of the environment dimension of the IWRM model.

A study of land fragmentation was then undertaken. The extent to which these changes influenced the local ecological processes and pattern of the land then followed (Apan et al. 2000). The research confirmed the degeneration of the landscape in the Lockyer Valley due to fragmentation from land clearing, farming practices and structural change. Such work added pressure for the development of alternative water sources for this important agricultural area in the Lockyer Valley (Halliburton KBR 2002; Psi-Delta 2001). These were important overlapping components of the economic dimension of the IWRM model.

The SEQ Recycled Water Task Force

The Lockyer Valley region's proximity to major wastewater treatment plants (WWTPs) and other water infrastructure represented significant new water re-use opportunities for the area. The SEQRWT formed in September 2001 and investigated the feasibility of collecting, pumping, further treating, transporting and distributing effluent from Ipswich, Logan and Brisbane Councils to industry and agriculture in the Warrill, Bremer and Lockyer Valleys and the Darling Downs (Psi-Delta 2003). The study, *City to Soil* (Psi- Delta 2001), commenced initial investigations into a market assessment of recycled water use in the Lockyer Valley. Estimates of Lockyer Valley rural water demand were based on new demand surveys conducted by *City to Soil* (Psi-Delta 2001) and these results were later incorporated into the SEQRWT report (Psi-Delta 2003).

Of the various scenarios investigated the four preferred options included:

1. Full Scheme ("WLD2") – 126,600 ML at full capacity servicing Lockyer, Warrill and Bremer Valleys (Class A water) and Darling Downs (Class C water);
2. Truncated Full Scheme ("LD2") – 91,000 ML. Truncated distribution network that does not supply some outlying and low demand areas. Services Lockyer (Class A) and Darling Downs (Class C);
3. Lockyer Valley Scheme ("L1") – 22,000 ML servicing all potential customers in the Lockyer Valley (Class A); and

> *4. Truncated Lockyer Valley Scheme ("L2a") – 15,000 ML. Truncated distribution network that does not supply some low demand areas. Services Lockyer Valley (Class A)* (Psi-Delta 2003, appendix 3 p.1).

The value of this research carried out by ABN AMRO (2002), GHD (2003), Halliburton KBR (2002), and Psi-Delta (2001) for the Psi-Delta (2003) report was in its integrated approach to incorporating the financial, hydrogeological and socio-economic components into the analysis. These components corresponded to the respective economic, environment, social, economic and policy dimensions of the IWRM model. Although the Psi-Delta (2003) study investigated some environmental, social and economic aspects of IWRM it did not perform total economic valuation (TEV), nor apply full social cost pricing of common pool resources, nor fully investigate all aspects of the ITWC as discussed in Chapter 2. Further, the Psi-Delta study adopted a sectoral approach that investigated the rural use of recycled water – ignoring the urban and industrial sector overlaps and possible synergies from a multi sectoral focused IWRM as adopted in the IWRM model. The importance of this omission was revealed, as SEQ was the only region in Australia where urban (including industry) water use exceeds the nearby rural water use (FSA 2006; DNRM 2005b).

Irrigation water demand estimates provided by the KBR (2002), that form the basis Psi-Delta (2003) water demand estimates, did not encompass the Upper Lockyer Valley (Upper Tenthill and Upper Laidley Creeks). These areas were also excluded from the GHD (2004) study. The study also surveyed members of the LVWUF – large commercial users of water with different willingness to pay (WTP) and demand for water than the average irrigator in the Lockyer Valley. SEQRWT (Psi-Delta 2003) water demand estimates, therefore, were also inadequate. All water users and uses were required for a comprehensive IWRM assessment using the IWRM model.

Research on the hydrology of the catchment was conducted at the time of the SEQRWT by Halliburton KBR (2002). Previous hydrological studies investigated the feasibility of using recycled water for the sustainable crop irrigation locations in the Lockyer Valley and surrounding areas. A summary of these studies was provided in Halliburton KBR (2002). An early understanding of the entire catchment's response to potential recycled water recharge and monitoring of recharge was a key component missing from these research consultancies. As with many of the previous studies, hydrological modelling was hampered by assumptions made about run off, salinity, soil, crop types and more (Halliburton KBR 2002; Heiner 1999). Some of the findings about mobilisation of salt and clay (Helm et al. 2009; Connell Wagner 2005a; Wilson 2005; Cox & Wilson 2005) were not available until after the SEQRWT report (Psi-Delta 2003). The decision was made to place the WCRWP on stand-by in 2009. The missed opportunity in these studies was in their inability to inform future IWRM decisions in the Lockyer Valley.

The environmental impacts of the large loads of phosphorous and nitrogen via wastewater flows from urban Brisbane water catchment were a major concern to policy makers driving the recycled water project in SEQRWT (Psi-Delta 20013; Stevens et al. 2003a). Solutions were sought to the problem of sediment from overland and stream flows upstream in the rural Lockyer Valley that enters the downstream Brisbane Valley and makes its way to Moreton Bay. The recycled water option for Lockyer Valley irrigators was favoured at that time.

SEQRWT (Psi-Delta 2003) estimates of the value of the scenarios, based on full social cost analysis, were provided in Table 3-2. None of these scenarios delivered net positive gains. These attempts at estimating full social cost did not reflect the array of costs included in a rigorous environmental economic full social cost analysis using TEV, as explained in Chapter 2. All components of the TEV needed to be part of any IWRM assessment involving the IWRM model. With the energy costs at nearly 50 per cent, the operating cost proved too burdensome for the Lockyer Valley (and Darling Downs) scenarios (Psi-Delta 2003, p.43). The environmental and socio-economic costs of these scenarios outweighed the scientific and technical feasibility of most of these SEQRWT scenarios (Psi-Delta 2003).

Table 3-2 Estimated Full Social Costs of SEQRWT Scenarios

	Financial	**Economic**	**Social**	**Properties**	**Environmental**
Scheme	Cost to Government NPV $M	Gain/loss to Society NPV $M	Jobs	No. of Properties	Impact p.a. 2011 onward $M
Full	(810)	(493)	(903)	(421)	(6)
Truncated Full	(557)	(319)	(708)	(265)	(4)
Lockyer Alone	(199)	(76)	(383)	(173)	(0.2)
Truncated Lockyer	(124)	(22)	(302)	(125)	(0.5)

NPV: Net present value $M. (Brackets indicate negative values)
Note: Financial costs are based on the principles of build, own and operate, or build, operate and transfer
Source: Psi-Delta, 2003, p. 2.

Expected social impacts of not proceeding with the recycled water project in the area, were based on estimates of decreases in employment and agricultural production (Psi-Delta 2003). Psi-Delta (2003) surveys revealed that without the recycled water project there would be expected reductions in community size and adaptability, and associated negative physical and mental health impacts, reduced amenities and employment in associated industries and surrounding communities (Psi-Delta 2003). Although these were not calculated, these social aspects belonged in the social dimension of the IWRM model.

Minor positive on-farm impacts from recycled water were expected from potential increased farm size, values, crop intensities and innovations and continuity of family farms (Psi-Delta 2003, pp. 58-9). Social acceptance of infrastructure options and alternatives were not fully examined in the Psi-Delta study. For example, the hydrological report by GHD (2003) determined that aquifer recharge of the central Lockyer Valley although technically feasible, did not benefit all irrigators. Approval from State government (DNRM) and community also had not been sought at the time (GHD 2003). These unexplored social aspects of the SEQRWT study provided additional components of the social dimension for analysis with the proposed IWRM model in Figure 3-2.

3.3.3. Research Studies and Consultancies Post SEQRWT

Of the post SEQRWT assessments none employed ecological economic theory or principles such as TEV, full social cost pricing of common pool resources or the concept of ITWC. Few performed in depth environmental or social analysis outlined in literature in IWRM and models in Chapter 2.[12] Research and policy making at the time focused on single sector use of recycled water – urban, agriculture or environment (Hajkowicz et al. 2006; Psi-Delta 2003; Hamlyn-Harris 2003). The industrial sector was generally included in the urban sector in these research studies. Yet even where urban and rural sectors were considered (e.g. Connell Wagner 2005a, b), a comprehensive multidimensional study of all water users and sources in the Lockyer Valley was not undertaken.

These research studies and consultancies highlighted the problems with obtaining consistent estimates of rural water usage and demand for recycled water in the Lockyer Valley. A large proportion of these post SEQRWT research studies and consultancies relied upon the demand survey by GHD (2003), and water pricing estimates of Psi-Delta (2003). Subsequent studies (Connell Wagner 2005a, b; Hamlyn-Harris 2005; GHD 2004; Psi-Delta 2003) and policy decisions, such as the WCRWP proposal, relied on KBR (2002) estimates of demand and WTP for recycled water for the entire Lockyer Valley. No new insights were provided into the demand and willingness to pay for recycled water in the Lockyer Valley, until estimates by van Opstal 2012 emerged, in a study based on six farms, and later by QUU (2013) and Wolf (2013) using hydrogeological and demand modelling. These estimates have impacted on water policy decisions during this period as explained later in Chapter 4. The data from the research studies and consultancies was then analysed to determine its accuracy for use in this study.

3.3.4. Analysis of Data from Lockyer Valley Research Studies and Consultancies Rural Water Demand Estimates

According to the literature in Chapter 2, demand for water is estimated in a variety of ways using productive land estimates multiplied by crop type and average crop irrigation rates, actual water usage data (dam and groundwater allocations) and survey estimates of

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[12] The Socio Economic report into employment and production impacts was prepared by Psi-Delta Pty Ltd in 2003.

quantities based upon WTP and capacity to pay data. Lockyer Valley demand for irrigation water remained relatively constant throughout the year compared with other rural areas like the Darling Downs (Psi-Delta 2003). The estimates of demand for water in the Lockyer Valley varied with the method of estimation as shown in Table 3-3.

There are a few approaches to demand estimation. In one approach, the irrigated agricultural production in the SEQ Region was collated on a commodity-by-commodity basis for the Lockyer Valley. In a second approach, historical rural water access was enhanced using data collected in the Water Resource Planning (WRP) process for the SEQ catchments (FSA 2006). A third approach, relied on demand surveys of irrigators, generally responding to questions about quantity of demand and willingness to pay. These estimates were summarized in Table 3-3.

Using the commodity based approach based on 1996 ABS Census data, an estimate of water demand of 83,000 ML/p.a. was produced (FSA 2006). Under the approach using water entitlements in the water resource planning process, the estimate of current average rural water was 50,820 ML/p.a. (DNRM&W 2006b). The DNRM&W (2006b) rural water usage estimates were below commodity use at 32,180 ML/p.a. The reasons for the discrepancies ranged from variations in water use efficiency, climate variability, water pricing and crop selection and alternative water supplies (FSA 2006). The wide variation in rural water demand estimates was demonstrated in Table 3-3. The annual demand estimates of Psi-Delta (2003) and GHD (2003) were expected to be supplemented with rural demand for recycled water at an estimated price of $150/ML. At this price all crops still could make a positive return using gross margin analysis (FSA 2006). An average estimate of rural water demand for the Lockyer Valley over the decade, based on the estimate in Table 3-3, is 53,419 ML/p.a. Although these estimates varied, they reflected the increased rural water demand over time as expected from a growing agricultural region.

Table 3-3 Annual Estimated Rural Water Demand in the Lockyer Valley

Demand Estimates	ML/ p.a.
Halliburton KBR (2002) estimated existing rural water use	50,000
Psi-Delta (2003) estimated using a demand survey	30,944
NRM&E (2004)* estimated existing rural water use	56,100
GHD (2004) using estimates by KBR (2002) & NRM&E (2004)	45,400
RidgePartners (2004) entitlements & estimates	39,646
LWUF estimates and GHD (reported in RidgePartners, 2004)	52,665
Irrigators representatives estimate (reported in RidgePartners, 2004) (Irrigation area x application rate 15 000 ha x 3.5 ML/ha)	52,500
LWUF estimates* (RidgePartners 2004)	68,100
Preliminary IQQM Historical (DNRM& E)** modelling full allocations	41,268
DNR&M (2005)	74,000
DNRM&W 2006b	50,820
FSA (2006) average annual water use (ABS Census data 1996 commodity based)	83,000
Average	53,419

Source: adapted from RidgePartners (2004)

*Reported in RidgePartners, 2004
**DNRM&E estimates provided to GHD (2004) and does not include use of groundwater and overland flows

Given that the SEQRWT was such a pivotal study for the Lockyer Valley it was important to understand the data that was used to reach its conclusions. Psi-Delta (2003) and GHD (2003) estimates of Lockyer Valley rural water demand were based on new demand surveys conducted, and previous surveys conducted by City to Soil (Psi-Delta 2001). The estimates from Psi-Delta (2003) for Lockyer Valley annual rural water demand of 30,944 ML/p.a. were considerably less than those used in other studies. Irrigation water demand estimates provided by the KBR (2002), that formed the basis Psi-Delta (2003) water demand estimates, did not encompass the Upper Lockyer Valley (Upper Tenthill and Upper Laidley Creeks). This was due to two reasons - 1) the high cost of getting water to these areas and 2) these parts of the catchment have sufficient groundwater and are reluctant to pay for high cost PRW. These studies recognised the high capital infrastructure costs of extended pipelines and operating costs of pumping over varying elevations and distances. The estimated pipeline infrastructure costs would have exceeded the expected value-added returns of PRW to agriculture. Other cost effective, less energy-intensive options, including further gravity-fed pipelines, siphons, tunnels and created wetlands, were also not explored. If these costs were included these demand estimates may otherwise have been higher.

These areas were also excluded from the GHD (2004) study. Subsequent studies and policy decisions reliant on KBR (2002) or Psi-Delta (2001) water demand estimates, were also inadequate. Specifically, the SEQRWT (Psi-Delta 2003) findings based on these data did not provide accurate estimates of demand and WTP for recycled water for the entire Lockyer Valley. GHD (2004) also used the demand estimates of KBR (2002) and supplemented these with DNRM data (GHD 2004) as shown in Table 3-3.

RidgePartners (2004) reported the estimates from these previous studies and those of a survey of Lower Lockyer Irrigators by the Lockyer Water Users Forum Association Incorporated (LVWUF) and DNRM&E modelling. A low demand estimate of 41,268 ML/p.a. was provided by DNRM&E IQQM historical modelling, while the LVWUF estimate of demand for water was the highest at the time at 68,100 ML/p.a. RidgePartners (2004) estimate came in at 39,646 ML/p.a. - the second lowest demand estimate after the Psi-Delta (2003) estimate. Variations in groundwater licensing, monitoring and pricing of different water sources, impacted on the validity of these water demand and WTP results, and water supply options investigated. This variable access to and pricing of different water sources for example in the upper Lockyer Valley, also impacted on the validity of these water demand and WTP results and water supply options investigated. The demand for treated water in these areas was lower, because the price of alternatives (groundwater and dam water) was too low and did not reflect its scarcity to downstream users and the environment.

The DNRM (GHD 2004, p. 23) estimate was considered a reliable estimate of long-term average yield for the Lockyer Valley at 56,100 ML/p.a. This estimate was relatively high but, was soon exceeded if RidgePartners (2004) and FSA (2006) estimates were taken into account. When compared to the safe annual yield of the Lockyer Valley alluvial aquifers

(25,000 ML), all the estimates of demand for irrigation water were much higher than the demand estimates of the period (DNRW 2006a, p. 30). Working on the assumption that the Lockyer Valley was 80 per cent dependent on groundwater (42,650 ML per year), demand for irrigation exceeded this safe annual yield by at least 17,650 ML on average per year (DNRW 2006a, p. 30). Accordingly, these estimates for demand for rural water, influenced estimates of demand for recycled water. A review of recycled water demand estimates used in the various research studies and consultancies was then conducted.

Impact of this Data on Demand for Recycled Irrigation Water

The estimates of potential demand for supplementary irrigation water at various prices were governed by the price and availability of natural water resources in the catchment at the time (Wolf 2013). Various research studies and consultancies on the Lockyer Valley estimated the demand and WTP for recycled water in the area, and these estimates were then used to calculate the perceived costs and benefits of recycled water projects. It was apparent that a large number of research studies and consultancies since the SEQRWT, relied upon the economic analysis of the Lockyer Valley water demand, and capacity, and or WTP issues provided by the Psi-Delta (2003) report.[13] The adequacy of these estimates was investigated and answers to research questions 2 and 3 sought.

Table 3-4 Annual Estimated of Demand for Recycled Water in the Lockyer Valley

Study	**ML/ p.a.**
Psi-Delta & GHD (2003)	38,138
GHD (2004)	18,600-19,000
Connell Wagner (2005b)	29,930
Enhance Management (2005)	28,000*

*demand at price $150/ML used

Psi-Delta (2003) estimated demand for recycled water at 38,138ML p.a. at $150 and demand doubled at $75/ML (cited in FSA 2006, p. 68). Table 3-4. Demand fell a further

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[13] Industrial and commercial demand was not accounted for in the Psi-Delta surveys although an attempt was made to estimate demand for these users, based on interstate statistics (an extra 1000 ML each for these two uses) (Psi-Delta, 2003, p.27).

60-70 per cent if recycled water prices increased to $200/ML (cited in FSA 2006, p.68). GHD (2004) estimated demand for recycled irrigation water to supplement existing supplies for three case studies. These estimates ranged from 18,600 ML/p.a. to 19,000 ML/p.a. for the water piped directly to farms or to connect to existing irrigation schemes (including dams) respectively (GHD 2004, p. 24).

Hajkowicz et al. (2006) recommended the use of recycled water in the Lockyer Valley based on the economic returns from irrigated agriculture and demand and WTP estimates of GHD and Psi-Delta (2003). More recent demand estimates for recycled water (QUU cited in MEP 2013, p. 24) at given prices, still indicated significant interest in recycled water - particularly at prices less than $100/ML and even at $130/ML. Class A+ water was still of greatest interest to irrigators. At $130/ML, demand for recycled water was estimated to reach 2,500 ML p.a. and rise to 4,000 ML p.a. at $100/ML (QUU cited in MEP 2013, p. 24). Whether the level of demand at these prices was sufficient to cover cost of operating the recycled water scheme was a question addressed in the next sections of this Chapter.

Water Pricing and Estimates of WTP for Recycled Water for Irrigation

As the literature review showed in Chapter 2, the market price for water was determined by demand and supply factors. These supply factors included cost of supply, the number of water providers and more. Table 3-5 showed the diversity in irrigation water prices for the Lockyer Valley and elsewhere in Australia for comparison. Often, these high capital costs were offset with economic strategies involving farm subsidies, low-interest loans, grants, water rates and rate structures, free services and/or rebates.

Recycled water costs can exceed freshwater prices due to high sunk cost of wastewater treatment and distribution. The majority of irrigators in various scenarios investigated in the Lockyer Valley research studies and consultancies, were unwilling to pay more than $150/ML for recycled water (Halliburton KBR, 2002; Psi-Delta 2003).

Table 3-5 Comparative Irrigation Water Prices

SunWater Tariffs	$/ML (2008-09)	$/ML (2013-14)
Central Lockyer[14]	31.84 includes fixed & user charge	9.89[15]
Lower Lockyer	39.27 includes fixed and user charge	51.23
Morton Vale	n.a.	40.56
Warrill Valley	33.39	n.a.
Goulburn Murray Water - Shepparton	3,288.82 infrastructure fee/day 8.64 infrastructure use fee 62.29 casual use fee	n.a.
Macquarie	9.64 includes fixed and user charge	n.a.
Murrumbidgee	4.47 (includes fixed and user charge)	n.a.
Hunter	15.56 (includes fixed and user charge)	n.a.

Sources: SunWater (2006); Essential Services Commission (2008); IPART (2006).

As a result, the majority of recycled water options explored in the research studies and consultancies were ruled out on economic grounds (GHD 1992; Psi-Delta 2003; GHD 2004; Hamilton et al. 2005; Connell Wagner 2005a, b; Moreton Rural Service 2005; Enhance Management 2005; EHA 2006; Hajkowicz et al. 2006; FSA 2006; Turner et al. 2007; CH2M Hill 2008; Helm et al. 2009; Ward & Dillon 2009; Saxton 2009; Wallington et al. 2010; Psi-Delta 2010). Estimates of WTP for recycled water for rural use varied. Table 3-6.

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[14] Hardship Schemes are those that cannot achieve lower bound pricing including Central Lockyer Valley WSS, Lower Lockyer Valley WSS and Mary Valley WSS.

[15] A continuation of existing arrangements applies in the Central Lockyer Valley WSS where some fixed charges have been temporarily suspended due to the absence of specified volumes of customer water access entitlements (WAE).

Table 3-6 The Percentage of those Willing to Pay for Recycled Water in the Lockyer Valley

$/ML	50	75	100	130	150	200	250
Hamlyn-Harris 2003	60	52	41	n.a.	28	10	6
QUU 2013 (Gatton WWTP)	100	n.a.	n.a.	35	20	n.a.	n.a.

*Survey included 50 farms from the Lockyer, Bremer and Fassifern Valleys
Enhance Management demand estimates at various prices were the same as those reported by Psi-Delta (2003) as cited in FSA (2006).
Sources: FSA (2006)

Although no allowances were made for inflation changes, results of willingness and capacity to pay surveys varied. This economic information assisted in understanding the policy decisions made regarding recycled water in the Lockyer Valley. In 2002, $100–150/ML was the maximum WTP for recycled water by many Lockyer Valley irrigators (Psi-Delta 2003).

According to MJA (2012a), PRW cost in excess of $500/ML to process relative to current water maximum charges of $30/ML. The proposed water charges calculated by (Psi-Delta 2003, p. 29) included an entitlement fee ($1000/ML one off), connection costs ($4000 per customer), and water use fees ($150/ML p.a.). These were still below the full social cost of service (including non-use cost). The water use fees reflected the buyer's capacity to pay using gross margin analysis, given that capital and operating costs were higher for deeper bore water in the Lockyer Valley (Psi-Delta 2003, pp. 31-2). A study by MJA (2012a, p. 40) assessed the economic value of groundwater for consumptive and non-consumptive purposes as ranging from $50-200/ML for agriculture. This value was far less than for any other purpose, including use by households ($1,000-$5,000/ML) or industry ($2,000-4,000/ML) (MJA 2012a, p. 40). Another case study of the Lockyer Valley estimated groundwater values ranging from $382/ML to $977/ML (MJA 2012a, p. 40). These results reflected a more realistic value for groundwater, thus making choices about water alternatives such as recycled water, more attractive to potential users when priced closer to their full social cost.

To demonstrate the demand sensitivity to changing water prices, the SEQRWP revealed that if the price of water was reduced from $150/ML to $75/ML, demand doubled (Psi-Delta 2003, p. 23). A 60 to 70 per cent reduction in demand was observed if the water price increased to $200/ML (Psi-Delta 2003, p. 23). In other words, the higher the price the lower the demand. At the time of the release of the SEQRWP (Psi-Delta 2003), some Lockyer Valley irrigators did not pay for water. Instead, they paid for extraction costs (i.e. licences where applicable and pumping costs). This was only part of the TEV of the water.

In some scenarios in the SEQRWP, it was proposed that PRW be mixed with existing water in dams and aquifers, and therefore not priced as PRW. Users indicated in previous surveys (Psi-Delta 2003) that they were satisfied with low cost lesser quality recycled water in accordance with QLD recycled water guidelines. The most recent estimates of demand for the Class A+ recycled water from Gatton WWTP, were $130/ML for 2,400ML (QUU 2013 in MEP 2013, p. 24). At $50 demand rose to 5,800ML and at $250 demand fell to 800ML (QUU 2013 in MEP 2013, p. 24). At these prices, the project was still not commercially viable due to the estimated $15m for capital costs (QUU 2013 in MEP 2013, p.24). Regional benefits of $20m were estimated based on the avoidance of an estimated 15 per cent loss to production during drought (AEC 2013 in MEP 2013, p. 24). The required State subsidy was also unlikely to be forthcoming (MEP 2013). This study also reviewed the operating cost price of offering recycled water via the WCRWP (over $500/ML) and concluded that there was a low WTP for this water (MEP 2013, p. 25). Compared to the capacity to pay for recycled water in the Lockyer Valley, these WTP estimates also appeared low.

As with most of the Lockyer Valley water studies and consultancies, there was a gap between WTP and capacity to pay for recycled water. It was reported that 70 per cent of farms could afford to pay for water at $375/ML, and that Lockyer Valley farms had the best capacity to pay for recycled water (Enhance Management 2005 in FSA 2006 p. 68). Yet growers were only willing to pay $125/ML (Enhance Management 2005 in FSA 2006, p. 84). Where the minimum cost for recycled water is $120/ML, demand increased to 28,000ML (Enhance Management 2005 in FSA 2006, p. 84).[16] This estimate was not very reliable as the

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[16] Assumed an acceptable capital contribution from farmers of $150/ML

response rate for the survey was only 15 per cent of farms from all three areas of the Lockyer, Bremer and Fassifern Valleys (Enhance Management 2005 in FSA 2006, p. 84). Table 3-7. At these water prices, demand for irrigation water appeared to be very elastic (a large change in demand relative to a small change in price). These estimates differed slightly from demand in the Lockyer Valley at $150/ML reported by GHD (2003) and may be attributed to issues with the sample size.

Table 3-7 The Percentage of Those with the Capacity to Pay for Recycled Water[17]

Capacity to pay expressed as $/ML										
$/ML	0	75	150	225	300	375	450	525	600	675
Lower Lockyer a	89	89	89	78	67	67	56	56	44	44
Central Lockyer a	90	90	90	90	80	80	80	80	70	70
Upper Lockyer a	83	83	83	83	83	83	83	75	67	58
Lockyer Valley b	n.a.	n.a.	n.a.	75	n.a.	70	n.a.	50	n.a.	n.a.

Source a: DSDI QLD based on GHD 2003 survey data as reported in van Opstal (2010)

Source b: Enhance Management (2005)

Ability to pay was reported as 64 per cent of farms operating at full potential. They had positive gross margins when using 100 per cent of recycled water priced at $450/ML (GHD 2004, p. 24). The differences between these WTP estimates related to the amount of recycled water estimated as used on farms, and whether or not the farms were operating at full capacity or in drought (FSA 2006).

Van Opstal’s survey results were based on a sample of only six farms (only one of which is in the Upper Lockyer Creek area) and were conducted during a drought when town water and groundwater prices did not reflect total cost of supply. These factors seriously affected survey responses. More importantly, water property rights provided access to groundwater, limited only by the natural recharge rates of aquifers, and at relatively low cost to irrigators. This low-cost groundwater provided irrigators with a viable alternative to proposed relatively higher-priced recycled water.

Comparisons of national prices for recycled water and water alternatives was often

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[17] Capacity to pay was based on farm business performance (profitability).

provided as justification for lowering recycled water prices (Psi-Delta 2003). The SEQRWT (Psi-Delta 2003 p. 35) found that the average price of recycled water in Australia at that time was $216/ML. This comparison was unreliable, as it was based on non-standardised calculations of costs involved, and different policy arrangements in most cases (e.g. subsidy levels, infrastructure contributions and pipeline logistics) (Radcliffe 2003). Radcliffe (2003) attributed national variations in recycled water prices to differences in calculating the full cost of recycled water. He found these discrepancies were due to the omissions of the cost and source of capital and environmental externalities, profit levels, and pricing and marketing strategies, reflecting lack of integration of potable water, sewage, stormwater, and groundwater resources (confirmed by Connell Wagner, 2005a and Hamilton et al. 2005). Variability in supply cost and prices charged for recycled water around the nation and the world was also attributed to water subsidies.

In March 2010, the SEQ Water Grid Manager provided a review of the opportunities for purified recycled water market. The sound economic option of two-tiered pricing was recommended to overcome the issue of the gap between WTP and capacity to pay for recycled water as follows:

1. *Those involved with the production of low margin crops, e.g. fodder and lucerne, to pay at current rates (to the limit of their existing allocations) and be capped at a high reliability level.*
2. *Those who want greater volumes of water with good reliability of supply to pay for a first tier of supplementary supplies at approximately $300 /ML*
3. *Those who recognise that they have the capacity to pay up to $450/ML, paying for a second tier of supplementary supplies* (RDAIWM 2013, p. 18)

In this way those who have the higher WTP for guaranteed supplementary water in the area of the Lockyer Valley (such as those having a high capacity to pay as established in studies such as Enhance Management 2005 but on a broader scale) can receive recycled water in the future.

3.4. Synthesis of results from Research Studies and Consultancies

Post SEQRWT (2003) research studies and consultancies highlighted a number of unresolved issues and inconsistencies in IWRM in the Lockyer Valley including:

- An appropriate scale of IWRM;
- Stressed groundwater (lowering of water table and salinity issues);
- A range of unexplored options to close the ITWC such as recycled water from within the Lockyer Catchment - Gatton WWTP, storm water, wetland and aquifer recharge;
- Opportunities and incentives for recycled water use by other industries;
- Environmental and social assessment of catchment recharge options;
- Water demand, pricing and allocation issues;
- Multiple estimates of rural water and recycled water demand;
- High capacity to pay but low willingness to pay for recycled water;
- Lack of coordination of water infrastructure and access arrangements;
- Appropriate economic policy instruments;
- Capacity of soils to cope with recycled water;
- Co-management of groundwater;

Through the National Water Initiative (NWI) the Australian Government, States and territories, commissioned ACIL Tasman (2005) to investigate impediments to investment in recycled water schemes generally. The study investigated the perceived social, economic and environmental impediments to investment in Australian recycled water projects including the proposal to construct the SEQRWP. The impediments to investment in recycled water infrastructure highlighted in that report aligned with the dimensions of the IWRM model:

- Access entitlements to recycled water (economic dimension)
- Social and ‘community perception’ impediments (social dimension)
- Economic and financial impediments (economic dimension)
- Policy and regulatory impediments (policy dimension)
- Physical and technical impediments (economic/technical dimension)
- Environmental impediments (environmental dimension)
- Legal impediments (policy dimension)

The interactions and overlapping complexities of these issues were not explored in the ACIL

Tasman (2005) analysis. Yet the issues raised can be dealt with in the dimensions of the IWRM model, and the interactions between them explored further using this model. Another dimension that emerged from the ACIL Tasman study was the technical aspects of IWRM. In the IWRM model, the technical aspects could be dealt with under a variety of dimensions due to its dependency on capital investment, policy, social acceptability and environmental conditions. The addition of a fifth dimension for technical aspects or simply adding these components to the existing environmental dimension (via the integrated water cycle model imbedded within) could accommodate this. These aspects overlapped with other dimensions such as policy, which played a large role in encouraging technical innovation and development. For the purposes of this study, the technical dimension was dealt with in the ITWC model within the environmental and policy dimensions of the IWRM model as shown in Figure 3-2.

The legal aspects of IWRM emerging from the ACIL Tasman study added further depth and complexity to the institutional arrangements of the policy dimension in the IWRM model. See Figure 3-2. So too, the environmental aspects such as geophysical access to infrastructure and water alternatives necessarily involved the environmental dimension of the model. This was consistent with the complexity and overlap in dimensions in the IWRM models outlined in the literature critique in Chapter 2.

These were important components of the IWRM model also emerging from research studies and consultancies to be further investigated using the case study of the Lockyer Valley in Chapter 4. The ACIL Tasman (2005) study provided further components of the dimensions for review in Chapter 4 and for potential inclusion in the IWRM model:

- Investment risk and uncertainty (economic dimension);
- Lack of consistent evaluation methodologies (economic and technical dimensions);
- Inadequate physical access (technical and environmental dimensions); and
- Liability risks (economic dimension)

While the SEQRWT (Psi-Delta 2003) proposals for recycled water supply to the Lockyer Valley were rejected on economic grounds, other alternatives including industrial and commercial demand scenarios were not assessed. Psi-Delta surveys attempted to estimate demand for these users, based on interstate statistics (an extra 1000 ML each for these two uses) (Psi-Delta 2003, p.27). A more extensive analysis of demand and WTP by all potential users of recycled water may have altered the feasibility of the SEWRWT proposed schemes. Such a study was conducted by Connell Wagner (2005a). This study investigated the prospect of adding value to recycled water schemes through urban, industrial and residential use of recycled water prior to distribution to agriculture. This was the major difference between the proposed Ipswich Regional Recycled Water and Economic Structural Adjustment (ESA) Strategy, and previous studies undertaken. The study provided sound economic, technical, policy and environmental analysis of using recycled water from Ipswich for rural and other industry users in the Lockyer Valley and surrounding catchment.

The Connell Wagner study (2005a) also recognised the need for community input and Community focus groups associated with the *Ipswich 2020 and Beyond* project, to be engaged in communication and consultation activities related to the ESA Strategy. In particular, the study of water “values”, and the determination of sustainability criteria and their respective weightings to support strategic decision making, were conducted through a Deliberative Panel (Connell Wagner 2005b). The Panel adopted a collaborative approach to managing water supply options by selecting 8-12 community representatives from the existing *Ipswich 2020 and Beyond* community focus groups. This approach recognised the social value in maximising beneficial use of recycled water, with regard to quality of life as viewed by the community. Whilst the study contained no rigorous social analysis, it recognised the risks of underestimation of,

> *the value of water evident in an improved economy, an improved environment, or the social benefit of greener sporting fields and employment. It is very difficult to quantify these outcomes, but if the value of water is not determined, and the implementation is based solely on the Cost/Price Model, then this could jeopardise the progression of the whole scheme* (Connell Wagner 2005b, p. 18).

The Connell Wagner (2005b) report recognised QLD government requirements for triple bottom line accounting of economics, social and environmental impacts and proceeded to undertake complementary social and environmental assessment of preferred project options. The main report then performed some sensitivity analysis around economic social and environmental risks, but that was the extent of this approach. This study revealed significant social and environmental issues emerging from a collaborative approach to managing water supply options, that may impact on the sustainability and desirability of the IWRM projects, and these issues became components of the social dimension of the IWRM model in Figure 3-2.

Some consultancies performed social and environmental assessments that focused on reducing groundwater stress and improving water quality by providing recycled wastewater (FSA 2006; Psi-Delta 2003). The technical and environmental feasibility of secure, reliable irrigation water to the Lockyer Valley and Darling Downs proved inadequate for the project to proceed (Psi-Delta 2003). This research was not subjected to rigorous environmental economic analysis as outlined in the critique of literature in Chapter 2. A proper social cost benefit analysis, as outlined in the literature in Chapter 2, was required of all scenarios in these research studies and consultancies, as the economic cost effectiveness of a project was not the only criteria for such an assessment. Rigorous economic investigation of alternative recycling options was also necessary (such as recycling of storm water, local wastewater, wetland creation, wetland and aquifer). These analyses were not carried out at the time of these studies.

Further, the environmental and community impacts may alter the cost effectiveness of the project in the long run. The fundamental environmental and economic advantage for the Lockyer was seen as providing an alternative water supply to stressed and overused aquifers. Supplementary water for irrigation was also expected to offset the drought impacts and improve the water quality in the connected Brisbane River and Moreton Bay systems (Psi-Delta 2003). Production, economic and biophysical issues from investment in recycled water were investigated in many of these post SEQRWT research studies (Ellis & Wolf 2012; Wolf et al. 2010; Saxton 2009; Cox & Wilson 2005; Radcliffe 2003). These biophysical measures related to water balance, salt, clay dispersion, crop yield, drainage and run-off provided additional components for the environmental and economic dimensions proposed IWRM model in Figure 3-2.

Research on other major impediments to the use of reclaimed water by the Australian horticultural industry identifies additional components of the IWRM dimensions that can be included in the IWRM model:

- insufficient knowledge of impacts on market access;
- commitment to provide continuity of quality and supply to markets;
- implications of substitution of alternative water sources on security of supply;
- insufficient knowledge of food safety issues;
- inadequate understanding of consumer perceptions; and
- uncertainty about pricing of reclaimed water (Hamilton et al. 2005, p.182).

From the extensive range of Lockyer Valley research studies and consultancies, the extent to which these issues were addressed in post SEQRWT research, was investigated. Several themes emerged from these research studies and consultancies for further investigation including:

- Inadequate social analysis,
- Poor governance and institutional arrangements,
- Limited environmental assessments,
- Full economic analysis required,
- Insufficient and inconsistent data on demand for water,
- Inadequate investigation of full range of technical and non-structural options for supplementary water.

A brief summary of these shortcomings and their implications for the IWRM model was produced.

3.4.1. Inadequate Social Analyses in Lockyer Valley Research Studies and Consultancies

Social aspects of Lockyer Valley IWRM raised, but not thoroughly investigated in the various research studies and consultancies prior to the SEQRWP study (Psi-Delta 2003), could be further investigated using the IWRM concept model. Improvements to irrigation efficiency can be achieved through non-structural options such as improved education, training and self-management of the water and other resources. Some of these options involved changes to education and attitudes, regulation, on farm irrigation equipment and water pricing (GHD 2004, p.140). Although recommended by GHD (2004), few investigations of an integrated technical and non-technical approach to IWRM in Lockyer Valley were undertaken at that time.

The ACIL Tasman study (2005) highlighted the social issues associated with recycled water in the Lockyer Valley and elsewhere in Australia. Subsequent consultancies recognised the importance of improved social outcomes, community involvement (Fielding & Russell 2008; SGS Economics & Planning 2006; MJA 2007; FSA 2006) and co-management of rural water resources (FSA 2006). Recommendations ranged from: improved communication, information and coordination to facilitation of partnerships for water management (Fielding & Russell 2008; MJA 2007; FSA 2006); and clearer consistent water entitlements and irrigation water market involving irrigators (FSA 2006). The research studies and consultancies that involved irrigator surveys, focus groups and shed discussions recognised and incorporated the value of broad communication and community involvement in capturing the diversity of landholders' values, attitudes, behaviour and socioeconomic circumstances in rural communities (note attitudes to sustainable water use were investigated by Baldwin 2008; Emtage et al. 2006). Beyond this, a full social analysis of the Lockyer Valley IWRM and its impacts had not been undertaken, although the AEC (cited in MEP 2013) conducted a social impact analysis of the recycled water scheme in the Lockyer Valley. Findings of this report appeared in the MEP (2013) study but were not publicly available.

Hajkowicz et al. (2006) suggested supplying additional recycled water at a subsidised cost that reflected the range of social and environmental costs mitigated as a result of the project. The consultancy also advocated increased water prices to reflect the full costs of supplemented supply, and the introduction of charges for externalities arising from the use of water, to dampen rural water demand growth. A full social analysis was not conducted.

