Irrigation with reclaimed water Down Under: A bottom-up approach

M.Sc. Thesis by Jonna van Opstal

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Irrigation with reclaimed water Down Under: A bottom-up approach

Master thesis Irrigation and Water Engineering submitted in partial fulfilment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

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PREFACE

During the process of writing this report, I came across an inspiring quote from The National Geographic special 'Water' issue in April 2010: *"May the waters from the snowy mountains bring health and peace to all people. May the spring water bring calm to you and may the rains be a source of tranquillity to all."*
It reminded me of the serenity water can provide to people. When studying water management, this seems far from reality with challenges and conflict situations present throughout the world. It is astonishing that a simple substance as water (H_2O) can result in such contrasting perceptions.

This intriguing aspect of water enthused me to continue my Masters of Science degree in irrigation and water management with a special focus on the use of (treated) wastewater for irrigation. The latter is a fascinating research area becoming more relevant for several (arid) countries. I choose to conduct my thesis work in Australia for it is an interesting setting being a water scarce country and developing novel research projects for using reclaimed water.

Working with Australian irrigators taught me about agricultural know-how but also introduced me to the 'Down Under' culture. The multi-stakeholder involvement achieved throughout this thesis work became evident at the final presentation in Brisbane, which was for a diverse group (irrigator, government, scientists etc.).

The Lockyer Valley project was truly a rewarding experience. It improved my knowledge on reclaimed water irrigation whilst having great joy in conducting the work.

Hopefully this report can guide you through the interesting work done in the Lockyer Valley and reveals the delightful time spent on achieving this thesis.

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CSIRO Long Pocket Laboratories fellow office workers making the working place truly enjoyable. Several humoristic jokes about cultural difference introduced me to the astonishing, typical Australian culture.

My parents for their continuous encouragement throughout this thesis and my Masters degree.

Above all I am grateful to my Lord, proving to be trustworthy anytime and anywhere.

EXECUTIVE SUMMARY

The Lockyer Valley is an important agricultural region for South East Queensland, producing mainly lucerne, vegetables and fruits. It has seen a decline of annual average rainfall over recent drought years, impacting the region's ability to generate sufficient market produce. The introduction of reclaimed water (i.e. treated wastewater) as a supplementary irrigation water supply is investigated. This option partly ensures sufficient future food security for the rapidly expanding urban areas of South East Queensland. Additionally, the use of reclaimed water decreases the discharge of treated wastewater to the natural environment, in particular the outflow of the Brisbane River to the protected Moreton Bay marine park. The Brisbane City Council and Queensland Government jointly initiated the extensive Western Corridor Project, which treats and transports domestic wastewater, and diverts it for use by industry, agriculture and potentially households.

The several issues involved in the introduction of reclaimed water for irrigation are interconnected and require research in various study areas. The complexity of managing reclaimed water for irrigation motivated the choice of the 'systems thinking theory' as the basis of this research study, whereby individual issues and interrelationships are treated as part of an overall irrigation system within a site-specific environment. The irrigation system is divided in the hard system, which comprises the physical attributes of the system; and the soft system covering regulations and stakeholders involved. From this theory the 'reverse water chain approach' is derived, which takes the preferences and needs of the water users at field level to aid the design of the (irrigation) system at upper levels. This 'bottom-up' approach contrasts to the conventional water chain approach, whereby decisions of authorities are imposed on the water users.

This study is divided into 3 stages: the first gaining insight in the irrigation system with reclaimed water and the latter two stages focussing specifically at the farm level. Methods used during the study involved: reviewing project reports; attending meetings; conducting interviews with experts and irrigators; and running farm-scale computational model simulations.

The information gathered from project reports, meetings and expert interviews were used to develop an overview of the reclaimed water irrigation system and the issues involved. Irrigator interviews increased the involvement of the irrigators in the process of introducing reclaimed water to the Lockyer Valley. Preferences and needs of the irrigators were identified during the interviews. Additionally, information was acquired on the current cropping systems and irrigation practices, which provided the input for the model simulations. The software model used was APSIM (Agricultural Production Systems sIMulator) version 7.1 developed by the ASPRU (Agricultural Production Systems Research Unit) group of scientists. Simulations were conducted with a daily time step over a 40 year simulation period presenting predictions on biophysical and productivity effects for the farming system.

Interview results identified a general preference of the irrigators to increase both the irrigation area and cropping intensity, should reclaimed water become available. The water balances derived from the model simulations showed variable increases for plant water uptake. Increasing crop rotations gave the largest benefits in crop yields, as did the change from dry land to irrigated lucerne. These results contributed to the irrigation system by indicating potential profitability for the irrigators and increased food security for South East Queensland. Additionally, values found in the water balances for drainage indicate potential recharge of ground water, and at catchment scale the movement of solutes can be discussed.

These results are predictions of the potential impact reclaimed water irrigation can have in this region and can be used as an aid for decision-makers at both farm and catchment level.

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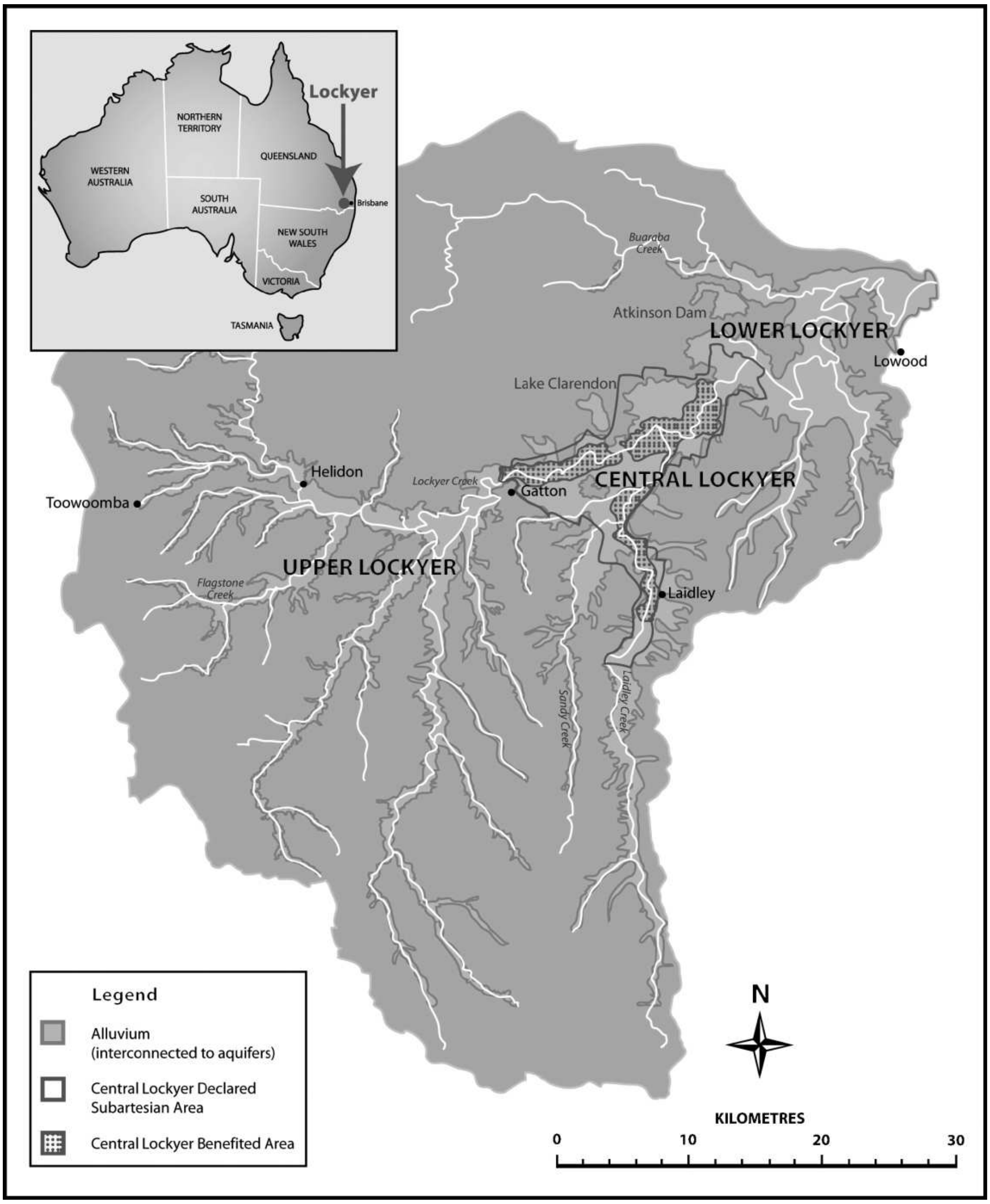
LIST OF ABBREVIATIONS

a	annually
APSIM	Agricultural Production Systems sIMulator
ASRIS	Australian Soil Resource Information System
ASW	Available Soil Water
AWTP	Advanced Water Treatment Plant
BD	Bulk Density
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Coefficient of Variance
DERM	Department of Environment and Resource Management
DIP	Department of Infrastructure and Planning
DNR	Department of Natural Resources
DPI	Department of Primary Industries
DSDI	Department of State Development and Innovation
DUL	Drained Upper Limit
EPA	Environmental Protection Agency
ha	hectare = 10^4 m^2
kg	kilogram = 10^3 gram
KL	Water extraction parameter
LL	Lower limit
LWUF	Lockyer Water Users Forum
ML	megalitre = 10^6 litres = 10^3 m^3
mm	millimetre = 10^{-2} ML/ha
PAWC	Plant Available Water Capacity
SAT	Saturation
SE	Standard Error
STD	Standard Deviation
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant
XF	Root exploration parameter

SECTION A : INTRODUCTION AND RESEARCH APPROACH



(source: Queensland Department of Natural Resources and Water)

1. INTRODUCTION

This research study took place in Australia in the Lockyer Valley catchment, which is located in South East Queensland. Queensland has seen a rapid population growth during recent years (Stevens, 2006), which requires investment in ensuring sufficient food and water security, thus satisfying this increased demand. Over the past decade severe droughts have occurred (Radcliffe, 2006) thereby indicating the limitations of current freshwater resources (Stevens, 2006). This leaves the option of allocating water more efficiently and searching for other sources of water supply (Keremane and McKay, 2007).
Recently the Queensland State Government has initiated several reclaimed water projects including the Western Corridor Project. This scheme transfers reclaimed water from wastewater treatment plants (WWTPs) in Brisbane to several destinations such as pumping stations, dam storages and agricultural areas (Watersecure, 2009-II). Supplying reclaimed water for irrigation in the Lockyer Valley is currently one of the options being considered. The Lockyer Valley is an important agricultural area with fodder crops, vegetables and fruits (Sarker *et al.*, 2009). Introduction of reclaimed water for irrigation in this area requires investigation due to the absence of historical experience on the impact it can potentially have for the region (Stevens, 2006). Insights need to be gained on the views and desires of the irrigators, being the end-users of the reclaimed water (Madi *et al.*, 2003). Especially the needs and preferences of irrigators considering the water quantity and quality is relevant. Unnecessary high treatment levels results in high costs and can pose to be a threat for the viability of a potential reclaimed water irrigation scheme (Toze, 2006).

This research focussed on the irrigators and farm-scale impacts of implementing reclaimed water irrigation. It was found necessary to investigate irrigator perceptions and increase irrigator involvement in the process. Additionally, quantifying the potential impacts of reclaimed water irrigation, assists irrigators in making farm decisions and provides the state government with increased insight on its potential.

The research approach chosen for this study is explained in section A, which covers the problem statement, theoretical framework and methodology. Section B presents the results found providing an overview of the reclaimed water irrigation system in stage 1; irrigator preferences in stage 2; and farm-scale model simulations in stage 3. These results are brought together in the concluding section C, with a discussion, conclusions and some recommendations.

2. PROBLEM STATEMENT

The need for implementing a reclaimed water irrigation system in the Lockyer Valley follows from several ongoing issues, which will be presented in this chapter. The first section gives a description of the Lockyer Valley and the current situation regarding water problems. Section 2.2 elaborates on the views and goals the state government has set concerning the use of reclaimed water. The final section discusses water quality concerns, which are relevant for reclaimed water irrigation.

2.1. Location

The Lockyer Valley is located in South East Queensland approximately 80 km inland of Brisbane city and east of the Great Dividing Range. The Lockyer Creek is one of the tributaries to the Brisbane River, which flows from Wivenhoe Dam to the water treatment plant (WTP) at Mount Crosby, which treats the water for Brisbane households, and eventually to the ocean into Moreton Bay. The Lockyer Creek enters the Brisbane River downstream of Wivenhoe Dam but upstream of Mount Crosby WTP. Therefore the discharge from the creek has important consequences for the water treatment at Mount Crosby.

Important towns in the Lockyer Valley are Gatton, which is the largest of the valley; Laidley and Lowood in the east; and Helidon in the west. The main crops cultivated in the area are lucerne (for fodder), vegetables, brassicas, stone fruit and seed crops (Heiner *et al.*, 1999).

The area has seen a decrease in average precipitation during recent years of more than 100 mm. compared to the long-term average (1900-2004;DPI&F Gatton). The average annual rainfall from 1990 to 2003 was 650 mm. Rainfall is unevenly spread during the year and also throughout the area, having typically summer rainfall events resulting in higher values for evaporation during the growth season of summer crops (Shaw *et al.*, 1994). The potential annual evaporation for the region is estimated to be 1870 mm. (Thorburn, 1990).

Excessive use of groundwater in the past, to supplement surface water use, has led to a depletion of aquifers. It has been estimated that groundwater withdrawal was up to 74,000 ML annually, whilst the estimated safe limit is 27,000 ML/a for sufficient recharge (Sarker *et al.*, 2009). Groundwater level decreases have been observed in areas of the valley of up to 11 m over the decade from 1990 to 2000 (NR&M, 2004).

Additionally, the water quality of the aquifers is deteriorating, with conductivity levels being observed up to 14,000 μS/cm in some areas of the valley (NR&M, 2004). Since 1994 salinity levels have increased considerably, as shown in figure **2.1**.

Salinity levels in Australia are generally high with several areas of accumulated salts in the soils. Prior to intensive agriculture, these salts were periodically leached down below the root zone, particularly along alluvial river courses, but accumulate in regions of lower recharge (Steven, 2006). With irrigation being practised using groundwater sources, the water is used several times before exiting the catchment (Tien *et al.*, 2004), having a cumulative effect and increasing salinity. The Lockyer Valley has very fertile soils, therefore in the past irrigation intensified, which in combination with exceedingly high salinity levels in the irrigation water, led to increased salinity of the aquifers in this area (Shaw *et al.*, 1994).

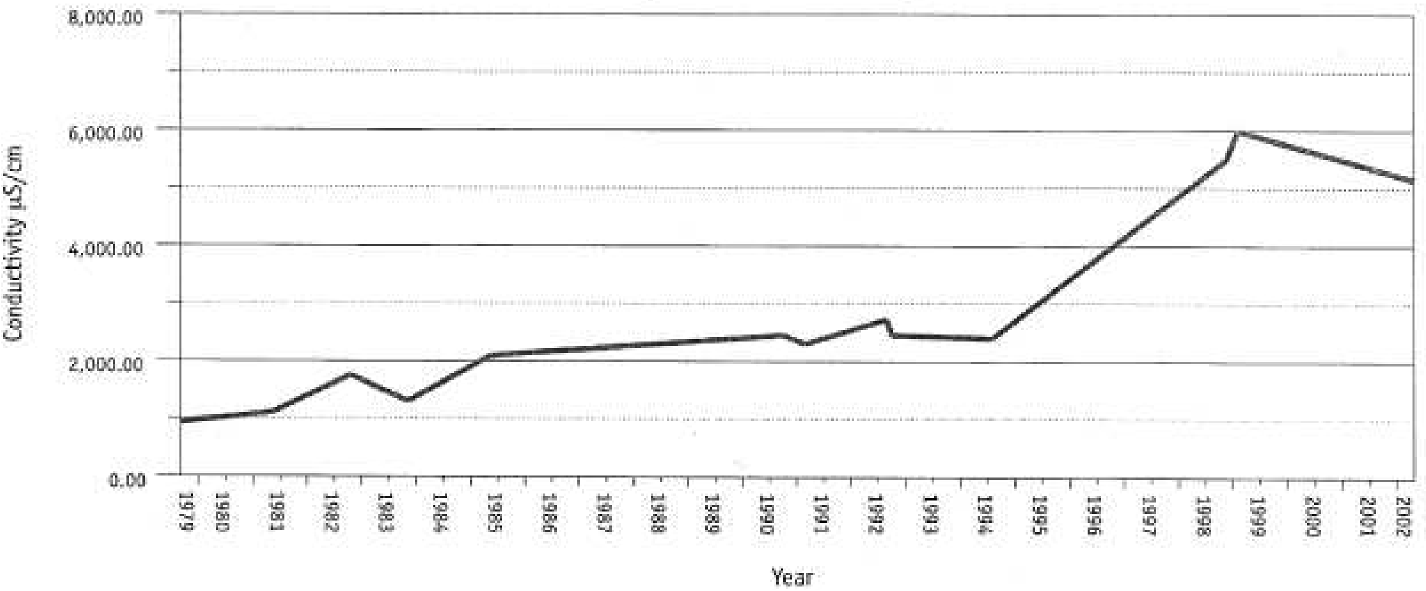


Figure 2.1 Conductivity measured in a bore hole north of Laidley between 1979 and 2002 (source: NR&M, 2004)

With the reduced availability of sufficient quality irrigation water, productivity of the Lockyer Valley has decreased with approximately one third of the productive farmland currently being uncultivated (Sarker *et al.*, 2009). Introducing reclaimed water for irrigation to this area would enable sufficient irrigation of the farmland and can lead to increased yields (Shani *et al.*, 2007). Although, increased irrigation might also lead to the mobilisation of the salts in the underlying aquifers (Stevens, 2006 and Shani *et al.*, 2007). This is a concern if the saline water exits the catchment ending up in the Brisbane river, which is the main supply of Brisbane's drinking water.

2.2. Political setting

There is a need for increased food and water security in Queensland, with the population having a rapid growth of 40% over the past 20 years (Stevens, 2006). The implementation of reclaimed water use has become a necessity especially in the state capital city, Brisbane. Figures on reclaimed water use are shown in table **2.1** indicating only a small percentage of reclaimed water use. The objective of the government was to achieve 17% of reclaimed water use by 2010. This is partly achieved with the immense Western Corridor Project, which treats the sewage of Brisbane and conveys the reclaimed water to several destinations: cooling of power stations; irrigation of agricultural and public areas; non-potable use in households and potentially drinking water (WaterSecure, 2009-II).