In other social analyses of potential recycled water use in the Lockyer Valley, a behavioural survey and workshops identified general community concerns about system risk and its influence on health risk of using PRW (Nancarrow et al. 2007; Alexander et al. 2008). Developing an informed basis from which the community and technical experts can communicate and discuss these risk issues, and cultivate a trusted dialogue and relationship in the early stages of the implementation of the scheme, was seen by respondents as very important in managing these concerns. For example, repondents requested readily available information on the PRW scheme. Social marketing and persuasion were not found to be effective in gaining community support for potable reuse of water (see Po et al. 2004).

Of these social analyses, only the study by Alexander et al. (2008) specifically mentioned agricultural use and concerns. The survey respondents included Lockyer Valley residents, who revealed their main concerns about using PRW is the cost to agriculture (Alexander et al. 2008). Rural landholders in the Lockyer Valley workshops were concerned with "distributive justice issues…. and concerns regarding potential impacts of the scheme on farmers' water allocations, the quality of PRW water and potential for increased algal blooms, and water affordability affecting agricultural production and viability" (Alexander et al. 2008, p.18). Agricultural producers particularly required greater certainty about the direct and indirect cost implications for their businesses (Alexander et al 2008, p. 21). Van Opstal (2012, 2010) undertook semi structured interviews to ascertain the irrigators' demand for water. Such studies highlighted the importance of continued irrigator involvement in determining the success of the planning and implementation of reclaimed water schemes. It was these planning and governance arrangements, investigated in these research and consultancies of the Lockyer Valley, that were analysed next.

The study by MJA (2012a), while extensive in terms of the economic and technical aspects, lacked social (equity considerations) and environmental estimation of the non-use value of groundwater (surface water to groundwater connectivity). It did refer to social analysis undertaken by DERM (2011 unpublished cited in MJA 2012a). In terms of the IWRM model, the inclusion of a broader range of components of the social dimension of IWRM, as revealed in the Lockyer Valley research studies and consultancies, was required. These inclusions provided for improved social outcomes from IWRM options. Some examples included the provision for the co-management of all water resources and the social analysis of wider options for providing irrigators with supplementary water (discussed by Baldwin 2008). The successful implementation of improved social options relied on the governance and institutional arrangements for IWRM in the Lockyer Valley.

3.4.2. Poor Governance and Coordination of Institutional Arrangements Exposed in Lockyer Valley Research Studies and Consultancies

The Lockyer Valley research studies and consultancies revealed a number of existing government programs or potential future actions required to achieve adequate and well-maintained water supplies and water quality management. Some of these recommendations were summarised in rural futures strategy for SEQ (DSDIP 2008, p.32), and included improved coordination of water management and water use efficiency (e.g. continuing the Rural Water Use Efficiency initiative that commenced in 1998).

These research studies and consultancies showed that improved coordination of water management was assisted by providing Lockyer Valley irrigators with guaranteed supplementary water (perhaps through recycled water). It was apparent in the research studies and consultancies, and the moves by government (Water Act 2000 and Moreton ROP) to introduce ROP for more of the water resources in the Lockyer Valley (i.e. groundwater), that completion and implementation of water resource operations plans for the Lockyer Valley and surrounding water catchments was required. Water sharing plans were also required to introduce flexibility for rural water users. Yet water sharing and trading suggestions may not encourage increase of environmental flows or adherence to the precautionary approach (Bjornlund et al 2013). The performance of existing irrigation schemes and distribution networks needed to improve, and more water meters were required to assist in informing water planning and management decisions. In the area of water use efficiency better education, incentives and programs would assist here (further discussed in Chapter 4).

Investigation into the legislative framework, institutional arrangements, power and decision-making, pricing and other factors impeding or facilitating investment in potable purified water facilities was undertaken by MJA (2012b, p. 3). Using the WCRWP and two other case studies the MJA (2012b) research identified issues relating to:

- Timing of key decisions
- Decision makers and the information used
- Impediments and facilitating factors and how these were dealt with
- Scope for improvement in pricing and governance arrangements

The inadequate, complex and changing institutional and governance arrangements relating to water supply planning at the time, lacked transparency:

- No regional planning had been undertaken prior to the SEQRWSS. Although there was a water plan and related discussions
- Accountability, authority and financial capacity for water planning and supply were unclear and inadequate for the emerging challenge (e.g. state and local government entities on the SEQ Regional Water Supply Strategy committee often had conflicting incentives where urban water supply was concerned and the goal of revenue maximisation via increased water sales outweighed the goal of conservative water use).
- While initial construction of new water infrastructure was funded by both local and State government (depending on the infrastructure, a 40 per cent headworks subsidy was provided) infrastructure development costs rose during the state of emergency, such that the state government took over decision-making responsibility (MJA 2012b, p. 20).

An example of complexity and poor coordination of water institutions affecting the Lockyer Valley were the arrangements prior to 2013. The Queensland Water Commission (QWC) was established as an independent statutory authority in June 2006 under the *Water Act 2000*.[18] It was responsible for the securing safe and sustainable water for regional prosperity, lifestyles and healthy ecosystems (QWC, 2009).

The *SEQ Water (Restructuring) Act 2007)* aimed to improve regional coordination and management of water supply (QLD Government 2014 Chapter 1 section 3). It established two State Government owned bulk water entities (LinkWater and Seqwater) under the

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[18] The Water Resources Administration Act 1978 established the Irrigation and Water Supply Commission which later became the Queensland Water Resources Commission (renamed the Water Resources Commission in 1988 and became a business group within the Primary Industries Department in 1989). The Primary Industries Corporation was established, the Water Resources Commission was abolished and Water Resources Division of the Primary Industries Department was established in 1992 (Queensland Water Resources Commission).

control of the QWC. A third entity, the Water Grid manager then coordinated the production and transport of this water as shown in Figure 3-3 below. One of the main aims of the amendment was the delivery of high-quality purified recycled water via the WCRWP (QLD Government 2014). Queensland Urban Utilities has been the distributor of rural water to the Lockyer Valley under this system from 2010 (Harman & Wallington 2010).

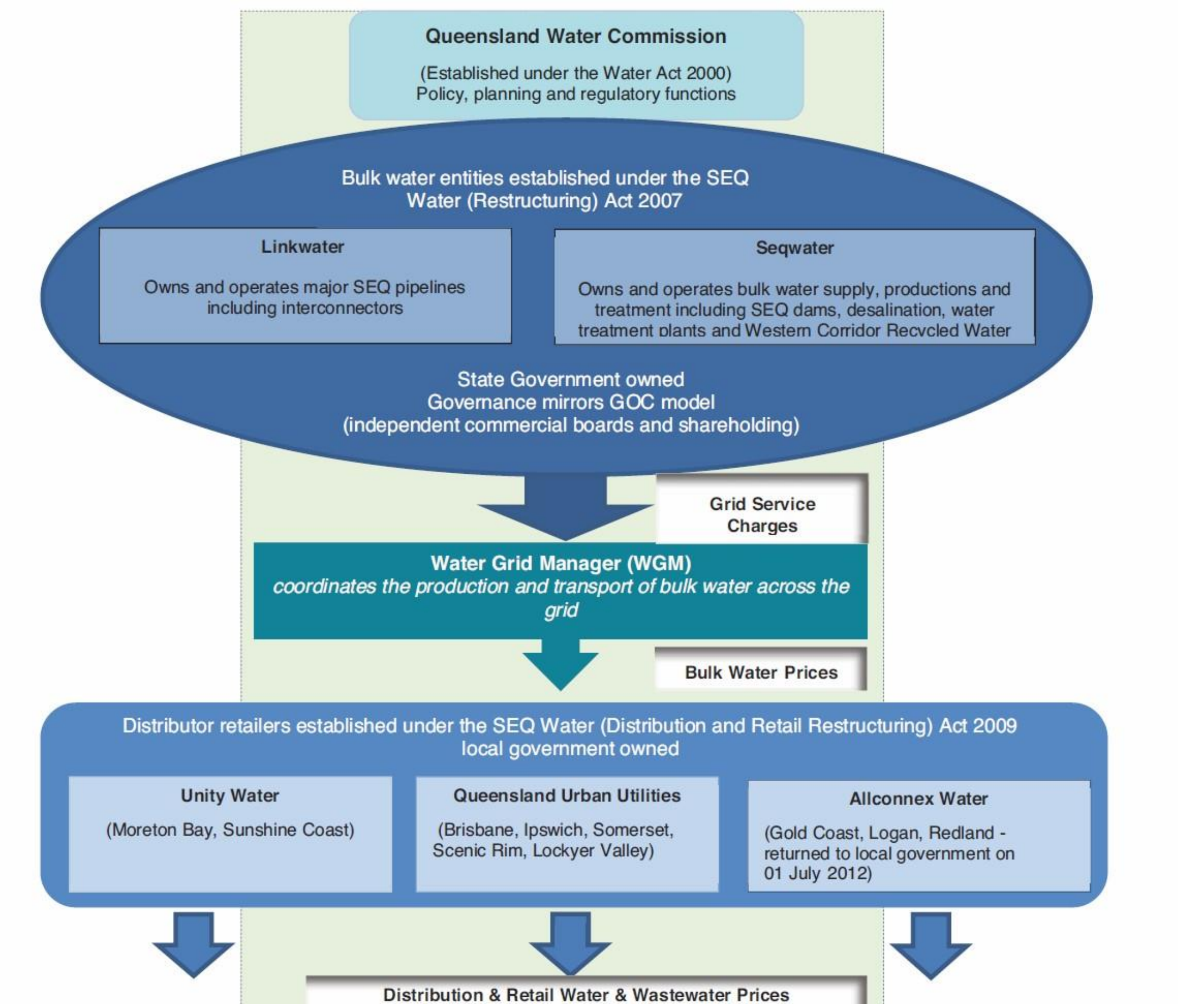

Figure 3-3 The SEQ Water Sector Pre-January 2013

Source: QAO 2013 p. 2-209

In 2013, the QWC was abolished and the Department of Energy and Water Supply became responsible for policy, pricing, planning and regulation (QLD Government 2015a). Figure 3-4.

LinkWater and the SEQ Water Grid Manager combined to form Seqwater with the statutory authority for bulk water supply and distribution. The QLD Competition Authority (QCA) has since recommended and monitored annual water prices. This has kept prices more in line with costs and maintained Seqwater accountability to its customers (QAO 2013 p. 2-212). SunWater remains the bulk water infrastructure developer and manager across QLD. These simplifications would have assisted IWRM during the time of the construction of the WCRWP and proposed extension to the Lockyer Valley prior to 2010. For example, the possibility of SunWater's eight channel irrigation schemes transitioning to local management arrangements is only now under investigation. These arrangements would mean the channel irrigation schemes can be owned and operated by local irrigators (QLD Government 2015b). There are no such schemes in the Lockyer Valley yet. The current aim of water industry regulatory reform is greater transparency and accountability for customers about their services (QLD Government 2015 a).

SunWater is created as a government-owned entity to own and operate regional water supply schemes across QLD. The QLD government now sets irrigation prices, negotiating with irrigators to meet their operating and capital needs (QLD Government 2015b). The complexity of the water pricing policy and the institutions responsible for these decisions contributes to the high cost of administering these arrangements and obscures the real costs of water to users (Harman & Wallington, 2010). The introduction of triple bottom line accounting for all water providers would strengthen the precautionary approach, and encourage social and environmental equity as per the new IWRM model.

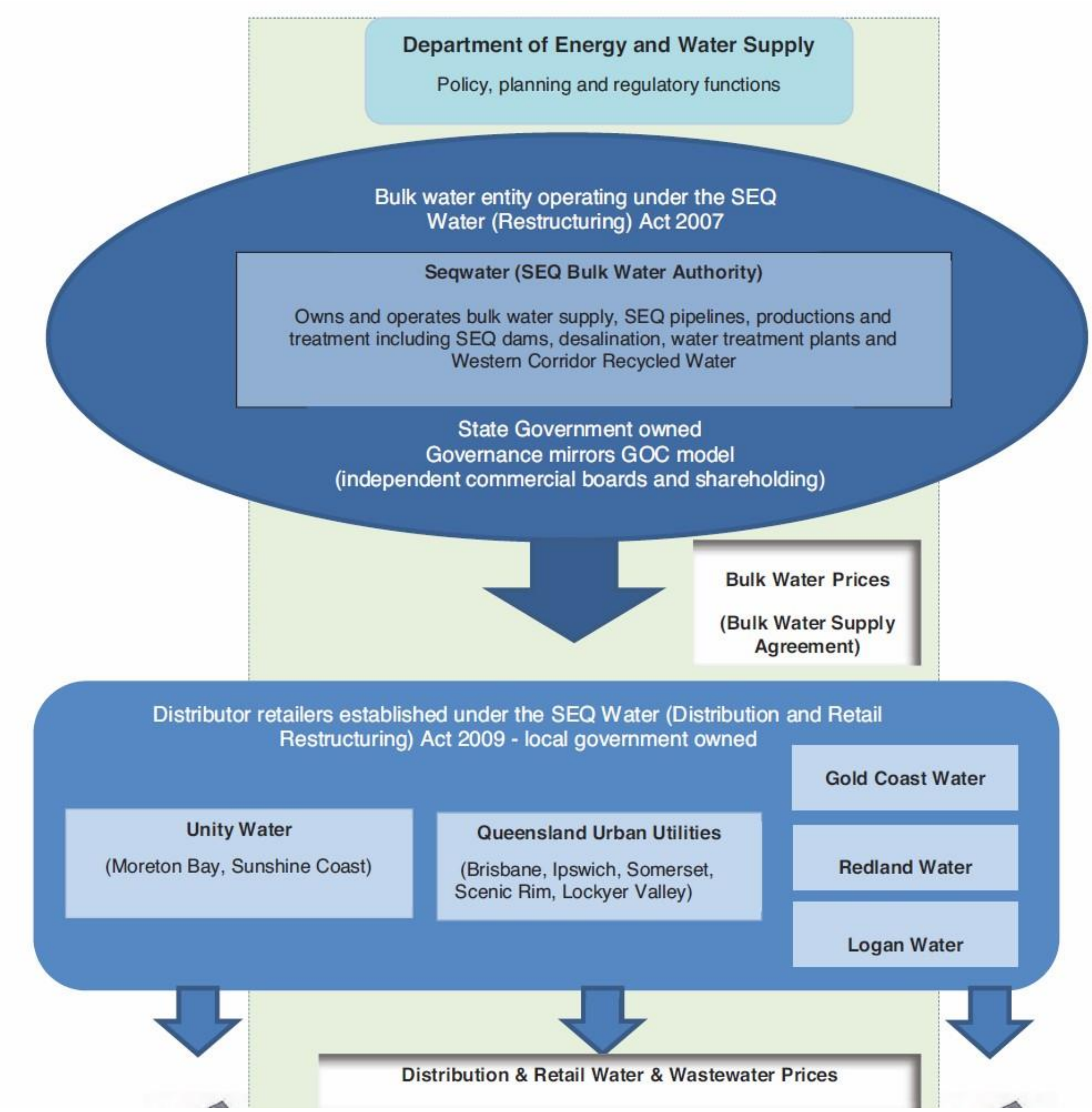

Figure 3-4 Restructured SEQ Water Sector post- January 2013

Source: QAO 2013 p. 2-212

3.4.3. Limited Environmental Assessments in Lockyer Valley Research Studies and Consultancies

As far as environmental assessment was concerned, there were few examples of these issues in the various research studies and consultancies. Some of these were reviewed. Scenarios testing the impact of irrigation with various classes of recycled water on Lockyer Valley soils, salinity and groundwater were found to be environmentally and technically feasible. Further environmental analysis and understanding were still required for long-term irrigation management using saline water until the complex interactions of salinity and dispersion effects are known in each case. The catchment wide environmental impacts of recycled water use were assessed in terms of reduced sedimentation flows from urban Brisbane into marine environments. Ellis and Wolf (2012) investigated the capacity of Lockyer Valley soils to cope with PRW and dismissed the risk of soil structural degradation, from the use of PRW for irrigation in the Lockyer Valley, as manageable by irrigators. More of the potential impacts of excess water storage in the Lockyer Valley were required in light of the findings of post 2010-11 and 2013 flood investigations (SEQ Catchments Ltd. 2013). One such example was the impact of excess water in dams, creeks and aquifers and the potential for flooding in the catchment. Whether as a result of natural rainfall or excess recycled water, these impacts will need to be planned for and managed. The environmental values of such investigations could be more thoroughly explored through TEV analysis of supplementary water recharge scenarios.

A few of the research studies and consultancies considered the components of the environment dimension (soils, biodiversity, groundwater, overland flow, water storage, drainage and quality) but did not go as far as valuing these environmental aspects or adopting a TEV approach. More extensive environmental impact assessments were catered for in the IWRM model.

3.4.4. Full Economic Analysis Was Not Conducted Despite the Plethora of Lockyer Valley Research Studies and Consultancies

A flurry of investigations into the economic importance of the vegetable producing regions (Henderson 2004, 2003; GHD 2004; CDI Pinnacle 2004) justified the imperative for preserving the future of vegetable producing regions such as the Lockyer Valley.
This research generated further research into water access (HAL 2003), water reliability (GHD 2004) and ultimately the SEQRWSS (RidgePartners 2004). Investigations into recycled water options such as the SEQRWP were compromised because a pricing policy was not established at the time. The only criterion was that it provided recycled water at marginal cost (Psi-Delta 2003). Only afterwards, when drought broke did pricing become an issue with QWC (MJA 2012b). These issues added depth and complexity to IWRM decision

making for the Lockyer Valley that required analysis using these components of economic policy instruments in the economic dimension of the IWRM model.

While analysis by Psi-Delta (2003) and AEC (cited in MEP 2013) reported that the Lockyer Valley Recycled Water Scheme (PRW available through the WCRWP) was commercially unviable due to the high capital cost, there may be other significant benefits in terms of deferred or avoided capital costs elsewhere (QUU 2013). There may also be regional economic benefits from extra employment (AEC cited in MEP 2013). In addition, the regional value of production would increase by approximately $20 million if the scheme goes ahead (AEC 2013 reported in MEP 2013, p. 24). Yet MEP (2013) reported that the amount of water available through the scheme is likely to be less (4%) and therefore the benefits to regional production from the Lockyer Valley Recycled Water Scheme are probably overestimated.

Work by DAE (2013) and MJA (2012a) assessed more of the TEV of these recycled water recharge options than previous research, albeit for groundwater only. The total direct use of water for Australian irrigated agriculture was estimated at an average of $200/ML (DAE 2013, p. 26). The non-use values of groundwater listed in this research but not valued included: the natural water flows for ecosystems and wetlands; ‘baseflow’ for surface water resources and supporting recreational activities at discharge sites, prevention of land subsidence and as a barrier against seawater intrusion into aquifers; and the option values individuals derived from maintaining or preserving the groundwater for their own future benefit, or for future generations (DAE 2013, p. 14). These Lockyer Valley research studies and consultancies provided the use value of recycled and above ground water. Further valuation was required, in research studies and consultancies, of the use value of Lockyer Valley above ground water and non-use values for all water sources. Knowledge of and application of these components in an approach to IWRM in the Lockyer Valley assisted in answering the three research questions in this study.

3.5. Conclusions about Data and Depth of Analysis from Lockyer Valley Research Studies and Consultancies

These added complexities of availability of data, variability of demand estimates and the gap between WTP for recycled water and capacity to pay, raised challenges for any IWRM approach to managing water in the Lockyer Valley. It appeared that few of the research studies and consultancies into options for IWRM in the Lockyer Valley included the level of interconnectedness and complexity between key components and IWRM dimensions catered for in the IWRM model. This study now looked at the way in which the three research questions were addressed.

1. The research studies and consultancies provided insights into the key components of the IWRM model required to close the ITWC and better manage water as a common pool resource. These components included:

- Consistent and transparent access entitlements to groundwater and recycled water (economic dimension);
- Social and 'community perception' impediments (social dimension);
- Economic and financial impediments including the use of TEV, full cost pricing of all water sources (economic dimension);
- Policy, institutional and regulatory impediments including co-management of water resources and removal of policy inconsistencies (policy dimension)
- Physical and technical impediments including comprehensive hydrological and hydrogeological studies and openness to non-technical IWRM options (economic/technical dimension);
- Assessment of environmental impediments and consideration these in all IWRM options (environmental dimension)
- Legal impediments to be resolved with consistent and clear policy changes (policy dimension)

A summary of these components was included in Figure 3-2. Although not included in any one research study or consultancy, the implications of these omissions were investigated further in Chapter 4.

In response to research question two, the research studies and consultancies failed to apply a range of sound principles and theory of ecological economics and hydrogeology to achieve these aims in research question one. The importance of full cost pricing, TEV and sound estimates of water demand, willingness and capacity to pay and an accurate hydrogeological study of the catchment were demonstrated in the Lockyer Valley research studies and consultancies in Chapter 3. The consequences of inadequate implementation of these principles and theories meant that the full range of options to solve IWRM in the Lockyer Valley were not explored (e.g. created wetlands, wetland recharge, stormflow reuse and the widespread education about these options). Each study focused on particular issues and no one study included all the components of the IWRM model that may explain why the water problems of the Lockyer Valley remain unresolved (e.g. social and environmental considerations).

The IWRM catchment scale conceptual model had the capacity to include that which the research studies and consultancies did not address in order to answer research question three. Most of these studies were not intended to look at IWRM. In order to aid the management of the demands on water from climate variability, population growth and intensification of agriculture in view of limited further viable above ground water storage options, reliable and consistent water demand estimates and pricing of all water substitutes were required to alter irrigation water demand and use. Water planning for increased population and agricultural production prior to embarking on IWRM schemes, such as the WCRWP, ensured the full range of environmental, economic and social benefits of all the options were considered. This approach promoted informed decision making that is based on broader socio-economic analysis than previous research studies and consultancies performed. The implications of inadequate social analysis, poor governance and institutional coordination, limited environmental assessment and inadequate economic investigations in the case of the Lockyer Valley were examined in the policy decisions in Chapter 4. Inadequacies such as institutional failure (e.g. in monitoring agency) led to lack of data to assist in informing water planning and management decisions.

When compared to the new definition of IWRM in section 2.3, Lockyer Valley IWRM decisions reflected in the background and research studies and consultancies revealed the process could have been more adaptive and participatory. While consultancies do not make

IWRM decisions, decision making could promote more coordinated development and management of water, land and related resources as common pool resources, in order to maximize the resultant economic, social and ecological welfare. Research and decision making processes at the time, did not pursue IWRM through principles of common, but differentiated responsibilities (equity), polluter pays or precautionary approach, nor use of triple bottom line accounting or use legislative instruments to address environmental issues effectively. These unresolved water issues and the appropriateness of the policy decisions in the case of the Lockyer Valley were analysed.

Chapter 4 Application of the IWRM Model to the Case Study of the Lockyer Valley

4.1. Introduction to the Lockyer Valley Case Study

A complex multidimensional analysis of IWRM in the Lockyer Valley was used to verify the key components of the IWRM model. This chapter applied the IWRM definition and conceptual model to the Lockyer Valley to assist in increasing understanding and resolving of the issues of managing water as a common pool resource and further closing the ITWC (research questions 1 and 2). Lastly, the IWRM model's ability to assist with managing the changing demand on water in the Lockyer Valley was tested (research question 3). Some examples provided during interviews conducted for this study demonstrated the key components of the IWRM model and the complexity and interrelatedness of IWRM dimensions.

The approach taken in this Chapter combines the inductive approach (Goddard and Melville 2004) taken in analysing the literature from Chapter 2, findings of the Lockyer Valley research studies and consultancies from Chapter 3, with publicly available data and data from eight interviews with irrigators conducted for this study. In a deductive approach (Monsen et al. 2009) these interviews provided themes for discussion in this Chapter summarised in Table 4-1.

These interviews were conducted following heavy rainfall and flows from the ranges in 2010-11 breaking the millennium drought. This rainfall replenished the Lockyer Valley groundwater, stream and dam levels, and since then there has been no urgency to supplement the natural water cycle with recycled water. New issues emerged including concern shifting to recovering market shares lost to southern markets during drought. The interview questions consisted of both open ended and close ended questions. This ensured that quantitative data on willingness to pay and qualitative data on what irrigators believe they are going to pay for PRW, was collected (see Appendix 1 for interview questions). The snowballing technique (Biernacki & Waldorf 1981) was used to reach irrigators for interviews – each interviewee recommended additional contacts.

Interviews continued until the saturation point was reached, after eight interviews (Beiten, in

Gubrium et al. 2012). At this point it became clear that, on the subject of WTP for recycled water, irrigators were no longer prepared to pay for recycled water under the current policy environment (unmonitored groundwater usage and pre-existing surface water allocations).

In keeping with the iterative approach used in this study, the methodology employed in this Chapter used examples from the Lockyer Valley policies to provide support for, or evidence that contradicts the new definition and approach taken in the IWRM model. By considering IWRM issues in an interrelated way, this analysis confirmed the key components required for successful IWRM. The role of the key components of the IWRM model was then tested using some key policy making decisions concerning the Lockyer Valley. The results from semi-structured interviews raised themes for discussion in this Chapter listed in Table 4-1. These interviews were used to confirm or refute the various findings of previous surveys in research studies and consultancies in section 4.2.

Table 4-1 IWRM Themes provided by interviews which were supported by data from research studies and consultancies

IWRM Themes	Interview support	Research & Consultancy support
Water Pricing	Landholders are not WTP for recycled water (unless they already pay for water and it is comparable)	yes
	Landholders desire secure and guaranteed water supply and that is what they will pay	yes
	Landholders feel they already pay for water security in higher land prices and it is easier to move to/rent land with better water access than it is to connect to improved water access	no
	Landholders recognise the amenity/environment value of recycled water but are not prepared to pay for it	no
Derived demand for water	Demand for recycled water is driven by demand for commodities, (un)available export market, acceptability to produce buyers and available competitively priced water substitutes.	somewhat
	Smaller irrigators demand for water is not assessed in Psi-Delta (2003) estimates.	yes
Environmental assessments	Recognise contamination of recycled water is a risk that landholders are not prepared to take.	yes

	Full environmental (hydrogeological and recharge) assessment are required prior as some dams have natural catchment recharge already.	somewhat
Adequate social analyses	Irrigators are still pursuing co-management of the groundwater.	somewhat
	Involvement of a broad range of uses and users in all sectors is required.	somewhat
Policy	Inconsistent governance and coordination of institutional arrangements prior to introducing an IWRM strategy such as the WCRWP.	no
	Groundwater monitoring is still not implemented outside the Central Lockyer Valley.	yes
	Adequate understanding of the hydrogeology of the extended catchment boundaries.	no

4.2. The Issue of Scale in the Lockyer Valley IWRM using the IWRM Model

The literature in Chapter 2, and research studies and consultancies in Chapter 3 showed that the appropriate spatial scale for the Lockyer Valley water catchment included the Warrill, Bremer and Fassifern Valleys and downstream Brisbane River Valley. The principles and theory of hydrogeology provided support for this IWRM decision by explaining the ITWC – inclusive of all its water sources and users.

Accordingly, the extended Lockyer Valley water catchment consists of the Lockyer Creek and its tributaries, overland flows connecting aquifers, wetlands and sources of recycled water. Unlike the local government area showing the Lockyer Valley Regional Council, the extended Lockyer Valley water catchment goes further than the council boundaries. Based on hydrological studies, the extended catchment area includes the connections upstream to the Clarence-Moreton Basin, via the Surat Basin through the Kumbarilla Ridge and the Condamine catchment (DERM 2011, p.4). The catchments of the Condamine, Bremer Valley and Teviot Brook are also connected this way. Downstream areas include the Warrill, Bremer, Fassifern and Brisbane river catchments (Raiber et al. 2012). The urban-rural connectivity to upstream Toowoomba and downstream Brisbane River and its users were not investigated nor dealt with thoroughly enough in recent IWRM policy making decisions for the catchment. Where recycled water availability was proposed, these parts of the catchment were included in the IWRM model.

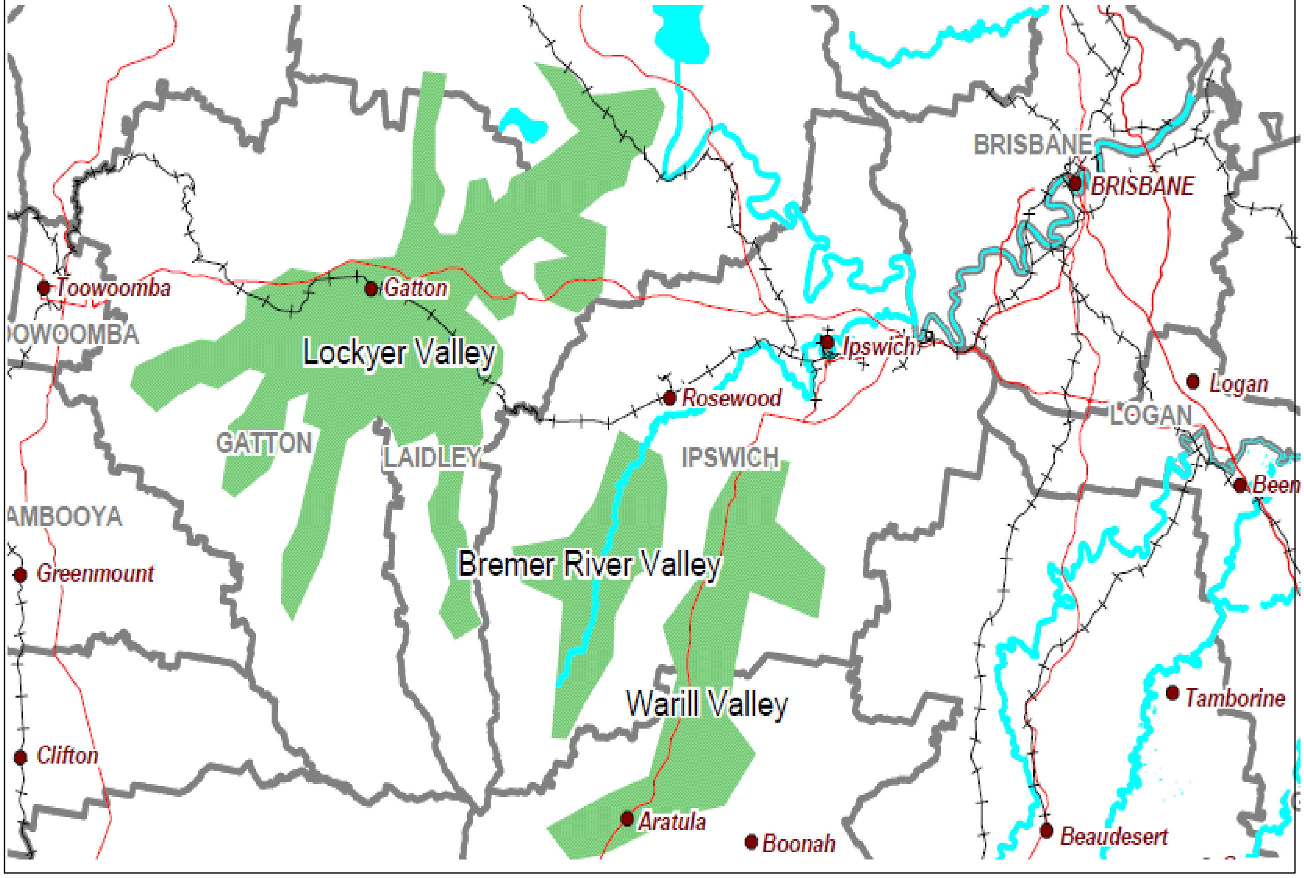

Figure 4-1 The connected water systems of the Extended Lockyer Valley Catchment Area Source: Psi-Delta (2003, p.38).

Hydrological modelling undertaken in parts of the Lockyer Valley confirmed the assumption of the extended Lockyer Valley catchment (Wolf 2013; Pavelic & Cox 2011; Wolf et al. 2010; Cox & Picarel 2010; Galletly 2007; Cox & Wilson 2005; Wilson 2005; Halliburton Kellogg, Brown & Root (KBR) in 2002). The complexities of the hydrogeological connections were beyond the scope of this study. See further research by Cox & Raiber in Wolf 2013. Research on geomorphology and aquifers also confirmed these connections (Galletly 2007; ANRA

2007b, c; Wilson 2005; McTaggart 1963). Some of the research studies and consultancies extended to the Darling Downs, Warrill-Bremer and Fassifern regions (GHD 2003). None of the research studies and consultancies based their economic, social and environmental analysis modelling of the areas of the Brisbane River Valley, that would benefit from downstream recycled water recharge and reduced ocean outflows shown in Figure 4-1

Given the role of wetlands in the hydrogeological profile of the Lockyer Valley, wetland policy was also an important consideration of the IWRM model. In the Lockyer Valley local government area alone 3.3 per cent of the area is wetland (DEHP 2013). Based on the literature in Chapter 2 the potential for water storage and recharge of connected wetlands, streams and aquifers were also important considerations to be investigated in IWRM decision making. Many of the research studies and consultancies included the connected catchments of the Warrill, Bremer, Fassifern and Brisbane river catchments and tributaries of the catchments (Psi-Delta 2003; Hamlyn-Harris 2003; GHD 2004; CDI Pinnacle 2004; RidgePartners 2004; Connell Wagner 2005a,b; Enhance Management 2005; Hajkowicz et al. 2005; EHA 2006; FSA 2006; MJA 2007; Saxton 2009). None of these studies included wetlands or basalt aquifers of the Toowoomba ranges or reinjection of aquifers or wetlands. Investigation of recycled water use for the water catchment area by UWSRA (Wolf 2013) did not incorporate the surrounding areas of Warrill and Bremer Valleys. Few included the upstream catchments, underestimating demand for the entire catchment and WTP in these research studies and consultancies.

The Lockyer Catchment Association performed a preliminary study of Lockyer Valley wetlands in 2003, but the opportunities to create or use natural wetlands to store and recapture treated water required further investigation and inclusion into IWRM policy making. The IWRM model incorporated the social, environmental, economic and policy dimensions of wetlands in IWRM decision making. In recognition of the some of this hydrological connection to nearby water systems, the existing Moreton Resource Operations Plan (ROP) 2009 was amended in 2014, to combine the Central Brisbane River Water Supply Scheme with those of the Warrill and lower Lockyer Valleys (DNRM 2014a).

As of 2014, the Queensland Government has supported the whole-of-catchment approach to water management in QWater – the 30 Year Water Plan for QLD (DEWS 2014). The SEQ water supply area in the Plan has been extended from Noosa, south to the New South Wales border and west to Toowoomba including shires reliant on water from the Wivenhoe – Somerset Dam system or the Mary River (DEWS 2014). Whether the IWRM policy decisions emerging from QWater recognise the hydrogeologically connected areas of the Bremer, Fassifern Valleys, and Toowoomba and of lower Brisbane River as part of the Lockyer Valley water catchment, remains to be seen. The Government recognised the need to reduce overlap and better coordinate water sector regulations in QWater (DEWS 2014 Section 6). This policy direction was in keeping with literature reviewed in Chapter 2 and the approach taken in the new catchment scale IWRM model developed in Chapter 1 (DEWS 2014).

With groundwater mapping improvements the importance of other environmental factors and interconnections between rainfall, overland flow patterns, evaporation and transpiration patterns, geography, geomorphology and soils, the boundaries of an extended Lockyer Valley water catchment became clearer. These water sources were depicted in the ITWC model (Figure 1-1). This approach combined with the extended view of the Lockyer Valley water catchment, were major contributions of the IWRM model (answered research questions 1 and 2). The extended view incorporated more water sources and users than did any other approach used in current Lockyer Valley IWRM policy making decisions (research question 3).

Based on the estimates of demand and WTP from the extended catchment it was expected that IWRM decision making using the IWRM model would be more accurate (research question 2). Although there were major operational issues with the extended catchment approach taken in the IWRM model. This approach required coordination of various regional shire councils and budgets. There were anomalies in the case of SEQ, where it was the only region in Australia where urban (including industry) water use exceeded the nearby rural water use (FSA 2006; DNRMW 2005b). There may be consequences for the coordination and operation of urban-rural IWRM in this case. These operational issues remain outside the scope of this study, but were important considerations in the social and policy dimensions of

IWRM. Evidence from international cases in Chapter 5 offered some insights into how this has been done internationally.

In summary the case study of the Lockyer Valley demonstrated the difficulties associated with IWRM decisions for the region without adequate multidimensional information about ITWC at that scale. A multidimensional conceptual model of IWRM enabled a broader picture of water sources, users and uses that govern IWRM decision making. This next section addressed the issue of groundwater stress in the extended catchment in the Lockyer Valley.

4.3. An Approach to Managing Stressed Groundwater in the Lockyer Valley with the aid of the IWRM Model

In section 4.2 the groundwater problem in the extended Lockyer Valley was apparent through an understanding of the hydrogeological connections between Lockyer Valley and surrounding aquifers and other water sources. As outlined in the literature in Chapter 2 and research studies and consultancies in Chapter 3 (data chapter), knowledge of this interconnectivity governed water infrastructure placement (weirs, bores and channels), water pumping rates, water allocations and even crop choice, irrigation and farming practices (soil quality and permeability). These findings about the connectivity of water systems – the ITWC, linked the environmental dimensions of the Lockyer Valley IWRM to other dimensions in the IWRM model. This knowledge about aquifers informed the social, economic and policy decisions on supply and management of groundwater, its use and quality and indeed impacts on all water sources in the catchment as depicted in the ITWC model.

An example of the importance of understanding hydrogeological connectivity and its impact on scale of IWRM had its foundations in the alluvial water in the Lockyer Valley that derive from base flow in basalt aquifers in the Main Range upstream (Galletly 2007, pp. 231-2). It was apparent that salinity did not stem from ‘cross-formational flow’ from sandstone formations in the Lockyer Valley, as previously believed (DNRM 2005a; Talbot & Dickson 1969). Investigations into the natural recharging of Lockyer Valley water systems revealed that without prolonged periods of rain these water systems are unable to balance agricultural demand for water (Galletly 2007). Lockyer Creek and groundwater depletion leads to the streams becoming ephemeral (Galletly 2007). During the 2000-2009 drought, research studies and consultancies urgently seek solutions to the low levels of water available for irrigation in Lockyer Creek, its tributaries, dams and groundwater. Yet it was not until research by Galletly in 2007, that this hydrogeological connection using a baseflow model of the Lockyer Valley aquifer system was confirmed. This knowledge influenced the findings and recommendations of the SEQRWT (Psi-Delta 2003). The urgency of reduced groundwater use and finding supplementary water sources would have been magnified if this hydrogeological information had been available at that time. This information showed that the groundwater yield and recharge process in the Lockyer Valley extends the catchment further than the original research studies and consultancies suggested. Thus an extended catchment view of the Lockyer Valley as suggested in the IWRM model was justified (research question 1).

The concerns raised in the research studies and consultancies, regarding mobilisation of salinity plumes following recharge with recycled water, were later allayed by research by Wolf (2013). This evidence supported the use of artificial aquifer recharge in salt affected areas to safeguard groundwater levels in the Lockyer Valley. These added benefits of the WCRWP were unknown at the time of the SEQRWT. The research however, flagged concerns about clay dispersion following recharge with PRW (Wolf 2013). These findings contributed to answering research questions one and two – confirming that the application of sound principles and theory of hydrogeology assisted in the development of IWRM catchment scale conceptual model to achieve the aims of further closing the ITWC and better managing water as a common pool resource. This knowledge and findings explained the policy focus on recycled water options in the Lockyer Valley over the past two decades and its role in potentially expanding the ITWC to include recycled urban water supply. The lack of understanding about the extended catchment hydrogeology and wider impact from groundwater on the ITWC explained why the policy of recycled water remains unimplemented in the Lockyer Valley.

Another example of hydrogeological knowledge driving policy decisions is the placement of dams, weirs and pipelines throughout the Lockyer Valley. Several artificial recharge weirs were constructed throughout the Lockyer Valley in the 1970s. These weirs were intended to retard the flow of surface water and increase the amount of recharge of alluvial aquifers below the stream channels (Baldwin 2008; Wilson 2005). These decisions were based on the conventional unofficial model of recharge and discharge of water and hydrological processes in the Lockyer Valley (DRM&W 2006; DPI-WR 1994; QWRC 1982). The belief at the time was that recharge in the area derived from a combination of natural flows and releases from water storage areas (ANRA 2001). As low rainfall continued after weir placement and water levels in aquifers and creeks drops further, obtaining the correct information on the natural recharge process for aquifers and streams in the Lockyer Valley became essential to the placement of infrastructure and success of IWRM policy decisions (QWC 2010; Galletly 2007).

Groundwater and stream levels did not recover from intermittent rainfall or even from heavier more frequent rainfalls at those extraction rates for irrigation (Halliburton KBR 2002; Psi-Delta 2003). Environmental and scientific knowledge just did not support the continuing drops in groundwater after weirs were placed (Galletly 2007). Excessive unregulated extraction of upstream irrigation water continued to deplete downstream aquifers and jeopardises irrigated farming in the Central and Lower Lockyer Valley (Galletly 2007). Literature in Chapter 2 referred to this as the “tragedy of the commons,” requiring careful management and consideration of sustainable groundwater yields in allocations. The “tragedy of the commons” was exacerbated by inequitable regulation of some areas of Lockyer Valley groundwater (e.g. lower Lockyer Valley). Galletly’s baseflow model demonstrated that the alluvial aquifers in the Lockyer Valley were recharged by baseflow and storm flow from basalt aquifers on the Main Range north west of the Lockyer Creek (Galletly 2007). Galletly (2007) further revealed that in the Central and Lower Lockyer the aquifers sloped diagonally away from creeks and that there was minimal recharge of sandstone aquifers in the Lockyer Valley by deep percolation from rainfall, given this hydrogeology and low rainfall patterns. Understanding of the baseflow model potentially changes the way the ITWC is managed in the Lockyer Valley and can better informs IWRM policy decisions.

One of these policy decisions was about placement of weirs and pipelines in the Lockyer

Creek and tributaries. The Lockyer Creek and tributaries had become influent (recharged inadequately by short infrequent stormflow) and required prolonged base flow recharge of aquifers throughout the Valley (Galletly 2007, p. 25). The nature of derived demand for irrigation water and other complex environmental, economic and social dimensions impacting on policy decisions about infrastructure placement should have been considered. The sustainable yield of the Lockyer Valley water catchment was still being exceeded. Groundwater outside the Central Lockyer Valley was, and is, still not metered. This resulted in inadequate monitoring of the water Plan. Both were due to the lack of support by some local irrigators, to regulation of some parts of the Lockyer Valley's groundwater (MEP 2013). Using the IWRM model, policy on monitoring, licensing and managing groundwater to take such environmental (hydrogeological and technical) and demand considerations into account, could close the integrated water cycle with additional recycled water supplies and lower allocations from the natural yields in the catchment.

This explained how aquifers had been used unsustainably for agriculture and largely depleted prior to the flood events in SEQ in 2010-11 (Natural Resource Management Standing Committee 2002). The early warnings in 1986 that the Central and Upper Lockyer groundwater levels had reached their sustainable yield threshold were underestimated (National Land & Water Resources Audit 2000). The fact that the Lockyer Valley had been listed as the fifth most stressed groundwater system in Australia (DNRM 2005a) was also ignored. The need to correct overstressed groundwater was apparent in the NWI (NWC 2004) objective to restore overused groundwater levels to sustainable levels (DNRM 2005a). Yet the urgency of stressed groundwater the lower Lockyer Creek area remained unaddressed by policy makers.

The various research studies and consultancies underestimated the severity of the situation based on the existing knowledge of the groundwater to surface water connectivity at the time. The main option investigated at the time focused on recycled water demand and WTP estimates from larger more central Lockyer Valley irrigators. In an interview conducted for this study here, a lower Lockyer Valley irrigator explained these estimates, "... the LWUF had such a large input into the previous studies that their views on recycled water demand and willingness to pay really reflected large producers' views only" and that, "non-LWUF members, particularly small landowners, were not encouraged to attend sessions and had vastly different views on recycled water" (Interviewee 1, 2011). Further he stated that, "We would not pay for recycled water because our margins were too low already. I move to water and rent small land holdings (with water rights) when necessary instead" (Interviewee 1, 2011). These views emphasised the importance of understanding the hydrogeology of the area, the level of local knowledge (social capital) overlooked in policy making and IWRM decision making regarding groundwater stress.

The policy hurdles relating to monitoring and use of groundwater did not appear to be well understood in the Lockyer Valley research studies and consultancies. Under ROPs, land and water titles are separated where hydrological data are considered adequate to specify water security and environmental flow objectives, and where the community supports such trade (Tan et al. 2012, p. 39). ROPs are used by State Government (DNRM) to implement monitoring requirements, ecological outcomes, strategies for improved environmental flow and water security objectives under water trading (Tan et al. 2012). At the time of the SEQRWP (Psi-Delta 2003) and many other research studies and consultancies, an ROP (and water trading) for the Lockyer Valley did not exist. The Moreton ROP was invoked after the construction of the WCRWP – this delay created a vacuum in the region's policy and planning for the Lockyer Valley (DERM 2009).

Social aspects of the water problem become apparent as the drought worsened. Options for the supply of recycled water for irrigation in the Lockyer Valley were again raised by the DDV 2000 and C2S groups. In 2005, DDV 2000 made a submission for funding through the South-East Queensland Infrastructure Plan and Program, and the LWUF investigated the likelihood of Wivenhoe Dam water for agricultural use in the Lockyer Valley. Their proposal included co-management of groundwater in the Moreton Water Resource Plan and pipeline infrastructure for transporting recycled wastewater to the Lockyer Valley for irrigation. The prospect of co-management of recycled water for irrigation was not investigated at the time although some academic studies dealt with this (Baldwin 2008).

Societal acceptance is important in the use of recycled water and recharge of natural catchments in IWRM (Higgins et al. 2002). Potential risks of PRW use in the case of SEQ WCRWP were addressed (QWC 2010), but as with all recycled water projects the risks raised in literature in Chapter 2 persisted. These risks of treatment malfunction, temperature and pulse changes and pulses at injection points, the ‘precautionary principle,’ lack of nutrients in PRW for irrigated agriculture, and the impact of infrastructure placement could have been managed better through education and dissemination of information at the time of the SEQ WCRWP. The proposal concerning pumping of PRW directly to farms rather than aquifers, brought with it the risk of paying for, but not using this PRW in times of high rainfall. Through the multidimensional approach of the IWRM model, the social components of groundwater use, recharge and connectivity were addressed. For example, in interviews for this study, a member of the LWUF stated that,

> *Lockyer Valley farmers will never accept recycled water into aquifers [foreign material contaminating their aquifers]. There would be marching in the street if Government tries to introduce this* (Interviewee 6, 2011).

Further he claified that,

> *Farmers in the Lockyer Valley will not accept recycled water into aquifers because:*
>
> 1. *Equity concerns regarding water sharing (everyone will have it and yet some have not paid as much for their land as others but would have same access to water as those who paid higher land prices)*
> 2. *Land prices currently reflect water availability (higher land prices reflect better access to water) and community perception (about recycled water)*.

A participatory approach to decision making in the IWRM model addressed this requirement. Another irrigator in the Lockyer Valley confirmed that, “although technically putting recycled water into aquifers is possible it is not acceptable” (Interviewee 7, 2011). These social components of public acceptability and awareness of the benefits and risks deserved greater attention in research studies, consultancies and public policy making at the time that policy decisions about the WCRWP were made. An upper Lockyer Creek irrigator and council representative stated that since the drought had passed, he was “not interested in recycled water since it is more isolated and expensive to pipe the water there" (Interviewee 2, 2011).

A Lower Lockyer Valley irrigator revealed that, "some irrigators who already pay for water may be interested if the price is right and salinity managed." He explained that, "conductivity [salinity] is very important to crop choice because low conductivity can make cropping unviable" (Interviewee 3, 2011). Some aquifers became unusable due to salinity. One proposal included pumping PRW direct to farms and not aquifers. The risks there included the management of PRW when it is not needed (i.e. paid for, but not used). These were important socio-economic inputs relevant to water use. This hydrogeologically relevant information was vital to IWRM policy decisions, and were incorporated in the approach taken in the IWRM model. The uncertainty that also existed at the time of the SEQRWP reflected the inadequate understanding of the impact of recycled water on salinity. This gap in knowledge impacted on the estimates of demand for recycled water.

The question of ownership of and access to groundwater resources, and recycled water from stormwater and greywater sources remains unresolved in the Lockyer Valley. As demonstrated in Chapter 3, groundwater throughout the Lockyer Valley historically, had not been fully metered or licensed and had been over allocated (Helm et al. 2009). Some examples of IWRM policy were considered with regard to supplementing and recharging stressed Lockyer Valley groundwater levels.

As previously mentioned under the *Water Act 2000*, only the groundwater in the Central Lockyer Valley is regulated. The remaining areas of the upper and lower Lockyer Valley are unmetered, unallocated and overused even after update of the Water Resource (Moreton) Plan 2007 (DERM 2011). To assist with the long term plan to implement widespread groundwater metering and more accurate water allocations, the Lockyer Valley area has since been subdivided into:
(a) Central Lockyer Creek (implementation area 1);
(b) Upper Lockyer Creek (implementation area 2);
(c) Sandy Creek (implementation area 3); and
(d) Lower Lockyer Creek and Buaraba Creek (implementation area 4). See Figure 4-2.

The policy inconsistency regarding groundwater monitoring and allocations has long term management implications for the groundwater in the Lockyer Valley. Legislation exists to license and allocate groundwater under the water regulation as follows. A water licence is required “to take or interfere with artesian water for purposes other than stock and domestic” in all four implementation areas (*Water Act 2000*). See *Water Reform and Other Legislation Amendment Act 2014* for changes. Under the *Water Act 2000* no new bores are to be drilled without permission in the Lockyer Valley water catchment. Yet a number of existing private bores in implementation areas 2A and B, 3 and 4 in Figure 4-2 remain unlicensed and unmonitored (CSIRO report 2009). Even under the updated Moreton Water Resource Plan (2011), some areas of the Lockyer Valley still do not have clear and appropriate water property rights governing recycled water, groundwater and managed aquifer recharge. The management of PRW had not been clearly outlined in the Plan and pricing is still not comparative between PRW and other water sources. There would have be little demand for PRW at such high prices (plus capital costs) and plans to extend the pipeline in the past, depended in part on estimates of demand and WTP that reflected this.

The Resource Operations Plan (ROP) for Moreton released in 2009, and amended in 2013 (DNRM, 2014a), provided for the conversion of interim water allocations to permanent water allocations in the Lower Lockyer Valley Water Supply Schemes (WSS) (Section 101 of the Water Act 2000). The area circled in red in Figure 4-2. (DNRM 2014a). For example, this WSS west of Lowood can supply surface water for irrigation (Seqwater 2015a). The amended ROP intends that interim water allocations be converted to water allocations that are separate from land and available for trading on a seasonal or permanent basis (Seqwater 2015a). The “Lower Lockyer Valley” tariff group has 150 irrigation customers with water access entitlements in 2015 (Seqwater 2015a) and includes weirs, gauging stations, diversion and supply channels, pump stations and customer water meters.

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Figure 4-2 Implementation areas 2A and B, 3 and 4 in the Lockyer Valley remain unlicensed and unmonitored

Source: DNRM (2014b)

The amended Moreton ROP (DNRM 2014a) does not include all areas of the extended Lockyer Valley catchment. Seqwater consulted with customers about the network service plan and customer service standards, although groundwater licences and trading in this implementation area were still to be implemented as at September 2015 (Seqwater 2015a). According to the IWRM model these allocations are to be based on sustainable yield of aquifers, to manage common pool resources appropriately and therefore require widespread groundwater monitoring, metering now. In fact, this monitoring was needed earlier.

CSIRO (Wolf 2013) findings showed that three consecutive wet years and a major flood event of January 2011 had restored the groundwater in the Lockyer Valley close to its long term maximum level in most areas. Natural recharging of this groundwater system requires prolonged periods of rain, that are historically infrequent, to balance with agricultural demand for water (Galletly 2007). As indicated in literature in Chapter 2 and data in Chapter 3, meteorological issues were an important aspect of any IWRM model. Within the environmental dimension of the IWRM model and the ITWC model, the important issue of rainfall and overland flows, recharge of catchment and storage were dealt with adequately. These examples provided evidence for answering the three research questions. In other words, the problem of managing demand, population and climate extremes were not solved by IWRM policy in the Lockyer Valley in the absence of the IWRM approach and model. The added issue of unused urban wastewater was also not addressed and impacted on research question three.

The key hydrogeological, meteorological and other environmental components of the IWRM model provided vital information required to close the ITWC and better manage water as a common pool resource (research question 1). The application of hydrogeological theory about water connectivity, placement of built water infrastructure and economic policy instruments such as water monitoring and licensing assisted in the development of environment, economic and policy dimensions of the IWRM catchment scale conceptual model to achieve these aims (research question 2). In this way the IWRM model aided management of the demands on water from climate variability, population growth and intensification of agriculture given the limits of further viable above ground water storage options and unused wastewater (research question 3). The policy implications of stressed groundwater in IWRM and specifically the ITWC were explored next.

In summary, an understanding of the environmental, social, economic and policy aspects of groundwater in the Lockyer Valley catchment provided insight into the derived nature of demand (and supply) of water. The multidimensional approach of the IWRM model with its recognised biophysical constraints outlined in section 4.2 highlighted the other dimensions of the IWRM model explored further in section 4.3. The impact of stressed groundwater on the ITWC provided insight into the management of the groundwater situation in the Lockyer Valley using the IWRM model. There were policy implications of this stressed groundwater in the Lockyer Valley catchment.

4.4. The Policy Implications of Stressed Groundwater in the Integrated Total Water Cycle

This section provided evidence of how groundwater stress is managed as part of the ITWC and IWRM. In 2003, the BCC spent approximately $330M on pollution and nutrient reduction schemes for the Brisbane River and Moreton Bay (Psi-Delta 2003, p. 20). The BCC had a policy of increasing sales of recycled water to major industry and commercial users (e.g. the Local Governing Bodies' Capital Works Subsidy Scheme). These costs were expected to be saved by the SEQRWT proposal to redirect this recycled water to inland agricultural communities (Psi-Delta 2003). Policy is still required to manage sediment from overland and stream flows upstream in the rural Lockyer Valley entering downstream Moreton Bay. The BCC adheres to other policies to improve water quality in the Brisbane River and Moreton Bay (e.g. *Queensland Environmental Protection Act* 1999 and *Local Government Act* 1993). These hydrogeological interconnections created opportunities in policy making for application of the new catchment scale IWRM model in further closing the water cycle. Recycled water use has the potential to connect wastewater, recycling and water quality and close the ITWC (research question 1). The IWRM model offered the means to analyse and incorporate these and other options to recharge the extended Lockyer Valley water catchment, and ascertain the economic, social, policy and environmental consequences.

Further evidence was sought from publicly available data on the extended Lockyer Valley catchment to answer research questions 1 and 2 on policies and strategies used to close the ITWC. Accordingly, the absence of such policies, institutions and strategies had implications for the key components identified in the IWRM model.

Recycled water strategies are linked to requirements of the Intergovernmental Agreement on the National Water Initiative 2004 and other policies including the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks, Storm water Harvesting and Reuse: Managing Health and Environmental Risks, Managed Aquifer Recharge* and more (see relevant government websites). To demonstrate the complexity of legislation required to manage recycled water, some of this legislation was summarised in Table 4-2.

The slow clarification of access rules for recycled water relative to potable water was highlighted by ACIL Tasman in 2005. Other issues for redress included the coordination of the thirteen sub-catchments in SEQ. Each had its own different potential water delivery schemes which add to the expense and complexity of moving water between areas (QLD Water Plan 2005-10). Such inconsistencies in water regulation and policy interfered with further closing of the ITWC and did not address the interconnectivity of water sources in the Lockyer Valley.

Table 4-2 Integrated Water Resource Management Legislation and Guidelines

Local Government Act 1993
Environmental Protection Act 1994
Queensland Environmental Protection Act 1999
Water Act 2000 (Queensland) Water Management Plans
Environmental Protection (Water) Policy 2000
Queensland Water Recycling Strategy (2001)
Intergovernmental Agreement on the National Water Initiative 2004
Integrated Planning Act 1997 (amended in 2004)
South East Queensland Regional Water Supply Strategy 2004 and 2005
The South East Queensland Regional Plan 2005–2031
South East Queensland Infrastructure Plan and Program 2005
Public Health Regulation 2005
Queensland Water Plan 2005–2010

Water Amendment Regulation (No.6) drought strategy & emergency legislation 2006
Queensland Water Commission 2006
Water Act (2007) (Commonwealth) – Land & Water Resource; Resource Operations Plans
Moreton water resource plan (listed under the *Water Act 2000*) 2007
South East Queensland Water (Restructuring) Act 2007
Water Amendment Act 2008
Water Supply (Safety and Reliability) Act 2008
Water Efficiency Management Plans 2008
Sustainable Planning Act 2009
Moreton Resource Operations Plan December 2009
South East Queensland Regional Plan 2009–2031 (revised 2009)
South East Queensland Water (Distribution and Retail Restructuring) Act 2009
South East Queensland Infrastructure Plan and Program 2009-2026
The Regional Water Security Program for South East Queensland 2010
South East Queensland Water Strategy 2010
The Regional Plan 2010
Moreton Resource Operations Plan December 2009 (amended in 2014)
QLD 30-year water plan – WaterQ 2014

The major potential source of recycled water for irrigation of interest to policy makers was treated municipal effluent (DPI 2000). The Queensland Water Recycling Strategy (EPA 2001) outlined an approach to recycled water use mainly in urban areas. The Regional Water Security Program (2006) facilitated the construction of significant infrastructure for SEQ. An outcome of this was the SEQ Water Grid and seven stage water purification scheme. The scheme provided the technical means to close the ITWC but did not have the economic, social or policy support to implement at the time. The WCRWP remains the largest reclaimed water scheme in Australia, and consists of over 200 km of pipeline, and is capable of providing up to 66 ML/day of recycled water (Queensland Government 2009, p. 59).

Brisbane urban water users contribute to a severe leakage in the integrated water cycle by producing vast quantities of wastewater, the majority of which is treated and discharged back into Moreton Bay. About 245,000 ML of treated wastewater was being discharged from wastewater treatment plants in SEQ in 2006 (QWC 2010, p.119). Approximately seven per cent of SEQ effluent was recycled at the time (DNRM&W 2006c p. 41). Added to this was uncollected, untreated and unused storm water and rainwater in some areas.

Treated wastewater is forecast to reach more than 400,000 ML/year by 2056 (QWC 2010 p.119). Purified recycled water was available to the gateway of the Lockyer Valley (Lowood) via the WCRWP from 2009 to 2013, after which it was shut down (Seqwater 2015b). A strategy was required to utilise more of the effluent SEQ produces and close the ITWC (research question 1).

The SEQ Water Strategy (QWC 2010) outlined options for recycled water use through the use of existing dams and weirs, supply augmentation with stormwater, purified recycled water (PRW) or water harvesting. The QLD Government reviewed the regulatory framework to streamline recycled water regulation in its new 30-year water plan – *WaterQ* (DEWS 2014, Action 6.2 & 6.3). *WaterQ* recognises that ITWC with appropriate policy support are key components of IWRM; these were missing in the case of the Lockyer Valley (research question 1).

The interconnectivity of groundwater and other water sources in the Lockyer Valley is recognised in policies such as the Regional Planning Interests Act 2014 (RPI Act). This policy recognises land highly suitable for cropping because soil, climate and landscape features, and protects it from mining and other development in the Lockyer Valley and elsewhere in Queensland. The policies and strategies of the Queensland government are moving towards further closing the ITWC by including constructed water infrastructure and recycled water of SEQ and the Lockyer Valley into the Moreton Resource Operations Plan December 2009 (amended 2014). Although the policy framework existed for recycled water use and recharge options at the time of the WCRWP, there remains no large scale capture and re-use of recycled water, stormwater flows, artificial wetland recharge or aquifer reinjection or storage schemes in the Lockyer Valley at the time of this study. This limits the opportunity to close the ITWC using recycled water options. Yet there were a variety of constructed water infrastructure and recycled water options available to recharge the Lockyer Valley as discussed in the SEQRWT in Chapter 3. In keeping with the IWRM model approach, the economic, policy and social dimensions of recycled water options required further investigation. In this section of Chapter 4, the issue of the unused wastewater from urban and rural SEQ remained and leakage from the ITWC persisted in the Lockyer Valley water catchment (research question 1).

The current policy requires entitlements be purchased to access irrigation water from existing surface water sources including dams, channels and pipelines in the Lockyer Valley and groundwater in the Central area. Examples include Atkinson Dam in the Lower Lockyer Valley that receives and redirects water to and from Buaraba creek via a pipeline, channel and weir system (QCA 2013). Yet historical water entitlements to creeks, streams and aquifers on or adjacent to properties given to landholders in the upper and lower Lockyer Valley still exist as mentioned in Chapter 3. Further leakages from the ITWC in the Lockyer Valley occur through water runoff into stream and creeks, unused wastewater available for possible reuse, storage in aquifers and wetlands – both natural and created. The policy dimension of the IWRM model required inclusion of all these water sources in the ITWC model and to close the water cycle in the Lockyer Valley and downstream water catchments (contributing to research question 1). Using the approach in the IWRM model an analysis of the dimensions of the WCRWP was provided to demonstrate the application of the model and policy implications.

4.4.1. The Environmental, Social, Economic Assessment of Recycled Water Issues Prior to WCRWP

Social Issues

GHD constructed the WCRWP, and prepared an environmental impact statement (EIS) as required under the *Environmental Protection Act 1994*. GHD also included a social impact assessment to identify social impacts directly related to the project and strategies to build on social opportunities and to avoid, manage, mitigate or offset the predicted detrimental project impacts (DSDIP 2014). These results were not publicly available, but assisted DPSIR to prepare Environmental and Social Impact Assessments (ESIAs) including the full range of environmental impacts and mitigation requirements, and the community engagement activities around the project (GHD 2014). For example, to minimise the risk of incidents during construction of the WCRWP project horizontal directional drilling was used. Construction Environmental Management Plans and offsets for vegetation clearing were implemented to manage these construction risks. This limited environmental impact assessment dealt more with the construction than the ongoing or wider impacts to the environment. Since the pipeline did not connect to the Lockyer Valley, the social and environmental impacts for that area were not reported at the time.

The social issues surrounding community trust, acceptability of recycled water and involvement of the community in decisions such as access to and cost of recycled water and infrastructure still required understanding and investigation. Generally, these investigations were not undertaken (Hurlimann 2010). Surveys invariably asked about WTP and demand at different price points, but the social acceptance of recycled water use was not investigated in these feasibility studies. A report (Heiner et al. 1999) into private sector investment in and health considerations regarding the use of recycled water in nearby rural areas including the Lockyer Valley, did not investigate the social acceptability of recycled water use. Yet, this was a large determinant in the success of recycled water projects (Hurlimann 2010). Later negative public opinion regarding acceptability of drinking PRW led to the loss of a referendum to introduce recycled water in Toowoomba in 2010.

Environmental Issues

Investigation of possible environmental impacts of recycled water use in irrigated agriculture ws needed to minimise the risks of changing soil characteristics (salinity, nutrients and clay components) or drinking water quality in downstream areas. Research conducted on these issues in the Lockyer Valley well after the SEQRWT found these risks were minimal (Wolf 2013; Ellis & Wolf 2012). In fact, the quality of PRW exceeded existing water quality levels in the Lockyer Creek downstream from Gatton (Wolf 2013). While trace organic compounds and pharmaceuticals from the upstream Lockyer Valley catchment were found to exist in this water already, PRW was expected to dilute these trace elements (Wolf 2013). Modelling of recharge did not support the mobilisation of salt plumes in salt affected areas following the introduction of PRW (Wolf 2013). International research confirmed similar findings (Massmann et al. 2004). Any further technical, economic, policy or social changes required to accommodate these impacts needed to be investigated using the IWRM model prior to implementation of such policy.

Economic Issues

Prior to such water management solutions being implemented, the economic issues required further investigation and understanding. The extent to which this was done prior to construction of this recycled water scheme was used as an example. At the time of construction, expensive water supply infrastructure of the WCRWP and GCDP was expected to play a key role in the integrated management of the SEQ regions water supply including the Lockyer Valley.

At full production, the variable costs of the WCRWP were estimated to average $597/ ML – nine times higher than the average variable cost of water for bulk water storage treatment plants (QAO 2013, p.32). At $2.493 billion (b), the full cost of the WCRWS may never have been recovered (QAO 2013, p.26). The question remained whether the full capacity of this infrastructure would be utilised if links to the rural Lockyer Valley were pursued. In 2010-11 the combined annual maximum water production capacity of WCRWS was 133.2 billion litres (BL).[19] In 2010-11 demand for recycled water was 19.3 BL of which 5.8 BL of water was supplied from the WCRWS[20] and 13.5 BL from the Gold Coast Desalination Plant (WaterSecure 2011, pp. 9-10). Yet the water supply infrastructure of SEQ operated 113.7 BL under capacity in 2010-11. Of the 219 BL of water put through the SEQ water grid in 2010-11 (LinkWater 2011, p. 6), less than nine per cent came from recycled sources (at a cost of a least $9.3b).[21] This spare capacity still exists for future drought and even flood management (QAO 2013) and need not be fully utilised at all times. The question of the cost effectiveness and the environmental and social appropriateness of this strategy remained. An audit prepared for QLD Parliament in 2013, found that the State paid significantly more to construct the WCRWP and the GCDP than it would have under less urgent circumstances.

In summary the need to establish the appropriate scale of IWRM involving the Lockyer Valley was central to the success of IWRM policy making. There was a role for government in funding or assisting full hydrological assessment prior to water projects commencing. The government's role in monitoring and allocation of water was also essential to the

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[19] The WCRWS can supply up to 84.6 BL and the GCDP can supply 48.4 BL.

[20] This was mainly supplied to power stations, with some water provided for flood clean up in January 2011.

[21] Based on operating costs for recycled water (Seqwater 2012 p.23).

understanding of the sustainable yield of the water catchment and its management. There remained a need for government regulation and financial support in building and maintaining infrastructure, given the existence of economies of scale, equity and environmental considerations. The case study of the WCRWP to the Lockyer Valley highlighted the opportunities for third party access to infrastructure provided initially by government. The high level of certainty required in water allocations for rural producers was noted in the current Regional Plan. The need for reliable data existed at the time of the WCRWP proposal. As the main economic driver of this certainty, demand for water and associated water pricing (QWC 2010) was examined next.

4.5. Using the IWRM Model to Manage the Impacts of Inconsistent Water Demand Estimates on Policy Decisions in the Lockyer Valley

Major themes emerged out of the eight interviews with irrigators in the Lockyer Valley including the economic issues of derived demand for irrigation water, inconsistent water demand estimates and water pricing. An overreliance on economic and technical solutions to IWRM also featured heavily in many of the Lockyer Valley research studies and consultancies. In literature (Chapter 2) the associated policy issues of demand and supply management and adequate pricing for all water sources were central to IWRM. Even where economic analysis was undertaken in research studies and consultancies, the assumptions and limited scope of water supply options limited the usefulness of the findings and chances of successfully implementing IWRM policy using recycled water. The IWRM model used ecological economic principles and theory to help resolve these economic issues in the following subsections of Chapter 4, and to answer research questions one and two for the case study of the Lockyer Valley.

4.5.1. Derived Demand for Irrigation Water in the Lockyer Valley

Demand for irrigation water in the Lockyer Valley is dependent on a number of variables or drivers as established in the literature in Chapter 2, including population growth, rural water use, demand for agricultural production and water use efficiency. Literature in Chapter 2 established that the rural sector generally is a relatively large water user elsewhere, but by comparison, rural SEQ is a relatively small overall water user. Based on actual water consumption data, rural SEQ consumed 25 per cent of total water consumption in 2005, compared to 83 per cent used by rural Australia (QWC 2010, p. 53). The bulk of the water consumed in SEQ was by urban and industrial users (QWC 2010). In general, rural water allocations are small compared to existing urban demand (QWC 2010). This unusual characteristic of the SEQ rural area had implications for the way water was managed in the SEQ water catchments. For example, rural water entitlements in supplemented schemes were generally specified as medium priority water, with a lower reliability of supply than urban or industrial water high priority water (QWC 2010). The issues of obtaining reliable estimates of water demand for agriculture generally and the Lockyer Valley specifically were addressed.

Inconsistent Demand Estimates from Research Studies and Consultancies

Despite the fact that various research studies and consultancies in Chapter 3 found that groundwater extraction rates were unsustainable in the Lockyer Valley (DNRM 2005; ANRA 2007a; DNRW 2006; GHD 2004; Psi-Delta 2003; NRWSC 2002; Barraclough & Co. 1999) irrigated water supply was found to be adequate (The State of QLD Submission 2007; DNRM 2004; GHD/Kinhill 2003, 1999). The review of literature in Chapter 2 and research studies and consultancies in Chapter 3 identified a major socio-economic driver of Lockyer Valley demand for irrigation water had not been estimated accurately - rapid population growth. The average annual population growth in the Lockyer Valley increased 2.7 per cent during 2008-2013 (ABS 2013b). The Lockyer Valley (East) was the fourth fastest population growth area in a QLD statistical area (SA2), growing 4.6 per cent to 19,300 from 2012-2013 (ABS 2013b). This rapid population growth placed significant pressure on limited water resources in the Lockyer Valley catchment. These population statistics highlighted the importance of getting water demand estimates correct.

The Lockyer Valley is an integral part of horticultural production in Queensland and is central to Queensland Government plan to increase State food production by 50 percent by 2040 (QLD Government 2012). The Lockyer Valley remains a significant contributor to agriculture, traditionally providing 35 per cent of QLD irrigated vegetables (ABS 2012). This demand for irrigation water drives water use in the Lockyer Valley. As established in the Chapter 3, a large proportion of these research studies and consultancies relied upon the demand survey by GHD (2002) and water pricing estimates of Psi-Delta (2003).

Apart from a survey involving less than 50 irrigators from the Lockyer Valley (Enhance Management 2005), there have been no new insights into the demand for recycled water since DNRM&W (2006a). Further, when the estimated price of additional or recycled water exceeds $150/ML the estimated demand for irrigation water fell dramatically.

The related issue of demand was reflected by one Lockyer Valley irrigator during interviews who said that, “since the deluges the aquifers are full enough to last me the rest of my lifetime” (Interviewee 1). This sentiment was backed up by the other seven irrigators interviewed who also express their unwillingness to pay for recycled water as aquifers become full again after the deluges. The approach in this IWRM model helped to understand that the Lockyer Valley IWRM problem did not go away when the aquifers were restored to capacity. A member of the LVWUF cautioned during interviews that during the millennium drought, “Lockyer Valley farmers are prepared to pay up to $150 M/L for recycled water but since then are no longer prepared to do so” since floods have recharged creeks, aquifers and dams (Interviewee 6, 2011). Yet he believed that, “there are still reasons to demand recycled water including food security and regional futures”. He felt that “European and US agricultural subsidies interfere with demand for Australia exports and reduce the ability to pay for water” (Interviewee 6, 2011). Findings from the eight interviews conducted for this study indicated that, landholders felt that they have already paid for good access to groundwater in rural land prices. Where additional water supplies were needed, buying or leasing properties with access to water were preferred options to paying for expensive recycled water infrastructure to farms (Interviewee 1, 2011).

There are other key components of IWRM decision making that emerged during these irrigator interviews. A Lower Lockyer Valley irrigator said, “We will not pay for recycled water because our margins are too low already. I move to water and rent small land holdings (with water rights) when necessary instead” (Interviewee 1, 2011). Policy makers would benefit from this information about demand and WTP for recycled water. As the IWRM model suggested, there are a multitude of key components impacting on water pricing to be established prior to Lockyer Valley water policy decision making. The consequences of getting this understanding wrong or ignoring an important key component in IWRM is demonstrated in low demand for recycled water in the catchment before, during and after the closure of the WCRWP.

Another irrigator said that, "during drought he grew less tomatoes and bought a nearby farm in Helidon with access to water" (Interviewee 5, 2011). Another Lower Lockyer Valley irrigator said, "Farmers who don't currently pay for water are not interested in recycled water in the foreseeable future" (Interviewee 3, 2011). These were issues of derived demand not well investigated at the time of the WCRWP studies. Another Lockyer Valley irrigator explained that, "this recycled water (at $150/ML) is agreed to at lowest marginal cost prices [operating costs only – no infrastructure costs]" and that "farmers apply to the Commonwealth for funds to assist with infrastructure" (Interviewee 6, 2011). He explained, "that irrigators even then are only be interested in a certain standard of recycled water - the Lockyer Valley has only ever wanted A Class water ... and that power station unions wanted higher than A Class water. The LWUF proposes treatment to greater standard than A Class at sites only where demand for such exists" (Interviewee 6, 2011). These drivers of demand needed to be understood when water projects were costed prior to commencement.

This data on demand and WTP for water was a vital missing consideration in the IWRM policy decisions in the Lockyer Valley. With such knowledge, policy decisions about delaying the introduction of groundwater metering, allocations based on sustainable yield and connections to water infrastructure may have been dealt with differently. If these and other social considerations such as community views on recycled water, and the various classes of water required had been known at the time, the recycled water scenarios investigated by policy makers may have been different.

At least half of the eight irrigators interviewed emphasised that, the size of the market and demand for their produce were primary factors in determining their demand for water. This underscored the importance of understanding that, derived demand for water is dependent on the users and the use of that water. Many of the smaller irrigators during interviews expressed concerns that, the market for Lockyer Valley agricultural produce was limited. They had lost market share to expanding south Australian producers using recycled water during the drought. This also caused losses in market share to larger Lockyer Valley producers. Smaller Lockyer Valley producers struggled to gain export market share and did not anticipate growing demand for recycled water for exports. These derived demand issues were considered in the IWRM model and were key components in understanding and making IWRM decisions. This information would have assisted policy makers with the WCRWP and other irrigated water supply options.

Research flagged the urgent need to secure supplies of water for environmental allocation and to reduce excess nutrient drainage into coastal waters (Cottingham et al. 2010; Hamilton et al. 2005). One Lockyer Valley irrigator said he, “sees the environmental and amenity value in using PRW to recharge the catchment ... but is not interested in paying for it” (Interviewee 1, 2011). Where there is alternative low priced irrigation water, the WTP for more expensive recycled water remained low and according to the “tragedy of the commons” – overused.

Policy to Manage Water Demand

The Australian Government developed a range of policies to manage demand for water. The COAG water reforms led to a National Framework for Implementation of Property Rights in Water compiled by the Standing Committee, Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), in 1995 (Tisdell, et al. 2002). A State of Environment report was released in 1996 and established the need for an environmental allocation of water, achievable through the substitution of recycled water for use in agriculture and urban irrigation (State of the Environment Advisory Council (SEAC) 1996). This report flagged urgent attention for the issues of inadequate disposal of sewage and excess nutrients draining into coastal areas (Hamilton et al. 2005). In keeping with this framework, the Queensland Government has introduced various policies, guidelines and institutions to manage water resources.

Policies to Manage Excess Wastewater

Some of these policy responses were based on the growing body of research around excess demand for water and wastewater. Research links reduced sewerage related nutrient levels, and improved plant species, algae and fauna health in Moreton Bay to sewerage treatment plant upgrades (Pitt et al. 2009). The implication was that increased recycling of wastewater and even increased reuse of this recycled water greatly improved water quality in Moreton Bay and connected water ways (Pitt et al. 2009). Yet recycled wastewater entering Moreton Bay decreased with the WCRWP shutdown. Sales of recycled water from the Brisbane, Ipswich, Lockyer Valley, Scenic Rim and Somerset areas fell from 12,660ML in 2012-13 (QUU 2013, p. i) to 10,000 ML in 2013-14 (QUU 2014, p.17). Of 107,000 ML of available treated sewage this represented only 9.4 per cent of recycled water sold for commercial use in 2013-14 (QUU 2014, p. 17). Given that demand is the main driver for this recycled water, the environmental and economic benefits of recycled water use would significantly increase WTP for it. These are important factors in estimating demand and guiding policy makers in decisions about recycled water schemes at the time of the WCRWP.

As established in the Chapter 3, a large proportion of these research studies and consultancies relie on the demand survey by GHD (2002) and water pricing estimates of Psi-Delta (2003). Aside from a survey involving less than 50 irrigators from the Lockyer Valley by Enhance Management (2005), there has been no new insight into the demand for recycled water since DNRM&W (2006a) or WTP for recycled water in the Lockyer Valley (since van Opstal surveyed 6 farms in 2012). A member of the LWUF (Interviewee 6, 2011) interviewed in the course of this study, explained that he believes the demand estimates of Psi-Delta (2003) and Enhance Management (2005) were still current. Yet after conducting eight interviews with Lockyer Valley irrigators for this study, many irrigators still had access to unpriced, unmetered groundwater and were no longer WTP for recycled water (Interviewees 1-8, 2011). Those who wanted further water security had constructed private dams and even private recycled water irrigation on their properties (Interviewees 6 and 8, 2011).