The Brisbane government also aims to reduce the discharge of treated wastewater to the protected marine environment of Moreton Bay and eventually eliminate discharge to the bay (Radcliffe, 2006). Additionally, the government supports schemes using reclaimed water, which replace current fresh water demands and enable the collection and transport of wastewater (Radcliffe, 2006). The concept of 'environmental flows' is also incorporated into water studies, taking note of ecological water requirements (Stevens, 2006).

Table 2.1 Use of reclaimed water as percentage of treated wastewater, in Australian state capital cities (source: Radcliffe, 2006) *[3]: Radcliffe, 2004; [10]: Water proofing Adelaide, 2004; [13]: Philips, 2004*

State capital	Percent of recycled water use 2001–2002 [3]	Percent of recycled water use 2004 [13]	Future recycling targets [3, 10, 13]
Sydney	2.3	2.6	35% reduction in per capita consumption by 2011
Melbourne	2.0	14	15% reduction in water consumption, 20% wastewater recycling by 2010
Brisbane	6.0	3.5	Increase recycling to 17% by 2010
Adelaide	11.1	19.2	30,000 ML/y (33%) recycling, 2025
Perth	3.3	4.1	20% recycling by 2012
Hobart	0.1	Negligible	10% reduction in water consumption

Developing a successful system using reclaimed water for irrigation requires a sustainable approach, which can be achieved in three different areas, namely: economic, environmental and social sustainability. These aspects have been suggested to form a management concept referred to as the triple bottom line, which assesses the benefits and problems on all three aspects (Raucher, 2009). Currently, investigation is needed in several areas especially considering effects on the market of food produce and public perceptions to irrigation with reclaimed water (Hamilton *et al.*, 2005). Financial profitability determines the irrigators' motivation for using reclaimed water (Haruvy *et al.*, 1999). Although, the public adoption of reclaimed water irrigation will influence market dynamics, especially considering their perceptions of risk and food preferences (Stevens, 2006). Governmental authorities and scientists need to ensure the trust of the public community in reclaimed water use for irrigation (Radcliffe, 2006). This can be achieved by the involvement of the water users and consumers during the development of a reclaimed water irrigation scheme (Hurlimann and McKay, 2007).

2.3. Water quality

The general advantage for the irrigators in using reclaimed water for irrigation is the reliability of a constant water supply and in some cases the provision of nutrients, which can reduce fertiliser costs (Haruvy, 1997). Additionally, various salts are required in certain amounts for the growth of the crop (Stevens, 2006), although, problems might occur with salinity if concentrations are toxic: high salt concentrations in the root zone can decrease the potential crop yields (Shani *et al.*, 2007). Water uptake decreases at high salt concentrations around the roots, due to osmotic effects (Stevens, 2006). Contaminants in wastewater, which are of concern include pathogens, hormones and pharmaceuticals. These are removed in the case of reclaimed water to a degree recommended by Queensland recycled water guidelines (EPA, 2005). Required treatment levels should depend on the end use of the reclaimed water, hence there are differences based on whether products are consumed raw or cooked; and the lower treatment levels for pastures and fodder crops. It is of importance to adjust treatment levels to the requirements of irrigation to avoid high expenses for unnecessary high-quality reclaimed water (Toze, 2006).

3. THEORETICAL FRAMEWORK

The theoretical framework presented in this chapter provided the basis for the research study. The first section elaborates on the 'systems thinking theory' and the motivation for taking this theory in this study. The second section presents the 'reverse water chain approach', which is a specific application of the 'systems thinking theory'. Sections 3.3 and 3.4 discuss the conceptual framework indicating the different issues involved in reclaimed water irrigation, and providing definitions of the various concepts.

3.1. Systems thinking theory

Water management issues involve several aspects and disciplines, such as physics, chemistry and economics (Meta Systems Inc., 1975). These study areas involve mostly quantifiable parameters. Additionally, other study areas involve the social and institutional aspects of water management. Social problems can bring in a degree of complexity as they involve different perceptions and opinions from individuals or a group of individuals (Pearson and Ison, 1997). Therefore tackling water resource problems should consider the specific local situation and communities (Attwater *et al.*, 2006). The interdisciplinary character and complexity of water issues requires a holistic approach, thus looking at the water resource management and design as a whole (Lazarova, 2005). This is often referred to as 'the systems thinking theory', which takes into account "the set of elements standing in relation amongst themselves and with the environment" (Von Bertalanffy, 1972 p.417).

The systems thinking theory is not a novel concept; it was already evident in Greek philosophy. Aristotle is quoted by Von Bertalanffy (1972 p.407): 'the whole is more than the sum of its parts'. Von Bertalanffy explains that systems should be perceived as a whole, which means that not only the individual parts are understood but also the interactions between these parts. Systems thinking theory also supports the understanding of differences in perceiving the system by individual stakeholders. Each stakeholder brings its own experience, interests, needs and other issues in the system. In such a complex and dynamic system it cannot be expected to achieve one satisfactory, static solution, which fulfils the needs of each individual stakeholder. Systems thinking theory incorporates the different perceptions of stakeholders and relationships between stakeholders and the physical environment (Pearson and Ison, 1997). Such an approach covers the several requirements, preferences, knowledge and objectives of the various stakeholders.

Applying systems thinking theory for irrigation considers both the hard and soft system. The hard system covers the physical properties of the irrigation system such as the off-take and division structures; canals or pipelines etc. The soft system considers the different stakeholders involved in the irrigation system and the division of tasks and responsibilities (van Halsema, 2002). The introduction of using reclaimed water for irrigation in the Lockyer Valley irrigation scheme will have implications on both the hard and soft system. The link between the hard and soft system is interrelated, thus both having an influence on each other. This can be brought together in developing a system design and management structure.

This research study focuses on the introduction of reclaimed water irrigation in an agricultural area and changes that are necessary for the design and management of the irrigation system. It is beneficiary to take the systems thinking theory as the basis of this study because through the interdisciplinary approach it achieves more sustainable solutions to problems (Attwater *et al.*, 2006). Additionally, it helps the development of suitable and practical solutions, which are sustainable in both economical and health aspects (Lazarova, 2005).

3.2. Reverse water chain approach

The reverse water chain approach is derived from the systems thinking theory (Huibers and Raschid-Sally, 2005). The usual water chain approach links the different elements of a water systems according to the physical flow of water. It takes into account the quality and quantity of water. Physical and chemical aspects of the water are studied at source, in-between treatment processes and consumers (Huibers and Van Lier, 2005). Furthermore, at each level the management and interaction between regulating actors and the physical environment is analysed (Huibers and Raschid-Sally, 2005). In the case of the reverse water chain, the sequence of analysis is taken from agricultural user back to the source. The objective of the irrigation system design and management is to achieve the water quality and quantity preferences of the end users, thus in the case of agriculture being the irrigators (Van Lier and Huibers, 2009).

Appointing the irrigators as the main drivers of the system gives several advantages. The local knowledge of the irrigators can be valued and used; monitoring and adapting the system is easier and therefore faster and cheaper (Lopez-Gunn and Martinez Cortina, 2006). There are also pitfalls in having irrigators operate the irrigation of a system, such as the lack of scientific knowledge and possibly only short-term interests. It is important to develop a management system, which can prevent this pitfall, through balancing responsibilities over different stakeholders. For this research the starting point will be the irrigators, for they are the users of the system.

3.3. Conceptual framework

Following from these theories and concepts described in literature, a conceptual framework presenting a simplified perception of reclaimed water irrigation in a developed region (such as the Lockyer Valley) is constructed. The different parts and linkages are presented in a diagram in figure **3.1**.

The framework takes the division of an irrigation system into a hard and soft system as the main approach of structuring the different parts. The hard system takes the flow of water from source to destination as the method of distinguishing between different levels. Water is taken from the catchment area either in the form of surface, rain or ground water. This water is used in different sectors: nature, agriculture and urban areas. Within the agricultural and urban areas, the water is conveyed to lower scale levels with a water distribution infrastructure. In the case of reclaiming the water, the wastewater from households and industries is transported to a treatment plant, after which it becomes available as a source of water for the catchment area.

The soft system takes the same division of different levels and indicates the regulating mechanisms at each level. These regulating stakeholders influence the hard system by being the decision makers at that level. Thus at catchment level both the state government and the catchment managers are the policy makers. Allocations of irrigation water and transport are managed within the irrigation scheme ideally by an organisation or cooperation of water users. At field level the irrigators are the regulating actors making decisions on the use and specific destination of the water.

The hard and soft systems continuously interact and influence each other at different scales. The overall result of these parts and interrelationships is covered in the irrigation system design and management.

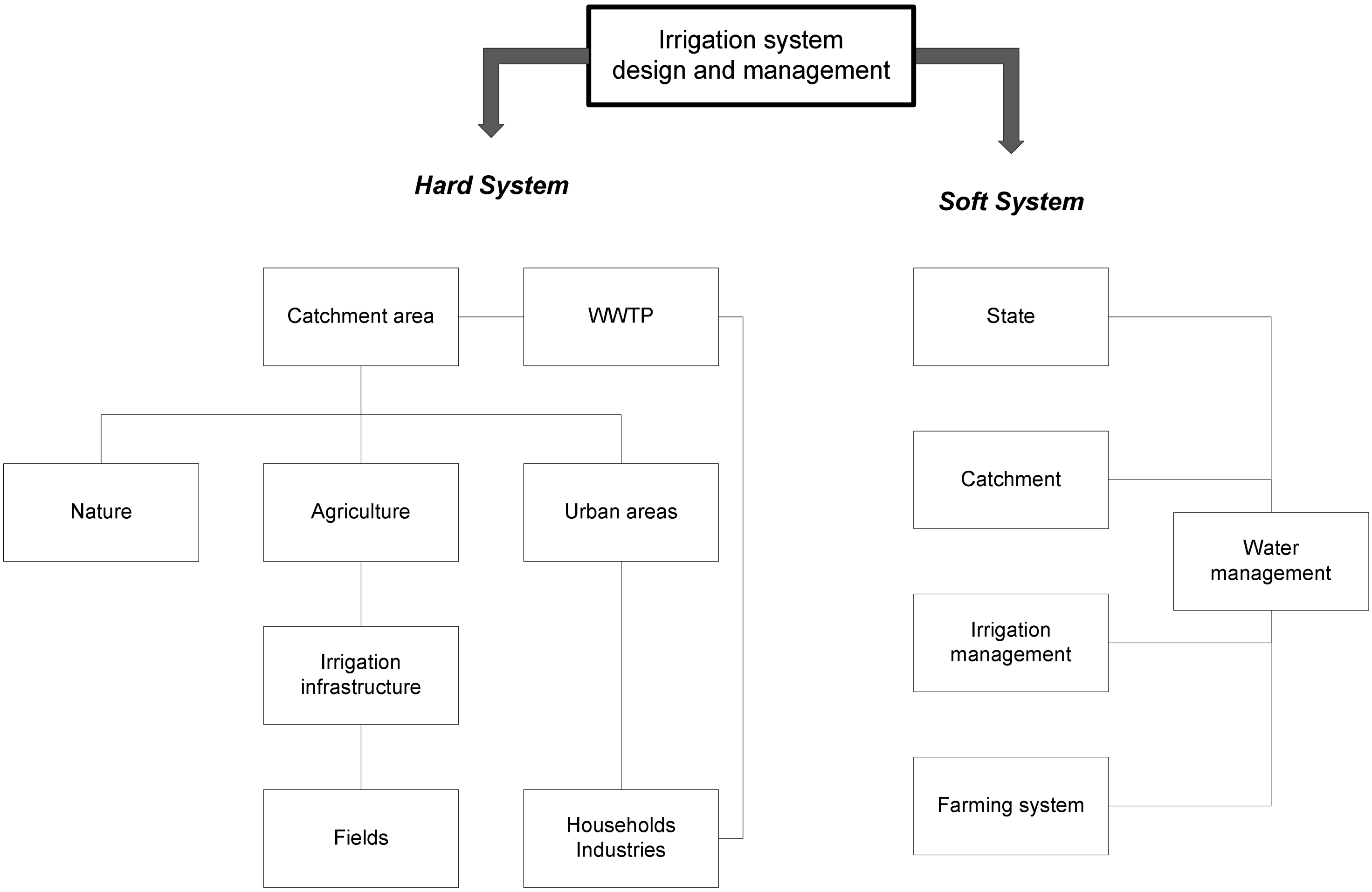


Figure 3.1 Diagram of conceptual framework with different elements of the irrigation system and the interrelationships

3.4. Concepts

Irrigation Irrigation is defined as “spraying or causing water to flow over arable land for farming and to benefit crops” (Nelson *et al.*, 2005 p.179)

System “System is a model of general nature, that is, a conceptual analog of certain rather universal traits of observed entities…It refers to very general characteristics partaken by a large class of entities conventionally treated in different disciplines.” (von Bertalanffy, 1972 p.416)

Irrigation system “Irrigation systems can be regarded as hybrid systems, in which designed physical systems and human systems occupy a prominent and interrelated role” (van Halsema, 2002 p.12). In the context of this research thesis the use of the term irrigation system, acknowledges both physical properties of irrigation and the social properties such as the operation, scheduling and distribution of irrigation water.

Irrigation scheme	The irrigation scheme is the location of the irrigation system, which is in this case the Lockyer Valley. It encompasses the distribution and physical conveyance of the irrigation water to the irrigators.
Hard system	The hard system is the physical object, which is studied. In the case for irrigation this is the irrigation infrastructure thus encompassing the gates, off-take and division structures, canals etc (van Halsema, 2002)
Soft system	The soft system considers the social structures of an irrigation system. This would encompass relations between the inhabitants, politics on the local but also the regional or national level. The operation, regulation and water allocation of the irrigation scheme are also part of the soft system. (van Halsema, 2002)
Design	Traditionally, the design of an irrigation system only covers the water conveying part of the irrigation system. Considering the irrigation system as having both hard and soft system properties, it is important to anticipate to the practical use of the system (van Halsema, 2002).
Management	A management structure for an irrigation system covers the operation and maintenance practices of the system (van Halsema, 2002).
Irrigators	The irrigators are the farmers in the Lockyer Valley who are irrigating (or will potentially irrigate) their farmlands.
Wastewater	Effluent water is defined as "liquid discharged from a processing step" (Metcalf and Eddy, 2004 p.4).In this research the general term wastewater will be used for effluent from urban areas. The wastewater will be limited to that produced by the domestic sector in urban areas.
Wastewater use	For controlled wastewater use with collection and treatment, this is defined as the "beneficial use of reclaimed or repurified wastewater" (Metcalf and Eddy, 2004 p4). The wastewater use considered in this project is for irrigation of farmlands.
Reclaimed water	There are several terms used for wastewater, which has been treated at a wastewater treatment plant (Menegaki *et al.*, 2009). The term reclaimed water is one of the terms often used; and will be applied during this research project. It considers the water to be of a second (or more) use and is treated to make it suitable for a specific application.
Class A water	Queensland defines treatment classes for wastewater ranging from A to D, with A being the highest class and thus suitable for various applications such as non-potable use in households and the irrigation of field crops eaten raw. The quality of this water is achieved through additional tertiary disinfection treatments (EPA, 2005).
PRW	Purified Recycled Water (PRW) is achieved after advanced treatment of the water with microfiltration, reverse osmosis and advanced oxidation. PRW is suitable to be used as drinking water (WaterSecure, 2009-II)

4. Research Methodology

Approach and methods used for this study are presented in this chapter. The research question determined the main focus of the study. The following section presents the research design covering the basic methodology chosen for responding to the research question. Methods used for this study are elaborated on in the final sections including literature gathering, meetings, interviewing and modelling.

4.1. Research question

Within a developing reclaimed water irrigation system, what changes can be expected at farm scale in cropping patterns and irrigation practices and how will these changes influence other parts of the irrigation system?

4.2. Research design

Results were found following a three stage sequence: the first gaining insight on the reclaimed water irrigation system and the latter two stages focussing specifically on the farm level. The irrigation system overview provided essential knowledge on the current situation and determined missing links and information. Irrigator involvement was necessary for answering the research question, which required the identification of irrigators' needs. This in combination with the lacking information were fundamental for developing the specifics of stage 2 and 3. It was chosen to conduct model simulations, due to the use irrigators would have with modelling results. They would be more willing to participate when there is a benefit for them in the study.

In the first stage several issues playing a role in the irrigation system as a whole were identified. Findings from previously conducted studies are presented giving information on several aspects of the system, which introduces reclaimed water irrigation.

In stages 2 and 3, detailed analysis was conducted with a selection of farms in the Lockyer Valley. Stage 2 made use of interview meetings for achieving information on the current farming system and discussing options assuming reclaimed water becomes available for irrigation. In stage 3, a modelling tool was used to predict biophysical and crop productivity effects in the situation of reclaimed water irrigation according to the information given by the irrigators in the interviews. Results of the modelling were discussed with the irrigators on its plausibility; with this feedback, simulations were adjusted.

4.3. Literature review

Previous studies have presented information on issues considering the implementation of reclaimed water for irrigation in the Lockyer Valley. It is useful to firstly identify the found information, thereby attempting to contribute with relevant new insights. Several reports were made available through networking with other local scientist and consultants involved in the Lockyer Valley.

4.4. Meetings

Group meetings discussing reclaimed water for the Lockyer Valley were attended frequently to gain insights on current activities and for networking with relevant stakeholders or experts.

- A number of meetings were organised by the CSIRO Lockyer Valley project team (Cresswell, 2008) with other team members to update recent findings and discuss the project proceedings. Additionally, a meeting was set with members of the reference panel, which could provide their expert knowledge for the project.

- The Reuse09 conference was attended providing information about reclaimed water projects in Australia and other countries. This conference took place in Brisbane therefore several seminars were on the current reclaimed water projects in the region. Additionally, seminars were attended presenting a summary of the Australian guidelines for using reclaimed water.
- A Lockyer Water Users Forum (LWUF) meeting was attended on February 24th 2010. Representatives of the different membership areas were part of the meeting. An update was given on the negotiation process with the government on implementing reclaimed water for irrigation and a discussion followed presenting the opinions of the several irrigators.

4.5. Interviewing

Experts

Several open interviews were conducted with experts, who could provide useful information for this research study.