During interviews conducted for this study, a lower Lockyer Valley irrigator was asked if the views on demand for recycled water expressed in the Psi-Delta report (2003) were accurate. He responded, "... LWUF had such a large input into these previous studies that their data on recycled water demand and willingness to pay really reflect large producers' views only." Further, he commented upon the input to the Psi-Delta (2003) study that, "Non-

LWUF members, particularly small landowners, were not encouraged to attend sessions and had vastly different views on recycled water" (Interviewee 1, 2011). Given this feedback, the estimates of demand and WTP for recycled water provided by LWUF members to Psi-Delta (2003) may have been overestimated. When considering these issues using the IWRM model, the value of sound estimates of demand achieved through consistent monitoring of water and groundwater use was vital to the success of managing irrigation water in the Lockyer Valley.

Water Efficiency Improvement Strategies

The Lockyer Valley remains subject to some policies that encourage water efficiency improvements discussed here. Even the shift away from open dams known to result in high levels of evaporation, represented significant improvements in water use efficiency in the Lockyer Valley. Advances in technical irrigation efficiency were also addressed in some of the research studies and consultancies undertaken in the Lockyer Valley. There is always room for more policies such as these to improve TWCM. In the area of reduced demand for irrigation water, through improved water efficiencies, the Government introduced a number of initiatives. In 1999, the Queensland Government commenced the rural water use efficiency (RWUE) initiative to support industry; providing services to irrigators to improve on-farm irrigation management practices and the efficient use of water and energy (DNRM 2013). SEQ Irrigation Futures (SEQ-IF) programs are another example of demand side water management strategies that have been implemented. Since then landholders have adopted a variety of innovations to help improve irrigation water efficiency including: irrigation scheduling devices (e.g. tensiometers, gypsum blocks, capacitance probes, logging matrix sensors); changed pump configurations and performance to enhance energy efficiency and meet system requirements; reconfiguration of sprinkler systems; best management practice activities; and attendance at *Water for Profit* program workshops (Henderson 2006).

The trend in improved water efficiency has been assisted by information and training programs such as the CRC Irrigation Futures, DPI&F information and research and development activities, Irrigation Association of Australia, consultancy and agribusiness services and the QLD Government Financial Incentive Scheme. The Queensland

Government calculated a return of $23 in efficiency gains for every dollar invested in the *Water for Profit* program (Clark 2003). GHD costed a non-infrastructure option to reduce pressure on existing Lockyer Valley water supplies and demand for supplementary water. Recommendations included training of water users and water equipment users, supply of water efficient sprinkler heads and drippers, extended water metering, new water charges and water efficiency certification options are valued and estimated benefits provided. This evidence suggested that rural water use efficiency programs were successful in reducing demand for irrigation water. In applying the IWRM model to the issues of irrigation efficiency, perhaps a larger role for the private sector could be considered in future.

In 2005 the Rural Water Taskforce Group (RWTG) investigated the development of a rural water strategy in the areas of intensive irrigated agriculture within SEQ. These areas included the Lockyer Valley, Warrill–Fassifern Valleys, Logan–Albert Valleys and the Sunshine Coast (DNRM 2005b). The Rural Water Task Group recommendations for SEQRWSS (DNRM 2005b) supported the conclusions in this chapter regarding the need for sound water demand data, and improved management of population growth, irrigation areas and access to additional water.

Water Infrastructure Policies

During the interviews conducted for this study, very little mention was made of capital contributions to recycled water scenarios, with the expectation of government funding pervading the discussion. The QLD Government was reluctant to provide subsidies for recycled water schemes, preferring to fund consultancies to build own and operate or build own operate and transfer to private operators (Psi-Delta 2003). CSIRO (Hajkowicz et al. 2006) found the option to supply recycled water to the Lockyer Valley was not economically viable without subsidy (proposing a subsidy of $350/ML out of the $450/ML cost of supplying recycled water). Although social (equal access to clean water) and policy factors (community service obligations) governed these subsidies, there has been a trend towards economic goals of cost recovery and efficiency as outlined in the literature reviewed in Chapter 2. Alternative access arrangements to water infrastructure were explored further in section 4.6.

Water Pricing Strategies

IWRM strategies that included the use of recycled water have attempted to establish demand and price for recycled water. Other factors mentioned in literature in Chapter 2, were substitutes and cost of complementary goods (infrastructure, licensing and pumping costs) and subsidies. At the time of SEQRWP research into recycled water options involving the Lockyer Valley, water prices exceeded $1000/ML for Brisbane, Ipswich and Logan Council urban customers (Psi-Delta 2003, p. 33).

Other legislation and strategies that encourages cost recovery and improved efficiency in water prices included:

- *Water Act QLD 2000*
- SEQ Regional Plan (2005-2016 and 2009-2051)
- QLD Water Plan 2005-2010
- SEQRWSS 2006
- SEQ Water Strategy 2010

Yet full cost recovery for rural irrigation water and infrastructure is yet to be implemented for a variety of social, economic and policy reasons. The viability of recycled water projects depended on distance to markets, high-quality agricultural land, and water treatment facilities. To ensure the financial viability of recycled water projects, most recycled water was to be provided to within 50 km of populations larger than 100,000 (Psi-Delta 2003, p. 35). This may work for urban water management schemes, but costs would be altered when integrating with urban users and water of varying quality. The nearest entry point for the WCRWP to the Lockyer Valley is Lowood - approximately 34 km from Bundamba Advanced Water Treatment Plant (AWTP) and at least another 34 km to the lower Lockyer Valley. These distances (and intervening elevations), plus the relatively low population density of the Lockyer Valley of 37,652 people (ABS 2015) radically impacted on the cost of supplying recycled water to the entrance of the region.

The Connell Wagner (2005a, b) scoping study recognised the high capital infrastructure costs of extended pipelines and operating costs of pumping over varying elevations and distances. It recommended options that first provided the Ipswich region with recycled water before extending the supply to rural Bremer, Warrill and Lockyer Valleys. In this scenario, the estimated pipeline infrastructure costs did not exceed the expected value-added returns to agriculture. Other cost effective, less energy-intensive options, including further gravity-fed pipelines, siphons, tunnels and created wetlands, were not explored. While the direct supply of recycled water to agricultural areas at water prices of $150/ML was not viable, Connell Wagner (2005b, p. 60) found that recycled water sourced from WWTPs in Brisbane and Ipswich and nearby industrial parks delivered positive returns when recycled water was offered first to higher paying[22] urban, residential and industrial customers (in Ipswich) and then reticulated to rural customers. These costs were calculated prior to the construction of the Western Corridor recycled and Toowoomba[23] water pipelines and may even be lower now that this water infrastructure exists. The Connell Wagner (2005a, b) recommendations for agricultural users were not implemented and hinged upon infrastructure costs and the WTP for recycled water by Ipswich and rural users. These users were further deterred from paying for this recycled water while the cost of existing water substitutes remained comparatively low.

The SEQRWP (Psi-Delta 2003, p. 19) did not apply a council effluent charge, on the basis that the opportunity cost of that water was near zero. This was justified by the low number of buyers for council effluent. Instead councils continued to discharge most of this wastewater into the Brisbane River or Moreton Bay.

Total Water Cycle Management Plans

In June 2012 Queensland Government Total Water Cycle Management Plans (TWCMPs) were introduced to enforce IWRM by larger local governments for urban water (DEHP 2012). These plans required plans for recycled water. The Lockyer Valley had until June 2014 to implement a TWCMP. This policy inconsistency meant that the Lockyer Valley was not required to have a TWCMP until recently. This TWCMP, known as the *Netserv Plan,* focused on urban water (QUU 2014). Meanwhile mandatory planning and reporting were still required under the Environmental Protection (Water) Policy 2009. TWCMPs in larger

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[22] Used full cost pricing of Brisbane, Ipswich and Logan Council residential customers, values of up to $1000M/L were paid (Psi-Delta (2003).

[23] The Wivenhoe - Perseverance Dam pipeline was completed in 2011

local government areas overlap other mandatory plans such as the *Water Supply (Safety and Reliability) Act* (QLD Water Directorate 2014). The water industry position now is that IWCM must be complementary to existing planning requirements to be effective (Queensland Water Directorate 2014). Until TWCMP are applied to the Lockyer Valley rural and connected water systems, integration of the total water cycle (including recycled water) will not be implemented. Meanwhile other policies that could improve irrigation water efficiency in these catchments have been slow to eventuate. The Moreton Bay Regional Council Total Water Cycle Management (TWCM) Strategy identified goals including:

- greater use of recycled water and other alternative water sources;
- increased resource recovery;
- use of fit-for-purpose water (e.g. use non-potable water when appropriate); implementation of urban water design principles and rural best management practices; and
- capping of population growth within the catchment area.

Such a plan must identify the interrelationships between all elements of the water cycle (eWater 2014). This would go a long way towards meeting the principles of TWCM and other policies relevant to the Lockyer Valley as recommended in the IWRM model (research question 1 and 2). The TWCM linked to the Regional Plan, SEQWS (QWC 2010) and Regional Water Security Program and other key legislation. Further improvements to water use efficiency could be achieved through the use of recycled water for irrigation (research question 3).

4.5.2. Water Trading

Under the Queensland water supply schemes (WSS) a resource operations plan (ROP) is required for the temporary and permanent trading of water. In other WSS where Interim Resource Operations License had Interim Water Allocations (IWA), some temporary water trading of known water access entitlement (WAE) volumes could occur. In the Central Lockyer Valley WSS for those customers with water licences, but where no individual nominal volumes have been specified in ML, temporary or permanent trade of WAEs are not possible.[24]

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[24] WAEs may be surrendered if there is an IWA as opposed to water allocations that are separate from land and can be

Table 4-3 below reinforced the fact that until all the Lockyer Valley groundwater use is monitored, and water licences introduced (and water use volumes are known), water trading between these customers will not occur (QCA 2013, p.16). To assist with this process, the QLD Competition Authority has been directed by Government to develop irrigation prices to apply to seven Seqwater WSSs from 1 July 2013 to 30 June 2017.

Table 4-3 Inconsistency in Lockyer Valley Water Access Entitlements (WEA)

WEA	Tariff Groups	Permanently Tradable	Temporarily Tradable	Able to surrender	Contract	Targets
Interim Water Allocation	Lower LV	no	yes	yes	yes	yes
Interim Water Allocation	Warrill Valley	no	yes	yes	yes	yes
Interim Water Allocation	Central LV part	no	no	yes	yes	no
Water License	Central LV part	no	no	yes	yes	no
1995 Morton Vale Contract	Morton Vale Pipeline	no	yes	yes (with termination fee)	yes	yes

Source: (QCA 2013b, p.17).

After examining the policy and environment surrounding water management in SEQ and the Lockyer Valley, it was evident that the assumptions about willingness and capacity to pay and available water supply options needed further investigation. The ownership of SEQ recycled water and associated infrastructure now rests with Seqwater. The WCRWP remains unconnected to irrigators. Issues of pricing and third party access to such infrastructure are still to be resolved in Lockyer Valley (Bosworth et al. 2002; Baumol 1982). Under the interim Moreton ROP (effective from 5 February 2015 to 31 December 2016) seasonal water assignment requests are to be checked against usage records and maximum allowable water use volumes to ensure over allocation does not occur. Daily total volume data is then to be reported by the resource operations licence holder to DNRM

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permanently traded but cannot be surrendered.

(DNRM 2014a).

4.5.3. Price of water substitutes

Recently the QLD Government lowered bulk water prices increases through a range of measures including:

- abolishing the Queensland Water Commission
- removing the previous requirement to build additional infrastructure in the foreseeable future from the regional water security program for SEQ
- merging the bulk water entities into one entity, reducing administration costs (DEWS 2015). These efficiencies are needed as urgently if the introduction of TEV in pricing of scarce natural resources is to be implemented. As literature in Chapter 2 and data from research studies, consultancies and interviews in Chapters 3 and 4 indicated, the price mechanism plays a key role in the use and distribution of water.

As the theory of demand explained in Chapter 2, the demand for water is affected by the price and availability of substitutes. Whilst groundwater is free or priced relatively low, it remains in high demand. While alternative water (from dams and creeks) is low, the demand for more expensive recycled water remains low. According to ecological economic principles, all water sources should be valued according to TEV. This would ultimately increase all water prices and reflect its scarcity and need for careful management. Connell Wagner (2005a, b) performed community consultation to assess the community value of water using a method similar to TEV. This analysis looked at water values including health and safely, social value (quality of life), environmental value (habitat and ecosystem benefits), local water reliability, operational reliability, water quality, cost, ability to implement and energy consumption (Connell Wagner 2005b, p. 45). No analysis of WTP, capacity to pay or guaranteed minimum supply scenarios involving potential industrial users was conducted at the time.

In summary the case study of the Lockyer Valley highlighted the necessity for IWRM decisions to capture all affected water and users. To do this adequately an understanding of the derived nature of demand (and supply) of water was facilitated by the multidimensional approach suggested in the IWRM model. The use of TEV in valuation and pricing of all water in the ITWC encouraged all water alternatives to be priced consistently. Data on all catchment flows and users was vital. Further, clear and consistent water property rights and pricing applied to all water and users throughout the catchment was necessary for a comprehensive understanding of the demand, water use efficiency and sustainable yield for the water catchment to be achieved. The coordination of infrastructure and policy were examined next in this context.

4.6. Improving Coordination of water infrastructure and policy in the Lockyer Valley with the Aid of the IWRM Model

In order to demonstrate the value of the IWRM model in improving coordination of water infrastructure and policy, examples of inconsistencies in the area in relation to the WCRWP were used. Background policy was examined first. Although the National Framework for Improved Groundwater Management was delivered in 1997, the Intergovernmental Agreement on the NWI was not signed by COAG until 2004.

Yet four years later, the NWI 2009 Australian Water Reform found inconsistent and unclear implementation of entitlements to water still persisted. Other inconsistencies in policy arrangements impacting on IWRM in the Lockyer Valley included: 1. Unclear agreed threshold sizes for existing and new water access entitlements (especially environmental water access entitlements)[25] 2. Disparate water trading schemes throughout the Lockyer Valley, and 3. Lack of water pricing for full cost recovery.

Examples of issues with coordination of water infrastructure and policy from the Lockyer Valley were used to demonstrate the relevance of the policy dimension in the IWRM model (research question 1). This assisted to answer the research question about further closing the ITWC in the presence of overlapping and inconsistent infrastructure and policy in the Lockyer Valley.

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[25] A Commonwealth Environmental Water Holder was established under the Water Act (2007) to manage Commonwealth owned water for the protection and restoration of the environmental assets.

One example of this was the issue of third party access to water infrastructure that needed to be resolved in SEQ. As literature in Chapter 2, and data in Chapters 3 and 4 demonstrated, the economies of scale and cost of infrastructure often precluded competition in the provision of water infrastructure. Whilst the WCRWP to the Lockyer Valley was not justified on economic grounds, another pipeline to divert untreated water from Wivenhoe Dam to Toowoomba (Cresswell Dam) was constructed in 2010. This pipeline can deliver 10,000ML of raw water to relieve the growing water demand pressure on Toowoomba supplies (Toowoomba Regional Council n.d.). An environmental assessment was undertaken and $187m received from QLD government funded the underground pipeline (Toowoomba Regional Council n.d.).

The difference between the WCRWP and the Toowoomba pipeline was that the Toowoomba Regional Shire Council (TRSC) took on the responsibility for the pipeline. As a council larger than the Lockyer Valley Shire Council, with more available capital and borrowing capacity, the TRSC had the financial capability to pay off and operate the pipeline to Cresswell Dam. Another major difference was that Toowoomba pipeline delivered fresh water from Wivenhoe dam. The standard of the water was not PRW and expensive reverse osmosis purification costs were not incurred. Although there was considerable debate about the cost and method of delivery of recycled water to the Lockyer Valley in most of the research studies and consultancies (e.g. Psi-Delta 2003), ultimately the decisions about IWRM in the Lockyer Valley were far more complex than the technical solution to the supply of recycled water to a community via the WCRWP. The social, policy and environment aspects of IWRM outlined in Chapter 3 are equally important.

Some of these aspects that impacted on the WCRWP included continued irrigation water stress in the Lockyer Valley and problems with the existing water management system. The Lockyer Valley water management system consisted of stream flow from overland flow and base flow, in-stream weirs designed to recharge aquifers and constructed public dams, pipelines, channels, bores and private dams and rainwater tanks.[26] Atkinson Dam had been

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[26] No data on water in private dams, rainwater tanks, stormwater flows and wetland storages was available and therefore estimates of water supply and demand are likely to be understated.

unreliable and infrequently supplied full irrigation allocation in the Lockyer Valley (1993 & 1996).[27] It was apparent this water infrastructure had been constructed with inadequate environmental and technical knowledge of catchment flows and recharge (see earlier section on weir placement). The approach taken in the IWRM model highlighted the importance of addressing these other dimensions of the IWRM issue before commencing the WCRWP. These constructed elements of the water system – the ITWC, should be considered in decision making concerning water infrastructure.

The provision and coordination water infrastructure in the examples above showed the Queensland Government was reactive in the provision of such infrastructure (DEWS 2014). This water infrastructure and the WCRWP were provided as a last resort response to the millennium drought, failing groundwater in the Lockyer Valley and inadequate dam storages. The WCRWP and associated PRW treatment facilities were reactive infrastructure solutions that proved to be costly and ineffective in solving the water crisis and are now placed on standby). Although offering a buffer for future drought and rising demand pressure, it remains to be seen whether the WCRWP can provide a long term IWRM solution for the government, water sector and community.

Regarding the complex issue of investment in water infrastructure, the WCRWP scheme may have been approached differently if an understanding of aquifer and creek recharge was widely known (Galletly 2007). Following major deluges in 2010-11 the short term need for recycled water in the Lockyer Valley for irrigation was seen by some as redundant, and WTP for it negligible (Interviewees 1 to 8, 2011). Future new regional bulk water storages in QLD are to be developed by the private sector unless there are compelling reasons of public good or market failure not to do so (QCA 2013). In future the private sector and government will only consider viable funding models for future infrastructure planning based on user pays system (DEWS 2014, p.8). It is important to get demand and WTP estimates correct.

Since the deluges of 2010-11, the number and size of privately owned dams in the Lockyer

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[27] In a Submission to the Minister for Environment and Heritage and Minister for Natural Resources by the Wivenhoe Dam to Atkinson Dam Pipeline Reference Group (1999).

Valley has increased, reflecting irrigators’ preference for the security of privately owned and controlled water sources. A number of large irrigators have installed large recycled water infrastructure on their properties in frustration over waiting for the WCRWP to reach the Lockyer Valley (Interviewee 6, 2011). Such issues of community trust, perception, choice and acceptability of recycled water featured heavily in IWRM literature in Chapter 2, but not in the research studies and consultancies informing policy makers at the time. The IWRM model was designed to incorporate such complex social environmental, economic and policy issues.

Preceding sections of this chapter outlined the complex arrangement of overlapping policy and institutional arrangements that governed water management in the Lockyer Valley. Some specific examples were examined in more detail to illustrate this point with regard to the Lockyer Valley. The Rural Water Task Group (RWTG) investigated South East Queensland Regional Water Supply Strategy (SEQRWSS). The SEQRWSS was an opportunity to “examine alternative water sources and demand management options, developing a strategic direction for water supply in the region through to 2050” (DNRM 2004). The aim of SEQRWSS was to support long-term growth in the region, as detailed in the SEQ Regional Plan 2005–2026 (QWC 2010). The work of the SEQRWSS (DNRM 2005b, p.1) was carried out by six task groups in the following areas:

- Water availability and entitlements (environment & policy)
- Integrated urban water management and accounting (economic & policy)
- Bulk supply infrastructure (environment & policy)
- Rural water (environment, economic & policy)
- Information, implementation, communication and coordination (social & policy)
- Water balance (environment).

These task groups roughly corresponded to the dimensions of the IWRM as denoted in brackets after each group above. The RWTG confirmed that urban and industrial water usage dominated in SEQ, unlike the rest of Australia, where rural water use dominated (DNRM 2005b, p. 3). The SEQ region was earmarked for rapid population growth and development pressures, unlike most rural areas, which had declining or static populations.

Irrigation water in the Lockyer, Fassifern and Warrill Valleys was found to be overused, water available from infrastructure schemes was either unreliable or suspended during the drought, and the possibility of recycled water use was urgently flagged for further investigation (DNRM 2005b). The findings supported the need for:

- *Regional irrigated agricultural data*
- *Sustainable irrigated agriculture for the SEQ Region*
- *Access to additional water*
- *Better management of irrigation areas* (DNRM 2005b p. 9).

Although these issues were flagged by the RWTG these issues remained unresolved. Other policies included in Table 4-2 demonstrated the State Government's emphasis on the need to "(P)rotect and enhance the ecological health, environmental values and water quality of surface and groundwater, including waterways, wetlands, estuaries and Moreton Bay" in the SEQ Regional Plan (SEQRP) 2009 (DSDIP 2009, p.136). Regional plans have statutory support through the *Integrated Planning and Other Legislation Amendment Act 2004*. Strategies involving recharge of wetland and groundwater are required to adhere to complex interrelated environmental policy. Examples include the SEQ Natural Resource Management Plan 2009-13 and 2014 update, and the SEQ Healthy Waterways Strategy assisting in sustainable urban water management and water catchment quality monitoring (Healthy Waterways 2015). The multidimensional approach taken in the IWRM model explained the pressure for the SEQRP to be redrafted to consider the social, economic, environmental acceptance of wastewater recharge of wetland and aquifers (Hopgood Ganim 2014). Further examples of the complex and overlapping policies continuing to impact on Lockyer Valley groundwater and therefore ITWC were investigated.

Since 2009, land owners in implementation area 2A had been asked to provide information to DNRM relating to groundwater works and water use for purposes other than stock and domestic. In 2013 the DNRM deferred the Notice of Works process in this Implementation Area. It was determined that groundwater licences for this area would not be issued at the time, and groundwater use in the Upper and Lower Lockyer Valley would remain unregulated (DNRM 2013). In order for an IWRM in the area to be successful, supplemented and unsupplemented water from implementation areas 2, 3 and 4 needs to be regulated and water sharing rules included in resource operations plan for the unsupplemented groundwater in the management area (*Water Act 2000* s. 74). As mentioned earlier, under the Moreton Plan 2007, existing bores continue to take groundwater (*Water Act 2000* s.72 Water Resource (Moreton) Plan 2007). Even where licences have been implemented, an annual volumetric limit is based on the previous 10-years water take (*Water Act 2000* s.72). This reinforces the riparian rights of these irrigators - rights to the water adjacent to or on land they own, rather than an approach based on sustainable yield.

Until all the groundwater in the Lockyer Valley is regulated, an IWRM plan and water trading throughout the catchment cannot eventuate. Before groundwater allocations in the Upper and Lower Lockyer can be implemented, water meters and monitoring bore networks require expansion (DNRM 2013; GHD 2004). This was supported by the LWUF, "the LWUF proposal for co-management of underground water has never eventuated ... and the LWUF wanted metered water throughout the valley, but this is still to happen" (Interviewee 6, 2011). These policy inconsistencies in the Lockyer Valley perpetuated the overuse of groundwater and impact on the ITWC (research question 1).

There were a number of other policy inconsistencies regarding groundwater throughout Australia including the Lockyer Valley. Sleeper licences exist in the Lockyer Valley. These sleeper licences use none of their allocation over the course of the Water Year (State Water 2015). These sleeper licences further perpetuated the allocation of water property rights according to historical water rights. A suggested solution to these inconsistencies has been either the reduction or removal of such entitlements and replacement with new entitlements for maximum past use or restriction to periods of high flow (Young 2013). Further appropriate use of common pool resources requires such entitlements to centre on sustainable use, not maximum past use, as has been the practice in the central Lockyer Valley (Senate Standing Committee on Rural and Regional Affairs and Transport 2007). These water licensing issues remain to be addressed in IWRM policy.

Further examples of these policy inconsistencies in the management of Lockyer Valley groundwater related to unlicensed bores, conjunctive use licences,[28] and the existing hierarchy of access rights (irrigation with precedence over industry research, recreation, stock, domestic, town and village water supply and groundwater). Some rural landholdings in the Lockyer Valley effectively retained riparian land rights beyond the right to use it for domestic and on-farm purposes such as drinking, stock watering and fishing purposes. This occurred when historical volumetric limits were maintained through interim water allocation and licenses in parts of the upper and lower Lockyer Valley (Australian Government 2010). As a result, relatively cheap groundwater and dam water resources were overused and depleted during the millennium drought. Until these complex interrelated policy issues are resolved IWRM policy cannot effectively manage the common pool resource of water in the Lockyer Valley or close the ITWC (research questions 1 and 2). Extending the investigation of this groundwater policy example further, the interconnectivity of other water sources in the Lockyer Valley was examined using the multi-dimensions of the IWRM model.

An example of further policy inconsistency relates to environmental allocations of water. Since the release of the *State of Environment Report* 1996 the need for an environmental allocation of water was established (SEAC 1996). The report recognised the role of recycled water in agriculture and urban irrigation in boosting available water for environmental use (SEAC 1996). This report flagged for urgent attention, the issues of inadequate disposal of sewage and excess nutrients draining into coastal areas (Hamilton et al. 2005). It was not until the National Water Quality Management Strategy (1998), that various guidelines for water management were released to facilitate recycled water use in QLD. The national guidelines (ARMCANZ & ANZECC 1996, ANZECC & ARMCANZ 1994) for reclaimed water use were designed to protect and enhance Australia's and New Zealand's water resources quality during economic and social development. These guidelines were under revision at the time of this study and there were still no commercial scale recycled irrigation projects or environment allocations for the Lockyer Valley water

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[28] This is a special category or license which enables use of ground water to be used to supplement when surface allocations are restricted.

catchment.

The lack of recycled commercial scale water schemes for irrigation in the SEQ persisted although a number of technical reports supported the use of recycled water for irrigation in the Lockyer Valley (Wolf 2013; FSA 2006; Psi-Delta 2003). These technical reports relied on the scientific evidence about engineering capability, energy requirements, salt mobilisation, water quality, health and safety requirements (Wolf 2013; CSIRO 2011; Saxton 2009; Wilson 2005; Halliburton KBR 2002; Heiner et al. 1999). These technical and scientific aspects of IWRM were incorporated in the environment dimension of the IWRM model (within the ITWC model) to integrate this information into IWRM policy making. While some environmental and technical reports were completed, none conducted rigorous social, environmental, policy and economic analysis of the depth and complexity described in the new multidimensional IWRM model developed in this study. The non-technical non-structural solutions for IWRM in the Lockyer Valley including water efficiency improvements and education required further attention and integration into policy making.

An issue closely connected to the technical feasibility of recycled water projects was the safety and quality standards and legislation required to govern water reuse for irrigation. These standards and legislative requirements varied according to national and state/regional spatial, temporal, usage and legislative factors as outlined earlier in the IWRM literature. Of primary focus of such legislation is that reused water be treated to a standard that is “fit for purpose” (DNRM 2013). In Australia, recycled water is classified by water quality parameters and subsequent safe uses, but definitions vary between the States (Uhlmann & Head 2011). The Water Supply Services Legislation Amendment Bill 2014 was aimed at simplifying regulation in QLD and has linked to statutory plans more recently This was not the case at the time of the WCRWP. Since 2014, such plans include the Strategic Asset Management Plans, Total Management Plans, System Leakage Management Plans, Drought Management Plans and Recycled Water Management Plans (DEWS 2014). This level of consistency in water policy was required prior to the construction of the WCRWP if it were to be successfully connected to irrigators in the Lockyer Valley.

In the example of the WCRWP, a lower class of water could have been considered to reduce the costs of water catchment recharge. Where crop type was suitable and or further purification was achieved during time spent in aquifers and wetlands, this could have been an option (see DEWS 2008 on the classes of recycled water used in Australia). For example, recycled “Class A plus” water was more than adequate for crop use in Australia and PRW was of higher standard again (DEWS 2008). Where this quality of water is all that is legally required for irrigation, assessment of WTP for water at that standard is all that is required. Such political, social, environmental and economic considerations of recycled water use may be usefully examined using the IWRM model and this knowledge used to close the ITWC (research questions 1 and 2). Only once these policy, institutions and social and community management issues are resolved using the type of integrated approach outlined in the IWRM model, can a recycled water project be implemented successfully. The urban-rural IWRM scenario for the Lockyer Valley was examined for its role in understanding the key IWRM components of the IWRM model.

4.7. Urban-Rural IWRM

The urban-rural IWRM model provided scope for further reduction in leakages from the ITWC with potential recharge of connected rural water catchments receiving urban recycled water (or vice versa). Using supply modelling various recharge scenarios were tested (e.g. Arnold et al. 1998). Where this recharged water can be returned to the urban water catchment, further leakages from the ITWC could be reduced (research question 1). Rural proximity and hydrogeology played a large role in the success of such an urban- rural IWRM approach and the international case examples were sought to provide a test of the IWRM model’s applicability to the issue in Chapter 5.

A rural area’s proximity and hydrogeological connectivity to nearby urban area such as the Lockyer Valley offered a relatively unique opportunity to fully integrate the region’s urban-rural water management. This option involved the potential recharge of the Lockyer Valley using recycled urban wastewater (WCRWP) before it was returned downstream to urban Brisbane. This scenario had the potential to close the ITWC by reducing run off into Moreton Bay and its tributaries. For that option to be economically viable, all the downstream catchment recharge benefits needed to be attributed to the beneficiaries through TEV approach and demand modelling (e.g. Arnold et al. 1998) as recommended in the IWRM model. These contributions to the refinement of the IWRM model were explored in the following section.

4.8. Contributions to the Refinement of the New Catchment Scale IWRM Model:

Based on the case study of the Lockyer Valley, the example of the Lockyer Valley did not fit the new definition of IWRM proposed in this study. However, the absence of key components in the case of the Lockyer Valley confirmed the importance of IWRM as an adaptive and participatory process which promotes the coordinated development and management of water, land and related resources as common pool resources, in order to maximize the resultant economic, social and ecological welfare. It can do this through the principles of common but differentiated responsibilities or equity, polluter pays and precautionary approach and the use of triple bottom line accounting and legislative instruments to address environmental issues.

Further refinements of the IWRM model provided by the case study of the Lockyer Valley to guide IWRM included recognition of these key components of IWRM:

- A good understanding of the extended catchment scale of the Lockyer Valley in further closing the ITWC and improving the accuracy of demand and WTP estimates.
- Inclusion of the role of environmental, social, policy and economic dimensions of recycled water, wetlands and aquifers are moves toward triple bottom line accounting in further closing the ITWC and reducing stress on existing Lockyer Valley groundwater.
- Understanding hydrogeological connectivity between components of the ITWC to further reduce leakages from and better manage IWRM in the extended Lockyer Valley catchment.
- Addressing improved coordination of water infrastructure and policy and institutions prior to implementing IWRM to close the ITWC.
- IWRM decisions that promote urban-rural integration to close the ITWC.

These were the key components of the IWRM model required to close the ITWC and better manage water as a common pool resource (research question1). In terms of managing the unused wastewater from urban and rural SEQ, leakages from the ITWC persisted in the Lockyer Valley water catchment. The absence of these key components contributed to the failure to resolve IWRM issues in the case of the Lockyer Valley. The case study of the Lockyer Valley provided contributions to the remaining research questions. The application of sound principles and theory of ecological economic (e.g. derived demand, WTP, TEV) and hydrogeology assisted in the development of IWRM catchment scale conceptual model to achieve these aims (research question 2). In terms of managing demand, population and climate extremes, these issues were not resolved by IWRM policy in the Lockyer Valley (research question 3). As demand for irrigation water continued to outstrip sustainable yield for the Lockyer Valley catchment, this remained an unresolved IWRM issue even when groundwater and surface storages were naturally recharged in deluges in 2010-11. The issue of underutilised wastewater also persisted.

Further support for these key components emerging from the analysis of the Lockyer Valley using the IWRM model were sought from international case examples in Chapter 5. The conclusions about Lockyer Valley IWRM emerging from the application of the IWRM model to these international cases were summarised next.

4.9. Conclusions about Lockyer Valley IWRM Emerging from the Application of the IWRM Model

In summary, the analysis of the Lockyer Valley using the IWRM model revealed that past, present and future water developments require rigorous integrated environmental, economic, technical, social and policy analysis to properly manage water. When this approach to IWRM was not undertaken and key components were not addressed, water issues remained unresolved. Based upon the case study analysis of the Lockyer Valley, prior to undertaking an urban-rural IWRM to close the leakages in the ITWC, several key components of IWRM were required. These key components included the establishment of the correct catchment scale, reliable water demand and use estimates, consistency in policy and institutions, coordination of infrastructure and water pricing of all water sources in the ITWC, social acceptance community participation and greater environmental understanding (research questions 1 and 2).

The example of the WCRWP highlighted the importance of establishing an appropriate scale of water catchment management and of the value of gathering sound hydrogeological and water demand data prior to IWRM decision making. In answer to research question two, the Lockyer Valley has been shown to be part of an extended catchment connected by aquifers and tributaries and constructed water infrastructure. While the SEQRWP did include the Lockyer, Warrill, Fassifern and Bremer areas of the extended water catchment, the plan neglected the full costs, benefits and options of the upper reaches of the catchment that recharge the Lockyer Valley aquifers and downstream Brisbane River. The RWTG (SEQRWSS) included the Lockyer, Warrill-Fassifern Valleys but the Bremer and upstream areas of the connected water catchment were not included as recommended in the IWRM model. Again the urban-rural connectivity to the downstream Brisbane River and its users were not included in the assessment. Policy such as the interim Moreton ROP and TWCMP did not and still do not apply to the Lockyer Valley or extended hydrogeological Lockyer Valley water catchment. These areas would be included in research and policy making decisions made using the IWRM model (research question 2).

The Lockyer Valley example of the WCRWP provided in this Chapter reinforced the importance of sound water demand and cost estimates for this extended catchment in any IWRM decision making. The environmental and social costs and benefits of the extended Lockyer Valley catchment were also considerations overlooked in the policy examples of the WCRWP and SEQRWSS provided in this Chapter (research questions 1 and 2). Neglect of these key components contributed to the unresolved IWRM issues in the extended Lockyer Valley water catchment. In adopting the IWRM model and the ITWC model, the extended Lockyer Valley catchment, groundwater characteristics and usage stood out as important components in reducing unused wastewater, improving water use efficiencies, supplementing natural water supplies and improved integration of wetlands, stormwater and rainwater. As key components of the IWRM model these issues required further data and investigation in policy decisions such as WCRWP in order to close leakages from the ITWC. Without adequate data and investigation, the Lockyer Valley IWRM decisions produced poor IWRM results in the case of the WCRWP (research question 2). Expected changes such as population growth, climate extremes and unused wastewater were not addressed in the extended Lockyer Valley water catchment (research question 3).

Analysis of the Lockyer Valley case study using the IWRM model led to the following conclusions:

- There is continued stress on groundwater and surface water storages at the current (underestimated) water demand and usage rates.
- Future demand for additional water has still not been resolved and management plans for climate, population changes in the extended Lockyer Valley catchment have not been implemented.
- Leakages from the ITWC continue while there was underutilised recycled water, inadequate or inappropriate wetland, and rainwater and stormwater management.
- Poorly placed or uncoordinated water infrastructure and policy exacerbates these issues.
- Environmental issues associated with sewage flows into Moreton Bay and tributaries and inadequate environmental water allocations persist.
- Inadequate estimates of water demand and usage impact on pricing and water access and entitlements policy.
- Interference with the water pricing mechanism (subsidies, pricing under marginal cost and unregulated groundwater) results in under/over use of such water, lack of incentive to provide private water infrastructure and recycled water schemes.
- There is a need for improved education and community involvement in IWRM decision making and understanding the key components of the IWRM model and the benefits for society this could bring (e.g. community acceptance

of recycled water and Lockyer Valley irrigators demand for Class A recycled water).

The enormity and implications of the continued stress on groundwater in the Lockyer Valley and its surrounding catchment became more apparent when compared to international cases of IWRM involving the rural sector. The impact of better coordination of policy and IWRM decisions was exemplified using international case examples in Australia, China, U.S., Spain and Japan.

Chapter 5 Literature Critique of International Cases in IWRM

5.1. Introduction to International Cases of IWRM

This chapter examined international IWRM cases in rural Australia, Asia, U.S. and Spain in order to complement or clarify examples in literature (Chapter 2), Lockyer Valley research studies and consultancies (Chapter 3) and Lockyer Valley case study (Chapter 4). These international cases provided evidence of the importance of understanding dimensions and including key components of IWRM in decision making that emerged from the case study analysis of Lockyer Valley IWRM in Chapter 4:

- Appropriate hydrogeological scale of the water catchment,
- Connectivity of all water and users in the water catchment (ITWCM and TWCM),
- Urban-rural IWRM
- Sound economic principles of water pricing,
- The importance of reliable data on demand and catchment hydrogeology,
- Changes to management of IWRM incorporating co-management and improved access to water infrastructure, and
- Consistency in policy making and institutions (e.g. groundwater monitoring, allocation and recycled water use).

International cases of IWRM were then examined for further evidence of the role of these key components IWRM. Alternative approaches to those taken in the case of the Lockyer Valley were offered and reasons for the failure of policy explained in terms of the IWRM model. These additional international insights were then used to challenge or provide support for the IWRM definition and conceptual model developed earlier in this study. These cases revealed the interrelationship between key components of the overlapping dimensions of the model necessary for IWRM decision making. This chapter focused on cases that offered opportunities for further closing the ITWC in the urban – rural context. For selected international cases, theory and principles of ecological economic and hydrogeology were applied to the IWRM model to answer research questions 1, 2 and 3.

5.2. The Importance of Establishing Scale in International IWRM

A river basin is the commonly accepted unit for international water resources management (e.g. China and Thailand). Yet the IWRM model proposef policy making and planning extension beyond river basin boundaries where groundwater networks and recycled water options. Literature in Chapter 2 and the case study of the Lockyer Valley showed that water management rarely extends beyond natural river basin boundaries. Also water catchment management that focuses on natural boundaries is reinforced by sectoral separation of water users and uses. The process is dependent upon the functions of water catchments diversion, storage, usage, quality and allocation of its resources. Usually the establishment of water management boundaries is the responsibility of government. The relationship between policy and scale outside of the Lockyer Valley was investigated for further insights into the relevance of the IWRM model.

Responsibilities for water management reside with the state governments as a residual power under the Australian constitution, and therefore they own much of the large scale irrigation infrastructure under the *Water Act (2000)*. Due to the scale and significance of the issues, a national approach was agreed to at the 1994 the Council of Australian Governments (COAG) meeting. Following this agreement, a Water Reform Agenda has been implemented. Along with the National Water Initiative in 2004, these policies address water over-allocation and over-extraction, sustainable yield and environmental demand for water and community management opportunities.

The COAG Water Reform Framework (1994) agrees on the following principles that are dimensions of both the water problem internationally and the IWRM model:

- Maximisation of national income and welfare contributions of water within its physical, social and ecological limits (environment and social dimensions);
- A comprehensive water allocation system supported by a water property rights system separate from land title (economic dimension);
- Interstate water trading within physical, social and ecological limits (economic, social and environment dimensions)

- Scientifically determined water allocations for the environment (environment dimension)

(Tisdell et al. 2002, p. 41; NCC 1998).

Nationally, the drive for sustainable water management comes from the National Strategy for Ecologically Sustainable Development, endorsed by the Council of Australian Governments (COAG 1992) and the creation of the Industry Commission (1992). Many of these changes are still to be fully implemented as shown in Australian and international cases the following section of this chapter.

5.2.1. The Virginia Horticultural Area, South Australia.

The case study of the Virginia Horticultural Area (VHA), South Australia contrasted with the horticultural area of the Lockyer Valley in Queensland. As a more developed example of urban-rural recycled water use on a catchment scale, the VHA was examined using the new catchment scale IWRM model. The VHA had suffered from declining groundwater and river levels for irrigation but an IWRM approach involving recycled water from nearby Adelaide addressed this decline (Kelly et al. 2003). Prior to the construction of a recycled water pipeline for irrigation in 1999, the stressed groundwater in the VHA was managed separately to the hydrogeologically connected areas of the Northern Adelaide Plains (Kelly et al. 2003). Since then the wider hydrogeologically connected water systems of the surrounding areas have been combined and managed as the Virginia and the Northern Adelaide Plains (VNAP). The issue of scale has been therefore, resolved early in this case example, providing support for this key component of the IWRM approach adopted in the IWRM model.

The VNAP area contains the Gawler and Little Para Rivers and is located north of Adelaide within the Council boundaries of the City of Playford and the District Council of Mallala (Jensen Planning & Design 2013). In more recent government policy such as the 30-Year Plan (South Australia Department of Planning & Local Government SA DPLG 2011), the VNAP boundaries have been extended to include the potential area of supply of recycled water into the Northern Adelaide Plains, and potential opportunities for horticultural expansion north of the Gawler River (Jensen Planning & Design 2013).

Research undertaken by the Goyder Institute for Water Research (2014) mapped the aquifers underlying Adelaide from the Adelaide Hills to the plains. Understanding this connectivity of aquifers assisted with the establishment of the true scale of the VNAP catchment.

Like the Lockyer Valley, the main source of recharge for the Tertiary aquifers of the Northern Adelaide Plains is rainfall-fed fractured rock aquifers in the Mt Lofty Ranges to the east of the prescribed area (AMLR NRMB 2013a). Consequently, the proposed Adelaide Plains Water Allocation Plan (WAP) covered the groundwater of the Northern Adelaide Plains, Central Adelaide and the Dry Creek prescribed wells areas (AMLR NRMB 2013a). This enabled the VHA and the Northern Adelaide and Barossa Catchment Water Management Board (NABCWMB) to facilitate a shallow water table monitoring network (Stevens et al. 2003b). These plans recognised the importance of water monitoring required for responsible catchment irrigation management. The interconnection of aquifers beneath the area were then monitored and managed as part of the extended water catchment area. Preceding chapters established the importance of linking natural and created water systems within the extended water catchment via the ITWC model, and the following case examples were examined for evidence of this approach using the IWRM model.

South Australia introduced a range of recycled wastewater and stormwater projects in both the urban and rural sectors. From the early 1800s, treated sewage had been used for crop and pasture irrigation around the capital city of Adelaide (Dillon et al. 2007). In 1944 Adelaide was the first capital city to treat all wastewater to secondary quality (Dillon et al. 2007). For decades, pipelines and WWTP have been owned by both public and private entities that service metropolitan and rural areas of SA. The recycled water is not for drinking, but has significantly reduced reliance on underground water sources in the north. It also assists with rising salinity problems in the State (Dillon et al. 2007). The VNAP IWRM area includes natural and constructed water sources:

- Para and Gawler Rivers
- Groundwater from T1 and T2 aquifers

- Treated wastewater from Bolivar and delivered by Water Reticulation Services Virginia WRSV
- Mains supply from SA Water potable water mains
- Capture and Reuse from storm water on site
- Capture and Reuse of storm water from Local Government Schemes, including: The City of Playford Wetland and ASR scheme, the City of Salisbury Wetland and ASR scheme, and the Gawler Water Re-Use Scheme
- Larger growers in the VNAP invest in infrastructure to gather water from greenhouse rooftops to store in dams to supplement supply (Jensen Planning & Design 2013, p.44)
- Irrigation infiltration from domestic, groundwater, recycled water; wetland, dam and bore leaks;
- Salt pans, sewerage lagoons and channels, drainage from wells and trenches

(Gerges & Kelly 2002).

These inflows included natural and created water supplies which form part of the ITWC as described in Chapter 1. According to the ITWC sub-model, recycled water options also determined the extended water catchment boundaries. This interaction between the key components of scale and the ITWC was further explored using international examples of recycled water schemes in section 5.5. The next Australian case of appropriate IWRM scale was the Murray Darling Basin (MDB).

5.2.2. The Murray-Darling Basin Catchment Area, Australia

The water in the MDB derives from the Great Dividing Range and into 23 major rivers, including the Murray, Murrumbidgee and Darling (MDBA 2015a). The *Water Act 2007 (Act No. 137*) was amended in 2011 and provision was made for the management of the water resources of the Murray-Darling Basin at the catchment scale (MDBA 2015a). Since 2012, integrated management of MDB water resources has occurred at the catchment scale governed by the environmental boundaries of the interconnected water system of four States (QLD, NSW, VIC, SA) and the Australian Capital Territory (ACT) (MDBA 2015a). Data on MDBA water sources and storages has been compiled by the governments involved – QLD, NSW, VIC, SA and ACT. These data enable the connection between water sources within the MDB to be understood and allocations for the Basin determined. This approach is less constrained by state boundaries and administrative jurisdictions and is consistent with the integrated approach to the hydrogeologically determined scale adopted in the IWRM model (research question 1).

5.2.3. The United States of America

The Cheney Lake watershed in Kansas, U.S. represented another example of integration of water resources on a catchment scale (Selfa & Becerra 2011). The watershed supplies 99 per cent of its water to agriculture production with the remainder supplied to the city of Wichita, Kansas and surrounding cities (Wichita Government 2013, p.2). The water supply is derived from the *Equus* Beds aquifer (40%) and Lake Cheney Reservoir (60%) (Wichita Government 2013, p. 3). The watershed encompasses land in five counties, but for administration purposes the watershed is subdivided into four smaller watersheds (Cheney Lake Watershed 2014). Water monitoring in this watershed, undertaken by the U.S. Geological Survey, determined that the watershed resides within the Lower Arkansas Basin (Hansen et al. 2014). Significant hydrogeological modelling, water use and demand studies are undertaken regularly by The U.S. Geological Survey and the U.S Department of the Interior and the Kansas Water Office (Hansen et al. 2014). These data help to establish the boundaries and water resources of the watershed and Basin. This case examples showed that water catchment boundaries may change with further closure of the ITWC. Provision of additional water supplies through recycled water and water trading can expand the sources and users of catchment water.

These case examples highlighted the importance of managing water on an appropriate catchment scale in order to encompass the ITWC and all its users. The cases supported the non-sectoral approach in the new IWRM model. The issue of urban-rural integration is addressed next in section 5.3. Section 5.4, presented evidence from these international cases for the need for consistent data, and methods to estimate demand and WTP, before water policy and project decisions were made. Section 5.5 addressed the options for integrated water management and links between policy, economic and community dimensions. The importance of involving stakeholders in decision making at the local level to ensure acceptance and understanding of local conditions was considered in these case studies in section 5.6. International case examples, where decisions about the scale and options for closing the ITWC through water markets or facilitated by improvements in policy coordination and reductions in institutional overlap, were addressed in sections 5.6 and 5.7.

In international cases, whether utilising a centralised (top-down) approach or a decentralised (bottom up) approach, the level of integration between institutions and cooperation amongst policymakers appeared critical. International examples of the top-down approach, traditionally adopted around the world to improve environmental (including water) management and coordination, often resulted in coordination problems (Lane & Robinson 2009). A combined top-down and bottom up approach appeared to resolve some of the issues that emerged in the Lockyer Valley case study – with the real focus on the coordination of policy and institutions remaining paramount.

In summary these cases showed the success of a whole of government approach to IWRM with clear, consistent and transparent water property rights. Ideally these property rights have legislated national or state government support with local level monitoring enforcement to encourage community involvement and commitment. The case of urban-rural water integration and the achievement of these aims were examined. The model was again applied to develop a deeper understanding of the water problem, the IWRM dimensions and key components its applications for wider use. The implications and consequences of this approach were used to assist in refining the model and understanding IWRM in the Lockyer Valley and elsewhere. The multidimensional approach to IWRM was then used to answer research question one, related to managing recycled water as a common pool resource and as an option to closing the ITWC.

5.3. International and Australian Examples of Urban-Rural Integration

The separation of water into sector use dominated past international water policy and practice (World Bank 2010). This was reinforced by the separation in IWRM of sector disputes and water supply in both the centralized (top down) and separated (bottom up) approaches to IWRM discussed further below (Zeng et al. 2006). Using the definition of the urban sector which included industrial users outlined in Chapter 2, examples of urban-rural integration were reviewed for opportunities to apply and refine the IWRM model and close the ITWC and manage drivers of water demand (research questions 1, 2 and 3).

There has been a long history of using untreated wastewater from urban areas to irrigate rural areas in Rome (Hansen n.d.), Greece (Koutsoyiannis & Angelakis 2003), China (Tian et al. 2011), Israel (Blair & Turner 2004), Flanders, Belgium (Angelakis et al. 2003), California, U.S. (Hutchinson & Wilson 1974), Mezquital Valley, Mexico, Spain (Angelakis et al. 2003; Pescod 1992) and Sweden (Angelakis et al. 2003). Table 5-1 summarised some of these.

5.3.1. China

Shenzhen, Guangdong Province, China is an example of urban-rural water IWRM. It established the first Water Affairs Bureaus (WAB) in 1995. The centralised Ministry of Water Resources (MWR) and the water administrative department (WAD) of State Council replaced these WABs in 1999. The latter promoted integrated urban-rural water affairs management in China (Shen & Liu 2008). In China, industrial and urban water use crowds out rural water use (Tian et al. 2011). The urban area derives water resources from the rural area and water supply infrastructure is expected to supply stable good quality water from reservoirs and groundwater aquifers (Shen & Liu 2008). Conversely in China, large quantities of untreated wastewater from the urban and industrial areas flow to and pollute the rural environment (Shen & Liu 2008).

Table 5-1 International Wastewater Projects

Year	**Water Class**	**Wastewater Project**
<1940s		**China wastewater reuse** for irrigated agriculture
1962	Drinking indirect PRW since 1962 via sedimentation and activated sludge treatment, sand filtration and disinfection with chlorine (PRW)	**Montebello Forebay Groundwater Recharge Project, California, USA** Soil aquifer treatment using reclaimed water via spreading basins into the Rio Hondo and San Gabriel Coastal Spreading Grounds and aquifer storage and recovery
1966	Direct untreated	**Mezquital Valley, Mexico** wastewater recharge of valley and aquifers for crop irrigation
1970s		**Northern Adelaide Plains**, SA, via the VPS
1974-8	high quality tertiary treated indirect	**Lower Molongo Sewage Treatment Plant, A.C.T, Australia** Tertiary treated effluent used to irrigate vineyards.
1978	Secondary treatment only	**Dan Region WRP Israel**, soil aquifer treatment and spreading basin for irrigation
1978	Drinking standard indirect use	**Upper Occoquan USA** PRW Upper Occoquan Sewerage Authority Water Reclamation Plant in Fairfax County North Virginia, USA - reservoir augmentation with treated domestic and industrial wastewater
1980s	Tertiary treated indirect	**Monterey Bay California, USA** seawater intrusion and vegetable irrigation
1983		**Florida California, USA** aquifer storage and recovery
1988	Non-drinking standard	**Las Vegas, Nevada**, USA aquifer recharge
1987	Non-drinking indirect use of river water (not	**Angas-Bremer** irrigation area of SA Australia MAR via wells for

	wastewater)	viticulture
1991		**El Prat de Llobregrat WWTP Spain** treated wastewater in agricultural irrigation and aquifer recharge
1995	Advanced treatment indirect into basin for drinking and other uses	**West Basin Water Recycling Program, El Segundo**, California, USA aquifer storage and recovery using treated wastewater
1999	Class A, indirect use, activated sludge treatment plant, aeration lagoons and reclaimed in a dissolved air flotation and filtration plant with chlorination	**Bolivar STP, Salisbury Adelaide, Australia** aquifer storage and recovery for horticulture
2000	Class D Secondary treatment indirect to aquifers	**Halls Head WA, Australia** MAR via infiltration ponds for green space irrigation
2002	indirect drinking, ultra-filtration, reverse osmosis and ultraviolet disinfection treatment (PRW)	**Wulpen WWTP, Belgium** aquifer storage and recovery using treated wastewater
2004	Class A ultra-filtration and reverse osmosis	**Kwinana Plant Woodman Point WWTP** Australia, aquifer recharge for industry
2005		**Bolivar STP, Salisbury, Adelaide** reclaimed water from Salisbury wetlands to 1000 homes at Mawson Lakes.
2007		**Blanes WWTP, Spain** reclaimed wastewater reuse for private farm irrigation community
2008		**Point C Gnangara Mound**, Perth, Australia aquifer storage and recovery trial

Sourced from: Pescod 1992; ACTEW 2000; Hafi 2002; Angelakis et al. 2003; Chen et al. 2003; Kamizoulis et al. 2003; Steenvoorden 2003; Blair & Turner 2004; Dillon et al. 2007; Stratton n.d.; Yu et al. 2008; Xuan & Xu 2009; McGhie 2009; Winpenny et al. 2010; QWC 2011.

In China rural areas often contain large wetlands for paddy agriculture. These wetlands provide environmental benefits such as temperature, moisture and gas (carbon dioxide and oxygen), waste and water storage balance in local areas, cities and forests (Xingqing 2009). The National Government provides compensation for the ecosystem services offered by these agriculture and rural services (Xingqing 2009). This recognition of environmental services in IWRM demonstrated the thinking in the IWRM model by combining environmental, economic and policy dimensions in China's IWRM for managing common pool resources (research question 1). China also uses rural financial reform to provide incentives for urban-rural IWRM to close the ITWC. This was a prime example of the thinking proposed in the IWRM model – employing economic theory and policy instruments to manage the multiple dimensions of IWRM (research question 2).

5.3.2. Japan

Water allocation is managed as a common pool resource in the Nishikanbara and Kamedago Land Improvement Districts (LIDs) of Japan (Sarker & Itoh 2003, 2001). Japan has a policy of "state-reinforced self-governance" where governments and irrigators share management of irrigation systems (Sarker 2013; Sarker & Itoh 2003). Irrigators have responsibility for water allocation through self-regulation, while government provides financial support for infrastructure (Ross & Powell 2008). The government has strong financial, technological, statutory, and policy support for irrigators but does not coerce the users to manage the commons nor take control itself (Sarker 2013). The government facilitates a multitude of irrigation user associations intervening only in areas such as agricultural protectionism and trade liberalization (Sarker 2013). Farmers form legal associations at national, prefectural, and local levels or LIDs. These associations follow a decentralised approach to self-govern and develop irrigation and drainage facilities (Sarker 2013). Japan's large-scale irrigation commons are a closed-access common-pool resource (CPR) with clearly defined common-property rights (Sarker 2008; Sarker & Itoh 2001, 2003).

Japan's state reinforced self-governance system provides the resource users with financial, technological, statutory, and political support without undermining self-governance (Sarker 2013). Irrigators utilise their own institutional arrangements including peer pressure to manage these common pool resources (Sarker 2013). A suggested reason for this is that agricultural use is much less important in Japan than in other countries (Ogoshi et al. 2001). The socio-political dimensions of the water problem were dealt with effectively in the example of Japan and provided support for the IWRM model in its multidimensional approach (research question 1). It was also an example of the relevance and applicability of the theory of co-management of water as a common pool resource referred to in Chapter 2 (Ostrom 2010; Sarker et al. 2008). This co-management approach to managing water as a common pool resource was lacking in the case of the Lockyer Valley.

5.3.3. The VNAP Area

Until recently there have been few Australian examples of catchment scale IWRM that manage water effectively as a common pool resource. The Northern Adelaide Plains groundwater is managed in the prescribed wells area. A major difference between the case study of the Lockyer Valley and the VNAP was that the deficiency in water planning had been evident for a long time for the Virginia system and had been accepted by the community and policy makers. Since 1959, reclaimed wastewater from Bolivar sewage treatment plant north of Adelaide, has been reused for irrigation of horticulture (Dillon et al. 2007). The VPS is an example of collective action outline by Ostrom (1990). The private water reticulation company, Water Reticulation Services Virginia (WRSV), prepares irrigation management plans which are approved by the EPA and supported by education and information about recycled water in irrigation available from the farmers’ cooperative the Virginia Irrigation Association (VIA) (Bolan et al. 2008). The VPS is a BOOT (Build, Own, Operate and Transfer) project which represented a contribution to social capital derived from the trust and cooperation in the VPS by its various stakeholders (Keremane & McKay 2008).

It appeared from the VNAP case study that early links between community and policy makers was important to the success of IWRM. In the VNAP evidence was presented linking the issues with poor groundwater monitoring data and modelling to inaccurate estimates of demand for irrigation water (included recycled water) and determination of sustainable catchment yield and water allocations. These catchment management issues were not resolved in the case of the Lockyer Valley and represented a major difference in the approach taken in the VNAP. Some of these issues required a consistent approach to community involvement and acceptance of groundwater monitoring, calculation of sustainable yield and acceptance and WTP for recycled water.

Some River Murray water is supplied via the Swan Reach-Stockwell pipeline to the northern Adelaide is managed through water licenses and allocations covered in Water Allocation Plans (National Water Account (NWA) BOM 2014). This Plan has rules that facilitate water trading within the prescribed well area (BOM 2014). Many of the existing examples of urban-rural water trading in Australia involve small volume ad hoc arrangements including SA Water Corporation purchased water entitlements from Lower Murray Swampland Irrigators dairy farmers (Hampstead 2006; SA Water 2004).

A major difference between the VNAP case study and Lockyer Valley was the underestimation of the Lockyer Valley water problem by government. As mentioned in Chapter 3 the impact of a prolonged drought had not been factored into estimates of water supplies of plans for water security in the case of the Lockyer Valley. Policy makers consistently underestimated the demand for irrigation water and overestimated the sustainable yield of the aquifers in the area (MEP 2013; DNRM 2005a). Water allocation plans for the VNAP had recognised the pressure placed on aquifers by irrigation well before the crisis emerged there in the 1960s and recycled water for irrigation had been implemented back then to meet demand (Dillon et al. 2007).

The early introduction of legislation for recycled water in South Australia assisted the introduction of large scale recycled water projects in areas such as the VNAP. The changes introduced about by the Water Act 2000 (Qld) brought the regulation of recycled water and drinking water in line with the regulation of other water service providers in the State (Allens 2008). Further, the relevant ROPs for the Lockyer Valley were not introduced until 2008. Even now there are no groundwater licences in the Lockyer Valley outside the central area. The overreliance on economic and technical solutions to Lockyer Valley IWRM (and in research studies and consultancies) continued as the policy environment struggled to catch up during the SEQRWT.

5.3.4. The MDB

The Murray Darling Basin Plan supports the new IWRM model by integrating the components of scale, economic incentives, and coordinated policy decisions on water entitlements and water trading. The Plan is a catchment scale framework for an area containing about 40 per cent of Australia's farms and 70 per cent of Australia's irrigated land area (Murray Darling Basin Authority MDBA 2015a).[29] MDBA supports the integrated management of the water resources of the MDB through coordination with various levels of government, research organisations and business (MDBA 2015a). This is another example of the established urban-rural IWRM using water trading as suggested in the new IWRM model. This was further investigated.

The Basin Plan aims to balance environmental, economic and social considerations whilst improving outcomes through a sustainable diversion limits adjustment mechanism and a constraints management strategy (MDBA 2015a). The Commonwealth Government supports the Plan through investment in irrigation infrastructure and voluntary water purchasing through the Environmental Water Recovery Strategy (MDBA 2015a). The Plan operates on a catchment scale governed by the environmental boundaries of the interconnected water system of four States and the ACT. The IWRM model supported decision making on a water catchment scale and the multidimensional approach adopted in the MDB Plan. The key components of establishing the appropriate scale and catchment water plan prior to introduction of IWRM policy and instruments aided decision makers in the MDB Plan as was demonstrated in section 3.2.1. The SEQRWT was attempted before the Water Resource (Moreton) Plan was released in 2007 and then the amendment included the Lockyer Valley in October 2008. The original ROP (2009) did not extend to the nearby Warrill and lower Lockyer Valleys (DNRM 2014a). Establishing Water Plans prior to IWRM decision making assisted to reduce overlap and provided better institutional coordination in IWRM in the basin (research question 1).

The water of the MDB is treated as a common pool resource and managed to some extent according to the principles of TEV (Chapter 2) through the extension of water allocations

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[29] The MDBA was established under the Commonwealth Water Act 2007 as an independent, expert statutory agency.

and water trading for users in the northern Basin. The southern-connected Murray-Darling Basin is one of the most mature water markets in the world (MDBA 2015b). Temporary Basin water allocations have been traded since the 1980s and volumetric water licensing since the 1970s (MDBA 2015b). The MDBA allows irrigators to trade water across state borders. Extension of water trading and entitlements to the northern MDB endorses the principles of managing common pool resources throughout the Basin (Reeve et al. 2009). Care must be taken to ensure that the environmental demand for water is met under such water trading arrangements.

The new Basin Plan (2014) establishes clearer and more consistent water trading rules in a bid to reduce duplication of existing state rules (Reeve et al. 2009). Urban-rural overlaps and inconsistencies are yet to be addressed in the MDB plan. For example, existing reservoirs, dams and other storage structures have altered normal river flow patterns and the impact on trading require redress (MDBA 2015c). Urban development could be incorporated into the entitlement system to address some of these urban-rural integration and common pool resource issues between sectors (Reeve et al. 2009; Young and McColl 2008, Price Waterhouse Coopers 2006). This was consistent with the non-sectoral approach of the IWRM model.

Using the multiple dimensions of the IWRM model policy issues can be considered in urban-rural water integration. Key components emerged from these case examples including governance of investment, access to water infrastructure and services, cost recovery and environmental issues such as maintaining groundwater levels, environmental management and protection, public health and sanitation, land and energy resource development (including rural development) and food security. Some additional Australian urban-rural IWRM cases were then examined for evidence of this thinking.

5.3.5. Other Australian Urban-Rural IWRM cases

The lack of physical proximity and hydrological or engineering viability has been a barrier to integration of urban and rural water systems (Lin et al. 2008; Pumphrey et al. 2008; Dwyer et al. 2005). The lack of viable physical options (pipelines) was a major reason cited for policy inertia in Australian urban-rural water integration (Lin et al. 2008). In

Australia the only capital cities physically connected to nearby agricultural water systems are Canberra, Adelaide and Melbourne. Even in these examples there is limited integration between urban and rural water systems (Dwyer et al. 2005).

Since Australian Federation, water rights have resided with the state governments (McKay in Crase 2007; *Water Act 2000*). Each state manages groundwater and surface water under different legal and institutional frameworks but in the past this effectively provided unlimited access to groundwater (McKay in Crase 2007). Only in the last 10 years have Water Plans addressed the issue of access to groundwater. Despite a high degree of urbanization in Australia a strong agrarian tradition persists within rural areas (Botterill 2009). Australia has a history of subsidising rural industries, providing assistance and programs for rural communities, drought relief, income support and interest rate subsidies, and tax incentives for agricultural investments (Lin et al. 2008; Crase 2007). For example, the Australian Wheat and Sugar Boards and Grains Council implemented price floors for produce and fixed quantity contracts (Hilmer et al. 1993). The resulting resource rents favour the agricultural sector and the retention of agricultural water rights (Lin et al. 2008).

Australia has experienced declining terms of trade in agriculture from 0.5 per cent in 2003-04 to 0.1 per cent in 2011-12 (ABS 2012). Government support of water use in the agricultural sector represents an artificial resource rent for water in agriculture - a sector that experiences a relatively low rate of return (ABS 2012; Lin et al. 2008). Moves toward volumetric charges for water and recovery of infrastructure costs will mean that large rural water users will pay more for water in a water market and with tight product margins, will have their gains from water trade reduced (Lin et al. 2008 p. 135).

Dwyer et al (2005) models the effects of inter-sectoral trade under different trading scenarios in Canberra, Adelaide and Melbourne and the irrigation areas in the southern MDB and south east Victoria. They find the gains from water trade (in terms of gross output) accrue to the urban sector under each scenario. Further, a reduction in outputs results in each irrigation districts under all the water trading scenarios. Crase and Dollery (2005) offered an insight into the cause, citing state government retention of water infrastructure ownership with irrigators responsible for management and control of the infrastructure. Culminating in a higher price for urban water. In NSW private irrigation companies can own infrastructure, but in all three States (NSW, SA and VIC) the daily control of water resources rests with the private sector and users (Crase et al. 2008).

The answer to successful IWRM appeared to rest partially on water infrastructure ownership and management of the water resources themselves. The gains from trading water between irrigators in Victoria showed that ongoing water entitlements have been significantly more expensive than temporary trades (Productivity Commission 2005). Further, the simulated gains from water trading (in terms of gross output) accrued to the urban sector and less water was available in each irrigation district under each scenario (Dwyer et al. 2005). This study expanded to include urban-rural water trade from the metropolitan regions of Adelaide, Canberra and Melbourne (Dwyer et al 2005). The results of the simulation indicated that water trade involving urban centres with high levels of water consumption (Melbourne and the Gippsland) have had a significant effect (Dwyer et al. 2005). These examples of urban-rural water trade produced gains for both buyers and sellers of water. They reflect “the relative levels of water use by the trading regions and the ability of users to substitute water for other inputs” (Dwyer et al. 2005, p.15). Dwyer et al. (2005) study did not include the option of recycled water and other changes in water storages or climate which would impact on the derived demand for water gains from trade (providing substitutes and potentially lowering the price of water). The literature in Chapter 2 showed that these are key components of a coordinated non overlapping system of water infrastructure and water trading rights. This was not the experience in the Lockyer Valley (Chapters 3 and 4).

In summary these examples of urban-rural water integration highlighted the importance of understanding and managing for the derived nature of demand and supply of water. The IWRM model included all the aspects of urban-rural demand (price, water substitutes, use and users, water markets and trading) and of urban-rural supply (costs, alternative supplies, water management and operations, technology and private water providers and cooperatives). These examples showed that a comprehensive understanding of all dimensions of IWRM used in calculating the sustainable yield and allocations of water in catchments (including the environment) assisted this process. The involvement of multiple stakeholders from urban and rural areas provided much needed information about demand

and use of water in catchments in rural contexts. The influence and impact of available data on water demand and pricing were then examined in the rural context.

5.4. The Importance of Consistent Data and Methods for Determination of Water Pricing, Demand and Sustainable Yields

A common key component that emerged from literature and missing from the case study of the proposed Lockyer Valley recycled water scheme was the early comprehensive determination of appropriate pricing of all water substitutes in the ITWC. Comparative Australian and international cases where such pricing was achieved contributed to resolving the IWRM issues and were examined. Thereafter, a review of the importance of consistent data of demand and catchment hydrogeology was offered in support of the IWRM model internationally.

5.4.1. Water Pricing

COAG's main water policy agreement, the National Water Initiative (NWI) signed in 2004, established the National Water Commission (NWC). The NWI agreement intended to establish a nationally compatible market, regulatory and planning based system to manage surface and groundwater resources for rural and urban use, and optimise economic, social and environmental outcomes (NWC 2004). From here the imperative for an Australian National Competition Policy (NCP) emerged and became the focus of microeconomic reform. The push towards improved competitiveness, competition, efficiency and flexibility in business was driven by the NCP Review Committee (Hilmer et al. 1993) and signing of NCP in 1995. The water industry was specifically mentioned with regard to efficiency in provision of water services (NCC 1998; Hilmer et al. 1993). Intergovernmental agreements in the reform package were relevant to water management - opening the water sector to greater competition through wider access to water infrastructure, and publicly and privately owned water monopolies (NCP 1998). Yet by 2005 the National Water Commission noted water resource management had improved but there had been inadequate progress in addressing interstate water trading, water planning and over allocated systems (NCC 2007). The following example was provided to illustrate.

Upon signing the COAG agreement state governments agreed to full cost recovery for all urban and regional water systems and committed to meet both lower and upper bound pricing (NWC 2007c). The COAG defined lower bound pricing for water charges as sufficient to recover the operational, maintenance and administrative costs, externalities, taxes or tax equivalents, the interest cost on debt, any dividends and provision for future asset refurbishment or replacement (NWC 2004, clauses 65-77). Upper bound pricing for water charges was to be set above lower bound charges but avoid monopoly rents and commercial returns on the assets (NWC 2007c, p.1). Thus pricing rules have been established to correct for these market failures related to economies of scale and monopoly control. While urban water systems achieved the upper bound pricing by 2008, regional water systems continue moving towards both lower and upper bound pricing where practicable (NWC 2007c).

Under the broader microeconomic reforms that have been introduced, the water sector has focused on water pricing (lower bound pricing, price transparency and incentives to remove subsidies) and separation of service delivery (non-government organisations or statutory bodies) from regulation (government) (OECD 2010). The NWI continues to focus on nationally consistent approaches to matters such as capital recovery and the identification of water planning and managements costs (Tisdell et al. 2002). In reality water prices across States and between sectors vary greatly. The NWC encourages reform and has advised COAG in line with National Competition Policy (NCC 1998). For example, it has been recommended that agricultural water prices cover the costs of those businesses through water storage and delivery charges (NWC 2007c). These prices are still to be implemented widely for reasons explained next.

Since the 1994 COAG Agreement (COAG 2004) water prices have been moving towards being reflective of the cost water supply. These prices are intended to “give effect to the principles of user-pays and achieve pricing transparency in respect of water storage and delivery in irrigation systems and cost recovery for water planning and management” (NWC 2004, clause 64). For example, since 2006 SunWater in Queensland is responsible for price setting in consultation with water users. The Queensland Competition Authority (QCA) independently reviews pricing when required (SunWater 2006).

At the peak of the millennium drought, national water prices reach $1000/ML on average for crop areas but most of these cases received subsidies for economic and environmental equity (Psi-Delta 2003, p.34). Since 2006, where government entities have been required to provide water supply services to irrigators at a price that is less than lower bound levels, the balance is paid by government as a transparent community service obligation (CSO) payment (SunWater 2006). The level of these payments represents the extent to which the different entities are not yet achieving lower bound pricing. For example, SunWater had received just under five per cent of its revenue as a CSO payment during drought in 2008/09 (SunWater 2006). This payment has been reduced by 50 per cent under the current price path, in 2010/11 (SunWater 2006). In Victoria neither of the two major rural water supply authorities receives CSO payments (SunWater 2006) as shown in Table 5-2. In the literature in Chapter 2, the removal of subsidies is shown to improve the function of the price mechanism and provide a more accurate message about relative water costs to customers (e.g. reflects its scarcity and the availability of substitutes). It may be that subsidies are retained for social and equity purposes but the consequences needed to be explored using the social and economic dimensions of the IWRM model.

According to Table 5-2 estimates of subsided Virginia, Western Water and Barwon schemes in Victoria were closer to WTP for Lockyer Valley recycled water estimated at the time of the SEQRWP (Psi-Delta 2003). At $150/ML, these Lockyer Valley estimates of WTP have been overestimated given that these irrigators outside the central Lockyer Valley area did not pay for groundwater. A more recent estimate of Lockyer Valley placed groundwater value at $600/ML (MJA 2012a). Interstate groundwater prices were provided in Table 5-3 for further comparison.

These estimates related only to the direct use value and do not include estimates of the non-use (non-extractive or option) value of groundwater. Therefore, the price of groundwater is expected to be much higher when non-use values are added. These estimates of economic value are likely to rise substantially in the future given surface storage issues and the fact that groundwater usage for agricultural irrigation exceeds the sustainable yield in most cases (DAE 2013). If used as shadow prices for recycled water this evidence suggested that the price of all water for irrigation would be closer to $600/ML than $150/ML estimate by

Table 5-2 The Subsidies Provided for Australian Recycled Water Schemes

Scheme	$/ML p.a.	Crops	Subsidy	Comment
Class A Water				
Virginia (SA) 22,000ML	$110	Vegetables, viticulture	>80%	Federal, State and Water Authority Contributions on environmental and economic benefits
Eastern Irrigation Scheme (SA)	$250 (p)	Vegetables, pasture, recreation and residential	n/a	Distance from treatment plant > 20 kms requires major subsidy
Class B & C Water				
Barwon (VIC) 2,000ML	$150 and increasing	Horticulture, viticulture and turf	<10%	Price path 50% potable
McLaren Vale (VIC) 5000 ML	$800+	viticulture	0%	Capture of increased land value and use on high value crops made scheme more viable
Western Water (VIC) 1500ML	$200	viticulture	50%	
Clarence (TAS) 3,000ML	$30 (p)	Viticulture, pasture production	>80%	
McLaren Vale (VIC) 5,000 ML	$800+	viticulture	0%	Capture of increased land value and use on high value crops made scheme more viable
Wetalla (QLD) 10,000ML	$150 (p)	Cereal, irrigated pasture, cotton	n/a	Scheme is for cotton and fodder crops in Eastern Downs
South Eastern (VIC) 1,500ML	$35	Viticulture, turf	variable	Customer usually installs pipe

Source: SEQRWP (Psi-Delta 2003) pp. 35-6. Note: (p) proposed

Psi-Delta (2003). These estimates were based on data for the years 2006 - 2012. These Psi-Delta (2003) estimates were adjusted for inflation at an average of 3 per cent p.a. (Reserve Bank of Australia 2015). The estimate of water prices became $586/ML. At this price, demand for all types of irrigation water would change significantly and affect the findings about the economic viability of the WCRWP extension (Psi-Delta 2003) and current demand for irrigation water.

Table 5-3 Australian Groundwater Prices

Scheme	Horticulture & Agriculture Users
Gnangara, Western Australia (MJA, 2012a)	$900-1870/M
Shepparton, Victoria (MJA, 2012a)	Upper traded value of $750/ML in 2007 droughts Lower traded value of $25/ML in 2011 floods. Long run average over 2007-2011 approximately $290/ML
Daly River, Northern Territory (MJA, 2012a)	$452/ML
Northern Tasmania (MJA, 2012a)	Vegetables: $1000/ML Other crops including poppies, pyrethrum and berries: $1900/ML Dairy: $600/ML
Goonoo Goonoo Creek, Tamworth, New South Wales (NSW Office of Water 2010)	Lucerne production $402/ML

Source: DAE 2013, pp. 22-3.

The TEV approach discussed in Chapter 2 should be applied to water in order to reflect the non-use values for the environmental aspects such as ecosystem function (research question 2). Unless this is done the full benefits of artificial catchment recharge and reduced stress on surface and groundwater are underestimated and financial assessments fail to return favourable economic results as in the case of the WCRWP to the Lockyer Valley. There are few international examples of the TEV approach used in policy making. A case study of the Coorong, Lower Lakes and Murray Mouth regions in SA (Hatton MacDonald et al. 2011) outlined the TEV approach but did not apply these non-use values (MJA 2012c). The reason given was the extensive time and cost involved in initial TEV assessments (MJA 2012c). These costs declined with widespread use and dissemination of these values (DAE 2013). Practical methods for TEV needed further development and as the availability of estimates grows these can be used for comparisons and basic calculations (Tisdell 2012). As previously shown, failure to reflect the TEV approach in water markets and pricing results in failure to manage water as a common pool resource.

In the case of rural China, the compensation for ecological dividends afforded by reafforested farmlands to retain water, was an example of the TEV approach. These non-use benefits (amenity, bequest, intrinsic and vicarious value) of water were recognised. Industrial and urban water users in China pay for these benefits through water quotas drawn from agriculture and rural areas (Xingqing 2009). These non-use values are funded by urban water charges or metered water usage fees in downstream cities. Elsewhere in China rural infrastructure projects funded by state bonds for rural drinking-water projects also recognised some of the non-use benefits of water and the externalities provided by protection of environmental demand for water (Xingqing 2009). The MDB Environmental Watering Plan also promotes recognition of the benefits of environmental watering basin-wide across state and territory borders (MDBA 2015b).

In summary these case examples highlighted the importance of understanding and managing for the derived nature of demand and supply of water and its connection to price. The multidimensional approach of the IWRM model facilitated this understanding by combining all the aspects of demand (price, water substitutes, use and users) and of supply (costs, alternative supplies, water management and operations, technologies and suppliers and policies). The TEV approach makes valuation of these benefits possible and therefore provided the opportunity to closing the ITWC by making water users pay the full value of all water. Recycled water would then be too valuable not to use. For now, full cost pricing based only upon the use value of water is the norm in these case studies. The extent to which reliable consistent demand and hydrogeological data can assist cost reflective pricing and IWRM was then considered.

5.4.2. Data

Policy makers understood that part of the stressed groundwater problem in the VNAP related to insufficient data (Marks & Boon 2005). Data was needed on water use patterns, leaching losses beneath crops with and without management systems, and groundwater monitoring and natural tracer studies (Marks & Boon 2005). As mentioned in section 5.2.1 the early conduct of groundwater modelling monitoring throughout the VNAP area established the sustainable yield of the aquifers (NABCWMB 2000). This facilitated the introduction of groundwater monitoring in the area and more accurate estimation of demand for irrigation water (included recycled water).

An Irrigation Management Plan (IMP) became a licensing requirement of the scheme. See South Australian Reclaimed Water Guidelines (DEHAA&EPA 1999, p. 33) at the time. A

Water Quality Management Committee now meets annually to approve and accept the IMP water data from the regular monitoring reports. Monitoring is now carried out on groundwater data collected from the NAP prescribed wells area (BOM 2011a), the River Murray water supplied to the Barossa Valley and northern Adelaide and the water supplied by SA Water Swan Reach-Stockwell pipeline (BOM 2011a). This data is used to determine water access under the Water Allocation Plan (WAP) and for the allocation of water licences (AMLR NRMB 2013b).