- Ray Ferdinand is the LWUF consultant and negotiates with government officials on implementing reclaimed water. Useful experience on the interaction with irrigators was shared during the interview. Additionally, proposals for irrigation distribution networks were discussed.
- Dr. Claudia Baldwin conducted her PhD thesis in the Lockyer Valley identifying the values and needs of the irrigators.
- Linton Brimblecombe is the chairman of the LWUF, therefore his cooperation and support for this research study was required. During an interview, ideas were presented and feedback was provided.
- Lisa Brennan performed a similar modelling study in the Darling Downs catchment. During an interview information was given on her project including experience with irrigators and using a farming system model.
- Kelly Fielding interviewed several food industries to identify their perspectives on reclaimed water irrigation.
- Craig Henderson is contributing to the development of additional vegetable crop modules to the farming system model used in this research study.
- Shaun Verrall gave a short training in the use of the farming system model and provided support in conducting simulations

Irrigators

A selection was made for choosing irrigators to participate in this study. Firstly, a list of participants from a previous reclaimed water irrigation survey was taken as these irrigators might be interested in receiving reclaimed water. Secondly, a short list was developed based on farm location, crops cultivated, farm size and fraction of farmland under irrigation. The aim was to achieve a diversity of farms varying on all these aspects and representing the different farming systems present in the Lockyer Valley. At the end a sufficient number of irrigators responded to the request for participation to achieve a variety of farming systems.

Semi-structured interviews were used for collecting data on the farming systems of these participating irrigators. Questions on the current situation consisted of closed questions that later provided input data for calculations and modelling. These questions identified the general aspects of the farm location, current cropping patterns, irrigation practices, water sources and fertilizer management. The second part of the interview discussed the future plans of the farm owners when reclaimed water is implemented. This consisted of open questions, aiming to achieve insight in potential options the farm owner considers when making use of reclaimed water. Results of the interviews were verified with the individual irrigators.

4.6. Modelling

Model choice

A farming system simulator was chosen to achieve more information at farming system level. For understanding the interactions of various processes at a farm-scale it is useful to use a model for simplification and achieving more insight on predicted effects of changing to reclaimed water irrigation (Meta Systems Inc. 1975). The biophysical aspects are studied by taking the water balance components and the crop productivity (taken as the harvestable yield or for some crops the change in biomass). The required input data and the output variables can be found in figure **4.1**.

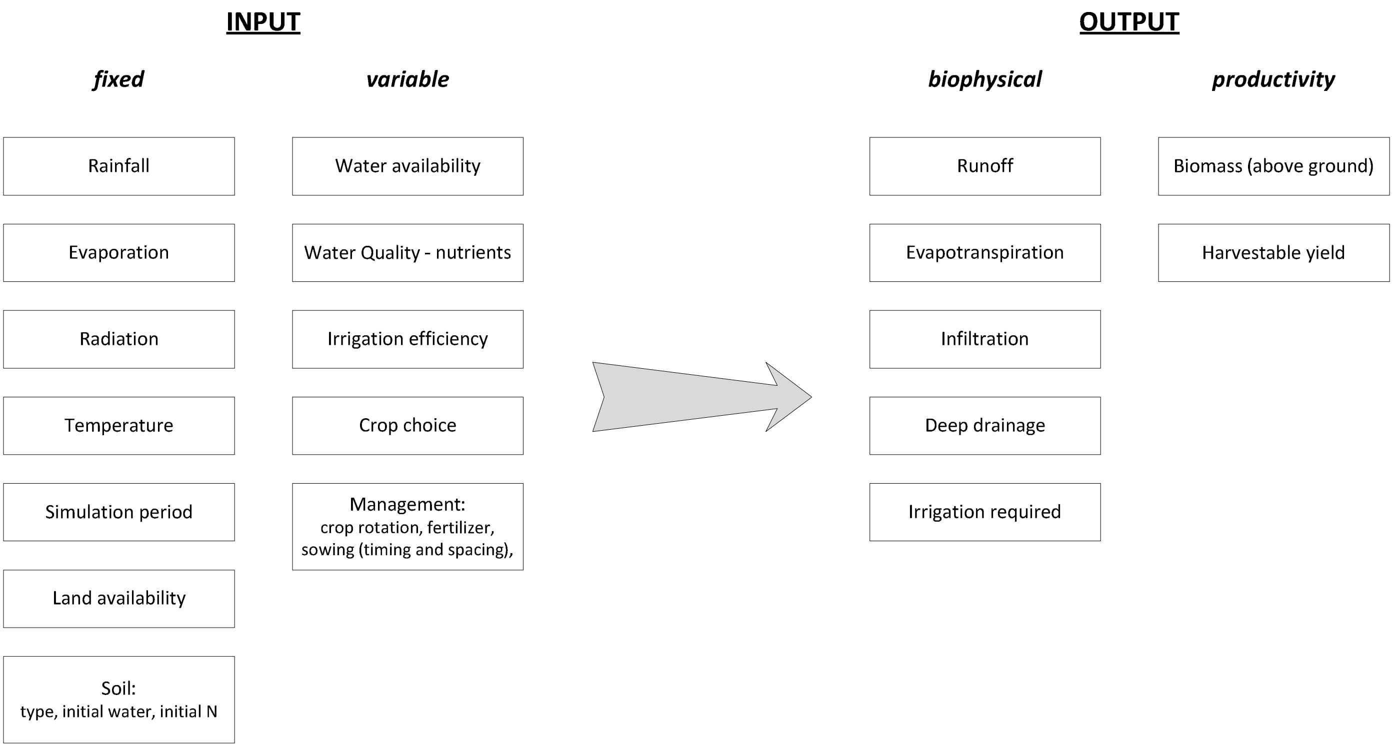


Figure 4.1 Diagram of modelling process with input parameters and output variables listed

The model chosen for this research study is called APSIM (Agricultural Production Systems sIMulator) version 7.1. This model is able to simulate the input and output variables and generate data for further interpretation. It is developed by the APSRU group (Agricultural Production Systems Research Unit), which is a collaboration between CSIRO, Queensland Department of Primary Industries (DPI), Queensland Department of Environment and Resource Management (DERM) and the University of Queensland.

For the farming system simulations it was important to find a model with the ability to predict biophysical and productivity effects. APSIM was found to be suitable for these types of simulations and required output. Additionally, APSIM was a user-friendly model and if necessary, support from APSIM experts was at hand.

Model design

APSIM is made up of several modules brought together in the simulation engine. Individual modules for crops and biophysical aspects exist. Additionally, a manager module gives the opportunity to place certain irrigator's decisions in the model An overview of the model is shown in figure **4.2**.

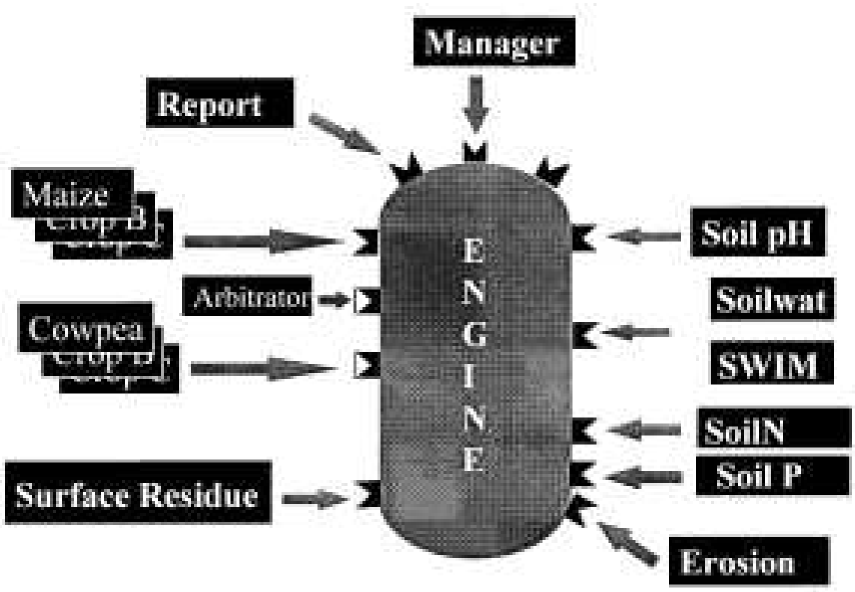


Figure 4.2 Diagram of the APSIM simulation framework with individual modules and the simulation engine (source: Keating *et al.*, 2003)

APSIM is an area simulator thus calculates the output variables in units of 1 ha, which makes it a 1-D model. The depth of calculation is the root zone thus ranging from 150 to 180 cm. The plant modules undergo several physiological stages and are influenced by the daily weather data, crop, soil and management modules (Keating *et al.*, 2003). Calculations are therefore performed at a daily time step.

Model input

The input data was mainly taken from the interviews conducted with the irrigators on their current cropping system and irrigation practices. Additional input data, which could not be provided by the irrigators on soil characteristics, was found on the ASRIS (Australian Soil Resource Information System) site (www.asris.csiro.au). This information system provides data on soil profiles at different locations in Australia. Required information about crop characteristics, management and profitability was found through Queensland DPI&F (www.dpi.qld.gov.au).

A 40 year simulation period (1970-2009) was chosen because it gave a good average between dry and wet years and thus indicates the variability in crop productivity. It also gave insight into long-term effects, assuming that the rainfall patterns in the future will be similar (this does not consider the possible effects of climate change). The variation in annual rainfall can be found in figure **4.3**, which shows the importance of taking a 40 year simulation period as an average. The seasonal distribution and its variation are indicated in figure **4.4**, which shows the large difference between the dry period in the winter and the wet months in the summer. The potential evaporation also increases during the wet months due to the warmer temperatures. The potential evaporation is higher than the rainfall throughout the year (figure **4.4**). Therefore only shorter periods of heavy rainfall exceeds the evaporative demand and allows stream flow. This results in a soil water deficit throughout the year, requiring irrigation to sustain plant growth.

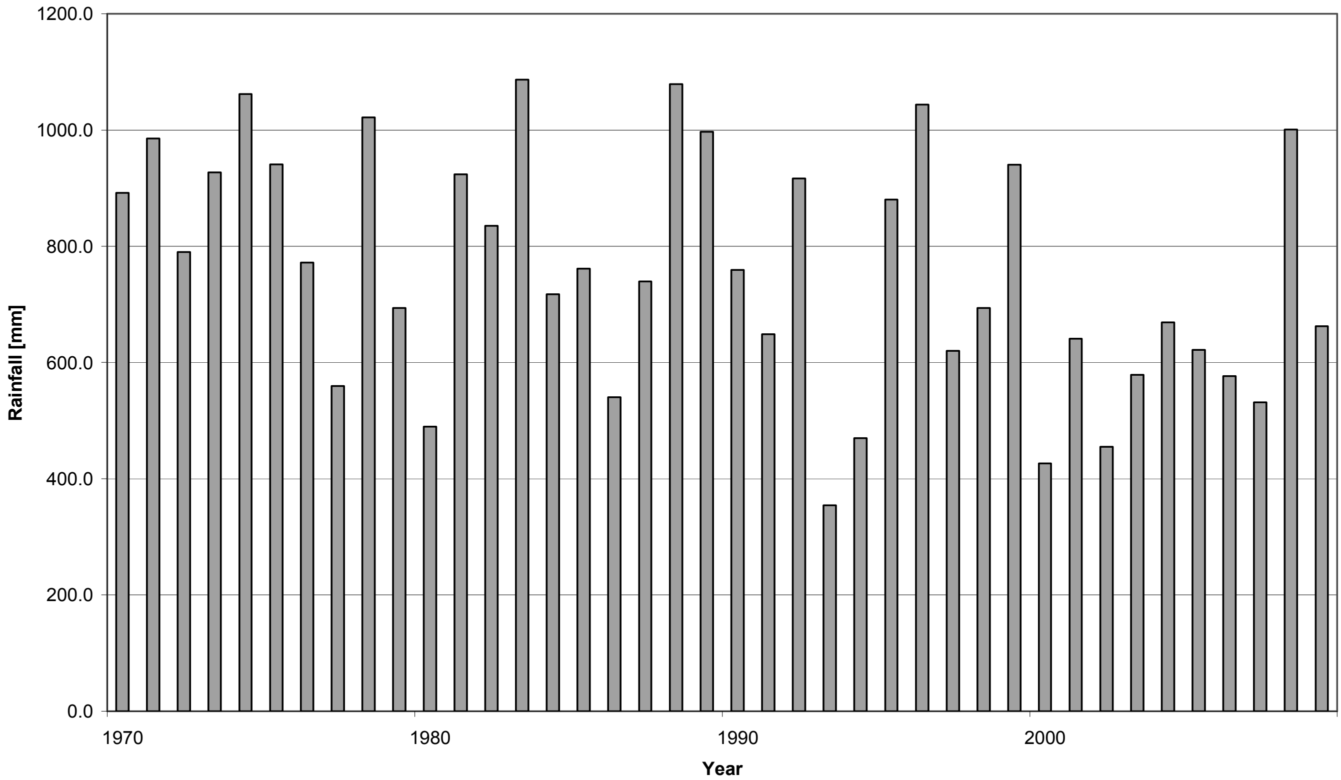


Figure 4.3 Annual rainfall from 1970 to 2009 recorded by Gatton Research Station

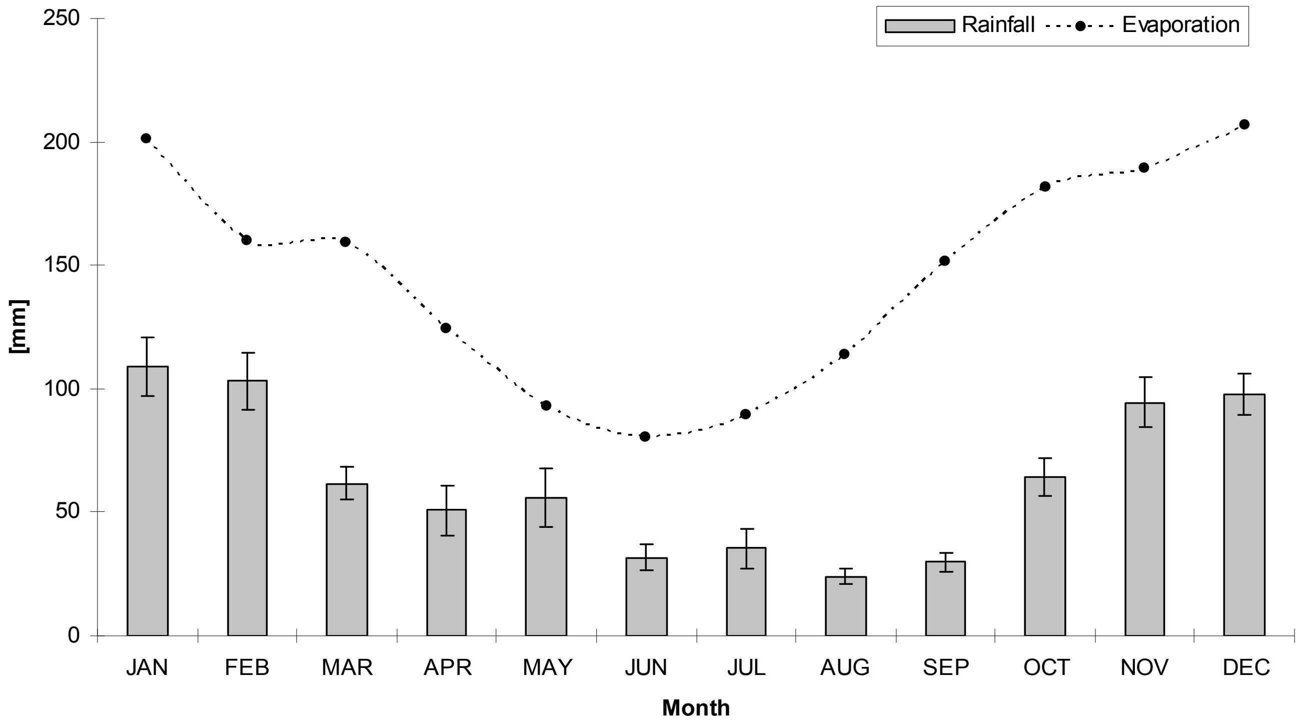


Figure 4.4 Average monthly rainfall and evaporation during the 40 year simulation period, with standard error (SE) indicated as variation

Model calculations

The soil modules calculated the available soil water (ASW) daily using the soil characteristics and water input to the soil. The soil characteristics used are the lower limit (LL15), drained upper limit (DUL) and saturated (SAT) volumetric water contents (Keating *et al.*, 2003). These are consistent with wilting point, field capacity and saturation in a pF curve of a soil. The ASW is expressed as a fraction of soil volume.

Soil evaporation assumingly occurs in two different behaviours. The first is the situation where soil is saturated with water and therefore achieves values of potential evaporation. The second behaviour covers the situation that soil is not saturated with water and soil evaporation is less than potential soil evaporation. In the Soilwat module of APSIM, these behaviours are described using the U and cona parameters. The parameter U represents the cumulative amount of soil evaporation at saturation. The cona parameter is used for the second behaviour expressing decreased soil evaporation (compared to potential soil evaporation) against the square root of time.

Runoff is calculate using curve numbers and the total amount of precipitation during a day (thus excluding rain intensity). The curve number of wet and dry conditions are determined and the model takes the relevant response curve, which should be used at a given soil moisture level.

Data analysis
The data analysis of the modelling outputs was processed in Microsoft Office Excel by configuring the information into monthly and annual averages. This gave a better overview of the variation and averages during the 40 year simulation period. Averages and standard deviations (STD) were calculated.
For the water balance the following equation described by the FAO (1998) was used:

$$P + I = E + T + RO + DP + \Delta R$$

P = Precipitation
I = Irrigation
E = Evaporation
T = Transpiration
RO = Runoff
DP = Deep percolation
ΔR = change in soil water storage

These components are also indicated in figure **4.5**, with the change in soil water being a combination of 'subsurface flow in' and 'subsurface flow out'. The irrigation component used in this research study consists of the total irrigation multiplied by application efficiency, which expresses the actual amount of irrigation water applied to the field.

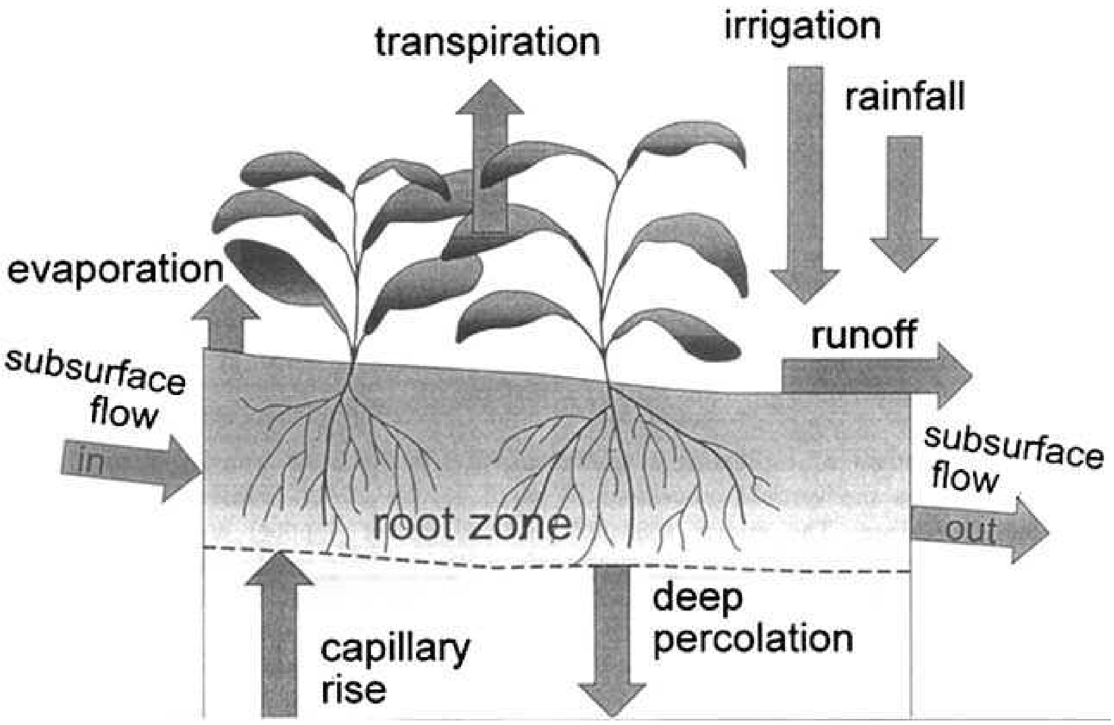


Figure 4.5 Water balance components (FAO, 1998)

SECTION B : RESULTS

(source: Veolia Water)

Foreword Section B

The results of this research study are presented according to a three stage approach, each covered in an individual chapter.

Stage 1

This stage identified the different issues playing a role in the irrigation system concerning the implementation of irrigation with reclaimed water. Information was gathered through reviewing past (scientific) projects on this topic, attending meetings and undertaking interviews with relevant experts and stakeholders. Results are presented and provide the overview of the reclaimed water irrigation system being both a preliminary and foundational study for the continuing stages.

Stage 2

The study continues with the main focus on the irrigators gaining insight on their current situation and preferences in the case of reclaimed water irrigation. Potential changes to the farming system, which irrigators are considering, were discussed during interviews. The information found is relevant for the irrigation system for changes at farm-scale level has an effect on different parts of the irrigation system.

Stage 3

Information provided by the irrigators during the interviews was used as the input for the farm-scale model simulations. A selection of case studies was set up for the simulations. Results indicated potential biophysical and productivity effects when reclaimed water is implemented. This insight is valuable for the irrigators for making changes to their farming system, thus achieving optimal profits. Results were therefore presented to the irrigator and discussed on its plausibility.

5. THE RECLAIMED WATER IRRIGATION SYSTEM

Different parts of the irrigation system and the interrelationships will be discussed in the following chapter presenting an overview of the several issues playing a role in this irrigation system. Firstly section 5.1 will elaborate on existing infrastructure for the treatment and transport of wastewater. Additionally, proposed schemes will be presented and discussed considering financial, environmental and social effects. Section 5.2 will present the three important groups of stakeholders namely the state government, the public sector and the irrigators. Scientific studies in the Lockyer Valley considering aquifer changes, and water demands will be presented in section 5.3.

5.1. Infrastructure

Wastewater Treatment Plants (WWTPs)

Wastewater is collected through a network of pipes and brought to several WWTPs in Brisbane. The location of these WWTPs can be found in Annex A, which shows that the majority of the plants are found near the coast, thus making use of gravity for conveyance. Three of these plants are Advanced Water Treatment Plants (AWTP) receiving secondary treated effluent water from WWTPs and improving the water quality to purified recycled water (PRW) standards. This is done through microfiltration, reverse osmosis and advanced oxidation, which are components of the '7 barrier treatment process for indirect potable reuse' (Davies, 2009). The Bundamba AWTP, which is the treatment plant nearest to the Lockyer Valley (in Annex A), has the capacity to produce up to 66 000 m^3 per day (= 66 ML/d) (DIP, 2008-I).

The possibility of using the wastewater from towns located in the Lockyer Valley (e.g. Helidon and Gatton) is not discussed in these projects, mainly due to the small volume of water produced compared to Brisbane city. These treatment plants can potentially be a small part of the overall reclaimed water irrigation scheme (DNR, 1998). It has been reported that 3 farms in Gatton have successfully implemented the use of reclaimed water to irrigate persimmons and passionfruit (Stevens, 2006).

Western Corridor Project

The government has invested 2.5 billion AU$ (1 AU$ ≅ €0.65) in the Western Corridor Project, which is the largest reclaimed water scheme in Australia, with a capacity to provide 232,000 m^3 of PRW a day (= 232 ML/d) (DIP, 2008-III).

The PRW is taken from the three AWTPs to power stations, industries, agriculture and Wivenhoe Dam, which is Brisbane's main supply for drinking water. When the dam level falls below 40%, the PRW is brought to Wivenhoe Dam, to ensure a sufficient supply for Brisbane (WaterSecure, 2009-II). The PRW blends with the dam water and undergoes the same standard water treatment processes before being distributed to the consumers. It is necessary to bring the PRW to Wivenhoe Dam, because at time of adequate water supply, the dam is a storage for the PRW (WaterSecure, 2009-I).

Proposed irrigation infrastructure

Several possible schemes for conveying the reclaimed water to the Lockyer Valley are investigated on their viability. Variation exists in the location of the treatment plant and the water quality (PRW or Class A); and the method of distribution (refilling local dams, reticulation to farm-gate or managed aquifer recharge). These options are analysed according to their financial, environmental and social feasibility.

A consultancy report published by Department of Natural Resources (1998) proposes five different routes of conveying reclaimed water to the Lockyer Valley. The route following the river valley is the most practical as it provides the best access for the irrigators and it is less costly due to the least elevation differences.

Another study was conducted by South East QLD Recycled Water Taskforce (2003), which found that conveying Class A water to the Lockyer Valley will have both financial and environmental negative effects. The costs of the infrastructure and pumping will lead to high water prices of 0.841 AU$/m^3 (= 841 AU$/ML) to 1.079 AU$/m^3 (= 1079 AU$/ML) and a cost recovery of 16 to 21 %. The environmental benefit was the decreased discharge to Moreton Bay, although this was outweighed by the cost of greenhouse gases for pumping the reclaimed water to the Lockyer Valley. The social benefit was that the scheme will increase employment and the population in this area.

With the current construction of the Western Corridor pipeline, the financial and environmental costs of bringing reclaimed water to the Lockyer Valley are reduced. The pipeline to Wivenhoe Dam can be used by placing an off-take at Lowood, from where the water can be distributed to existing local dams. This will decrease infrastructure costs and the cost of pumping the water, because from Lowood water can be transported through gravity. Additionally, a new reticulation water scheme for reclaimed water can supplement the local dams and provide water to the irrigators, which are not connected to the dams. The drawback of this proposed scheme is that the PRW will be used for irrigation. The high water quality of the PRW is unnecessary for irrigation, as Class A also suffices. If Class A water is desired by the irrigators, the Western Corridor pipeline cannot be used, which will result in higher infrastructure and pumping costs. Annex B gives an overview of the different options currently implemented or being discussed.

5.2. Stakeholders

Irrigators

The irrigators of the Lockyer Valley have organised themselves into a group called the Lockyer Water Users Forum (LWUF). Frequently 17 representatives of the different member groups divided according to the irrigation areas, meet. At times other stakeholders are invited such as scientists or consultants, to communicate relevant information for the irrigators (Brimblecombe, undated). Currently, the search for other sources of water such as reclaimed water is an important discussion topic during meetings. A consultant was appointed for the negotiation process for bringing reclaimed water to the Lockyer Valley, which is part of the government initiated Western Corridor Project. The irrigators desire to be part of this process and be able to state their views as the project influences their future (see box **5.1**).

Box 5.1

"Essentially the irrigators wish to take control of their own destiny."
(source: Brimblecombe, undated)

Irrigator: "It would be best to tell straight from the start where the farmers stand and what the farmers consider as reasonable options."
(source: LWUF meeting, 24 February 2010)

There is a discussion on the different options the government are considering including the option of recharging ground water aquifers. Variable opinions were expressed on this topic during a LWUF meeting, which are reflected in box **5.2**.

Box 5.2

Irrigator: "The government wants sustainability and does this through calculating the environmental flows of the catchment. … Irrigators want to pay for what comes from the pump and not for what is injected in aquifers."
(source: LWUF meeting, 24 February 2010)

Irrigator: "An advantage to putting PRW in groundwater aquifers is the support the community will give, because the water will go partly to environmental flows. This may accelerate the process."
(source: LWUF meeting, 24 February 2010)

Irrigator: "It should be a stand alone project; there will probably be no consensus of different pricing. A pipe network will support this, as it can be metered how much water is taken."
(source: LWUF meeting, 24 February 2010)

Additionally, issues concerning the quality of the reclaimed water provided were under discussion. The high quality of water is perceived to be unnecessary especially in comparison to the quality of irrigation water currently in use (see box **5.3**)

Box 5.3

Irrigator: "Why would you ruin the PRW with dam water? The water from Atkinson dam did not pass the previous quality test. It may even be worse than class A water."
(source: LWUF meeting, 24 February 2010)

An important concern for the irrigators is the payment of the reclaimed water, for in most scenarios the water will be pumped from downstream areas. Major investments will be necessary for constructing necessary pipelines, and paying the treatment and pumping costs. A study funded by the Queensland Department of State Development and Innovation (2005) conducted a survey in the Lockyer Valley to investigate the capacity and willingness to pay for reclaimed water. The results on capacity to pay for reclaimed water covered 50 farms throughout the Lockyer (and two adjacent valleys: Warrill and Bremer). The survey for willingness to pay involved 339 participants in total for the three valleys (the majority 79% located in the Lockyer Valley), which was a response rate of 15%. The willingness to pay was determined at the water price of 0.120$/m^3 (=120$/ML). Table **5.1** indicates the percentage of irrigators able to pay for the reclaimed water at different prices, calculated from farming budget analysis.

Table 5.1 Capacity to pay expressed as $/ML = 10^{-3} $/m^3 *(source: DSDI, 2005)*

$/ML:	**$0**	**$75**	**$150**	**$225**	**$300**	**$375**	**$450**	**$525**	**$600**	**$675**
Lower Lockyer	89%	89%	89%	78%	67%	67%	56%	56%	44%	44%
Central Lockyer	90%	90%	90%	90%	80%	80%	80%	80%	70%	70%
Upper Lockyer	83%	83%	83%	83%	83%	83%	83%	75%	67%	58%

Government

The state government is responsible for regulating reclaimed water projects. In Queensland this is a high priority due to the severe droughts of the past decade and the rapid population increase (Stevens, 2006). Brisbane City Council proposed to limit

discharge of wastewater to Moreton Bay and achieve 100% sustainable recycling of water (Radcliffe, 2006). Several studies are conducted for the implementation of reclaimed water either for public use or agricultural irrigation. Guidelines for treating the water are set up by the Environmental Protection Agency (EPA) to ensure the safety of public health (EPA, 2005). Studies conducted by scientists or consultants cover issues such as impact on groundwater aquifers, public acceptance, willingness to pay by irrigators etc.
The public opinion and trust in the government (and science) is of importance when implementing a reclaimed water project (Radcliffe, 2006), although the method of gaining this trust and acceptance is argued. A referendum deems to be unnecessary and even problematic, as was the case in Toowoomba, where negative campaigning caused the rejection of a reclaimed water project even in times of drought (Fielding and Russell, 2008). A better approach would be to engage the community rather than persuade them to accept a certain reclaimed water project (Brisbane Institute, 2005). This is being done through for example open days at the Bundamba treatment plant to provide information on the treatment processes and give the community an opportunity for questions.

Industries and public sector
The public opinion on purchasing or consuming products irrigated with reclaimed water will assist predictions on potential market responses.
A study conducted by Fielding and Russell (2008) presented the perspectives of several food industries on purchasing crops irrigated with reclaimed water. It was found that the industries show confidence in the use of PRW for irrigation. The view on irrigation with other water treatment classes (e.g. Class A water) was not part of this study. Furthermore, it was mentioned that there could be negative impacts for the industries depending on consumer behaviour, but these effects can probably be managed (reflected in the statement shown in box **5.4**) It will be necessary to obtain and present scientific information on the implementation of PRW through a public awareness raising campaign.

Box 5.4

> *Industry representative:* "If it's down to consumer perspective it'll be ok. It will only be a problem if a competitor wants to make a big deal out of it".
> *(source: Fielding and Russell, 2008)*

A survey on the public opinion of city and country residents on reclaimed water, indicates a general confidence in eating food irrigated with reclaimed water when meeting quality standards (Baldwin, 2007). Over 80% of the city residents and 70% of the country residents were willing to eat the crops irrigated with reclaimed water. They strongly supported (90%) the payment of infrastructure to bring the reclaimed water to the Lockyer.
Although this survey gave valuable insights on consumer opinions, it would be useful to conduct an additional survey using contingent valuation, which is often used for investigating consumer behaviour. The consumer is presented with the choice between food irrigated with traditional water sources and food irrigated with reclaimed water, thus indicating their preference, which might be dependent on several factors (price, quality etc.) (Carson, 2000).

5.3. Lockyer Valley water demand

Annual crop water requirements for crops commonly grown in the Lockyer Valley were reported in a reclaimed water irrigation study (DNR, 1998). For vegetables and fruits values were 3,000 to 4 ,000 m^3/ha (= 3 to 4 ML/ha). Lucerne has a high water requirement of 6,000 m³/ha (=6ML/ha) and grain crops required 3,000 m³/ha (=3ML/ha) of water. Lucerne is grown year round, whilst several vegetables are either grown in the summer or in the winter as shown in table **5.2**. The survey conducted by DSDI (2005) mentioned in section 5.2 made an inventory of the crops grown in the Lockyer Valley. The most frequently grown crop was lucerne, cultivated by 50% of the respondents. An overview of the results can be found in annex C.

Table 5.2 Supply capability chart for the Lockyer Valley (source: DPI, 2010)

	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Beans (proc)						x	x	x	x	x	x										x	x	x	x
Beans (fresh)					x	x	x	x													x	x	x	x
Beetroot (proc)									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Broccoli										x	x	x	x	x	x	x	x	x	x	x	x			
Cabbage										x	x	x	x	x	x	x	x	x	x	x	x			
Capsicum	x	x	x	x	x	x	x	x															x	x
Carrots (proc)																	x	x	x	x	x	x		
Carrots (fresh)													x	x	x	x	x	x	x	x	x	x		
Cauliflower										x	x	x	x	x	x	x	x	x	x					
Celery									x	x	x	x	x	x	x	x	x	x	x	x				
Chinese Cabbage									x	x	x	x	x	x	x	x	x	x						
Garlic																		x	x	x	x	x		
Lettuce								x	x	x	x	x	x	x	x	x	x	x	x	x				
Onion																x	x	x	x	x	x	x	x	
Peas (proc)																	x	x	x	x				
Potato										x	x	x	x					x	x	x	x	x	x	
Pumpkin Jarrahdale	x	x							x	x	x	x												x
Pumpkin Jap			x	x	x	x			x	x	x	x												
Sweet Corn (proc)	x	x	x	x	x																			x
Sweet Corn (fresh)	x	x	x	x	x	x	x	x	x												x	x	x	x
Tomato	x	x	x	x	x	x	x	x													x	x	x	x
Sweet Potato						x	x																	
Watermelon	x	x	x																					x

6. Irrigator interviews

Interviews were conducted with Lockyer Valley irrigators, gaining a better understanding of their relation to a reclaimed water irrigation system and underlying views, needs and desires. The results of the interviews are presented in section 6.1 on the current farming system and section 6.2 on the considerations of the irrigator for future options in the case of irrigation with reclaimed water.

6.1. Current farming systems

Several aspects on the current farming system were questioned in the interview to gain a better insight in the farming practices. An overview of the answers is presented in table **6.1**. As a mere minority of the irrigators (irrigators 1 and 2) have conducted and archived field measurements, the information provided was limited. Especially figures on water use and salinity were inaccurate in a few cases.
General information about the farm location, size and soil was acquired. A map indicating the locations of the farms is found in figure **6.1**. All farms were only irrigating a part of their farm due to limited water availability. The irrigated area indicated by the irrigators was mainly the area under irrigation during an average year. In the several drought years of the past decade, irrigation was frequently not possible for some irrigators. The geology of the farm location was determined with the geology map in annex D. Irrigators 1 and 5 have problems with saline irrigation water, although for the fruit tree irrigator (5) this is less harmful for it is located on a sandy loam soil and fruit trees are more salt tolerant (DERM, 2009). Irrigator 1 will have more trouble being on a heavy clay soil and cultivating sensitive vegetable crops (DERM, 2009). The most common irrigation method was the use of sprinkler irrigation as it is efficient and distributes the irrigation water uniformly (Hill *et al.*, 2000).