The Adelaide Plains Water Allocation Plan (WAP) for the northern part of this area adopted in 2000, is currently under review for further extension as data on users and water sources becomes available to policy makers (AMLR NRMB 2013a). An example of where data assists in policy coordination is water trading within the prescribed well area. Trade of water rights is subject to the rules of the relevant water allocation plan (NAP) and the *Natural Resources Management Act 2004* within the prescribed area (BOM 2013). Once these data established the declining state of groundwater and river levels for irrigation in the VNAP area, the main policy approach to supplement this water was the use of recycled water (Malinin et al. 2011; NABCWMB 2000). A Water Management Plan for the VNAP area has been designed around the environmental requirements for dependent ecosystems and estimates of sustainable yield (Marks & Boon 2005). There is a clear link between the need for reliable consistent data on water demand and supply and consistent policy to address the deficiencies highlighted by the data. The use of recycled water to close the ITWC in case examples was investigated.

5.5. Further closing the Integrated Total Water Cycle Internationally

Further closing the ITWC or total water cycle management (TWCM) as it is sometimes known, involves the coordination of all water sources and users in the catchment (or project management area). Closing the ITWC has been approached in various ways including recycled water use, aquifer and wetland recharge, dam, pipeline and waterway improvements and in efficiency gains in water use. Examples from South Australia, Western Australia, Europe and the United States were investigated.

Since 1959 Class C reclaimed wastewater from Bolivar sewage treatment plant north of Adelaide, has been reused for agricultural irrigation (Dillon et al. 2007). Irrigators initially accessed this water was from an outfall channel from Bolivar WWTP via their own reticulation pipelines (Keremane 2007). Since 1999 the Virginia Pipeline Scheme (VPS) has supplied Class A reclaimed water 35 kms north of Adelaide to farmers within the 200 km^2 Virginia Triangle Horticultural Area (VTHA) (Keremane & McKay 2006 p. 29; Kelly et al. 2003). This reclaimed water replaced the use of groundwater and River Murray extractions for irrigation (Kracman et al. 2001; Hamilton et al. 2005). Prior to the VPS, horticultural crop irrigation had lowered the aquifers of the Northern Adelaide plains (NAP) beyond sustainable limits (Keremane & McKay 2006; Stevens et al. 2003a). The VPS was the first and remains the largest functioning recycled water scheme for irrigation in Australia, delivering up to 23 GL p.a. in place of groundwater for irrigation (Wong & Maywald 2009). The extent to which recycled water was used to close the ITWC depended on environmental, legal, social and economic factors or key components that emerged from these case examples.

5.5.1. Environmental Issues and Recycled Water

Where recycled water is “fit for purpose”, lower classes of water may be used to reduce costs of water catchment recharge. This occurs where crop type is suitable and or further purification is achieved during time spent in aquifers and wetlands. Case examples of recycled water used to close the integrated water cycle in the urban-rural context included the VNAP area in SA, MAR projects in WA and MDB in Australia and Wichita, U.S.

In South Australia there are strict rules governing the allocating of recharged water drained or discharged to a well. Subject to a permit issued under section 18 of the *Water Resources Act (“recharged water”)* the entitlement to take water for the year generally does not exceed 80 per cent of the volume artificially recharged in the previous water use year (AMLR NRMB 2013a). There are provisions to access unused entitlements from the preceding period including strict criteria around the location and use of this recharged water (see section 18 of the *Water Resources Act “recharged water”*). IWRM planning that aligns with environmental guidelines and data concerning sustainable catchment yields has better prospects for balancing stressed water resources against consumer, environment and climate demands for water.

The SA Government commissioned a study on the environmental water requirements of the groundwater dependent ecosystems of the Adelaide Plains and McLaren Vale (Ecological Associates & SKM 2012). From this data and research, the SA Government established environmental water requirements essential to the water allocation planning and licensing for the prescribed wells areas. Section 18 of the *Water Resources Act ("recharged water")* ensures that these environmental requirements are factored into the sustainable yield estimates and water allocations for the area. Another factor in the widespread use of recycled water in SA is the Government's focus on the environmental dimension of reduction of nutrient discharge from wastewater into the nearby Gulf St Vincent (Mainali et al. 2011; Wong & Maywald 2009). The VPS assisted with reducing nutrient discharge to the Gulf by decreasing nitrogen and phosphorus loadings approximately 75 and 40 per cent respectively from 1996 to 2003 (Kelly et al. 2008, p.1). This result largely reflected the Government's policy priority in reducing these discharges. Although a stated priority in QLD water policy there was little coordination of this goal in the construction of the WCRWP. There was little incentive or estimation of expected benefits to recycled water users offered to achieve reductions in wastewater discharges into Moreton Bay apart from cost savings to council (Psi-Delta 2003). Wider community benefits of recycled water use had been one of the more successful incentives used internationally.

Aquifers are vital to the management of water on the Swan Coastal Plain, Western Australia (WA) as more than 70 per cent of Perth's water comes from groundwater (Blair & Turner 2004, p. 451). One third of this derives from the Gnangara Mound, north of the city whilst the remainder is used for non-potable water supply. This is mainly for use by agriculture, local government, household 'garden bores' native vegetation and wetlands (Blair & Turner 2004, p. 451). The WA State Water Strategy relies heavily on recycling to provide water 'fit for purpose' for irrigated horticulture, green space irrigation and industry (Po et al. 2005). Some examples of MAR trails to increase water availability in WA groundwater systems and to maintain environmental values were provided.

The Kwinana WWTP supplies treated wastewater from the Woodman Point WWTP, and treated further for major industrial users. The industrial reuse scheme recharges the Kwinana aquifer with 1.1GL/year of treated wastewater (Blair & Turner 2004, p. 452). The WA Water Corporation through The Kwinana Water Reclamation Plant also supplies industrial users with high quality recycled water (Blair & Turner 2004). Wastewater from Water Corporation is supplied for viticulture at Mount Barker. There are two major Perth wastewater treatment plants at Subiaco and Beenyup in Western Australia. Coastal aquifers in Subiaco are recharged with treated wastewater to offset salinity problems (Radcliffe 2004) and irrigate the University of WA playing fields (Blair & Turner 2004). MAR using treated sewerage from Halls Head Wastewater Treatment Plant is recovered from aquifers in Mandurah for irrigation of green spaces in new housing developments (Radcliffe 2004). Perth represented an excellent example of stormwater reuse, using 80 per cent of stormwater from residential roofs for garden irrigation (Radcliffe 2004 p. 110). Recognition of the wider benefits from continued expansion of such schemes were then examined.

5.5.2. Wider Benefits of Recycled Water

In SEQ areas, government involvement in the provision of recycled water infrastructure and services has been purposely limited. Limited government funding of new water infrastructure projects such as the extended WCRWP is established in Chapter 4. Community involvement in managing common pool resources remained an unexplored policy option for the Lockyer Valley at the time of the WCRWP scheme. Shared arrangements with community and business in the VNAP area, MDB and the U.S. offer insights into this key component of IWRM. For example, the AMLR NRMB is supported in its planning and decision making by a number of advisory committees. These committees advise the board about community consultations during water allocation plan development and assist with evaluating data collected in the water monitoring program (AMLR NRMB 2013c).

While the water issues elaborated in Chapter 2 exist in many countries and regions, IWRM had been approached differently and with varying degrees of understanding of complex overlapping dimensions of IWRM. International examples of treated recycled water use as alternative and supplementary water sources to close the ITWC included:

- Wastewater storage and blending with water in rivers, creeks, streams, wetlands and land spreading treatment, and aquifers for indirect potable reuse
- Wastewater for direct potable reuse.

Land application of recycled water has been common practice in Mediterranean and European civilizations since the 14th and 15th centuries respectively (Angelakis et al.). This trend continues in Australia, Israel, South Africa, the United States and more as shown in Table 5-1.

Ancient Rome addressed water quality problems by mixing different water qualities. Methods included settling basins combined with the ground as a natural filter for poor quality water and as storage for such water in the treatment and supply process, sedimentation tanks gravity fed connections for mixing and transporting water via aqueducts and canals have been refined over centuries (Sklivaniotis & Angelakis 2006; Hansen, n.d.). Underground cisterns also provided underground water storage for wastewater (Suetonius Transquillus, trans. J.C. Rolfe 1951). Greece combined innovations in utilising water capture and storage for irrigation via aqueducts, sewer systems, hydraulics, and lake draining for agriculture, canal systems and polder construction for improved drainage of natural sinkholes and rainwater harvesting and reuse (Koutsoyiannis & Angelakis et al. 2003). These options have long been available to solve IWRM issues in urban-rural IWRM.

Examples of constructed wetlands for wastewater treatment exist throughout Europe in Flevoland in The Netherlands, near Lake Balaton to treat Keszthely wastewater, Hungary and the Montebello Forebay Groundwater Recharge Project, California to the spreading basins of the Rio Hondo and San Gabriel Coast in the U.S. (Vymazal et al. 1998). Table 5-1 contains a summary of some of these schemes. Policy options involving recycled water use in wetlands requires government legislation and or guidelines prior to implementation. Israel has been the pioneer in water reuse for irrigation using soil aquifer treatment and spreading basin for irrigation in the Dan Region WRP Israel (Blair & Turner 2004). These practices also occur in Tunisia, Cyprus, and Jordan and Mediterranean countries. Kuwait was the first country in the Near East region to introduce treated wastewater for agricultural purposes (Steduto 2004). Sometimes this wastewater is even used for drinking after undergoing aquifer purification e.g. California (Pescod 1992).

As mentioned in WA, aquifer recharge can also reduce saltwater intrusion due to overuse of groundwater. Since the late 1960s, the California Water Plan (CWP) has assisted California to import water from Northern to Southern California, storing it for aquifer recharge (California Government 2009). By the 1970s this wastewater was being used to supplement groundwater for irrigation (Watercorporation 2012). See Table 5-1 for a summary of these international examples. California has strict water quality criteria for aquifer recharge with domestic water (Jiménez 2003). Untreated and treated wastewater for crop irrigation depends on the water quality level and standards in that country or region as well as the community's acceptance levels (Winpenny et al. 2010; Jiménez & Asano 2008; Lazarova 2005; California State Water Resources Control Board 1990). These examples confirmed the importance of key social, environmental and legal components determining how recycled water is used to close the ITWC.

Recycled wastewater treated and then directly reused without further storage or holding is referred to as direct potable reuse. Very few international examples of direct potable reuse are for drinking purposes due to the health and safety risks and legislation designed to minimise such risks. An example includes the Upper Occoquan Sewerage Authority Water Reclamation Plant in Fairfax County Virginia, U.S. (Table 5-1). There are unplanned examples of direct potable reuse of recycled water for drinking including the Thames River, England, Los Angeles, California, Wivenhoe Dam and Brisbane River, Australia, QLD towns of Dalby, Nanango and Kingaroy (Stratton n.d.). There have been no major reported health risks associated with these unplanned examples (Stratton n.d.) although it seemed that the incidence of recycled water use in these examples is not be widely known in the community (Stratton n.d.). These existing cases involving lack of community awareness contradicted the importance of social acceptance in the IWRM model. Yet it still seems that, community acceptance is vital for new recycled water projects. This was demonstrated in the case of the WCRWP and Toowoomba in QLD where the community rejected the mixing of recycled water with drinking water (Hurlimann 2010; Nancarrow et al. 2007).

U.S. states have varying standards and criteria for diverse reuse practices (Cotruvo 2001). U.S. Federal legislation (Underground Injection Control) covers injection into aquifers but not production or recovery from aquifers (US EPA 2012). U.S. States vary in their mandatory, community or voluntary approach to The Wellhead Protection Program to ensure pollution prevention and management of underground sources of drinking water (US EPA 2012).

In summary there are a variety of international case examples of opportunities to close the ITWC using recycled water. The IWRM model and ITWC sub-model recommended consideration of deeper analysis of these water sources using the multiple dimensions (social, environment, economic and policy). It was apparent from these case examples that closing the ITWC through coordination of multiple water sources was a key component in the success of the international IWRM cases. There were lessons for the Lockyer Valley and elsewhere for overcoming stressed water systems and lack urban- rural IWRM with recycled water schemes.

Other opportunities to close ITWC include stormwater reuse. Expected stormwater reuse based on current projects will reach 10 GL p.a. by 2015 in South Australia (MJA 2012, p.51). Examples of commercial stormwater reuse include agreements between Salisbury Council and Northern Adelaide Plains Barossa Catchment Management Board in SA (ACIL Tasman 2005). Stormwater capture and reuse projects are provided for in the Waterproofing Northern Adelaide policy which supplies 4,700 ML/year (AMLR NRMB 2011, p.10). Whilst this SA example integrates urban-rural users to close the water cycle there are other sources of water and users still to be included. A fully integrated water cycle would include all recycled water, sewerage, stormwater, rainwater, overland flows and groundwater to meet the criteria of IWRM used in this study.

The cities of Salisbury and Playford collect and re-use stormwater via wet lands and aquifer recharge but these sources are not yet available for irrigation in VNAP. Storage of Bolivar treated wastewater in the VNAP aquifers is technically possible but community and environmental concerns about potential contamination have thus far prevented it (City of Playford 2008). A collaborative process between the four councils – Mallala, Light, Gawler and Barossa continues the process of integrating water infrastructure from mains, aquifers and recycling schemes for the NAP horticulture industry.

This integrated approach to managing hydrogeologically connected water ways and constructed water infrastructure followed that recommended in the IWRM model. Through IWRM coordination by four councils this recycled scheme could provide a minimum 40 GL p.a. non potable water supply scheme by 2040 (City of Playford 2008). This integrated approach to IWRM was assisted by coordination of water, agricultural and regional planning policy and strategies of the area including:

- District Council of Mallala Strategic Plans (2013 - 2016)
- South Australian Food Strategy 2010 – 2015
- Regional Development Australia Barossa – Regional Roadmap 2012 (City of Playford 2008).

Three ASR and wetland projects have been introduced involving integration of storm water, groundwater, and wastewater and drinking water systems in the NAP urban area. This example of urban-rural IWRM closes the ITWC as the urban area provides wastewater to the VNAP agricultural area via the VPS (research question 1). Further treated stormwater replaced the use of drinking water for industrial and urban irrigation (12.1 GL/p.a.) and reduced the ocean outfalls by 20 GL/p.a. (Environment Protection Authority SA EPA n.d). Other examples of IWRM in North Adelaide involving wastewater, stormwater, wetlands and ASR trials include the Cities of Tea Tree Gully, Salisbury and Playford (EPA SA n.d.). Another trial of domestic rainwater tanks harvested for community reuse was achieved in 2008 (EPA SA n.d.). These cases of IWRM in SA truly are the closest examples to date, of Australian urban-rural IWRM incorporating that closes the ITWC. The question remains whether the extended Lockyer Valley can achieve urban-rural IWRM and close the ITWC.

The Cheney Lake Watershed has only one aquifer recharge project operating in the Ogallala Aquifer (The United States Department of Agriculture 2015). The Ogallala Aquifer Recovery and Storage (ASR) project, extracts extra water from the Arkansas

River during high flows, treats it for drinking and stores it in the aquifer (The U.S. Department of Agriculture 2015; Wichita Government 2013). The Ogallala Aquifer supplies 30 percent of the groundwater for U.S. irrigation (Postel 2010). There were no widespread rainwater, stormwater or recycled water projects in the Cheney Lake Watershed, at the time of this research although the City used grey (recycled) water from the Herman Hill Water Center to water trees (Wichita Government 2013).

The important finding in the Wichita case example was that ITWC closure can be achieved through water access arrangements such as those in the Cheney Lake Watershed. From these case examples it was clear that coordinated policy and institutions can assist management of multiple water sources and users in the catchment. The importance of collaboration between community and government and levels of government was a key component of IWRM demonstrated in many of these international cases. The role of community and government in closing the ITWC through water markets was then explored.

5.5.3. Water Markets

The water markets in U.S. cities of Denver and Colorado Springs enable urban water users to buy agricultural water rights to meet their demand for water (Saliba & Bush 1987). These water rights are traded for municipal, industrial, rural domestic and or agricultural use according to legal requirements. Other examples include cities purchasing “water ranches” in order to access agricultural water rights in Tucson, Phoenix, Albuquerque, Nevada and Salt Lake City (Saliba & Bush 1987). Masterson Ranch water bank uses water from Yakima River Basin and transferred some irrigation rights on the Teanaway River to the State’s Trust Water Right Program for mitigation purposes. The Department of Ecology Washington (DECY WA Government) and Masterson Ranch negotiated the trust water right agreement for this program and made water available to third parties (DECY WA Government 2015). Closing of the ITWC was facilitated by trading water through markets. Such market based economic policy instruments determined the scale of the IWRM catchment – in some cases extending it beyond the natural boundaries of the catchment. The interaction between the key components of scale, policy and institutional coordination and economic policy instruments confirmed the complex multidisciplinary approach of the IWRM model required for IWRM decision making. These findings contributed positively to answering research questions 1 and 2.

Excess water has been exchanged under water conservation strategies between the Metropolitan Water District of California and the growers' association since 1989 (Schwabe et al. 2014). In this way water rights facilitate the management of environmental demand for water. California irrigators have also transferred water to urban areas during drought (Jones & Colby 2012). Another example includes the Colorado-Big Thompson Project system of water trading (Carey & Sunding 2001). This is an example of one way voluntary compensated transfers. To further close the ITWC, water could be recycled and transferred back to the original source as was suggested in the case of the WCRWP in this study. The Metropolitan Water District also has an "option" agreement with the Palo Verde Irrigation District to buy water in dry periods. This example of rural to urban water trade represented IWRM options that did not require large contributions to infrastructure by water users. These alternatives demonstrated the usefulness of the four-dimensional approach and component analysis focused on the ITWC model, imbedded in the IWRM model. Water markets in these international cases closed the ITWCM and in so doing altered the scale of the catchment. The hydrogeological boundaries of the catchment were managed through market based policy instruments such as water markets. This insight provided support for the multidimensional approach taken in the IWRM model (research question 1). The research returned to the physical means of closing the ITWCM using examples of infrastructure cooperatives and improved policy coordination next.

5.6. Infrastructure Cooperatives and Improved Coordination Internationally

Large water infrastructure projects involving irrigation often require external funding to cover all costs (Bosworth et al. 2002). In literature and the case study of the Lockyer Valley the possibility of third party (Build, Own, Operate and Transfer BOOT) access to publicly owned infrastructure was offered. This option had the potential to solve the issues of large sunk costs of water infrastructure and lack of usage where users were required to contribute towards capital costs and maintenance of the infrastructure. Some OECD members have achieved full cost recovery (operating and maintenance and some capital costs) including Japan, France, and the VNAP in Australia, Spain and the Netherlands (Bosworth et al. 2002). Generally, such IWRM projects rely upon subsidies to offset the high costs to farmers. Such subsidies can overcome inappropriate or the lack of fee collection strategies, pricing policy and funds to maintain infrastructure to encourage future investment (Bosworth et al. 2002).

To address economies of scale in water infrastructure referred to in the literature of Chapter 2, the VPS in SA required a minimum scale for viable operation of 16,000 ML of contracts for reclaimed water (Wright 2000). The VPS was developed by a cooperative consisting of the Virginia Irrigation Association (VIA), SA Water and Water Reticulation Services Virginia (Keremane & McKay 2006). The VPS is an example of collective action outlined by Ostrom (1990) and of a shared community and government financial arrangement. Both are absent in the case of the Lockyer Valley and emerge as key components in IWRM. The VPS was a BOOT project that contributed to social capital based on the trust and cooperation in the VPS by its various stakeholders (Keremane & McKay 2008). This approach also solved the dilemma of third party access to large and expensive water infrastructure in the example of the Cheney Lake Watershed. Many of the issues arising from the socio-economic dimension that prevented the construction of a connection from the WCRWP to the Lockyer Valley, could have been overcome with this cooperative approach to IWRM taken in the VNAP area and Cheney Lake Watershed. The cost and pricing considerations were considered next.

Pre-scheme marketing was used to ensure the viability of the VPS prior to operation (Wright 2000). Negotiations between the reclaimed water supplier (Water Reticulation Services Virginia - WRSV) and the Virginia Irrigation Association (representing growers) and contracts were established in 1997 (Kelly et al. 2003). Similar negotiations between the parties ensured that the price of recycled water covered costs (Kelly et al. 2003). As a result of these negotiations between the reclaimed water supplier (Water Reticulation Services Virginia - WRSV) and the Virginia Irrigation Association (representing growers) in 1997, the price for recycled water was set at (WRSV 1997). Individual growers and WRSV further negotiated contracts with agreed customer rules and an annual increase p.a. fixed until 2007. The pricing structure reflected an understanding of social and economic aspects of water pricing and highlighted the benefits of community and business negotiation in IWRM decision making. These were key components of IWRM missing from the WCRWP project in the Lockyer Valley.

As with the initial WCRWP to the Lockyer Valley, the VPS to the VNAP area received government funding. WRSV were contracted to connect and supply recycled water to VHA clients after government agencies paid almost half the capital requirements for the VPS (Wong & Maywald 2009). The VPS extension in 2009 added an extra 3 billion litres (BL) of water to that which was available to farmers in Virginia-Angle Vale (Wong & Maywald 2009). This extension received was $4.6m from the SA Government and $2m from the Commonwealth Government (Wong & Maywald 2009). No further government funding was offered for the extension of the WCRWP to the Lockyer Valley.

Another major difference between the two case studies was the rate of recycled water use encouraged in SA relative to other States. At that time of the VPS extension, Adelaide recycled 45 per cent of its water compared to Australia's average of 9 per cent (Wong & Maywald 2009). The use of South Australia Water's pipeline by the Barossa Infrastructure Ltd is another example of third party access to publicly owned water infrastructure. The mix of private-public funding of the recycled water infrastructure and consistent policy on recycled water use in the VNAP area demonstrates the importance of including these key components of IWRM into decision making prior to the construction of the recycled water scheme. These funding options were available to the WCRWP for capital construction costs but not for the Lockyer Valley irrigator's capital contributions to the WCRWP extension (Psi-Delta 2003). The policy on recycled water use in irrigation also did not encourage the switch to recycled water use from groundwater and river fed irrigation in the Lockyer Valley as demonstrated in Chapter 4.

Another key component in the IWRM case study of the Lockyer Valley was the coordination of water storage and water pipeline systems. The SEQ water grid and WCRWP offered the means to transport recycled water to the gateway of the Lockyer Valley, but not enough irrigators were prepared to take or pay for this water (Psi-Delta 2003). A storage option for the recycled water was required prior to the WCRWP extension construction. In the case of the VNAP area steps were taken to close the ITWC through aquifer storage and recovery (ASR). This option was trialled successfully from 1997 to store recycled water from Bolivar and Christies Beach WWTP in winter for agricultural irrigation later. Highly treated and disinfected wastewater was injected into a confined aquifer to overcome salinity issues arising from over pumping and seepage from more saline aquifers (Blair & Turner 2004). The project proved that this water could be safely used for ASR using this brackish confined tertiary aquifer near Bolivar WWTP (Dillon et al. 2007). An understanding of the technical and environmental implications of ASR with wastewater, offered the opportunity to close the ITWC in the VHA catchment. This ASR project offered technical and environmental reassurance for the recharge and storage of recycled water. The key components of social acceptance of aquifer recharge and other environmental and social dimensions did not appear to be issues in the case of the VNAP, given the long history of recycled water use in SA and the amount of community education and engagement involved. This social acceptance and public education were however, further key components missing in the case of the Lockyer Valley. Artificial recharge of central Lockyer Valley aquifers was found to be technically feasible (Wolf 2010 et al.; GHD 2003).

The VPS heavily involved community and business in the development, planning and construction and roll out of the project. The private water reticulation company WRSV prepared irrigation management plans were approved by the EPA. They were also supported by education and information about recycled water in irrigation available from the farmers' cooperative VIA (Bolan et al. 2008). Various training packages relating to the use of reclaimed water for horticultural production were delivered personally to the contracted reclaimed water uses. By the year 2000, 90 per cent of contracted users had received reclaimed water information package (Stevens 2000). This approach assists in understanding irrigator's needs and educating them about improving their production and business skills. Since 2001, a reclaimed water user manual is distributed to all contracted reclaimed water users (Kelly et al. 2001). The knowledge and gained and use of the VPS are valuable resources for the national growth of reclaimed water use and provide insights into public perceptions and communication vital to the development of reclaimed water schemes across Australia (Kelly et al. 2001). This knowledge would have assisted with the acceptance and WTP for recycled water for irrigation in the Lockyer Valley and perhaps elsewhere.

Another point of difference between the VNAP and the Lockyer Valley was, that the latter did not focus on exports. The potential to develop the export market in VNAP was increased through a Horticulture Australia Limited project to assist in the development of export opportunities (Kelly et al. 2001). The prospects for export depended on more than just availability of water but IWRM management utilising recycled water offered a solution. Expansion of export markets also increased the attraction of paying for recycled water in the VNAP area (Kelly et al. 2001). The economic dimension of potential expansion of the export market was not investigated fully nor well understood in the case of the Lockyer Valley WCRWP extension as demonstrated in the eight interviews conducted for this study. The importance of understanding the derived demand for irrigation water and its relationship to agricultural export demand was a key component of the IWRM model absent from the case study of the Lockyer Valley and present in the VNAP area example.

In another example of successful SA community and business collaboration, the Willunga Pipeline Scheme was constructed. A water users group – Willunga Basin Water Company (WBWC) sought a pipeline to use water from the Christies Beach Waste Water Treatment plant. The group accepted that no Government funding was available and contributed their own funds towards construction of the pipeline (Keremane 2007). The distribution scheme from the Christies Beach WWTP in the Willunga Basin of south of Adelaide provides up to 5.4 GL p.a. of Class B recycled water for Adelaide's Southern Vales grape-growers (Keremane 2007). Those grape growers in the WBWC initially received 25 per cent of the WWTP recycled water allocation, with the remainder available to other irrigators in the area (Keremane 2007). The Willunga Basin Water scheme reduced the demand for water from the Murray River and groundwater sources and eliminated some treated effluent discharged into the Gulf St Vincent (Sickerdick & Desmier 2000). Thus this scheme successfully combined social, economic, policy and environmental dimensions of IWRM to resolve issues with stressed groundwater, access to expensive recycled water infrastructure, community acceptance of recycled water, policy coordination between community, business and government and the means to close the ITWC (research questions 1 and 2).

While the VPS relied upon a mixture of public and private equity, the Willunga Pipeline was privately funded. The success of both demonstrated the range of funding options and the importance of full community/business involvement in IWRM. The WBWC won the right to negotiate with SA water in 1997 to build and operate the pipeline and now 70 irrigators including third party users have water supply agreements with the WBWC for reclaimed water from the scheme. The water is delivered at the farm gate without any on-farm storage (Keremane 2007). The importance of understanding the water users' needs for water and storage facilitated the co-management of these resources in the way of Ostrom (1992) and others outlined in literature in Chapter 2. It also explained some of the lack of WTP for recycled water by more irrigators in the Lockyer Valley (Psi-Delta 2003). These economic issues deserved further attention in the approach adopted in the IWRM model.

5.6.1. Economic Issues

Literature and the Lockyer Valley case study pointed to the importance of the financial viability and access to financial support in IWRM. The WCRWP required private investment, particularly those involving large scale irrigation and large sunk costs outlined earlier in Chapter 2. OECD (1999) and the Water Framework Directive (2000) require full cost recovery of large scale IWRM projects involving irrigation, yet many such projects worldwide struggle to recover capital costs. Understanding the opportunities for investment in or arrangements for access to such infrastructure partially explained the lack of success in such projects. Where users were required to contribute towards capital costs and maintenance of the infrastructure, these key components of IWRM required further investigation.

To assist with integration of urban-rural sectors of China's economy, reforms were made to existing rural financial institutions including rural credit cooperatives, mutual and micro credit funds and the Agricultural Bank of China (Xingqing 2009). This restructure saw the removal of unprofitable assets and management structures and increased credit functions (Xingqing 2009). The new arrangements provided county- based community divisions with greater business decision making powers than the previous county branches (Xingqing 2009). Where once farming communities raised funds for rural infrastructure, a reform of rural taxes and other levies in 2000 led to state funded rural infrastructure construction projects e.g. hydrological engineering projects funded by state bonds for rural drinking-water projects (Xingqing 2009).

Compensation for ecological dividends provided by the rural sector in China is offered in the form of grain and cash where farmland is afforested. For example, water use quotas, water trading rights and charges per capita or metered water fees in downstream cities recognise the non-use value of water retention in upstream forests (Xingqing 2009). Industrial and urban water users rely upon the purchase of water quotas from agriculture and rural areas (Xingqing 2009). Shortcomings of China's IWRM stemmed from a lack of economic principles to recover costs of water services and make the polluter-pay (Song et al. 2010). An understanding of the economic and social dimensions of the urban-rural water integration issues provided China's policy makers with an informed approach to managing issues of high urban water use and wastewater impacting on rural areas. This was a key component lacking in the case study of the Lockyer Valley.

5.6.2. Spain

In another case example of community management of irrigation water, since 2007 the Blanes WWTP in Spain has provided private irrigation for a nearby farming community with overdrawn aquifers. The government contributed 70 per cent of the funds to build the infrastructure to carry recycled water to farms (FAO 2012). A community of farmers paid the remainder (FAO 2012). Regardless of whether a top down or bottom up approach was taken, the key components of ownership and access arrangements of the Blanes water infrastructure and the social aspects of community co-management determined the success of the Blanes recycled water project. This example again reinforced the consequences of the absence of these key components in the Lockyer Valley case study.

5.6.3. Kansas, U.S.

In the Cheney Lake Watershed in Kansas, the Kansas Department of Agriculture has primary responsibility for water regulation water and infrastructure. The public acting through the Cheney Lake Watershed Incorporated (CLWI) manages these responsibilities (Fletcher & Davis 2005). The CLWI partnership between the Citizens Management Committee (CMC) and the city of Wichita is another example where water quality services are self-funded and generate income for the city (Fletcher & Davis 2005). The city's residents reimburse farmers up to 40 per cent for their contribution to structural improvements and offer incentives for voluntary management improvements in water pollution mitigation. Farmers in the watershed receive grants and incentives from the state and federal government for up to 70 per cent (Cheney Lake Watershed Organization 2006).

Lake Cheney reservoir was financed in 1965 with revenue bonds and then sold to the public in the 1960s (Selfa & Becerra 2011). Citizens representing the CLWI formed a taskforce to develop and implement voluntary management of water quality. The farmers wanted this water and were prepared to pay for it and the urban water users recognised the wider agricultural benefits and also contributed to them. This was an example of users recognising the broader value of water. The overlapping social, policy and economic dimensions in the IWRM model explained the complexity required of IWRM decision making.

Voluntary water protection practices were implemented via CLW board members working with farmers to address water quality concerns on their farms and cost share in solutions. These practices included fencing, water quality and conversion of expired conservation grassland to pasture rather than crops. These practices were eligible for funding towards cost sharing from the city of Wichita, state and federal government. This partnership between watershed farmers and the City of Wichita recognised the community benefits of reduced pollution entering the reservoir and prolonged the life of the reservoir (Cheney Lake Watershed 2014). The success of the IWRM in Wichita was attributed to, "the mutual benefits that can be derived from different stakeholders working together for a common goal from both inside and beyond the watershed" (Selfa & Becerra 2011 p. 131). In this approach to IWRM, "(T)he city recognizes that Cheney Reservoir water is a public good for which the farming community cannot bear sole responsibility" (Cheney Lake Watershed Organization 2006) and from which the City benefited. The importance of considering the social and environmental dimensions in IWRM decision making in this case example reinforced the findings of those emerging from the Lockyer Valley case study. The common pool characteristics of public irrigation water were effectively managed under properly coordinated co-management arrangements in the Cheney Lake Watershed.

Policy makers relying upon implementing water management schemes rather than discussing options and engaging with community about implementation generally had less success in implementation (Nancarrow et al. 2007). Examples of the problems associated with this approach - known as the ‘Decide-Announce-Defend’ approach, include the San Diego water purification project, San Gabriel Valley groundwater recharge project, the Wivenhoe Dam recharge with PRW and Toowoomba PRW experiences in SEQ (Nancarrow et al. 2007). Research found social marketing and persuasion alone were not effective in gaining community support for potable reuse of water (see Po et al. 2004). It seemed that inclusive and participatory catchment management programs were more effective than those based on centralised decision-making (Po et al. 2004). Another key concept emerging from this example was the importance of informed community involvement in IWRM at the local level prior to the commencement of water projects.

5.6.4. Other Australian IWRM examples

In other Australian examples, lack of community involvement in water management has been cited as a factor inhibiting further closing of the ITWC. Dwyer et al. (2005) modelled the effects of inter-sectoral trade under different water trading scenarios in Canberra, Adelaide and Melbourne. They found that the gains from water trade in terms of gross output accrued to the urban sector under each scenario. Further, a reduction in outputs was experienced in each irrigation districts in all water trading scenarios. Crase and Dollery (2005) offered an insight into the cause, citing state government retention of water infrastructure ownership where irrigators were responsible for management and control of the infrastructure. The literature also noted that in NSW private irrigation companies can own infrastructure, but in all three States the daily control of water resources rested with the private sector and users. The answer to successful IWRM appeared to rest partially on a consistent coordinated approach to infrastructure ownership and management of the water resources.

The gains from water trade between irrigators in Victoria were simulated in research by Peterson et al. (2004). The simulation results indicated that, “water entitlements, … were significantly more expensive than temporary trades (Productivity Commission 2005; Peterson et al. 2004). Further this water trade had the potential to reduce the effects of water scarcity on gross regional product (Peterson et al. 2004).

This study expanded to include urban-rural water trade from the metropolitan regions of Adelaide, Canberra and Melbourne, and the irrigation areas in the southern MDB and south east Victoria (Dwyer et al. 2005). Water trade involving urban centres with relatively low levels of water consumption (Adelaide and Canberra) had a negligible effect on water markets in the southern MDB (Dwyer et al. 2005). Meanwhile water trade involving centres with high water consumption (Melbourne and the Gippsland) had a significant effect on water markets for example with the dairy industry. In those cases, urban-rural water trade produced gains for both buyers and sellers of water (Dwyer et al. 2005). These gains from trade reflected “the relative levels of water use by the trading regions and the ability of users to substitute water for other inputs” (Dwyer et al. 2005, p.15). This was a key finding in understanding how to close the ITWC in urban-rural IWRM by providing alternative water sources either through physical means (recycled water) or market mechanisms (water trade). Such options impacted on derived demand for irrigation water and the user’s ability to adapt changes in climate or water storages. Examples of social and policy factors that impact on demand for water were then investigated further.

Cross-sectoral issues such as subsidies for groundwater, rural bulk electricity tariffs, intensive cropping and fertilization practices, urban land use and sanitation are major issues in rural groundwater sustainability and IWRM (Foster et al. 2013a, b; Garduno & Foster 2010). Since agriculture is a major driver in groundwater use, it became the focus of IWRM in many countries such as Australia, the U.K, the US (west), South Africa, Chile, Singapore and China and the EU. Yet most of these IWRM strategies have focused on integration of water resources in the urban sector (Wallington et al. 2010). Attempts to address this neglect of the rural sector in IWRM have resulted in a more regional focus of the NWI in Australia (NWC 2008). Where a rural area is located near a large city, the focus turns to managing wastewater from urban and industry water users. The way in which countries manage rural water security for agricultural production is often overlooked in literature and case examples. SEQ is an example with a large capital city (Brisbane) using large quantities of water for urban use relative to the nearby rural area of the Lockyer Valley (FSA 2006; ACIL Tasman 2005).

The needs of the environment as a water user, added to the pressure to manage urban-rural IWRM. Often the solution has been water subsidies or low cost access for rural water users. This solution is at odds with the economic principles of full cost recovery in water pricing. The dilemma is often solved with increasing block tariffs (Savenije & van de Zaag 2002). The problem emerges when water use shifts from high volume low value water sector (agricultural) users to lower volume high value water sector (urban) users as a result of subsidies or inappropriate tariffs. The use of TEV and an understanding of the non-use benefits and externalities of water can overcome the underestimation of the value of water in all sectors although it raises the cost of a necessity. This raised the issue of the appropriateness of the IWRM model for developing countries where access to quality water is a struggle (Miller & Hirsch 2002; GWP-TAC 2000). Given these vastly different social, political and economic circumstances the IWRM model, and its application to developing countries with water crises may require further investigation outside the scope of this study.

In summary IWRM case examples from Australian, Spain and the U.S. provided additional understanding and refinement of the dimensions and key components of IWRM. These international cases assisted to identify key components of the IWRM model of opportunities for water infrastructure cooperatives, community input, education and incentives and consistent policy for co-management of all water in the ITWC. The issues of institutional and policy overlap and lack of coordination were then addressed using international case examples.

5.7. International Cases of Reduced Policy and Institutional Overlap and Coordination of IWRM

Countries vary in their approach the key component of coordination of water policy and institutions. Examples of policy that facilitates private and community involvement in IWRM are sought. A major difference between the SA and QLD case examples is this treatment of the key component of coordination of water policy and institutions. Early corporatisation of water and wastewater supply in SA facilitated expensive water infrastructure and services to recover costs. In 1995, the operation and maintenance of water and wastewater services in the Adelaide metropolitan area (including the delivery of capital works for rehabilitation and augmentation) were outsourced to United Water (MJA 2005). Private sector involvement in water and wastewater services was relatively new to Australia in 1996 and this contract was the largest water outsourcing contract in Australia. The arrangement related to metropolitan water service supply rather than water infrastructure and the focus was on efficiency gains, performance improvements and risk transfer while SA Water retained ownership and investment control thus enabling SA Water to provide rural water services and bulk water supply (Class A recycled water). This contract produced cost savings of an estimated 20 per cent when compared to SA Water's historical costs - a saving in excess of $160 million over the life of the contract (MJA 2005). Some of these savings would have been available to Lockyer Valley irrigators had Class A water been provided in the WCRWP instead of PRW (with the latter being exceedingly more expensive to produce and for users to pay).

Third party access to SA Water pipelines was achieved by voluntary negotiation and contract. Under State Government provisions the arrangement to manage third party access in water and sewerage infrastructure was unique (MJA 2005). As with recent QLD reforms in the water management sector, SA Water with its partners, managed, maintained and operated recycled water, waste water treatment plants, mains water, water treatment plants and sewer mains. Establishing these policy and infrastructure access arrangements led to an early resolution of the issue of the high cost of managing declining groundwater and river water for irrigation in SA.