Table 6.1 Overview current farming systems of 6 farms in the Lockyer Valley

	Irrigator 1	Irrigator 2	Irrigator 3	Irrigator 4	Irrigator 5	Irrigator 6
Total area [ha]	573	400	60.7	35	47	315
Area farmed [ha]	448	168	40.5	23	27	315
Area irrigated [ha]	404	46	20.2	19	19	113
Irrigated/farmed [%]	90.2	27.4	49.9	82.6	70.4	35.9
Area not farmed	diary cattle and dams	beef cattle	dams and buildings	cattle	bush and house	-
Soil type	Black alluvial self cracking clay	Sandy Loam	Sandy Loam	Alluvial	Sandy Loam	sandy loam and heavy black
Geology	Alluvium	Sandstone	Sandstone	Alluvium	Alluvium	Alluvium
FARMING SYSTEM						
Crops	vegetable crops, wheat, lucerne, sunflower, sorghum	turf: green and blue couch	turf: green couch and tropika	sorghum, oats, lucerne	stonefruit, persimmons, figs	vegetable crops, water melons, grains
Water use [10^3?m^3/a]	1000	276	81	50	80	?
Irrigation method	lateral move boom, hand sprinklers	traveller, k-line, centre pivots	hand-move, booms, guns	hand line 10m. sprinklers	micro sprinklers, inline drippers	boom and solid set sprinklers
Source of water	surface water	surface and ground water	ground water	bore water	ground water	runoff collection, groundwater
Salinity [ppm]	2450	300	150	300	1700 - 2000	No problems
Irrigation efficiency [%]	85 - 95	85 - 95	No idea	75 - 85	85 - 100	85 - 95
On-farm storage [10^3 ?m^3]	900 + 1000	130 + 30	120 + 120	5	0.14	140 + 18 + 9 + 9 + 5
Dam allocation [10^3?m^3/a]	150	200	-	-	-	-
Fertilizer application [kgN/ha]	100	100	3 to 4x yearly manure	none	10 to 75 (crop specific)	1 to 6 bags/acre (crop specific)

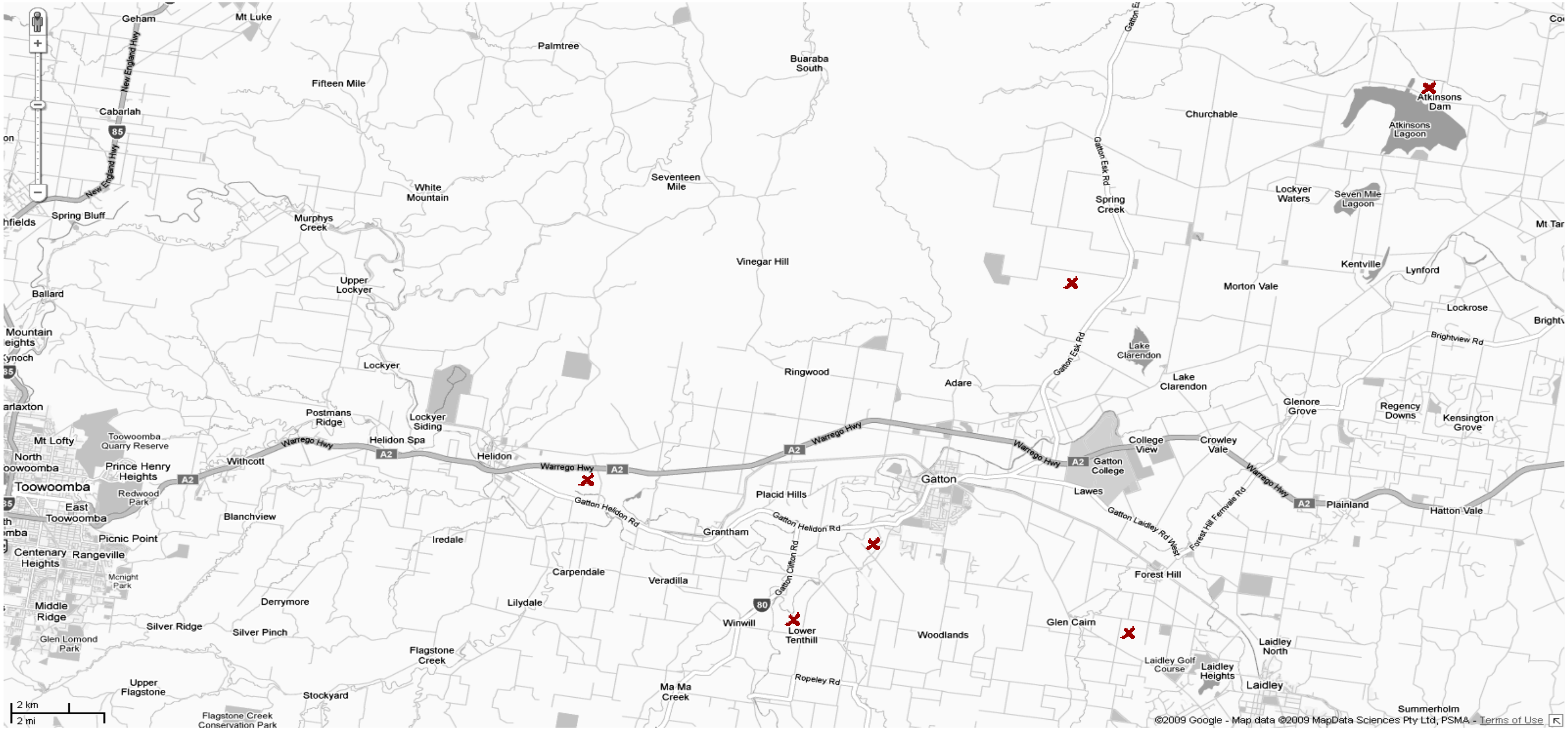


Figure 6.1 Location of the participating Lockyer Valley irrigators indicated with a x

6.2. Future options with reclaimed water irrigation

During the interviews irrigators indicated the changes they would consider if reclaimed water becomes available for irrigation. A list of suggestions was discussed, which was prepared beforehand according to experiences recorded in literature (see chapter 2 section 3). Irrigators also came with novel or more specific ideas and an indication of maximum water price and desired allocation. The results are found in table **6.2**.

Table 6.2 Irrigators' views on future possibilities in the case of irrigation with reclaimed water

	Irrigator 1	Irrigator 2	Irrigator 3	Irrigator 4	Irrigator 5	Irrigator 6
FUTURE OPTIONS						
Expansion irrgated area	yes	yes	yes	yes	yes	yes
Increase area owned	no	no		no	maybe	
Increase cropping rotation	yes	yes	yes	no	-	yes
Change crop	yes	yes	yes	no	yes	no
Change irrigation method	yes	yes	no	no	yes	no
Invest in irrigation infrastructure	yes	yes	yes	yes	yes	no
Blending of water	yes	-	no	no	maybe	yes
Stop using bore hole	-	yes	yes	maybe	no	no
Change in fertiliser control	no	yes	no	-	yes	yes
Enter long term contract	yes	no		maybe	yes	
Water price [$/10³ ?m³]	200	200 - 300	300	200	500	200
Allocation [10³ ?m³]	2000	1000	300 - 400		400	

The main preference of all irrigators was to expand their irrigated area. The land currently farmed is sometimes partly or not irrigated. When reclaimed water becomes available these areas can be irrigated to fulfil crop water requirements. This change will require investment in irrigation infrastructure as the irrigation practices are intensified. Furthermore, investment in infrastructure is sometimes indicated because the irrigator would prefer to change to a more efficient or suitable irrigation method.

Crop rotation will intensify at several farms, where expansion is possible. Currently fallow periods are necessary as growing two crops in a year is not possible. When water becomes available and optimal conditions for the crop are achieved, the crop will have shorter growing periods and rotation will become possible. The majority of the irrigators would think about adding new crops to their cropping system if reclaimed water becomes available due to the year-round security of water for irrigation. This could either be in the form of developing a tree orchard or introducing special turf grasses, which have higher market prices. The irrigators preferring to keep the same cropping system gave as their reason that these crops are familiar and have been grown there for generations.

As was indicated in table **6.1**, irrigators 1 and 5 have problems with high salinity levels in the irrigation water. It would be an interesting option for these irrigators to blend the water with the reclaimed water. When discussing this option with the irrigators, it was less of a discussion concerning quality issues but the price of the water would be the deciding factor. Additionally, the preference for class A water carrying nutrients was discussed with the irrigators. Yet again the irrigators would let price be the decision-making factor (see box **6.1**). If they would receive class A water, some irrigators would decide to reduce their fertilisation practices.

The majority of the irrigators suggested a maximum water price of 200 to 300 AU$/$10^3 \cdot m^3$ (= 1 ML). The fruit tree irrigator was the exception indicating a water price of 500$/$10^3 \cdot m^3$ (= 1 ML). The reason for this is failure of an orchard will cause loss for several years, therefore water security is essential. Water allocation preferences were suggested by the irrigators, although most irrigators would rather give an indication when exact water prices become clear.

Overall the impression was that the irrigators are eager to receive reclaimed water especially after the devastating droughts of the past decade (see box **6.2**).

Box 6.1

Irrigator: "Reliability and pricing is more important than the quality of the water."
(source: interview 16 December 2009)

Box 6.2

Irrigator: "Recycled water will give a guarantee for maximum production and reliability."
(source: interview 16 December 2009)

Irrigator: "I'll start digging the trenches for the pipes then."
(source: interview 17 December 2009)

7. FARM-SCALE MODEL SIMULATIONS

The results found from the irrigator interviews (in the previous chapter) were used for setting up case studies. These selection and a description of these case studies is presented in section 7.1. The case studies were simulated with APSIM and provided results on potential changes in the farming system. A division is made between impact on biophysical and productivity aspects. Biophysical effects are expressed with changes in the water balance, which is analysed in section 7.2. The productivity effects indicate changes in crop yield, as shown in section 7.3. In these sections comparisons are made between the results from the different case studies, analysing the suitable and profitable options. Some key points in section 7.4 will summarize the findings of the case studies. As a conclusion to the chapter a few remarks on the limitations of the modelling are mentioned in section 7.5.

7.1. Case studies

With the information from the interviews, scenarios were developed incorporating the different changes irrigators are considering if reclaimed water becomes available for irrigation. A selection of five case studies was generated with these scenarios. Most case studies are based on fields from farm 1 and 4, for APSIM support the modules for the crops grown on these farms. The selection of case studies focussed on variability and relevance for the Lockyer Valley. Lucerne and grain crops are frequently found throughout the region; and turf growing is an upcoming industry.

The reclaimed water scenarios either induces a change in irrigation practices or in cropping intensity, which were both indicated by the majority of the irrigators to be highly desired changes. For irrigation the critical available soil water (ASW) fraction was chosen to automatically initiate an irrigation event. These values were used to make changes in irrigation practices from partial irrigation to full irrigation. For full irrigation the value was chosen through an iterative process, thereby running simulations and decreasing water stress fractions. Through this process a balance was found between minimizing water stress and avoiding over-irrigation. This explains the different chosen values for critical ASW in the case studies.

Input values for simulations are found in annex E. Most values are based on the knowledge provided by the irrigators in the first interview or their adaptations in the second (evaluative) interview. This results in case studies, which resembles real-life farming systems.

Case study 1: Lucerne cutback

This case study with lucerne cutback is derived from the farming system on farm 4. The crop lucerne is harvested through cutting the crop and leaving a fraction for regrowth. For this case study the lucerne is cutback for a period of 4 years after sowing. The lucerne is removed and a new lucerne crop is started repeating the cycle, therefore providing an almost continuous crop cover. In the scenario of reclaimed water irrigation, changes occurs in the irrigation practices. In the current situation (benchmark) there is partial irrigation at 20% ASW; in scenario 1, full irrigation will occur at 80% ASW. An overview of the basic input data for this scenario is found in table **7.1**. A black vertosol soil is typical for the alluvial areas in the Lockyer Valley and is mainly clay to heavy clay.

Table 7.1 Scenarios for case study 1: Lucerne cutback

	Benchmark	Reclaimed water
Soil	Black Vertosol	Black Vertosol
Crop rotation	Lucerne cutback (4 years)	Lucerne cutback (4 years)
Irrigation	Partial irrigation: 20% ASW	Full irrigation: 80% ASW
Irrigation efficiency	75%	75%
Fertiliser	None	None

Case study 2: Mungbean lucerne rotation

The case study described and analysed in this section is taken from a field at farm 1. Mungbean and lucerne crops are grown in rotation, with mungbean being the summer crop. Lucerne is grown for a duration of 4 years with cutback and regrowth. After 4 years the lucerne crop is removed and a winter fallow period takes place for recovery of the soil. Two summer seasons with mungbeans are grown, after which the growing of lucerne crop is started again. In the current farming system there is dry land farming on this field due to limited water availability. If reclaimed water becomes available, full irrigation will be possible, which is simulated in scenario 1 at 80% ASW. Both scenarios are presented in table **7.2**.

Table 7.2 Scenarios for case study 2: Mungbean lucerne rotation

	Benchmark	Reclaimed water
Soil	Black Vertosol	Black Vertosol
Crop rotation	Mungbean – lucerne (4y) – WF – mungbean – WF	Mungbean – lucerne (4y) – WF – mungbean – WF
Irrigation	No irrigation	Irrigation: 80% ASW
Irrigation efficiency	n.a.	80%
Fertiliser	100 kg N/ha per year	100 kg N/ha per year

Case study 3: Sunflower wheat rotation

A field is taken from farm 1 growing sunflower and wheat in rotation. For this case study two interventions are studied for the situation of reclaimed water irrigation, resulting in two simulated scenarios. These scenarios are compared with the benchmark scenario. The current farming system (benchmark) only irrigates the summer crop, which is sunflower. There are also several fallow seasons, due to limited water availability. When reclaimed water becomes available both crops can be fully irrigated up to 80% of ASW, which is presented in scenario 1. Additionally, crop rotation can increase by avoiding any fallow periods. Scenario 2 shows this situation having both full irrigation and increased crop rotation. Table **7.3** indicates the different values taken for the basic input parameters.

Table 7.3 Scenarios for case study 3: sunflower wheat rotation

	Benchmark	Reclaimed water 1	Reclaimed water 2
Soil	Black Vertosol	Black Vertosol	Black Vertosol
Crop rotation	WF – sunflower – wheat – SF – wheat - sunflower	WF – sunflower – wheat – SF – wheat – sunflower	Sunflower – wheat – sunflower - wheat
Irrigation	Sunflower: 20% ASW Wheat: no irrigation	Sunflower: 70 % Wheat: 70%	Sunflower: 70% ASW Wheat: 70% ASW
Irrigation efficiency	80%	80%	80%
Fertiliser	100 kg N/ha per year		100 kg N/ha per year

Case study 4: Sorghum oats rotation

On farm 4 the irrigator grows sorghum in rotation with oats, with sorghum being the summer crop and oats cultivated in the winter. This field is used for deriving more information on fodder crops and changes in the case of reclaimed water irrigation. Currently irrigation is limited to the sowing periods of sorghum. During the rest of the year dry land farming is practised. It is projected that in the case of reclaimed water irrigation, full irrigation will become possible. The simulations of scenario 1 cover this situation with full irrigation at 80% ASW. These scenarios are presented in table **7.4**.

Table 7.4 Scenarios for case study 4: sorghum oats rotation

	Benchmark	Reclaimed water
Soil	Black Vertosol	Black Vertosol
Crop rotation	Sorghum – oats	Sorghum - oats
Irrigation	Sorghum: irrigation at sowing Oats: no irrigation	Full Irrigation: 80% ASW
Irrigation efficiency	75%	75%
Fertiliser	None	None

Case study 5: Turf cutback

This case study is chosen from the two turf-growing farms. The information used in this case study is from farm 2, which is the larger farm of the two. The farm is located on a different soil type namely sandy loam. Turf growing uses the same principle as lucerne, namely cutting back the crop at harvest and letting the crop regrow. After 10 years the turf is removed and a new turf crop is sown. Partial irrigation is practised currently due to limited water availability. When irrigation water can be secured through reclaimed water, full irrigation becomes possible. An overview of basic input parameters for each scenario is shown in table **7.5**.

Table 7.5 Scenarios for case study 5: turf cutback

	Benchmark	Recycled water
Soil	Sandy loam	Sandy loam
Crop rotation	Turf cutback (10years)	Turf cutback (10years)
Irrigation	Partial irrigation: 15% ASW	Full irrigation: 80% ASW
Irrigation efficiency	80%	80%
Fertiliser	100 kg N/ha	100 kg N/ha

7.2. Biophysical effects

It is chosen to present the biophysical aspects with water balances. The different components are expressed in 1 mm (= 10 m^3/ha); results for each case study are found in table **7.6**. These values are averages for each component during the 40 year simulation period. Additionally for each component the percentage of change is indicated comparing the benchmark scenario with the reclaimed water (RW) irrigation scenario. For an improved insight on the benefits of reclaimed water irrigation, each output component is expressed as percentage of increased water input: $\frac{\Delta \text{ output [mm]}}{\Delta \text{ input [mm]}} \times 100\%$

The irrigation component, on the input side of the water balance, varied due to the different irrigation practices in each scenario. The highest values were found for lucerne and turf, which was coherent with the irrigators' expectations, for these crops have a relatively high water demand.

On the output side of the water balance, the soil evaporation and plant uptake components are the largest in nearly all case studies with the exception of case study 4 with a sorghum oats rotation. This case study shows a relatively large value for drainage. The drainage component in case study 5 for turf was also relatively high. This can be explained by the shallow rooting system of turf in combination with the sandy loam soil at that location. The sandy loam soil typically has high hydraulic conductivity, therefore less water is retained in the root zone and will be lost to drainage. Both case studies with lucerne indicate low values for drainage, which is partly due to continuous crop cover especially in the first case study. Additionally the irrigator mentioned that lucerne is a good water consuming crop due to a deep rooting system. Values found for soil evaporation were high, in some case studies higher than plant uptake. Similar water balances were found in a farm-scale study located in the Murray-Darling Basin (Keating *et al.*, 2002). Soil evaporation values for certain crop types were higher, for example in the sunflower rotation, due to limited crop cover during irrigation (FAO, 1998). Average values for the change in soil water indicated that no relevant change during the simulation period, was found in the moisture of the soil in the root zone.

From an irrigators' perspective, maximum plant uptake is desired and soil evaporation, runoff and drainage are losses. Differences between case studies were found in the beneficial use of the increased irrigation water. In case study 2 the lowest value of 20% for relative soil evaporation was found; and a high plant uptake of 66% indicated increased benefits for the plant. This case study has a benchmark scenario with dry land farming, which might explain the results. Case study 3 with sunflower wheat rotation indicates that increasing crop intensity was more effective resulting in a decrease of drainage, due to the change in crop cover. Comparing the two case studies with lucerne (case study 1 and 2), the continuous crop cover case study (1) surprisingly shows higher relative losses to evaporation. This indicates that the uptake of water decreases with the amount of irrigation water applied. Case study 2 compares dry land farming with full irrigation, therefore the plant uptake could increase more.

Table 7.6 Overview results water balance components for 5 case studies

		IN		*OUT*				**Δ**
Case study	**Scenario**	**Rain [mm]**	**Irrigation [mm]**	**Soil evaporation [mm]**	**Runoff [mm]**	**Drainage [mm]**	**Plant uptake [mm]**	**Soil water [mm]**
1. Lucerne cutback	Benchmark: partial irrigation	758	289	-479	-56	-3	-508	<1
	RW 1: full irrigation	758	776	-774	-81	-11	-668	<1
	Change [%]		*169%*	*62%*	*43%*	*239%*	*31%*	
	Relative to input increase [%]			*61%*	*5%*	*2%*	*33%*	
2. Mungbean lucerne rotation	Benchmark: no irrigation	758	0	-402	-61	-19	-276	<1
	RW 1: full irrigation	758	460	-493	-78	-63	-582	<1
	Change [%]			*23%*	*29%*	*226%*	*111%*	
	Relative to input increase [%]			*20%*	*4%*	*10%*	*66%*	
3. Sunflower wheat rotation	Benchmark: partial irrigation	758	76	-408	-77	-63	-284	'1
	RW 1: full irrigation	758	276	-504	-94	-91	-341	<2
	Change [%]		*263%*	*24%*	*23%*	*45%*	*20%*	
	Relative to input increase [%]			*48%*	*9%*	*15%*	*29%*	
	RW 2: full rotation	758	361	-508	-89	-53	-466	<2
	Change [%]		*375%*	*25%*	*16%*	*-16%*	*64%*	
	Relative to input increase [%]			*35%*	*4%*	*-3%*	*64%*	
4. Sorghum oats rotation	Benchmark: partial irrigation	758	56	-346	-45	-206	-211	<5
	RW 1: full irrigation	758	219	-385	-51	-263	-273	<4
	Change [%]		*295%*	*11%*	*13%*	*28%*	*29%*	
	Relative to input increase [%]			*24%*	*4%*	*35%*	*34%*	
5. Turf cutback	Benchmark: partial irrigation	758	243	-443	-44	-100	-414	<1
	RW 1: full irrigation	758	816	-698	-56	-181	-638	<1
	Change [%]		*237%*	*58%*	*28%*	*82%*	*54%*	
	Relative to input increase [%]			*44%*	*2%*	*14%*	*39%*	

The graphs presented in figures **7.1** to **7.5** indicate the water balance components and the year-to-year variability for each component, shown as the standard deviation (STD). In general these results show large variability in the input components: rain and irrigation. Although less variability occurs in the output components, indicating that the input component (either rain or irrigation) does not influence output variability.
The variability for soil water change shows that part of the soils' water holding capacity is used. This water holding capacity is less for sandy loam soils in case study 5 (figure **7.5**) compared to the heavy clay soils in the other case studies.
Remarkably high values were found for the variability in plant uptake in case study 2 (mungbean lucerne rotation) shown in figure **7.2**. The crop rotation with crops of different characteristics and water needs, may explain the variability in year-to-year averages. Mungbean will take up less water than the lucerne.
Figure **7.5** shows that an average irrigation allocation is required of 800 mm/a (=8ML/a), which was the same amount considered by the irrigator. This indicates that the module used to simulate turf, gave water usage values which are coherent with actual irrigator experience.

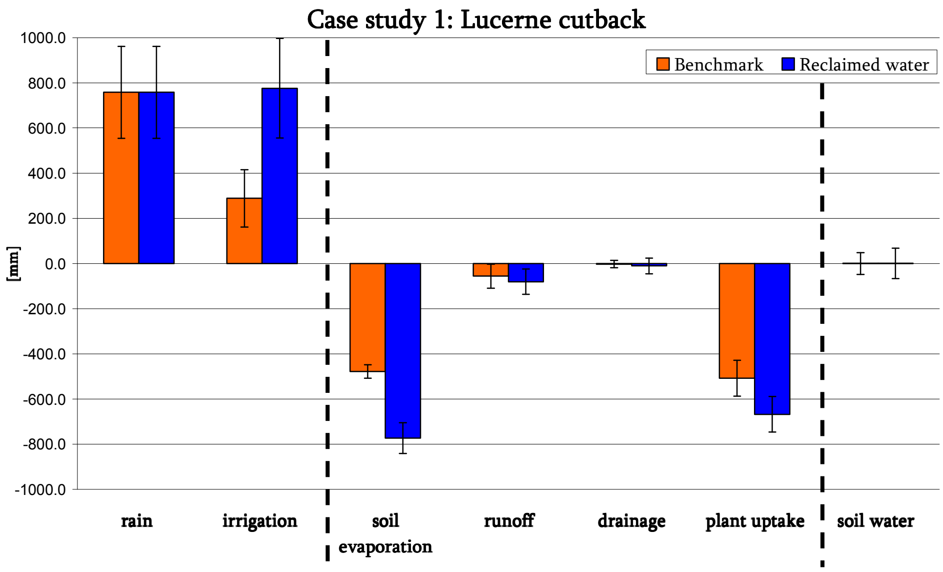


Figure 7.1

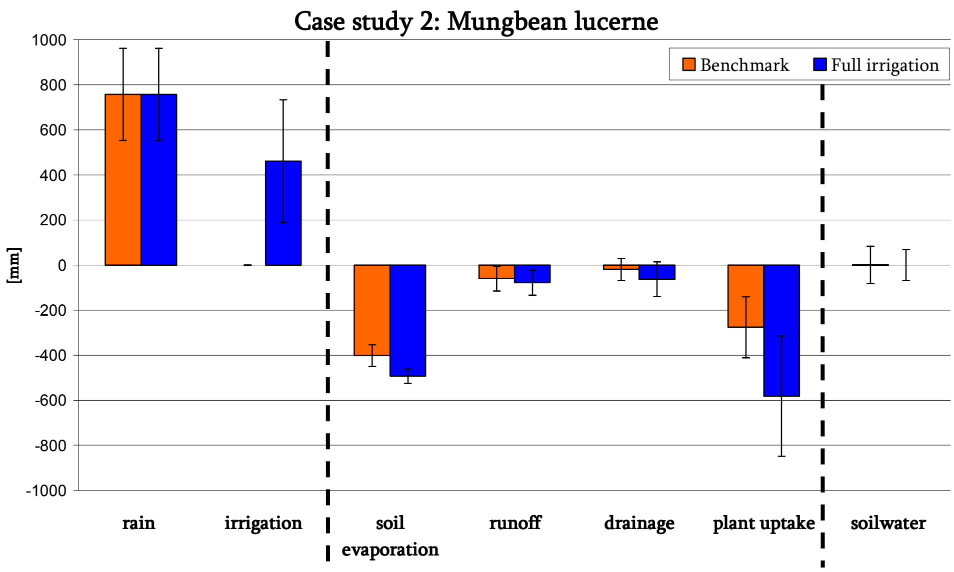


Figure 7.2

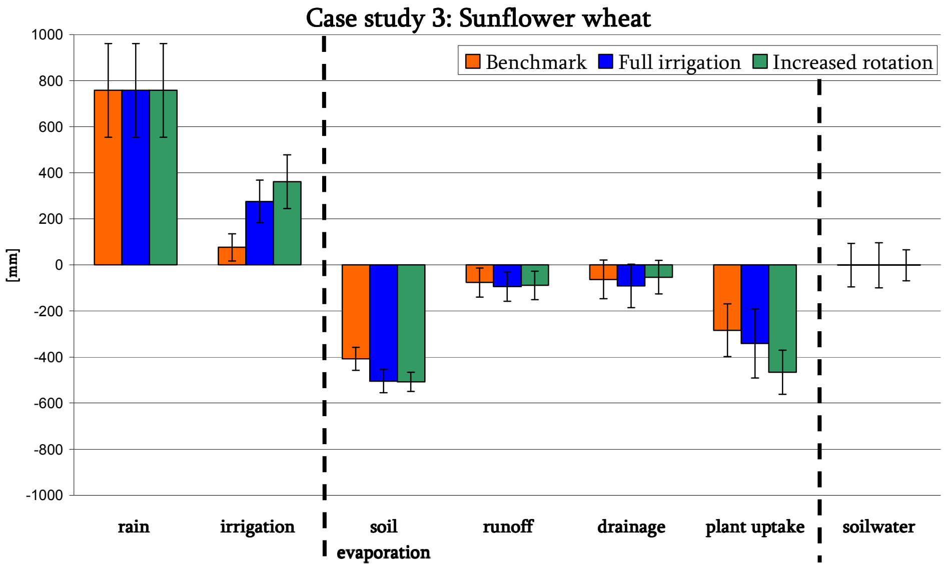


Figure 7.3

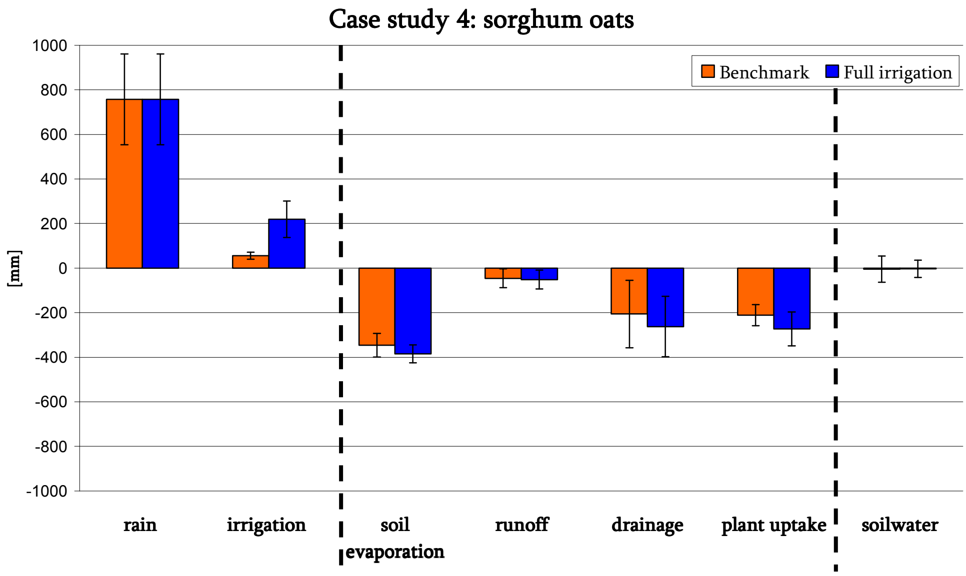


Figure 7.4

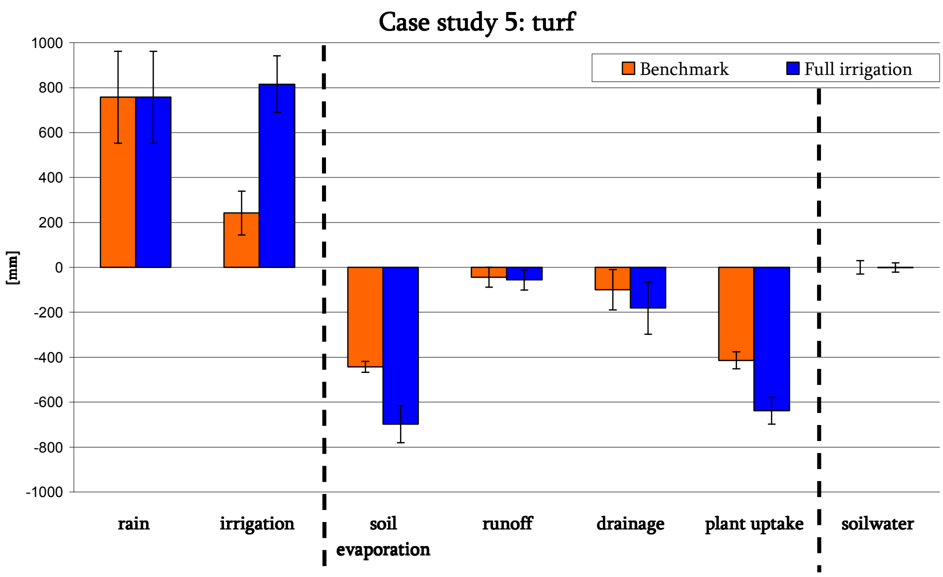


Figure 7.5

7.3. Productivity effects

Crop productivity is usually expressed as harvestable yield in kg/ha as most crops are sold on the market for a price per mass (e.g. tonne or kg.). Turf is the exception being sold for a price per area (e.g. m^2) of turf. APSIM expresses yield with kg/ha for all simulated crops. Therefore the values for turf are only an indication of the change in productivity. Results are presented in table **7.7** showing sum and average yields during the 40 year simulation period and the year-to-year variation expressed as the standard deviation (STD) and the coefficient of variance (CV). Additionally changes between the scenarios are indicated with a percentage. Due to the rotation pattern of case studies 2 and 3, where in some years only one crop is grown, it is chosen to not present the STD and CV. These gave high values, because the crop yield was zero in some years.

A major change in productivity was found for lucerne in case study 2, which doubled due to the change in irrigation. This increase is larger than in case study 1, which started with partial irrigation in contrast to case study 2 with dry land lucerne in the benchmark. Apparently, dry land lucerne gives much lower yields compared to either partial or full irrigation. The value for lucerne yield was higher in case study 1, where more irrigation water was applied. The values for mungbeans show an increase in yield although this was less than the irrigator expected. During the interview he mentioned that mungbean yield may double or even more, when irrigated. This is not perceived in the results of this case study probably due to the chosen crop rotation. Results for case study 3, with 2 different reclaimed water scenarios, showed that wheat yield increase under scenario 1 was negligible. This indicates that wheat is less responsive to irrigation increase, when partial irrigation is already practised. Increasing crop rotation did give a larger productivity as more wheat crops can be grown. Sunflower yields show an increase under each intervention, with the crop rotation being slightly more effective. Turf yield increased with 49%, which is lower than the irrigators' expectations. Currently they have 1 to 1.5 cuts a year, which in the case of increased irrigation could expand to 2 to 3 cuts a year. This is a doubling of the yield, which is not found in the modelling results, probably due to the output variable used for expressing harvestable yield.

Values on year-to-year variation provided the irrigator with useful information, which they can use for making choices on their farm. Irrigators are less keen on large yield ranges as they would like to secure their predicted yields and thus profits each year. If there is large variability for certain crops, measures can be taken to combine different crops and thus have an overall security of profits in a year.
The CV for both sorghum and oats in case study 4 had high values even in the case of full irrigation. For sorghum the CV did decrease slightly, but remained high. It would therefore be better for the irrigator to rotate with different crops, which can provide reliability on predicted yields. For lucerne in case study 1 the variation decreased in the case of full irrigation. This is an important advantage for the irrigator to change to reclaimed water irrigation.

Table 7.7 Overview results of average and sum crop yields for 5 case studies

Case study	Scenario	Crop	Yield sum [kg/ha]	Yield average [kg/ha.a]	STD [kg/ha]	CV [-]
1. Lucerne cutback	Benchmark: partial irrigation	Lucerne	662,538	16,563	3,300	0.20
	RW 1: full irrigation		837,165	20,929	2,826	0.14
	Change [%]		*26%*			*-32%*
2. Mungbean lucerne rotation	Benchmark: no irrigation	Mungbean	165,507	4,138		
	RW 1: full irrigation		217,409	5,435		
	Change [%]		*31%*			
	Benchmark: no irrigation	Lucerne	310,144	7,754		
	RW 1: full irrigation		636,149	15,904		
	Change [%]		*105%*			
3. Sunflower wheat rotation	Benchmark: partial irrigation	Sunflower	659,922	16,498		
	RW 1: full irrigation		859,889	21,497		
	Change [%]		*30%*			
	RW 2: full rotation		1,170,597	29,265		
	Change [%]		*77%*			
	Benchmark: partial irrigation	Wheat	2,312,961	57,824		
	RW 1: full irrigation		2,331,953	58,299		
	Change [%]		*1%*			
	RW 2: full rotation		3,293,433	82,336		
	Change [%]		*42%*			
4. Sorghum oats rotation	Benchmark: partial irrigation	Sorghum	2,748,422	68,711	32,481	0.47
	RW 1: full irrigation		3,758,398	93,960	38,553	0.41
	Change [%]		*37%*			*-13%*
	Benchmark: partial irrigation	Oats	600,798	15,024	6,625	0.44
	RW 1: full irrigation		895,792	22,395	10,393	0.46
	Change [%]		*49%*			*5%*
5. Turf cutback	Benchmark: partial irrigation	Turf		13,483	1,335	0.10
	RW 1: full irrigation			20,089	1,441	0.07
	Change [%]			*49%*		*-28%*

7.4. Key points

A few key points can be drawn from the five case studies:

- In general the water balance gave large variability on the input side for rain and irrigation components. The major output components were in most cases soil evaporation and plant uptake. The values found for drainage were lowest in the case studies with lucerne and highest for the sorghum oats rotation. The change in soil water storage was negligible in all case studies. The variability in soil water storage was smallest for the sandy loam soil, indicating a limited soil water holding capacity compared to the heavy clay soils of the other case studies.
- The average irrigation allocation required ranged from 219 mm for the sorghum oats rotation to 816 mm for the turf irrigator. Both turf and lucerne are known for their high water requirements.
- A comparison was made between irrigation and cropping intensity in case study 3. Measures for increasing crop rotation was more effective resulting in relatively less soil evaporation losses and increased plant uptake.
- All crops indicated an increase in yield in the reclaimed water scenario. This increase was highest for the lucerne in the case of changing from dry land farming to full irrigation. Changing from partial irrigation to full irrigation had less effect on lucerne. Overall the yield increase ranged from 26% to 105% with both smallest and highest value being for lucerne.
- In some cases the year-to-year variability decreased in the scenario with reclaimed water, which would provides the irrigator with more reliable yield predictions. Yield values for sunflower showed a gradual increase at each intervention (full irrigation and crop rotation increase). For wheat the change in yield due to full irrigation was negligible, although crop intensification did increase the yield.

7.5. Model limitations

As was implied in chapter 4 section 4, modelling is a simplified manner of portraying real-life situations. It is a method of understanding the situation and being able to predict long-term effects (Meta Systems Inc., 1975). It is important to continuously be aware that models are a representation of a situation and is used as a decision-support tool (Pearson and Ison, 1997). Therefore the following section will indicate which real-life aspects were not incorporated in the model and thus limit the validity of the results. Several notes listed below, were taken from interviews with the irrigators as they have practical knowledge of farming systems.

- The irrigation method was not an input parameter. The model did not simulate differences in methods of applying the irrigation water. In practice the water flow and distribution is different. The choice of irrigation method will determine the amount of water, which infiltrates to the root zone.
- Intensity of rainfall is an important factor in tropical Queensland. A summer rainfall event will have a higher rainfall intensity than during the winter, when rain usually falls as drizzle. Rainfall intensity will influence the amount infiltrating to the root zone and the water lost to runoff. The model takes the total rainfall for a day and is therefore not covering the intensity rainfall at a more detailed level (such as every hour).

- The irrigators in this research study (and probably in the rest of the Lockyer Valley) did not make use of computer-automated irrigation. Therefore the irrigators themselves are the decision-makers in when to time the irrigation. One important factor for them is <u>weather predictions</u>. Irrigation will not take place when rainfall is predicted in the same week. This was not taken into account with the simulations, which might cause higher values for irrigation than in practice would be necessary.
- The model assumes <u>uniformity of soils</u>, although in practice this is not reasonable in real-life situations. Particularly for clay soils preferential flow is an important aspect to take into account. Cracks in the soil or local impermeable layers will influence the drainage component.
- The effect of <u>water quality</u> on crops and soil could not be simulated. High salinity levels decrease crop yields and will cause compaction of the soil. The model could simulate solute movement but reduction of crop productivity due to saline irrigation water was not possible with this specific model.

SECTION C : CONCLUSIONS

(source: photo Lockyer Valley, December 2009)

8. DISCUSSION

The relevance of results found from the irrigator interviews (stage 2) and model simulations (stage 3) is argued in this discussion, comparing it with the irrigation system as presented in stage 1. Missing knowledge and links can be distinguished with this information.