Since then various levels of government collaborated to produce Water Proofing Northern Adelaide and Water Proofing the South programs. These involved Federal, State and local governments working with local communities and the private sector, universities and the Willunga Basin Water Company (South SA DPLG 2011). The SA 30 Year Plan (2011) aimed to provide appropriate policy links and consistency between Stormwater Management Plans, Structure Plans and Development Plans to address stormwater and flood management matters (SA DPLG 2011). These are examples of SA attempts to reduce policy and institutional overlap and improve coordination of water policy that plagued the Lockyer Valley. It remains to be seen whether either State's 30- year water plan can achieve these aims.

The Australian example of the MDB Commission (Kellow 1992) was the solution to the need for better coordination of government and non-government institutions and their general complexity, fragmentation and duplication in managing the environment (Margerum & Born 2000). Four states and the Australian Capital Territory Government struggled to coordinate water management prior to the MDB. Since 2012 the MDBA has supported the sustainable and integrated management of the water resources of the MDB at the catchment scale. The MDBA through the Basin Plan coordinates planning with the various levels of government and States, research organisations and business. The Basin Plan (2012) was supported by Commonwealth Government investment in irrigation infrastructure and voluntary water purchasing through the environmental water recovery strategy (MDBA 2015a).

5.7.1. China's approach to Water Policy and Institutions

IWRM in China was based on a centralised water management approach at river basin scale known as Integrated River Basin Management (IRBM) (Zeng et al. 2006). State Water Policy Agencies formulated uniform policies within the river basin, coordinating and managing water supply and drainage between districts (Zeng et al. 2006). State governments divided districts further into watershed units managed uniformly through the committee for natural resources of each state's government (Zeng et al. 2006). The State continued to manage the distribution and quality of surface water and groundwater. This fragmented management approach separated the planning and designing of water resources management according to the separate sectors or districts involved. This combined approach labelled the Integrated Management of Water Resources in River Basins (IMWRRB) introduced uniform management for the entire river basin with a higher level of comprehensive management (Zeng et al. 2006). The centralised institution coordinated the governing laws, acts and standards but did not involve itself with water resources directly (Zeng et al. 2006). Whether adopting a centralized or decentralized approach to IWRM, the analysis of the Lockyer Valley using the IWRM model suggested better coordination of IWRM policies would assist with the determination of an appropriate scale and management of IWRM issues. This finding was tested using international case examples in a bid to answer research questions 1 and 2.

China's IRBM system operated along the lines of the separated style of management, but had issues with overlapping state departments that govern water quantity, power, supply and drainage (Zeng et al. 2006). Under the amended Water Law in 2002, “the State adopted a ‘combined diversion responsibility’ system of river basin management in conjunction with jurisdictional management” (Art. 9, MWR 2007) and “the plan for a region within a river basin shall be subordinated to the comprehensive river basin plan” (Art. 15, MWR 2007; Song et al. 2010, p. 501). A separated management system uses separate sectors or districts to plan and design water resources management. As literature indicated in Chapter 2 this approach often resulted in poor coordination of planning, management and administration across regions and departments, and conflict amongst sectors in China (Zeng et al. 2006).

Although China has been categorized in literature as a centralised water management system, various other China Ministries and Administrations assist with the management of urban and groundwater, water quality, fisheries, water and soil conservation (Shen & Liu 2008). One of the main criticisms levelled at this approach to water resource management in China has been that the IWRM concepts and methodology were underdeveloped and interfered with the adoption and implementation of IRBM (Shen & Liu 2008). Investigation of the policy dimension internationally, produced some evidence that the degree of centralisation of the water management system, plan and style was less relevant than the degree of coordination and overlap in water policy, planning and institutions (Shen & Liu 2008). Examining international IWRM policy decisions using the IWRM model, the key component of reduction in policy and institutional overlap provided lessons for the Lockyer Valley. An international example of the combined approach to IWRM is the “nested enterprises” or *huertas* in Spain. Spanish *huertas* organise irrigators on the basis of three or four nested levels, at the local, regional and national governmental jurisdiction levels (Ostrom 1994, pp. 101-102). The combined (bottom up and top down) approach to integrating water sources, users and all stakeholders in Spain has the advantages of dynamic and flexible water policy making for improved integrated resource management outlined in literature in Chapter 2 (Ostrom 1990).

In countries where a bottom-up approach to water management was adopted there was often more coordination, cooperation and horizontal integration of stakeholders and interests. There are few international examples of a bottom up approach in developed countries. Usually, community based IWRM arrangements existed in societies where local input and knowledge have been traditionally valued as for example, in Japan (Sarker & Itoh 2001, 2003). An example of the bottom up approach in water policy making includes the European Union European Water Framework Directive (EC 2000). Where this approach was not feasible a combined approach (of bottom up and top down) was successful (Foster & Ait-Kadi 2012; GWP 2006; Hooper 2005). The combined approach has the advantages of a bottom-up approach that was useful where water requirements for the environment in a fully allocated system are still to be ascertained (Brizga 2007). It also had the advantages of a top down approach useful where allocations remain uncertain (Brizga 2007). In this way the top down aspects of national or regional development and fostering of river basin organizations and governance are provided. The bottom up aspects of collective action required to govern common resources complemented this top-down approach (Davis 2007; Ostrom 1990).

The virtues and shortcomings of both the bottom up and top down approaches to IWRM were considered along with the overlapping issues of social, environment and economics using the multidimensional approach and key conceptual analysis of the IWRM model. Institutional and policy overlaps and fragmentation of water and natural resource strategies were features of both the centralised and decentralised approaches in these international case examples. As revealed in previous sections of this Chapter 2, key components of the determination of infrastructure access in the VNAP area and Wichita, U.S. were consistent policy and institutional and community /business co-management. Further examples of policy and institutional consistency in Singapore and Thailand were examined next.

5.7.2. Singapore

Perhaps the most developed IWRM in the world is in Singapore. Singapore's holistic approach to water management involves a 'whole-of-government' system of land-use planning, water management, constructed environment and pollution control. The Public Utilities Board (PUB) is a statutory authority that regulates and provides water service. The PUB manages the technical framework of Singapore's water supply, water catchment and sewerage as an integrated single system (Ong 2010). Singapore's success in IWRM is attributed to the combination of sound technical and institutional frameworks for long term water and land use planning (Ong 2010).

In the 1960s, Singapore’s land-use planning and development were governed by the Planning Department (Planning Act) under its Master Plan (Motha & Yuen 1999). The Water Planning Unit developed the Water Master Plan in the 1970s integrating planning of land use, the environmental and water across the government agencies (Ong 2010). These government ministries had clear roles and responsibilities yet worked effectively together in a coordinated way to plan long term integrated water and land use (World Bank et al. 2006). Under long term land-use planning, land was already designated for water, waste management and development (Ong 2010). Since 1987, the Simplified Planning Approval System integrates the planning and technical aspects of all developments under several agencies to ensure that legislative requirements on infrastructure safety, environmental health, water supply and discharge, and occupational safety aspects are met (Motha & Yuen 1999). Building plans are subject to further scrutiny and other controls to minimize risk to the public water system (Tan 2009). Singapore’s ‘whole of government’ approach to development protects both the public water system and natural watercourses (Ong 2010, p. 63). Singapore's success has come from more than just reliance on technical innovation and infrastructure. The approach combines legislation and enforcement, water pricing, public education as well as research and development (Luan 2010).

Singapore is very effective in integrating land-use planning and water management despite having a very small rural sector. Reduced inter-sectoral conflict of interest was achieved by cross-sector coordination among relevant government agencies in water management (World Bank et al. 2006). Both private and public sector applications for water development works are dealt with by several government agencies under the Simplified Planning Approval System (Motha & Yuen 1999). In Singapore cross sectoral subsidisation of water has decreased as domestic water users are no longer subsidised by industrial water users (Luan 2010). Both sectors are now subject to volumetric tariffs where domestic users have a two-part tariff with ordinary and excess consumption (Luan 2010). Singapore is a clear demonstration of the IWRM model’s ability to combine the policy, environment, technical, economic and social dimensions of IWRM. This coordination was missing in the Lockyer

Valley case study.

Singapore does not rely on a sector approach to IWRM and water policy and agencies are coordinated in a decentralised environment. Water, waste, land and planning decisions are coordinated and integrated in the manner recommended in the IWRM model. Moves toward market pricing and the removal of intersectoral subsidies were consistent with the economic elements of the IWRM model. The Singapore case also showed that IWRM at any scale can be achieved through a mix of top down and bottom up approaches. Although the IWRM model recommended IWRM at the catchment scale, it can be adapted to smaller scale IWRM projects.

5.7.3. Thailand

In Thailand, River Basin Committees (RBCs) have been established, and by 2001, many of these RBCs had a new organizational set-up and a new set of key responsibilities. In 2002, the Department of Water Resources (DWR) was established with the main tasks of promoting the establishment of RBCs in all major river basins. Twenty-five RBCs were established for each main River Basin. RBC membership comprises mainly three stakeholders' groups - government officials, community and academics/nongovernment organisations. Government and community stakeholders are usually represented in equal numbers in each RBC and are selected internally. The DWR, as the regulatory body, manages water resources and integrated IWRM in the national water management process. RBCs evolved from increased understanding of water resources management and implementation of IWRM. Nine representatives from the 25 RBCs are members of the National Water Resource Committee to promote stronger linkages between national institutions to basin and sub-basin institutions (Anukularmphai 2010). Again, the success of Thailand's IWRM policy relies heavily upon the coordination of policy and institutions and co-management of water resources with all water users. This case study supported another important finding of the Lockyer Valley case study about the importance of embedding the ITWC model in the policy and social dimensions of IWRM.

In summary, the way in which the key components water policy and infrastructure coordination were managed, determined IWRM outcomes in the examples of Australia, China, Singapore and Thailand. Poor policy and institutional coordination was a feature in the case of the Lockyer Valley. Community involvement in financial and management decisions and operations were other notable components in international IWRM case examples. Although government has responsibility for overarching water policies and influence over water institutions in these case examples, it is the community who are ultimately responsible for the daily management and operations of water sharing and access arrangements. Public perception and education of the range of benefits provided by including all water sources is also an important role of government, at least initially. The focus in these international cases is mostly on developed countries with established political, economic, environmental and social platforms for water management. The IWRM model has applications for developing countries, but the socio-economic and political diversity in such cases remains largely outside the scope of this chapter. For example, government assistance and local content feature very strongly in water management experiences in developing countries (Miller & Hirsch 2002; GWP-TAC 2000).

In response to research question one, the new catchment scale IWRM conceptual model incorporated details about the multidimensional aspects of IWRM in international case examples for comparison with the Lockyer Valley. The examples of the IMWRRB in China, the Simplified Planning Approval System in Singapore and policies of the River Basin Committees in Thailand demonstrated a more coordinated policy approach to IWRM. Cooperation with government overcame issues with economies of scale, third party infrastructure access and monopoly conditions through such arrangements in both centralised and decentralised approaches in these international case examples.

5.8. Conclusions about the IWRM Conceptual Model Based on International Cases in IWRM

In summary, the approach in the IWRM model used to analyse these case examples helped to close gaps in understanding the derived demand for and supply of water as a common pool resource. The diverse approaches taken in Australia, China, Japan, Thailand, Singapore, Spain and the U.S. demonstrated common key components for effective IWRM. The cases demonstrated the key components of IWRM including the importance of establishing scale in IWRM, taking opportunities for closing the ITWC through urban-rural IWRM, the importance of consistent demand and hydrogeological data and improved coordination of water policy and institutions to close the ITWC. The conclusions that emerged from these international examples are synthesised with those of the Lockyer Valley to answer the three research questions in Chapter 6.

Chapter 6 Synthesis of Findings from Literature and Data Chapters and Relevance to the Application of the IWRM Conceptual Model

6.1. Introduction to the Synthesis of Results

This study supported the thesis statement that a new multidimensional and dynamic catchment scale IWRM conceptual model was needed to explore the relevant dimensions and components of IWRM issues. In an iterative approach this study built an IWRM model from literature and developed the dimensions and key components using the case study of the Lockyer Valley and other Australian and international case examples to answer the three research questions.

The key components of the IWRM conceptual model were identified and used to explain how water can be better managed when all aspects of an integrated water cycle are considered and water is managed as a common pool resource (research question 1). This study also demonstrated how the application of sound principles and theory of ecological economics and hydrogeology assisted in the development of an IWRM catchment scale conceptual model designed to achieve these aims (research question 2). The IWRM catchment scale conceptual model aided management of the demands on water from climate variability, population growth, and the intensification of agriculture and unused wastewater given limited above ground water storage options (research question 3). The IWRM model was evaluated against these criteria using the case study of the Lockyer Valley and other Australian and international case examples.

To close a gap in literature, case studies with urban-rural IWRM opportunities demonstrated the application of the IWRM model. An urban-rural IWRM conceptual example model applied to the Lockyer Valley demonstrated this progress in Chapters 3 and 4. To test the assumption that ecological, economic and hydrogeological theory, principles and tools strengthened the IWRM model, the five conceptual sub-models and economic analytical tools were applied. The five sub-models included the ITWC, the DPSIR approach, five sector economic, demand and hydrogeological models. A legal framework for policy consistency and set of IWRM principles for the extended water catchment were provided to assist with the wider dissemination and application of the findings of this study.

6.2. Key Components of the IWRM Conceptual Model

In answer to research question one, the six key components required for improved IWRM included:

- Catchment scale IWRM hydrogeological investigation and estimates of sustainable yield and water allocations prior to IWRM decision making (*through a hydrogeological sub-model*).
- Inclusion of all water sources (*ITWC sub-model*)
- An understanding of the derived demand for water and the need for sound data about demand, price, WTP and use of all water in the catchment facilitated the use of the IWRM model (*through the addition of ecological economic theory and principles and demand sub-model and DPSIR approach model*).
- Involvement of multiple stakeholders in iterative and dynamic IWRM decision making, co- management of water and provision of access to water infrastructure assisted IWRM outcomes (*through community participation*).
- The involvement of government in regulation, policy coordination, provision of financial support and incentives for building, maintaining and accessing water infrastructure. Government has a role at least in the short-medium term in the presence of economies of scale, equity and environmental considerations and in the provision of guidelines for IWRM (*through the addition of the five sector economic sub-model*).
- Strong links between urban and rural IWRM including consistent water pricing, allocations and infrastructure access (*through the example of the urban-rural example model*).

The four dimensions and six key components of IWRM in the IWRM conceptual model provided insights for the Lockyer Valley and internationally as follows.

6.3. The Application of Sound Principles and Theory of Ecological Economics and Hydrogeology to the Development of IWRM Model

6.3.1. Hydrogeological Modelling Assists Catchment Scale IWRM

The importance of scale in IWRM was demonstrated in the literature, Lockyer Valley case study and international examples in this study. The IWRM conceptual model operated within the boundary of environmental limits assumed in ecological economics (precautionary principle). The ultimate upper scale in all IWRM decision making was global (Savenije et al. 2014; van der Zaag et al. 2002). The IWRM scale adopted influences the understanding and measurement of the sustainable yield of catchments. Decisions relating to parts of a catchment invariably impacted on the entire water catchment as demonstrated by the ITWC model imbedded in the IWRM conceptual model.

Literature in Chapter 2 and case examples in this study reinforced the need for hydrogeological information to establish the scale of IWRM catchments and boundaries. Hydrogeological data and modelling facilitated estimation of sustainable yield, individual water allocations, tradable quantities, water licensing, pricing, removal of perverse subsidies, natural and recycled catchment recharge and policy requirements for water use (including groundwater) monitoring (Newson 2004; Wester & Werner 2002; Turton 2002). This information and data can help resolve issues identified in IWRM literature and case studies including stressed above ground water and groundwater, limited water storage, rising irrigation demand, climate extremes, and growth in population and unused wastewater.

Partial hydrogeological groundwater modelling undertaken in the Lockyer Valley prior to the review conducted by the SEQRWT on the WCRWP has led to difficulties in defining water catchment boundaries, underestimation of losses from the ITWC and problems estimating sustainable yield, water allocations, demand and WTP (Psi-Delta 2003; KBR 2002). From the international case examples, this incomplete approach to hydrogeological modelling, monitoring and the assessment of allocations and ultimately demand was shown to interfere with plans for urban-rural IWRM. The failure to integrate urban recycled water into the ITWC via the WCRWP extension to the Lockyer Valley contributed to the closure of the WCRWP. The Lockyer Valley case demonstrated the importance of the ITWC as the basis for calculating the sustainable yield of the catchment. The policy, social and economic dimensions of the issues relating to recycled water in the ITWC had not been thoroughly considered prior to the construction of the WCRWP. This recycled wastewater continues to flow into Moreton Bay and the irrigation demand continues to outstrip sustainable catchment yields in the Lockyer Valley.

The characteristics of recycled water and groundwater as common pool resources were not addressed adequately in the case of the Lockyer Valley. When non excludability and divisibility were not managed, the tragedy of the commons resulted (Ostrom 1992) – stressed above ground water and groundwater, and underutilised wastewater resulted from underpriced and over allocated irrigation water. In this way, lack of attention to components such as scale and hydrogeological data, estimates of sustainable yield, environmental flows and water allocations, full water licensing, and removal of perverse subsidies, use of the precautionary motive and the triple bottom line approach prior to IWRM decision making in the Lockyer Valley, led to failures to close the ITWC and to better manage water as a common pool resource (research question 1).

The way in which the IWRM model combined this synthesis of results with the aid of the five sub-models was depicted in Figure 6-1. The five sub-models included:

- ITWC – represents total water supply by combining created water with the natural water cycle
- DPSIR approach model – assists understanding of the drivers for demand, pressures of human actions, the state of the environment, the impact on the resource and the appropriate policy responses
- five sector economic model – facilitates understanding of derived demand from all sectors in the economy
- demand modelling – uses data and estimates of demand to forecast scenarios
- hydrogeological modeling – combines hydrological and geological data to predict water outcomes of change in these variables

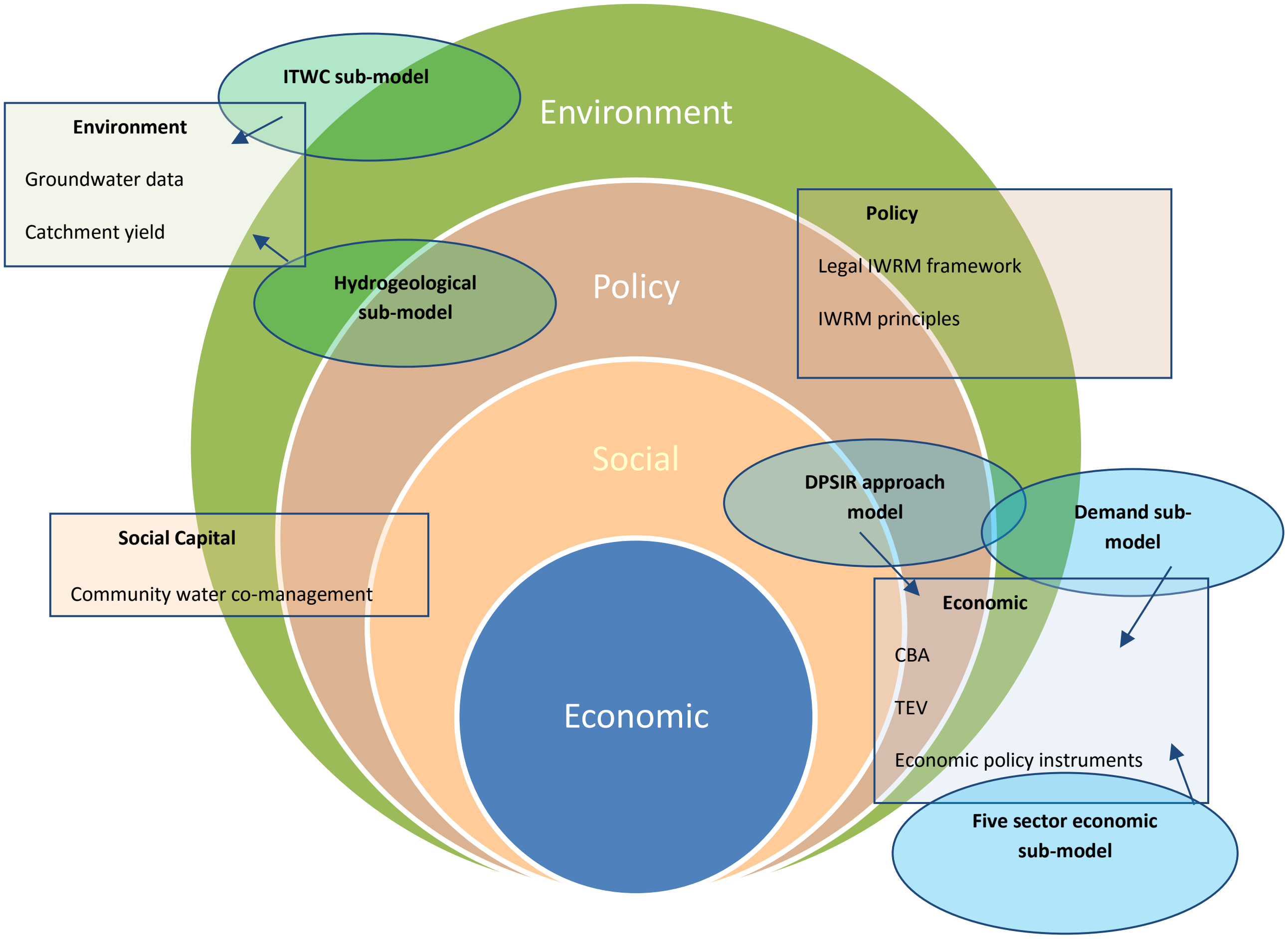

Figure 6-1 Refinement of the new catchment scale IWRM conceptual model from the synthesis of results and addition of five sub-models

Hydrogeological modelling based on sound data obtained from consistent water monitoring allowed more precise calculation of the sustainable yield, water allocations and licensing and what, if any, subsidies were required in the catchment. The VNAP area case wa contrasted with the Lockyer Valley. The gap between demand and supply was addressed through the construction and operation of the VPS, market pricing of VPS water, removal of perverse subsidies, more comprehensive water licensing, contracts for VPS infrastructure access, rainwater recycling, VNAP aquifer injection trials using treated wastewater from Bolivar WWTP and stormwater recycling agreements for VNAP area. In that way, sound hydrogeological modelling, reliable estimates of sustainable yield, available urban wastewater and water allocations prior to IWRM decision making in the VNAP area helped to better integrate the management of catchment water as a common pool resource (research question 1).

Application of the IWRM model to the case studies demonstrated the importance of understanding historical social, economic and policy issues and their influence on IWRM decision making. The Lockyer Valley case showed how social, economic and policy issues can interfere with the introduction of groundwater monitoring, establishment of sustainable yield and catchment size. The lack of community WTP for recycled water and rejection of aquifer injection limited the IWTC and impacted on catchment size. While the VNAP area and Wichita cases also exhibited historical overuse and deterioration in groundwater quality, both had a long history of community acceptance and use of recycled water, monitoring, water trading, market pricing and widespread water licensing, removal of perverse subsidies, expansion of export markets, co-management of recycled water, infrastructure and improvements to water quality (in Gulf St Vincent and Cheney Lake respectively). Thus by considering the other dimensions, in determining the catchment's water supply, the IWRM model helped to manage demands on water influenced by from climate variability, population growth, intensification of agriculture and unused wastewater (research question 3).

The cases showed that all water from the ITWC and all its users and beneficiaries need to be considered in future IWRM determinations. This included balancing supply side economics with demand management. Sound demand data and modelling in the IWRM model was a second key component of the model that emerged from the synthesis of cases.

6.3.2. The Need for Sound data and demand modelling in the IWRM model

To understand the users and uses of water as a common pool resource, the IWRM model provided a framework for the complex and overlapping drivers of demand for this water. The application of the economic theory of derived demand and demand modelling enables IWRM decision makers to comprehend the scale of water usage (and match available supply). Understanding of the social, environmental, economic and technical complexities of demand enables policy makers (government and private sector) to work towards IWRM solutions (research question 1). Ideally, water management options need to be socially acceptable, technically feasible, environmentally sustainable and economically viable prior to embarking on an IWRM project. The case studies of the Lockyer Valley, VNAP area, MDB, Singapore and Wichita demonstrated the importance of sound demand analysis conducted using all dimensions of the IWRM conceptual model in policy decision-making. The gaps in estimating demand for irrigation water in the feasibility studies conducted for the Lockyer Valley recycled water project illustrated this point. Results of demand modelling based on groundwater monitoring did not adequately reflect demand in the upper and lower Lockyer Valley, where groundwater monitoring has not been fully implemented. Estimated demand for groundwater irrigation in these parts of the Lockyer Valley remains uncertain.

Gaps identified in the Lockyer Valley demand modelling included inadequate investigation of social factors driving demand for irrigation water and lack of involvement of the general community in identifying demand factors. Large commercial irrigators, who are members of the LWUF, were repeatedly offered the alternative of high cost recycled water from nearby urban catchments. Smaller commercial irrigators were not widely consulted. Although estimates of demand for recycled water in feasibility studies for the Lockyer Valley varied, the key demand estimates provided by one feasibility study (KBR 2002 in Psi-Delta 2003) were used repeatedly in feasibility studies for some time after the SEQRWP project was rejected. These estimates excluded large parts of the Lockyer Valley and its community. These demand estimates did not factor in the derived nature of demand for irrigation water for the extended Lockyer Valley water catchment. Nor did they factor in the potential for the millennium drought to break, infrastructure costs to be fully recovered, access arrangements and consistent water rights to be implemented, subsidies removed nor the social acceptability of recycled water and aquifer injection options. Without this prior knowledge of irrigation water demand, any IWRM decision was ill-informed (research question 2).

A full social cost benefit analysis of the extended Lockyer Valley catchment was required including potential industrial water users from the downstream Brisbane Valley. Apart from the potential environmental benefits to Moreton Bay, the wider urban benefits of disposing of large quantities of recycled Brisbane water were not and have not been assessed. The five sector economic model demonstrated the importance of demand and decision making in all sectors. Yet, a non-sectoral focus of the IWRM model was preferred for reasons discussed in Chapter 2. The DPSIR approach was also a useful analytical ecological economic tool to understand the drivers, impacts and decisions required in IWRM. In the Lockyer Valley catchment, the full economic, social and environmental benefits of recycled water as calculated using the TEV approach were not provided nor were urban Brisbane users expected to pay for them. The results of the inadequate demand modelling and analysis for irrigation water in the Lockyer Valley, particularly recycled water, have been underestimated, inaccurately estimated and undervalued. Weighed against the high cost of recycled water infrastructure and the original smaller Lockyer Valley catchment, all feasibility studies involving recycled irrigation water showed the use of recycled water to be uneconomic. Demand theory showed the impact of low priced groundwater substitutes on demand for recycled irrigation water. This has reduced the sustainable management of the ITWC in the Lockyer Valley. Drivers for increased demand for irrigation water including climate changes, population pressures, demand for agriculture production and underutilised wastewater needed to be included in demand modelling in the IWRM model (research question 3).

Even where full TEV is not adopted, the practice of extending benefits beyond the use value demonstrated the important contribution of ecological economics in China and Wichita. A social and environmental levy paid by urban water users in China and Wichita could be imposed on downstream water users in the Brisbane Valley to offset the recycled water costs for extended Lockyer Valley catchment irrigators. This levy could encourage rural use of recycled irrigation water which would impact on derived demand and WTP for recycled water. The inclusion of sound demand data and modelling for the extended catchment was a feature of the VNAP area, China, Singapore and Wichita.

In the case of the Lockyer Valley, feasibility studies revealed the difference between natural and estimated recycled water prices to be over 75 per cent - too great to attract buyers of recycled water (MJA 2013). With the removal of inefficient subsidies and the use of TEV in water pricing, the price of natural water would be expected to rise. Tiered water tariffs ensured access to drinking water but competition with subsidised rural water interfered with the price and allocation mechanism. These economic theories and principles applied to the IWRM conceptual model explained how inconsistency in water pricing and allocations for the ITWC interfered with WTP for this water (research question 2).

Some of the wider benefits and costs (and WTP estimates) of IWRM projects determined through derived demand analysis brought recycled irrigation water and groundwater costs into alignment with water substitutes from dams. The social dimension of the IWRM model became clear in case examples involving community involvement or co-management of water resources in the face of changing demand.

6.4. Multiple Stakeholders Involvement in IWRM Decision Making

The synthesis of results from case examples provided an insight into the key component of community involvement and social capital in the IWRM conceptual model (research question 1). Case examples that have a combination of top down aspects of national or regional development, catchment scale governance, and bottom-up collective management have had sound IWRM results. There was little direct evidence to support a top-down or bottom-up approach to IWRM. However, sound urban-rural IWRM decisions resulted in communities becoming more involved in water monitoring, greater water efficiencies, and reinforced water usage and allocations (Patrick et al. 2014). Case examples of rural Spain, Japan, Wichita in the US, China and VNAP demonstrated that connections with and between communities have created community responsibility for demand, use, monitoring and reinforcement of allocations. This connection with community can be achieved through participation in demand and supply modelling and support for demand and hydrogeological data collection (research question 2). Coordination was also required in policy and institutions (covered in section 6.4 of this chapter).

The case examples of Wichita and the VNAP area demonstrated the success experienced when irrigators and urban users work together to protect and improve water quantity and quality throughout the catchment. In recognising that common pool resources represent mutual benefits across the catchment, all users can acknowledge that the agricultural community is not solely responsible for IWRM. Irrigators and urban users can both work towards managing common pool resources within sustainable limits. This process is iterative and dynamic adjusting to changes in population, demand, climate, and water storage and wastewater availability (research question 3).

The VNAP area and Wichita cases showed the advantages in involving business and community in the provision of water infrastructure and services. Negotiations for the construction and operation of the VPS occurred between members of the VPS cooperative consisting of government, business and irrigators. The VPS was an example of collective action by community with shared private and government financial arrangements. Those irrigators involved in negotiations were the ones who contract and pay for the recycled water, and also the infrastructure. The VPS BOOT arrangements solved the dilemma of third party access to large and expensive water infrastructure. After initial price negotiations, pricing, capital costs and contracts were solved iteratively with stable prices and links to inflation.

Although in parts of the Lockyer Valley irrigators participated in recycled water feasibility studies for the WCRWP, these people belonged to large irrigator groups. Local councils - Gatton Shire Council then Lockyer Valley Regional Council, and BCC and large food industry groups (Coles and Woolworths) commissioned these feasibility studies for the options they preferred. Although there was some community and business input, the interests of many lower Lockyer Valley irrigators were not captured.

Although these studies are about WTP, these lower Lockyer Valley irrigators showed no WTP. This would change if all water were priced comparatively using TEV. These irrigators had suffered the loss of stream and groundwater flows but could not afford recycled water to the farm gate or higher quality water (class A or PRW). Further input from the extended catchment community was required about the quantity, price and delivery options for recycled water prior to IWRM decision making.

The LWUF has long lobbied unsuccessfully for co-management of underground water and metered water throughout the Lockyer Valley. Since the millennium drought broke in 2011, the WCRWP pipeline has closed and the decision about recycled water has been deferred. Many large irrigators have constructed their own dams and reticulation systems and are no longer interested in paying for PRW. The future success of expensive water infrastructure projects involves communication of information about changing demand and supply issues and resolution of policy issues such as monitoring and comparable water pricing for the entire ITWC.

6.5. The Role of Government in Policy Coordination, Information and Provision of Financial Incentives in IWRM.

Literature and case examples showed clear roles for government in IWRM. There remains a need for some government regulation, better policy coordination and financial support in building and maintaining water infrastructure at least in the short-medium term. Given economies of scale, equity and environmental considerations, a coordinating role for government was a key component of IWRM (research question 1). Seven principles for IWRM were synthesised from the case examples. The traditional role of government to provide and fully finance water infrastructure projects is declining in developed countries as communities and businesses take opportunities to manage water infrastructure and services for profit (such as in the VNAP area, Wichita and Japan). Where necessary, financial incentives are needed for developing stronger self-governing institutional arrangements (research question 2).

Equity-based rural water subsidies are limited in the case examples outside the Lockyer Valley. They have been replaced with fees and charges in the cases of the MDB, Japan and China. As in the VNAP case study, there is justification for some policy and financial assistance (BOOT) for initial planning and construction of irrigated water infrastructure on the grounds of economies of scale and externalities. The Lockyer Valley case showed that where cheaper (groundwater) substitutes were available, even the BOOT option was unattractive to private investors.

Government has a role in assisting with feasibility studies that provide sound estimates of demand for, and supply of, water from the extended catchment ITWC. The case examples demonstrated the important role that government can play in facilitating hydrogeological modelling, estimation of sustainable yield and catchment boundaries, monitoring of water use and establishment of water property rights. Once these foundations are established, there is scope for co-management of IWRM (as per Ostrom 2010).

These case studies raised questions about the conditions and motivations for radical change in IWRM including community culture, technological “quick fixes” and lack of accountability in the water bureaucracies (see Dingle et al. in Troy Ed. 2008). Failure to reconsider the present water-supply and waste-management systems has led to panic and searching for 'new' expensive and environmentally damaging sources of water without first addressing the demand for potable water and the ways in which wastes are managed (Dingle et al. 2008). For further research on the motivations to develop and maintain ITWC and political issues attention cycle see Troy (Ed.,2008). Other issues, such as social, geographic and trade scales also relate to the hydrogeology of catchments and regions (see Patrick et al 2014).

Finally, case examples from the VNAP area, China and Japan demonstrated the role for government in safeguarding and educating the community about the environmental demand for water, overseeing IWRM through basic policy coordination and some legislation at least in the short to medium term. The ecological economic theory of strong sustainability in natural resource management favours voluntary economic policy instruments (education and community involvement in decision making) featured in the case examples (research question 2). In addition, more long term options include demand management strategies (e.g. rural water use efficiency incentives). The case studies supported these aspects of integrated water management and highlight the role of wider stakeholders as the water economy matures. From the case studies, suggestions for a legal and policy framework emerged.

6.5.1. The Legal Framework Required for IWRM Emerging from Case Studies

The necessary legal and policy framework included:

1. Prescribed areas for water catchment monitoring, water property rights, licensing and allocations (including environmental allocations), water trading and calculations of sustainable yield of ITWC within the catchment (policy, environment and economic dimensions);
2. Legislation around equity, access and pricing of water for basic survival and cost recovery (policy and economic dimensions);
3. Support for and education about the implementation of full analysis of derived demand for water and use of TEV in pricing, feasibility studies and policy decisions (policy and economic dimensions);
4. Promotion of community involvement and co-management of ITWC within the

catchment (policy and social dimensions).

The legal framework addressed the four dimensions of the IWRM model as shown in brackets above (research question 1). These components contributed to the success IWRM case examples have had in managing the issues of changing climate, population, demand, intensified agriculture, water storage and general management of the ITWC as a common pool resource (research question 3).

The cases also demonstrated the way in which the model identifies practices that support the integrated management of water (research question 3). Some principles also emerged that were useful in developing the key components for the IWRM model.

6.5.2. Principles to Assist the Development of the Key IWRM Components

- **Protecting water catchments** - Manage water catchments and the ITWC through a whole of catchment approach through integration of water use planning, water quality planning and water recycling
- **Consistent water yield and use data to guide planning** - Monitor all water use to inform water infrastructure and management planning (including environmental allocations).
- **Optimise rural production** - Optimise reliable water supply for all sectors including rural, by clarifying entitlements through the implementation of water recycling, water conservation and efficiency measures.
- **Infrastructure and planning coordination** - Align government infrastructure planning with regional infrastructure priorities and timelines.
- **Infrastructure funding and access** - Explore all available options to fund, deliver and access infrastructure (encourage partnerships etc.).
- **Water funding and access** - Explore all available options to fund and deliver water to all water users (TEV, triple bottom line accounting, polluter pays, full cost pricing and remove subsidies from ITWC).
- **Total catchment scale IWRM** - Develop and implement an IWRM strategy for the extended catchment (essentially an urban-rural IWRM):
  - Total water cycle management

  - Water recycling options
  - Water use efficiency information, goals and incentives
  - Derived demand management
  - TEV pricing
  - Open access to water infrastructure
  - Sound catchment hydrogeological studies
  - Consistent water monitoring and water rights

(Adapted from Connell Wagner 2005b, pp. 23-4).

In each of the seven principles for IWRM, the establishment of goals, incentives and dissemination of information was facilitated by the joint efforts of government and community. The first step towards further closing the ITWC was the adoption of the non-sectoral approach to IWRM using the urban-rural IWRM conceptual model.

6.6. Urban-rural integration: A Step towards closing the ITWCM

The case examples of Wichita, China, Spain and the VNAP area showed opportunities for urban-rural integration. Consistent application of economic principles of full cost pricing of water across sectors (including the removal of government subsidies, recognition of environmental benefits and charges for capital costs) and hydrogeological modelling were key components in urban-rural IWRM. The urban-rural case examples demonstrated the value of the non-sectoral approach taken in the IWRM conceptual model (research question 1).

Urban-rural water integration in California, Colorado-Big Thompson Projects, San Diego and in the southern Murray-Darling Basin have been achieved though water trading. These examples demonstrated the benefits of water trading in directing water use to where it has been valued (and priced) more highly (according to demand theory). Where water markets operate unfettered in the presence of market failures such as subsidies, economies of scale, imperfect information and unclear water rights, the market price responded to the economic laws of demand and supply. Higher prices for water will translate into lower demand (Law of Demand) where these market failures are corrected (government involvement in the creation of water markets, environmental water allocations, triple bottom line accounting procedures and a precautionary approach in policy making). These economic theories and policy instruments were key components of the IWRM model (research question 2). Australian case study examples (VNAP in SA and Gnangara WA) demonstrated the success of urban-rural IWRM using technical solutions such as recycled water, stormwater and rainwater, advanced purification and aquifer injection. A major insight from the Lockyer Valley case study was that IWRM issues remained unresolved when no established market for recycled water existed prior to undertaking a recycled water project (research question 2).

The Lockyer Valley case illustrated the repercussions of inconsistencies in water pricing and allocations in an urban-rural context. These included the reluctance to switch to and pay full costs for recycled water, and continued overuse of relatively low priced groundwater, river and dam water. This evidence answered research question three in that it explained how to reduce the demands on water from climate variability, population growth, the intensification of agriculture and unused wastewater.

In the Lockyer Valley several components of integrated water management were missing, or could not be appropriately implemented due to a range of social, institutional, political and cultural factors. Major water management difficulties persisted in the Lockyer Valley such as overstressed surface water and groundwater, the inability to manage growth in irrigation water demand, climate extremes, and population, excess wastewater flows into Moreton Bay and expensive underutilised water purification and WCRW pipeline infrastructure. Application of the urban-rural IWRM conceptual sub-model can help close the ITWC (research question 1). The IWRM model can be applied by using ecological economic theory to better value common pool resources, demand modelling for irrigation water and DPSIR analysis of drivers of this demand, and understanding the five sector economic model in influencing demand. It can also integrate the use of appropriate economic policy instruments, IWRM policy coordination and improved funding options for water infrastructure (research question 2).