Several studies have been conducted in the Lockyer Valley focussing on an improved understanding of the irrigators, for example the study on willingness to pay (DSDI, 2005). Information was not collected, however, on the opinions irrigators have on implementing reclaimed water for irrigation. Through interviews with a diverse group of irrigators, this essential information was acquired. Preferences were indicated on changes to the farming system in the case of reclaimed water being available for irrigation. These changes can influence several parts of the irrigation system. For example the highly-preferred intervention of increasing irrigated area will require adaptations in the capacity of irrigation infrastructure. Moreover it can potentially affect the groundwater aquifers if drainage increases due to this change. The change of cropping systems may affect product supply to food industries and eventually consumers. The majority of the irrigators interviewed, indicated to change crops to higher value crops for example trees or luxury turf varieties. It is important to prevent overproduction of certain crops and scarcity of other crops (Hamilton *et al.*, 2005).
It should be noted that no statistical analysis was performed with the interview results due to the limited number of participants. Therefore conclusions drawn from these interviews are merely indicative of views mentioned by irrigators. Although the results already show that several differences exist between farming systems and that no farm can be the same. Moreover, when taking the personality of the irrigators into account, each farm should be treated individually. Only general assumptions can be made with these interviews, though results do give insight in the way the irrigators think and their main preferences.

The challenge of quantifying the benefits of reclaimed water irrigation in agriculture, has frequently been mentioned in studies. At farm level, it brings several challenges and uncertainties for the irrigator due to the novelty of reclaimed water irrigation for their farm (Brennan *et al.*, 2008). Model simulations in stage 3 provided irrigators with predictions on biophysical and productivity effects. Crop productivity increased with values above 25% up to doubling current yields. These results indicate potential profitability for the irrigators if reclaimed water irrigation is implemented. Moreover, a productivity increase ensures a better food security for South East Queensland.
Unfortunately crop modules were currently not available for vegetables and fruits, therefore these could not be simulated. Modules for potato, broccoli and lettuce are currently under development and may be used in future model simulations (Huth, 2009). It would be useful to do additional simulations for these vegetable crops for they are, together with lucerne and grain crops, the most commonly cultivated crops in the Lockyer Valley.

Introducing reclaimed water irrigation can potentially have an effect on drainage. The farm-scale model simulations indicated variable changes for drainage either increasing or decreasing depending on soil, crop type, and cropping pattern. An increase of drainage at farm level results in ground water recharge and can potentially influence ground water and solute movement in the catchment. These effects are relevant for determining the catchment outflow into the Brisbane river, which eventually influences the WTP at Mount Crosby.

The information on farming systems and irrigators' preferences focuses on a small part of the irrigation system. Although the contribution is valuable for improving the reclaimed water project in the Lockyer Valley, it is yet a limited part of the complex system.

9. CONCLUSIONS

The situation in the Lockyer Valley and South East Queensland region, where potentially reclaimed water can be introduced for irrigation, involves several different, multi-disciplinary issues and interrelationships. Due to this complexity, this study required taking a systems approach for analysing the situation and making research contributions. A response to the research question is given below, supported by the findings achieved.

Key issues playing a role in the reclaimed water irrigation system for Lockyer Valley are:

- The Western Corridor provides a pipeline that brings water close to the Lockyer Valley, thus reducing infrastructure costs
- Several infrastructure options for distributing the reclaimed water within the Lockyer Valley exist and are analysed for financial, environmental and social effects. Options currently considered are: aquifer recharge, reticulation and dam storage.
- Irrigators are eager to participate in on-going political negotiations.
- Lucerne (for fodder) is most commonly cultivated, followed by grain crops and vegetables.

Interviews with irrigators achieved insights on possible changes in their farming system, which they might consider if reclaimed water is available for irrigation. Preferences were given to expanding the irrigated area and increasing cropping intensity. The issue of water quality was considered to be dependent on the pricing of the reclaimed water.

Farm-scale model simulations found predictions of biophysical and productivity effects in a selection of five case studies consisting of farming systems with lucerne, grain crops, mungbeans and turf. It was found that the change from dry land farming to full irrigation gave the largest change in crop yield. Crop intensification was more effective in increasing plant water uptake and reducing evaporation losses when compared to increasing irrigation alone.

The results from the model simulations gave quantifiable benefits to reclaimed water irrigation, which is useful for the irrigators for making future decisions. The insights gained on the farming systems, irrigators opinions and preferences are a contribution to the information required for analysing the reclaimed water irrigation system. This information can indicate potential changes in irrigation practices and cropping systems in the Lockyer Valley, when reclaimed water becomes available.

Essentially, this research study has achieved an improved irrigator involvement in the planning process for using reclaimed water for irrigation in the Lockyer Valley.

10. RECOMMENDATIONS

The irrigation system is complex and extensive; for the introduction of reclaimed water, several areas remain uncertain, indicating the need for further investigation. A few suggestions are made, which would make a valuable continuation of this research.

- The crop modules for a number of vegetables are still in development. When finished these can be used for acquiring predictions on the impact reclaimed water irrigation will have on these different cropping systems.
- Additional simulations could be run to investigate the effect irrigation water quality might have, by varying the nutrient and salt content of the applied water. APSIM simulates solute movement, but does not limit crop growth due to high concentrations of nutrients or salts. Another model can be used, or crop values can be modified in APSIM using ground-based knowledge and verification before actual use.
- Conducting field experiments can verify the chosen input values and the plausibility of simulation results. The Lockyer Valley project is currently setting up field experiments to study effects on drainage and solute movement.
- Combining the results on predicted crop yields with market prices can give insight into the financial profitability (or loss) for the irrigator. Financial modelling can be used to indicate an average market price and the range for variation.
- The possibilities for using water from other WWTPs might also potentially reduce infrastructure and pumping costs. There are also benefits to using reclaimed water holding nutrients (i.e. Class A water), for valuable nutrients can be utilized by the crops. Moreover, fertiliser costs can be reduced for the irrigator.
- Continued irrigator involvement in the planning and implementation of reclaimed water is important. The opinion of the irrigators on certain issues, such as water distribution, will influence the success of implementing reclaimed water for irrigation in the Lockyer Valley.

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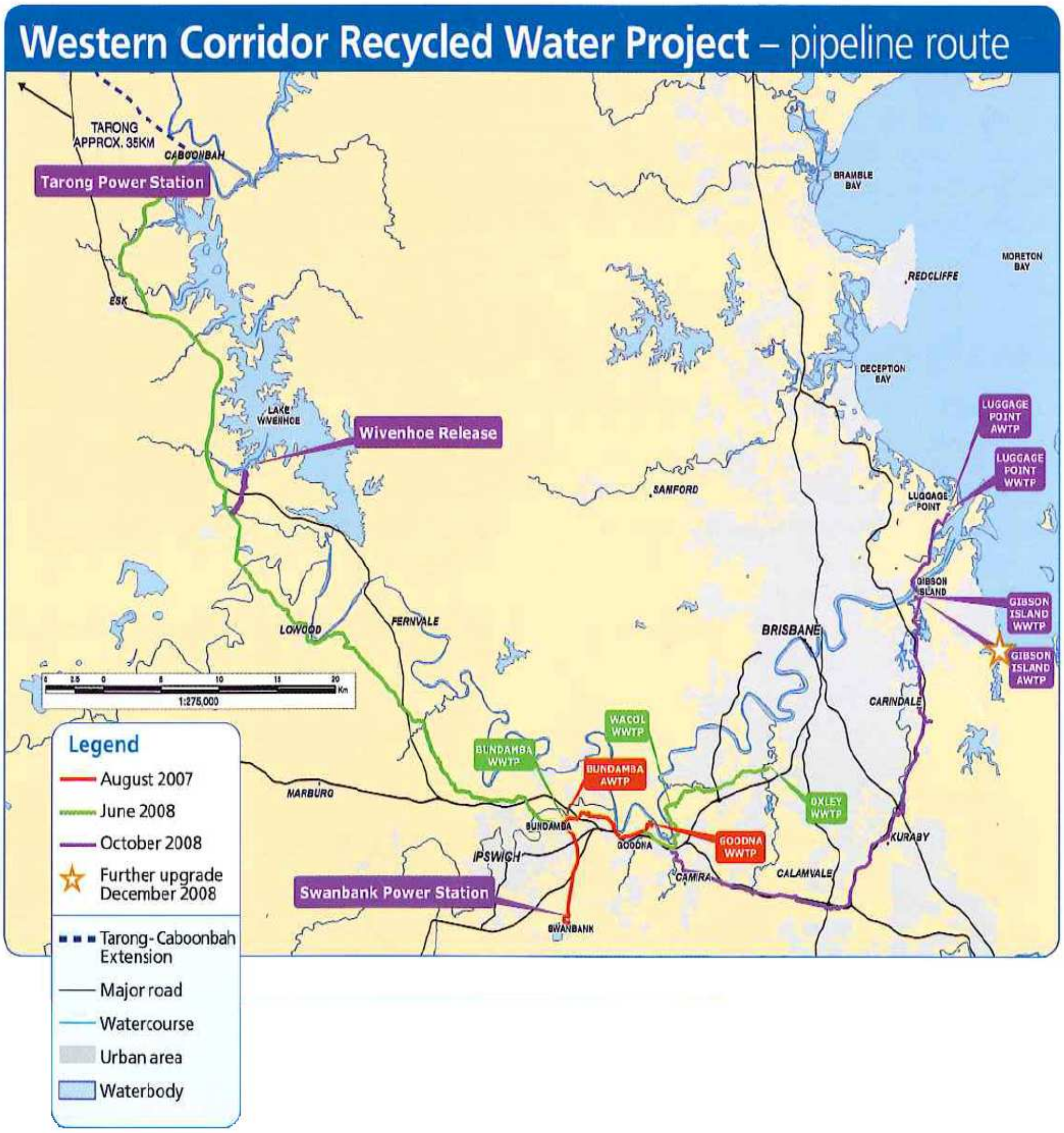
ANNEXES

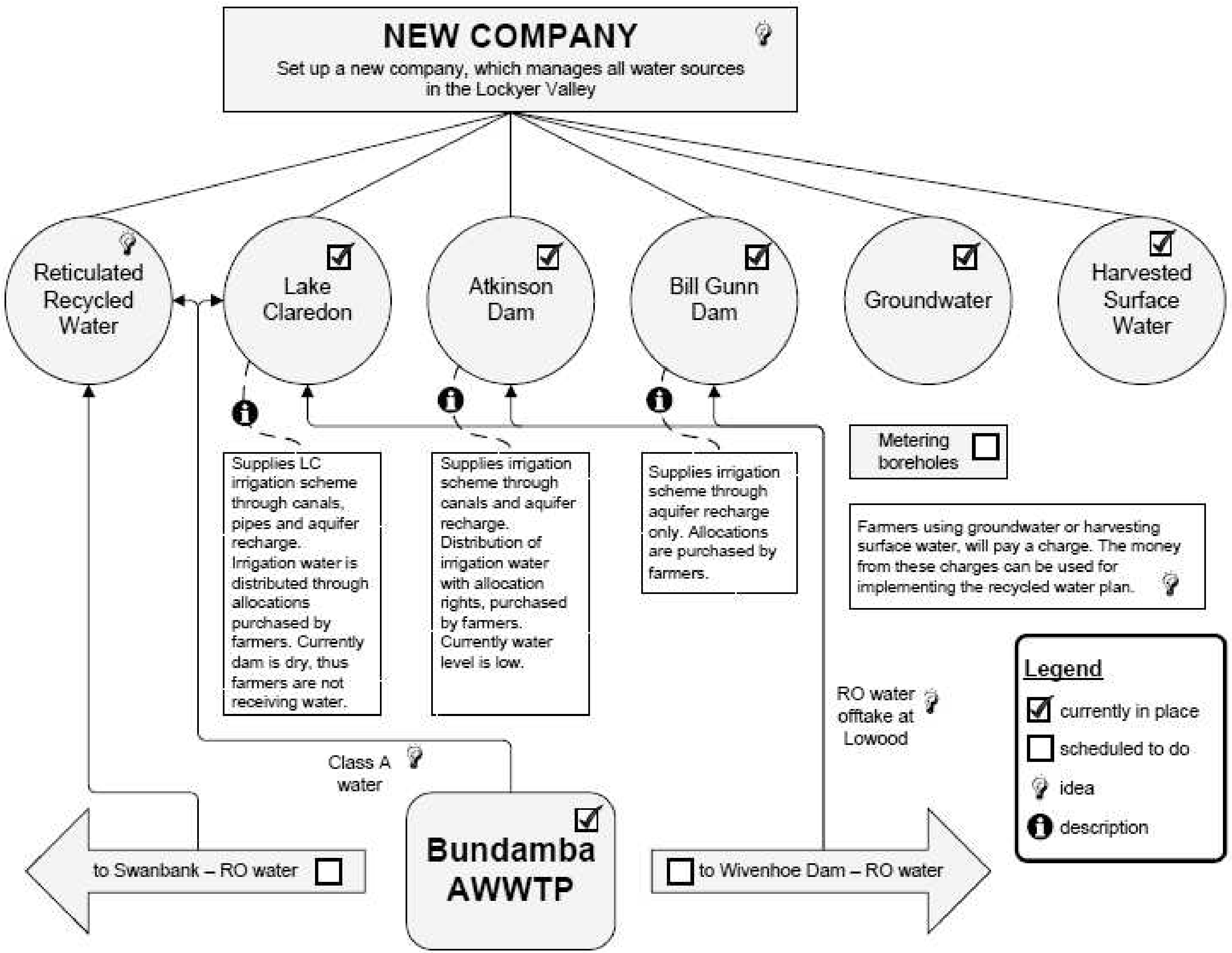
A. Western Corridor Recycled Water Project – WWTPs and pipelines



(source: DIP, 2008-II)

(source: DIP, 2008-III)

B. Proposed irrigation infrastructure for reclaimed water irrigation



C. Lockyer Valley crops

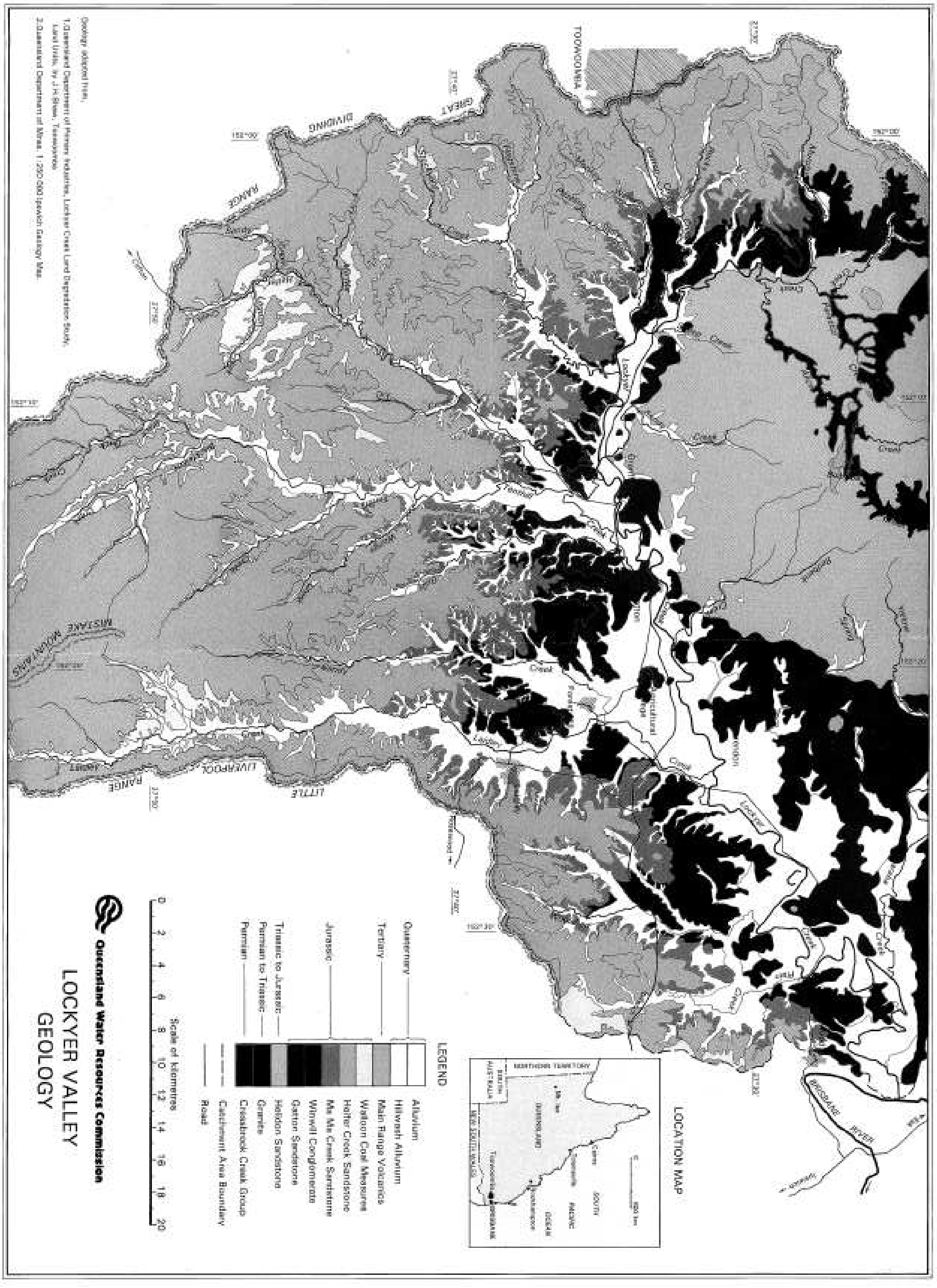
	% crop mentioned	Crop Size		Irrigation Status*		
		Total Hectares	Average Hectares	Fully Irrigated Hectares	Fully Non-irrigated Hectares	Partially Irrigated Hectares
Lucerne	50%	2267	16	2112	150	280
Barley	34%	1388	12	575	683	114
Grazing	29%	6036	66	132	4597	1009
Sorghum	28%	1414	16	361	826	154
Pumpkins	26%	867	10	720	70	61
Grass Hay	18%	627	10	237	326	28
Onions	15%	306	7	290	0	0
Broccoli	12%	1113	30	1028	0	0
Soybeans	12%	516	17	165	148	175
Wheat	11%	385	12	179	178	26
Maize	9%	307	13	226	49	8
Potatoes	9%	541	20	441	80	0
Beans	9%	855	31	727	1	0
Lettuce	9%	1028	40	1020	0	0
Millet	9%	283	11	174	105	0
Beetroot	8%	936	36	795	3	0
Sweet Corn	8%	1112	43	1028	0	0
Watermelons	8%	139	6	134	0	0
Cauliflower	7%	247	12	239	0	0
Cabbage	5%	137	10	136	1	0
Carrots	5%	332	20	311	0	0
Oats	5%	120	7	45	18	57
Rockmelons	3%	33	3	33	0	0
Capsicum	3%	48	5	48	0	0
Silverbeet	3%	37	4	24	0	0
Nectarines	3%	44	5	44	0	0
Forage Sorghum	3%	181	20	12	163	0
Sunflowers	2%	70	10	40	16	12
Adzuki Beans	2%	91	13	65	26	0