The inclusion of recycled water (waste, stormwater and rainwater) and wetlands in the ITWC represented an improved catchment management. The integration of all water sources assisted water users (through the ITWC model) and policy makers to manage losses from the water cycle (unused wastewater). It also provided more water supply options to manage climate, demand and population changes. Options for policy makers included a legal framework and principles for the IWRM conceptual approach to accompany the IWRM model.

6.7. Conclusions about the IWRM Conceptual Model and Study Applications

The IWRM model was developed and evaluated against the key components using the case study of the Lockyer Valley and international and Australian case examples. Selection of the four dimensions of the IWRM model (environment, policy, social and economic) and the six key components of IWRM model directly concurred with literature and case studies. The use of the IWRM conceptual model closed the ITWC and allowed better management of water as a common pool resource (research question 1). The cases also demonstrated how the application of sound principles and theory of ecological economics and hydrogeology assists in the development of IWRM catchment scale conceptual model to achieve these aims (research question 2) and aid management of the demands on water from climate variability, population growth and intensification of agriculture and underutilised wastewater (research question 3).

The key components of the model supported by case examples included:

- Catchment scale hydrogeological investigation of boundaries and water supply
- Understanding and applying sound principles of ecological economics
- Understanding derived demand for water and its influence on water prices
- The importance of stakeholder involvement and co-management
- The role of government in regulation, funding and incentives for ITWC and common pool resources
- Urban-rural IWRM as a step towards closing the ITWC.

This study addressed the thesis statement by identifying the key components of IWRM required to close the ITWC and manage common pool resources. The Lockyer Valley and other examples of urban-rural water management demonstrated the role of economic theory, principles and tools in strengthening the IWRM conceptual model and provided support for the three research questions. The review of these results and the scope for further research to address knowledge gaps in literature was provided in Chapter 7.

Chapter 7 The IWRM Model and its Contributions to the Management of the ITWC

7.1. The IWRM Conceptual Model: Introduction to the Study Contributions

In seeking a new paradigm to solve integrated water resource management issues, an approach for the assessment of water catchment conditions and issues has been developed throughout this study. The study first investigated the integration of water management issues internationally through a literature review, to refine the research problem. The critique of literature revealed the need for the development of a catchment scale IWRM conceptual model, to better incorporate all aspects of water management in an integrated water cycle, to support better management of water as a common pool resource. Three specific research questions emerged relating to closure of the ITWC, the use of ecological economic and hydrogeological theory and principles and management of rising water demand. Expected outcomes and further applications of the research were presented and the approach then outlined in each chapter. The study identified the key components of IWRM required to close the ITWC in an IWRM conceptual model. The study reviewed the Lockyer Valley as a case study and compared it with other Australian and international cases of integrated water management. A new catchment scale IWRM conceptual model was developed and refined using the data from the case study of the Lockyer Valley and international case examples. A summary of the conclusions synthesised from the literature and data chapters was then provided. A legal framework for IWRM and principles for assisting with the wider dissemination of the study findings was also proposed.

7.2. The IWRM Conceptual Model: World IWRM Issues in Literature

The pressure of worldwide population growth, food shortages, rapid urbanisation, climate change extremes and uncertainties, agricultural intensification, water intensive lifestyles, reactive water policies and recognition of environmental demands on water have put enormous pressure on the World's finite water supplies. As IWRM literature focused on the worsening international problem of water supply, the need emerged for a catchment scale IWRM conceptual model (IWRM model) to better manage water public water as a common pool resource. This model required a multidimensional approach to tackle the complex and dynamic problem of water and its common pool characteristics that see water diminish with successive use, from which its users cannot naturally be excluded. The IWRM model needed to assist in managing the ITWC as a common pool resource where previous models fell short and unresolved IWRM issues persisted.

7.2.1. Unresolved IWRM Issues from Literature

Unresolved IWRM issues emerged from literature including poor intergovernmental overlap and inconsistent policy, poor use of social capital in co-management opportunities, inadequate economic and hydrogeological analysis and incomplete environmental assessments. These unresolved issues were also present in the Lockyer Valley and warranted a new conceptual approach.

Poor integration of water management has led to a range of unresolved environmental, social, economic and coordination issues. Unresolved environmental issues in IWRM include overuse and reduced quality of water, high use of energy, land and other resources in engineered water management solutions, communities without access to quality drinking and irrigation water, excess and underutilised wastewater, water use inefficiencies, reduced environmental flows and underdeveloped ecosystem services (prevention of erosion, drought and flood mitigation).

Intergovernmental overlap and inconsistent application of IWRM policy by various levels of government has resulted in a plethora of institutions responsible for IWRM (Savenije & van der Zaag 2008; UN 1992; WMO 1992). Overlaps in water governance, finance, education, water businesses and related service providers created such policy inconsistencies as:

- Inappropriate scale and degree of coordination of IWRM policy (Savenije & van der Zaag 2008; Ravesteijn & Kroesen 2007; Hooper 2005; GWP-TAC 2000),
- Poor coordination of natural resources in IWRM including land, air and energy resources (Biswas 2004; Falkenmark 1997),
- Sectoral focus in IWRM (Crase et al. 2007; Young et al. 2006; NWC 2006; Tisdell et

al. 2002),

- Literature, existing models or principles of IWRM that did not include operational aspects and often interfered with the successful implementation of IWRM (OECD 2010; GWP 2005; Biswas 2004).

The social complexities of the community involvement in decision making required greater community involvement in IWRM (Ostrom 1992, 1990; Baldwin 2008). The equitable treatment of water involves balance between understanding the culture, attitudes, knowledge, values, awareness, social acceptance, amenity functions and historical practices in water management (Munasinghe 1993). It also includes the economic principle of user pays versus the equity of water being available to all, the environmental need for water and sustainable use for future needs. Water users need to be involved in collective decisions about using, monitoring and managing water through cooperative management. Water users also need to contribute their significant social capital (Hutchinson & Vidal 2004) to developing successful resource management outcomes for managing common pool resources to close the ITWC, and manage water pricing, entitlements and access to infrastructure.

Unresolved economic issues in IWRM included an understanding of the complexities of the finite limits of water, the role of recycled water in further closing the ITWC, derived demand for water and the supply of water. Where these complexities were not well understood or are not addressed, economic issues of market failure, water pricing, quantity allocations, quality control, reuse and access to infrastructure persisted. The common pool characteristics of water were managed to reduce over reliance on the quantities of water used once through recycling of rainwater, stormwater, and wastewater. The examples showed that access to water as a common pool resource and avoidance of the Hardin's "tragedy of the commons" can be managed through the consistent application of property rights and full social cost pricing (TEV), elimination of inefficient subsidies, development of transparent water markets and third party access to infrastructure. The four overlapping dimensions of the new catchment scale IWRM model (environment, policy, society and economic) helped to understand these issues, their complex drivers and management drawing on a range of economic theories, principles and tools (social cost benefit analysis, TEV, marginal cost pricing, derived demand analysis using the DPSIR approach, biophysical limits (thermodynamics), management of market failure (externalities and economies of scale) and more.

Agriculture was the focus of the study as a major user of freshwater from the water cycle. The literature gap in urban-rural IWRM was a result of the traditional sectoral approach to IWRM (Foster & Ait-Kadi 2012; Tian et al. 2011; Shen & Liu 2008; Zeng et al. 2006). The study first aimed to improve urban-rural IWRM and close the water cycle using the IWRM conceptual model. The IWRM model developed an integrated approach to examining the four dimensions of the IWRM problem – environment, policy, society and economy. The model was based on the integrated total water cycle rather than the natural water cycle used in existing IWRM models (Carden & Armitage 2012; Khatri et al. 2011; Ross et al. 2006; Koudstaal et al. 1992).

Five sub-models were applied to strengthen the IWRM model and to help answer the three research questions. The four dimensions of the IWRM conceptual model were explained and refined using international literature and urban-rural case examples. From these case study insights, key components required for IWRM were identified, that strengthened the IWRM conceptual model and thus addressed the research problem.

7.3. The IWRM Conceptual Model: The Research Problem

In addressing the research problem, a more comprehensive IWRM definition and description of the four dimensions of the IWRM model were provided. The IWRM model utilised the four dimensions of environment, policy, social and economic to examine policy attempts to manage the ITWC at the catchment scale to address issues of increasing demand for irrigation water, population growth, intensification of agriculture, climate changes and large quantities of unused wastewater. Potential users of the IWRM model, given the current institutional structure, would include researchers interested in further refinement and application to case studies, policy makers interested in moving towards a more integrated approach to IWRM from a multidisciplinary perspective and stakeholders in participating in IWRM decision making.

7.3.1. The IWRM definition adopted for this study

The new definition of IWRM derived from IWRM literature and recognised that IWRM needs to be an adaptive and participatory process. It promoted the co-ordinated development and management of water, land and related resources as common pool resources, in order to maximize the resultant economic, social and ecological welfare. The IWRM definition achieved this through the principles of ecological economics, which include: equity, polluter pays and precautionary approaches, the use of triple bottom line accounting, and legislative instruments to address environmental issues (adapted from Turner et al. 2007; UN 2002, 2000; GWP-TAC 2000; Postel 1992; WMO 1992; Koudstaal et al. 1992; Ehrlich & Holdren 1971). The value of early hydrogeological modelling also emerged as a key component in the Lockyer Valley (absent) and other case examples (present) to establish the scale of the water catchment and opportunities for ITWC management.

The wider use of this definition in IWRM decision making would see the rise of stakeholder participation in collection of water use data – a major problem in planning for current and future demand relative to sustainable catchment yield. Broader adoption of this definition incorporating ecological economic principles would assist to manage common pool resources more equitably without the need for complex overlapping policy institutions and instruments (e.g. complex networks of subsidies, fees and charges).

7.3.2. The IWRM Model

The IWRM catchment scale conceptual model emerged out four existing IWRM conceptual models and frameworks:

1. The IWRM model (Koudstaal et al. 1992)
2. The Three Pillar approach to IWRM (UN 1992)
3. The conceptual framework for catchment-scale integrated water resource management (Ross et al. 2006).
4. The Urban IWRM model (Carden & Armitage 2012).

The model comprises four dimensions – the environment, social, policy and economic. Each dimension overlapped and interacted with the other, in a dynamic way, to explain and manage IWRM. With its foundations in the Three Pillar Basic Model (United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, World Bank 2005), the IWRM model built upon the IWRM principles advanced in literature on the sustainable development models - equity, ecological integrity and efficiency (Postel 1992); the Rio-Dublin principles (UN, 1992; WMO 1992) and Turner et al. (2007).

The new catchment IWRM conceptual model was supported by the ecological economic principles of finite natural resources and the need to manage these resources for future generations. It was limited by the constraints of the environment, based on the ITWC that included all water sources and users regardless of the sector in which they resideded. The model was flexible across scales and water issues as tested through the case study of the Lockyer Valley and various case examples, by specifically addressing gaps in the urban-rural context (using an urban-rural IWRM conceptual example model). The new IWRM model can promote understanding of current international water management issues that are transferrable across disciplines including economics, policy, social science and environmental science. Potential users of the IWRM model, given the current institutional structure, would include researchers interested in further refinement and application to case studies, policy makers interested in moving towards a more integrated approach to IWRM from a multidisciplinary perspective, and stakeholders in participating in IWRM decision making.

Ongoing issues with unresolved economic, environmental, social and policy aspects of the public water in IWRM will benefit from a combined physical and (ecological) economic approach to understanding, developing and refining an IWRM conceptual model. These contributions included an understanding of the laws of thermodynamics, derived demand, supply, pricing and allocation, valuation using the TEV approach, management of economies of scale and externalities, and economic policy instruments. The model was refined with the application of various sub-models including demand and hydrogeological modelling, ITWC, the five sector economic model and the DPSIR approach to IWRM policy making. The economic model included tools such as social cost benefit analysis with TEV techniques for valuing use and non-use values. Other sub-models included water demand

and WTP estimates contributing to the dynamic flow of information about interrelated issues, impacts and IWRM policy decisions in the broader model. These sub-models were representative of similar contributions from other disciplines that can be accommodated in the IWRM model.

Integrated water management is complex and dynamic consisting of unresolved and changing issues best managed in an interdisciplinary way engaging stakeholders. This reflects international moves away from command and control approaches to IWRM and the shift towards voluntary and mixed market economic policy instruments (education and user pays). These dynamic issues were addressed with four equally dynamic dimensions in the IWRM conceptual model – environment, social, policy and economic.

7.4. The IWRM Conceptual Model: Bridging the Research Gaps

The IWRM conceptual model addressed the research gaps literature on the development and implementation of catchment scale IWRM by providing:

1. A comprehensive IWRM definition and ITWC model that included all water sources.
2. An IWRM model that addressed issues of governance, economics, society and environment with a legal framework and IWRM principles,
3. Catchment hydrogeology to assist with the implementation of catchment scale IWRM and data collection,
4. Sound application of ecological economic principles to catchment scale IWRM,
5. Examples of catchment scale urban-rural IWRM.

The study used a critique of literature on IWRM conceptual models and international IWRM issues (Chapter 2), analysis of the background and application of the IWRM model to the Lockyer Valley case study (Chapters 3 and 4), comparison of international case examples of IWRM (Chapter 5) and a synthesis of results (Chapter 6). This approach was necessary because the collection of primary data from interviews was limited by communities in the Lockyer Valley who were exhausted by over-consultation and research fatigue. Rather, it was appropriate to critically review the 20 studies that had already been conducted in the Lockyer Valley to draw out new insights, contrasting this existing information and applying the new IWRM model. These previous studies were inconsistent in their approaches to complex multidimensional IWRM issues. Often these studies focused on one or two dimensions of IWRM (generally the technical and economic) and neglected basic issues with data collection (demand and hydrogeology), community input, and an appropriate policy environment. The lesson was for government assistance in the initial stages of catchment data collection and provision of incentives (legal and financial), to encourage community involvement in provision of water infrastructure and services. One notable incentive missing from many IWRM approaches was consistency in water price and allocation.

The findings of this study call for all water use to be measured in catchments, for all water sources to be accounted for in water allocations, for licensing and water prices to reflect TEV, for the issue of subsidies to be better managed through levies and charges on the user, reduced overlap in IWRM policies and institutions, and for more community input into water infrastructure access and service provision (co-management).

7.5. The IWRM Model: Answers to the Three Research Questions

Adopting an iterative approach, case studies and international case examples were used to develop, refine and test the IWRM model. In so doing the three research questions were answered:

1. What are the key components of the new IWRM conceptual model required to close the ITWC and better manage water as a common pool resource? (Addressed in Chapter 2, 3, 4, 5 and 6).
2. Can the application of sound principles and theory of ecological economic and hydrogeology assist in the development of a new IWRM catchment scale conceptual model which will achieve these aims? (Addressed in Chapters 2, 3, 4, 5 and 6).
3. Can the new IWRM catchment scale conceptual model aid management of the demands on water caused by climate variability, population growth and intensification of agriculture, in view of limited further viable above ground water storage options and unused wastewater? (Addressed in Chapters 3, 4, 5 and 6).

7.5.1. Research Question 1: The Key IWRM Components

The key components of IWRM synthesised from this study included:

- Catchment scale IWRM requires hydrogeological investigation and estimates of sustainable yield and water allocations prior to IWRM decision making (through hydrogeological modelling).
- An understanding of the derived demand for water and the need for sound data about demand, price, WTP and use of all water in the catchment facilitates the use of the IWRM model (through the addition of ecological economic theory and principles and demand modelling).
- Involving multiple stakeholders in iterative and dynamic IWRM decision making, co-management of water and provision of access to water infrastructure assists IWRM outcomes (through community participation).
- There remains a role for government in regulating, policy coordination, provision of financial support and incentives for building and maintaining water infrastructure at least in the short-medium term in the presence of economies of scale, equity and environmental considerations and in the provision of guidelines for IWRM (through the addition of the five sector environmental economic sub-model).
- Urban-rural IWRM is a step towards closing the ITWC where consistency in water pricing, allocations and infrastructure access was achieved (through the example of the urban-rural model).

Decision-making about common pool resources at the catchment scale was enhanced by application of the IWRM conceptual model in international case examples. The IWRM model used sub-models for ITWC, hydrogeological and demand assessment, and the five sector environmental economic model, to gather further evidence of the key IWRM components in these examples. Results from the application of the urban-rural example model in the case study of the Lockyer Valley demonstrated the failings of an IWRM approach lacking these key components. These consequences for the Lockyer Valley were complex and span the four dimensions of the IWRM model:

- the inability to calculate sustainable yield (supply),
- inadequate understanding of derived demand and inconsistent allocations of

irrigation water in the extended catchment (including environment),

- lack of community input and support for IWRM options,
- poorly coordinated IWRM policy and inappropriate water infrastructure,
- use of groundwater and above ground irrigation water in excess of the sustainable catchment yield,
- excess nutrients entering the downstream and Moreton Bay water system and expensive unused treated wastewater that could close the TWCM.

These findings from other case examples demonstrated the value of the approach in the IWRM model in managing public water as a common pool resource and closing the ITWC.

7.5.2. Research Question 2: The Application of Sound Ecological Economic Principles and Theory and Hydrogeological Modelling

Ecological economic theory and principles helped the understanding of the derived nature of demand for irrigation water. With the aid of sound water demand and use data, the multidimensional approach of the IWRM conceptual model assisted decision making about economies of scale, contestability, derived demand, TEV, WTP, price and the role of ITWC in case examples of China, Japan, Wichita, the VNAP area and the MDB. The lack of these theories and principles explained some poor integration of water management in the Lockyer Valley.

To assist in the development of an IWRM catchment scale conceptual model, ecological economics was important. It showed the value of:

- Managing all water in the ITWC as a common pool resource;
- Using TEV to value the use and non-use benefits all water and including these in the price;
- Applying water property rights consistently to all water sources and users in the integrated water cycle;
- Conducting feasibility studies into the derived demand for water prior to commencement of water projects;
- Establishing a water market prior to commencement of water projects;
- Application of appropriate voluntary economic policy instruments including community co-

management and education of society about TEV, common pool resource management and environmental demand for water;
- Understanding the derived demand for water using economic theory and tools to obtain consistent reliable data on derived water demand, price and use of all water in the catchment scale ITWC; and
- There remains a need for some government regulation, financial support and incentives for building and maintaining infrastructure at least in the short-medium term due to the existence of economies of scale, equity and environmental considerations and the provision of guidelines for IWRM.

Undertaking thorough hydrogeological investigation, and obtaining estimates of sustainable yield and water allocations (supply modelling) prior to IWRM decision making, also verified the correct scale of the IWRM project and the supply of total water available in the ITWC.

7.5.3. Research Question 3: Management of the Demands on Water

In view of limited further viable above ground water storage options, the IWRM model can help manage the demands on water from climate variability, population growth, intensification of agriculture and unused wastewater. The international examples of the VNAP area, Wichita, China and Japan demonstrated closure of the ITWC further than the example of the Lockyer Valley. Yet no international IWRM examples fully closed the ITWC in water catchments – incorporating wetlands (created, natural vertical), stormwater, wastewater, aquifer re-injection (hydrogeology permitting). The extended VNAP area came close with its integrated approach. The new catchment scale IWRM conceptual model offered some resolution of the demands by applying the key components of the IWRM model:

- utilising wastewater to reduce losses in ITWC,
- reducing pressure on stressed groundwater,
- community co-management of irrigation water,
- reduced overlaps in IWRM policy and improved infrastructure coordination,
- improved consistency in water pricing, water rights and
- recognition of the social and environmental values of public water.

Many of these issues remained unresolved in the case of the Lockyer Valley in the absence of these key IWRM components.

The dimensions of the IWRM conceptual model, issues raised and tested, insights offered and key components identified were complex and interconnected. When examined using the dimensions of the IWRM conceptual model, insights and key components contained insights into real IWRM issues and provided assistance in managing water for climate variability, population growth, intensification of agriculture, limited above ground water storage options and unused wastewater (in the VNAP area example). The thesis statement was addressed and the goal of this research achieved - to identify the key components of IWRM required to close the ITWC and managing common pool resources in the urban-rural context through the application of case studies to an IWRM conceptual model.

7.6. Conclusions: Relevance of the IWRM Model for International IWRM

The study provided a unique approach to the complex and dynamic problem of IWRM by combining existing analytical and conceptual tools into one IWRM conceptual model. This solved the research problem of the need to develop a new catchment scale IWRM conceptual model to close the ITWC and develop more integrated water management at the catchment scale. Potential users of the IWRM model would include researchers interested in further refinement and application to case studies, policy makers interested in moving towards a more integrated approach to IWRM from a multidisciplinary perspective and stakeholders in participating in IWRM decision making.

The study delivered the key components for IWRM demonstrating their role in closing the ITWC in the Lockyer Valley, VNAP area, Wichita, Japan, Spain, China and MDB. These components included catchment scale hydrogeological investigations, application of sound principles of ecological economics, understanding derived demand for water and the role of stakeholder involvement and co-management, the role of government in and urban-rural IWRM as a step towards closing the ITWC. A more comprehensive definition of IWRM also provided goals and principles for IWRM implementation lacking in previous definitions. This definition provided an indication of progress towards IWRM in the case study of the Lockyer Valley and international case examples. There is potential for further applications

Worldwide. The IWRM model demonstrated the benefits of including interdisciplinary sub-models, theory and principles (ecological economics and hydrogeology).

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Appendix 1

Interview questions with Lockyer Valley irrigators about demand and willingness to pay for recycled water after the 2010-11 floods.

Participant Consent Form
Farm Decision making with greater water security provided by Assured Clean Water ACW.

The project aims to better understand how water security affects the interests and values in a water management decisions. A variety of different methods are used to involve individuals in the research, including use of photographs, participation in small discussion groups and personal interviews. The project has been approved by the USQ Ethics Committee for Research. If you have a concern regarding the implementation of the project, you should first contact me, and then if still not satisfied contact my supervisor Associate Professor RJS (Bob) Beeton at 0419714533 or The Secretary, Human Research Ethics Committee UQ on telephone (07) 336 **53924**.

Things to be aware of:

- Participation in the project is completely voluntary, and individuals can withdraw at any time. That means that if you choose to end an interview or to leave a focus group for any reason, this will be understood without any justification required.
- Information about you and your property will be treated as strictly confidential.
- The survey work will involve individuals taking photographs, completing an audiotaped interview, and participating in small focus groups.
- Photographs taken for various stages of the research may be used in publications and media communications including promotion of the project.
- Reported results will be based on grouped data.
- Respondent comments may be quoted in project reports, however your name will not be used and we will not report any personal information that could identify you in any way.
- The study will be reported in an end-of-project report and available to participants. It may also be published in an appropriate research journal, presented at conferences etc.
- In the unlikely event that you have concerns about any aspect of the interview or group phase, the researcher is available to debrief at the earliest opportunity.

If you agree to take part in this study, please complete and sign the consent form below.

I have read the information above and agree to take part in this study.

☐ I understand that my participation is voluntary and that my personal and property-related information will not be identified individually, either in connection with my responses to the interview, survey questionnaire or in any report. I also understand that the results of the research will be reported in an appropriate way to enable decision makers to improve decision processes in relation to natural resource management.

☐ I understand that photographs of project participants and activities will be taken, from time to time, and I hereby give my permission for photographs of me to be included in project-related publications and media communication.

Name and Signature: ____

Date: _____________________________

Farm location (full mailing address):____

Contact number:______________________

Farm Decision making with greater water security provided by Assured Clean Water ACW.

Survey Number: ____________________

Interviewer Name:___________

PS Coordinates: ____________________ Date: ___________________________

Part 1. Respondent Profile:

1. Age (s) (please tick) (where there is >1 respondent per farm also place an M for male or F for female in the appropriate age bracket)	15-19	20-24
	25-29	30-34
	35-39	40-44
	45-49	50-54
	55-59	60-64
	65-69	70-74
	75-79	80-84
	>85	
2. Sex (es) (circle)	Male	Female
3. Highest level of education completed (please tick)	Postgraduate degree	
	Graduate Diploma/Graduate Certificate	
	Bachelor Degree	
	Advanced Diploma/Diploma	
	Certificate III or IV	
	Certificate I or II	
	Year 12 High School	
	Year 11 or below High School	
4. Home Farm Size (hectares) please tick	Less than 5 000 ha	
	5001-10000 ha	
	10 001-30000 ha	
	30 0001-50 000 ha	
	50 001-80 000 ha	
	80 001- 100 000 ha	
	More than 100 000 ha	
5. Home Farm type	Irrigated Dryland Other (please state)	
6. Predominant soil type (may be combinations)	solodic	
	soloth	

	Soloth (red)	
	lithosol	
	Podsolic (red)	
	Podsolic (yellow)	
	Black earth	
	Light clay	
	Medium clay	
	Grey clay	
	Brown Clay	
	Red Clay	
	Other Please State:	
7. Are you a member of Lockyer Valley Water Users Forum or another organisation (please state)		

8. **Do you share or have other farms? Circle Yes/No**

Note: If farms are contiguous, please treat as the one farm and continue and relate all the interview questions to the one farm. If farms are not contiguous, please complete a separate interview form for each separate farm with a consecutive survey number (with an extension to indicate which farm number it is eg. xxxxxx-2)

9. **If yes, where and what type(s) of farms are these:**

Irrigated

Dryland

Other (please state)

10. **What range does your combined net farm income fall into**? Please tick

Income bracket	**Tick if applicable**	**Income bracket**	**Tick if applicable**
< $50 000		$1mn - $1.25mn	
$51 000- $80 000		1.26mn - $1.50mn;	
$81 000 - $100 000		$1.51mn - $2mn;	
$10 001 - $120 000		$2.1mn - $2.5mn;	

$121 000- 150 000		$2.51mn - $3mn	
$151 000 - $180 000		>$3mn	
$181 000 - $200 000			
201 000 - $500 000			
501 000 - $800 000			
$801 000 - $1mn			

11. **Do you have other sources of income? Circle Yes/ no**

12. **Indicate the main source of your company income using the table below:**

Income Type	**Proportion (%)**
Irrigated crops	
Dryland	
Off farm source	

13. **What proportion of your land is irrigated? (percentage)**

____

____

____

14. **What is your current irrigation source? Please tick**.

Water Source	**Tick if applicable**
Own dams	
Public dams	
Aquifers	
Creek or stream	
Other: please state	

15. **What is your current irrigation method? Please tick.**

Surface	
Basin	
Border	
Furrow	
Sprinkler	
Hand move or portable	
Water Canon	
Centre pivot or lineal move	

Solid set or permanent	
Micro-irrigation	
With point source emitter	
With line source emitters	
Other: please state here	

16. **Do you currently pay for any water? Circle Yes/No**

17. **What proportion of water do you pay for? (%)________________________________**

18. **What price per Mega Litre (ML) do you pay for various types of water?**

Water Type (source)	**$/ML**
bore	
Dam	
recycled	
Other please state:	

Part 2. Possible ACW Supply Scenarios:

The method of water supply has not yet been determined, however assured clean water is guaranteed purified clean water supplied via the western corridor pipeline and mixed with existing supplies in dams and or aquifers will be of Class A standard suitable for all crops types and for contact with humans

Although the price of ACW is yet to be determined, the following are hypothetical ACW supply scenarios from which you may base your responses on: Please circle an option

(printed card handed to respondents)

Scenario	**Description**	**Water price**
A	ACW available instream	<$200/ML
B	ACW available from existing dams Atkinsons, Bill Gunn and Clarendon (mixed with dam water)	$200-300/ML
C	ACW available instream and from existing dams	$300-500/ML
D	ACW available direct to farm gate via publicly pipeline and privately owned takeoff	$500-1000/ML
E	ACW available direct to farm gate via publicly owned pipeline and takeoff	>$1000/ML

*Scenarios involving privately owned take offs and/or pipelines required an initial connection fee of $1500 and annual service fee of $500

#Scenarios involving take and pay option require purchaser to have adequate storage for contracted amounts (even when ACW is not required in periods of wet weather or lower seasonal requirement)

Part 3. Proposed ACW Use

Various hypothetical supply scenarios are being investigated to supply the Lockyer Valley with ACW

19. Based your chosen preferred scenario, do you expect to use ACW in future? Circle Yes/no

The following responses will indicate your proposed use of ACW in the future with regard to crop type and planting patterns.

You have selected Scenario ____ . Do you expect to use ACW:

A. To replace existing water source
B. To supplement existing water source
C. Only in periods of drought or low rainfall
D. Never
E. No plans

20. Do you plan to alter your current irrigation system with introduction of ACW? Circle Yes/No

21. What crops are you watering with existing water supply and in which proportions? Why?

Crop type	**Percentage of total crops planted**	**Typical Water Use ML/Ha**
Wheat and other cereals		
Lucerne		
Vegetable, root and tuber crops eg. red beet, carrot, potatoes, onions		
Brassicas, spring onions and salad vegetables eg. broccoli, lettuce, cabbage, chinese cabbage		
Other crops please state		
Other crops please state		

Please write comments here:

____

____

____

22. **What crops did you plant 10 years ago (prior to severe water shortages) and in which proportions? Why?**

Crop type	**Percentage of total crops planted**	**Typical Water Use ML/Ha**
Wheat and other cereals		
Lucerne		
Vegetable, root and tuber crops eg. red beet, carrot, potatoes, onions		
Brassicas, spring onions and salad vegetables eg. broccoli, lettuce, cabbage, chinese cabbage		
Other crops please state		
Other crops please state		

Please write comments here:

____

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23. **What crop planting pattern do you currently have (eg. % and style 2 rows X 1 row gaps)? Why?**

Crop type	**Percentage**	**Planting Pattern (how it is grown)**

Please write comments here:

____

____

____

24. **Historically what crop planting pattern did you have (eg. % and style 2 rows X 1 row gaps)? Why?**

Crop type	**Percentage**	**Planting Pattern (how it was grown)**

Please write comments here:

____

____

25. Referring to the hypothetical price you have selected on the printed card you were handed earlier, with ACW what crops would you grow on your land in future, in what proportions and with how much water (insert selected price in column 3 below)?

Crop type	**Percentage of total crops planted**	**Typical Water Use ML/Ha at $______ML**
Wheat and other cereals		
Lucerne		
Vegetable, root and tuber crops eg. red beet, carrot, potatoes, onions		
Brassicas, spring onions and salad vegetables eg. broccoli, lettuce, cabbage, chinese cabbage		
Other crops please state		
Other crops please state		

26. What crop types will you replace or substitute given ACW is available? Why?

____

____

____

Please write comments here:

____

____

____

27. **What factors affect your crop type choice and changes to choices?**
    Rank according to importance with 1 being of little importance and 9 being very important.

Factors	**Preference 1 to 9**
Water price	
Crop price	
Crop contract	
Crop type	
Soil type	
Geography – slope and terrain	
Past experience	
Additional infrastructure costs (of privately owned take offs and/or pipeline	
Other please state:	

28. **What future crop types will you consider planting given ACW is available and why?**

____

____

____

29. **In the future would you expect to alter crop rotations if ACW was available?** Yes/no

30. **If Yes, what changes to crop rotations will you make? Why?**

Crop type	**Crop Rotation changes (frequency)**

Please write comments here:

31. **Do you have concerns about the quantities of supply of various crops after ACW?** Yes/no, **Why?**

Please write comments here:

32. **What price per ML would you be willing to pay for ACW given Scenario A, B, C, D and E?**

Scenario	**Description**	**Water price $/ML**
A	ACW available instream	
B	ACW available from existing dams Atkinsons, Bill Gunn and Clarendon (mixed with dam water)	
C	ACW available instream and from existing dams	
D	ACW available direct to farm gate via publicly pipeline and privately owned takeoff	
E	ACW available direct to farm gate via publicly owned pipeline and takeoff	

33. **Do you have adequate pump equipment to switch to ACW available through the above sources?** Circle Yes/No
If not, which scenarios do you have inadequate pump equipment for ACW use?

Please write comments here:

34. How much would you have to spend on infrastructure and other capital works such as privately owned take offs and pipelines if you elected to have ACW piped directly to the farm gate?

35. How many full time equivalent employees (besides yourself) do you currently employ on your property (2 employees for 6 months is equal to 1 full time equivalent)?

____

____

____

36. With ACW, how many extra full time equivalent employees do you estimate will be required to cope with the expanded production on your property?

____

____

____

This question is asking you to think about how you might change your crop mix under different prices for an assured water supply and how normal market crop price fluctuations might influence this.

ACW prices and crop mix

	Cost 1	**Cost 2**	**Cost 3**	**Cost 4**	**Cost 5**
Crop Type	**<$200/ML**	**$200-$300/ML**	**$300-500 M/L**	**$500-$1000 M/L**	**>$1000 M/L**

37. Please indicate how ACW prices could affect your crop mix in the <u>above</u> table by filling out each cell using this coding:

1. No change

2. Consider change possibly by reducing planting to manage risk

3. Consider change possibly by increasing planting to manage risk

4. There is a point where you would change to another crop. If so can you indicate that price using today's production costs

5. Unsure

38. **Please indicate how crop normal price fluctuations might influence your decision on crop choice in the table below by filling out each cell using this coding:**

Crop market price fluctuations and crop mix.

Crop Type	**Cost rise/fall <5%**	**Cost rise/fall <7%**	**Cost rise/fall <10%**	**Cost rise/fall > 10%**

39. **Below are farm prices and gross margins tables not adjusted for inflation that currently appear on the Agbiz website (DEEDI) please indicate if you expect price to go up, down or remain constant in future (with assured water supply?): (may insert ? for unsure)**

Crop Type	**On-Farm Price $/ha**	**Directions**	**Gross Margin $/Ha**	**Directions**
Avocados (nth QLD)	$10,006.50		$4,542.14	
Bananas (nth QLD)	$61,380		$16,472	
Green beans	$5,414.93		$822.00	
Beetroot	$22,572.72		$11,973.13	
Broccoli	$20,418.75		$9,541.31	
Cabbage	$5,673.75		($1,564.98)	
Capsicum	$30,447.86		$1,494.77	
Carrots	$11,134.00		$1,241.84	
Corn	$10,463.38		($539.47)	
Lettuce	$74,070.00		$51,220.54	
Lucerne-hay	$5,452.92		$3,704.52	
Rockmelon	$20,392.17		$4,478.92	
Watermelon	$5,625.00		$1,747.74	
Onion	$13,994.05		$2,986.85	
Potato	$12,294.15		$2,825.71	
Pumpkin	$14,161.62		$6,552.86	
Squash	$21,761.25		$5,239.49	
Tomato	$27,196.00		($1,692.94)	
Zucchini	$21,715.83		$4,061.20	

This question is seeking your views on alternative approaches to providing ACW, such as the use of water of varying quality:

40. **Would you be prepared to pay for and use:** Please circle answer in table below:

Water Quality	**Preference**
purified recycled water > A+ Class	yes/no
recycled water Class A	yes/no
Recycled water < Class A yet meeting standards for use on horticultural crops here and overseas	yes/no

41. What is your preferred minimum rate of delivery of ACW in percentage terms? (eg.1%)

42. Under what arrangements would you prefer to access ACW?

Please rank options in table below using 1 for least preferred and 7 for most preferred.

Payment Options	Preference 1 to 7
Take or pay (agree to pay for water contracted even if not used)	
Pay and pay (agree to pay for water and accept delivery even if not used)	
Renewable contract 10 years	
Renewable contract 20 years	
Renewable contract 30 years	
Non-renewable contract	
Other: please state	

Part 4. Proposed Land Use

In this section I am asking about the land type and quality required for cropping patterns given the level of water security that ACW offers.

43. Is the property developed to maximum output? Please circle Yes/no

44. Is the property developed to maximum profitability? Please circle Yes/no

45. Is your farm land *good quality agricultural land*? Please circle Yes/no

46. Will you consider using land of lower quality for future cropping patterns given ACW is available? Please circle Yes/no

47. Would you consider expanding or moving to lands of lower quality given ACW is available? Please circle Yes/no

48. **Would you consider moving or altering cropping patterns on land of lower quality given greater water security with ACW?** Please circle Yes/no.

Part 5. Environmental Values

I am interested in your views on the environmental consequences of ACW and its impact on biodiversity and water catchment health.

49. **Do you benefit from having minimum water supply for health catchment flows?** Please circle Yes/no

50. **How important are minimum water flows to the ecological health of the water catchment generally (outside of your farm)?** Please rank by circling the most correct answer below.

1. not important______________3. neutral________________5. Very important__________

51. **Do you believe healthy catchment flows have a positive or negative impact on the ecology and biodiversity in the area?** Please circle: positive/negative; yes/no; rank and state how?

1. not important______________3. neutral________________5. Very important

Please explain here:

____

____

____

52. **Do healthy levels of water in the catchment (creeks and aquifers) impact on crop and land values?** Please circle: positive/negative; yes/no; rank and state how?

1. not important______________3. neutral________________5. Very important_________

Please explain here:

____

____

____

53. **Do healthy levels of water in the catchment (creeks and aquifers) impact on your crop and land**

use decisions? Please circle: yes/no; rank below and state how in the table below.

1. **not important** **3. neutral** **5. Very important_**

Crop Types	Land use

Please explain here:

____

____

____

54. **Are healthy catchment flows important to the region's community?** Please circle: yes/no; rank below and state how?

1. **not important______________3. neutral________________5. Very important________**

Please explain here:

____

____

____

55. **Is it important to minimise disturbance to creek bank vegetation and wildlife when placing pipelines and infrastructure?** Please circle: yes/no; rank below and state how?

1. **not important______________3. neutral________________5. Very important________**

Please explain here :

____

____

____

57. **Where would you prefer pipeline and and associated infrastructure to be located so as to cause minimal disruption to the environment?**
State your preferences in the table below using the ranking of 1 being least preferred and 6 being most preferred.

Location	Preference (1 to 6)
River banks	
Utility corridors	

State forest	
Public land	
Private land	
Other: please specify	

58. **In your opinion, which factors should ultimately determine the location of the Lockyer Valley section of the recycled water pipeline and associated infrastructure?**

    State your preferences in the table below using the ranking of 1 being least preferred and 4 being most preferred.

Factor determining pipeline location	**Preference (1 to 4)**
Economic cost to users	
Environmental impact	
Proximity to users	
Other: please specify	

59. **Would you like a copy of the project results mailed to you upon completion?** Please circle: Yes/no

printed card handed to respondents

Scenario	**Description**	**Water price**
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