Onions Spring	2%	20	4	18	0	0
Shallots	2%	71	12	70	0	0
Rye Grass	2%	70	12	70	0	0
Avocadoes	2%	16	3.2	16	0	0
Navy Beans	2%	69	14	69	0	0
Sweet Potato	2%	4	2	4	0	0
Citrus	2%	11	2	11	0	0
Flowers	2%	24	8	0	24	0
Mangoes	2%	17	3	5	12	0
Peaches	2%	20	4	20	0	0
Tomatoes	2%	154	31	152	2	0
Turf	2%	376	94	376	0	0
Celery	1%	67	17	67	0	0
Olives	1%	9	2	6	3	0
Figs	0.9%	8	3	7	1	0
Parsley	0.6%	1	1	1	0	0

NB: The hectares reported in Irrigation Status may not add up to the Total Hectares column due to missing responses to this question. Base: All respondents (n=339)

(source DSDI, 2005)

D. Geological map Lockyer Valley



E. APSIM input data

Case study 1: lucerne cutback

GENERAL

Weather input	
met file	Gatton UQ Station

10 year simulation	
clock start	1/01/2000
clock end	31/12/2009

40 year simulation	
clock start	1/01/1970
clock end	31/12/2009

Soil	
soil name	Black Vertosol
site	Lawes, QLD
initial water [mm]	72
initial NO3 [kg/ha]	15
initial NH4 [kg/ha]	6

SOIL

						Lucerne			
Depth [cm]	**BD [g/cc]**	**SAT [mm/mm]**	**DUL [mm/mm]**	**AirDry [mm/mm]**	**LL15 [mm/mm]**	**LL [mm/mm]**	**PAWC [mm]**	**KL [-]**	**XF [-]**
0-15	1.32	0.47	0.41	0.13	0.26	0.26	22.5	0.1	1
15-30	1.30	0.48	0.43	0.21	0.26	0.26	25.5	0.1	1
30-60	1.23	0.51	0.46	0.26	0.26	0.28	54.0	0.1	1
60-90	1.27	0.49	0.44	0.26	0.26	0.27	51.0	0.1	1
90-120	1.37	0.45	0.40	0.25	0.25	0.26	42.0	0.1	1
120-150	1.35	0.46	0.41	0.26	0.26	0.27	42.0	0.1	1
150-180	1.35	0.46	0.38	0.26	0.26	0.27	33.0	0.1	1

BENCHMARK

Paddock	
Area [ha]	16
Crop	Lucerne

Sowing start	1-Apr
Sowing end	15-Jun
Cultivar	aquarius
Spacing [plants/m2]	180
Row [mm]	250
Depth [mm[	20
Amount rainfall [mm]	10
Rainfall days [days]	2
Minimum ASW [mm]	50

Cutback	
# years inley	4
Harvest heigh crop [mm]	50
Fraction removed [0-1]	0.95
Date crop removed	25-Mar

Surface Organic Matter	
Type	lucerne
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Depth ASW calculated [mm]	200
Minimum Fraction ASW [0-1]	0.2
Irrigation efficiency [0-1]	0.75

SCENARIO 1 - Full irrigation

Paddock	
Area [ha]	16
Crop	Lucerne

Sowing start	1-Apr
Sowing end	15-Jun
Cultivar	aquarius
Spacing [plants/m2]	180
Row [mm]	250
Depth [mm[	20
Amount rainfall [mm]	10
Rainfall days [days]	2
Minimum ASW [mm]	50

Cutback	
# years inley	4
Harvest heigh crop [mm]	50
Fraction removed [0-1]	0.95
Date crop removed	25-Mar

Surface Organic Matter	
Type	lucerne
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Depth ASW calculated [mm]	200
Minimum Fraction ASW [0-1]	0.8
Irrigation efficiency [0-1]	0.75

Case study 2: mungbean lucerne rotation

GENERAL

Weather input	
met file	Gatton UQ Station

10 year simulation	
clock start	1/01/2000
clock end	31/12/2009

40 year simulation	
clock start	1/01/1970
clock end	31/12/2009

Soil	
soil name	Black Vertosol
site	Lawes, QLD
initial water [mm]	52
initial NO3 [kg/ha]	20
initial NH4 [kg/ha]	7

SOIL

						Mungbean				*Lucerne*			
Depth [cm]	**BD [g/cc]**	**SAT [mm/mm]**	**DUL [mm/mm]**	**AirDry [mm/mm]**	**LL15 [mm/mm]**	**LL [mm/mm]**	**PAWC [mm]**	**KL [-]**	**XF [-]**	**LL [mm/mm]**	**PAWC [mm]**	**KL [-]**	**XF [-]**
0-15	1.32	0.47	0.41	0.13	0.26	0.26	22.5	0.1	1	0.26	22.5	0	1
15-30	1.30	0.48	0.43	0.21	0.26	0.26	25.5	0.1	1	0.26	25.5	0	1
30-60	1.23	0.51	0.46	0.26	0.26	0.36	30.0	0.1	1	0.28	54.0	0	1
60-90	1.27	0.49	0.44	0.26	0.26	0.33	33.0	0.0	1	0.27	51.0	0	1
90-120	1.37	0.45	0.40	0.25	0.25	0.34	18.0	0.0	1	0.26	42.0	0	1
120-150	1.35	0.46	0.41	0.26	0.26	0.35	18.0	0.0	1	0.27	42.0	0	1
150-180	1.35	0.46	0.38	0.26	0.26	0.35	9.0	0.0	1	0.27	33.0	0	1

BENCHMARK

Paddock		
Name	College	
Area [ha]	16.2	
Crops	Mungbean	
	Lucerne	

	Mungbean	*Lucrne*
Sowing start	1-Oct	1-Apr
Sowing end	31-Oct	1-Jun
Cultivar	berken	aquarius
Spacing [plants/m2]	35	180
Row [mm]	750	250
Depth [mm[	40	20
Amount rainfall [mm]	25	50
Rainfall days [days]	1	2
Minimum ASW [mm]	100	100

Lucerne Cutback	
# years inley	4
Harvest heigh crop [mm]	50
Fraction removed [0-1]	0.95
Date crop removed	25-Mar

Rotation	
Sequence	mungbean - lucerne - wf - mungbean - wf
Winter fallow end	1-Sep

Surface Organic Matter	
Type	lucerne
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Fertilizer	
Frequency [x per year]	4
Amount [kg/ha]	10 to 20
Type	urea_N

SCENARIO 1 - Full irrigation

Paddock		
Name	College	
Area [ha]	16.2	
Crops	Mungbean	
	Lucerne	

	Mungbean	*Lucrne*
Sowing start	1-Oct	1-Apr
Sowing end	31-Oct	1-Jun
Cultivar	berken	aquarius
Spacing [plants/m2]	35	180
Row [mm]	750	250
Depth [mm[	40	20
Amount rainfall [mm]	25	50
Rainfall days [days]	1	2
Minimum ASW [mm]	100	100

Lucerne Cutback	
# years inley	4
Harvest heigh crop [mm]	50
Fraction removed [0-1]	0.95
Date crop removed	25-Mar

Rotation	
Sequence	mungbean - lucerne - wf - mungbean - wf
Winter fallow end	1-Sep

Surface Organic Matter	
Type	lucerne
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Depth ASW calculated [mm]	600
Minimum Fraction ASW [0-1]	0.8
Irrigation efficiency [0-1]	0.8

Fertilizer	
Frequency [x per year]	4
Amount [kg/ha]	10 to 20
Type	urea_N

Case study 3: sunflower wheat rotation

GENERAL

Weather input	
met file	Gatton UQ Station

10 year simulation	
clock start	1/01/2000
clock end	31/12/2009

40 year simulation	
clock start	1/01/1970
clock end	31/12/2009

Soil	
soil name	Black Vertosol
site	Lawes, QLD
initial water [mm]	52
initial NO3 [kg/ha]	20
initial NH4 [kg/ha]	7

SOIL

						Wheat				*Sunflower*			
Depth [cm]	**BD [g/cc]**	**SAT [mm/mm]**	**DUL [mm/mm]**	**AirDry [mm/mm]**	**LL15 [mm/mm]**	**LL [mm/mm]**	**PAWC [mm]**	**KL [-]**	**XF [-]**	**LL [mm/mm]**	**PAWC [mm]**	**KL [-]**	**XF [-]**
0-15	1.32	0.47	0.41	0.13	0.26	0.26	22.5	0.1	1	0.26	22.5	0	1
15-30	1.30	0.48	0.43	0.21	0.26	0.26	25.5	0.1	1	0.26	25.5	0	1
30-60	1.23	0.51	0.46	0.26	0.26	0.26	60.0	0.1	1	0.28	54.0	0	1
60-90	1.27	0.49	0.44	0.26	0.26	0.26	54.0	0.0	1	0.29	45.0	0	1
90-120	1.37	0.45	0.40	0.25	0.25	0.25	45.0	0.0	1	0.28	36.0	0	1
120-150	1.35	0.46	0.41	0.26	0.26	0.29	36.0	0.0	1	0.30	33.0	0	1
150-180	1.35	0.46	0.38	0.26	0.26	0.36	6.0	0.0	1	0.38	0.0	0	1

BENCHMARK

Paddock	
Name	Pituras
Area [ha]	24.3
Summer	Sunflower
Winter	Wheat

	Sunflower	*Wheat*
Sowing start	1-Aug	15-Mar
Sowing end	1-Sep	15-Apr
Cultivar	SunGold	Saphire
Spacing [plants/m2]	5	100
Row [mm]	400	200
Depth [mm[	75	60
Amount rainfall [mm]	10	10
Rainfall days [days]	1	2
Minimum ASW [mm]	100	100

Rotation	
Sequence	wf - sunflower - wheat - sf - wheat - sunflower
Winter fallow end	1-Aug
Summer fallow end	15-Mar

Surface Organic Matter	
Type	wheat
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Automatic Irrigation start	15-Jul
Automatic Irrigation end	1-Feb
Depth ASW calculated [mm]	200
Minimum Fraction ASW [0-1]	0.2
Irrigation efficiency [0-1]	0.8

Fertilizer	
Frequency [x per year]	5
Amount [kg/ha]	20
Type	urea_N

SCENARIO 1 - Full irrigation

Paddock	
Name	Pituras
Area [ha]	24.3
Summer	Sunflower
Winter	Wheat

	Sunflower	*Wheat*
Sowing start	1-Aug	15-Mar
Sowing end	1-Sep	15-Apr
Cultivar	SunGold	Saphire
Spacing [plants/m2]	5	100
Row [mm]	400	200
Depth [mm[	75	60
Amount rainfall [mm]	10	10
Rainfall days [days]	1	2
Minimum ASW [mm]	100	100

Rotation	
Sequence	wf - sunflower - wheat - sf - wheat - sunflower
Winter fallow end	1-Aug
Summer fallow end	15-Mar

Surface Organic Matter	
Type	wheat
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Depth ASW calculated [mm]	200
Minimum Fraction ASW [0-1]	0.7
Irrigation efficiency [0-1]	0.8

Fertilizer	
Frequency [x per year]	5
Amount [kg/ha]	20
Type	urea_N

SCENARIO 2 - Rotation

Paddock	
Name	Pituras
Area [ha]	24.3
Summer	Sunflower
Winter	Wheat

	Sunflower	*Wheat*
Sowing start	1-Aug	15-Mar
Sowing end	1-Sep	15-Apr
Cultivar	SunGold	Saphire
Spacing [plants/m2]	5	100
Row [mm]	400	200
Depth [mm[	75	60
Amount rainfall [mm]	10	10
Rainfall days [days]	1	2
Minimum ASW [mm]	100	100

Rotation	
Sequence	wheat - sunflower

Surface Organic Matter	
Type	wheat
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Depth ASW calculated [mm]	200
Minimum Fraction ASW [0-1]	0.7
Irrigation efficiency [0-1]	0.8

Fertilizer	
Frequency [x per year]	5
Amount [kg/ha]	20
Type	urea_N

Case study 4: sorghum oats rotation

GENERAL

Weather input	
met file	Gatton UQ Station

10 year simulation	
clock start	1/01/2000
clock end	31/12/2009

40 year simulation	
clock start	1/01/1970
clock end	31/12/2009

Soil	
soil name	Black Vertosol
site	Lawes, QLD
initial water [mm]	72
initial NO3 [kg/ha]	15
initial NH4 [kg/ha]	6

SOIL

						Sorghum				*Oats*			
Depth [cm]	**BD [g/cc]**	**SAT [mm/mm]**	**DUL [mm/mm]**	**AirDry [mm/mm]**	**LL15 [mm/mm]**	**LL [mm/mm]**	**PAWC [mm]**	**KL [-]**	**XF [-]**	**LL [mm/mm]**	**PAWC [mm]**	**KL [-]**	**XF [-]**
0-15	1.32	0.47	0.41	0.13	0.26	0.26	22.5	0.1	1	0.26	22.5	0.1	1
15-30	1.30	0.48	0.43	0.21	0.26	0.26	25.5	0.1	1	0.26	25.5	0.1	1
30-60	1.23	0.51	0.46	0.26	0.26	0.35	33.0	0.1	1	0.3	48.0	0.1	1
60-90	1.27	0.49	0.44	0.26	0.26	0.32	36.0	0.1	1	0.29	45.0	0.1	1
90-120	1.37	0.45	0.40	0.25	0.25	0.29	33.0	0.1	1	0.26	42.0	0.1	1
120-150	1.35	0.46	0.41	0.26	0.26	0.31	30.0	0.0	1	0.28	39.0	0.0	1
150-180	1.35	0.46	0.38	0.26	0.26	0.31	21.0	0.0	1	0.28	30.0	0.0	1

BENCHMARK

Paddock	
Area [ha]	7
Summer	Sorghum
Winter	Oats

	Sorghum	*Oats*
Sowing start	15-Oct	1-Mar
Sowing end	15-Nov	15-Apr
Cultivar	medium	Algerian
Spacing [plants/m2]	15	80
Row [mm]	750	250
Depth [mm[	20	20
Amount rainfall [mm]	40	50
Rainfall days [days]	2	3
Minimum ASW [mm]	100	50

Rotation	
Sequence	sorghum - oats

Surface Organic Matter	
Type	sorghum
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Automatic Irrigation start	1-Oct
Automatic Irrigation end	15-Feb
Depth ASW calculated [mm]	600
Minimum Fraction ASW [0-1]	0.2
Irrigation efficiency [0-1]	0.75

Irrigation - at sowing	
Amount [mm]	73
Crop	sorghum

SCENARIO 1 - Full irrigation

Paddock	
Area [ha]	7
Summer	Sorghum
Winter	Oats

	Sorghum	*Oats*
Sowing start	15-Oct	1-Mar
Sowing end	15-Nov	15-Apr
Cultivar	medium	Algerian
Spacing [plants/m2]	15	80
Row [mm]	750	250
Depth [mm[	20	20
Amount rainfall [mm]	40	50
Rainfall days [days]	2	3
Minimum ASW [mm]	100	50

Rotation	
Sequence	sorghum - oats

Surface Organic Matter	
Type	sorghum
Initial residue [kg/ha]	1000
C:N ratio	80
Fraction standing	0

Irrigation	
Depth ASW calculated [mm]	600
Minimum Fraction ASW [0-1]	0.8
Irrigation efficiency [0-1]	0.75

Irrigation - at sowing	
Amount [mm]	73
Crop	sorghum

Case study 5: turf cutback

GENERAL

Weather input	
met file	Gatton UQ Station

10 year simulation	
clock start	1/01/2000
clock end	31/12/2009

40 year simulation	
clock start	1/01/1970
clock end	31/12/2009

Soil	
soil name	Sandy Loam
site	Kerribee, NSW
initial water [mm]	63
initial NO3 [kg/ha]	2
initial NH4 [kg/ha]	7

SOIL

Depth [cm]	BD [g/cc]	SAT [mm/mm]	DUL [mm/mm]	AirDry [mm/mm]	LL15 [mm/mm]	*Weed* LL [mm/mm]	PAWC [mm]	KL [-]	XF [-]
0-10	1.29	0.46	0.13	0.04	0.07	0.07	6.0	0.1	1
10-20	1.53	0.37	0.17	0.04	0.08	0.08	9.0	0.1	1
20-40	1.44	0.41	0.19	0.1	0.1	0.12	14.0	0.1	1
40-60	1.49	0.39	0.22	0.12	0.12	0.13	18.0	0	1
60-80	1.57	0.36	0.22	0.13	0.13	0.14	16.0	0	1
80-100	1.63	0.32	0.21	0.13	0.13	0.15	12.0	0	1
100-120	1.63	0.32	0.19	0.15	0.15	0.16	6.0	0	1
120-150	1.63	0.32	0.19	0.14	0.14	0.16	9.0	0	1

BENCHMARK

Paddock	
Area [ha]	31
Crop	Turf: Winter green couch

Sowing start	15-Mar
Sowing end	15-Apr
Cultivar	early
Crop growth class	winter_grass
Spacing [plants/m2]	100
Row [mm]	150
Depth [mm[	100
Amount rainfall [mm]	10
Rainfall days [days]	2
Minimum ASW [mm]	50

Cutback	
# years inley	10
Harvest heigh crop [mm]	25
Fraction removed [0-1]	0.95
Date crop removed	15-Feb

Irrigation	
Depth ASW calculated [mm]	300
Minimum Fraction ASW [0-1]	0.2
Irrigation efficiency [0-1]	0.8

Fertilizer - at sowing	
Amount [kg/ha]	20
Type	urea_N

Fertilizer - at critical level	
Max. NO3 required top 3 layers [kg/ha]	7
Critical NO3 top 3 layers [kg/ha]	2
Type	urea_N

SCENARIO 1 - Full irrigation

Paddock	
Area [ha]	31
Crop	Turf: Winter green couch

Sowing start	15-Mar
Sowing end	15-Apr
Cultivar	early
Crop growth class	winter_grass
Spacing [plants/m2]	100
Row [mm]	150
Depth [mm[	300
Amount rainfall [mm]	10
Rainfall days [days]	2
Minimum ASW [mm]	50

Cutback	
# years inley	10
Harvest heigh crop [mm]	25
Fraction removed [0-1]	0.95
Date crop removed	15-Feb

Irrigation	
Depth ASW calculated [mm]	300
Minimum Fraction ASW [0-1]	0.8
Irrigation efficiency [0-1]	0.8

Fertilizer - at sowing	
Amount [kg/ha]	20
Type	urea_N

Fertilizer - at critical level	
Max. NO3 required top 3 layers [kg/ha]	7
Critical NO3 top 3 layers [kg/ha]	2
Type	urea_N